How to cite: *Angew. Chem. Int. Ed.* **2021**, *60*, 4491–4495
International Edition: doi.org/10.1002/anie.202014781
German Edition: doi.org/10.1002/ange.202014781

C–C Coupling Reactions

Enantioselective Three-Component Coupling of Heteroarenes, Cycloalkenes and Propargylic Acetates

*Shenghan Teng, Yonggui Robin Chi, and Jianrong Steve Zhou**

Abstract: *Asymmetric coupling proceeds efficiently between propargylic acetates, cycloalkenes and electron-rich heteroarenes including indoles, pyrroles, activated furans and thiophenes. 2,3-Disubstituted tetrahydrofurans and pyrrolidines are produced in trans configuration and excellent enantiomeric ratios. The reaction proceeds via Wacker-type attack of nucleophilic heteroarenes on alkenes activated by allenyl Pd^{II} species.*

Asymmetric Friedel–Crafts alkylation allows direct incorporation of heteroarenes, such as indoles, pyrroles and some other electron-rich (hetero)arenes, into useful chiral building blocks. In these reactions, diverse types of alkylating reagents with innate polar bonds can be used, including carbonyl compounds, imines, epoxides and aziridines, allylic electrophiles and Michael acceptors.[1] Some of these catalytic methods have been applied in total syntheses of bioactive natural products.[2]

Unactivated alkenes are an alternative and attractive class of alkylating reagents. Alkenes can survive under many reaction conditions entailed in a multi-step synthesis, and can be activated to react with heteroarenes once properly activated. For example, alkenes can be readily activated by electrophilic metal complexes (Pt, Pd and Au) towards nucleophilic attack by pendant indoles and pyrroles to form 5- or 6-membered rings (Figure 1a).[3] The intermolecular version proved to be more challenging. Chen et al. recently disclosed stereoselective γ-selective addition of indoles to alkenes activated by palladacycles in situ derived from *N*-8-quinolinyl-amides (Figure 1b).[4] Asymmetric heteroarylation of alkenes is deemed to be even more difficult without aid of a directing group or covalent linkage to metal centers, because of inherent difficulty in controlling conformations of alkenes during external attack.

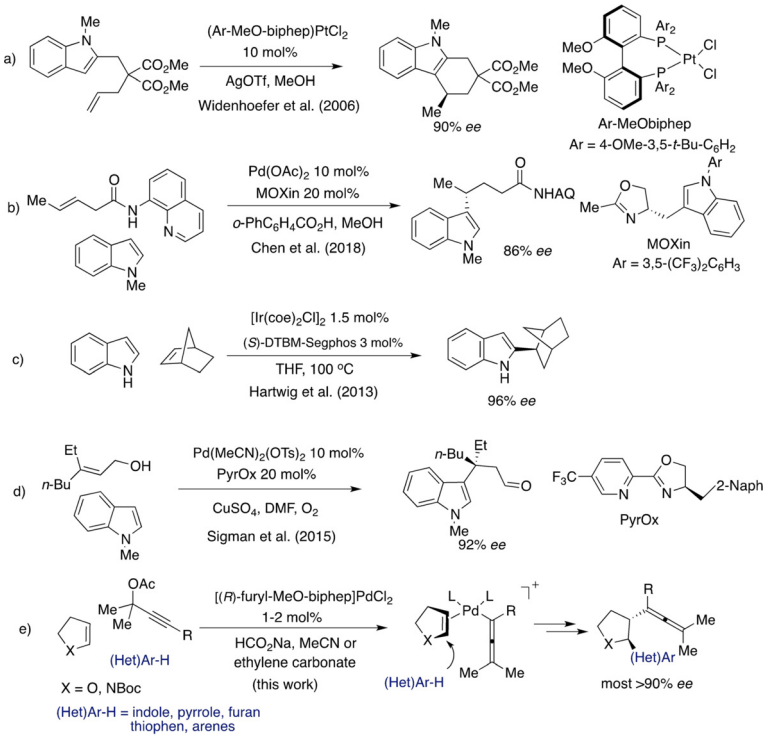


Figure 1. Asymmetric heteroarylation of alkenes based on a,b,e) Wacker-type nucleophilic attack and c,d) β-insertion of heteroaryl metal species.

