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PHOSPHINOMETHYL-OXAZOLINES AS EFFICIENT LIGANDS FOR THE IRIDIUM-CATALYZED ENANTIOSELECTIVE HYDROGENATION OF UNFUNCTIONALIZED TETRASUBSTITUTED OLEFINS

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Dedicated to Professor Ryoji Noyori on the occasion of his 70th birthday

Abstract – Iridium-catalyzed enantioselective hydrogenation has become the method of choice for the enantioselective reduction of unfunctionalized olefins. In particular, tetrasubstituted olefins are interesting substrates, which allow the generation of two adjacent stereocenters in a single hydrogenation step. For this class of substrates, chiral phosphinomethyl-oxazolines have proved to be very efficient ligands. Herein we report a short and practical synthesis of differently substituted phosphinomethyl-oxazolines and the corresponding iridium(COD) complexes. The scope of these catalysts is demonstrated by hydrogenation studies of four tetrasubstituted olefins.

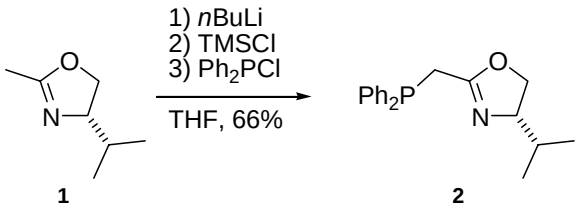
INTRODUCTION

Recently we found that tetrasubstituted olefins can be hydrogenated with high enantioselectivity using iridium catalysts derived from oxazoline-based P,N ligands.[1] Among the various ligands tested phosphinomethyl-oxazolines, which form a 5-memebred chelate ring, proved to be particularly efficient. Herein we report a new practical synthesis which makes this class of ligands, and the corresponding iridium complexes, readily available from 2-(chloromethyl)oxazolines.

RESULTS AND DISCUSSION

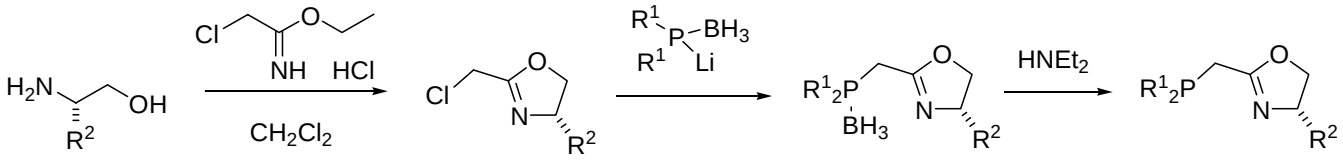
The first example of a phosphinomethyl-oxazoline was reported by Sprinz and Helmchen, who prepared ligand **2** by the route shown in Scheme 1.[2] Methyl oxazoline **1** was deprotonated with *n*BuLi and the resulting anion quenched with trimethylsilyl chloride. Subsequent addition of chlorodiphenylphosphine

gave ligand **2** in 66% yield.[2] In our hands this method proved to be very sensitive to the reaction conditions and gave variable yields.



Scheme 1. Ligand synthesis by Sprinz and Helmchen.[2]

Therefore, we decided to investigate the alternative route shown in Scheme 2. 2-(chloromethyl)oxazolines were chosen as convenient and readily available precursors.[4] They smoothly underwent nucleophilic substitution with lithiated phosphine boranes to give the air-stable BH_3-protected phosphinomethyl oxazolines, which were converted to the free ligands by deprotection with diethylamine. Various $(aryl)_2P$- and $(alkyl)_2P$-substituted ligands[3] were prepared by this route.

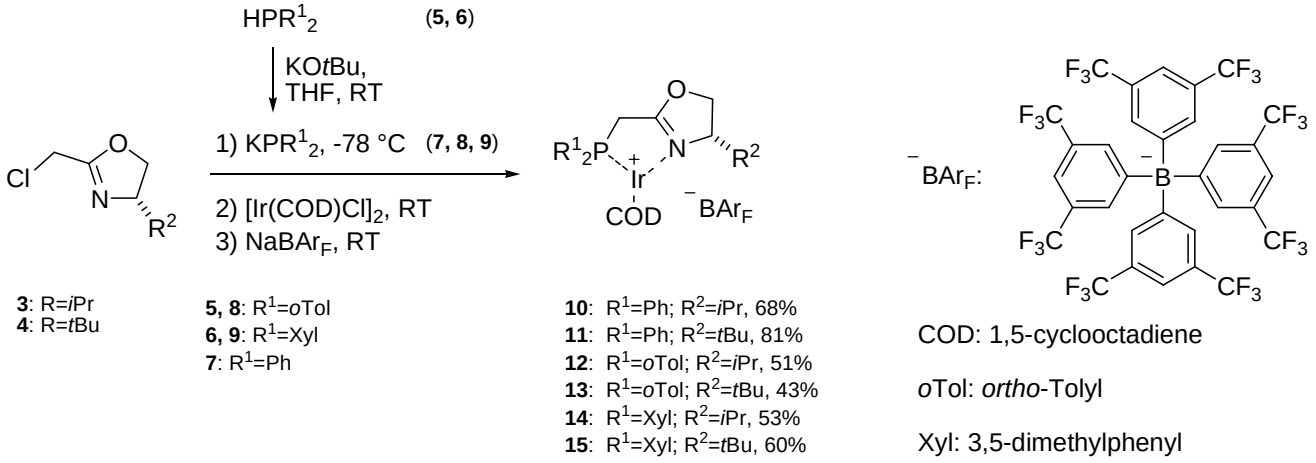


Scheme 2. Ligand synthesis using nucleophilic substitution with BH_3-protected phosphines.

However, for the preparation of structurally diverse catalyst libraries, it was desirable to shorten the synthesis by eliminating the protection and deprotections steps. We therefore studied the protecting group free synthesis, shown in Scheme 3, leading directly to the desired iridium complexes.

