Enantioselective Gold Catalysis

DOI: 10.1002/anie.201401067

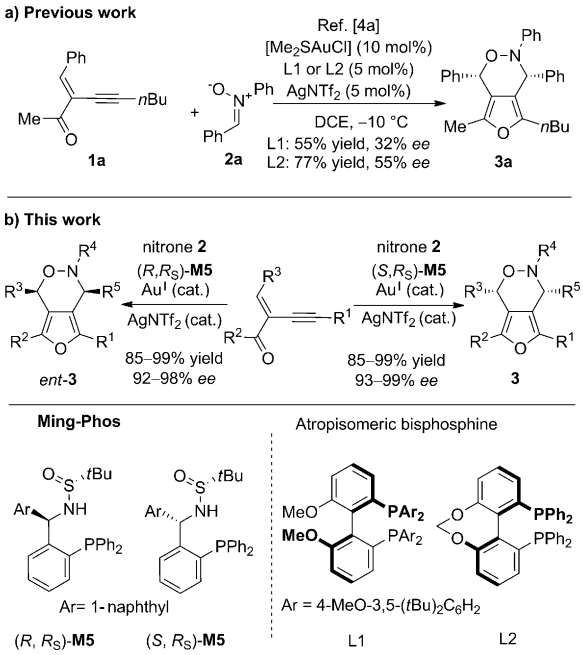
A New Type of Chiral Sulfinamide Monophosphine Ligands: Stereodivergent Synthesis and Application in Enantioselective Gold(I)-Catalyzed Cycloaddition Reactions**

*Zhan-Ming Zhang, Peng Chen, Wenbo Li, Yanfei Niu, Xiao-Li Zhao, and Junliang Zhang**

Abstract: *A simple, new type of chiral sulfinamide monophosphines, the so-called Ming-Phos ligands, is reported; these ligands could be easily prepared from inexpensive and commercially available starting materials. The Ming-Phos ligands performed well in the enantioselective gold-catalyzed cycloaddition reaction of 2-(1-alkynyl)-alk-2-en-1-ones with nitrones. Both enantiomers of the products could be obtained in good yields and with excellent diastereo- and enantioselectivity through transformations that were catalyzed by gold complexes derived from two diastereomers of Ming-Phos ligand* ***M5*** *(Ar = 1-naphthyl).*

Gold complexes have shown their unrivalled power in organic synthesis over that past decade, which is due to their high capability to activate π bonds.[1] However, the development of enantioselective gold-catalyzed processes[2] poses considerable challenges, because gold(I) complexes strongly prefer a linear geometry, which forces the active reaction site to be far away from the chiral ligand, thus limiting its capability to transfer chirality. To date, only a few approaches have been developed that address these issues; these methods employ chiral atropisomeric biaryl phosphines or spirocyclic bisphosphines,[3,4] phosphoramidites that often bear bulky or extended substituents,[5] or helically chiral trivalent phosphines[6] as ligands and chiral phosphoric acid derivatives as counterions.[7,8] The atropisomeric biaryl bisphosphines are among the most successful ligands in enantioselective gold(I) catalysis. However, these elaborate biaryl bisphosphine ligands are difficult to modify and can be more expensive than the noble metal itself; therefore, alternative principles for the design of new chiral ligands are highly desirable.

We recently reported a gold(I)-catalyzed asymmetric cycloaddition of 2-(1-alkynyl)-2-alken-1-ones with nitrones.[4a] The enantioselectivity was highly dependent on the substituent of the alkyne moiety of the 2-(1-alkynyl)-2-alken-1-one; with aryl substituents, excellent enantioselectivity was observed, whereas only low *ee* values could be obtained for substrates with aliphatic substituents. For example, the reaction of 2-(1-alkynyl)-2-alken-1-one **1a** with nitrone **2a** gave the corresponding product **3aa** in only 32% and 55% *ee* in the presence of the bulky chiral ligands (*R*)-MeO-dtbm-biphep (L1) and (*R*)-C_1-tunephos (L2), respectively (Scheme 1a). A series of known chiral ligands, such as 2,2′-bis(diphenylphosphino)-1,1′-binaphthyl (BINAP), (6,6′-dimethoxybiphenyl-2,2′-diyl)bis[bis(3,5-dimethoxyphenyl)-phosphine] (ECNU-Phos), (*R*)-2-(diphenylphosphanyl)-2′-methoxy-1,1′-binaphthyl ((*R*)-MOP), and phosphoramidites that are derived from 3,3′-disubstituted BINOL derivatives (BINOL = 1,1′-binaphthalene-2-ol), were also examined, but unfortunately, no satisfactory enantioselectivity was observed (see the Supporting Information). Thus, the design of chiral ligands with a novel structural motif may be the only way to address this issue.



