Manganese(I)-Catalyzed Asymmetric Hydrophosphination of α,β-Unsaturated Carbonyl Derivatives

Postolache, Roxana; Pérez, Juana M.; Castiñeira Reis, Marta; Ge, Luo; Sinnema, Esther G.; Harutyunyan, Syuzanna R.

Published in:
Organic letters

DOI:
10.1021/acs.orglett.2c04256

OL Organic Letters

pubs.acs.org/OrgLett

Letter

Manganese(I)-Catalyzed Asymmetric Hydrophosphination of α,β-Unsaturated Carbonyl Derivatives

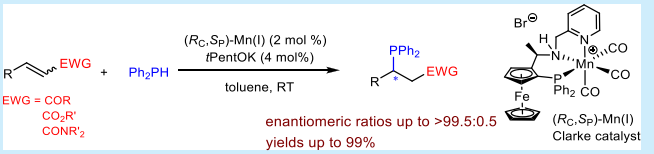
Roxana Postolache,[†] Juana M. Pérez,[†] Marta Castiñeira Reis, Luo Ge, Esther G. Sinnema, and Syuzanna R. Harutyunyan*

Cite This: *Org. Lett.* 2023, 25, 1611−1615

Read Online

ACCESS | Metrics & More | Article Recommendations | Supporting Information

ABSTRACT: Here we report catalytic asymmetric hydrophosphination of α,β-unsaturated carbonyl derivatives using a chiral Mn(I) complex as a catalyst. Through H−P bond activation, various phosphine-containing chiral products can be accessed via hydrophosphination of various ketone-, ester-, and carboxamide-based Michael acceptors.



Phosphines containing carbon stereocenters make up an important class of compounds that have found applications in asymmetric catalysis,[1] both as ligands, in combination with various transition metals, and in their own right as chiral organocatalysts.[2,3] These phosphines are often difficult to access, due to their laborious, multistep synthesis, and therefore are expensive. In addition, their preparation commonly requires stoichiometric amounts of chiral auxiliaries or performing optical resolutions of preformed racemates.[4] These aspects have hindered ready access to the library of chiral derivatives of phosphine ligands.[5]

Stereoselective hydrophosphination reactions offer an attractive strategy for accessing chiral compounds bearing phosphine moieties that can be further modified into chiral phosphine ligands. Consequently, the development of synthetic procedures for the formation of C−P bonds[6] stereoselectively using metal-catalyzed hydrophosphination has been an active field of research in the past two decades.[7,8] In 2001, the group of Glueck demonstrated the potential of catalytic asymmetric hydrophosphination reactions by obtaining moderate enantioselectivity in the Pt(0)-catalyzed hydrophosphination reaction of methacrylonitrile.[9] Following this report, the use of noble metals such as Pt and Pd has been extensively explored for the synthesis of enantioenriched phosphines with stereogenic carbon.[10] However, in recent years, the focus of the catalysis community has gradually shifted to the development of new competitive catalysts based on earth-abundant, readily available metals. In this context, a small number of examples of enantioselective hydrophosphinations have also been reported, all of which make use of chiral earth-abundant metal-based complexes of Ni:[8e,f,11] and Cu.[8g,12] Apart from organometallic catalysts, a few examples of asymmetric organocatalytic hydrophosphinations have also been reported.[13] Recently, our group has reported the first case of asymmetric hydrophosphination of α,β-unsaturated nitriles using a readily available chiral manganese(I) complex.[14] In addition to offering an attractive catalytic route to a variety of phosphines, this method stands out as the first example of catalytic H−P bond activation via metal−ligand cooperation.

Encouraged by these initial results, we decided to investigate the potential of Mn(I) catalysis for hydrophosphination of other Michael acceptors, namely α,β-unsaturated carbonyl derivatives of ketones, esters, and carboxamides.

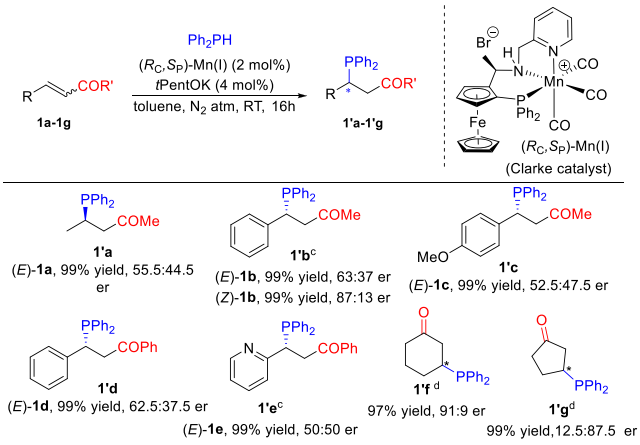
We started our studies by testing hydrophosphination of α,β-unsaturated ketones catalyzed by the Clarke catalyst,[15] (R_C,S_P)-Mn(I) (Scheme 1).

