Electronic Supplementary Material (ESI) for Chemical Science. This journal is © The Royal Society of Chemistry 2015

Electronic Supplementary Information

Enantioselective Reductive Multicomponent Coupling Reactions between Isatins and Aldehydes

Matthew A. Horwitz,^{§a} Naoya Tanaka,^{§b} Takuya Yokosaka,^a Daisuke Uraguchi,^b Jeffrey S. Johnson,^{*a} Takashi Ooi^{*bc}

^a Department of Chemistry, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina 27599-3290, United States

^b Institute of Transformative Bio-Molecules (WPI-ITbM), and Department of Applied Chemistry, Graduate School of Engineering, Nagoya University, Chikusa, Nagoya 464-8602, Japan

^c CREST, Japan Science and Technology Agency (JST), Chikusa, Nagoya 464-8603, Japan

[§] These authors contributed equally.

jsj@unc.edu

tooi@apchem.nagoya-u.ac.jp

Table of Contents	Page
General Information (Materials and Methods)	S2
Racemic three component reactions using KO'Bu	S3-S5
Enantioselective three component reactions using chiral iminophosphorane	S6-S14
Details of crossover experiment	S15
Crystallographic structure determination	S16-17
References	S17
Crude ¹ H NMR spectra for the racemic reaction	S18-S27
Crude ¹ H NMR spectra for the asymmetric reaction	S28-S45
HPLC traces	S46-S64
¹ H and ¹³ C NMR spectra of new compounds	S65-S118

General Information:

Methods: Infrared (IR) spectra were obtained using an ASI ReactIR 1000 Fourier transform infrared spectrometer or a Shimadzu IRAffinity-1 spectrometer. Magnetic resonance spectra (¹H, ¹³C, ¹⁹F, and ³¹P NMR) were recorded on a Bruker model DRX 400 (¹H NMR at 400 MHz, ¹³C NMR at 101 MHz, ¹⁹F NMR at 376 MHz, and ³¹P NMR at 162 MHz), a Bruker model DRX 600 (¹H NMR at 600 MHz, ¹³C NMR at 151 MHz, and ³¹P NMR at 243 MHz), a JEOL JNM-ECS400 (¹H NMR at 400 MHz, ¹⁹F NMR at 376 MHz, and ³¹P NMR at 162 MHz), ECA-800 (¹H NMR at 800 MHz), a Bruker AVANCE III-OneBay500 (¹³C NMR at 126 MHz) spectrometer with solvent resonance as the internal standard (¹H NMR: CDCl₃ at 7.26 ppm and ¹³C NMR: CDCl₃ at 77.16 ppm), or benzotrifluoride (¹⁹F NMR: -64.0 ppm) and H₃PO₄ (³¹P NMR: 0.0 ppm) resonances as the external standard. ¹H NMR data are reported as follows: chemical shift, multiplicity (s = singlet, br = broad, d = doublet, dd = doublet of doublet, t = triplet, dt = doublet of triplet, m = multiplet), coupling constants (Hz), and integration. High resolution mass spectra were obtained with a Thermo Fisher Scientific Exactive, FinniganTM LTQ-ICR FTTM, or Micromass Quattro II (triple quad) instrument with nanoelectrospray ionization (all samples prepared in methanol). Melting points were obtained using a Stanford Research Systems OptiMelt MPA100 or Thomas Hoover UniMelt Capillary Melting Point Apparatus. Analytical thin layer chromatography was carried out using Whatman 0.25 mm silica gel 60 plates, Sorbent Technologies 0.20 mm Silica Gel TLC plates, or Merck precoated TLC plates (silica gel 60 GF254, 0.25 mm). Visualization was allowed by UV light, phosphomolybdic acid in ethanol, or aqueous ceric ammonium nitrate solution. HPLC analysis was performed on a Shimadzu SPD-M20A PDA detector with a Shimadzu SPD20AD eluent system using DAICEL CHIRALPAK IA or AD3 columns (\$\$\phi\$ 4.6 mm x 250 mm, constant flow at 1.00 mL/min), using hexane, 2-propanol, and ethanol as eluents. To perform HPLC trials at 4 °C, a Shimadzu LC-2010C HT unit was used. Asymmetric reactions were carried out under an atmosphere of argon, in oven-dried glass with magnetic stirring, using a UC Reactor (Techno Sigma) or a PSL-1810 (EYELA) reactor. Purification of the reaction products was carried out by using Siliaflash-P60 silica gel (40-63 µm) purchased from Silicycle, or silica gel 60 (spherical, 40-50 µm) from Kanto Chemical Co., Inc. Yields refer to isolated yields after flash column chromatography; some samples contain residual minor diastereomers. Since all results are the averages of two trials, the stereochemical outcomes listed in the paper may not exactly match those represented in the NMR and HPLC data below.

Materials: Tetrahydrofuran (THF) was supplied from Kanto Chemical Co., Inc. as "Dehydrated solvent system" and further purified by passing through neutral alumina under nitrogen atmosphere. Isatins were purchased from Acros Organics or Wako Chemical Co. and alkylated according to literature procedures.¹ Triaminoiminophosphorane catalysts **C1-C5** were prepared according to literature procedures.² Commercially available dimethyl phosphite, diethyl phosphite, and diisopropyl phosphite were distilled using a Kügelrohr apparatus prior to use. Commercially available aldehydes were freshly distilled directly before the reactions. Potassium *tert*-butoxide was purchased from Sigma Aldrich and used as is.

General procedure for the three component reaction using KO'Bu:



To a stirred solution of isatin derivative (0.20 mmol), diethyl phosphite (30.4 mg, 0.22 mmol, 1.1 equiv) and aldehyde (1.0 mmol, 5.0 equiv) in THF (2.0 mL) at 0 °C was added KO'Bu (2.2 mg, 0.02 mmol, 10 mol%). The reaction was allowed to proceed at the same temperature and was followed by TLC. Once the isatin was fully consumed (typically 5-10 minutes), the reaction mixture was quenched with saturated aqueous NH₄Cl, and extracted twice with EtOAc. The combined organic layers were washed with brine, dried over Na₂SO₄, filtered, and concentrated *in vacuo*. The residue was purified by silica gel column chromatography to give the desired products **4**.



OPO₃Et₂

но

Mé

°0

1-Allyl-3-((((diethyl- λ^3 -oxidanyl)(λ^1 -oxidanyl)phosphoryl)oxy)(*p*-tolyl)methyl)-3-hy droxyindolin-2-one ((±)-4b): The title compound was prepared according to general procedure. The diastereomeric ratio was determined by ¹H NMR spectroscopic analysis of the crude reaction mixture by comparison of the resonances at δ 6.58 (minor

diastereomer) and δ 6.53 (major diastereomer). Clear oil; ¹**H** NMR (600 MHz, CDCl₃) δ 7.71 (d, *J* = 7.3 Hz, 1H), 7.30-7.27 (m, 1H), 7.16-7.13 (m, 1H), 6.91 (d, *J* = 8.0 Hz, 2H), 6.85 (d, *J* = 8.0 Hz, 2H), 6.56 (d, *J* = 7.7 Hz, 1H), 5.72 (d, *J* = 8.6 Hz, 1H), 5.28-5.22 (m, 1H), 4.87 (d, *J* = 10.4 Hz, 1H), 4.48-4.44 (m, 2H), 4.29-4.20 (m, 2H), 4.14-4.01 (m, 2H), 3.77 (dd, *J* = 5.4, 16.8 Hz, 1H), 2.24 (s, 3H), 1.32 (t, *J* = 7.2 Hz, 3H), 1.24 (t, *J* = 7.2 Hz, 3H), OH-proton was not found probably due to broadening; ¹³C NMR (151 MHz, CDCl₃) δ 174.5, 143.2, 138.7, 130.9, 130.4, 130.0, 128.4, 127.6, 126.2, 122.8, 118.1, 116.8, 109.0, 83.5 (d, *J* = 5.6 Hz), 79.3 (d, *J* = 4.5 Hz), 64.5 (d, *J* = 5.7 Hz), 64.3 (d, *J* = 5.9 Hz), 42.0, 21.0, 16.1 (d, *J* = 6.8 Hz), 16.0 (d, *J* = 7.1 Hz); ³¹P NMR (162 MHz, CDCl₃) δ 0.23; **IR** (thin film) v 3288.0, 2984.3, 1725.0, 1614.13, 1468.5, 1368.3, 1257.4, 1028.8, 754.0, 663.4 cm⁻¹; **HRMS** (ESI⁺) Calcd. for C₂₃H₂₈NNaO₆P 468.155197 (M+Na⁺) found 468.1565; **TLC** (2:1 EtOAc/Hexanes): *R*_f = 0.17.

$3-((((Diethyl-\lambda^3-oxidanyl)(\lambda^1-oxidanyl)phosphoryl)oxy)(p-tolyl)methyl)-3-hydroxy-$



procedure. The diastereomeric ratio was determined by ¹H NMR spectroscopic analysis

of the crude reaction mixture by comparison of the resonances at δ 6.59 (minor diastereomer) and δ 6.51 (major diastereomer). The product was found to be unstable to silica gel chromatography. The percent yield was calculated by ¹H NMR spectroscopy using mesitylene as an internal standard.