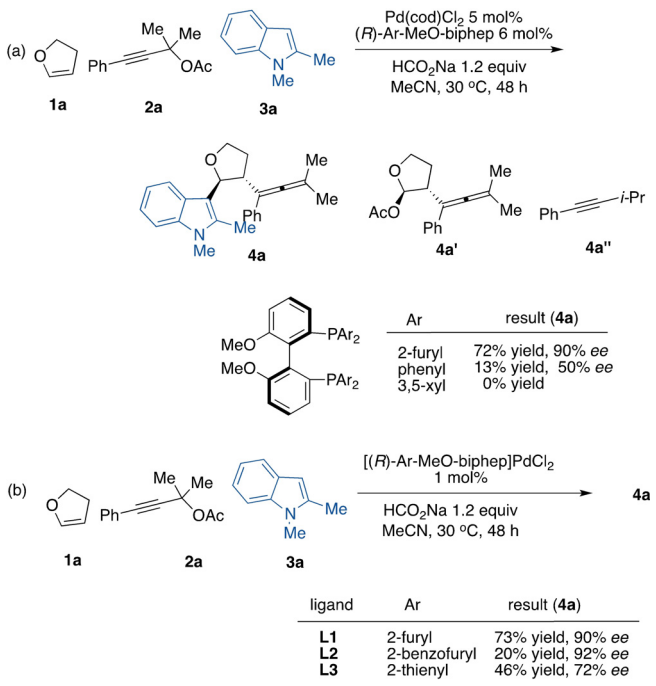
In another type of reaction pathway, low-valent late transition metals (Ni,[5] Rh[6] and Ir[7]) were reported to cleave heteroaryl C–H bonds and then promote asymmetric β-insertion to pendant alkenes.[8] The intermolecular insertion of this type, however, is also challenging and such examples are limited. In Fe- or Co-catalyzed directed alkylation of indoles, insertion into styrene occurred in good *ee* values, but stoichiometric amounts of Grignard reagents were needed to in situ produce active low-valent metal catalysts.[9] In iridium-catalyzed enantioselective alkylation of indoles and other heteroarenes, insertion was limited to reactive bicyclic norbornenes and alike (Figure 1c), as disclosed by Hartwig et al.[10] Recently, Sigman et al. reported that in oxidative Heck reaction, in situ generated indolyl Pd species underwent β-insertion of acyclic alkenols in good enantiomeric ratios (Figure 1d).[11] Additionally, Zhu et al. reported that oxadiazoles and other heteroarenes containing acidified C–H bonds were in situ deprotonated by bases and intercepted alkyl palladium species, which were produced from asymmetric Heck-type cyclization.[12]

[*] Prof. Dr. J. S. Zhou
State Key Laboratory of Chemical Oncogenomics, Key Laboratory of Chemical Genomics, School of Chemical Biology and Biotechnology, Peking University Shenzhen Graduate School, Room F-312
2199 Lishui Road, Nanshan District, Shenzhen 518055 (China)
E-mail: jrzhou@pku.edu.cn
Dr. S. Teng, Prof. Dr. Y. R. Chi
Division of Chemistry and Biological Chemistry, School of Physical and Mathematical Sciences, Nanyang Technological University
21 Nanyang Link, 637371 Singapore (Singapore)
Supporting information and the ORCID identification number(s) for the author(s) of this article can be found under: https://doi.org/10.1002/anie.202014781.

Previously, we reported Pd-catalyzed enantioselective Wacker-type coupling of propargylic acetates, cycloalkenes and weak *O*- and *N*-nucleophiles, such as alcohols, water and (hetero)arylamines.[13] Herein, we extend the Wacker reactivity to nucleophilic heteroarenes including indoles, pyrroles and some activated furans and thiophenes, as well as some anilines. The three-component coupling produces *trans* adducts in excellent enantiomeric ratios, without the aid of directing groups (Figure 1e).

Substituted pyrrolidines and tetrahydrofurans are among the most frequently used heterocycles in pharmaceuticals.[14] In recent years, incorporation of saturated azacycles, in place of unsaturated azaarenes, has become a common strategy to increase chance of clinical success of drugs.[15] But catalytic methods to access 2,3-disubstituted pyrrolidines and tetrahydrofurans are still limited.[16] The allene functionality in the products are useful intermediates in stereoselective synthesis.[17] Many catalytic methods are now available for stereo- and regioselective transformations of allenes.[18]

We used a model reaction of propargylic acetate **2a**, 2,3-dihydrofuran (2 equiv) and 1,2-dimethylindole **3a** (3 equiv). In our initial study, common diphosphines including Segphos, Difluorphos and P-Phos did not produce active Pd catalysts. To our gratification, a Pd catalyst of electron-deficient MeO-biphep **L1** carrying *P*-furyl substituents[19] promoted formation of desired adduct **4a** in good yield and 90% *ee* (Scheme 1a). Minor side products included a ternary adduct with acetic acid **4a′** and, to a lesser extent, another ternary adduct with formic acid. In comparison, a Pd catalyst of parent MeO-biphep[20] having *P*-phenyl groups led to formation **4a** in 13% yield, along with reduction of propargylic acetate to **4a″** (56% yield) as main side reaction.