Mn(I) catalysis requires the use of a base to activate the catalyst via deprotonation of the benzylic amine moiety. We anticipated that the background base-catalyzed hydrophosphination might be a problem with α,β-unsaturated ketones, because of their enhanced reactivity compared to that of the α,β-unsaturated nitriles previously explored in this reaction.[14a]

The initial reaction was carried out between (*E*)-pent-3-en-2-one **1a** and diphenylphosphine, using 2 mol % (R_C,S_P)-Mn(I), 4 mol % *t*PentOK, and toluene as the solvent at room temperature (RT) under a nitrogen atmosphere (Scheme 1). While full conversion to the desired product was obtained, the enantiomeric ratio (er) was only 55.5:44.5. Similarly, a low er was found when using β-*p*-OMePh- and β-Ph-substituted substrates (*E*)-**1b** and (*E*)-**1c**, respectively. Interestingly, (*Z*)-**1b** resulted in hydrophosphinated product **1′b** with an er higher than that obtained for (*E*)-**1b**. This was unexpected, because in our previous studies, (*Z*)- and (*E*)-configured β-alkyl-substituted aliphatic nitriles resulted in products with similarly high er values, while lower er's were obtained from (*Z*)-β-aryl-substituted nitrile substrates. Hydrophosphination

Received: December 19, 2022
Published: March 9, 2023

Scheme 1. Catalytic Asymmetric Hydrophosphination of α,β-Unsaturated Ketones[a,b]



[a]Reaction conditions: 0.1 M **1** in toluene, (R_C,S_P)-Mn(I) (2 mol %), *t*PentOK (4 mol %), and Ph_2PH (1.0 equiv) at RT under a N_2 atmosphere. Isolated yields reported. [b]For the assignment of the absolute configurations of **1′a−1′e**, see the Supporting Information. The absolute configuration of **1′f** and **1′g** was not determined. [c]Reaction quenched with H_2O_2. The oxidized product was isolated and characterized (see the Supporting Information). [d]Reaction carried out at 0 °C.

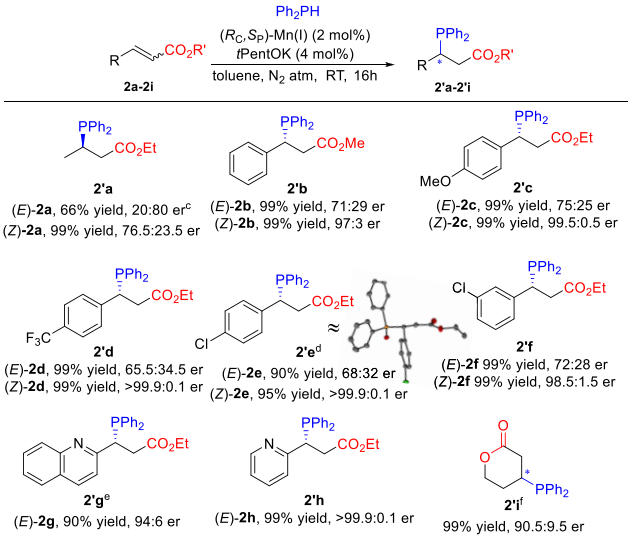
of chalcone (*E*)-**1d** afforded the corresponding product with a moderate er, similar to that obtained with (*E*)-**1b**. A racemic product was obtained with heteroaromatic substrate (*E*)-**1e**. Decreasing the temperature to 0 °C did not improve these results. Interestingly, in the case of cyclic aliphatic ketones (*E*)-**1f** and (*E*)-**1g**, this decrease in temperature did prove beneficial, yielding enantioselectivities of ≤91:9 (Scheme 1) at 0 °C. The initial conclusion from these results is that the stereochemical outcome of the reaction strongly depends on the configuration of the alkene. More specifically, (*Z*)-configured substrates are better suited for enantiodiscrimination by the chiral catalyst.

Next, we moved to study another class of Michael acceptors, namely the less reactive α,β-unsaturated esters (Scheme 2).