1-Benzyl-3-((**4-bromophenyl**)(((**diethyl-** λ^3 **-oxidanyl**)(λ^1 **-oxidanyl**)**phosphoryl**)**oxy**)**me thyl**)**-3-hydroxyindolin-2-one** ((±)-**4d**): The title compound was prepared according to general procedure. The diastereomeric ratio was determined by ¹H NMR spectroscopic

analysis of the crude reaction mixture by comparison of the resonances at δ 4.92 (minor diastereomer) and δ 4.83 (minor diastereomer). White solid (mp 168-169 °C); ¹**H** NMR (400 MHz, CDCl₃) δ 7.73 (d, *J* = 7.2 Hz, 1H), 7.26-7.16 (m, 6H), 7.11 (t, *J* = 7.6 Hz, 1H), 6.89 (d, *J* = 8.0 Hz, 2H), 6.57-6.55 (m, 2H), 6.42 (d, *J* = 8.0 Hz, 1H), 5.78 (d, *J* = 8.8 Hz, 1H), 5.00 (d, *J* = 16.0 Hz, 1H), 4.71 (br, 1H), 4.28 (d, *J* = 16.0 Hz, 1H), 4.22-4.07 (m, 2H), 4.00 (quintet, *J* = 7.2 Hz, 2H), 1.29 (t, *J* = 6.8 Hz, 3H), 1.20 (t, *J* = 6.8 Hz, 3H); ¹³C NMR (151 MHz, CDCl₃) δ 174.8, 143.2, 134.6, 133.3 (d, *J* = 3.5 Hz), 131.2, 130.3, 129.7, 128.7, 127.5, 126.5, 126.3, 126.0, 123.2, 123.1, 109.5, 82.9 (d, *J* = 5.7 Hz), 78.9 (d, *J* = 4.7 Hz), 64.6 (d, *J* = 5.6 Hz), 64.4 (d, *J* = 5.6 Hz), 43.8, 16.1 (d, *J* = 7.2 Hz), 16.0 (d, *J* = 6.6 Hz); ³¹P NMR (243 MHz, CDCl₃) δ -0.6; **IR** (thin film) v 3402.8, 2984.3, 1720.2, 1614.1, 1488.8, 1369.2, 1251.6, 1028.8, 1007.6, 971.9 cm⁻¹; **HRMS** (ESI⁺) Calcd. for C₂₆H₂₇BrNO₆P 560.0838 (M+H⁺) found 560.0820; **TLC** (2:1 EtOAc/Hexanes): *R*_f = 0.33.

$1-Benzyl-3-((((diethyl-\lambda^3-oxidanyl)(\lambda^1-oxidanyl)phosphoryl)oxy)(4-methoxyphenyl)(\lambda^1-oxidanyl)phosphoryl)oxy)(4-methoxyphenyl)(\lambda^1-oxidanyl)phosphoryl)oxy)(4-methoxyphenyl)(\lambda^1-oxidanyl)phosphoryl)oxy)(4-methoxyphenyl)(\lambda^1-oxidanyl)phosphoryl)oxy)(4-methoxyphenyl)(\lambda^1-oxidanyl)phosphoryl)oxy)(4-methoxyphenyl)(\lambda^1-oxidanyl)phosphoryl)oxy)(4-methoxyphenyl)(\lambda^1-oxidanyl)phosphoryl)(\lambda^1-oxidanyl)phosphoryl)(\lambda^1-oxidanyl)phosphoryl)(\lambda^1-oxidanyl)phosphoryl)(4-methoxyphenyl)(\lambda^1-oxidanyl)phosphoryl)(4-methoxyphenyl)(\lambda^1-oxidanyl)phosphoryl)(\lambda^1-oxidanyl)(\lambda^1-oxidanyl)phosphoryl)(\lambda^1-oxidanyl)(\lambda^1-oxidanyl)phosphoryl)(\lambda^1-oxidanyl)(\lambda^1-oxida$

)methyl)-3-hydroxyindolin-2-one $((\pm)$ -4e): The title compound was prepared according to general procedure. The diastereometric ratio was determined by ¹H NMR

spectroscopic analysis of the crude reaction mixture by comparison of the resonances at δ 5.76 (major diastereomer) and δ 5.71 (minor diastereomer). White solid (mp 157-158 °C); ¹H NMR (400 MHz, CDCl₃) δ 7.75 (d, J = 7.2 Hz, 1H), 7.21-7.05 (m, 5H), 6.91 (d, J = 8.4 Hz, 2H), 6.62 (d, J = 8.4 Hz, 2H), 6.48 (d, J = 7.6 Hz, 2H), 6.37 (d, J = 7.6 Hz, 1H), 5.78 (d, J = 8.8 Hz, 1H), 4.99 (d, J = 16.0 Hz, 1H), 4.76 (s, 1H), 4.24 (d, J = 16.0 Hz, 1H), 4.21-3.91 (m, 4H), 3.73 (s, 3H), 1.27 (t, J = 7.2 Hz, 3H), 1.20 (t, J = 7.2 Hz, 3H); ¹³C NMR (151 MHz, CDCl₃) δ 174.9, 160.1, 143.3, 134.7, 130.1, 129.4, 128.4, 127.3, 126.5, 126.4, 126.3, 126.2 (d, J = 4.1 Hz), 123.0, 113.4, 109.4, 83.4 (d, J = 6.2 Hz), 79.2 (d, J = 5.0 Hz), 64.4 (d, J = 5.6 Hz), 64.3 (d, J = 5.6 Hz), 55.1, 43.6, 16.1 (d, J = 7.2 Hz, 16.0 (d, J = 6.9 Hz); ³¹P NMR (243 MHz, CDCl₃) δ -0.5; IR (thin film) v 3416.3, 2983.3, 2931.3, 1721.2, 1614.1, 1514.8, 1441.4, 1368.3, 1250.5, 1027.9 cm⁻¹; HRMS (ESI⁺) Calcd. for C₂₇H₃₀NO₇P 512.1838 (M+H⁺) found 512.1803; TLC (2:1 EtOAc/Hexanes): $R_f = 0.19$.



$1-Benzyl-3-((((diethyl-\lambda^3-oxidanyl)(\lambda^1-oxidanyl)phosphoryl)oxy)(\textit{m-tolyl})methyl)-3-hyd$

roxyindolin-2-one $((\pm)-4f)$: The title compound was prepared according to general

 $Bn' = M_{Me}$ procedure. The diastereomeric ratio was determined by ¹H NMR spectroscopic analysis of the crude reaction mixture by comparison of the resonances at δ 6.24 (major diastereomer) and δ 4.46 (minor diastereomer). White solid (mp 109-110 °C); ¹H NMR (400 MHz, CDCl₃) δ 7.75 (d, J = 6.8 Hz, 1H), 7.19-6.89 (m, 7H), 6.82 (s, 1H), 6.78 (d, J = 7.6 Hz, 1H), 6.45 (d, J = 7.6 Hz, 2H), 6.33 (d, J = 7.6 Hz, 1H), 5.77 (d, J = 8.4 Hz, 1H), 4.96 (d, J = 16.4 Hz, 1H), 4.89 (br-s, 1H), 4.27 (d, J = 16.0 Hz, 1H), 4.22-3.95 (m, 4H), 2.10 (s, 3H), 1.26 (t, J = 6.8 Hz, 3H), 1.19 (t, J = 6.8 Hz, 3H); ¹³C NMR (151 MHz, CDCl₃) δ 174.9, 143.3, 137.7, 134.7,

133.9 (d, J = 3.0 Hz), 130.0, 129.7, 128.7, 128.6, 127.9, 127.2, 126.4, 126.3, 126.3, 125.0, 123.0, 109.4, 83.7 (d, J = 6.0 Hz), 79.2 (d, J = 4.5 Hz), 64.5 (d, J = 6.0 Hz), 64.4 (d, J = 6.0 Hz), 43.6, 21.2, 16.1 (d, J = 6.0 Hz), 16.0 (d, J = 7.6 Hz); ³¹**P** NMR (162 MHz, CDCl₃) δ -0.6; **IR** (thin film) v 3290.0, 1724.1, 1614.1, 1468.4, 1366.3, 1250.6, 1027.9, 753.1, 699.1 cm⁻¹; **HRMS** (ESI⁺) Calcd. for C₂₇H₃₀NO₆P 496.1889 (M+H⁺) found 496.1815; **TLC** (2:1 EtOAc/Hexanes): $R_f = 0.25$.



1-Benzyl-3-((((diethyl- λ^3 -oxidanyl)(λ^1 -oxidanyl)phosphoryl)oxy)(*o*-tolyl)methyl)-3-hy droxyindolin-2-one ((±)-4g): The title compound was prepared according to general procedure. The diastereometric ratio was determined by ¹H NMR spectroscopic analysis of

the crude reaction mixture by comparison of the resonances at δ 4.86 (major diastereomer) and δ 4.54 (minor diastereomer). White solid (mp 170-171 °C); ¹H NMR (400 MHz, CDCl₃) δ 7.69 (d, J = 7.2 Hz, 1H), 7.26-7.04 (m, 7H), 6.82 (t, J = 7.6 Hz, 1H), 6.63 (d, J = 8.0 Hz, 1H), 6.46-6.39 (m, 3H), 6.13 (d, J = 8.8 Hz, 1H), 5.06 (d, J = 16.0 Hz, 1H), 4.61 (s, 1H), 4.21 (d, J = 16.0 Hz, 1H), 4.16-3.88 (m, 4H), 2.45 (s, 3H), 1.23 (t, J = 7.2 Hz, 3H), 1.16 (t, J = 6.8 Hz, 3H); ¹³C NMR (151 MHz, CDCl₃) δ 175.0, 143.4, 137.4, 134.8, 132.7 (d, J = 4.5 Hz), 130.5, 130.2, 128.9, 128.7, 127.8, 127.2, 126.6, 126.4, 126.3, 125.5, 123.1, 109.4, 79.1 (d, J = 4.5 Hz), 78.9 (d, J = 6.0 Hz), 64.3 (d, J = 4.5 Hz), 64.1 (d, J = 6.0 Hz), 43.7, 19.8, 16.0 (d, J = 7.6 Hz), 15.9 (d, J = 7.6 Hz); ³¹P NMR (162 MHz, CDCl₃) δ -0.5; **IR** (thin film) v 3263.9, 2982.4, 2341.2, 1716.3, 1613.2, 1468.4, 1361.5, 1241.0, 1016.3, 753.1 cm⁻¹; **HRMS** (ESI⁺) Calcd. for C₂₇H₃₀NO₆P 496.1889 (M+H⁺) found 496.1812; **TLC** (2:1 EtOAc/Hexanes): R_f = 0.29.