Initial experiments used commercially available potassium diphenylphosphide solution in THF and (*S*)-2-(chloromethyl)-4-isopropyl-oxazoline **3**. After removal of KCl and evaporation of the reaction solvent, the crude ligand was treated with $[Ir(COD)Cl]_2$ in CH_2Cl_2 followed by anion exchange with NaBArF (sodium tetrakis[3,5-di(trifluoromethyl)phenyl]borate) and column chromatography on silica gel. In this way analytically pure iridium complex **10** was be obtained in 68% yield.

The Xyl_2P-substituted complex **15** was prepared in a similar fashion. Xyl_2PH was deprotonated with KO*t*Bu in THF to give a solution of the corresponding phosphide which was added to (*S*)-2-(chloromethyl)-4-*tert*-butyl-oxazoline **4**. Following the procedure developed for complex **10**, the Xyl_2P-substituted iridium complex **15** was obtained in 60% yield.



Scheme 3. Optimized synthesis of iridium complexes **10**-**15**.

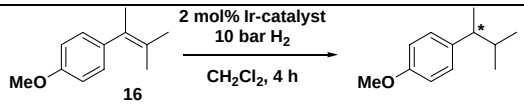
The synthesis was further improved by avoiding any workup after ligand formation. After nucleophilic substitution in THF, $[Ir(COD)Cl]_2$ was directly added to the reaction solution containing the crude ligand. After anion exchange with $NaBAr_F$ and column chromatography, complex **11** was isolated in 81% yield. Using the same procedure, complexes **12**-**14** were obtained in 43 - 53% yield. This method proved to be very convenient, as it gave moderate to good overall yields and allowed the rapid generation of libraries of iridium catalysts starting from easily accessible precursors.

We next tested these catalysts in the enantioselective hydrogenation of unfunctionalized tetrasubstituted olefins (Table 1). In our previous study we found that low hydrogen pressure had a positive effect on the enantioselectivity without affecting the conversion.[1] Therefore, we applied 10 bar of hydrogen pressure in this catalyst screening using 2 mol% of catalyst and a reaction time of 4 hours.

As expected, using $(aryl)_2P$-substituted ligands the enantioselectivities obtained for the reduction of olefin **16** were moderate. Previous studies from our group showed that Cy_2P-substituted ligands (Cy = cyclohexyl) are better suited for this substrate; the corresponding iridium catalyst with R^1 = Cy and R^2 = Ph gave up to 97% *ee* at 1 bar.[1] On the other hand, for conformationally more restricted indenes $(alkyl)_2P$-substituted ligands gave only moderate enantioselectivities, whereas $(aryl)_2P$-substituted ligands proved to be the ligands of choice in this case.[1]

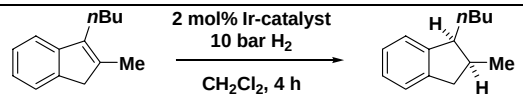
In line with our previous study, iridium catalysts **10**-**15** gave good to very good enantioselectivities in the hydrogenation of indenes **17**-**19**. In the case of **17** full conversion could be obtained with all catalysts, while for **18** and **19** conversions were often not complete after 4 hours. The sterically less demanding *i*Pr-substituted complexes (**10**, **12**, **14**) reacted faster and more selectively than the corresponding *t*Bu-substituted analogs (**11**, **13**, **15**), as seen from the higher conversions and *ee* values.

Table 1. Enantioselective hydrogenation of tetrasubstituted olefins.



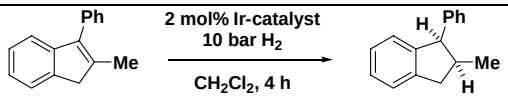
16

entry	complex	conversion [%]	*ee* [%]
1	**10**	>99	58 (−)
2	**11**	64	44 (−)
3	**12**	>99	67 (−)
4	**13**	99	48 (−)
5	**14**	>99	23 (−)
6	**15**	90	41 (−)



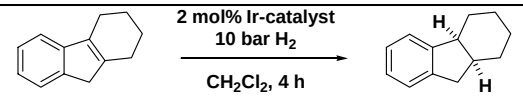
17

entry	complex	conversion [%]	*ee* [%]
1	**10**	>99	93 (−)
2	**11**	>99	88 (−)
3	**12**	>99	91 (−)
4	**13**	>99	77 (−)
5	**14**	>99	92 (−)
6	**15**	>99	85 (−)



18

entry	complex	conversion [%]	*ee* [%]
1	**10**	91	96 (+)
2	**11**	6	83 (+)
3	**12**	>99	97 (+)
4	**13**	22	81 (+)
5	**14**	87	96 (+)
6	**15**	10	80 (+)



19

entry	complex	conversion [%]	*ee* [%]
1	**10**	43	90 (+)
2	**11**	17	80 (+)
3	**12**	>99	95 (+)
4	**13**	62	81 (+)
5	**14**	88	95 (+)
6	**15**	29	78 (+)

CONCLUSION

We have presented a short and efficient synthesis of iridium(phosphinomethyl-oxazoline) complexes for the enantioselective hydrogenation of unfunctionalized tetrasubstituted olefins. Hydrogenation studies with a series of indenes showed that sterically less demanding catalysts react faster and give better enantioselectivities than catalysts bearing bulky substituents on the oxazoline unit.

EXPERIMENTAL

General: For general information regarding instrumentation refer to our previous publications.[1] All chemicals were purchased from Acros Organics, Aldrich, Fluka, Lancaster Synthesis, Merck Molecula or

Strem Chemicals. 2-(chloromethyl)oxazolines **3** and **4** were synthesized according to a previously published procedure[4]. The ligands were synthesized using standard Schlenk techniques. NMR: chemical shifts are reported in ppm and calibrated to the residual proton and carbon resonance of the solvent: CD_2Cl_2 (δH 5.32, δC 53.1 ppm).