As with the ketones, we initially tested aliphatic (*E*)-enoate **2a**, obtaining the corresponding product with a promising 20:80 er. A similarly moderate er was obtained when the reaction was performed using (*Z*)-**2a**. In contrast, greatly improved er's were observed for products **2′b−2′f** derived from the corresponding (*Z*)-configured β-aryl-substituted α,β-unsaturated esters compared to the results with their (*E*)-counterparts. Importantly, both electron-donating (**2′c**) and electron-withdrawing functionalities (**2′d−2′f**) in the aromatic ring were tolerated. Unexpectedly, high enantioselectivities were obtained for (*E*)-configured substrates with heteroaryl-substituted esters (*E*)-**2g** and (*E*)-**2h**. We were pleased with these results because the corresponding (*Z*)-substrates are difficult to access and the chiral products obtained have potential for applications as precursors for chiral ligands in asymmetric catalysis.

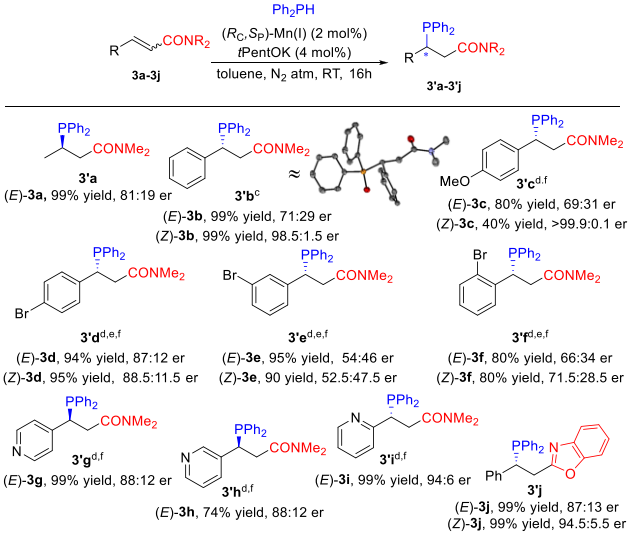
As the carboxamide functional group is a common moiety in pharmaceuticals and biologically active compounds,[16] we embarked on evaluating the scope of hydrophosphination of α,β-unsaturated carboxamides (Scheme 3). Highly enantioselective hydrophosphination of similar substrates was reported recently by the group of Yin using copper catalysis.[8g] Given the

Scheme 2. Scope of α,β-Unsaturated Esters[a,b]



[a]Reaction conditions: 0.1 M **2** in toluene, (R_C,S_P)-Mn(I) (2 mol %), *t*PentOK (4 mol %), and Ph_2PH (1.0 equiv) at RT under a N_2 atmosphere. Isolated yields reported. [b]For the assignment of the absolute configurations of **2′a−2′h**, see the Supporting Information. The absolute configuration of **2′i** was not determined. [c]*i*PrOH was used as a solvent in this case because of its slightly better er. This also resulted in a change in product configuration. [d]The oxidized compound was used for X-ray crystallography. [e]Reaction quenched with H_2O_2. The oxidized product was isolated and characterized (see the Supporting Information). [f]Reaction carried out at 0 °C.

Scheme 3. Scope of α,β-Unsaturated Amides[a,b]



[a]Reaction conditions: 0.1 M **3** in toluene, (R_C,S_P)-Mn(I) (2 mol %), *t*PentOK (4 mol %), and Ph_2PH (1.0 equiv) at RT under a N_2 atmosphere. Isolated yields reported. [b]For the assignment of the absolute configurations of **3′a−3′j**, see the Supporting Information. [c]The oxidized compound was used for X-ray crystallography. [d]Here, 4 mol % (R_C,S_P)-Mn(I) and 8 mol % *t*PentOK were used. [e]Reaction quenched with H_2O_2. The oxidized product was isolated and characterized (see the Supporting Information). [f]Reaction time of 3 days.

low reactivity of these substrates, we wondered whether Mn(I) catalysis will also be competitive and how it would compare with the results obtained with nitriles, ketones, and esters.

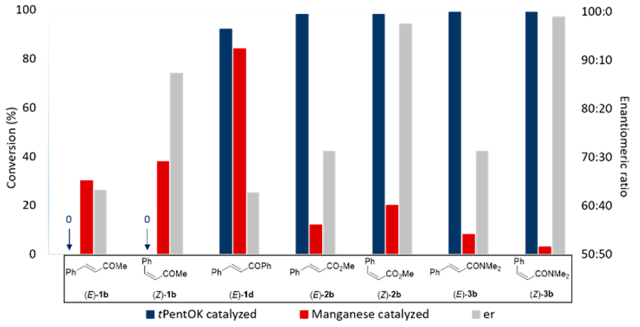
https://doi.org/10.1021/acs.orglett.2c04256
Org. Lett. 2023, 25, 1611−1615