Meo HO HO HO HO HO Me Bn

1-Benzyl-3-((((diethyl- λ^3 -oxidanyl)(λ^1 -oxidanyl)phosphoryl)oxy)(*p*-tolyl)methyl)-**5-methoxy-3-hydroxyindolin-2-one** ((±)-4k): The title compound was prepared according to general procedure. The diastereomeric ratio was determined by ¹H NMR

Bn⁻¹ Spectroscopic analysis of the crude reaction mixture by comparison of the resonances at δ 6.24 (minor diastereomer) and δ 6.15 (major diastereomer). White solid (mp 128-129 °C); ¹H NMR (400 MHz, CDCl₃) δ 7.35 (d, J = 2.4 Hz, 1H), 7.26-7.05 (m, 3H), 6.95-6.90 (m, 4H), 6.67 (dd, J = 2.4, 8.0 Hz, 1H), 6.52 (d, J = 7.6 Hz, 2H), 6.25 (d, J = 8.8 Hz, 1H), 5.77 (d, J = 8.8 Hz, 1H), 4.95 (d, J = 16.0 Hz, 1H), 4.76 (s, 1H), 4.25-4.07 (m, 2H), 3.99 (quintet, J = 7.2 Hz, 2H), 3.79 (s, 3H), 2.30 (s, 3H), 1.29 (t, J = 7.2 Hz, 3H), 1.19 (t, J = 6.8 Hz, 3H); ¹³C NMR (151 MHz, CDCl₃) δ 174.7, 156.1, 138.7, 136.5, 134.9, 131.1 (d, J = 3.8 Hz), 128.7, 128.4, 128.0, 127.7, 127.2, 126.6, 114.6, 113.4, 109.8, 83.6 (d, J = 5.6 Hz), 79.5 (d, J = 4.4 Hz), 64.4 (d, J = 5.6Hz), 64.3 (d, J = 6.0 Hz), 55.8, 43.8, 21.3, 16.1 (d, J = 6.8 Hz), 16.0 (d, J = 6.8 Hz); ³¹P NMR (243 MHz, CDCl₃) δ -0.3; IR (thin film) v 3401.8, 2985.9, 1717.3, 1604.5, 1493.6, 1370.2, 1350.9, 1252.5, 1183.1, 1027.9 cm⁻¹; HRMS (ESI⁺) Calcd. for C₂₈H₃₂NO₇P 526.1995 (M+H⁺) found 526.1944; TLC (2:1 EtOAc/Hexanes): $R_f = 0.19$.

General procedure for three component reaction using chiral iminophosphorane:



An oven-dried test tube was evacuated and filled with argon, then charged sequentially with the isatin substrate (0.1 mmol) and THF (0.5 mL), followed by the dialkylphosphite (0.11 mmol, 1.1 equiv) and the aldehyde (0.5 mmol, 5.0 equiv). THF (0.5 mL) was then added and used to wash the residual solids on the sides of the test tube to the bottom. The reaction was stirred at -78 °C in a cryogenic cooling apparatus, then the iminophosphorane catalyst **C1** (5.81 mg, 0.01 mmol, 0.1 equiv) was added. The reaction was then stirred at -78 °C and monitored by TLC until the reaction was complete. Trifluoroacetic acid in toluene (40 µL of an 0.5 M solution) was added to quench the reaction and the reaction was concentrated on a rotatory evaporator. The crude materials thusly obtained were purified using flash column chromatography, with a gradient from 1:1 hexane/EtOAc to 1:2 hexane/EtOAc.

1-Benzyl-3-((((diethyl- λ^3 -oxidanyl)(λ^1 -oxidanyl)phosphoryl)oxy)(*p*-tolyl)methyl)-3-h ydroxyindolin-2-one ((±)-4a): The title compound was prepared according to general procedure. The diastereomeric ratio was determined by ¹H NMR spectroscopic analysis

of the crude reaction mixture by comparison of the resonances at δ 5.73 (major diastereomer) and δ 4.44 (minor diastereomer). White solid (mp 166-167 °C); ¹**H NMR** (400 MHz, CDCl₃) δ 7.73 (d, J = 7.2 Hz, 1H), 7.18-7.07 (m, 5H), 6.94-6.89 (m, 4H), 6.56 (d, J = 7.6 Hz, 2H), 6.37 (d, J = 7.6 Hz, 1H), 5.77 (d, J = 8.8 Hz, 1H), 4.98 (d, J = 16.0 Hz, 1H), 4.38 (s, 1H), 4.28 (d, J = 16.0 Hz, 1H), 4.22-3.97 (m, 4H), 2.30 (s, 3H), 1.30 (t, J = 6.8 Hz, 3H), 1.22 (t, J = 6.8 Hz, 3H); ¹³**C NMR** (151 MHz, CDCl₃) δ 175.0, 143.3, 138.7, 134.8, 131.1 (d, J = 3.6 Hz), 130.1, 128.7, 128.4, 127.9, 127.2, 126.6, 126.5, 126.3, 123.0, 109.4, 83.6 (d, J = 5.7 Hz), 79.1 (d, J = 4.5 Hz), 64.5 (d, J = 5.7 Hz), 64.3 (d, J = 5.9 Hz), 43.7, 21.3, 16.1 (d, J = 7.2 Hz), 16.0 (d, J = 6.9 Hz); ³¹**P NMR** (162 MHz, CDCl₃) δ -0.3; IR (thin film) v 3420.1, 2927.5, 1721.2, 1615.1, 1468.5, 1368.3, 1249.7, 1123.3, 1080.9, 1028.8, 909.3 cm⁻¹; **HRMS** (ESI⁺) Calcd. for C₂₇H₃₀NO₆P 496.1889 (M+H⁺) found 496.1893; **HPLC** Chiralpak IA column, Hex/^{*i*}PrOH = 85:15, flow rate = 1.0 mL/min, λ = 210 nm, 11.3 min (minor isomer), 15.3 min (major isomer); **TLC** (2:1 EtOAc/Hexanes): R_f = 0.33.



OPO₃Et₂

HO

Bn

(*R*)-1-Benzyl-3-((*S*)-(((diethyl- λ^3 -oxidanyl)(λ^1 -oxidanyl)phosphoryl)oxy)(*p*-tolyl)met hyl)-5-fluoro-3-hydroxyindolin-2-one (4h): The title compound was prepared according to general procedure. The diastereomeric ratio was determined by ¹H NMR spectroscopic analysis of the crude reaction mixture by comparison of the resonances at

 δ 5.79 (major diastereomer) and δ 5.70 (minor diastereomer). White solid; ¹H NMR (400 MHz, CDCl₃) δ 7.50

(dd, J = 2.8, 7.8 Hz, 1H), 7.18-7.07 (m, 3H), 6.96-6.90 (m, 4H), 6.86 (dt, J = 2.7, 8.7 Hz, 1H), 6.51 (d, J = 7.3 Hz, 2H), 6.28 (dd, J = 4.1, 8.7 Hz, 1H), 5.79 (d, J = 8.7 Hz, 1H), 4.98 (d, J = 16.0 Hz, 1H), 4.28-4.09 (m, 3H), 4.00 (quintet, J = 7.3 Hz, 2H), 2.31 (s, 3H), 1.32 (dt, J = 0.9, 7.3 Hz, 3H), 1.22 (dt, J = 0.9, 7.3 Hz, 3H), OH-proton was not found probably due to broadening; ¹³C NMR (126 MHz, CDCl₃) δ 174.8, 159.2 (d, J = 243.0 Hz), 139.2₀, 139.1₉, 138.9, 134.5, 130.8, 128.8, 128.5, 127.8, 127.4, 126.6, 116.3 (d, J = 23.6 Hz), 114.4 (d, J = 25.0 Hz), 110.0 (d, J = 8.2 Hz), 83.4 (d, J = 5.5 Hz), 79.4 (d, J = 4.6 Hz), 64.6 (d, J = 5.5 Hz), 64.4 (d, J = 5.5 Hz), 43.8, 21.3, 16.1 (d, J = 7.3 Hz), 16.0 (d, J = 7.3 Hz); ³¹P NMR (162 MHz, CDCl₃) δ 0.48; ¹⁹F NMR (376 MHz, CDCl₃) δ -119.6; **IR** (thin film) v 3275.1, 2980.0, 2247.1, 1714.7, 1620.2, 1485.2, 1257.6, 1176.6, 1006.8, 902.7 cm⁻¹; **HRMS** (ESI⁺) Calcd. for C₂₇H₂₉FNO₆P 536.1614 (M+Na⁺) found 536.1605; **HPLC** Chiralpak IA column, Hex/ⁱPrOH/EtOH = 95:4:1, flow rate = 1.0 mL/min, $\lambda = 210$ nm, 28.5 min (minor isomer), 44.2 min (major isomer); **TLC** (1:4 EtOAc/Hexanes): $R_f = 0.38$.



