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Ni(II)-Catalyzed Enantioselective 1, 3-Dipolar Cycloaddition of Nitrones with *α, β*-Unsaturated Acyl Carboxylates

Lei Xie, Xuan Yu, Jiaqi Li, Zhenhua Zhang, Zhaohai Qin and Bin Fu*

Abstract: A highly enantioselective 1, 3-dipolar cycloaddition of nitrone with *α, β*-unsaturated acyl carboxylate was realized for the first time by a chiral Ni complex of indane-bis(oxazoline). The reaction can proceed smoothly under mild condition, providing isoxazolidines with three contiguous stereocenters in high yields with excellent diastereo-(>20:1 dr) and enantioselectivities (up to 99% ee). The reaction could be scaled up to gram scale, and the products were readily transformed into *γ*-amino alcohol or other potential bioactive compounds.

Introduction

Over the past two decades, the asymmetric 1,3-dipolar cycloaddition (1,3-DC) reactions have become one of the most important approaches to enantiomerically enriched heterocyclic compounds which maybe serve as therapeutic agents, agrochemicals or the key intermediates of natural products.[1] So far a variety of Lewis acid-catalyzed and organocatalyzed methods have been successfully developed for this type of reaction.[2] Among various 1, 3-dipoles reported in the literatures, nitrone is undoubtedly the most widely studied one due to its stability and easy preparation. In addition, the resulting isoxazolidine products can be converted to biologically active *β*-amino acids, *β*-lactams, amino alcohols and alkaloids.[3]

On the other hand, the dipolarophiles of 1, 3-DC reaction are mainly electron-deficient alkenes or alkynes which easily form 1, 5-metal-coordinated species (**Figure 1, A**) in the Lewis acid-catalyzed process, such as N-enoyl derivatives of oxazolidinone,[4] thiazolidinethione,[5] pyrrolidinone,[6] and pyrazolidinone,[7] as well as alkylidene malonate,[8] and pyridinyl N-oxide.[9] However, few substrates introducing 1, 4-metal-coordination pattern in this reaction were reported (**Figure 1, B**). In 2005, Palomo[10] *et al.* explored the addition of nitrone with α′-hydroxy enones in BOX-Cu(II)-catalyzed reactions to obtain the *endo* adducts in excellent enantioselectivity. In 2006, Evans *et al*.[11] reported the nitrone cycloadditions of α,β-unsaturated acyl imidazoles using pybox-cerium(IV) complex, giving the products in high endo/exo selectivity and excellent enantioselectivity. In 2010, Ishihara *et al*.[12] reported a chiral copper(II) complex of 3-(2-naphthyl)-L-alanine amide successfully catalyzed the enantioselective 1, 3-dipolar cycloaddition of nitrones with propioloylpyrazole and acryloylpyrazole derivatives, providing endo-cycloadducts with high enantioselectivities. Despite these advances, studies on the 1, 4-metal-coordination pattern are less explored in contrast to a number of reports of 1, 5-metal-coordination pattern in the Lewis acid-catalyzed 1, 3-DC reaction of nitrones.[13] A straightforward strategy is to utilize the alkenes bearing 1, 2-dicarbonyl unit as dipolarphiles for the cycloaddition of nitrones, which is rarely reported, highly valuable and desirable (**Figure1**, **B**).

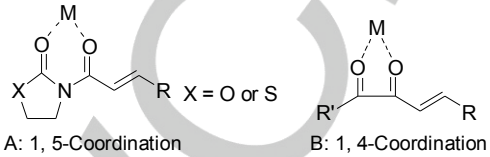

Figure 1. Different coordination pattern with metal salt.

In a continuation of our ongoing efforts in the development of new and efficient catalytic asymmetric methods,[14] we found that unsaturated acyl carboxylate were successfully employed to the enantioselective Michael addition with indoles.[15] Inspired by this finding and some reports of cycloaddition reaction,[16] we envisioned that *α, β*-unsaturated acyl carboxylate as a dipolarophile could be successfully applied in the asymmetric 1, 3-dipolar cycloaddition reaction. To our knowledge, there is only one report involving unsaturated acyl carboxylate as a dipolarophile in 1, 3-DC reaction documented by Gong's group.[17] in which the reaction with isocyanoester produced optically active dihydropyrrole derivatives by a chiral Ag(I) catalyst. Herein we report our studies on the asymmetric cycloaddition of unsaturated acyl carboxylates with nitrones catalyzed by indane-bisoxazoline-Ni(II) complexes, affording the isoxazolidines in high yields with excellent diastereo- (>20:1 dr) and enantioselectivities (up to >99% ee).