The results were similar to those obtained with enoates, except that the difference in the stereochemical outcome between (*Z*)- and (*E*)-configured substrates was less pronounced. The (*Z*)-configured *α*,*β*-unsaturated carboxamides provided hydrophosphinated products with improved enantiomeric purities, but the stereochemical outcome of the reaction was to a larger extent dependent on the nature of the substituent at the *β*-position, albeit without a clear trend. Keeping in mind the possible application of the phosphine products derived from carboxamides as potential chiral ligands in asymmetric catalysis, we were grateful to see high er's and yields for products **3′i** and **3′j** when using carboxamide substrates with a heteroaromatic group.

The ability of the Mn(I) complex to catalyze the hydrophosphination of various classes of Michael acceptors, together with several stereochemical observations made in this process, is intriguing. Among these observations are (i) the alkene class-dependent (*E*)- or (*Z*)-configuration required to achieve high er's for aromatic substrates (nitriles vs other alkenes studied in this work) and (ii) the same sense of asymmetric induction for all of the (*E*)- and (*Z*)-configured substrates but the opposite sense of asymmetric induction when switching from aliphatic to aromatic substrates. While not aiming to rationalize all of these observations in this work, we undertook additional experimental studies to gain more insight. The fact that the same sense of asymmetric induction is observed when using an (R_C,S_P)-Mn(I) catalyst for hydrophosphination of (*E*)- and (*Z*)-configured alkenes could be indicative of alkene double bond isomerization during the reaction. However, the higher er's obtained with the (*Z*)-alkenes investigated in this work are convincing proof against isomerization happening during the reaction catalyzed by manganese. This is further supported by the lack of base- or base/Mn(I)-catalyzed (*Z*)- and (*E*)-isomerization of enoate **2b**, as confirmed by ^{1}H NMR monitoring of the reaction (see the Supporting Information).

The outcome of the hydrophosphination reaction depends critically on the relative rates of the desired Mn(I)-catalyzed and the undesired base-catalyzed pathways. Control experiments with nitriles[14a] showed that there is base-catalyzed conversion of alkene substrates in the presence of only 4 mol % base at RT. On the contrary, a slight excess of base with respect to the Mn(I) catalyst is required as using equimolar amounts with base resulted in poor substrate conversion.[14] Therefore, a delicate balance between the amount of catalyst and base is critical to ensure a minimal amount of free base present in the reaction mixture. To understand the role of the base-catalyzed reactions for the substrates studied in this work, we selected for every class of alkene (*E*)- and (*Z*)-configured substrate (**1b**−**3b**) to carry out the base- and Mn-catalyzed reactions. The substrate conversion and er of the product were analyzed after a 5 min reaction time (Scheme 4). We found that the base-catalyzed reactions with 3 mol % *t*PentOK proceed to full conversion toward the racemic phosphine products in all cases, with the exception of ketone **1b**. This ketone undergoes a side reaction due to base-promoted enolization. To avoid the enolization, we used non-enolizable ketone **1d** instead, and also in this case, full conversion to the product was obtained under base catalysis. These results show that base catalysis is very efficient and therefore can cause some erosion of er's during the Mn(I)-catalyzed reaction. However, this is not always the case, as evidenced from the different enantioselectivities obtained for (*E*)- and (*Z*)-**1b**, while no hydrophosphination product is being formed under base catalysis. Therefore, the obtained data are not conclusive and do not by themselves evidence a direct correlation between the relative rate of the base-catalyzed reaction and the obtained er's for various substrates. Most likely, both the detrimental effect of the free base and the level of enantiodiscrimination offered by the chiral catalyst are dependent on the specific structure of the alkene. More detailed mechanistic studies are required to elucidate this further.

Scheme 4. Outcome of the Base- and (R_C,S_P)/Mn(I)-Catalyzed Reactions[a]



[a]Reaction conditions: 0.1 M (*E*)-**1b**, (*Z*)-**1b**, (*E*)-**1d**, (*E*)-**2b**, (*Z*)-**2b**, (*E*)-**3b**, or (*Z*)-**3b** and Ph_2PH (1.0 equiv) in toluene at RT under a N_2 atmosphere. For the base-catalyzed reaction, *t*PentOK (3 mol %) was used. For the Mn(I)-catalyzed reaction, (R_C,S_P)-Mn(I) (2 mol %) and *t*PentOK (4 mol %) were used. Conversions and er's were measured after 5 min.