Scheme 1. Effect of MeO-biphep ligands on model reaction of 2,3-dihydrofuran and 1,2-dimethylindole using a mixture of a) $Pd(cod)Cl_2$ and diphosphines and b) isolated Pd complexes.

Stirring of $Pd(cod)Cl_2$ and **L1** generated complex (**L1**)$PdCl_2$ as yellow precipitate in acetonitrile. The isolated complex provided similar results in the model reaction and also improved its reproducibility (Scheme 1b). Thus, 1 mol% Pd complex of **L1** was sufficient to promote full conversion and gave adduct **4a** in 73% yield and 90% *ee*. Complexes of modified MeO-biphep's **L2** and **L3** carrying *P*-benzofuryl and *P*-thienyl groups, respectively, were less reactive, in comparison. Sodium formate was found to be optimal to reduce (**L1**)$PdCl_2$ to generate the active Pd^0 catalyst in situ, but it also led to 10% of side product **4a″**. Potassium formate led to 61% of **4a** in the model reaction, whereas neither K_3PO_4 nor NEt_3 produced an active catalyst at all.

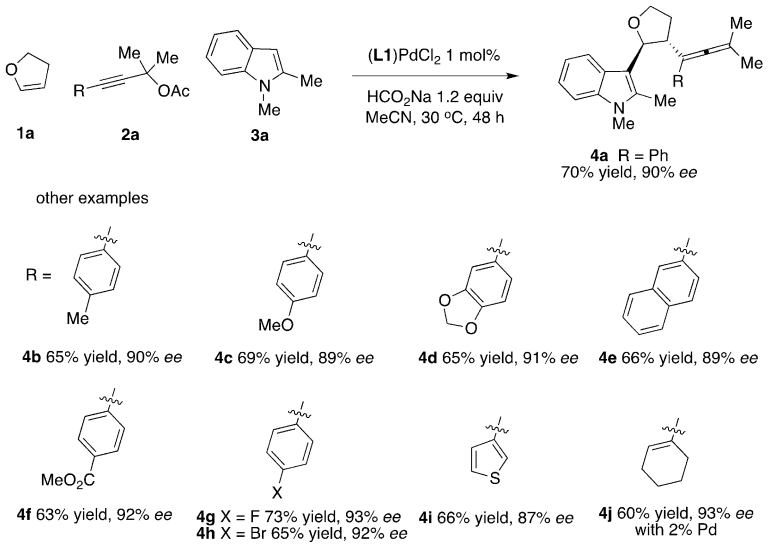
Intuitively, the choice of polar solvents was crucial to stabilizing a cationic allenyl palladium complex, a key species in the catalytic cycle. **4a** was formed in 73% and 63% yields in the model reaction in acetonitrile and ethylene carbonate, respectively. The yields were much lower in some polar solvents, 23% in EtOH, 31% in *i*PrOH and 43% in CH_2Cl_2, whereas no desired product was formed in DMF, DMSO and dioxane.

Palladium dichloride complex of **L1** (1 mol%) was successfully applied to reactions of 2,3-dihydrofuran with different propargylic acetates, carrying both electron-donating methoxy and electron-withdrawing ester groups on aryl rings (**4c**, **4f**) (Scheme 2). The reaction also tolerated aryl fluoride and bromide (**4g–h**). Furthermore, the C3-substituents can be thienyl and cycloalkenyl rings (**4i–j**). However, omission of two methyl groups on the propargyl fragment led to the loss of the desired reactivity.