10: In a Schlenk-tube 2-(chloromethyl)oxazoline **3** (90.0 mg, 557 μmol, 1.37 eq) was dissolved in THF (0.7 mL) and cooled down to −78 °C. A $KPPh_2$-solution (1.0 mL, 0.5 M in THF) was added dropwise using a syringe (immediate decolorization), and the syringe was rinsed with 0.5 mL of THF. The cooling bath was removed and the solution was stirred for 2 h at rt. The solvent was removed *in vacuo* and the crude product was dissolved in toluene (2 × 1 mL) and filtered through a disposable HPLC-filter (CHROMAFIL® O-20/15 MS, pore size 20 μm). The solvent was removed *in vacuo* and the ligand was dissolved in 2 mL of CH_2Cl_2. This solution was added dropwise under stirring to a solution of $[Ir(COD)Cl]_2$ (170 mg, 253 mmol, 0.50 eq) in 1 mL of CH_2Cl_2. The resulting solution was refluxed for 45 min and cooled down to rt. $NaBAr_F$ (535 mg, 604 mmol, 1.20 eq) was added and the mixture was stirred for 30 min. Silica gel (3 g) was added and the solvent was removed *in vacuo*. Flash chromatography on silica gel (40 g; h × d = 15 × 2.5 cm, a: 150 mL of MTBE, b: 150 mL of CH_2Cl_2) gave 502 mg of the title compound as an orange solid (340 mmol, 68%, R_f = 0.85, CH_2Cl_2).

Elemental Analysis for $C_{60}H_{48}BF_{24}IrNOP$ (1475.0), calc.: C, 48.04; H, 3.14; N, 0.95; found: C, 48.02; H, 3.27; N, 0.83; $[\alpha]^{20}_D$ +3 (*c* 0.14, CH_2Cl_2); **IR** (υ[cm^{-1}]) = 2970w, 2842w, 1603m, 1483w, 1431m, 1357s, 1278s, 1128s, 1005w, 938w, 889m, 742w, 712m, 675m; **^{1}H-NMR** (400.1 MHz, CD_2Cl_2, 300 K): δ = 7.82 (m, 2H, H_{Ar}), 7.72 (s, 8H, $H_{ArF,\,o}$), 7.65 (m, H_{Ar}), 7.56 (s, 4H, $H_{ArF,\,p}$), 7.56 (m, 5H, H_{Ar}), 7.38 (m, 2H, H_{Ar}), 5.19 (m, COD-C*H*), 5.01 (m, COD-C*H*), 4.64 (dd, *J* = 3.8 Hz, *J* = 9.9 Hz, OCH_2), 4.54 (dd, *J* = 9.5 Hz, *J* = 9.6 Hz, OCH_2), 4.06 (m, NC*H*), 3.99 (m, COD-C*H*), 3.75 (dd, *J* = 11.3 Hz, *J* = 18.5 Hz, PCH_2),3.50 (ddd, *J* = 1.7 Hz, *J* = 6.8 Hz, *J* = 18.3 Hz, PCH_2), 3.02 (m, COD-C*H*), 2.51 (m, COD-CH_2), 2.43 (m, COD-CH_2), 2.37 (m, COD-CH_2), 2.29 (m, COD-CH_2), 2.19 (m, COD-CH_2), 1.99 (m, 2H, C*H*$(CH_3)_2$, COD-CH_2), (m, COD-CH_2), 1.78 (m, COD-CH_2), 1.59 (m, COD-CH_2) , 0.90 (d, 3H, *J* = 6.9 Hz, CH(CH_3)$_2$), 0.40 (d, 3H, *J* = 6.8 Hz, CH(CH_3)$_2$); **^{13}C{^{1}H}-NMR** (125.8 MHz, CD_2Cl_2, 300 K): δ = 182.9 (d, J_{CP} = 19 Hz, O*C*=N), 162.1 (q, J_{CB} = 50 Hz, H$C_{ArF,\,ipso}$), 135.5 (d, J_{CP} = 13 Hz, HC_{Ar}), 135.2 (H$C_{ArF,\,o}$), 133.6 (d, J_{CP} = 2 Hz, HC_{Ar}), 132.6 (d, J_{CP} = 2 Hz, HC_{Ar}), 131.7 (d, J_{CP} = 11 Hz, HC_{Ar}), 130.2 (d, J_{CP} = 11 Hz, HC_{Ar}), 130.0 (d, J_{CP} = 11 Hz, HC_{Ar}), 129.2 (qq, J_{BC} = 3 Hz, J_{CF} = 31 Hz, $C_{ArF,\,m}$), 129.1 (d, J_{CP} = 52 Hz, C_{Ar}), 125.0 (q, J_{CF} = 270 Hz, *C*F_3), 125.2 (d, J_{CP} = 54 Hz, C_{Ar}), 117.8 (sept, J_{CF} = 4 Hz, H$C_{ArF,\,p}$), 97.3 (d, J_{CP} = 10 Hz, COD-*C*H), 91.2 (d, J_{CP} = 14 Hz, COD-*C*H), 73.5 (OCH_2), 68.5 (NCH), 64.9 (COD-*C*H), 62.8 (COD-*C*H), 35.7 (d, J_{CP} = 4 Hz, COD-*C*H_2), 32.4 (*C*H$(CH_3)_2$), 32.3 (COD-*C*H_2), 31.4 (d, J_{CP} = 33 Hz, P*C*H_2), 29.6 (d, J_{CP} = 2 Hz, COD-*C*H_2), 27.6 (d, J_{CP} = 2 Hz, COD-*C*H_2), 18.5

($CH(CH_3)_2$), 13.6 ($CH(CH_3)_2$); **$^{31}P\{^1H\}$-NMR** (162.0 MHz, CD_2Cl_2, 300 K): δ = 25.2; **$^{19}F\{^1H\}$-NMR** (376.5 MHz, CD_2Cl_2, 300 K): δ = −64.0; **MS** (+ESI), m/z:. 612 ($[M-BArF]^+$, 100).

