Organic LETTERS

Letter

Cite This: Org. Lett. 2018, 20, 740−743

pubs.acs.org/OrgLett

Rh(III)-Catalyzed Acceptorless Dehydrogenative Coupling of (Hetero)arenes with 2-Carboxyl Allylic Alcohols

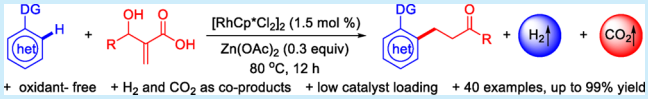
Jintao Xia,[†,‡] Zhipeng Huang,[†,‡] Xukai Zhou,[†,‡] Xifa Yang,[†,‡] Feng Wang,[†] and Xingwei Li*[,†]

[†]Dalian Institute of Chemical Physics, Chinese Academy of Sciences, Dalian 116023, China

[‡]University of Chinese Academy of Sciences, Beijing 100049, China

Supporting Information

ABSTRACT: Rhodium(III)-catalyzed C−H activation of (hetero)arenes and redox-neutral coupling with 2-carboxyl allylic alcohols has been realized for the construction of β-aryl ketones. This reaction occurred efficiently at a relatively low catalyst loading via initial dehydrogenative alkylation to give a β-keto carboxylic acid, followed by decarboxylation.

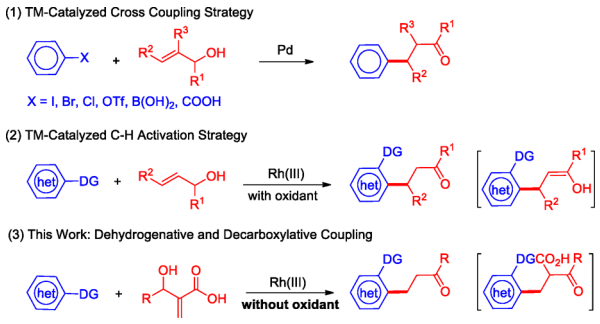


In the past decades, metal-catalyzed C(aryl)−H activation and functionalization[1] has evolved as an attractive alternative to classical organic synthesis which relies heavily on prefunctionalized starting materials for construction of new C−C bonds. By following this strategy, a great number of highly efficient protocols have been developed to deliver various organic functional materials and bioactive molecules.[2] The coupling between an arene and a nucleophilic reagent generally requires a stoichiometric amount of oxidant,[1i,j,3] together with generation of waste, which may limit the atom-economy and pose environmental issues. Ideally, the coupling system includes hydrogen-releasing conditions.

Olefins are commonly used substrates in C−H activation systems.[1e,4] In oxidative olefination of arenes, the employment of either external-oxidation or hydrogen-releasing conditions is dictated by the fate of the metal hydride species M(H)(X) in the catalytic cycle. Elimination of an HX from this metal hydride species leads to a lower valent metal species that is prone to re-oxidation to regenerate the active catalyst. Alternatively, protonolysis of the M−H bond by an acid may give rise to hydrogen evolution. However, this type of dehydrogenative coupling system is rather limited. Despite the challenges, Zhang,[5a] Wang,[5b] Yang,[5c] Jeganmohan,[5d,h] Li,[5e] Dong,[5f] and other groups[6] have independently developed dehydrogenative coupling reactions via C−H activation. On the other hand, β-aryl ketones[7] are versatile synthetic building blocks in organic transformations, and they have been accessed via cross-coupling of aryl (pseudo)halides, arylboronic acids, aryl carboxylic acids, or aryldiazonium salts with allylic alcohols or aldehydes in the presence or absence of external oxidants.[8] Recently, Rh(III)-catalyzed C−H activation has provided new avenues for synthesis of β-aryl ketones. In 2013, the Glorius group and the Jiang group independently reported synthesis of these products via C−H activation of arenes and coupling with allylic alcohols using $Cu(OAc)_2$ as an oxidant.[9] Our group[10] achieved synthesis of β-aryl ketones by taking advantage of the ring strain in the oxidative coupling of cyclopropanols with arenes. The Lu and Liu groups applied allenol or propargyl alcohols as a coupling reagent for oxidative synthesis of β-aryl ketones with a quaternary stereogenic center.[11] Although those methods were generally efficient, oxidants were required for the catalyst turnover. Alternatively, hydroarylation of olefins represents a useful method to access β-aryl ketones/aldehydes under redox-neutral conditions.[12] However, the olefins are limited to highly reactive enones/maleimides with stoichiometric amounts of base additives.