Results and Discussion

Initially, we screened the optimal condition by investigating the cycloaddition between methyl unsaturated acyl carboxylate **1a** and nitrone **2a** (Scheme 1).[18, 9] The results are listed in table 1. When the reaction was carried out in CH_2Cl_2 at room temperature for 12 hours in the presence of different metal complexes of ligand **L1**, most of Lewis acids including $Cu(OTf)_2$, $Cu(ClO_4)_2$, $Mg(ClO_4)_2$ and $Ni(acac)_2$ didn't work or showed very sluggish in the reaction (Entries 1~4). However, we were pleased to find that $Ni(ClO_4)_2{\cdot}6H_2O$-**L1** afforded the desired product **3aa** in high yield (87%) with exclusive regioselectivity and excellent diastereoselectivity (endo/exo >20:1, by ^1H NMR) regardless of very poor enantioselectivity (Entry 5). Subsequently, a series of bisoxazoline (BOX) were examined, and fortunately indane-BOX ligand **L4** gave rise to product **3aa** in 92% yield with 89% ee value (Entry 11). A survey of reaction solvents revealed that THF afforded the best results (93% yield and 94% ee, entry 17). Furthermore, the reaction temperature and the catalyst loading were tested. As expected, the enantioselectivity could be improved to 97% ee value when the reaction proceeded at 0 °C (Entry 18). Lowering the catalyst

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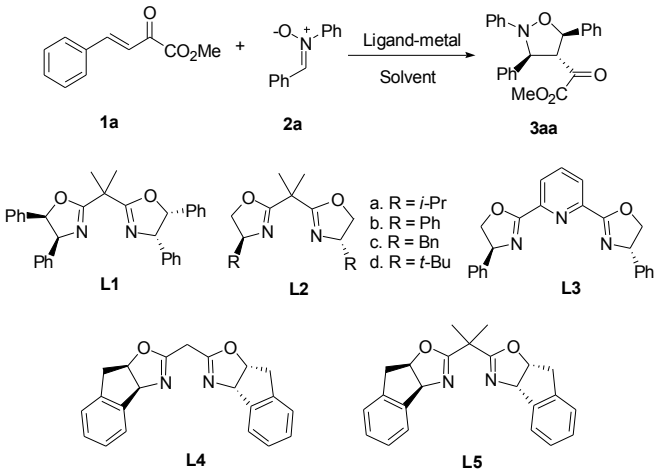


Scheme 1. The model reaction for optimization and screened bis(oxazoline) ligands.

Table 1. Optimization of the reaction condition. [a]

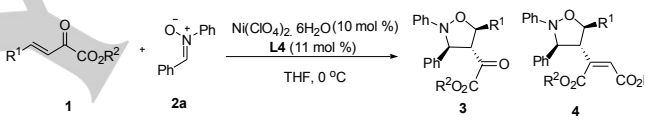
Entry	R^3	Metal salts	Solvent	Yield (%)[b]	Ee (%)[c]
1	**L1**	$Cu(OTf)_2$	CH_2Cl_2	-	-
2	**L1**	$Cu(ClO_4)_2{\cdot}6H_2O$	CH_2Cl_2	-	-
3	**L1**	$Mg(ClO_4)_2{\cdot}6H_2O$	CH_2Cl_2	-	-
4	**L1**	$Ni(acac)_2$	CH_2Cl_2	20	0
5	**L1**	$Ni(ClO_4)_2{\cdot}6H_2O$	CH_2Cl_2	87	10
6	**L2a**	$Ni(ClO_4)_2{\cdot}6H_2O$	CH_2Cl_2	93	45
7	**L2b**	$Ni(ClO_4)_2{\cdot}6H_2O$	CH_2Cl_2	92	43
8	**L2c**	$Ni(ClO_4)_2{\cdot}6H_2O$	CH_2Cl_2	88	12
9	**L2d**	$Ni(ClO_4)_2{\cdot}6H_2O$	CH_2Cl_2	46	12
10	**L3**	$Ni(ClO_4)_2{\cdot}6H_2O$	CH_2Cl_2	-	-
11	**L4**	$Ni(ClO_4)_2{\cdot}6H_2O$	CH_2Cl_2	92	89
12	**L5**	$Ni(ClO_4)_2{\cdot}6H_2O$	CH_2Cl_2	91	37
13	**L4**	$Ni(ClO_4)_2{\cdot}6H_2O$	MeOH	-	-
14	**L4**	$Ni(ClO_4)_2{\cdot}6H_2O$	Toluene	55	91
15	**L4**	$Ni(ClO_4)_2{\cdot}6H_2O$	EtOAc	90	90
16	**L4**	$Ni(ClO_4)_2{\cdot}6H_2O$	$CHCl_3$	93	91
17	**L4**	$Ni(ClO_4)_2{\cdot}6H_2O$	THF	93	94
18 [d]	**L4**	$Ni(ClO_4)_2{\cdot}6H_2O$	**THF**	**93**	**97**
19 [e]	**L4**	$Ni(ClO_4)_2{\cdot}6H_2O$	THF	68	97