In conclusion, we have demonstrated that Mn(I)-catalyzed hydrophosphination can be applied to various classes of Michael acceptors. Currently, the portfolio of the Mn(I) catalysis includes nitriles, esters, carboxamides, and to a lesser extent ketones. Although the enantioselectivities are not homogeneously high across the substrate scope, this methodology shows the potential of Mn(I) catalysis for targeted synthesis of phosphine products and thus for providing readily available precursors for chiral ligands in asymmetric catalysis. Further structural tuning of the Mn catalyst to improve the enantioselectivities and to expand the scope is underway.

■ ASSOCIATED CONTENT

Data Availability Statement

The data underlying this study are available in the published article and its Supporting Information.

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.orglett.2c04256.

Experimental procedures, characterization data, and NMR spectra (PDF)

Accession Codes

CCDC 2085288−2085289 contain the supplementary crystallographic data for this paper. These data can be obtained free of charge via www.ccdc.cam.ac.uk/data_request/cif, or by emailing data_request@ccdc.cam.ac.uk, or by contacting The Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK; fax: +44 1223 336033.

https://doi.org/10.1021/acs.orglett.2c04256
Org. Lett. 2023, 25, 1611−1615

AUTHOR INFORMATION

Corresponding Author

Syuzanna R. Harutyunyan − *Stratingh Institute for Chemistry, University of Groningen, 9747 AG Groningen, The Netherlands;* orcid.org/0000-0003-2411-1250; Email: s.harutyunyan@rug.nl

Authors

Roxana Postolache − *Stratingh Institute for Chemistry, University of Groningen, 9747 AG Groningen, The Netherlands*

Juana M. Pérez − *Stratingh Institute for Chemistry, University of Groningen, 9747 AG Groningen, The Netherlands;* orcid.org/0000-0002-6495-2591

Marta Castiñeira Reis − *Stratingh Institute for Chemistry, University of Groningen, 9747 AG Groningen, The Netherlands;* orcid.org/0000-0003-4204-3474

Luo Ge − *Stratingh Institute for Chemistry, University of Groningen, 9747 AG Groningen, The Netherlands;* orcid.org/0000-0001-9964-5156

Esther G. Sinnema − *Stratingh Institute for Chemistry, University of Groningen, 9747 AG Groningen, The Netherlands*

Complete contact information is available at: https://pubs.acs.org/10.1021/acs.orglett.2c04256

Author Contributions

†R.P. and J.M.P. contributed equally to this work.

Notes

The authors declare no competing financial interest.

ACKNOWLEDGMENTS

Folkert de Vries is acknowledged for the X-ray measurements. Financial support from the European Research Council (S.R.H., Grant 773264, LACOPAROM), The Netherlands Organization for Scientific Research (NWO-VICI to S.R.H.), and the China Scholarship Council (CSC, to L.G.) is acknowledged. M.C.R. thanks Xunta de Galicia (Galicia, Spain) for financial support through the ED481B-Axudas de apoio á etapa de formación posdoutoral (modalidade A) fellowship.

REFERENCES

(1) Dutartre, M.; Bayardon, J.; Juge, S. Applications and Stereoselective Syntheses of P-Chirogenic Phosphorus Compounds. *Chem. Soc. Rev.* **2016**, *45*, 5771−5794.

(2) Gilheany, D. G., Mitchell, C. M., Hartley, F. R., Eds. *The Chemistry of Organophosphorus Compounds*; John Wiley and Sons: Chichester, England, 1990; Vol. *1*, pp 151−190.

(3) Wei, Y.; Shi, M. Asymmetric Reactions Catalyzed by Chiral Tertiary Phosphines. *Chin. J. Chem.* **2020**, *38*, 1395−1421.

(4) (a) Tang, W.; Zhang, X. New Chiral Phosphorus Ligands for Enantioselective Hydrogenation. *Chem. Rev.* **2003**, *103*, 3029−3069. (b) Borner, A. *Phosphorus Ligands in Asymmetric Catalysis*, Vols. *1*−*3*; Wiley-VCH: Weinheim, Germany, 2008. (c) Kamer, P. C. J.; van Leeuwen, P. W. N. M. *Phosphorus(III) Ligands in Homogeneous Catalysis*; Wiley: Chichester, England, 2012. (d) Xie, J.-H.; Zhu, S.-F.; Zhou, Q.-L. Transition Metal-Catalyzed Enantioselective Hydrogenation of Enamines and Imines. *Chem. Rev.* **2011**, *111*, 1713−1760.