We envisioned that as a special allylic alcohol, 2-carboxyl allylic alcohol may serve as a suitable olefin substrate in C−H activation. Significantly, the migratory insertion of a M−Ar bond into the C = C bond of 2-carboxyl allylic alcohol and subsequent β-H elimination would give a β-keto acid that can readily undergo decarboxylation (Scheme 1c). We speculated

Scheme 1. Catalytic Synthesis of β-Aryl Aldehydes/Ketones



that decarboxylation and dehydrogenation might be integrated into a symbiotic system,[13] especially in the presence of a carboxylic or Lewis acid which may facilitate the protonolysis of the M−H bond for hydrogen evolution. We now report efficient hydrogen-releasing and decarboxylative coupling of arenes and 2-carboxyl allylic alcohols.

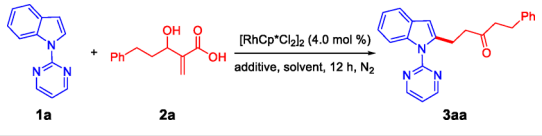
We initiated our exploration with the optimization studies of the coupling of *N*-(2-pyrimidinyl)indole (**1a**) and carboxylic

Received: December 13, 2017
Published: January 18, 2018

DOI: 10.1021/acs.orglett.7b03881
Org. Lett. 2018, 20, 740−743

acid **2a** (Table 1). Our initial studies revealed ketone **3aa** was isolated in 71% yield using $[RhCp^*Cl_2]_2$ catalyst and

Table 1. Screening of the Reaction Conditions[a]



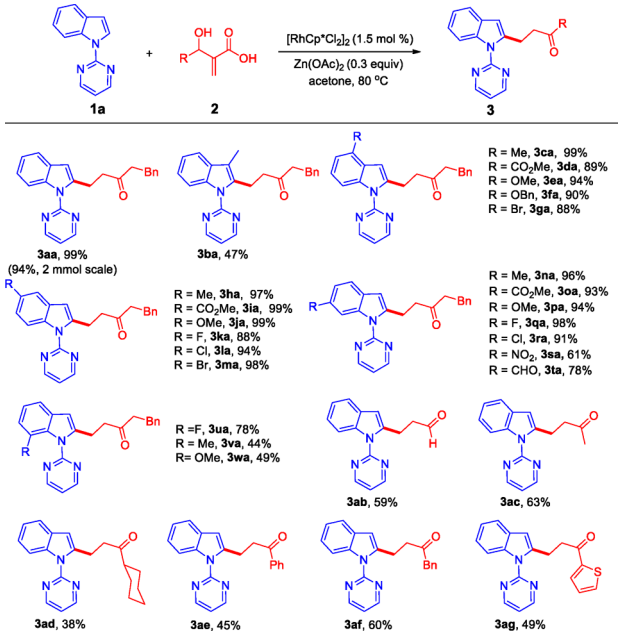
entry	additive (30 mol %)	solvent	yield[b] (%)
1[c]	$Zn(OAc)_2$	DCM	71
2[c]	$Zn(OAc)_2$	DME	70
3[c]	$Zn(OAc)_2$	acetone	74
4	$Zn(OAc)_2$	DME	91
5	$Zn(OAc)_2$	acetone	99
6	$Cu(OAc)_2$	acetone	24
7	AgOAc	acetone	20
8	CsOAc	acetone	trace
9[d]	$Zn(OAc)_2$	acetone	99
10[e]	$Zn(OAc)_2$	acetone	99
11[e,f]	$Zn(OAc)_2$	acetone	99
12		acetone	<5
13[g]	$Zn(OAc)_2$	acetone	

[a]Reaction conditions: **1a** (0.2 mmol), **2a** (0.5 mmol), Rh(III) catalyst, additive in a solvent (3 mL) under nitrogen at 80 °C. [b]Yield of the isolated product. [c]**2a** (0.3 mmol) was used. [d]$[RhCp^*Cl_2]_2$ (2.5 mol %). [e]$[RhCp^*Cl_2]_2$ (1.5 mol %). [f]Under air. [g]No $[RhCp^*Cl_2]_2$.

