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Nickel(II)-Catalyzed Cascade Vinylogous Mukaiyama 1,6-Michael/Michael Addition of 2-Silyloxyfuran with *N*-Sulfonyl-1-aza-1,3-dienes: Access to Fused Piperidine/Butyrolactone Skeletons

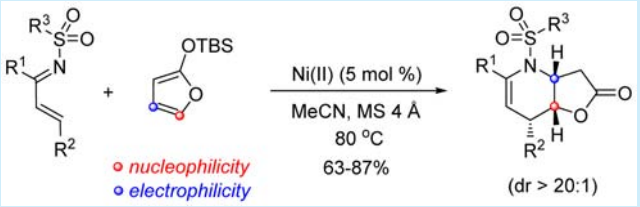
Kang Liu,[†,§] Xin Chang,[†,§] and Chun-Jiang Wang*[,†,‡]

[†]College of Chemistry and Molecular Sciences, Wuhan University, Wuhan 430072, China

[‡]State Key Laboratory of Elemento-organic Chemistry, Nankai University, Tianjin, China 300071

Supporting Information

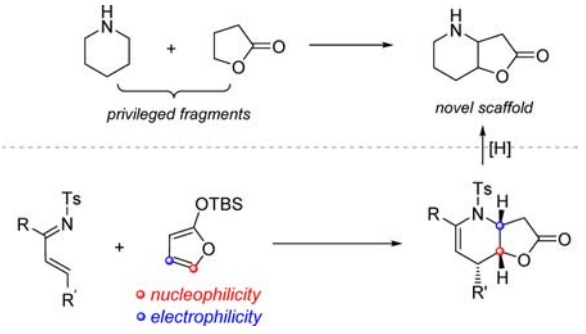
ABSTRACT: An unprecedented and highly efficient nickel-catalyzed cascade vinylogous Mukaiyama 1,6-Michael/Michael addition of 2-silyloxyfuran with *N*-sulfonyl-1-aza-1,3-dienes is reported, in which 2-silyloxyfuran was successfully employed as nucleophile and electrophile sequentially. This methodology combined with subsequent reduction provides a facile access to biologically important fused piperidine/butyrolactone skeletons in good yield with exclusive diastereoselectivity under mild reaction conditions.



Piperidine skeletons are ubiquitous modules in a number of natural products and pharmaceutically important molecules.[1] Many alkaloids possessing piperidine motifs also exhibit a wide range of biological activities, which have potential applications in the project of new drugs design and exploitation.[2] On the other hand, γ-butyrolactones, which constitute one of the most important classifications of compounds in organic chemistry, are the prevalent structural subunits distributed in many natural products.[3] Owing to their aforementioned potentially bioactive properties and applications, a large number of efficient synthetic methodologies have been developed to access those privileged building blocks.[4]

The practical combination of biologically important skeletons has been considered as a powerful tool for the construction of complex and diverse compounds with significant bioactivity. Actually, the functionalized piperidine-containing heterocycles, particularly fused with γ-butyrolactone moieties, are ubiquitous modules of the natural products and azasugar chemistry (Scheme 1),[5] such as tortifolisine, voacangalactone, (−)-sedacryptine. Therefore, intense interest has been devoted to the development of synthetic approaches to these fused piperidine/butyrolactone intermediates and biological target compounds.[6] For example, a Pd-catalyzed aminocarbonylation of protected aminoalkene had been reported to yield the piperidine/lactone with moderate diastereoselectivity.[6a,b] A direct γ-arylation of γ-substituted butenolides with aryl bromides was reported through a Pd-catalyzed cross-coupling reaction followed by conjugate addition to form the analogous structures.[6c] Recently, Chen and co-workers described a direct asymmetric γ-allylic alkylation of butenolides with MBH carbonates catalyzed by modified cinchona alkaloids, followed by tandem double aza-Michael additions of benzyl amine to provide the bicyclic piperidine lactone skeletons.[6d,e] Although those advances, the reported methods require complicated starting materials, multisteps procedures, or harsh reaction conditions, there is still a requirement for developing a facile and efficient methodology to access those core fused piperidine/butyrolactone frameworks.