Scheme 1. Previous results and this work on asymmetric [3+3] cycloadditions. Tf = trifluoromethanesulfonyl.

[*] Z.-M. Zhang, P. Chen, Dr. W. Li, Y. Niu, Prof. Dr. X.-L. Zhao, Prof. Dr. J. Zhang
Shanghai Key Laboratory of Green Chemistry and Chemical Processes
Department of Chemistry
East China Normal University
3663 N. Zhongshan Road, Shanghai 200062 (P.R. China)
E-mail: jlzhang@chem.ecnu.edu.cn
Homepage: http://faculty.ecnu.edu.cn/s/1811/t/20975/main.jspy

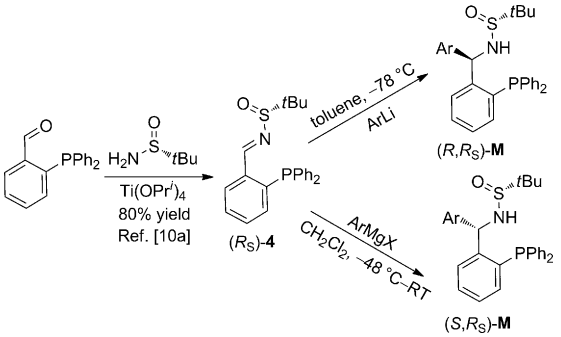
[**] We thank the National Natural Science Foundation of China (21372084), the Ministry of Science and Technology of China (2011CB808600), the Program of Eastern Scholar at Shanghai Institutions of Higher Learning, and the Changjiang Scholars and Innovative Research Team in University (PCSIRT) for financial support. We wish to thank Prof. Shengming Ma for beneficial discussions.

Supporting information for this article is available on the WWW under http://dx.doi.org/10.1002/anie.201401067.

During the course of our study on enantioselective gold catalysis, we found that monocationic [LAu_2ClX] species (L = bisphosphine, X = weak counteranion), which were generated in situ from a 1:1 mixture of [LAu_2Cl_2] and a AgX activator, can give better enantioselectivity than these bicationic [LAu_2X_2] species,[4a–b] indicating that the second gold site might either just exert a steric influence or be involved in a second interaction with the substrate. We thus designed a new type of chiral ligand, namely Ming-Phos, in which the chiral sulfinamide moiety might be able to undertake this interaction with the substrate to control the enantioselectivity. Herein, we wish to report our efforts on the stereodivergent synthesis of these new chiral ligands and their applications in enantioselective gold catalysis. We were pleased to find that the low enantioselectivity of the reaction of alkyl-substituted 2-(1-alkynyl)-2-alken-1-ones with nitrones could be well addressed (Scheme 1 b).

We started this research project with the stereodivergent synthesis of two sets of diastereomeric (R,R_S)- and (S,R_S)-configured Ming-Phos ligands through a two-step procedure (Table 1). Chiral sulfinyl imine (R_S)-**4** could be obtained in

Table 1: Stereodivergent synthesis of two sets of Ming-Phos ligands.[a]



Entry	M	Ar	Yield[b] [%] (R,R_S)-M	(S,R_S)-M
1	**M1**	Ph	86	85
2	**M2**	4-$EtOC_6H_4$	66	75
3	**M3**	4-$MeOC_6H_4$	65	70
4	**M4**	3,5-(tBu)$_2$-4-$MeOC_6H_2$	74	90
5	**M5**	1-naphthyl	79	83

[a] The diastereomeric ratios were determined by ^{1}H NMR analysis of the crude products to be >15:1 for all reactions.