$Zn(OAc)_2$ additive in DCM under rigorously oxidant-free conditions (entry 1). A similar yield was obtained in DME or acetone solvent (entries 2 and 3). The yield was drastically improved to 91% in DME when the amount of **2a** was increased to 2.5 equiv (entry 4), and a nearly quantitative yield was delivered in acetone (entry 5). These results might indicate hydrogen evolution or hydrogen acceptance by the olefin or acetone. In fact, ^1H NMR analysis of a reaction in acetone-d_6 indicted that neither 2-propanol-d_6 nor hydrogenation product of the olefin was formed, and absence of the latter was further confirmed by GC−MS and HRMS. The H_2 and CO_2 coproducts were directly observed by online GC-MS analysis. $Zn(OAc)_2$ play an important role in this system since inferior results were obtained when $Cu(OAc)_2$, AgOAc, or CsOAc was used (entries 6−8). Lowering the catalyst loading to 1.5 mol % did not affect the reaction outcome (entries 9 and 10), and the reaction proceeded equally well under air (entry 11). Control experiments confirmed that both $[RhCp^*Cl_2]_2$ and $Zn(OAc)_2$ were necessary (entries 12 and 13).

With the establishment of the optimal conditions in hand, the scope and limitations of this system (Scheme 2) were next examined. Introduction of electron-donating (OMe, OBn), -withdrawing (CO_2Me, NO_2, CHO), and halogen groups (F, Cl, Br) into the C4−C6 positions of the indole were all tolerated, and the products were isolated in 61−99% yields (**3aa**, **3ca**−**ta**). A relatively lower yield was isolated when the C3 (**3ba**) or C7 (**3ua**−**wa**) position was substituted, indicative of steric effects. Of note, useful functional groups such as NO_2 (**3sa**) and CHO (**3ta**) were also compatible. The scope of the 2-carboxyl allylic alcohol was next explored in the coupling with indole **1a**. 2-(Hydroxymethyl)acrylic acid reacted to afford *β*-aryl aldehyde **3ab** in 59% yield, and moderate yields were delivered when the C3 position of 2-carboxyl allylic alcohol was substituted by a (cyclo)alkyl or a benzyl group (**3ac**−**ag**).

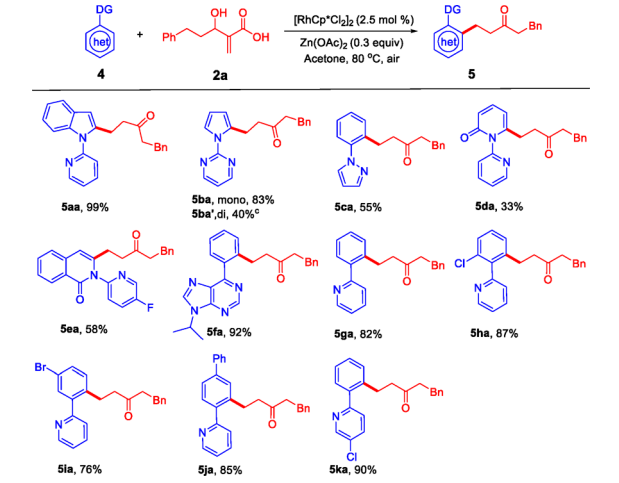
Scheme 2. Scope of Coupling *N*-(2-Pyrimidinyl)indoles and 2-Carboxyl Allylic Alcohols[a,b]



[a]Reaction conditions: **1a** (0.2 mmol), **2** (0.50 mmol), $[RhCp^*Cl_2]_2$ (1.5 mol %), $Zn(OAc)_2$ (0.3 equiv), acetone (3 mL) at 80 °C under air for 12 h. [b]Isolated yield.