[a] The reaction conditions: 11 mol% of ligand and 10 mol % of metal (1.1:1), solvent (2.0 mL), **1a** (0.25 mmol) and **2a** (0.3 mmol) for 12 h at rt. [b] Isolated yield. [c] Unless otherwise stated, dr >20:1, determined by ^{1}H NMR analysis and chiral HPLC. [d] The reaction at 0°C for 24 h. [e] 5 mol% **L4**-$Ni(ClO_4)_2.6H_2O$, at 0 °C for 24 h.

loading to 5 mol% led to a decreased yield of 68% but with the remained ee value (Entry 19).

Under the optimized conditions (Table 1, entry18, 10 mol % **L4**-$Ni(ClO_4)_2{\cdot}6H_2O$, THF as solvent, and 0 °C), we first investigated the scope of unsaturated acyl carboxylate in this reaction. The results are summarized in Table 2. The effect of substituents on *β*-phenyl unsaturated acyl carboxylates were examined. All reactions proceeded smoothly to provide the corresponding isoxazolidine products in high yields and, most notably, with excellent diastereo- and enantioselectivities (Table 2, entries 1~11, 75~95% yield, >20:1 dr and 94~99% ee), indicating that whatever an electron-donating or electron-withdrawing substituents at various positions on the phenyl ring had a minimal influence on the diastereo- and enantioselectivity of the reaction, except for different impacts on the reactivity (24~72 hours). It should be explained that, product **3fa** could be converted to the corresponding alkene **4fa** by Wittig reaction and followed determination by HPLC (Entry 5). Moreover, *β*-2-naphthyl unsaturated acyl carboxylate was also a suitable substrate, giving the same high reactivity and selectivity (75% yield and 95% ee, entry 12). To our delight, the reaction was successfully extended to *β*-alkyl group substituted substrates. Excellent enantioselectivities were observed in the reactions of *β*-cyclohexyl or -*tert*-butyl group unsaturated acyl carboxylate (97% and 98% ee, respectively, entries 13 and 14). Even if using *n*-hexyl substituted substrate, the reaction also furnished the product **3pa** in 86% yield with 88% ee value (Table 2, entry 15). It is noteworthy that the reaction could be accomplished within 3 hours for *β*-alkyl group unsaturated acyl carboxylates, demonstrating higher reaction activity than *β*-aryl group substituted substrates.

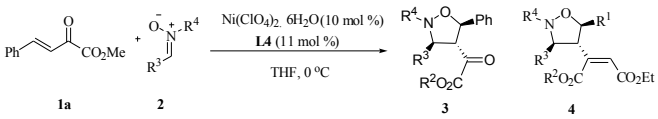
Table 2. The scope of unsaturated acyl carboxylate esters **1**[a]



Entry	R^1	R^2	T (h)	Yield (%)[b]	Ee (%)[c]
1	4-MeC_6H_4	Me	24	88(**3ba**)	98
2	4-$MeOC_6H_4$	Me	48	75(**3ca**)	98
3	4-FC_6H_4	Me	24	94(**3da**)	94
4	4-ClC_6H_4	Me	24	95(**3ea**)	96
5	4-$NO_2C_6H_4$	Me	48	78(**3fa**)	94(**4fa**)
6	3-MeC_6H_4	Me	24	80(**3ga**)	96
7	3-FC_6H_4	Me	24	85(**3ha**)	96
8	3-BrC_6H_4	Me	24	88(**3ia**)	96
9	2-$MeOC_6H_4$	Me	24	86(**3ja**)	97
10	2-BrC_6H_4	Me	24	90(**3ka**)	97
11	2,4-*di*-ClC_6H_4	Me	24	95(**3la**)	99
12	2-Naphthyl	Me	72	75(**3ma**)	95
13	Cyclohexyl	Et	3	88(**3na**)	97
14	*t*-Bu	Et	3	92(**3oa**)	98
15	*n*-hexyl	Et	3	86(**3pa**)	88

[a] All reactions were conducted in THF (2 mL) under nitrogen using 10 mol% of **L4**-$Ni(ClO_4)_2{\cdot}6H_2O$ at 0 °C. [b] Isolated yield. [c] Unless otherwise stated, dr >20:1, determined by ^{1}H NMR analysis and chiral HPLC.