80% yield by the condensation reaction of 2-(diphenylphosphino)benzaldehyde (2150 \$/kg)[9] and (R_S)-*tert*-butanesulfinamide (745 \$/kg)[9] according to a modified literature procedure.[10a] The stereoselective addition of RLi to (R_S)-**4** afforded a set of Ming-Phos derivatives (R,R_S)-**M1**–**M5** in 65–86% yield with excellent diastereoselectivity (d.r. > 15:1).[11] Accordingly, the other set of Ming-Phos ligands, namely (S,R_S)-**M1**–**M5**, could also be obtained in 70–90% yield from the stereoselective addition of RMgX to (R_S)-**4**. The absolute configurations of the two sets of Ming-Phos ligands were established by single-crystal X-ray diffraction analysis of (R,R_S)-**M3** and (S,R_S)-**M5** (Figure 1).[12] Fortunately, although

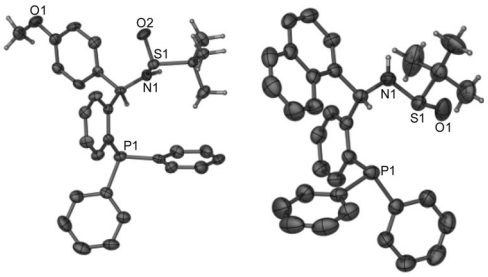


Figure 1. X-ray crystal structures of (R,R_S)-**M3** (left) and (S,R_S)-**M5** (right). Hydrogen atoms on the aryl rings were omitted for clarity.

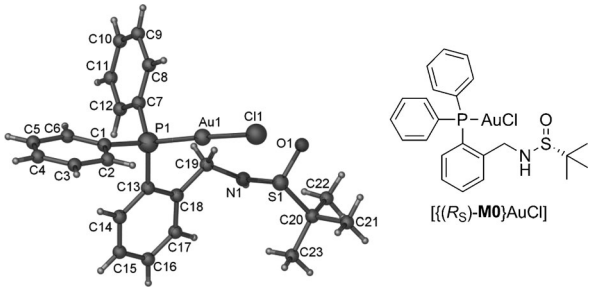
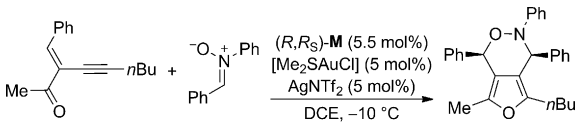


Figure 2. X-ray crystal structure of [{(R_S)-**M0**}AuCl].

attempts to obtain single crystals of the gold complexes of Ming-Phos **M1**–**M5** failed, a suitable single crystal of [{(R_S)-**M0**}AuCl] was finally obtained. X-ray diffraction analysis revealed that the gold atom selectively binds to the phosphine atom rather than to the other heteroatoms, such as nitrogen, oxygen, or sulfur, of the sulfinamide moiety (Figure 2).[12]

Next, we studied the performance of these two sets of diastereomeric Ming-Phos ligands **M1**–**M5** in enantioselective gold-catalyzed reactions. We initially chose 2-(1-alkynyl)-2-alken-1-one **1a** and nitrone **2a** as model substrates (Table 2). Several points are noteworthy: First, all of the reactions for which **M1**–**M5** were used as ligands furnished high yields (>85%). Second, very small modifications of the substituent on the aryl ring of the ligand led to significant variations in

Table 2: Screening of Ming-Phos ligands.[a]



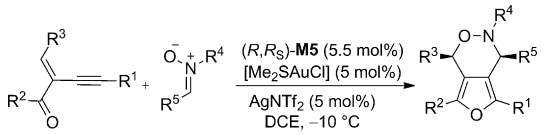
Entry	Ligand	*ee* of *ent*-**3a** [%]	Entry	Ligand	*ee* of **3a** [%]
1	(R,R_S)-**M1**	83	6	(S,R_S)-**M1**	89
2	(R,R_S)-**M2**	80	7	(S,R_S)-**M2**	91
3	(R,R_S)-**M3**	92	8	(S,R_S)-**M3**	73
4	(R,R_S)-**M4**	95	9	(S,R_S)-**M4**	93
5	(R,R_S)-**M5**	96	10	(S,R_S)-**M5**	94

[a] The *ee* was determined by HPLC analysis on a chiral stationary phase (AD-H). The absolute configuration of the product was determined by comparison of the HPLC spectrum with that in Ref. [4a]; *ent*-**3a** is the enantiomer of **3a**.

enantioinduction; for example, using (R,R_S)-**M3** (Ar = 4-$MeOC_6H_4$) instead of (R,R_S)-**M2** (Ar = 4-$EtOC_6H_4$) results in an increase in the *ee* of *ent*-**3a** from 80% to 92% (entries 2 and 3), whereas a large drop in enantiomeric excess was observed for **3a** when (S,R_S)-**M3** was used instead of (R,R_S)-**M2**. Third, both enantiomers of a chiral compound are nowadays often required in organic synthesis, biological chemistry, and the medicinal and pharmaceutical industries. Much to our delight, both enantiomers **3a** and *ent*-**3a** could be obtained in high yields and with 96% and 94% *ee*, respectively, when the diastereomeric ligands (R,R_S)-**M5** and (S,R_S)-**M5** were applied; this finding represents a significant improvement compared to our previous work.