The arene substrates are not limited to *N*-pyrimidylindoles (Scheme 3). *N*-Pyridylindole also coupled smoothly with **2a** in

Scheme 3. Scope of Other Arene Substrates[a,b]



[a]Reaction conditions: **4** (0.2 mmol), **2a** (0.5 mmol), $[RhCp^*Cl_2]_2$ (2.5 mol %), $Zn(OAc)_2$ (0.3 equiv), acetone (3 mL), 80 °C under air for 12 h. [b]Isolated yields. [c]**2a** (1.0 mmol) was used.

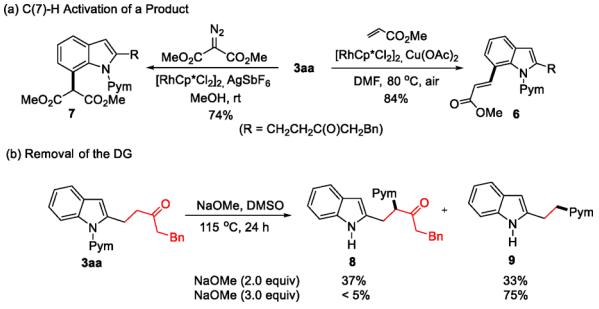
high efficiency (**5aa**). Pyrrole **4b** coupled with **2a** only to give the monoalkylated product (**5ba**) in 83% yield, while both mono- (**5ba**) and dialkylated (**5ba′**) products were obtained when the amount of **2a** was increased to 5 equiv. In addition, *N*-phenylpyrazole was amenable to the reaction conditions (**5ca**, 55%). Coupling of pyridone derivatives with **2a** provided products **5da** and **5ea** in moderate yields. Purine and pyridine were also applicable directing groups for C−H activation of

DOI: 10.1021/acs.orglett.7b03881
Org. Lett. 2018, 20, 740−743

benzene rings, as in formation of **5fa–ka** in good to excellent yields.

Several derivatization reactions were carried out to demonstrate the synthetic applications. Scaling up the reaction to 2 mmol gave **3aa** in 94% yield (Scheme 2). Further C(7)–H functionalization of **3aa** with methyl acrylate and dimethyl 2-diazomalonate afforded the olefination product **6** and alkylation product **7**, respectively (Scheme 4a). Attempted removal of the

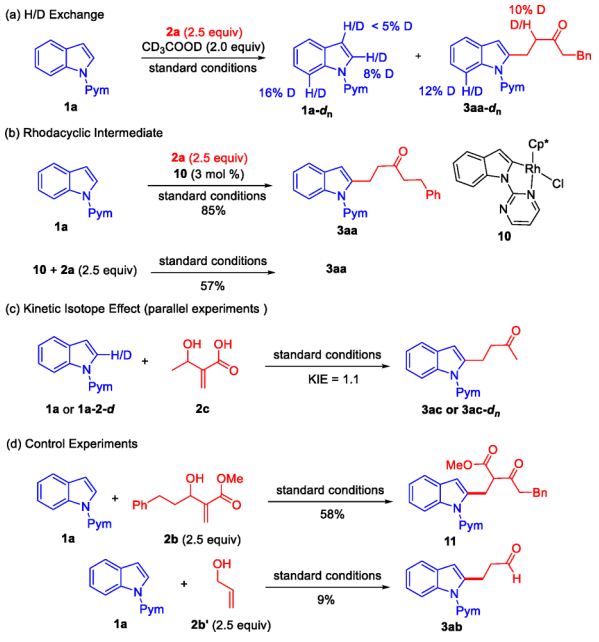
Scheme 4. Diversification of the Products



pyrimidyl group in **3aa** afforded an NH indole **8** together with 2-(2-(pyrimidin-2-yl)ethyl)-1*H*-indole (**9**), where **8** was generated via Smiles rearrangement (Scheme 4b).[10a,14] Furthermore, only **9** was isolated when NaOMe was used in 3 equiv amounts.