Scheme 1. Cascade Vinylogous Mukaiyama 1,6-MA/MA Reaction of 2-Silyloxyfuran with *N*-Sulfonyl-1-aza-1,3-dienes: Facile Access to Fused Piperidine/Butyrolactone Scaffolds



To our knowledge, 2-silyloxyfuran acts as γ-regioselective nucleophilic reagent in the abundant vinylogous addition reactions involving C−C bond formation.[7,8] Nevertheless, few examples have been reported to utilize 2-silyloxyfuran as a dipole-type synthon in cascade reaction in consideration of the potential nucleophilicity on C5 of 2-silyloxyfuran and the generated electrophilicity on C4 of the formed butenolide. Most recently, we have presented a Cu(II)-catalyzed asymmetric cascade vinylogous Mukaiyama 1,6-Michael/Michael addition of 2-silyloxyfurans with azoalkenes, in which

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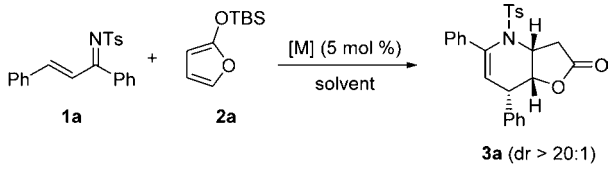
2-silyloxyfuran was successfully employed as nucleophile and electrophile sequentially.[9] Based on our continuous efforts on the synthesis of piperidine derivatives,[10] we envisaged that the combination of *N*-sulfonyl-1-aza-1,3-dienes and 2-silyloxyfuran into the designed cascade annulation followed by simple reduction step could contribute to furnish the fused piperidine/lactone moiety, as shown in Scheme 1.

To probe the validity of the proposed cascade annulation, we investigated a model reaction by reacting *N*-tosylimine **1a** with 2-silyloxyfuran **2a** in the absence of any catalyst in CH_2Cl_2 (Table 1). The cascade reaction occurred smoothly, and the

Table 1. Initial Investigations of the Cascade 1,6-VMA/MA of *N*-Sulfonyl-1-aza-1,3-dienes 1a and 2-Silyloxyfuran 2a[a]



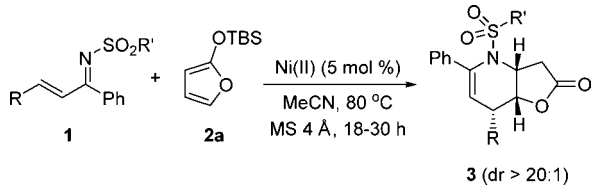
entry	[M]	solvent	temp (°C)	yield[b] (%)
1		CH_2Cl_2	rt	38
2	AgOAc	CH_2Cl_2	rt	trace
3	$Cu(MeCN)_4BF_4$	CH_2Cl_2	rt	trace
4	$Cu(ClO_4)_2$	CH_2Cl_2	rt	18
5	$Ni(ClO_4)_2{\cdot}6H_2O$	CH_2Cl_2	rt	52
6	$Fe(ClO_4)_2$	CH_2Cl_2	rt	disorder
7	$Fe(ClO_4)_3$	CH_2Cl_2	rt	disorder
8	$Sc(OTf)_2$	CH_2Cl_2	rt	disorder
9	$Ni(ClO_4)_2{\cdot}6H_2O$	$CHCl_3$	rt	41
10	$Ni(ClO_4)_2{\cdot}6H_2O$	THF	rt	35
11	$Ni(ClO_4)_2{\cdot}6H_2O$	PhMe	rt	31
12	$Ni(ClO_4)_2{\cdot}6H_2O$	MeCN	rt	64
13	$Ni(ClO_4)_2{\cdot}6H_2O$	MeCN	80	70
14[c]	$Ni(ClO_4)_2{\cdot}6H_2O$	MeCN	80	75

[a]All reactions were carried out with 0.30 mmol of **1a** and 0.60 mmol of **2a** in 1.5 mL of MeCN at 80 °C. [b]Isolated yield. [c]4 Å molecular sieves were employed as additive.