Having established the most suitable ligands for the synthesis of both **3a** and *ent*-**3a**, we next focused on the substrate scope of this transformation (Table 3). First, various nitrones with different electron-withdrawing and -donating aryl and styryl substituents were examined (entries 2–6). The corresponding optically active products *ent*-**3a**–**3f** were obtained in 85–96% yield as single diastereomers with excellent enantioselectivities (93–98% *ee*). Then, the scope of alkyl-substituted 2-(1-alkynyl)-2-alken-1-ones **1** was investigated, and the corresponding products *ent*-**3g**–**3k** were isolated in 85–99% yield and with 92–97% *ee* (entries 7–11). Gratifyingly, compounds **1b** and **1c**, which bear an alkyl chloride and an alkyl ester, respectively, were also compatible with this transformation, and gave the corresponding products *ent*-**3g** and *ent*-**3h** in 99% yield and 94% *ee* and in 92% yield and 96% *ee*, respectively (entries 7 and 8). Moreover, good results were obtained for the reactions of **1e** and **1f** with nitrone **2a**, which further emphasize the large substrate scope of this enantioselective transformation. We then turned to the use of (S,R_S)-**M5** as a chiral ligand (Table 4). To our delight, all of the reactions of a broad range of 2-(1-alkynyl)-2-alken-1-ones (**1a**–**1f**) with various nitrones (**2a**–**2f**) also furnished the desired enantioenriched products **3a**–**3k** in high yields and as single diastereomers with 93–99% *ee*.

Table 3: Synthesis of optically active *ent*-**3** with ligand (R,R_S)-**M5**.

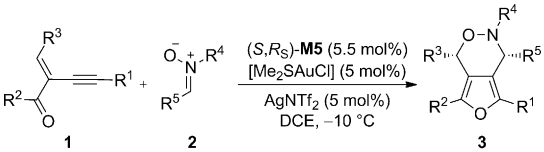


1 **2** (1.1 equiv) *ent*-**3**

Entry	R^1; R^2; R^3 (**1**)	R^4; R^5 (**2**)	*ent*-**3**	Yield[b] [%]	*ee* [%]
1	*n*Bu; Me; Ph (**1a**)	Ph; Ph (**2a**)	*ent*-**3a**	92	96
2	**1a**	4-MeC_6H_4; Ph (**2b**)	*ent*-**3b**	92	95
3	**1a**	Ph; 3,4,5-$(MeO)_3C_6H_2$(**2c**)	*ent*-**3c**	85	97
4	**1a**	Ph; 4-$MeOC_6H_4$(**2d**)	*ent*-**3d**	96	98
5	**1a**	3-ClC_6H_4; 4-$MeOC_6H_4$ (**2e**)	*ent*-**3e**	87	96
6	**1a**	Ph; styryl (**2f**)	*ent*-**3f**	85	93
7	$Cl(CH_2)_3$; Me; Ph (**1b**)	**2a**	*ent*-**3g**	99	94
8	$AcO(CH_2)_2$; Me; Ph (**1c**)	**2a**	*ent*-**3h**	92	96
9	*n*Pr; Me; Ph (**1d**)	**2a**	*ent*-**3i**	85	95
10	*n*Bu; Ph; 4-$CH_3OC_6H_4$ (**1e**)	**2a**	*ent*-**3j**	92	97
11	*n*Bu; Me; 4-$CH_3C_6H_4$ (**1f**)	**2a**	*ent*-**3k**	94	92

[a] Unless otherwise specified, the reaction was carried out using ketone **1** (0.4 mmol), nitrone **2** (0.44 mmol), (R,R_S)-**M5** (5.5 mol%), [Me_2SAuCl] (5 mol%), and $AgNTf_2$ (5 mol%) in DCE at −10°C. [b] Yield of isolated product. The diastereomeric ratios were determined to be >95:5 by ^{1}H NMR analysis of the crude products for all reactions. DCE = 1,2-dichloroethane.