A series of experiments have been performed to elucidate the reaction mechanism (Scheme 5). H/D exchange between **1a**

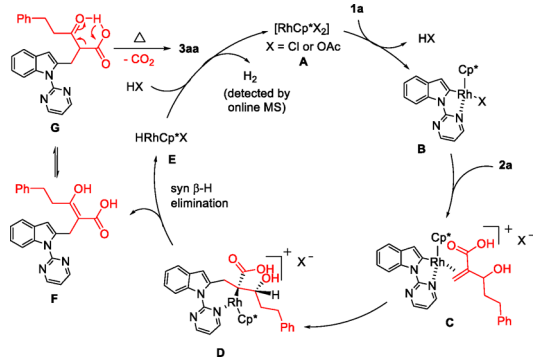
Scheme 5. Preliminary Mechanistic Studies



and CD_3CO_2D has been carried out in the presence of **2a** (Scheme 5a). Deuterium incorporation at the C2 and C7 positions was observed for the recovered indole substrate, suggestive of reversible C–H activation. In addition, H/D exchange at the α-position of the carbonyl group of the product was also detected. Rhodacyclic complex **10** was then synthesized, and it showed good activity in both stoichiometric and catalytic reactions (Scheme 5b), indicating relevancy of a C–H activation pathway. To further probe the C–H activation process, insignificant kinetic isotope effect (k_H/k_D = 1.1) of the reaction of indole **1a** was then obtained on the basis of two rate constants, suggesting that the C–H cleavage was not involved in the turnover-limiting step (Scheme 5c). A control experiment using the analogous ester suggested the reaction likely involve β-hydride elimination (Scheme 5d). In another control experiment, coupling of simple allyl alcohol under the standard conditions only afforded product **3ab** in 9% yield, indicating olefination activation by the carboxylic group (Scheme 5d).

On the basis of mechanistic studies and literature reports,[15] a plausible mechanism is proposed in Scheme 6. Starting from

Scheme 6. Proposed Mechanism



[RhCp*(OAc)X] (X = OAc or Cl), cyclometalation of indole produces a rhodacycle **B**. Subsequent coordination of **2a** gives a cationic olefin intermediate **C**, which undergoes selective migratory insertion to generate a tertiary alkyl species **D**, and this process is likely promoted by the $Zn(OAc)_2$ additive which activates the carbonyl.[15a,16] Subsequent β-hydride elimination provides a rhodium hydride species **E** together with the enol form of a β-keto acid. The β-keto acid **G** undergoes facile decarboxylation to furnish the final product. The rhodium hydride **E** is then protonolyzed by HX to regenerate the active rhodium species with hydrogen liberation. It is possible that the protonolysis is also facilitated by $Zn(OAc)_2$.

In conclusion, we have developed an efficient process to access β-aryl ketones via Rh(III)-catalyzed C–H activation of arenes and coupling with 2-carboxyl allylic alcohols, and the reactions tolerated a wide range of substrates with good functional group compatibility with H_2 and CO_2 as the coproducts. Efforts to explore other dehydrogenative coupling systems are underway in our laboratories.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.orglett.7b03881.

Detailed experimental procedures, characterization of new compounds, and NMR spectra (PDF)

■ AUTHOR INFORMATION

Corresponding Author

*E-mail: xwli@dicp.ac.cn.

ORCID

Feng Wang: 0000-0002-9167-8743

Xingwei Li: 0000-0002-1153-1558

DOI: 10.1021/acs.orglett.7b03881
Org. Lett. 2018, 20, 740–743

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

Financial support from the NSFC (Nos. 21525208 and 21472186) and the new technology of methanol conversion of Dalian Institute of Chemical Physics (Chinese Academy of Sciences) are gratefully acknowledged.