cycloaddition product **3a** was obtained with exclusive diastereoselectivity (dr >20:1) at room temperature albeit in 38% yield (Table 1, entry 1). Various commercially available Lewis acids were screened in order to improve the yield of this cascade annulation process considering the coordination between imine moiety and metal center would enhance the reactivity of *N*-tosylimine via LUMO activation.[11] Using AgOAc or $Cu(MeCN)_4BF_4$ as the catalyst, only a trace amount of cycloaddition product **3a** was obtained. We next carried out the reaction with $Cu(ClO_4)_2$ as Lewis acid, and no improvement was obtained (Table 1, entry 4). Gratifyingly, when $Ni(ClO_4)_2{\cdot}6H_2O$ was employed as the catalyst, the reactivity increased significantly and gave a 52% yield (Table 1, entry 5). This result encouraged us to further optimize the reaction conditions. However, we found that no better results were achieved after screening several other metal salts (Table 1, entries 6–8). We then turned our attention to investigate the solvent effects for the current reaction and found that the polar solvent CH_3CN was superior to other solvents in terms of reactivity and yield (Table 1, entries 9–12). Furthermore, full conversion was reached with 75% separated yield with $Ni(ClO_4)_2$ as the catalyst when the reaction temperature was improved to 80 °C and molecular sieves 4 Å were used as additive (Table 1, entry 14).

Having established the optimal reaction conditions, we next explored the substrate scope of the cascade vinylogous Mukaiyama 1,6-Michael/Michael addition reaction with a variety of *N*-sulfonyl-1-aza-1,3-dienes **1** and 2-silyloxyfuran **2a** (Table 2). All of the tested azadienes **1a–i**, derived from

Table 2. Nickel(II)-Catalyzed Cascade 1,6-VMA/MA of *N*-Sulfonyl-1-aza-1,3-dienes 1 Derived from Various Aldehydes and 2-Silyloxyfuran 2a[a]



entry	R	R′	1	3	yield[b] (%)
1	Ph	*p*-tolyl	**1a**	**3a**	75
2	*o*-ClC_6H_4	*p*-tolyl	**1b**	**3b**	76
3	*m*-ClC_6H_4	*p*-tolyl	**1c**	**3c**	75
4[c]	*p*-ClC_6H_4	*p*-tolyl	**1d**	**3d**	81
5	*p*-BrC_6H_4	*p*-tolyl	**1e**	**3e**	72
6	*m*-BrC_6H_4	*p*-tolyl	**1f**	**3f**	72
7	*p*-MeC_6H_4	*p*-tolyl	**1g**	**3g**	87
8	*o*-$MeOC_6H_4$	*p*-tolyl	**1h**	**3h**	80
9	1-naphthyl	*p*-tolyl	**1i**	**3i**	63
10	(*E*)-PhCH=CH	*p*-tolyl	**1j**	**3j**	66
11	Me	*p*-tolyl	**1k**	**3k**	65
12	^{t}Bu	*p*-tolyl	**1l**	**3l**	67
13	Ph	pyridin-2-yl	**1m**	**3m**	79
14	Ph	thiophene-2-yl	**1n**	**3n**	67
15	Ph	4-nitrophenyl	**1o**	**3o**	75

[a]All reactions were carried out with 0.30 mmol of **1** and 0.60 mmol of **2a** in 1.5 mL of MeCN at 80 °C. [b]Isolated yield.

various aldehydes with R bearing either electron-donating or -withdrawing substituents on the benzene ring, was converted efficiently to the corresponding fused piperidine/lactone derivatives **3a–i** in good yields (63–87%) with excellent diastereoselectivities (dr >20:1) (Table 2, entries 1–9). Notably, alkenyl and alkyl aldehyde-derived azadiene **1j** and **1k** also worked well giving rise to the fused heterocyclic **3j** and **3k** in good yield with a high level of diastereoselective control (Table 2, entries 10–12). The different substitution patterns of the sulfonyl groups had little effect on the reactivity of *N*-sulfonylimines. When the tolyl group was changed to pyridin-2-yl, thiophene-2-yl, or 4-nitrophenyl, these cascade annulation reactions proceeded well to completion in about 20 h with acceptable yields (Table 2, entries 13–15). The relative configuration of the fused cycloadduct **3d** bearing three contiguous tertiary carbon centers was determined as the *syn*- and *trans*-configuration by X-ray analysis of the single crystal (Figure 1).[12]

Given the encouraged reactivity and diastereoselectivity control achieved from the aldehyde derived *N*-sulfonyl-1-aza-1,3-dienes with 2-silyloxyfuran catalyzed by $Ni(ClO_4)_2$, we were intrigued to explore the generality of ketones derived *N*-sulfonyl-1-aza-1,3-dienes for constructing the diversified fused piperidine/lactone derivatives **5**. The results in Table 3 showed that a battery of aryl ketone-derived *N*-sulfonyl-1-aza-1,3-dienes