(*R*)-1-Benzyl-3-((*S*)-(((diethyl- λ^3 -oxidanyl)(λ^1 -oxidanyl)phosphoryl)oxy)(*p*-tolyl)me thyl)-5-chloro-3-hydroxyindolin-2-one (4i): The title compound was prepared according to general procedure. The diastereomeric ratio was determined by ¹H NMR spectroscopic analysis of the crude reaction mixture by comparison of the resonances at

δ 5.80 (major diastereomer) and δ 5.72 (minor diastereomer). White solid; ¹H NMR (400 MHz, CDCl₃) δ 7.72 (s, 1H), 7.18-7.06 (m, 4H), 6.99-6.91 (m, 4H), 6.50 (d, J = 7.3 Hz, 2H), 6.27 (d, J = 8.2 Hz, 1H), 5.78 (d, J = 9.2 Hz, 1H), 4.98 (br, 1H), 4.97 (d, J = 16.0 Hz, 1H), 4.28-4.10 (m, 3H), 4.00 (quintet, J = 7.3 Hz, 2H), 2.32 (s, 3H), 1.33 (t, J = 7.3 Hz, 3H), 1.22 (t, J = 7.3 Hz, 3H); ¹³C NMR (126 MHz, CDCl₃) δ 174.7, 141.9, 139.0, 134.5, 130.9, 130.0, 128.9, 128.6, 128.5, 128.4, 128.0, 127.5, 126.8, 126.7, 110.5, 83.4 (d, J = 6.4 Hz), 79.4 (d, J = 4.6 Hz), 64.8 (d, J = 5.5 Hz), 64.6 (d, J = 6.4 Hz), 43.9, 21.4, 16.2 (d, J = 8.6 Hz), 16.1 (d, J = 6.4 Hz); ³¹P NMR (162 MHz, CDCl₃) δ 0.51; **IR** (thin film) v 3269.3, 2987.7, 2245.1, 1726.3, 1612.5, 1483.3, 1253.7, 1172.7, 1006.8, 783.1 cm⁻¹; **HRMS** (ESI⁺) Calcd. for C₂₇H₂₉ClNO₆P 552.1319 (M+Na⁺) found 552.1309; **HPLC** Chiralpak IA column, Hex/ⁱPrOH/EtOH = 95:4:1, flow rate = 1.0 mL/min, $\lambda = 210$ nm, 28.8 min (minor isomer), 43.3 min (major isomer); **TLC** (1:4 EtOAc/Hexanes): $R_f = 0.41$.



(*R*)-1-Benzyl-3-((*S*)-(((diethyl- λ^3 -oxidanyl)(λ^1 -oxidanyl)phosphoryl)oxy)(*p*-tolyl)me thyl)-5-bromo-3-hydroxyindolin-2-one (4j): The title compound was prepared according to general procedure. The diastereomeric ratio was determined by ¹H NMR spectroscopic analysis of the crude reaction mixture by comparison of the resonances at

δ 5.78 (major diastereomer) and δ 5.69 (minor diastereomer). White solid; ¹H NMR (400 MHz, CDCl₃) δ 7.84 (d, J = 1.8 Hz, 1H), 7.29 (dd, J = 1.8, 8.2 Hz, 1H), 7.68-7.07 (m, 3H), 6.97-6.90 (m, 4H), 6.50 (d, J = 7.8 Hz, 2H), 6.23 (d, J = 8.7 Hz, 1H), 5.77 (d, J = 8.7 Hz, 1H), 4.96 (d, J = 16.0 Hz, 1H), 4.29-4.11 (m, 3H), 4.00 (quintet, J = 7.4 Hz, 2H), 2.32 (s, 3H), 1.35 (t, J = 6.8 Hz, 3H), 1.22 (t, J = 6.8 Hz, 3H), OH-proton was not found probably due to broadening; ¹³C NMR (126 MHz, CDCl₃) δ 174.6, 142.4, 139.1, 134.4, 133.0, 130.9, 130.8, 129.6, 129.0,

128.0, 127.5, 126.7, 115.8, 111.0, 83.4 (d, J = 6.4 Hz), 79.4 (d, J = 4.6 Hz), 64.8 (d, J = 5.5 Hz), 64.6 (d, J = 5.5 Hz), 43.9, 21.5, 16.2 (d, J = 7.3 Hz), 16.1 (d, J = 6.4 Hz), one carbon atom was not found probably due to overlapping; ³¹**P** NMR (162 MHz, CDCl₃) δ 0.67; **IR** (thin film) v 3292.5, 2982.9, 2908.7, 2245.1, 1726.3, 1608.6, 1479.4, 1247.9, 1028.1, 733.0 cm⁻¹; **HRMS** (ESI⁺) Calcd. for C₂₇H₂₉BrNO₆P 596.0814 (M+Na⁺) found 596.0809; **HPLC** Chiralpak IA column, Hex/^{*i*}PrOH = 95:5, flow rate = 1.0 mL/min, λ = 210 nm, 29.9 min (minor isomer), 43.0 min (major isomer); **TLC** (1:4 EtOAc/Hexanes): $R_f = 0.44$.

(*R*)-1-Benzyl-3-((*S*)-(((diethyl- λ^3 -oxidanyl)(λ^1 -oxidanyl)phosphoryl)oxy)(*p*-tolyl)



methyl)-5-methoxy-3-hydroxyindolin-2-one (**4l**): The title compound was prepared according to general procedure. The diastereomeric ratio was determined by ¹H NMR spectroscopic analysis of the crude reaction mixture by comparison of the resonances

at δ 5.77 (major diastereomer) and δ 5.74 (minor diastereomer). White solid; ¹H NMR (400 MHz, CDCl₃) δ 7.36 (d, J = 2.3 Hz, 1H), 7.18-7.07 (m, 3H), 6.97-6.92 (m, 4H), 6.69 (dd, J = 8.6, 2.5 Hz, 1H), 6.54 (d, J = 7.3 Hz, 2H), 6.28 (d, J = 8.9 Hz, 1H), 5.77 (d, J = 8.7 Hz, 1H), 4.99 (d, J = 16.0 Hz, 1H), 4.40 (br, 1H), 4.25 (d, J = 16.0 Hz, 1H), 3.81 (s, 3H), 3.78 (d, J = 11.4 Hz, 3H), 3.64 (d, J = 11.5 Hz, 3H), 2.31 (s, 3H); ¹³C NMR (126 MHz, CDCl₃) δ 174.9, 156.2, 138.9, 136.8, 135.0, 131.2, 128.9, 128.5, 128.1, 127.7, 127.3, 126.7, 114.7, 113.7, 110.0, 83.9 (d, J = 5.5 Hz), 79.5 (d, J = 4.6 Hz), 56.0, 54.8 (d, J = 5.5 Hz), 54.6 (d, J = 6.4 Hz), 43.9, 21.4; ³¹P NMR (162 MHz, CDCl₃) δ 2.55; **IR** (thin film) v 3300.2, 2951.1, 2243.2, 1712.8, 1604.8, 1487.1, 1257.6, 1163.1, 1026.1, 810.1 cm⁻¹; **HRMS** (ESI⁺) Calcd. for C₂₆H₂₈NO₇P 504.1552 (M+Na⁺) found 520.1499; **HPLC** Chiralpak IA column, Hex/^{*i*}PrOH/EtOH = 90:5:5, flow rate = 1.0 mL/min, $\lambda = 210$ nm, 34.2 min (minor isomer), 45.4 min (major isomer); **TLC** (1:4 EtOAc/Hexanes): $R_f = 0.17$.



(*R*)-1-Benzyl-3-((*S*)-(((diethyl- λ^3 -oxidanyl)(λ^1 -oxidanyl)phosphoryl)oxy)(*p*-tolyl)m ethyl)-5-methyl-3-hydroxyindolin-2-one (4m): The title compound was prepared according to general procedure. The diastereomeric ratio was determined by ¹H NMR spectroscopic analysis of the crude reaction mixture by comparison of the resonances

at δ 5.76 (major diastereomer) and δ 5.72 (minor diastereomer). White solid; ¹H NMR (400 MHz, CDCl₃) δ 7.54 (s, 1H), 7.17-7.06 (m, 3H), 7.00-6.91 (m, 5H), 6.54 (d, *J* = 7.3 Hz, 2H), 6.27 (d, *J* = 7.8 Hz, 1H), 5.75 (d, *J* = 8.7 Hz, 1H), 5.00 (br, 1H), 4.26 (d, *J* = 16.0 Hz, 1H), 3.74 (d, *J* = 11.0 Hz, 3H), 3.66 (d, *J* = 11.4 Hz, 3H), 2.36 (s, 3H), 2.31 (s, 3H); ¹³C NMR (126 MHz, CDCl₃) δ 175.1, 141.0, 138.9, 135.0, 132.7, 131.2 (d, *J* = 3.6 Hz), 130.5, 128.9, 128.5, 128.1, 127.3, 127.1, 126.7, 126.4, 109.3, 84.0 (d, *J* = 6.4 Hz), 79.2 (d, *J* = 5.5 Hz), 54.8 (d, *J* = 5.5 Hz), 54.6 (d, *J* = 5.5 Hz), 43.8, 21.4, 21.3; ³¹P NMR (162 MHz, CDCl₃) δ 2.55; **IR** (thin film) v 3336.9, 2924.1, 2850.8, 2243.2, 2115.9, 1714.7, 1620.2, 1492.9, 1259.5, 1031.9 cm⁻¹; **HRMS** (ESI⁺) Calcd. for C₂₆H₂₈NO₆P 504.1552 (M+Na⁺) found 504.1547; **HPLC** Chiralpak IA column, Hex/^{*i*}PrOH = 85:15, flow rate = 1.0 mL/min, λ = 210 nm, 13.4 min (minor isomer), 16.5 min (major isomer); **TLC** (1:4 EtOAc/Hexanes): *R*_f = 0.23.