11: In a Schlenk-tube 2-(chloromethyl)oxazoline **4** (61.8 mg, 352 μmol, 1.14 eq) was dissolved in THF (0.5 mL) and cooled down to −78 °C. A $KPPh_2$-solution (0.55 mL, 0.5 M in THF) was added dropwise using a syringe (immediate decolorization), and the syringe was rinsed with 0.5 mL of THF. The cooling bath was removed and the solution was stirred for 2 h at rt.

This solution was added dropwise to a solution of $[Ir(COD)Cl]_2$ (91.0 mg, 135 μmol, 0.50 eq) in 0.5 mL of THF, and the syringe was rinsed with 2 mL of THF. The resulting solution was refluxed for 45 min and cooled down to rt. $NaBAr_F$ (287 mg, 324 μmol, 1.20 eq) was added and the mixture was stirred for 30 min. Silica gel (3 g) was added and the solvent was removed *in vacuo*. Flash chromatography on silica gel (25 g; h × d = 10 × 2.5 cm, a: 150 mL of MTBE, b: 150 mL of CH_2Cl_2) gave 326 mg of the title compound as an orange solid (219 μmol, 81%, R_f = 0.91, CH_2Cl_2).

Elemental Analysis for $C_{60}H_{48}BF_{24}IrNOP$ (1489.0), calc.: C, 48.40; H, 3.25; N, 1.15; found: C, 48.24; H, 3.14; N, 1.15; **$[\alpha]^{20}_D$** +16 (*c* 0.22, $CHCl_3$); **IR** (υ[cm^{-1}]) = 2969w, 2891s, 2366w, 1601m, 1481w, 1357s, 1279s, 1132s, 997w, 890m, 837m, 747w, 675m; **^{1}H-NMR** (400.1 MHz, CD_2Cl_2, 300 K): δ = 7.82 (m, 2H, H_{Ar}), 7.72 (s, 8H, $H_{ArF,\,o}$), 7.66 (m, 1H, H_{Ar}), 7.61 (m, 2H, H_{Ar}), 7.56 (s, 4H, $H_{ArF,\,p}$), 7.54 (m, 2H, H_{Ar}), 7.34 (m, 2H, H_{Ar}), 5.23 (m, 1H, COD-C*H*), 4.87 (m, 1H, COD-C*H*), 4.76 (dd, *J* = 1.5 Hz, *J* = 8.6 Hz, OCH_2), 4.51 (dd, 1H, *J* = 8.6 Hz, *J* = 9.8 Hz, OCH_2), 4.21 (m, 1H, COD-C*H*), 3.96 (dd, 1H, *J* = 11.4 Hz, *J* = 18.7 Hz, PCH_2), 3.73 (d, 1H, *J* = 7.6 Hz, NC*H*), 3.57 (ddd, 1H, *J* = 1.7 Hz, *J* = 5.0 Hz, *J* = 18.7 Hz, PCH_2), 2.92 (m, 1H, COD-C*H*), 2.55 (m, 1H, COD-CH_2), 2.47 (m, 1H, COD-CH_2), 2.35 (m, 1H, COD-CH_2), 2.25 (m, 1H, COD-CH_2), 2.11 (m, 1H, COD-CH_2), 1.96 (m, 1H, COD-CH_2), 1.73 (m, 1H, COD-CH_2), 1.53 (m, 1H, COD-CH_2), 0.73 (s, 9H, C(CH_3)$_3$); **$^{13}C\{^1H\}$-NMR** (125.8 MHz, CD_2Cl_2, 300 K): δ = 180.3 (d, J_{CP} = 18 Hz, O*C*=N), 162.1 (q, J_{CB} = 50 Hz, $C_{ArF,\,ipso}$), 135.8 (d, J_{CP} = 24 Hz, HC_{Ar}), 135.2 (m, H$C_{ArF,\,o}$), 133.8 (d, J_{CP} = 2 Hz, HC_{Ar}), 132.6 (d, J_{CP} = 3 Hz, HC_{Ar}), 131.6 (d, J_{CP} = 14 Hz, HC_{Ar}),130.2 (d, J_{CP} = 11 Hz, HC_{Ar}), 130.0 (d, J_{CP} = 11 Hz, HC_{Ar}), 129.2 (qq, J_{BC} = 3 Hz, J_{CF} = 31 Hz, $C_{ArF,\,m}$), 125.0 (d, J_{CP} = 56 Hz, C_{Ar}), 125.0 (q, J_{CF} = 270 Hz, *C*F_3), 117.8 (sept, J_{CF} = 4 Hz, $C_{ArF,\,p}$), 97.4 (d, J_{CP} = 9 Hz, COD-*C*H), 89.3 (d, J_{CP} = 15 Hz, COD-*C*H), 75.1 (OCH_2), 71.7 (N*C*H), 64.1 (COD-*C*H), 63.2 (COD-*C*H), 36.6 (d, J_{CP} = 5 Hz, COD-*C*H_2), 34.9 (*C*(CH_3)$_3$), 33.1 (COD-*C*H_2), 31.5 (d, J_{CP} = 34 Hz, PCH_2), 29.3 (d, J_{CP} = 2 Hz, COD-*C*H_2), 26.2 (d, J_{CP} = 3 Hz, COD-*C*H_2), 25.1 (C(*C*H_3)$_3$); **$^{31}P\{^1H\}$-NMR** (162.0 MHz, CD_2Cl_2, 300 K): δ = 28.5 (br. s); **$^{19}F\{^1H\}$-NMR** (376.5 MHz, CD_2Cl_2, 300 K): δ = −64.0; **MS** (+ESI), m/z:. 626 ($[M-BArF]^+$, 100).