■ REFERENCES

(1) Selected reviews on catalytic C−H functionalization: (a) Lewis, J. C.; Bergman, R. G.; Ellman, J. A. *Acc. Chem. Res.* **2008**, *41*, 1013. (b) Chen, X.; Engle, K. M.; Wang, D. H.; Yu, J.-Q. *Angew. Chem., Int. Ed.* **2009**, *48*, 5094. (c) Colby, D. A.; Bergman, R. G.; Ellman, J. A. *Chem. Rev.* **2010**, *110*, 624. (d) McMurray, L.; O'Hara, F.; Gaunt, M. J. *Chem. Soc. Rev.* **2011**, *40*, 1885. (e) Yeung, C. S.; Dong, V. M. *Chem. Rev.* **2011**, *111*, 1215. (f) Kuhl, N.; Hopkinson, M. N.; Wencel-Delord, J.; Glorius, F. *Angew. Chem., Int. Ed.* **2012**, *51*, 10236. (g) Engle, K. M.; Mei, T.-S.; Wasa, M.; Yu, J.-Q. *Acc. Chem. Res.* **2012**, *45*, 788. (h) Neufeldt, S. R.; Sanford, M. S. *Acc. Chem. Res.* **2012**, *45*, 936. (i) Song, G.; Wang, F.; Li, X. *Chem. Soc. Rev.* **2012**, *41*, 3651. (j) Li, B.-J.; Shi, Z.-J. *Chem. Soc. Rev.* **2012**, *41*, 5588. (k) Hartwig, J. F. *Acc. Chem. Res.* **2012**, *45*, 864. (l) Ackermann, L. *Acc. Chem. Res.* **2014**, *47*, 281. (m) Song, G.; Li, X. *Acc. Chem. Res.* **2015**, *48*, 1007. (n) Zhu, R. Y.; Farmer, M. E.; Chen, Y. Q.; Yu, J. Q. *Angew. Chem., Int. Ed.* **2016**, *55*, 10578. (o) Ping, L.; Chung, D. S.; Bouffard, J.; Lee, S.-g. *Chem. Soc. Rev.* **2017**, *46*, 4299. (p) Kim, D.-S.; Park, W.-J.; Jun, C.-H. *Chem. Rev.* **2017**, *117*, 8977.

(2) (a) Satoh, T.; Miura, M. *Chem. - Eur. J.* **2010**, *16*, 11212. (b) Garcia-Melchor, M.; Braga, A. A.; Lledos, A.; Ujaque, G.; Maseras, F. *Acc. Chem. Res.* **2013**, *46*, 2626. (c) Li, S.-S.; Qin, L.; Dong, L. *Org. Biomol. Chem.* **2016**, *14*, 4554. (d) Hummel, J. R.; Boerth, J. A.; Ellman, J. A. *Chem. Rev.* **2017**, *117*, 9163. (e) Bhunia, S.; Pawar, G. G.; Kumar, S. S.; Jiang, Y.; Ma, D. *Angew. Chem., Int. Ed.* **2017**, *56*, 16136.

(3) Selected reviews: (a) Liu, C.; Zhang, H.; Shi, W.; Lei, A. *Chem. Rev.* **2011**, *111*, 1780. (b) Cho, S. H.; Kim, J. Y.; Kwak, J.; Chang, S. *Chem. Soc. Rev.* **2011**, *40*, 5068. (c) Liu, D.; Lei, A. *Chem. - Asian J.* **2015**, *10*, 806. (d) Liu, C.; Yuan, J.; Gao, M.; Tang, S.; Li, W.; Shi, R.; Lei, A. *Chem. Rev.* **2015**, *115*, 12138. (e) Yang, Y.; Lan, J.; You, J. *Chem. Rev.* **2017**, *117*, 8787.