Table 4: Synthesis of optically active **3** with ligand (S,R_S)-**M5**.[a]

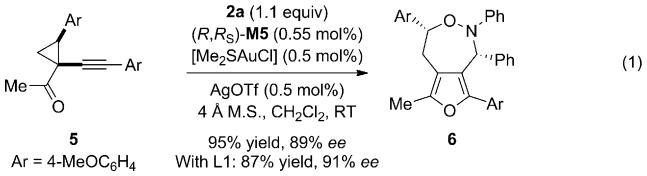


1 **2** (1.1 equiv) **3**

Entry	R^1; R^2; R^3 (**1**)	R^4; R^5 (**2**)	**3**	Yield[b] [%]	*ee* [%]
1	*n*Bu; Me; Ph (**1a**)	Ph; Ph (**2a**)	**3a**	86	94
2	**1a**	4-MeC_6H_4; Ph (**2b**)	**3b**	85	97
3	**1a**	Ph; 3,4,5-$(MeO)_3C_6H_2$ (**2c**)	**3c**	90	99
4	**1a**	Ph; 4-$MeOC_6H_4$ (**2d**)	**3d**	91	93
5	**1a**	3-ClC_6H_4; 4-$MeOC_6H_4$ (**2e**)	**3e**	88	98
6	**1a**	Ph; styryl (**2f**)	**3f**	86	95
7	$Cl(CH_2)_3$; Me; Ph (**1b**)	**2a**	**3g**	99	99
8	$AcO(CH_2)_2$; Me; Ph (**1c**)	**2a**	**3h**	95	99
9	*n*Pr; Me; Ph (**1d**)	**2a**	**3i**	88	97
10	*n*Bu; Ph; 4-$CH_3OC_6H_4$ (**1e**)	**2a**	**3j**	99	97
11	*n*Bu; Me; 4-$CH_3C_6H_4$ (**1f**)	**2a**	**3k**	91	97

[a] Unless otherwise specified, the reaction was carried out using ketone **1** (0.4 mmol), nitrone **2** (0.44 mmol), (S,R_S)-**M5** (5.5 mol%), [Me_2SAuCl] (5 mol%), and $AgNTf_2$ (5 mol%) in DCE at −10°C. [b] Yield of isolated product. All diastereomeric ratios were determined to be >95:5 by ^{1}H NMR analysis of the crude products.

To our delight, this new type of chiral ligand also performed well in other gold(I)-catalyzed asymmetric cycloaddition processes. For example, a gold complex derived from (S,R_S)-**M5** could be employed for the asymmetric gold-catalyzed formal [4+3] cycloaddition of 1-(1-alkynyl)cyclopropyl ketone **5** with nitrone **2a**, and the desired cycloadduct **6** was obtained in 94% yield with 89% *ee* [Eq. (1)]. These results are comparable with those obtained for the expensive chiral ligands (*R*)-MeO-dtbm-biphep (L1; 3 mol%, 87% yield, 91% *ee*).[13] More importantly, this formal [4+3] cyclo-



(1)

addition is a dynamic kinetic resolution and mechanistically distinct from the formal [3+3] cycloaddition of 2-(1-alkynl)-alk-2-en-1-ones with nitrones, indicating that Ming-Phos ligands may be applicable to other enantioselective gold-catalyzed reactions.

In summary, we have developed a new type of chiral sulfinamide monophosphine ligands, the so-called Ming-Phos ligands. Two sets of diastereomeric Ming-Phos ligands could be obtained in good yields with high diastereoselectivity from commercially available, inexpensive starting materials. Wide structural diversity can be achieved by changing the organometallic reagents. Moreover, Ming-Phos ligands performed well in two mechanistically distinct gold-catalyzed cycloaddition reactions. For the asymmetric cycloaddition reaction of 2-(1-alkynl)-alk-2-en-1-ones with nitrones, both enantiomers could be furnished in high yields with excellent diastereo- and enantioselectivity by the employment of (R,R_S)-**5** and (S,R_S)-**M5**, respectively. The salient features of these new chiral ligands, including their simple structure, air stability, the practical preparation from readily available starting materials, easy modification, and good results in enantioselective transformations, render these ligands very attractive. Further studies, such as an investigation of the performance of these ligands in other metal-catalyzed asymmetric reactions, are underway in our laboratory and will be reported in due course.