(*R*)-1-Benzyl-3-((*S*)-(((diethyl- λ^3 -oxidanyl)(λ^1 -oxidanyl)phosphoryl)oxy)(*p*-tolyl) methyl)-6-chloro-3-hydroxyindolin-2-one (4n): The title compound was prepared

according to general procedure. The diastereomeric ratio was determined by ¹H

NMR spectroscopic analysis of the crude reaction mixture by comparison of the resonances at δ 5.80 (major diastereomer) and δ 5.74 (minor diastereomer). White solid; ¹**H NMR** (400 MHz, CDCl₃) δ 7.66 (d, *J* = 7.8 Hz, 1H), 7.20-7.16 (m, 1H), 7.12-7.08 (m, 3H), 6.97 (d, *J* = 7.8 Hz, 2H), 6.90 (d, *J* = 8.5 Hz, 2H), 6.53 (d, *J* = 7.3 Hz, 2H), 6.38 (d, *J* = 1.8 Hz, 1H), 5.77 (d, *J* = 9.2 Hz, 1H), 4.98 (d, *J* = 16.0 Hz, 1H), 4.60 (br, 1H), 4.24 (d, *J* = 16.5 Hz, 1H), 3.76 (d, *J* = 11.4 Hz, 3H), 3.65 (d, *J* = 11.4 Hz, 3H), 2.32 (s, 3H); ¹³**C NMR** (126 MHz, CDCl₃) δ 175.1, 144.7, 139.2, 136.1, 134.3, 130.8 (d, *J* = 3.6 Hz), 129.1, 128.7, 127.9, 127.6, 127.5, 126.7, 125.0, 123.1, 110.2, 83.8 (d, *J* = 6.4 Hz), 78.9 (d, *J* = 4.5 Hz), 54.9 (d, *J* = 5.5 Hz), 54.7 (d, *J* = 6.4 Hz), 43.9, 21.5; ³¹**P NMR** (162 MHz, CDCl₃) δ 2.55; **IR** (thin film) v 3302.1, 2956.9, 2247.1, 1726.3, 1608.6, 1454.3, 1251.8, 1180.4, 1025.1, 731.0 cm⁻¹; **HRMS** (ESI⁺) Calcd. for C₂₅H₂₅CINO₆P 524.1006 (M+Na⁺) found 524.1003; **HPLC** Chiralpak IA column, Hex/ⁱPrOH = 90.9:9.1, flow rate = 1.0 mL/min, λ = 210 nm, 20.5 min (minor isomer), 30.6 min (major isomer); **TLC** (1:4 EtOAc/Hexanes): *R*_f = 0.41.

$(R) - 1 - Benzyl - 3 - ((S) - (((diethyl - \lambda^3 - oxidanyl))(\lambda^1 - oxidanyl)phosphoryl)oxy)(p - tolyl)me$



thyl)-7-fluoro-3-hydroxyindolin-2-one (40): The title compound was prepared

according to general procedure. The diastereomeric ratio was determined by ¹H NMR

spectroscopic analysis of the crude reaction mixture by comparison of the resonances at δ 5.75 (major diastereomer) and δ 5.67 (minor diastereomer). White solid; ¹H NMR (400 MHz, CDCl₃) δ 7.54 (d, J = 7.3 Hz, 1H), 7.18-7.04 (m, 5H), 6.99-6.86 (m, 4H), 6.70 (d, J = 7.3 Hz, 2H), 5.74 (d, J = 8.7 Hz, 1H), 4.91 (d, J = 16.0 Hz, 1H), 4.59 (d, J = 16.0 Hz, 1H), 4.21-4.15 (m, 2H), 4.00 (quintet, J = 6.9 Hz, 2H), 2.28 (s, 3H), 1.29 (dt, J = 0.9, 7.3 Hz, 3H), 1.21 (dt, J = 0.9, 7.3 Hz, 3H), 0H-proton was not found probably due to broadening; ¹³C NMR (126 MHz, CDCl₃) δ 174.7, 147.3 (d, J = 244.8 Hz) 139.0, 136.2, 130.7 (d, J = 3.6 Hz), 129.6 (d, J = 2.7 Hz), 128.9, 128.4, 127.9, 127.2, 126.8 (d, J = 1.8 Hz), 123.9 (d, J = 6.4 Hz), 122.4 (d, J = 3.6 Hz), 118.4 (d, J = 20.0 Hz), 83.4 (d, J = 5.5 Hz), 79.12 (d, J = 5.5 Hz), 79.10 (d, J = 4.6 Hz), 64.6 (d, J = 5.5 Hz), 64.5 (d, J = 5.5 Hz), 45.3 (d, J = 4.5 Hz), 21.4, 16.2 (d, J = 7.3 Hz), 16.1 (d, J = 7.3 Hz); ³¹P NMR (162 MHz, CDCl₃) δ 0.46; ¹⁹F NMR (376 MHz, CDCl₃) δ -133.6; **IR** (thin film) v 3296.4, 2985.8, 2237.4, 1730.2, 1631.8, 1487.1, 1247.9, 1022.3, 910.4, 733.0 cm⁻¹; **HRMS** (ESI⁺) Calcd. for C₂₇H₂₉FNO₆P 536.1614 (M+Na⁺) found 536.1608; **HPLC** Chiralpak IA column, Hex/[†]PrOH/EtOH = 85:5:10, flow rate = 1.0 mL/min, $\lambda = 210$ nm, 9.3 min (minor isomer), 12.5 min (major isomer); **TLC** (1:4 EtOAc/Hexanes): $R_f = 0.38$.



(*R*)-1-Benzyl-5-bromo-3-((*S*)-(((diethy λ^3 -oxidanyl)(λ^1 -oxidanyl)phosphoryl)oxy)(4-fl uorophenyl)methyl)-3-hydroxyindolin-2-one (4p): The title compound was prepared according to general procedure. The diastereometric ratio was determined by ¹H NMR

spectroscopic analysis of the crude reaction mixture by comparison of the resonances at δ 5.81 (major diastereomer) and δ 5.75 (minor diastereomer). White solid; ¹H NMR (400 MHz, CDCl₃) δ 7.83 (d, *J* = 1.8 Hz, 1H), 7.31 (dd, *J* = 2.3, 8.7 Hz, 1H), 7.21-7.12 (m, 3H), 7.03-6.99 (m, 2H), 6.86-6.81 (m, 2H), 6.54 (d, *J* = 7.4 Hz, 2H), 6.29 (d, *J* = 8.7 Hz, 1H), 5.79 (d, *J* = 9.2 Hz, 1H), 4.91 (d, *J* = 16.0 Hz, 1H), 4.89 (br-s, 1H), 4.28 (d, *J* = 16.5 Hz, 1H), 4.25-4.13 (m, 2H), 4.02 (quintet, *J* = 7.3 Hz, 2H), 1.37 (t, *J* = 6.9 Hz, 3H), 1.23 (t, *J* = 7.3 Hz, 3H); ¹³C NMR (126 MHz, CDCl₃) δ 174.5, 163.2 (d, *J* = 249.4 Hz), 142.4, 134.3, 133.2, 130.0 (d, *J* = 8.2 Hz), 129.6, 128.8, 128.4, 127.8, 127.0, 126.6, 115.9, 115.3 (d, *J* = 21.8 Hz), 111.1, 82.7 (d, *J* = 6.4 Hz), 79.3 (d, *J* = 4.6 Hz), 64.9 (d, *J* = 5.5 Hz), 64.6 (d, *J* = 5.5 Hz), 43.9, 16.3 (d, *J* = 7.3 Hz), 16.1 (d, *J* = 6.3 Hz); ³¹P NMR (162 MHz, CDCl₃) δ 0.27; ¹⁹F NMR (376 MHz, CDCl₃) δ -111.6; **IR** (thin film) v 3252.0, 2985.8, 2245.1, 1726.3, 1606.7, 1510.3, 1479.4, 1346.3, 1228.7, 1022.3 cm⁻¹; **HRMS** (ESI⁺) Calcd. for C₂₆H₂₆BrFNO₆P 600.0563 (M+Na⁺) found 600.0552; **HPLC** Chiralpak IA column, Hex/⁷PrOH/EtOH = 95:4:1, flow rate = 1.0 mL/min, λ = 262 nm, 29.6 min (minor isomer), 43.8 min (major isomer); **TLC** (1:4 EtOAc/Hexanes): R_f = 0.45.



(*R*)-1-Benzyl-5-bromo-3-((*S*)-(((diethyl- λ^3 -oxidanyl)(λ^1 -oxidanyl)phosphoryl)oxy)(4iodophenyl)methyl)-3-hydroxyindolin-2-one (4q): The title compound was prepared according to general procedure. The diastereomeric ratio was determined by ¹H NMR spectroscopic analysis of the crude reaction mixture by comparison of the resonances at

δ 5.76 (major diastereomer) and δ 5.69 (minor diastereomer). White solid; ¹H NMR (400 MHz, CDCl₃) δ 7.83 (d, J = 1.8 Hz, 1H), 7.48 (d, J = 8.2 Hz, 2H), 7.30 (dd, J = 1.8, 6.4 Hz, 1H), 7.25-7.23 (m, 3H), 6.78 (d, J = 8.7 Hz, 2H), 6.56-6.54 (m, 2H), 6.28 (d, J = 8.7 Hz, 1H), 5.75 (d, J = 8.7 Hz, 1H), 4.99 (d, J = 16.0 Hz, 1H), 4.98 (br-s, 1H), 4.28-4.15 (m, 3H), 4.03 (quintet, J = 8.2 Hz, 2H), 1.36 (dt, J = 0.9, 6.9 Hz, 3H), 1.24 (dt, J = 0.9, 6.9 Hz, 3H); ¹³C NMR (126 MHz, CDCl₃) δ 174.3, 142.4, 137.5, 134.2, 133.6, 133.2, 129.8, 129.6, 129.0, 128.3, 127.8, 126.6, 115.9, 111.2, 95.5, 82.8 (d, J = 5.5 Hz), 79.1 (d, J = 5.3 Hz), 65.0 (d, J = 6.4 Hz), 64.7 (d, J = 4.6 Hz), 44.0, 16.3 (d, J = 6.4 Hz), 16.1 (d, J = 6.4 Hz); ³¹P NMR (162 MHz, CDCl₃) δ 0.56; IR (thin film) v 3290.6, 2980.0, 2243.2, 1730.2, 1606.7, 1481.3, 1371.4, 1253.7, 1024.2, 910.4 cm⁻¹; HRMS (ESI⁺) Calcd. for C₂₆H₂₆BrINO₆P 707.9623 (M+Na⁺) found 707.9618; HPLC Chiralpak AD3 column, Hex/EtOH = 88:12 (4 °C), flow rate = 1.0 mL/min, $\lambda = 210$ nm, 18.9 min (minor isomer), 29.7 min (major isomer); TLC (1:4 EtOAc/Hexanes): $R_f = 0.47$.