(4) (a) Ritleng, V.; Sirlin, C.; Pfeffer, M. *Chem. Rev.* **2002**, *102*, 1731. (b) Li, C.-J. *Acc. Chem. Res.* **2009**, *42*, 335. (c) Satoh, T.; Miura, M. *Chem. - Eur. J.* **2010**, *16*, 11212. (d) Baeten, M.; Maes, B. U. W. *Adv. Organomet. Chem.* **2017**, *67*, 401. (e) Gini, A.; Brandhofer, T.; Mancheño, O. G. *Org. Biomol. Chem.* **2017**, *15*, 1294. (f) Ma, W.; Gandeepan, P.; Li, J.; Ackermann, L. *Org. Chem. Front.* **2017**, *4*, 1435. (g) Mishra, N. K.; Sharma, S.; Park, J.; Han, S.; Kim, I. S. *ACS Catal.* **2017**, *7*, 2821.

(5) Examples of catalytic coupling reactions with hydrogen evolution: (a) Yang, Y.; Xie, C.; Xie, Y.; Zhang, Y. *Org. Lett.* **2012**, *14*, 957. (b) He, R.; Huang, Z.-T.; Zheng, Q.-Y.; Wang, C. *Angew. Chem., Int. Ed.* **2014**, *53*, 4950. (c) Zhou, A.-X.; Mao, L.-L.; Wang, G.-W.; Yang, S.-D. *Chem. Commun.* **2014**, *50*, 8529. (d) Manikandan, R.; Madasamy, P.; Jeganmohan, M. *ACS Catal.* **2016**, *6*, 230. (e) He, K.-H.; Zhang, W.-D.; Yang, M.-Y.; Tang, K.-L.; Qu, M.; Ding, Y.-S.; Li, Y. *Org. Lett.* **2016**, *18*, 2840. (f) Li, W. H.; Wu, L.; Li, S.-S.; Liu, C.-F.; Zhang, G.-T.; Dong, L. *Chem. - Eur. J.* **2016**, *22*, 17926. (g) Lv, N.; Liu, Y.; Xiong, C.; Liu, Z.; Zhang, Y. *Org. Lett.* **2017**, *19*, 4640. (h) Manikandan, R.; Tamizmani, M.; Jeganmohan, M. *Org. Lett.* **2017**, *19*, 6678.

(6) Selected example of hydrogen-releasing couplings: (a) Toutov, A. A.; Liu, W.-B.; Betz, K. N.; Fedorov, A.; Stoltz, B. M.; Grubbs, R. H. *Nature* **2015**, *518*, 80. (b) Zhang, Q.-W.; An, K.; Liu, L.-C.; Yue, Y.; He, W. *Angew. Chem., Int. Ed.* **2015**, *54*, 6918. (c) Singh, S.; Butani, H. H.; Vachhani, D. D.; Shah, A.; Van der Eycken, E. V. *Chem. Commun.* **2017**, *53*, 10812.

(7) (a) Dounay, A. B.; Overman, L. E. *Chem. Rev.* **2003**, *103*, 2945. (b) Zhu, R.-Y.; Liu, L.-Y.; Park, H. S.; Hong, K.; Wu, Y.; Senanayake, C. H.; Yu, J.-Q. *J. Am. Chem. Soc.* **2017**, *139*, 16080.

(8) (a) Beletskaya, I. P.; Cheprakov, A. V. *Chem. Rev.* **2000**, *100*, 3009. (b) Hayashi, T.; Yamasaki, K. *Chem. Rev.* **2003**, *103*, 2829. (c) Edwards, H. J.; Hargrave, J. D.; Penrose, S. D.; Frost, C. G. *Chem. Soc. Rev.* **2010**, *39*, 2093. (d) Tian, P.; Dong, H.-Q.; Lin, G.-Q. *ACS Catal.* **2012**, *2*, 95. (e) Werner, E. W.; Mei, T.-S.; Burckle, A. J.; Sigman, M. S. *Science* **2012**, *338*, 1455. (f) Huang, L.; Qi, J.; Wu, X.; Huang, K.; Jiang, H. *Org. Lett.* **2013**, *15*, 2330. (g) Oliveira, C. C.; Angnes, R. A.; Correia, C. R. D. J. *J. Org. Chem.* **2013**, *78*, 4373. (h) Parveen, N.; Saha, R.; Sekar, G. *Adv. Synth. Catal.* **2017**, *359*, 3741.