(5) (a) van Leeuwen, P. W. N. M.; Chadwick, J. C. *Homogeneous Catalysts: Activity-Stability-Deactivation*; Wiley-VCH: Weinheim, Germany, 2014. (b) Blaser, H. U.; Federsel, H. J. *Asymmetric Catalysis on Industrial Scale: Challenges, Approaches and Solutions*; Wiley-VCH: Weinheim, Germany, 2010. (c) Pignolet, L. M. *Homogeneous Catalysis with Metal Phosphine Complexes*; Springer: Boston, 1983. (d) Pfaltz, A.; Drury, W. J., III Design of Chiral Ligands for Asymmetric Catalysis: From C_2-Symmetric P,P- and N,N-Ligands to Sterically and Electronically Nonsymmetrical P,N-Ligands. *Proc. Natl. Acad. Sci. U.S.A.* **2004**, *101*, 5723−5726.

(6) Wauters, I.; Debrouwer, W.; Stevens, C. V. Preparation of Phosphines Through C−P Bond Formation. *Beilstein J. Org. Chem.* **2014**, *10*, 1064−1096.

(7) (a) Moglie, Y.; González-Soria, M. J.; Martín-García, I.; Radivoy, G.; Alonso, F. Catalyst- and Solvent-free Hydrophosphination and Multicomponent Hydrothiophosphination of Alkenes and Alkynes. *Green Chem.* **2016**, *18*, 4896−4907. (b) Coles, N. T.; Mahon, M. F.; Webster, R. L. 1,1-Diphosphines and Divinylphosphines *via* Base Catalyzed Hydrophosphination. *Chem. Commun.* **2018**, *54*, 10443−10446. (c) Koshti, V.; Gaikwad, S.; Chikkali, S. H. Contemporary Avenues in Catalytic P-H Bond Addition Reaction: A Case Study of Hydrophosphination. *Coord. Chem. Rev.* **2014**, *265*, 52−73. (d) Espinal-Viguri, M.; King, A. K.; Lowe, J. P.; Mahon, M. F.; Webster, R. L. Hydrophosphination of Unactivated Alkenes and Alkynes Using Iron(II): Catalysis and Mechanistic Insight. *ACS Catal.* **2016**, *6*, 7892−7897. (e) Itazaki, M.; Katsube, S.; Kamitani, M.; Nakazawa, H. Synthesis of Vinylphosphines and Unsymmetric Diphosphines: Iron-catalyzed Selective Hydrophosphination Reaction of Alkynes and Vinylphosphines with Secondary Phosphines. *Chem. Commun.* **2016**, *52*, 3163−3166. (f) Di Giuseppe, A.; De Luca, R.; Castarlenas, R.; Pérez-Torrente, J. J.; Crucianelli, M.; Oro, L. A. Double Hydrophosphination of Alkynes Promoted by Rhodium: the Key Role of an N-Heterocyclic Carbene Ligand. *Chem. Commun.* **2016**, *52*, 5554−5557.

(8) (a) Rosenberg, L. Mechanisms of Metal-Catalyzed Hydrophosphination of Alkenes and Alkynes. *ACS Catal.* **2013**, *3*, 2845−2855. (b) Bange, C. A.; Waterman, R. Challenges in Catalytic Hydrophosphination. *Chem. - Eur. J.* **2016**, *22*, 12598−12605. (c) Pullarkat, S. A. Recent Progress in Palladium-Catalyzed Asymmetric Hydrophosphination. *Synthesis* **2016**, *48*, 493−503. (d) Sadow, A. D.; Haller, I.; Fadini, L.; Togni, A. Nickel(II)-Catalyzed Highly Enantioselective Hydrophosphination of Methacrylonitrile. *J. Am. Chem. Soc.* **2004**, *126*, 14704−14705. (e) Sadow, A. D.; Togni, A. Enantioselective Addition of Secondary Phosphines to Methacrylonitrile: Catalysis and Mechanism. *J. Am. Chem. Soc.* **2005**, *127*, 17012−17024. (f) Liu, X.; Han, X.; Wu, Y.; Sun, Y.; Gao, L.; Huang, Z.; Zhang, Q. Ni-Catalyzed Asymmetric Hydrophosphination of Unactivated Alkynes. *J. Am. Chem. Soc.* **2021**, *143*, 11309−11316. (g) Li, Y.; Tian, H.; Yin, L. Copper(I)-Catalyzed Asymmetric 1,4-Conjugate Hydrophosphination of *α,β*-Unsaturated Amides. *J. Am. Chem. Soc.* **2020**, *142*, 20098−20106. (h) Enders, D.; Saint-Dizier, A.; Lannou, M.-I.; Lenzen, A. The Phospha-Michael Addition in Organic Synthesis. *Eur. J. Org. Chem.* **2006**, *2006*, 29−49.