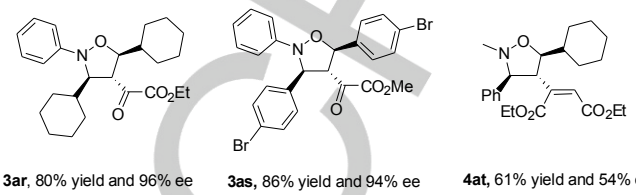
Table 3. The scope of nitrones **2** in the reaction[a]



Entry	R^3	R^4	T(h)	Yield (%)[b]	Ee (%)[c]
1	4-MeC_6H_4	Ph	24	91(**3ab**)	98
2	4-$MeOC_6H_4$	Ph	48	81(**3ac**)	96
3	4-ClC_6H_4	Ph	24	80(**3ad**)	97(**4ad**)
4	4-BrC_6H_4	Ph	48	72(**3ae**)	97
5	4-$NO_2C_6H_4$	Ph	72	78(**3af**)	93(4**af**)
6	3-MeC_6H_4	Ph	24	93(**3ag**)	97
7	3-$MeOC_6H_4$	Ph	24	90(**3ah**)	98(**4ah**)
8	3-$CF_3C_6H_4$	Ph	24	70(**3ai**)	98
9	2-MeC_6H_4	Ph	24	84(**3aj**)	94
10	2-$MeOC_6H_4$	Ph	24	83(**3ak**)	88
11	2-FC_6H_4	Ph	24	81(**3al**)	94
12	2-ClC_6H_4	Ph	48	71(**3am**)	92
13	2-Naphthyl	Ph	24	93(**3an**)	98
14	Cyclohexyl	Ph	24	86(**3ao**)	96
15	Ph	Me	72	-(**3ap**)	-
16	Ph	Bn	72	-(**3aq**)	-

[a] All reactions were conducted in THF (2 mL) under nitrogen using 10 mol% of **L4**-$Ni(ClO_4)_2{\cdot}6H_2O$ at 0 °C. [b] Isolated yield. [c] Unless otherwise stated, dr >20:1, determined by ^1H NMR analysis and chiral HPLC.

Next, the substrate scope was further extended by variation of nitrones, as summarized in Table 3. Initially, when N-phenyl substituted nitrone **2** was reacted with **1a** at 0°C for 24~72 h, giving the desired cycloadducts **3ab~3am** in 70~93% yields with 88~98% *ee* values, in which exhibited good reactivity and high enantioselectivity regardless of the electronic nature and position of substituent at phenyl group of nitrone **2** (Table 3, entries 1~12). Moreover, 2-naphthyl or cyclohexyl substituted nitrone was also very amenable substrates in this reaction, affording high yields and excellent ee values (98% and 96% ee, entries 13 and 14). Unfortunately, in the case of N-methyl or -benzyl group nitrone, the reaction became inert, and no desired products were yielded even after increasing the reaction temperature to room temperature (entries 15 and 16). Among cycloadducts **3ab~3ao**, some of them were transformed into the corresponding isoxazolidine alkenes **4** by Wittig reaction, whose enantiomeric excesses were readily determined by chiral HPLC. These results demonstrate that N-phenyl substitution in nitrone is critical for the reactivity and enantioselectivity of the reaction, which was also confirmed by the fact that, isoxazolidine products **3ar**, **3as** and **4at** bearing different substituents were achieved *via* the reaction of the corresponding unsaturated acyl carboxylates with nitrones in different yields and *ee* values (**Figure 2**).



3ar, 80% yield and 96% ee **3as,** 86% yield and 94% ee **4at,** 61% yield and 54% e

Figure 2. Several cycloadducts with various substituents.

The absolute configuration of the cycloadduct **3** was determined after conversion to the corresponding isoxazolidine nitro alcohol **5.** Treatment of product **3as** with nitromethane in the presence of triethylamine led to a couple of diastereomers **5a** and **5b**, whose single crystals were cultivated, and determined by X-ray diffraction analysis. As illustrated in **Figure 3**,[19] both diastereomers interact with each other through intermolecular hydrogen bonding between OH and C=O group. Obviously three contiguous chiral centers on the isoxazolidine ring of product **5a** and **5b** have *endo* relative configuration and (***3S***, ***4R***, ***5R***) absolute configuration. By analogy the absolute configuration of **3as** and other cycloadducts were also assigned to be (***3S***, ***4R***, ***5R***).