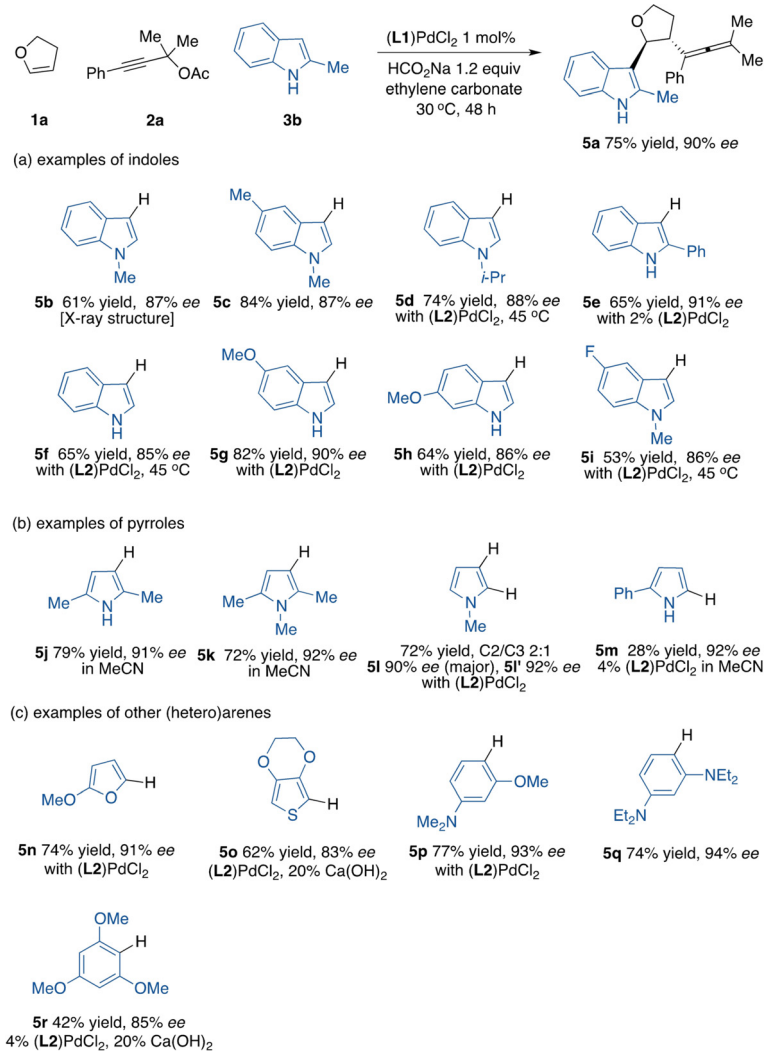
The model reaction of 1,2-dimethylindole provided good yield of adduct **4a** in acetonitrile. In exploration of other indoles, we found that most of indoles gave better yields in ethylene carbonate instead (Scheme 3a). Ethylene carbonate has an exceptional high dielectric constant of 95; with a melting point of 35 °C, it quickly melted in the reaction mixture upon heating. Furthermore, for most indoles without C2-substituents, $PdCl_2$ complex of ligand **L2** carrying *P*-benzofuryl rings led to higher conversions. Thus, indoles carrying both electron-donating and electron-withdrawing groups reacted smoothly to give adducts in reasonably good yields (**5g–i**). Adduct **5b** was crystalline and X-ray diffraction helped to set its absolute configuration and others by analogy.[21] Notably, 1,3-dimethylindole formed a ternary adduct (30% yield) at its C2-position.

Substituted pyrroles can also participate in the three-component reactions to furnish adducts **5j–m** in acetonitrile or ethylene carbonate (Scheme 3b). The reaction of *N*-methylpyrrole resulted in two isomers **5l** and **5l′** in 2:1 ratio, both in over 90% *ee*. 2,5-Diphenylpyrrole, unfortunately, was too hindered to react.

Furthermore, the new method was successfully applied to an activated furan, thiophene and several anilines to give **5n–q** (Scheme 3c). Without strongly electron-donating alkoxy or alkylamino groups on these substrates, no expected reaction was detected. Interestingly, very hindered 1,3,5-trimethoxybenezene also coupled to give adduct **5r**, although in moderate yield (42%). In some examples above, Pd complex of **L2** was used instead of **L1** to give better yields of



Scheme 2. Examples of propargylic acetates in 3-component coupling with 2,3-dihydrofuran.



Scheme 3. Examples of 3-component coupling of 2,3-dihydrofuran with indoles, pyrroles and other (hetero)arenes.