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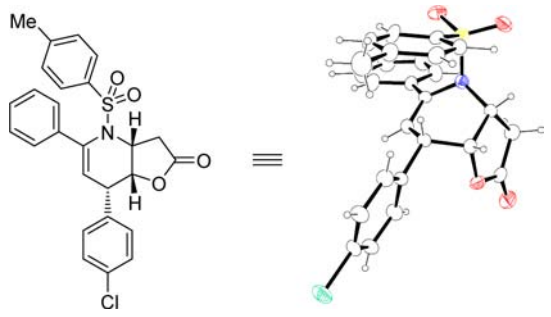
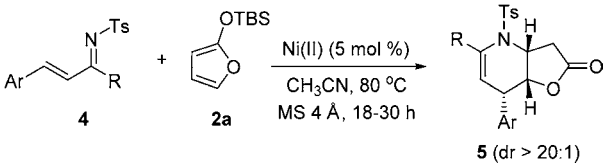


Figure 1. ORTEP representation of **3d**.

Table 3. Nickel(II)-Catalyzed Cascade 1,6-VMA/MA of *N*-Sulfonyl-1-aza-1,3-dienes 4 Derived from Various Ketones and 2-Silyloxyfuran 2a[a]



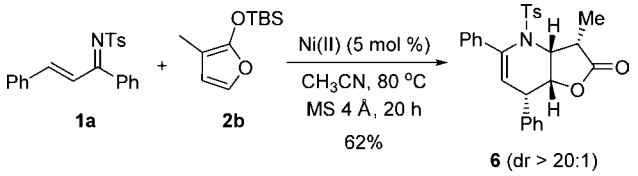
entry	Ar	R	4	5	yield[b] (%)
1	*p*-ClC_6H_4	*p*-ClC_6H_4	**4a**	**5a**	79
2	*m*-BrC_6H_4	*p*-ClC_6H_4	**4b**	**5b**	85
3	*o*-BrC_6H_4	*p*-ClC_6H_4	**4c**	**5c**	75
4	*p*-MeC_6H_4	*p*-ClC_6H_4	**4d**	**5d**	84
5	*o*-MeC_6H_4	*p*-ClC_6H_4	**4e**	**5e**	85
6	*p*-$MeOC_6H_4$	*p*-ClC_6H_4	**4f**	**5f**	78
7	*m*-$MeOC_6H_4$	*p*-ClC_6H_4	**4g**	**5g**	73
8	1-naphthyl	*p*-ClC_6H_4	**4h**	**5h**	71
9	2-Furyl	*p*-ClC_6H_4	**4i**	**5i**	61
10	(*E*)-PhCH=CH	*p*-ClC_6H_4	**4j**	**5j**	58
11	Ph	Me	**4k**	**5k**	63
12	Ph	H	**4l**	**5l**	56

[a]All reactions were carried out with 0.30 mmol of **4** and 0.60 mmol of **2a** in 1.5 mL of MeCN at 80 °C. [b]Isolated yield.

with different electronic properties at the *para*-, *meta*-, and *ortho*-positions of the phenyl ring could be transformed to the corresponding fused heterocyclic adduct **5a**−**i** in good yields (61−85%) with exclusive diastereoselectivity (dr >20:1) (Table 3, entries 1−9). Interestingly, the *N*-sulfonylimine of (1*E*,4*E*)-1,5-diphenylpenta-1,4-dien-3-one proved to be a viable substrate in this reaction and provided the corresponding cycloadduct **5j** in 58% yield with remaining diastereoselectivity control (Table 3, entry 10). Acetone-derived aza-diene **4k** worked well in this reaction, affording the desired heterocyclic **5k** in 63% yield with maintained diastereoselectivity (Table 3, entry 11). Remarkably, simple azadiene **4l** derived from cinnamyl aldehyde was also tolerated in this transformation, delivering the corresponding adduct **5l** in acceptable yield (Table 3, entry 12).