12: In a glovebox *o*Tol_2PH (30.0 mg, 140 μmol, 1.00 eq) was dissolved in THF (0.5 mL). KO*t*Bu (24.0

mg, 200 μmol, 1.20 eq) was added resulting in an orange solution which was stirred for 1 h. In a Schlenk-tube 2-(chloromethyl)oxazoline **3** (29.0 mg, 182 μmol, 1.30 eq) was dissolved in 0.5 mL THF and cooled down to −78 °C. The solution of the deprotonated phosphine was added dropwise using a syringe (immediate decolorization), and the syringe was rinsed with 2 × 0.5 mL of THF. The cooling bath was removed and the solution was stirred for 1 h at rt.

This solution was added dropwise to a solution of $[Ir(COD)Cl]_2$ (52.0 mg, 77.5 μmol, 0.55 eq) in 0.5 mL of THF. The resulting solution was refluxed for 45 min and cooled down to rt. $NaBAr_F$ (145 mg, 168 μmol, 1.20 eq) was added and the mixture was stirred for 30 min. Silica gel (3 g) was added and the solvent was removed *in vacuo*. Flash chromatography on silica gel (25 g, h × d = 10 × 2.5, a: 100 mL MTBE, b: 150 mL CH_2Cl_2) gave 107 mg of the title compound as a yellow solid (71.2 μmol, 51%, R_f = 0.94, CH_2Cl_2).

NMR-analysis was hampered by signal broadening caused by conformational equilibria.

Elemental Analysis for $C_{61}H_{50}BF_{24}IrNOP$ (1503.0), calc.: C, 48.75; H, 3.35; N, 0.93; found: C, 48.66; H, 3.38; N, 0.85; $[\alpha]^{20}_D$ +45 (*c* = 0.2, $CHCl_3$); **IR** (υ[cm^{-1}]) = 2980w, 1601m, 1458w, 1352s, 1271s, 1113s, 1011w, 939w, 885m, 839m, 756w, 744w, 711m, 680m, 669m; **^{1}H-NMR** (500.1 MHz, CD_2Cl_2, 300 K): δ = 8.31 (s, 1H, H_{Ar}), 7.73 (s, 8H $H_{ArF,\,o}$), 7.57 (m, 1H, H_{Ar}), 7.56 (s, 4H $H_{ArF,\,p}$), 7.46 (m, 1H, H_{Ar}), 7.42 (m, 3H, H_{Ar}), 7.22 (m, 1H, H_{Ar}), 7.06 (dd, 1H, *J* = 7.8 Hz, *J* = 13.4 Hz, H_{Ar}), 5.20 (m, 1H, COD-C*H*), 4.92 (m, 1H, COD-C*H*), 4.61 (dd, 1H, *J* = 4.0 Hz, *J* = 9.7 Hz, OCH_2), 4.53 (t, 1H, *J* = 9.5 Hz, OCH_2), 4.07 (m, 1H, NC*H*), 3.78 (m, 1H, COD-C*H*), 3.68 (dd, 1H, *J* = 10.8 Hz, *J* = 18.9 Hz, PCH_2), 3.61 (ddd, 1H, *J* = 1.8 Hz, *J* = 6.9 Hz, *J* = 18.9 Hz, PCH_2), 2.84 (s, 3H, $C_{Ar}CH_3$), 2.54 (m, 1H, COD-CH), 2.48 (dt, 1H, *J* = 5.9 Hz, *J* = 9.6 Hz, COD-CH_2), 2.38 (m, 2H, COD-CH_2), 2.30 (m, 1H, COD-CH_2), 2.26 (s, 3H, $C_{Ar}CH_3$), 2.17 (m, 1H, COD-CH_2), 2.05 - 1.92 (m, 2H, C$H(CH_3)_2$, COD-CH_2), 1.73 (dt, 1H, *J* = 8.2 Hz, *J* = 15.1 Hz, COD-CH_2), 1.52 (m, 1H, COD-CH_2), 0.91 (d, 3H, *J* = 7.1 Hz, CH(CH_3)$_2$), 0.39 (d, 3H, *J* = 6.8 Hz, CH(CH_3)$_2$); **^{13}C{^{1}H}-NMR** (125.8 MHz, CD_2Cl_2, 300 K): δ = 182.3 (d, J_{CP} = 21 Hz, O*C*=N), 161.4 (q, J_{CB} = 50 Hz, $C_{ArF,\,ipso}$), 141.6 (d, J_{CP} = 2 Hz), 140.2 (br. s), 140.1 (d, J_{CP} = 2 Hz), 140.0 (br. s), 134.4 (m, $C_{ArF,\,o}$), 133.2 (d, J_{CP} = 3 Hz), 132.8 (d, J_{CP} = 7 Hz), 132.3, 132.2 (d, *J* = 1 Hz), 132.1 (d, J_{CP} = 5 Hz), 128.5 (qq, J_{BC} = 3 Hz, J_{CF} = 31 Hz, $C_{ArF,\,m}$), 126.9 (d, J_{CP} = 52 Hz, C_{Ar}), 126.5, 126.4 (d, J_{CP} = 5 Hz), 124.3 (q, J_{CF} = 272 Hz, *C*F_3), 121.1 (d, J_{CP} = 53 Hz, $C_{Ar,\,ipso}$), 117.1 (sept, J_{CF} = 4 Hz, $C_{ArF,\,p}$), 95.1 (d, J_{CP} = 10 Hz, COD-*C*H), 89.0 (d, J_{CP} = 14 Hz, COD-*C*H), 72.5 (OCH_2), 67.7 (d, J_{CP} = 1 Hz, N*C*H), 65.4 (COD-*C*H), 63.2 (COD-*C*H), 32.1 (d, J_{CP} = 1 Hz, COD-*C*H_2), 31.6 (s, *C*H(CH_3)$_2$), 29.0 (d, J_{CP} = 33 Hz, P*C*H_2), 28.5 (d, J_{CP} = 2 Hz, COD-*C*H_2), 26.6 (d, J_{CP} = 2 Hz, COD-*C*H_2), 22.3 (d, *J* = 4 Hz), 21.6 (d, *J* = 8 Hz), 17.8 (CH(*C*H_3)$_2$), 12.9 (CH(*C*H_3)$_2$); **^{31}P{^{1}H}-NMR** (162.0 MHz, CD_2Cl_2, 300 K): δ = 19.1 (br. s); **^{19}F{^{1}H}-NMR** (376.5 MHz, CD_2Cl_2, 300 K): δ = −64.0; **MS** (+ESI), m/z:. 640 ([M−BArF]$^+$, 100).