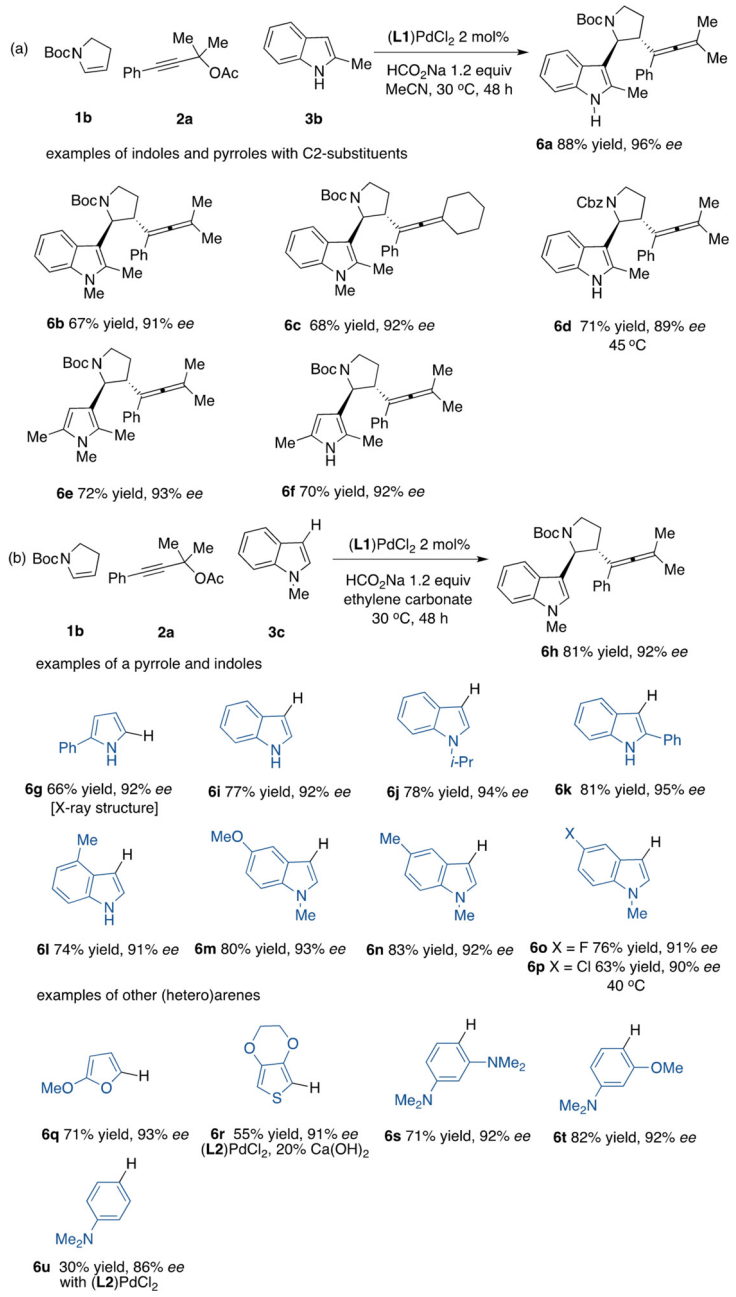
desired products. Addition of 20 mol% calcium hydroxide also helped to improve yields of some examples by neutralizing acetic acid produced from the reaction, but the yields did not further improve when used in stoichiometric amounts.

In the aforementioned reactions in Scheme 3 that gave poor or moderate yields, ternary adduct of 2,3-dihydrofuran and acetic acid **4a′** was the main side product. When isolated and added separately into another living catalytic reaction, **4a′** was not consumed indicating that it was not a competent intermediate for the generation of **4a** under catalytic conditions.

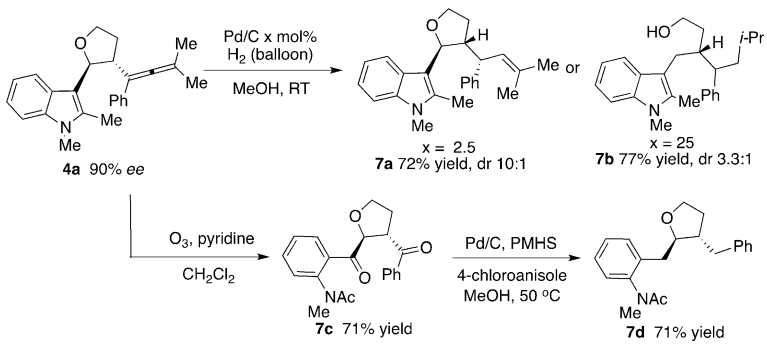
The complex of **L1** was applicable to asymmetric heteroarylation of *N*-Boc-2,3-dihydropyrrole. Herein, no ternary adduct with acetic acid analogous to **4a′** was detected as side product. Instead, a racemic Friedel–Crafts-type adduct of *N*-Boc-2,3-dihydropyrrole and indole was the main side product, which was catalyzed by in situ produced acetic acid. In acetonitrile, indoles and pyrroles carrying C2-substituents reacted efficiently to give adducts **6a–f** (Scheme 4a). 2-Phenylpyrrole coupled cleanly at C5-position (as confirmed by X-ray structure)[21] and its yield was higher in ethylene carbonate than acetonitrile. For most indoles without C2-substituents, higher yields were also obtained in ethylene carbonate (Scheme 4b). The reaction tolerated well substituents including a methoxy group, aryl fluoride and chloride on indoles (**6l–p**). An activated furan, thiophene and some anilines were also suitable substrates, giving adducts **6q–t**. Notably, *N*,*N*-dimethylaniline was moderately reactive to afford product **6u** in 30% yield when (**L2**)$PdCl_2$ was used as the catalyst.