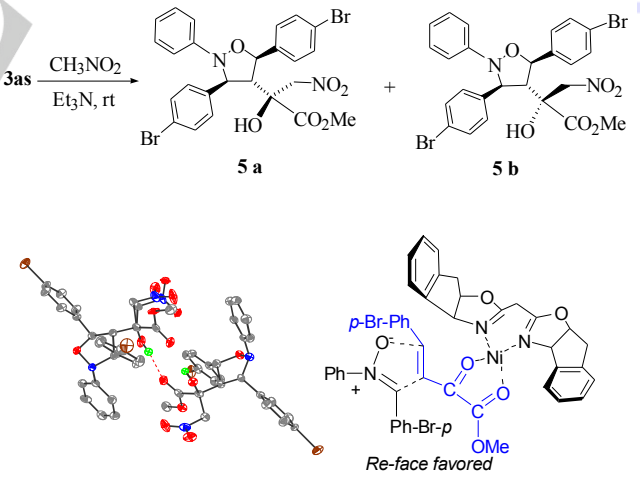
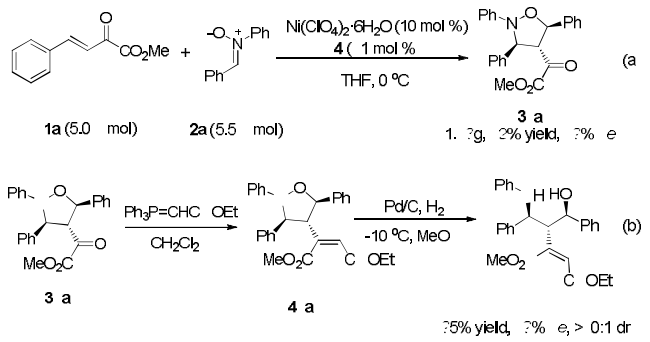


Figure 3. The determination of absolute configuration and possible asymmetric induction mode.

Based on the observed stereochemistry in this study we believe that the dipolarophile (unsaturated carbonyl carboxylate) coordinates to the Ni(II)-BOX complex through a 1, 4-coordinated pattern and is hence activated, as illustrated in **Figure 3.** Subsequently nitrone preferentially approaches the dipolarophile from the *Re*-face of the double bond due to the *Si*-

face steric hindrance from the bulky indane moiety of ligand, leading to the major (***3S***, ***4R***, ***5R***)-configured isoxazolidine product. According to some reports in the literature,[20] the anion ClO_4^- may coordinate to the Ni(II) center, and form complex intermediates in a solution. The detailed mechanism remains to be further studied.



Scheme 2. The synthetic utility of the catalyst system.

To show the synthetic utility of the catalyst system, the synthesis of the cycloadduct **3aa** was expanded to a gram scale. As shown in **Scheme 2** (a), treatment of 0.95 g of **1a** (5.0 mmol) with 1.08g of **2a** (5.5 mmol) in the presence of 5mol% of catalyst **L4**- $Ni(ClO_4)_2{\cdot}6H_2O$ under the optimal condition (Table 1, entry 18) afforded 1.78 g (92% yield) of the desired product **3aa** in 97% ee value. In addition, the resulting isoxazolidine could be further transformed into useful compounds. For example, **3aa** (97% ee) was reacted with phosphorus ylide to form the corresponding alkene **4aa** in almost quantitative yield,[21] which was subsequently hydrogenated by Pd/C in MeOH at -10 °C to give chiral *γ*-amino alcohol **6** bearing maleate subunit in 75% yield without any loss of diastereo- and enantioselectivity (**Scheme 2** (b)).[22]

Conclusions

In conclusion, A highly stereoselective 1, 3-dipolar cycloaddition of nitrones with unsaturated acyl carboxylates was realized for the first time by a indane-BOX-Ni(II) complex, which represents one typical 1, 4-coordination pattern in the Lewis acid-catalyzed 1, 3-DC reaction. The reaction proceeded smoothly at 0 °C, affording the isoxazolidine products in high yields with both excellent diastereo- (>20:1 dr) and enantioelectivities (up to 99% *ee*). A variety of unsaturated acyl carboxylates are compatible with the reaction, and for nitrone dipole N-phenyl substitution is important for the stereoselectivity and reactivity of the reaction. The present method shows some advantages including excellent endo/exo selectivity and enantioselectivity, simple and cheap catalyst, mild conditions and wide scopes. Therefore, this method provides a valuable and reliable pathway for the synthesis of isoxazolidines, *γ*-amino alcohol and other related bioactive derivatives. Studies to expand this methodology to other dipoles and dipolarophiles are currently underway in our laboratory.