13: In a glovebox *o*Tol$_2$PH (20.0 mg, 93.4 μmol, 1.00 eq) was dissolved in THF (0.5 mL). KO*t*Bu (17.0 mg, 152 μmol, 1.60 eq) was added resulting in an orange solution which was stirred for 1 h. In a Schlenk-tube 2-(chloromethyl)oxazoline **4** (21.0 mg, 121 μmol, 1.30 eq) was dissolved in 0.5 mL THF and cooled down to −78 °C. The solution of the deprotonated phosphine was added dropwise using a syringe (immediate decolorization), and the syringe was rinsed with 2 × 0.5 mL of THF. The cooling bath was removed and the solution was stirred for 1 h at rt.

This solution was added dropwise to a solution of [Ir(COD)Cl]$_2$ (35.0 mg, 52.2 μmol, 0.55 eq) in 0.5 mL of THF. The resulting solution was refluxed for 45 min and cooled down to rt. NaBAr$_F$ (99.0 mg, 112 μmol, 1.20 eq) was added and the mixture was stirred for 30 min. Silica gel (3 g) was added and the solvent was removed *in vacuo*. Flash chromatography on silica gel (25 g; h × d = 10 × 2.5, a: 100 mL MTBE, b: 150 mL CH_2Cl_2) gave 60 mg of the title compound as a yellow solid (40 μmol, 43%, R_f = 0.94, CH_2Cl_2).

NMR-analysis was hampered by signal broadening caused by conformational equilibria.

Elemental Analysis for $C_{64}H_{56}BF_{24}IrNOP$ (1517.05), calc.: C, 49.09; H, 3.45; N, 0.92; found: C, 49.10; H, 3.49; N, 0.72; $[\alpha]^{20}_D$ +55 (*c* 0.23, $CHCl_3$); **IR** (υ[cm^{-1}]) = 2970w, 1597m, 1474w, 1358m, 1273s, 1119s, 995w, 887m, 833m, 756w, 671m; **^{1}H-NMR** (500.1 MHz, CD_2Cl_2, 300 K): δ = 8.29 (br. s, 1H, H_{Ar}), 7.72 (s, 8H, $H_{ArF,\,o}$), 7.59 (m, 1H, H_{Ar}), 7.56 (s, 4H, $H_{ArF,\,p}$), 7.44 (m, 4H, H_{Ar}), 7.21 (m, 1H, H_{Ar}), 6.92 (br. s, 1H, H_{Ar}), 5.25 (s, 1H, COD-C*H*), 4.80 (m, 1H, COD-C*H*), 4.74 (d, 1H, *J* = 9.9 Hz, OCH_2), 4.51 (t, 1H, *J* = 9.2 Hz, OCH_2), 4.04 (s, 1H, COD-C*H*), 3.88 (dd, 1H, *J* = 11.0 Hz, *J* = 18.9 Hz, PCH_2), 3.75 (d, 1H, *J* = 8.4 Hz, NC*H*), 3.70 (d, 1H, *J* = 18.9 Hz, PCH_2), 3.01 (br. s, 3H, $C_{Ar}CH_3$), 2.55 (m, 1H, COD-CH_2), 2.46 (m, 1H, COD-CH_2), 2.35 (m, 1H, COD-CH_2), 2.26 (m, 1H, COD-CH_2), 2.21 (s, 3H, $C_{Ar}CH_3$), 2.09 (m, 1H, COD-CH_2), 1.94 (m, 1H, COD-CH_2), 1.67 (m, 1H, COD-CH_2), 1.48 (m, 1H, COD-CH_2), 0.77 (s, 9H, C(CH_3)$_3$); **^{13}C{^{1}H}-NMR** (125.8 MHz, CD_2Cl_2, 300 K): δ = 161.4 (q, J_{CB} = 50 Hz, $C_{ArF,\,ipso}$), 141.7 (C_{Ar}), 134.4 ($C_{ArF,\,o}$), 133.9 (C_{Ar}), 133.4 (C_{Ar}), 132.2 (d, J_{CP} = 8 Hz, C_{Ar}), 128.5 (qq, J_{BC} = 3 Hz, J_{CF} = 31 Hz, $C_{ArF,\,m}$), 126.4 (d, J_{CP} = 15 Hz, C_{Ar}), 124.2 (q, J_{CF} = 272 Hz, CF_3), 117.1 (sept, J_{CF} = 4 Hz, $C_{ArF,\,p}$), 74.1 (OCH_2), 70.8 (N*C*H), 64.0 (COD-*C*H), 36.2 (COD-*C*H$_2$), 34.4 (*C*(CH$_3$)$_3$), 32.8 (COD-*C*H$_2$), 24.5 (C(*C*H$_3$)$_3$), others not observed; **^{31}P{^{1}H}-NMR** (162.0 MHz, CD_2Cl_2, 300 K): δ = 21.5 (br. s); **^{19}F{^{1}H}-NMR** (376.5 MHz, CD_2Cl_2, 300 K): δ = −64.0; **MS** (+ESI), m/z:. 654 ([M−BArF]$^+$, 100).

14: In a glovebox Xyl$_2$PH (46.0 mg, 190 μmol, 1.00 eq) was dissolved in THF (0.5 mL). KO*t*Bu (27.0 mg, 241 μmol, 1.10 eq) was added resulting in an orange solution which was stirred for 1 h. In a Schlenk-tube 2-(chloromethyl)oxazoline **3** (40.0 mg, 247 μmol, 1.30 eq) was dissolved in 0.5 mL THF and cooled down to −78 °C. The solution of the deprotonated phosphine was added dropwise using a syringe (immediate decolorization), and the syringe was rinsed with 2 × 0.5 mL of THF. The cooling bath was

removed and the solution was stirred for 1 h at rt.