The allenes in the adducts can be readily converted to other functional groups (Scheme 5). For example, Pd/C-catalyzed selective monohydrogenation of **4a** afforded **7a** with 10:1 dr at 2.5 mol% Pd loading. But at higher 25 mol% Pd loading, not only the allene group was fully hydrogenated, but also the tetrahydrofuran ring was selectively cleaved at the benzylic site to provide **7b**. Thus, the hydrogenation process did not halt halfway after double hydrogenation of the allene. Additionally, both the allene and heterocyclic ring of indole were cleaved by ozone to give diketone **7c**.[22] Both aromatic ketone groups were then deoxygenated to give **7d** via Pd/C-catalyzed reduction using polymethylhydrosiloxane (PMHS).[23]

In summary, we report herein a three-component difunctionalization of cycloalkenes using propargylic electrophiles and heteroarenes such as indoles, pyrroles and some activated furans and thiophenes. Asymmetric Wacker-type attack of nucleophilic heteroarenes on cycloolefins without the aid of a directing group proceeds with



Scheme 4. 3-Component coupling of *N*-Boc-2,3-dihydropyrrole with indoles and pyrroles and other (hetero)arenes in a) MeCN and b) ethylene carbonate (Boc = *t*-butoxycarbonyl).



Scheme 5. Transformations of heteroarylative adducts.

excellent stereocontrol. 2,3-Disubstitututed tetrahydrofurans and pyrrolidines are generated in *trans* configuration and excellent *ee* values. Mechanistically, the electron-deficient σ-allenyl palladium center ligated by weakly donating MeO-biphep proved instrumental to sufficiently activating cycloalkenes for external attack by heteroarenes.

Acknowledgements

We acknowledge financial support from Peking University Shenzhen Graduate School, Shenzhen Bay Laboratory Institute of Chemical biology, Nanyang Technological University, GSK-EDB Trust Fund (2017 GSK-EDB Green and Sustainable Manufacturing Award) and A*STAR Science and Engineering Research Council (AME IRG A1783c0010). We thank Dr Li Yongxin for X-ray diffraction.

Conflict of interest

The authors declare no conflict of interest.

Keywords: alkene difunctionalization · allenes · heteroarylation · palladium catalysis · Wacker reaction

[1] Reviews: a) M. Bandini, A. Melloni, A. Umani-Ronchi, *Angew. Chem. Int. Ed.* **2004**, *43*, 550; *Angew. Chem.* **2004**, *116*, 560; b) A. Erkkilä, I. Majander, P. M. Pihko, *Chem. Rev.* **2007**, *107*, 5416; c) D. W. C. MacMillan, *Nature* **2008**, *455*, 304; d) T. B. Poulsen, K. A. Jørgensen, *Chem. Rev.* **2008**, *108*, 2903; e) M. Terada, *Chem. Commun.* **2008**, 4097; f) M. Bandini, A. Eichholzer, *Angew. Chem. Int. Ed.* **2009**, *48*, 9608; *Angew. Chem.* **2009**, *121*, 9786; g) S.-L. You, Q. Cai, M. Zeng, *Chem. Soc. Rev.* **2009**, *38*, 2190; h) V. Terrasson, R. Marcia de Figueiredo, J. M. Campagne, *Eur. J. Org. Chem.* **2010**, 2635; i) Q. Yin, Y. Shi, J. Wang, X. Zhang, *Chem. Soc. Rev.* **2020**, *49*, 6141.

[2] a) M. M. Heravi, V. Zadsirjan, P. Saedi, T. Momeni, *RSC Adv.* **2018**, *8*, 40061; b) Z. Wang, *Molecules* **2019**, *24*, 3412.

[3] Examples: a) X. Han, R. A. Widenhoefer, *Org. Lett.* **2006**, *8*, 3801; b) A. R. Chianese, S. J. Lee, M. R. Gagné, *Angew. Chem. Int. Ed.* **2007**, *46*, 4042; *Angew. Chem.* **2007**, *119*, 4118; c) C. Liu, R. A. Widenhoefer, *Org. Lett.* **2007**, *9*, 1935; d) M. Bandini, A. Eichholzer, *Angew. Chem. Int. Ed.* **2009**, *48*, 9533; *Angew. Chem.* **2009**, *121*, 9697; e) H. Huang, R. Peters, *Angew. Chem. Int. Ed.* **2009**, *48*, 604; *Angew. Chem.* **2009**, *121*, 612.

[4] a) H. Wang, Z. Bai, T. Jiao, Z. Deng, H. Tong, G. He, Q. Peng, G. Chen, *J. Am. Chem. Soc.* **2018**, *140*, 3542; b) Z. Bai, S. Zheng, Z. Bai, F. Song, H. Wang, Q. Peng, G. Chen, G. He, *ACS Catal.* **2019**, *9*, 6502.