Experimental Section

Typical procedure for the asymmetric 1,3-dipolar cycloaddition of unsaturated acyl carboxylate to nitrone: To a dry Schlenk tube, $Ni(ClO_4)_2{\cdot}6H_2O$ (0.025 mmol) was added, followed by ligand **L4** (0.0275 mmol) in a solvent of THF (1.0 mL) under nitrogen atmosphere. After the solution was stirred for 1 hour at room temperature, a solution of unsaturated acyl carboxylate (0.25 mmol) in THF (1.0 mL) was added. The resulting mixture was stirred for 15 min, cooled to 0 °C and stirred for another 15 min before the nitrone (0.3 mmol) was added. After the reaction was completed at 0 °C (monitored by TLC), the solution was directly purified by flash column chromatography on silica gel (ethyl acetate/petroleum ether, 1/50, v/v and dichloromethane/petroleum ether, 1/1, v/v) to afford the desired product **3aa** as a yellow oil; 93% yield; $[\alpha]_D^{25}$ = –40.8 (c 1.13, CH_2Cl_2); ^{1}H NMR (300 MHz, $CDCl_3$) *δ* 7.59–7.51 (m, 2H) 7.48–7.41 (m, 2H), 7.41–7.33 (m, 5H), 7.32–7.19 (m, 3H), 7.08–6.93 (m, 3H), 5.43 (d, *J* =7.8 Hz, 1H), 5.26 (d, *J*=6.2 Hz, 1H), 4.43 (dd, *J*=7.8, 6.3 Hz, 1H), 3.60 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) *δ* 190.29, 160.71, 150.34, 140.37, 136.33, 128.77, 128.74, 128.64, 128.47, 127.73, 126.67, 126.37, 122.03, 114.32, 81.99, 72.33, 69.30, 52.72; HRMS: Calcd for $C_{24}H_{22}NO_4^+$ ([M+H$^+$]): 402.1700; Found: 402.1697. HPLC analysis (Chiralcel AD-H, *n*-hexane/*i*-PrOH 80:20, 1.0 mL/min, t_r (major)=8.78 min, t_r (minor) =10.22 min, 97% ee).

Acknowledgements

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Keywords: 1, 3-Dipolar cycloaddition • Nickel • Nitrone • Isoxazolidine • *α, β*-Unsaturated acyl carboxylate

[1] a) Synthetic Applications of 1,3-Dipolar Cycloaddition Chemistry Toward Heterocycles and Natural Products (Eds: A. Padwa, W. H. Pearson), Wiley, New York, **2002**. b) B. Engels, M. Christl, *Angew. Chem. Int. Ed.* **2009**, *48*, 7968–7970; c) M. Baunach, C. Hertweck, *Angew. Chem. Int. Ed.* **2015**, *54*, 12550–12552; d) S. Hassana, T. J. J. Müller, *Adv. Synth. Catal*. **2015**, *357*, 617–666; e) C. R. Pitts, T. Lectka, *Chem. Rev*. **2014**, *114*, 7930−7953.

[2] a) K. V. Gothelf, K. A. Jørgensen, *Chem. Rev.* **1998,** *98,* 863–909; b) L. M. Stanley, M. P. Sibi, *Chem. Rev.* **2008,** *108,* 2887–2902; c) A. Bădoiu, Y. Brinkmann, F. Viton, E. P. Kündig, *Pure Appl. Chem.* **2008**, *80*, 1013−1018; d) M. Kissane, A. R. Maguire, *Chem. Soc. Rev.* **2010**, 39, 845−883; e) Y. Xing, N.-X. Wang, *Coord. Chem. Rev.* **2012**, 256, 938−952; f) G. Desimoni; G. Faita, P. Quadrelli, *Chem. Rev*. **2013**, 113, 5924−5988; g) L.-J. Wang, Y. Tang, *Comprehensive Organic Synthesis II,* **2014**, Volume 4, 1342–1383; h) B. Eftekhari-Sis, M. Zirak, *Chem. Rev*. **2015**, *115*, 151−264.

[3] a) K. V. Gothelf, K. A. Jørgensen, *Chem. Commun*. **2000**, 1449−1458; b) K. R. R. Kumar, H. Mallesha, K. S. Rangappa, *Arch. Pharm. Pharm. Med. Chem.* **2003**, *336*, 159–164; c) M. P. Sibi, N. Prabagaran, S. G. Ghorpade, C. P. Jasperse, *J. Am. Chem. Soc.* **2003**, *125*, 11796–11797; d) R. S. Kumar, S. Perumal, K. A. Shetty, P. Yogeeswari, D. Sriram, *Eur. J. Med. Chem.* **2010**, *45*, 124–133; e) B. Loh, L. Vozzolo, B. J. Mok, C. C. Lee, R. J. Fitzmaurice, S. Caddick, A. Fassati, *Chem. Biol. Drug Des.* **2010**, *75*, 461–474.