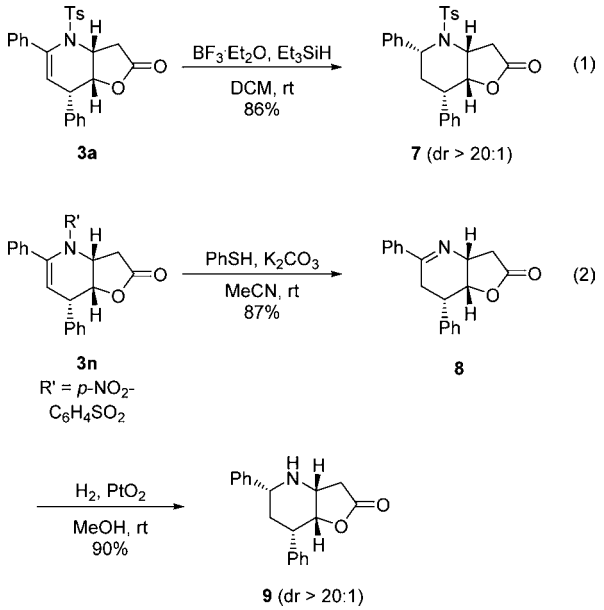
After the successful realization of the cascade annulation of a wide array of *N*-sulfonyl-1-aza-1,3-dienes with 2-silylfuran **2a**, we next investigated several different substituents on 2-silyloxyfuran with the *N*-tosylimine of chalcone **1a**. Although 4- or 5-substituted 2-silyloxyfuran is not a viable reaction partner in this annulation probably due to the disfavored steric hindrance, 3-methyl-substituted TBSOF **2b** worked well with *N*-tosylimine **1a** to provide the desired fused product **6** bearing four contiguous tertiary carbon centers in 62% yield with excellent diastereoselectivity (dr >20:1) (Scheme 2).

Scheme 2. Nickel-Catalyzed Cascade 1,6-VMA/MA of *N*-Sulfonyl-1-aza-1,3-dienes 1a and 3-Methyl-Substituted TBSOF 2b



To further illustrate the synthetic utility of this protocol, the reduction of the C=C bond in cycloproduct **3a** was carried out with Et_3SiH and $BF_3{\cdot}Et_2O$, affording the fused piperidine/lactone **7** in 86% yield with excellent diastereoselectivity (Scheme 3, eq 1). Straightforward removal of the nosyl group

Scheme 3. Synthetic Transformations of the Cycloadduct



by treatment cycloproduct **3n** with thiophenol and K_2CO_3 followed by isomerization provided a fused heterocyclic compound **8** in full conversion within good yield (Scheme 3, eq 2).[13] Subsequent hydrogenation of **8** with a catalytic amount of PtO_2 in MeOH led to the fused piperidine/butyrolactone skeleton **9** in good yield and with exclusive diastereoselectivity.

In summary, we have successfully developed an unprecedented Ni(II)-catalyzed cascade vinylogous Mukaiyama 1,6-Michael/Michael addition of *N*-sulfonyl-1-aza-1,3-dienes with 2-silyloxyfuran.[14] This method combined with subsequent reduction provides a facile and straightforward access to the biologically important fused piperidine/lactone skeletons with excellent diastereoselectivity and highly functional group tolerance. Further investigations on the asymmetric catalysis and applications of this tandem reaction in organic synthesis are underway in this laboratory.

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■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.orglett.6b03150.

Experimental data and NMR spectra for obtained compounds (PDF)
X-ray data for **3d** (CIF)

■ AUTHOR INFORMATION

Corresponding Author

*E-mail: cjwang@whu.edu.cn.

ORCID

Chun-Jiang Wang: 0000-0003-3629-6889

Author Contributions

§K.L. and X.C. contributed equally to this work.

Notes

The authors declare no competing financial interest.

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■ REFERENCES

(1) (a) Okitsu, O.; Suzuki, R.; Kobayashi, S. *J. Org. Chem.* **2001**, *66*, 809. (b) Amat, M.; Lozano, O.; Escolano, C.; Molins, E.; Bosch, J. *J. Org. Chem.* **2007**, *72*, 4431. (c) Yu, J.; Shi, F.; Gong, L.-Z. *Acc. Chem. Res.* **2011**, *44*, 1156. (d) Annadi, K.; Wee, A. G. H. *J. Org. Chem.* **2015**, *80*, 5236. (e) Csatayova, K.; Davies, S. G.; Fletcher, A. M.; Ford, J. G.; Klauber, D. J.; Roberts, P. M.; Thomson, J. E. *J. Org. Chem.* **2014**, *79*, 10932. (f) Li, J.-Y.; Li, Z.-L.; Zhao, W.-W.; Liu, Y.-K.; Tong, Z.-P.; Tan, R. *Org. Biomol. Chem.* **2016**, *14*, 2444.