$(R) - 1 - Benzyl - 5 - bromo - 3 - ((S) - (((diethyl - \lambda^3 - oxidanyl))(\lambda^1 - oxidanyl)phosphoryl)oxy)(phere) - ((A) - (A) -$

nyl)methyl)-3-hydroxyindolin-2-one (4r): The title compound was prepared according to general procedure. The diastereomeric ratio was determined by ¹H NMR spectroscopic analysis of the crude reaction mixture by comparison of the resonances at δ 5.82 (major

diastereomer) and δ 5.77 (minor diastereomer). White solid; ¹H NMR (400 MHz, CDCl₃) δ 7.86 (s, 1H), 7.32-7.26 (m, 3H), 7.18-7.14 (m, 3H), 7.11-7.04 (m, 4H), 6.46 (d, *J* = 7.8 Hz, 2H), 6.21 (d, *J* = 8.2 Hz, 1H), 5.81 (d, *J* = 9.2 Hz, 1H), 5.06 (br, 1H), 4.90 (d, *J* = 16.5 Hz, 1H), 4.29-4.11 (m, 3H), 4.01 (quintet, *J* = 7.8 Hz, 2H),

1.34 (t, J = 7.1 Hz, 3H), 1.21 (t, J = 6.8 Hz, 3H); ¹³C NMR (126 MHz, CDCl₃) δ 174.5, 142.4, 134.4, 133.9, 133.0, 129.6, 129.2, 128.8, 128.7 (d, J = 2.7 Hz), 128.3, 128.1, 127.5, 126.6, 115.8, 111.1, 83.5 (d, J = 6.4 Hz), 79.4 (d, J = 4.6 Hz), 64.9 (d, J = 5.5 Hz), 65.6 (d, J = 5.5 Hz), 43.9, 16.3 (d, J = 7.3 Hz), 16.1 (d, J = 6.4 Hz); ³¹P NMR (162 MHz, CDCl₃) δ 0.48; **IR** (thin film) v 3282.8, 2978.1, 2247.1, 1726.3, 1714.7, 1606.7, 1454.3, 1348.2, 1253.7, 725.2 cm⁻¹; **HRMS** (ESI⁺) Calcd. for C₂₆H₂₇BrNO₆P 582.0657 (M+Na⁺) found 582.0652; **HPLC** Chiralpak IA column, Hex/^{*i*}PrOH = 85:15, flow rate = 1.0 mL/min, $\lambda = 210$ nm, 18.1 min (minor isomer), 28.0 min (major isomer); **TLC** (1:4 EtOAc/Hexanes): $R_f = 0.44$.



(*R*)-1-Benzyl-5-bromo-3-((*S*)-(((diethyl- λ^3 -oxidanyl)(λ^1 -oxidanyl)phosphoryl)oxy) (4-(methylthio)phenyl)methyl)-3-hydroxyindolin-2-one (4s): The title compound was prepared according to general procedure. The diastereomeric ratio was determined by ¹H NMR spectroscopic analysis of the crude reaction mixture by

comparison of the resonances at δ 5.78 (major diastereomer) and δ 5.71 (minor diastereomer). White solid; ¹**H NMR** (400 MHz, CDCl₃) δ 7.85 (d, *J* = 1.8 Hz, 1H), 7.29 (dd, *J* = 2.3, 8.7 Hz, 1H), 7.18-7.17 (m, 3H), 7.03-6.93 (m, 4H), 6.47-6.45 (m, 2H), 6.24 (d, *J* = 8.2 Hz, 1H), 5.77 (d, *J* = 9.2 Hz, 1H), 5.01 (d, *J* = 16.0 Hz, 1H), 4.30-4.13 (m, 3H), 4.02 (quintet, *J* = 7.3 Hz, 2H), 2.42 (s, 3H), 1.36 (t, *J* = 6.9 Hz, 3H), 1.23 (t, *J* = 7.3 Hz, 3H), OH-proton was not found probably due to broadening; ¹³**C NMR** (126 MHz, CDCl₃) δ 174.5, 142.4, 140.0, 134.2, 133.1, 130.2, 129.6, 128.9, 128.8, 128.6, 128.5, 127.7, 126.5, 125.4, 115.8, 111.1, 83.2 (d, *J* = 5.5 Hz), 79.3 (d, *J* = 4.6 Hz), 64.9 (d, *J* = 5.5 Hz), 64.6 (d, *J* = 5.5 Hz), 43.9, 16.3 (d, *J* = 7.3 Hz), 16.1 (d, *J* = 6.4 Hz); ³¹**P NMR** (162 MHz, CDCl₃) δ 0.54; **IR** (thin film) v 3306.0, 2985.8, 2247.1, 1730.2, 1606.7, 1483.3, 1249.9, 1134.1, 1020.3, 731.0 cm⁻¹; **HRMS** (ESI⁺) Calcd. for C₂₇H₂₉BrNO₆PS 628.0534 (M+Na⁺) found 628.0526; **HPLC** Chiralpak IA column, Hex/^{*i*}PrOH = 85:15, flow rate = 1.0 mL/min, λ = 210 nm, 13.7 min (minor isomer), 20.7 min (major isomer); **TLC** (1:4 EtOAc/Hexanes): *R_f* = 0.42.



(*R*)-1-Benzyl-5-bromo-3-((*S*)-(((diethyl- λ^3 -oxidanyl)(λ^1 -oxidanyl)phosphoryl)oxy) (4-methoxyphenyl)methyl)-3-hydroxyindolin-2-one (4t): The title compound was prepared according to general procedure. The diastereomeric ratio was determined by ¹H NMR spectroscopic analysis of the crude reaction mixture by comparison of the

resonances at δ 5.78 (major diastereomer) and δ 5.71 (minor diastereomer). White solid; ¹H NMR (400 MHz, CDCl₃) δ 7.84 (d, J = 1.8 Hz, 1H), 7.29 (dd, J = 1.8, 8.2 Hz, 1H), 7.18-7.07 (m, 3H), 6.94 (d, J = 9.2 Hz, 2H), 6.67 (d, J = 8.7 Hz, 2H), 6.47 (d, J = 7.8 Hz, 2H), 6.24 (d, J = 8.7 Hz, 1H), 5.76 (d, J = 9.2 Hz, 1H), 4.98 (d, J = 16.5 Hz, 1H), 4.88 (br, 1H), 4.28-4.14 (m, 3H), 4.02 (quintet, J = 7.3 Hz, 2H), 3.76 (s, 3H), 1.36 (dt, J = 0.9, 6.9 Hz, 3H), 1.23 (dt, J = 0.9, 6.9 Hz, 3H); ¹³C NMR (126 MHz, CDCl₃) δ 174.5, 160.3, 142.5, 134.3, 133.0, 129.5, 129.4, 128.7, 128.6, 127.6, 126.6, 125.9 (d, J = 4.5 Hz), 115.8, 113.7, 111.0, 83.2 (d, J = 5.5 Hz), 79.4 (d, J = 4.6 Hz), 64.8 (d, J = 5.5 Hz), 64.6 (d, J = 5.5 Hz), 55.2, 43.8, 16.3 (d, J = 7.3 Hz), 16.1 (d, J = 6.4 Hz); ³¹P NMR (162 MHz, CDCl₃) δ 0.83; **IR** (thin film) v 3313.7, 2976.2, 2353.2, 2245.1, 1730.2, 1612.5, 1514.1, 1485.2,

1249.9, 1024.2 cm⁻¹; **HRMS** (ESI⁺) Calcd. for C₂₇H₂₉BrNO₇P 612.0763 (M+Na⁺) found 612.0754; **HPLC** Chiralpak IA column, Hex/^{*i*}PrOH = 85:15, flow rate = 1.0 mL/min, λ = 210 nm, 13.4 min (minor isomer), 18.9 min (major isomer); **TLC** (1:4 EtOAc/Hexanes): R_f = 0.39.



(*R*)-1-Benzyl-5-bromo-3-((*S*)-(((diethyl- λ^3 -oxidanyl)(λ^1 -oxidanyl)phosphoryl)oxy)(*m*-to lyl)methyl)-3-hydroxyindolin-2-one (4u): The title compound was prepared according to general procedure. The diastereomeric ratio was determined by ¹H NMR spectroscopic analysis of the crude reaction mixture by comparison of the resonances at δ 5.76 (major

diastereomer) and δ 5.71 (minor diastereomer). White solid; ¹H NMR (400 MHz, CDCl₃) δ 7.83 (d, *J* = 1.8 Hz, 1H), 7.28 (dd, *J* = 1.8, 8.2 Hz, 1H), 7.18-7.02 (m, 5H), 6.86 (s, 1H), 6.80 (d, *J* = 7.8 Hz, 1H), 6.45 (d, *J* = 7.3 Hz, 2H), 6.21 (d, *J* = 8.0 Hz, 1H), 5.75 (d, *J* = 8.7 Hz, 1H), 4.94 (d, *J* = 16.5 Hz, 1H), 4.86 (br, 1H), 4.30-4.12 (m, 3H), 4.02 (quintet, *J* = 7.4 Hz, 2H), 2.16 (s, 3H), 1.36 (t, *J* = 7.3 Hz, 3H), 1.24 (t, *J* = 7.1 Hz, 3H); ¹³C NMR (126 MHz, CDCl₃) δ 174.5, 142.5, 138.0, 134.5, 133.7, 133.0, 130.0, 129.6, 128.8, 128.2, 127.6, 126.5, 125.0, 115.8, 111.0, 83.5 (d, *J* = 5.5 Hz), 79.4 (d, *J* = 3.6 Hz), 64.9 (d, *J* = 6.4 Hz), 64.6 (d, *J* = 8.2 Hz), 43.9, 21.4, 16.3 (d, *J* = 7.3 Hz), 16.1 (d, *J* = 6.4 Hz), two carbon atoms were not found probably due to overlapping; ³¹P NMR (162 MHz, CDCl₃) δ 0.67; **IR** (thin film) v 3265.5, 2932.0, 2933.7, 1730.2, 1714.2, 1608.6, 1454.3, 1249.9, 1130.3, 1020.3 cm⁻¹; **HRMS** (ESI⁺) Calcd. for C₂₇H₂₉BrNO₆P 596.0814 (M+Na⁺) found 596.0795; **HPLC** Chiralpak IA column, Hex/⁷PrOH = 90.9:9.1, flow rate = 1.0 mL/min, λ = 210 nm, 14.5 min (minor isomer), 24.7 min (major isomer); **TLC** (1:4 EtOAc/Hexanes): *R*_f = 0.45.