[4] a) T. Saito, T. Yamada, S. Miyazaki, T. Otani, *Tetrahedron Lett.* **2004**, *45*, 9581–9584; b) T. Saito, T. Yamada, S. Miyazaki, T. Otani, *Tetrahedron Lett.* **2004**, *45*, 9585−9587; c) S. Iwasa, Y. Ishima, H. S. Widagdo, K. Aoki, H. Nishiyama, *Tetrahedron Lett.* **2004**, *45*, 2121−2124; d) M. P. Sibi, S. Manyem, H. Palencia, *J. Am. Chem. Soc.*

2006, *128*, 13660–13661; e) H. Suga, A. Funyu, A. Kakehi, *Org. Lett.* **2007**, *9*, 97–100.
[5] H. Suga, T. Nakajima, K. Itoh, A. Kakehi, *Org. Lett.* **2005**, *7*, 1431–1434.
[6] S. Iwasa, H. Maeda, K. Nishiyama, S. Tsushima, Y. Tsukamoto, H. Nishiyama, *Tetrahedron* **2002**, *58*, 8281–8287.
[7] M. P. Sibi, Z. Ma, C. P. Jasperse, *J. Am. Chem. Soc.* **2004**, *126*, 718–719.
[8] a) Z.-Z. Huang, Y.-B. Kang, J. Zhou, M.-C Ye, Y. Tang, *Org. Lett.* **2004**, *6*, 1677–1679; b) D. Chen, Z. Wang, J. Li, Z. Yang, L. Lin, X. Liu, X. Feng, *Chem. Eur. J.* **2011**, *17*, 5226–5229.
[9] a) S. Barroso, G. Blay, M. C. Muñoz, and J. R. Pedro, *Org. Lett.* **2011**, *13*, 402–405; b) A. Landa; A. Minnkilä, G. Blay, K. A. Jørgensen, *Chem. Eur. J.* **2006**, *12*, 3472–3483.
[10] C. Palomo, M. Oiarbide, E. Arceo, J. M. García, R. López, A. González, and A. Linden, *Angew. Chem. Int. Ed.* **2005**, *44*, 6187–6190.
[11] D. A. Evans, H. J. Song, and K. R. Fandrick, *Org. Lett.* **2006**, *8*, 3351–3354.
[12] A. Sakakura, M. Hori, M. Fushimi, and K. Ishihara *J. Am. Chem. Soc.* **2010**, *132*, 15550–15552.
[13] Some selected examples of 1, 5-coordination pattern: a) S. Kanemasa, T. Kanai, *J. Am. Chem. Soc*. **2000,** *122*, 10710–10711; b) M. P. Sibi, L. Venkatraman, M. Liu, C. P. Jasperse, *J. Am. Chem. Soc*. **2001,** 123, 8444–8445; c) S. Iwasa, S. Tsushima, T. Shimada, H. Nishiyama, *Tetrahedron*, **2002**, 58, 227–232; d) S. Iwasa, H. Maeda, K. Nishiyama, S. Tsushima, Y. Tsukamoto, H. Nishiyama, *Tetrahedron*, **2002**, 58, 8287–8287; e) M. P. Sibi, Z. Ma, C. P. Jasperse, *J. Am. Chem. Soc*. **2005**, *127*, 5764–5765; f) M. P. Sibi, L. M. Stanley, T. Soeta, *Adv. Synth. Catal.* **2006**, *348*, 2371–2375; g) H. Suga, T. Nakajima, K. Itoh, A. Kakehi, *Org. Lett*. **2005**, *7*, 1431–1434; h) L, Dong, C. Geng, P. Jiao, *J. Org. Chem.* **2015**, *80*, 10992–11002; i) A. Livieri, M. Boiocchi, G. Desimoni, G. Faita, *Chem. Eur. J.* **2011**, *17*, 516–520.