(2) (a) Strunz, G. M.; Findlay, J. A. *The Alkaloids*; Brossi, A., Ed.; Academic: New York, 1985. (b) Numata, A.; Ibuka, T. *The Alkaloids*; Brossi, A., Ed.; Academic: New York, 1987. (c) O'Hagan, D. *Nat. Prod. Rep.* **2000**, *17*, 435. (d) Daly, J. W.; Spande, T. F.; Garraffo, H. M. *J. Nat. Prod.* **2005**, *68*, 1556. (e) Michael, J. P. *Nat. Prod. Rep.* **2008**, *25*, 139. (f) Honda, T. *Heterocycles* **2011**, *83*, 1. (g) Amat, M.; Perez, M.; Bosch, J. *Chem. - Eur. J.* **2011**, *17*, 7724.

(3) (a) Toyota, M.; Nakaishi, E.; Asakawa, Y. *Phytochemistry* **1996**, *43*, 1057. (b) Thuring, J. W. J. F.; Heinsman, N. W. J. T.; Jacobs, R. W. A. W. M.; Nefkens, G. H. L.; Zwanenburg, B. *J. Agric. Food Chem.* **1997**, *45*, 507. (c) Li, C.-S.; Di, Y.-T.; He, H.-P.; Gao, S.; Wang, Y.-H.; Lu, Y.; Zhong, J.-L.; Hao, X.-J. *Org. Lett.* **2007**, *9*, 2509. (d) Ramana, C. V.; Srinivas, B. *J. Org. Chem.* **2008**, *73*, 3915. (e) Cantrell, C. L.; Pridgeon, J. W.; Fronczek, F. R.; Becnel, J. J. *Chem. Biodiversity* **2010**, *7*, 1681. (f) Sugimura, H.; Sato, S.; Tokudome, K.; Yamada, T. *Org. Lett.* **2014**, *16*, 3384.

(4) (a) Weintraub, P. M.; Sabol, J. S.; Kane, J. M.; Borcherding, D. R. *Tetrahedron* **2003**, *59*, 2953. (b) Felpin, F.-X.; Lebreton, J. *Eur. J. Org. Chem.* **2003**, *2003*, 3693. (c) Buffat, M. G. P. *Tetrahedron* **2004**, *60*, 1701. (d) Ishikawa, H.; Elliott, G. L.; Velcicky, J.; Choi, Y.; Boger, D. L. *J. Am. Chem. Soc.* **2006**, *128*, 10596. (e) Becker, M. H.; Chua, P.; Downham, R.; Douglas, C. J.; Garg, N. K.; Hiebert, S.; Jaroch, S.; Matsuoka, R. T.; Middleton, J. A.; Ng, F. W.; Overman, L. E. *J. Am. Chem. Soc.* **2007**, *129*, 11987. (f) Esquivias, J.; Arrayás, R. G.; Carretero, J. C. *J. Am. Chem. Soc.* **2007**, *129*, 1480. (g) Gu, J.; Ma, C.; Li, Q.-Z.; Du, W.; Chen, Y.-C. *Org. Lett.* **2014**, *16*, 3986. (h) Wee, A. G. H.; Fan, G.-J. *Org. Lett.* **2008**, *10*, 3869. (i) Ito, M.; Osaku, A.; Shiibashi, A.; Ikariya, T. *Org. Lett.* **2007**, *9*, 1821. (j) Tucker-Schwartz, A. K.; Garrell, R. L. *Chem. - Eur. J.* **2010**, *16*, 12718.

(5) (a) Fukuyama, T.; Yang, L. *J. Am. Chem. Soc.* **1989**, *111*, 8303. (b) Achmatowicz, M.; Hegedus, L. S. *J. Org. Chem.* **2004**, *69*, 2229. (c) Afarinkia, K.; Bahar, A. *Tetrahedron: Asymmetry* **2005**, *16*, 1239. (d) Wee, A. G. H.; Fan, G.-J. *Org. Lett.* **2008**, *10*, 3869. (e) Heretsch, P.; Rabe, S.; Giannis, A. *Org. Lett.* **2009**, *11*, 5410. (f) Harada, M.; Asaba, K. N.; Iwai, M.; Kogure, N.; Kitajima, M.; Takayama, H. *Org. Lett.* **2012**, *14*, 5800. (g) Taber, D. F.; DeMatteo, P. W. *J. Org. Chem.* **2012**, *77*, 4235.