(9) (a) Shi, Z.; Boultadakis-Arapinis, M.; Glorius, F. *Chem. Commun.* **2013**, *49*, 6489. (b) Huang, L.; Wang, Q.; Qi, J.; Wu, X.; Huang, K.; Jiang, H. *Chem. Sci.* **2013**, *4*, 2665.

(10) (a) Zhou, X.; Yu, S.; Kong, L.; Li, X. *ACS Catal.* **2016**, *6*, 647. (b) Zhou, X.; Yu, S.; Qi, Z.; Kong, L.; Li, X. J. *J. Org. Chem.* **2016**, *81*, 4869.

(11) (a) Zhou, Z.; Liu, G.; Lu, X. *Org. Lett.* **2016**, *18*, 5668. (b) Wu, X.; Wang, B.; Zhou, Y.; Liu, H. *Org. Lett.* **2017**, *19*, 1294.

(12) (a) Zhang, T.; Qi, Z.; Zhang, X.; Wu, L.; Li, X. *Chem. - Eur. J.* **2014**, *20*, 3283. (b) Lu, P.; Feng, C.; Loh, T. P. *Org. Lett.* **2015**, *17*, 3210. (c) Han, S.; Park, J.; Kim, S.; Lee, S. H.; Sharma, S.; Mishra, N. K.; Jung, Y. H.; Kim, I. S. *Org. Lett.* **2016**, *18*, 4666. (d) Boerth, J. A.; Ellman, J. A. *Chem. Sci.* **2016**, *7*, 1474. (e) Boerth, J. A.; Hummel, J. R.; Ellman, J. A. *Angew. Chem., Int. Ed.* **2016**, *55*, 12650. (f) Zhang, Z.; Tang, M.; Han, S.; Ackermann, L.; Li, J. J. *J. Org. Chem.* **2017**, *82*, 664. (g) Liu, B.; Hu, P.; Zhang, Y.; Li, Y.; Bai, D.; Li, X. *Org. Lett.* **2017**, *19*, 5402.

(13) Selected examples of C−H activation with decarboxylation: (a) Patra, T.; Maiti, D. *Chem. - Eur. J.* **2017**, *23*, 7382. (b) Qin, X.; Sun, D.; You, Q.; Cheng, Y.; Lan, J.; You, J. *Org. Lett.* **2015**, *17*, 1762. (c) Zhang, Y.; Zhao, H.; Zhang, M.; Su, W. *Angew. Chem., Int. Ed.* **2015**, *54*, 3817.

(14) For a leading review, see: (a) Holden, C. M.; Greaney, M. F. *Chem. - Eur. J.* **2017**, *23*, 8992. For related reports, see: (b) Zhang, Z.; Han, S.; Tang, M.; Ackermann, L.; Li, J. *Org. Lett.* **2017**, *19*, 3315. (c) Chen, S.-Y.; Han, X.-L.; Wu, J.-Q.; Li, Q.; Chen, Y.; Wang, H. *Angew. Chem., Int. Ed.* **2017**, *56*, 9939.

(15) (a) Xia, J.; Kong, L.; Zhou, X.; Zheng, G.; Li, X. *Org. Lett.* **2017**, *19*, 5972. (b) Zhang, S.-S.; Xia, J.; Wu, J.-Q.; Liu, X.-G.; Zhou, C.-J.; Lin, E.; Li, Q.; Huang, S.-L.; Wang, H. *Org. Lett.* **2017**, *19*, 5868.

(16) (a) Ramu, E.; Varala, R.; Sreelatha, N.; Adapa, S. R. *Tetrahedron Lett.* **2007**, *48*, 7184. (b) Xie, F.; Qi, Z.; Yu, S.; Li, X. *J. Am. Chem. Soc.* **2014**, *136*, 4780. (c) Xu, Y.; Zhou, X.; Zheng, G.; Li, X. *Org. Lett.* **2017**, *19*, 5256.

DOI: 10.1021/acs.orglett.7b03881
Org. Lett. 2018, 20, 740−743