[14] a) Y.-J. Sun; N. Li, Zh.-B. Zheng, L. Liu, Y.-B. Yu, Zh. -H. Qin, B. Fu, *Adv. Synth. Catal*. **2009**, *351*, 3113–3116; b) L. Liu, Q. -Y. Zhao, F.-P. Du, H. -L. Chen, Zh.-H. Qin, B. Fu, *Tetrahedron: Asymmetry* **2011**, *22*, 1874–1878; c) H.-L, Ma, J.-Q. Li, L. Sun, X.-H. Hou, Zh.-H. Zhang, B. Fu, *Tetrahedron* **2015**, *71*, 3625–3631; d) X. h. Hou, H. l. Ma, Z.-H. Zhang, L. Xie, Z.-H. Qin and B. Fu, *Chem. Commun.* **2016**, *52*, 1470–1473; e) H. -L. Ma, L. Xie, Zh.–H. Zhang, J.-Q. Li, Zh.-H. Qin, and B. Fu, *Adv. Synth.Catal.* **2016**, *358*, 1011–1016.
[15] L. Liu, H.-L. Ma, Y.-M. Xiao, F.-P. Du, Zh.-H. Qin, N. Li, B. Fu, *Chem. Commun.* **2012**, *48*, 9281–9283.
[16] a) G. Desimoni, G. Faita, and P. Quadrelli, *Chem. Rev*. **2013**, *113*, 5924−5988; b) B. Eftekhari-Sis, and M. Zirak, *Chem. Rev*. **2015**, *115*, 151−264.
[17] J. Song, C. Guo, P.-H. Chen, J. Yu, S.-W. Luo, L.-Z. Gong, *Chem. Eur. J*. **2011**, *17*, 7786–7790.
[18] K.-C. Lim, Y.-T. Hong, and S. Kim, *Adv. Synth. Catal*. **2008**, *350*, 380–384.
[19] Crystallographic Data Centre as supplementary publication number CCDC1444885. Copies of the data can be obtained, free of charge, on application to CCDC, 12 Union Road, Cambridge CB2 1EZ, UK. Fax: +44 1223 336033 or e-mail: deposit@ccdc.cam.ac.uk.
[20] For some recent examples of $Ni(ClO_4)_2$ as an efficient catalyst in asymmetric catalysis, see: a) R. Dalpozzo, G. Bartoli, L. Sambri, P. Melchiorre, *Chem. Rev*. **2010**, *110*, 3501–3551; b) H. Suga, Y. Furihata, A. Sakamoto, K. Itoh, Y. Okumura, T. Tsuchida, A. Kakehi, T. Baba, *J. Org. Chem*. **2011**, *76*, 7377–7387; c) Livieri, M. Boiocchi, G. Desimoni, G. Faita, *Chem. Eur. J.* **2011**, *17*, 516–520; d) Y.-Y. Zhou, L.-J. Wang, J. Li, X.-L. Sun, Y. Tang, *J. Am. Chem. Soc.* **2012**, *134*, 9066–9069; e) J.-R. Gao, H. Wu, B. Xiang, W.-B. Yu, L. Han, Y.-X. Jia, *J. Am. Chem. Soc.* **2013**, *135*, 2983−2986; f) J.-Q. Zhang, Y.-J. Xiao, and J. Zhang, *Adv. Synth. Catal*. **2013**, *355*, 2793–2797; g) J.-Q. Weng, Q.-M. Deng, L. Wu, K. Xu, H. Wu, R.-R. Liu, J. -R. Gao, and Y. -X. Jia, *Org. Lett.* **2014**, *16*, 776–779; h) R.-R. Liu, D.-J. Wang, L.Wu, B. Xiang, G.-Q. Zhang, J.-R. Gao, Y.-X. Jia, *ACS Catal.* **2015**, *5*, 6524−6528.
[21] M. Ostovar, C. M. Marson, *Tetrahedron* **2013**, *69*, 6639-6647.
[22] S. R. Yong, A. T. Ung, S. G. Pyne, B. W. Skelton, A. H. White, *Tetrahedron* **2007**, *63*, 5579-5586.

Entry for the Table of Contents

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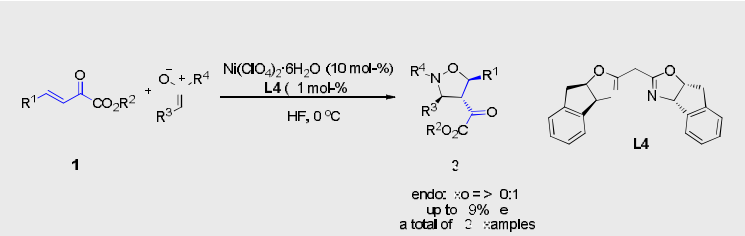

Key Topic*

*Lei Xie, Xuan Yu, Jiaqi Li, Zhenhua Zhang, Zhaohai Qin and Bin Fu**

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Ni(II)-Catalyzed Enantioselective 1, 3-Dipolar Cycloaddition of Nitrones with *α*, *β*-Unsaturated Acyl Carboxylates

1, 3-Dipolar Cycloaddition