This solution was added dropwise to a solution of $[Ir(COD)Cl]_2$ (70.2 mg, 105 μmol, 0.55 eq) in 0.5 mL of THF. The resulting solution was refluxed for 45 min and cooled down to rt. $NaBAr_F$ (200 mg, 228 μmol, 1.20 eq) was added and the mixture was stirred for 30 min. Silica gel (3 g) was added and the solvent was removed *in vacuo*. Flash chromatography on silica gel (25 g; h × d = 10 × 2.5, a: 100 mL MTBE, b: 150 mL CH_2Cl_2) gave 155 mg of the title compound as a orange solid (101 μmol, 53%, R_f = 0.82, CH_2Cl_2).

Elemental Analysis for $C_{63}H_{54}BF_{24}IrNOP$ (1531.07), calc.: C, 49.42; H, 3.55; N, 0.91; found: C, 49.54; H, 3.68; N, 0.68; $[\alpha]^{20}_D$ +6 (*c* 0.25, $CHCl_3$); **IR** (υ[cm^{-1}]) = 2962w, 2934w, 1597w, 1350m, 1273s, 1119s, 1010w, 941w, 887m, 841m, 671m; **^{1}H-NMR** (500.1 MHz, CD_2Cl_2, 300 K): δ = 7.73 (s, 8H, H_{ArF}), 7.56 (s, 4H, H_{ArF}), 7.39 (d, 2H, J_{CP} = 12.6 Hz, H_{Ar}), 7.25 (s, 1H, H_{Ar}), 7.18 (s, 1H, H_{Ar}), 6.96 (d, 2H, J_{CP} = 12.4 Hz, H_{Ar}), 5.13 (m, 1H, COD-C*H*), 4.94 (m, 1H, COD-C*H*), 4.62 (dd, 1H, *J* = 4.0 Hz, *J* = 9.7 Hz, OCH_2), 4.51 (t, 1H, *J* = 9.5 Hz, OCH_2), 4.02 (m, 2H, NC*H*, COD-C*H*), 3.68 (dd, 1H, *J* = 11.3 Hz, *J* = 18.4 Hz, PCH_2), 3.49 (ddd, 1H, *J* = 1.9 Hz, *J* = 6.7 Hz, *J* = 18.4 Hz, PCH_2), 3.02 (m, 1H, COD-C*H*), 2.48 (m, 2H, COD-CH_2), 2.34 (s, 6H, $C_{Ar}CH_3$), 2.31 (s, 6H, $C_{Ar}CH_3$), 2.30 (m, 1H, COD-CH_2), 2.16 (m, 1H, COD-CH_2), 1.98 (m, 2H, C*H*(CH_3)$_2$, COD-CH_2), 1.75 (dt, 1H, *J* = 8.0 Hz, *J* = 15.1 Hz, COD-CH_2), 1.57 (m, 2H, COD-CH_2), 0.90 (d, 3H, *J* = 6.9 Hz, CH(CH_3)$_2$), 0.43 (d, 3H, *J* = 7.2 Hz, CH(CH_3)$_2$); **^{13}C{^{1}H}-NMR** (125.8 MHz, CD_2Cl_2, 300 K): δ = 182.3 (d, J_{CP} = 19 Hz, O*C*=N), 161.4 (q, J_{CB} = 50 Hz, $C_{ArF,\ ipso}$), 139.4 (d, J_{CP} = 12 Hz, C_{Ar}), 139.3 (d, J_{CP} = 12 Hz, C_{Ar}), 134.5 ($C_{ArF,\ p}$), 133.5 (d, J_{CP} = 3 Hz, HC_{Ar}), 132.3 (d, J_{CP} = 14 Hz, HC_{Ar}), 128.5 (qq, J_{BC} = 3Hz, J_{CF} = 31 Hz, $C_{ArF,\ m}$), 128.4 (d, J_{CP} = 11 Hz, HC_{Ar}), 128.3 (d, J_{CP} = 11 Hz, C_{Ar}), 124.3 (d, J_{CP} = 56 Hz, C_{Ar}), 124.3 (q, J_{CF} = 272 Hz, *C*F_3), 117.1 (m, $C_{ArF,\ p}$), 95.6 (d, J_{CP} = 10 Hz, COD-C*H*), 89.3 (d, J_{CP} = 14 Hz, COD-C*H*), 72.7 (OCH_2), 67.7 (NC*H*), 63.9 (COD-C*H*), 62.1 (COD-C*H*), 35.2 (d, J_{CP} = 4 Hz, COD-*C*H_2), 31.8 (d, J_{CP} = 1 Hz, COD-*C*H_2), 31.6 (*C*H(CH_3)$_2$), 30.5 (d, J_{CP} = 33 Hz, P*C*H_2), 28.9 (d, J_{CP} = 2 Hz, COD-*C*H_2), 26.8 (d, J_{CP} = 2 Hz, COD-*C*H_2), 20.7 (d, J_{CP} = 3 Hz, C_{Ar}*C*H_3), 17.8 (CH(*C*H_3)$_2$), 12.7 (CH(*C*H_3)$_2$); **^{31}P{^{1}H}-NMR** (162.0 MHz, CD_2Cl_2, 300 K): δ = 21.3; **^{19}F{^{1}H}-NMR** (376.5 MHz, CD_2Cl_2, 300 K): δ = −64.0; **MS** (+ESI), m/z: 668 ([M−BArF]$^+$, 100).