[5] Examples: a) Y. Schramm, M. Takeuchi, K. Semba, Y. Nakao, J. F. Hartwig, *J. Am. Chem. Soc.* **2015**, *137*, 12215; b) Y.-X. Wang, S.-L. Qi, Y.-X. Luan, X.-W. Han, S. Wang, H. Chen, M. Ye, *J. Am. Chem. Soc.* **2018**, *140*, 5360; c) Y. Cai, X. Ye, S. Liu, S.-L. Shi, *Angew. Chem. Int. Ed.* **2019**, *58*, 13433; *Angew. Chem.* **2019**, *131*, 13567; d) J. Diesel, D. Grosheva, S. Kodama, N. Cramer, *Angew. Chem. Int. Ed.* **2019**, *58*, 11044; *Angew. Chem.* **2019**, *131*, 11160; e) J. Loup, V. Müller, D. Ghorai, L. Ackermann, *Angew. Chem. Int. Ed.* **2019**, *58*, 1749; *Angew. Chem.* **2019**, *131*, 1763; f) N. I. Saper, A. Ohgi, D. W. Small, K. Semba, Y. Nakao, J. F. Hartwig, *Nat. Chem.* **2020**, *12*, 276.

[6] a) R. K. Thalji, J. A. Ellman, R. G. Bergman, *J. Am. Chem. Soc.* **2004**, *126*, 7192; b) R. M. Wilson, R. K. Thalji, R. G. Bergman, J. A. Ellman, *Org. Lett.* **2006**, *8*, 1745.

[7] T. Shibata, N. Ryu, H. Takano, *Adv. Synth. Catal.* **2015**, *357*, 1131.

[8] Reviews: a) Z. Dong, Z. Ren, S. J. Thompson, Y. Xu, G. Dong, *Chem. Rev.* **2017**, *117*, 9333; b) G. Evano, C. Theunissen, *Angew. Chem. Int. Ed.* **2019**, *58*, 7202; *Angew. Chem.* **2019**, *131*, 7278; c) G. Evano, C. Theunissen, *Angew. Chem. Int. Ed.* **2019**, *58*, 7558; *Angew. Chem.* **2019**, *131*, 7638; d) P. Gandeepan, T. Müller, D. Zell, G. Cera, S. Warratz, L. Ackermann, *Chem. Rev.* **2019**, *119*, 2192; e) J. Loup, U. Dhawa, F. Pesciaioli, J. Wencel-Delord, L. Ackermann, *Angew. Chem. Int. Ed.* **2019**, *58*, 12803; *Angew. Chem.* **2019**, *131*, 12934; f) Q. Zhao, G. Meng, S. P. Nolan, M. Szostak, *Chem. Rev.* **2020**, *120*, 1981.

[9] a) P.-S. Lee, N. Yoshikai, *Org. Lett.* **2015**, *17*, 22; b) J. Loup, D. Zell, J. C. A. Oliveira, H. Keil, D. Stalke, L. Ackermann, *Angew. Chem. Int. Ed.* **2017**, *56*, 14197; *Angew. Chem.* **2017**, *129*, 14385.

[10] a) C. S. Sevov, J. F. Hartwig, *J. Am. Chem. Soc.* **2013**, *135*, 2116; b) T. Shirai, Y. Yamamoto, *Angew. Chem. Int. Ed.* **2015**, *54*, 9894; *Angew. Chem.* **2015**, *127*, 10032.

[11] C. Zhang, C. B. Santiago, J. M. Crawford, M. S. Sigman, *J. Am. Chem. Soc.* **2015**, *137*, 15668.

[12] a) W. Kong, Q. Wang, J. Zhu, *J. Am. Chem. Soc.* **2015**, *137*, 16028; b) X. Bao, Q. Wang, J. Zhu, *Angew. Chem. Int. Ed.* **2017**, *56*, 9577; *Angew. Chem.* **2017**, *129*, 9705; c) S. Tong, A. Limouni, Q. Wang, M.-X. Wang, J. Zhu, *Angew. Chem. Int. Ed.* **2017**, *56*, 14192; *Angew. Chem.* **2017**, *129*, 14380.

[13] S. Teng, Z. Jiao, Y. R. Chi, J. S. Zhou, *Angew. Chem. Int. Ed.* **2020**, *59*, 2246; *Angew. Chem.* **2020**, *132*, 2266.

[14] Reviews: a) M. Aldeghi, S. Malhotra, D. L. Selwood, A. W. E. Chan, *Chem. Biol. Drug Des.* **2014**, *83*, 450; b) R. D. Taylor, M. MacCoss, A. D. G. Lawson, *J. Med. Chem.* **2014**, *57*, 5845; c) E. Vitaku, D. T. Smith, J. T. Njardarson, *J. Med. Chem.* **2014**, *57*, 10257; d) C. M. Marson, *Adv. Heterocycl. Chem.* **2017**, *121*, 13; e) G. Wu, T. Zhao, D. Kang, J. Zhang, Y. Song, V. Namasivayam, J. Kongsted, C. Pannecouque, E. De Clercq, V. Poongavanam, X. Liu, P. Zhan, *J. Med. Chem.* **2019**, *62*, 9375.