(9) (a) Kovacik, I.; Wicht, D. K.; Grewal, N. S.; Glueck, D. S.; Incarvito, C. D.; Guzei, I. A.; Rheingold, A. L. Cyclometalation of Dimesitylphosphine in Cationic Palladium(II) and Platinum(II) Complexes: P−H vs C−H Activation. *Organometallics* **2000**, *19*, 950−953. (b) Glueck, D. S. Palladium-Catalyzed Asymmetric Phosphination: Enantioselective Synthesis of a P-Chirogenic Phosphine. *Coord. Chem. Rev.* **2008**, *252*, 2171−2179.

(10) (a) Huang, Y.; Pullarkat, S. A.; Li, Y.; Leung, P.-H. Palladium(II)-Catalyzed Asymmetric Hydrophosphination of Enones: Efficient Access to Chiral Tertiary Phosphines. *Chem. Commun.* **2010**, *46*, 6950−6952. (b) Feng, J.-J.; Chen, X.-F.; Shi, M.; Duan, W.-L. Palladium-Catalyzed Asymmetric Addition of Diarylphosphines to Enones toward the Synthesis of Chiral Phosphines. *J. Am. Chem. Soc.* **2010**, *132*, 5562−5563. (c) Huang, Y.; Chew, R. J.; Li, Y.; Pullarkat, S. A.; Leung, P.-H. Direct Synthesis of Chiral Tertiary Diphosphines via Pd(II)-Catalyzed Asymmetric Hydrophosphination of Dienones. *Org. Lett.* **2011**, *13*, 5862−5865. (d) Chen, Y.-R.; Duan, W.-L. Palladium-catalyzed 1, 4-Addition of Diarylphosphines to *α, β*-Unsaturated Aldehydes. *Org. Lett.* **2011**, *13*, 5824−5826. (e) Ding, B.; Zhang, Z.; Xu, Y.; Liu, Y.; Sugiya, M.; Imamoto, T.; Zhang, W.

Chemoselective Transfer Hydrogenation of α,β-Unsaturated Ketones Catalyzed by Pincer-Pd Complexes Using Alcohol as a Hydrogen Source. *Org. Lett.* **2013**, *15*, 5476−5479. (f) Lu, J.; Ye, J.; Duan, W.-L. Palladium-Catalyzed Asymmetric Addition of Diarylphosphines to α,β-Unsaturated Sulfonic Esters for the Synthesis of Chiral Phosphine Sulfonate Compounds. *Org. Lett.* **2013**, *15*, 5016−5019. (g) Chew, R. J.; Teo, K. Y.; Huang, Y.; Li, B.-B.; Li, Y.; Pullarkat, S. A.; Leung, P.-H. Enantioselective Phospha-Michael Addition of Diarylphosphines to β,γ-Unsaturated α-Ketoesters and Amides. *Chem. Commun.* **2014**, *50*, 8768−8770. (h) Chew, R. J.; Li, X.-R.; Li, Y.; Pullarkat, S. A.; Leung, P.-H. Pd-Catalyzed Enantiodivergent and Regiospecific phospha-Michael Addition of Diphenylphosphine to 4-oxo-Enamides: Efficient Access to Chiral Phosphinocarboxamides and Their Analogues. *Chem. - Eur. J.* **2015**, *21*, 4800−4804. (i) Yang, X.-Y.; Tay, W. S.; Li, Y.; Pullarkat, S. A.; Leung, P.-H. The synthesis and Efficient One-pot Catalytic "Self-breeding" of Asymmetrical NC(sp^3)*E*-Hybridised Pincer Complexes. *Chem. Commun.* **2016**, *52*, 4211−4214. (j) Sadeer, A.; Ong, Y. J.; Kojima, T.; Foo, C. Q.; Li, Y.; Pullarkat, S. A.; Leung, P.-H. Desymmetrization of Achiral Heterobicyclic Alkenes through Catalytic Asymmetric Hydrophosphination. *Chem. - Asian J.* **2018**, *13*, 2829−2833. (k) Lu, Z.; Zhang, H.; Yang, Z.; Ding, N.; Meng, L.; Wang, J. Asymmetric Hydrophosphination of Heterobicyclic Alkenes: Facile Access to Phosphine Ligands for Asymmetric Catalysis. *ACS Catal.* **2019**, *9*, 1457−1463. (l) Wu, Z.-H.; Cheng, A.-Q.; Yuan, M.; Zhao, Y.-X.; Yang, H.-L.; Wei, L.-H.; Wang, H.-Y.; Wang, T.; Zhang, Z.-T.; Duan, W.-L. Cobalt-Catalysed Asymmetric Addition and Alkylation of Secondary Phosphine Oxides for the Synthesis of P-Stereogenic Compounds. *Angew. Chem., Int. Ed.* **2021**, *60*, 27241−27246.