(*R*)-1-Benzyl-5-bromo-3-((*S*)-(((diethyl- λ^3 -oxidanyl)(λ^1 -oxidanyl)phosphoryl)oxy)(3-(m ethylthio)phenyl)methyl)-3-hydroxyindolin-2-one (4v): The title compound was prepared according to general procedure. The diastereomeric ratio was determined by ¹H

Bⁿ S_{Me} NMR spectroscopic analysis of the crude reaction mixture by comparison of the resonances at δ 5.78 (major diastereomer) and δ 5.72 (minor diastereomer). White solid; ¹H NMR (400 MHz, CDCl₃) δ 7.87 (s, 1H), 7.29 (dd, J = 2.3, 8.7 Hz, 1H), 7.19-7.11 (m, 4H), 7.05 (t, J = 7.8 Hz, 1H), 6.85 (d, J = 7.8 Hz, 1H), 6.81 (s, 1H), 6.49 (d, J = 7.3 Hz, 2H), 6.24 (d, J = 8.7 Hz, 1H), 5.78 (d, J = 8.7 Hz, 1H), 5.09 (br, 1H), 4.93 (d, J = 16.5 Hz, 1H), 4.31-4.13 (m, 3H), 4.03 (quintet, J = 6.9 Hz, 2H), 2.14 (s, 3H), 1.36 (t, J = 7.3 Hz, 3H), 1.23 (t, J = 6.8 Hz, 3H); ¹³C NMR (126 MHz, CDCl₃) δ 174.4, 142.4, 139.1, 134.7, 134.3, 133.0, 129.6, 128.6, 128.5, 127.9, 127.6, 126.5, 125.0, 124.9, 115.8, 111.2, 83.1 (d, J = 5.5 Hz), 79.3 (d, J = 4.6 Hz), 64.9 (d, J = 6.4 Hz), 64.7 (d, J = 6.4 Hz), 16.1 (d, J = 6.4 Hz), 15.6, one carbon atom was not found probably due to overlapping; ³¹P NMR (162 MHz, CDCl₃) δ 0.48; IR (thin film) v 3255.8, 2983.9, 2362.8, 1730.2, 1606.7, 1479.4, 1255.7, 1018.4, 972.1, 895.0 cm⁻¹; HRMS (ESI⁺) Calcd. for C₂₇H₂₉BrNO₆PS 628.0534 (M+Na⁺) found 628.0530; HPLC Chiralpak IA column, Hex/ⁱPrOH = 90.9:9.1, flow rate = 1.0 mL/min, $\lambda = 210$ nm, 16.4 min (minor isomer), 34.1 min (major isomer); TLC (1:4 EtOAc/Hexanes): $R_f = 0.41$.



(*R*)-3-((*S*)-Benzo[d][1,3]dioxol-5-yl(((diethyl- λ^3 -oxidanyl)(λ^1 -oxidanyl)phosphoryl)o xy)methyl)-1-benzyl-5-bromo-3-hydroxyindolin-2-one (4w): The title compound was prepared according to general procedure. The diastereomeric ratio was determined by ¹H NMR spectroscopic analysis of the crude reaction mixture by comparison of the

resonances at δ 5.72 (major diastereomer) and δ 5.64 (minor diastereomer). White solid; ¹**H** NMR (400 MHz, CDCl₃) δ 7.80 (d, J = 1.8 Hz, 1H), 7.31 (dd, J = 0.9, 8.2 Hz, 1H), 7.19-7.14 (m, 3H), 6.64-6.59 (m, 4H), 6.40 (s, 1H), 6.32 (d, J = 8.7 Hz, 1H), 5.88 (dd, J = 1.4, 5.0 Hz, 2H), 5.71 (d, J = 8.7 Hz, 1H), 5.01 (d, J = 16.0 Hz, 1H), 4.99 (br, 1H), 4.31-4.13 (m, 3H), 4.03 (quintet, J = 7.3 Hz, 2H), 1.38 (dt, J = 0.9, 6.8 Hz, 3H), 1.25 (dt, J = 0.9, 7.3 Hz, 3H); ¹³**C** NMR (126 MHz, CDCl₃) δ 174.5, 148.4 (d, J = 1.8 Hz), 147.5, 142.5, 134.6, 133.1, 129.5, 128.9, 128.7, 127.7, 127.0, 126.8, 122.4, 115.9, 111.0, 108.2, 108.1, 101.3, 83.3 (d, J = 5.5 Hz), 79.4 (d, J = 4.6 Hz), 64.9 (d, J = 5.5 Hz), 64.7 (d, J = 5.5 Hz), 43.9, 16.3 (d, J = 7.3 Hz), 16.1 (d, J = 7.3 Hz); ³¹**P** NMR (162 MHz, CDCl₃) δ 0.56; **IR** (thin film) v 3280.9, 2989.7, 2249.0, 1726.3, 1608.6, 1483.3, 1444.7, 1244.1, 1018.4, 733.0 cm⁻¹; **HRMS** (ESI⁺) Calcd. for C₂₇H₂₇BrNO₈P 626.0555 (M+Na⁺) found 626.0550; **HPLC** Chiralpak IA column, Hex/^{*i*}PrOH = 90.9:9.1, flow rate = 1.0 mL/min, $\lambda = 210$ nm, 26.2min (minor isomer), 43.4 min (major isomer); **TLC** (1:4 EtOAc/Hexanes): $R_f = 0.39$.



(*R*)-1-Benzyl-5-bromo-3-((*S*)-(((dimethyl- λ^3 -oxidanyl)(λ^1 -oxidanyl)phosphoryl)oxy)(2fluorophenyl)methyl)-3-hydroxyindolin-2-one (4x): The title compound was prepared according to general procedure. The diastereomeric ratio was determined by ¹H NMR spectroscopic analysis of the crude reaction mixture by comparison of the resonances at δ

6.21 (major diastereomer) and δ 6.16 (minor diastereomer). White solid; ¹**H** NMR (400 MHz, CDCl₃) δ 7.71 (s, 1H), 7.35-7.29 (m, 2H), 7.20-7.11 (m, 3H), 7.00 (t, J = 9.2 Hz, 1H), 6.96-6.90 (m, 2H), 6.65 (d, J = 7.3 Hz, 2H), 6.35 (d, J = 8.2 Hz, 1H), 6.14 (d, J = 9.2 Hz, 1H), 5.01 (d, J = 16.5 Hz, 1H), 4.35 (br, 1H), 4.33 (d, J = 16.0 Hz, 1H), 3.75 (d, J = 11.4 Hz, 3H), 3.68 (d, J = 11.4 Hz, 3H); ¹³C NMR (126 MHz, CDCl₃) δ 174.1, 160.0 (d, J = 252.1 Hz), 142.5, 134.6, 133.4, 131.2 (d, J = 8.3 Hz), 129.6, 128.9, 127.7, 126.7, 124.1 (d, J = 3.6 Hz), 121.5 (d, J = 3.6 Hz), 121.4 (d, J = 3.6 Hz), 115.9, 115.8, 111.1, 78.5 (d, J = 5.5 Hz), 75.9, (d, J = 5.5 Hz), 75.5₆ (d, J = 5.5 Hz), 55.0 (d, J = 6.4 Hz), 54.9 (d, J = 6.4 Hz), 44.0; ³¹P NMR (162 MHz, CDCl₃) δ 2.39; ¹⁹F NMR (376 MHz, CDCl₃) δ -114.0; **IR** (thin film) v 3273.2, 2355.1, 1730.2, 1608.6, 1483.3, 1454.3, 1344.4, 1263.4, 1180.4, 1028.1 cm⁻¹; **HRMS** (ESI⁺) Calcd. for C₂₄H₂₂BrFNO₆P 572.0250 (M+Na⁺) found 572.0245; **HPLC** Chiralpak IA column, Hex/^{*i*}PrOH/EtOH = 93:5:2 (4 °C), flow rate = 1.0 mL/min, $\lambda = 210$ nm, 76.3 min (minor isomer), 92.1 min (major isomer); **TLC** (1:4 EtOAc/Hexanes): $R_f = 0.42$.