(6) (a) Szolcsányi, P.; Gracza, T.; Koman, M.; Prónayová, N.; Liptaj, T. *Chem. Commun.* **2000**, 471. (b) Szolcsányi, P.; Gracza, T. *Tetrahedron* **2006**, *62*, 8498. (c) Hyde, A. M.; Buchwald, S. L. *Org. Lett.* **2009**, *11*, 2663. (d) Huang, X.; Peng, J.; Dong, L.; Chen, Y.-C. *Chem. Commun.* **2012**, *48*, 2439. (e) Cui, H.-L.; Huang, J.-R.; Lei, J.; Wang, Z.-F.; Chen, S.; Wu, L.; Chen, Y.-C. *Org. Lett.* **2010**, *12*, 720.

(7) For reviews see: (a) Casiraghi, G.; Zanardi, F.; Appendino, G.; Rassu, G. *Chem. Rev.* **2000**, *100*, 1929. (b) Martin, S. F. *Acc. Chem. Res.* **2002**, *35*, 895. (c) Denmark, S. E.; Heemstra, J. R., Jr.; Beutner, G. L. *Angew. Chem., Int. Ed.* **2005**, *44*, 4682. (d) Casiraghi, G.; Battistini, L.; Curti, C.; Rassu, G.; Zanardi, F. *Chem. Rev.* **2011**, *111*, 3076.

(8) (a) Ube, H.; Shimada, N.; Terada, M. *Angew. Chem., Int. Ed.* **2010**, *49*, 1858. (b) Singh, R. P.; Foxman, B. M.; Deng, L. J. *J. Am. Chem. Soc.* **2010**, *132*, 9558. (c) Szlosek, M.; Figadère, B. *Angew. Chem., Int. Ed.* **2000**, *39*, 1799. (d) Jiang, Y.-Q.; Shi, Y.-L.; Shi, M. *J. Am. Chem. Soc.* **2008**, *130*, 7202. (e) Zhang, Q.; Xiao, X.; Lin, L.; Liu, X.; Feng, X. *Org. Biomol. Chem.* **2011**, *9*, 5748. (f) Desimoni, G.; Faita, G.; Guala, M.; Laurenti, A.; Mella, M. *Chem. - Eur. J.* **2005**, *11*, 3816. (g) Deng, H.-P.; Wei, Y.; Shi, M. *Adv. Synth. Catal.* **2009**, *351*, 2897. (h) Ruan, S.-T.; Luo, J.-M.; Du, Y.; Huang, P.-Q. *Org. Lett.* **2011**, *13*, 4938. (i) Wieland, L. C.; Vieira, E. M.; Snapper, M. L.; Hoveyda, A. H. *J. Am. Chem. Soc.* **2009**, *131*, 570. (j) Akiyama, T.; Honma, Y.; Itoh, J.; Fuchibe, K. *Adv. Synth. Catal.* **2008**, *350*, 399.

(9) Li, J.; Huang, R.; Xing, Y.-K.; Qiu, G.; Tao, H.-Y.; Wang, C.-J. *J. Am. Chem. Soc.* **2015**, *137*, 10124.

(10) (a) He, Z.-L.; Teng, H.-L.; Wang, C.-J. *Angew. Chem., Int. Ed.* **2013**, *52*, 2934. (b) Teng, H.-L.; Yao, L.; Wang, C.-J. *J. Am. Chem. Soc.* **2014**, *136*, 4075. (c) Li, Q.-H.; Wei, L. *J. Am. Chem. Soc.* **2014**, *136*, 8685. (d) He, Z.-L.; Sheong, F. K.; Li, Q.-H.; Lin, Z.; Wang, C.-J. *Org. Lett.* **2015**, *17*, 1365.

(11) Walsh, P. J.; Kozlowski, M. C. *Fundamentals of Asymmetric Catalysis*; University Science Books, 2008.

(12) Detailed X-ray crystallographic data for **3e** (CCDC 1509845) can be obtained free of charge from the Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.

(13) Montgomery, T. D.; Rawal, V. H. *Org. Lett.* **2016**, *18*, 740.

(14) This annulation is believed to undergo a cascade vinylogous Mukaiyama 1,6-Michael/Michael addition reaction pathway based on our previous work.[9] However, the inverse-electron-demand aza-Diels–Alder reaction mechanism cannot be completely ruled out at this time.

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