(11) Wang, C.; Huang, K.; Ye, J.; Duan, W.-L. Asymmetric Synthesis of P-Stereogenic Secondary Phosphine-Boranes by an Unsymmetric Bisphosphine Pincer-Nickel Complex. *J. Am. Chem. Soc.* **2021**, *143*, 5685−5690.

(12) (a) Chen, Y.-R.; Feng, J.-J.; Duan, W.-L. NHC−Copper-Catalyzed Asymmetric 1,4-Addition of Diarylphosphines to α,β-Unsaturated Ketones. *Tetrahedron Lett.* **2014**, *55*, 595−597. (b) Yue, W.-J.; Xiao, J.-Z.; Zhang, S.; Yin, L. Rapid Synthesis of Chiral 1, 2-Bisphosphine Derivatives through Copper (I)-Catalyzed Asymmetric Conjugate Hydrophosphination. *Angew. Chem., Int. Ed.* **2020**, *59*, 7057−7062.

(13) (a) Carlone, A.; Bartoli, M.; Bosco, M.; Sambri, L.; Melchiorre, P. Organocatalytic Asymmetric Hydrophosphination of α,β-Unsaturated Aldehydes. *Angew. Chem., Int. Ed.* **2007**, *46*, 4504−4506. (b) Ibrahem, I.; Rios, R.; Vesely, J.; Hammar, P.; Eriksson, L.; Himo, F.; Cordova, A. Enantioselective Organocatalytic Hydrophosphination of α,β-Unsaturated Aldehydes. *Angew. Chem., Int. Ed.* **2007**, *46*, 4507−4510. (c) Ibrahem, I.; Hammar, P.; Vesely, J.; Rios, R.; Eriksson, L.; Cordova, A. Organocatalytic Asymmetric Hydrophosphination of α,β-Unsaturated Aldehydes: Development, Mechanism and DFT Calculations. *Adv. Synth. Catal.* **2008**, *350*, 1875−1884. (d) Maiti, R.; Yan, J.-L.; Yang, X.; Mondal, B.; Xu, J.; Chai, H.-F.; Jin, Z.-C.; Chi, Y. R. Carbene-Catalyzed Enantioselective Hydrophosphination of α-Bromoenals to Prepare Phosphine-Containing Chiral Molecules. *Angew. Chem., Int. Ed.* **2021**, *60*, 26616−26621.

(14) (a) Pérez, J. M.; Postolache, R.; Castiñeira Reis, M.; Sinnema, E. G.; Vargova, D.; de Vries, F.; Otten, E.; Ge, L.; Harutyunyan, S. R. Manganese(I)-Catalyzed H-P Bond Activation via Metal-Ligand Cooperation. *J. Am. Chem. Soc.* **2021**, *143*, 20071−20076. (b) Ge, L.; Harutyunyan, S. R. Manganese (I)-Catalyzed Access to 1,2-Bisphosphine Ligands. *Chem. Sci.* **2022**, *13*, 1307−1312.

(15) Widegren, M. B.; Harkness, G. J.; Slawin, A. M. Z.; Cordes, D. B.; Clarke, M. L. A Highly Active Manganese Catalyst for Enantioselective Ketone and Ester Hydrogenation. *Angew. Chem., Int. Ed.* **2017**, *56*, 5825−5828.

(16) (a) Bray, B. L. Large-scale Manufacture of Peptide Therapeutics by Chemical Synthesis. *Nat. Rev. Drug Discovery* **2003**, *2*, 587−593. (b) Pattabiraman, V. R.; Bode, J. W. Rethinking Amide Bond Synthesis. *Nature* **2011**, *480*, 471−479. (c) Valeur, E.; Bradley, M. Amide Bond Formation: Beyond the Myth of Coupling Reagents. *Chem. Soc. Rev.* **2009**, *38*, 606−631. (d) Gunanathan, C.; Ben-David, Y.; Milstein, D. Direct Synthesis of Amides from Alcohols and Amines with Liberation of H_2. *Science* **2007**, *317*, 790−792.

https://doi.org/10.1021/acs.orglett.2c04256
Org. Lett. 2023, 25, 1611−1615