(*R*)-1-Benzyl-5-bromo-3-((*S*)-(((dimethyl- λ^3 -oxidanyl)(λ^1 -oxidanyl)phosphoryl)oxy)(*o* -tolyl)methyl)-3-hydroxyindolin-2-one (4y): The title compound was prepared according to general procedure. The diastereometic ratio was determined by ¹H NMR spectroscopic

analysis of the crude reaction mixture by comparison of the resonances at δ 6.15 (major diastereomer) and δ 6.04 (minor diastereomer). White solid; ¹**H** NMR (400 MHz, CDCl₃) δ 7.81 (s, 1H), 7.33 (d, J = 8.7 Hz, 1H), 7.23-7.06 (m, 5H), 6.89 (t, J = 7.8 Hz, 1H), 6.69 (d, J = 8.2 Hz, 1H), 6.42 (d, J = 6.9 Hz, 2H), 6.29 (dd, J = 1.4, 8.7 Hz, 1H), 6.14 (d, J = 8.7 Hz, 1H), 5.05 (d, J = 16.0 Hz, 1H), 4.18 (d, J = 16.5 Hz, 1H), 3.74 (dd, J = 1.8, 11.5 Hz, 3H), 3.57 (dd, J = 1.4, 11.4 Hz, 3H), 2.44 (s, 3H), OH-proton was not found probably due to broadening; ¹³C NMR (126 MHz, CDCl₃) δ 174.7, 142.6, 137.6, 134.4, 133.2, 132.4 (d, J = 2.7 Hz), 130.8, 129.8, 129.3, 128.9, 128.7, 127.7, 127.5, 126.4, 125.9, 116.0, 111.0, 79.2 (d, J = 6.4 Hz), 79.0 (d, J = 6.4 Hz), 54.8 (d, J = 5.5 Hz), 54.5 (d, J = 5.5 Hz), 43.9, 19.8; ³¹P NMR (162 MHz, CDCl₃) δ 2.60; **IR** (thin film) v 3203.6, 2956.9, 2245.1, 1725.3, 1606.7, 1454.3, 1346.3, 1222.9, 1003.0, 812.0 cm⁻¹; **HRMS** (ESI⁺) Calcd. for C₂₅H₂₅BrNO₆P 596.0501 (M+Na⁺) found 596.0495; **HPLC** Chiralpak IA column, Hex/[†]PrOH = 90.9:9.1, flow rate = 1.0 mL/min, $\lambda = 210$ nm, 15.9 min (minor isomer), 21.6 min (major isomer); **TLC** (1:4 EtOAc/Hexanes): $R_f = 0.40$.



(*R*)-1-Benzyl-5-bromo-3-((*S*)-(((dimethyl- λ^3 -oxidanyl)(λ^1 -oxidanyl)phosphoryl)oxy)(naphthalen-1-yl)methyl)-3-hydroxyindolin-2-one (4z): The title compound was prepared according to general procedure. The diastereomeric ratio was determined by ¹H NMR spectroscopic analysis of the crude reaction mixture by comparison of the

resonances at δ 6.41 (minor diastereomer) and δ 6.17 (major diastereomer). White solid; ¹H NMR (400 MHz, CDCl₃) δ 8.29 (d, J = 8.7 Hz, 1H), 7.90 (d, J = 2.3 Hz, 1H), 7.82 (dd, J = 5.0, 8.2 Hz, 2H), 7.59-7.51 (m, 1H), 7.49-7.46 (m, 1H), 7.30 (dd, J = 1.4, 8.7 Hz, 1H), 7.17 (t, J = 7.8 Hz, 1H), 7.09-7.05 (m, 2H), 6.96-6.93 (m, 2H), 6.76 (d, J = 8.7 Hz, 1H), 6.22 (d, J = 8.2 Hz, 1H), 6.12, (m, 2H), 4.81 (d, J = 16.0 Hz, 1H), 4.65 (br, 1H), 4.01 (d, J = 16.0 Hz, 1H), 3.75 (dd, J = 1.8, 9.6 Hz, 3H), 3.57 (d, J = 11.4 Hz, 3H); ¹³C NMR (126 MHz, CDCl₃) δ 174.3, 142.7, 134.3, 133.5, 133.2, 130.8, 130.0, 129.7, 129.6, 129.0, 128.8, 128.7, 128.6, 127.5, 127.0, 126.6, 126.4, 126.2, 124.7, 123.5, 115.9, 110.9, 79.4 (d, J = 4.5 Hz), 55.0 (d, J = 5.5 Hz), 54.7 (d, J = 6.4 Hz), 43.9; ³¹P NMR (162 MHz, CDCl₃) δ 2.84; **IR** (thin film) v 3277.1, 2955.0, 2247.1, 1730.2, 1608.6, 1481.3, 1259.5, 1174.7, 1026.1, 731.0 cm⁻¹; **HRMS** (ESI⁺) Calcd. for C₂₈H₂₅BrNO₆P 604.0501 (M+Na⁺) found 604.0496; **HPLC** Chiralpak IA column, Hex/^{*i*}PrOH = 85:15, flow rate = 1.0 mL/min, $\lambda = 210$ nm, 16.3 min (minor isomer), 30.0 min (major isomer); **TLC** (1:4 EtOAc/Hexanes): $R_f = 0.38$.

Details of crossover experiment:

Three oven-dried test tubes were evacuated and filled with argon, then charged sequentially with the cross pinacol product (\pm)-4aa (49.6 mg, 0.1 mmol) and THF (1.0 mL), followed by 4-fluorobenzaldehyde (42.1 μ L, 0.4 mmol, 4.0 equiv). The reaction was stirred at 0 °C, or -40 °C, or -78 °C in an appropriate cooling apparatus, then the iminophosphorane catalyst C1 (5.81 mg, 0.01 mmol, 0.1 equiv) was added. The reaction was then stirred at the same temperatures for 24 h. Trifluoroacetic acid in toluene (40 μ L of an 0.5 M solution) was added to quench the reaction and the reaction was concentrated on a rotatory evaporator.

Analysis of crossover experiment:

The reactions were analyzed by ¹H NMR spectroscopy on an 800 MHz spectrometer. The ¹H NMR trace show below details the results of the above crossover experiment. The trace on bottom shows racemic starting material (3.2:1 d.r.). The major and minor diastereomer peaks of the starting material are identified with red wedges. As the temperature is increased from –78 °C to –40 °C, crossover starts to occur; the major and minor diastereomers of the crossover product are identified with green wedges. Additionally, at 0 °C the d.r. of the starting material was observed to sharply increase; we attribute this to a relatively rapid retro reaction of the minor diastereomer of starting material (which could also be responsible for the low diastereoselectivity of crossover product at that temperature). These results suggest that the crossover process shuts down between –40 °C and -78 °C.



Crystallographic structure determination:

The single crystal, which was obtained by the procedure described below, was mounted on MicroMesh. Data of X-ray diffraction were collected at 93 K on a Bruker D8 QUEST with fine-focus sealed tube Mo/K α radiation ($\lambda = 0.71073$ Å). An absorption correction was made using Bruker SMART APEXII ULTRA. The structure was solved by direct methods and Fourier syntheses, and refined by full-matrix least squares on F^2 by using SHELXTL-2014.³ All non-hydrogen atoms were refined with anisotropic displacement parameters. Hydrogen atom bonded to oxygen atom was located from a difference synthesis and their coordinates and isotropic thermal parameters refined. The other hydrogen atoms were placed in calculated positions and isotropic thermal parameters refined.

Recrystallization of 4j:

Recrystallization from a solution of **4j** in hexane/CH₂Cl₂ solvent system at room temperature afforded single crystals of **4j**. The crystallographic data were summarized in Table S1 and ORTEP diagram was shown in Fig. S1.

Table S1	. Crystal	data and	structure	refinement	for 4	4j	(CCDC-)	1055582).
	~							

Empirical formula	$C_{27}H_{29}BrNO_6P$
Formula weight	574.38
Temperature	93(2) K
Wavelength	0.71073 Å
Crystal system	triclinic
Space group	P1
Unit cell dimensions	$a = 10.2391(6) \text{ Å} \alpha = 91.3040(13)^{\circ}.$
	$b = 11.4922(6) \text{ Å}_{\beta} \beta = 98.3180(17)^{\circ}.$
	$c = 24.9637(12) \text{ Å } \gamma = 114.9350(14)^{\circ}.$
Volume	$2624.1(2) \text{ Å}^3$
Z	4
Density (calculated)	1.454 g/cm^3
Absorption coefficient	1.670 mm^{-1}
F(000)	1184
Crystal size	0.080 x 0.160 x 0.410 mm ³
Theta range for data collection	2.20 to 24.96°.
Index ranges	$-12 \le h \le 10, -12 \le k \le 13, -28 \le l \le 29$
Reflections collected	17679
Independent reflections	13136 [R(int) = 0.0359]
Completeness to theta = 27.46°	95.0 %
Absorption correction	multi-scan
Max. and min. transmission	0.8780 and 0.5480
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	13136 / 1803 / 1313
Goodness-of-fit on F^2	1.077
Final R indices [I>2sigma(I)]	$R_1 = 0.0399, wR_2 = 0.1044$
R indices (all data)	$R_1 = 0.0453, wR_2 = 0.1249$
Absolute structure parameter	0.1(0)
Largest diff. peak and hole	$0.955 \text{ and } -0.754 \text{ e.} \text{\AA}^{-3}$



Fig. S1. ORTEP diagram of **4j**. All calculated hydrogen atoms are omitted for clarity except for that attached to the olefinic carbons. Blue = nitrogen, red = oxygen, vermilion = bromine, gray = carbon.

References and notes:

- a) L. E. Overman, E. A. Peterson, *Tetrahedron* 2003, **59**, 6905-6919. b) D. J. Vyas, R. Froehlich, M. Oestreich, *J. Org. Chem.* 2010, 75, 6720-6723. c) R. Bouhfid, N. Joly, E. M. Essassi, V. Lequart, M. Massoui, P. Martin, *Synth. Commun.* 2011, **41**, 2096-2102.
- 2. D. Uraguchi, K. Yoshioka, Y. Ueki, T. Ooi, J. Am. Chem. Soc. 2012, 134, 19370-19373.
- 3. G. M. Sheldrick, Acta Cryst. 2008, A64, 112.

Crude ¹H NMR spectra for the racemic reaction:









































Crude ¹H NMR spectra for the asymmetric reaction:








































































HPLC traces:

4a:





4h:



4i:



4j:



4l:

4m:





4n:



4o:



4p:

4q:



2	29.693	122705	9370729	88.115
3	33.589	3604	296383	2.787
4	73.473	1450	224722	2.113
合計		138162	10634629	



4r:



4s:



4t:



4u:



4v:



4w:





ピーク#	保持時間	高さ	面積
1	76.305	3882	485233
2	92.055	210105	49009898
合計		213987	49495132

4x:



4y:

S63



4z:

Copies of ¹H and ¹³C NMR:

















































































































































































