[15] a) F. Lovering, J. Bikker, C. Humblet, *J. Med. Chem.* **2009**, *52*, 6752; b) F. Lovering, *MedChemComm* **2013**, *4*, 515; c) T. Y. Zhang, *Adv. Heterocycl. Chem.* **2017**, *121*, 1.

[16] Examples: a) F. Bertozzi, M. Gustafsson, R. Olsson, *Org. Lett.* **2002**, *4*, 3147; b) A. R. Reddy, C.-Y. Zhou, Z. Guo, J. Wei, C.-M. Che, *Angew. Chem. Int. Ed.* **2014**, *53*, 14175; *Angew. Chem.* **2014**, *126*, 14399; c) D. P. Affron, O. A. Davis, J. A. Bull, *Org. Lett.* **2014**, *16*, 4956; d) M. Shang, K. S. Feu, J. C. Vantourout, L. M. Barton, H. L. Osswald, N. Kato, K. Gagaring, C. W. McNamara, G. Chen, L. Hu, S. Ni, P. Fernández-Canelas, M. Chen, R. R. Merchant, T. Qin, S. L. Schreiber, B. Melillo, J.-Q. Yu, P. S. Baran, *Proc. Natl. Acad. Sci. USA* **2019**, *116*, 8721; e) D. Solé, A. Amenta, M. L. Bennasar, I. Fernández, *Chem. Commun.* **2019**, *55*, 1160; f) C. Xu, R. Cheng, Y.-C. Luo, M.-K. Wang, X. Zhang, *Angew. Chem. Int. Ed.* **2020**, *59*, 18741; *Angew. Chem.* **2020**, *132*, 18900.

[17] Reviews: a) A. Hoffmann-Röder, N. Krause, *Angew. Chem. Int. Ed.* **2004**, *43*, 1196; *Angew. Chem.* **2004**, *116*, 1216; b) G. Beutner, R. Carrasquillo, P. Geng, Y. Hsiao, E. C. Huang, J. Janey, K. Katipally, S. Kolotuchin, T. La Porte, A. Lee, P. Lobben, F. Lora-Gonzalez, B. Mack, B. Mudryk, Y. Qiu, X. Qian, A. Ramirez, T. M. Razler, T. Rosner, Z. Shi, E. Simmons, J. Stevens, J. Wang, C. Wei, S. R. Wisniewski, Y. Zhu, *Org. Lett.* **2018**, *20*, 3736.

[18] Reviews: a) S. Yu, S. Ma, *Angew. Chem. Int. Ed.* **2012**, *51*, 3074; *Angew. Chem.* **2012**, *124*, 3128; b) B. Alcaide, P. Almendros, *Chem. Soc. Rev.* **2014**, *43*, 2886; c) J. Ye, S. Ma, *Acc. Chem. Res.* **2014**, *47*, 989; d) R. Santhoshkumar, C.-H. Cheng, *Asian J. Org. Chem.* **2018**, *7*, 1151; e) B. Yang, Y. Qiu, J.-E. Bäckvall, *Acc. Chem. Res.* **2018**, *51*, 1520; f) G. Li, X. Huo, X. Jiang, W. Zhang, *Chem. Soc. Rev.* **2020**, *49*, 2060.

[19] M. J. Ardolino, J. P. Morken, *J. Am. Chem. Soc.* **2014**, *136*, 7092.

[20] a) R. Schmid, J. Foricher, M. Cereghetti, P. Schönholzer, *Helv. Chim. Acta* **1991**, *74*, 370; b) R. Schmid, E. A. Broger, C. Marco, C. Yvo, F. Joseph, L. Michel, R. K. Müller, M. Scalone, G. Schoettel, Z. Ulrich, *Pure Appl. Chem.* **1996**, *68*, 131.

[21] Deposition numbers 1938506 and 2043251 contain the supplementary crystallographic data for this paper. These data are provided free of charge by the joint Cambridge Crystallographic Data Centre and Fachinformationszentrum Karlsruhe Access Structures service.

[22] R. Willand-Charnley, T. J. Fisher, B. M. Johnson, P. H. Dussault, *Org. Lett.* **2012**, *14*, 2242.

[23] A. Volkov, K. P. J. Gustafson, C.-W. Tai, O. Verho, J.-E. Bäckvall, H. Adolfsson, *Angew. Chem. Int. Ed.* **2015**, *54*, 5122; *Angew. Chem.* **2015**, *127*, 5211.

Manuscript received: November 4, 2020
Accepted manuscript online: December 1, 2020
Version of record online: January 18, 2021