15: In a glovebox Xyl_2PH (72.7 mg, 300 μmol, 1.00 eq) was dissolved in THF (0.3 mL). KO*t*Bu (37.0 mg, 330 μmol, 1.10 eq) was added resulting in an orange solution which was stirred for 1h. In a Schlenk-tube 2-(chloromethyl)oxazoline **4** (72.1 mg, 410 μmol, 1.37 eq) was dissolved in 0.3 mL THF and cooled down to −78 °C. The solution of the deprotonated phosphine was added dropwise (immediate decolorization), and the equipment was rinsed with 2 × 0.5 mL of THF. The cooling bath was removed and the solution was stirred for 2 h at rt. The solvent was removed *in vacuo* and the crude product was dissolved in toluene (2 × 1 mL) and filtered through an HPLC-filter (CHROMAFIL® O-20/15 MS, pore

size 20 μm). The solvent was removed *in vacuo*, and the ligand was dissolved in 3 mL of CH_2Cl_2. This solution was added dropwise under stirring to a solution of $[Ir(COD)Cl]_2$ (100 mg, 150 mmol, 0.50 eq) in 2 mL of CH_2Cl_2. The resulting solution was refluxed for 45 min and cooled down to rt. $NaBAr_F$ (320 mg, 360 mmol, 1.20 eq) was added and the mixture was stirred for 15 min. Silica gel (3 g) was added and the solvent was removed *in vacuo*. Flash chromatography on silica gel (40 g; h × d = 15 × 2.5, a: 150 mL of MTBE, b: 150 mL of CH_2Cl_2) gave 278 mg of the title compound as an orange solid (180 mmol, 60%, R_f = 0.89, CH_2Cl_2).

Elemental Analysis for $C_{64}H_{56}BF_{24}IrNOP$ (1545.1), calc.: C, 49.75; H, 3.65; N, 0.91; found: C, 49.72; H, 3.63; N, 0.81; **$[\alpha]^{20}_D$** +2 (*c* 0.24, $CHCl_3$); **IR** (υ[cm^{-1}]) = 2968w, 1593m, 1354m, 1273s, 1117s, 993w, 885m, 839m, 712w, 681m, 669m, 638m; **^{1}H-NMR** (500.1 MHz, CD_2Cl_2, 300 K): δ = 7.73 (s, 8H, $H_{ArF,\,o}$), 7.56 (s, 4H, $H_{ArF,\,p}$), 7.40 (d, 2H, J_{CP} = 12.8 Hz, H_{Ar}), 7.26 (s, 1H, H_{Ar}), 7.17 (s, 1H, H_{Ar}), 6.94 (d, 2H, J_{CP} = 12.4 Hz, H_{Ar}), 5.16 (m, 1H, COD-C*H*), 4.82 (m, 1H, COD-C*H*), 4.73 (dd, 1H, *J* = 2.1 Hz, *J* = 9.8 Hz, OCH_2), 4.48 (dd, 1H, *J* = 8.7 Hz, *J* = 9.8 Hz, OCH_2), 4.21 (t, 1H, *J* = 6.6 Hz, COD-C*H*), 3.88 (dd, 1H, *J* = 11.4 Hz, *J* = 18.5 Hz, PCH_2), 3.71 (d, 1H, *J* = 8.5 Hz, NC*H*), 3.57 (ddd, 1H, *J* = 1.4 Hz, *J* = 4.9 Hz, *J* = 18.5 Hz, PCH_2), 2.92 (m, 1H, COD-C*H*), 2.54 (m, 1H, COD-CH_2), 2.46 (m, 1H, COD-CH_2), 2.37 (m, 1H, COD-CH_2), 2.35 (s, 6H, Ar-CH_3), 2.31 (s, 6H, Ar-CH_3), 2.22 (m, 1H, COD-CH_2), 2.09 (m, 1H, COD-CH_2), 1.93 (m, 1H, COD-CH_2), 1.69 (m, 1H, COD-CH_2), 1.52 (m, 1H, COD-CH_2), 0.74 (s, 9H, C(CH_3)$_3$); **^{13}C{^{1}H}-NMR** (125.8 MHz, CD_2Cl_2, 300 K): δ = 179.6 (d, J_{CP} = 18 Hz, O*C*=N), 161.4 (q, J_{CB} = 50 Hz, $C_{ArF,\,ipso}$), 139.4 (m, C_{Ar}), 134.5 ($C_{ArF,\,o}$), 133.5 (d, J_{CP} = 3 Hz, HC_{Ar}), 132.8 (d, J_{CP} = 14 Hz, HC_{Ar}), 128.5 (qq, J_{BC} = 3 Hz, J_{CF} = 31 Hz, $C_{ArF,\,m}$), 128.3 (d, J_{CP} = 11 Hz, HC_{Ar}), 124.3 (q, J_{CF} = 272 Hz, *C*F_3), 123.9 (d, J_{CP} = 56 Hz, C_{Ar}), 117.1 (sept, J_{CF} = 4 Hz, $C_{ArF,\,p}$), 95.6 (d, J_{CP} = 10 Hz, COD-*C*H), 87.7 (d, J_{CP} = 15 Hz, COD-*C*H), 74.3 (OCH_2), 70.9 (N*C*H), 63.0 (COD-*C*H), 62.2 (COD-*C*H), 36.0 (d, J_{CP} = 5 Hz, COD-*C*H_2), 34.2 (*C*(CH_3)$_3$), 32.5 (COD-*C*H_2), 30.6 (d, J_{CP} = 34 Hz, PCH_2), 28.6 (d, J_{CP} = 2 Hz, COD-*C*H_2), 25.5 (d, J_{CP} = 3 Hz, COD-*C*H_2), 24.3 (C(*C*H_3)$_3$), 20.7 ($C_{Ar}CH_3$), 20.6 ($C_{Ar}CH_3$); **^{31}P{^{1}H}-NMR** (162.0 MHz, CD_2Cl_2, 300 K): δ = 24.7; **^{19}F{^{1}H}-NMR** (376.5 MHz, CD_2Cl_2, 300 K): δ = −64.0; **MS** (+ESI), m/z: 682 ($[M-BArF]^+$, 100).

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