Experimental Section

Typical procedure for the synthesis of (S,R_S)-**M5**: The sulfinyl imine (R_S)-**4** was prepared according to a modified literature procedure;[10a] Ti(O*i*Pr)$_4$ was used instead of Ti(OEt)$_4$. A solution of 1-naphthylmagnesium bromide in Et$_2$O (2.0 equiv, 1.0 M, 10 mL) was added to a solution of (R_S)-**4**[10a] (5.0 mmol, 2.0 g) in CH_2Cl_2 (20 mL) at −48 °C. The mixture was stirred at this temperature for 4 h and then warmed to room temperature. After stirring overnight, the reaction mixture was quenched by the addition of aqueous NH_4Cl and diluted with EtOAc. After separation of the organic layer, the aqueous layer was extracted twice with EtOAc. The combined organic layers were dried over Na_2SO_4. After filtration and concentration, the residue was purified by flash column chromatography on silica gel to afford (S,R_S)-**M5** (2.2 g, 83 %).

Typical procedure for the synthesis of optically active **3a**: A solution of (S,R_S)-**M5** (5.5 mol %, 11.5 mg) and [Me$_2$SAuCl] (5.0 mol %, 5.9 mg) in CH_2Cl_2 (1 mL) was stirred at room temperature for 2 h; then, the solvent was removed in vacuum. A solution of $AgNTf_2$ (5.0 mol %, 7.8 mg) in DCE (1 mL) was added to the residue, and the mixture was stirred at −10 °C for 15 min. A solution of **1a** (0.40 mmol, 90.4 mg) and nitrone **2a** (0.44 mmol, 86.7 mg) in DCE (3 mL) was transferred to the above catalyst solution at −10 °C, and the resulting mixture was stirred at this temperature until the reaction was completed (determined by TLC). After removal of the solvent under reduced pressure, the residue was purified by flash column chromatography on silica gel to afford **3a** (146.0 mg, 86 % yield, 94 % *ee*).

Received: January 31, 2014
Published online: March 20, 2014

Keywords: asymmetric catalysis · cycloaddition · enantioselectivity · gold · phosphine ligands

[1] a) A. S. K. Hashmi, *Chem. Rev.* **2007**, *107*, 3180 – 3211; b) E. Jiménez-Núñez, A. M. Echavarren, *Chem. Rev.* **2008**, *108*, 3326 – 3350; c) D. J. Gorin, B. D. Sherry, F. D. Toste, *Chem. Rev.* **2008**, *108*, 3351 – 3378; d) S. M. Abu Sohel, R.-S. Liu, *Chem. Soc. Rev.* **2009**, *38*, 2269 – 2281; e) A. Fürstner, *Chem. Soc. Rev.* **2009**, *38*, 3208 – 3221; f) A. Corma, A. Leyva-Perez, M. J. Sabater, *Chem. Rev.* **2011**, *111*, 1657 – 1712; g) C. Aubert, L. Fensterbank, P. Garcia, M. Malacria, A. Simonneau, *Chem. Rev.* **2011**, *111*, 1954 – 1993; h) N. Krause, C. Winter, *Chem. Rev.* **2011**, *111*, 1994 – 2009; i) M. Bandini, *Chem. Soc. Rev.* **2011**, *40*, 1358 – 1367; j) B.-L. Lu, L. Dai, M. Shi, *Chem. Soc. Rev.* **2012**, *41*, 3318 – 3339; k) D. Garayalde, C. Nevado, *ACS Catal.* **2012**, *2*, 1462 – 1479; l) Y.-W. Sun, Q. Xu, M. Shi, *Beilstein J. Org. Chem.* **2013**, *9*, 2224 – 2232; m) F. López, J. L. Mascareñas, *Beilstein J. Org. Chem.* **2013**, *9*, 2250 – 2264; n) G. Cera, M. Bandini, *Isr. J. Chem.* **2013**, *53*, 848 – 855.

[2] a) R. A. Widenhoefer, *Chem. Eur. J.* **2008**, *14*, 5382 – 5391; b) N. Bongers, N. Krause, *Angew. Chem.* **2008**, *120*, 2208 – 2211; *Angew. Chem. Int. Ed.* **2008**, *47*, 2178 – 2181; c) A. S. K. Hashmi, C. Hubbert, *Angew. Chem.* **2010**, *122*, 1026 – 1028; *Angew. Chem. Int. Ed.* **2010**, *49*, 1010 – 1012; d) S. Sengupta, X. Shi, *ChemCatChem* **2010**, *2*, 609 – 619; e) A. Pradal, P. Y. Toullec, V. Michelet, *Synthesis* **2011**, 1501 – 1514; f) H. G. Raubenheimer, *Angew. Chem.* **2012**, *124*, 5128 – 5130; *Angew. Chem. Int. Ed.* **2012**, *51*, 5042 – 5044; g) I. D. G. Watson, F. D. Toste, *Chem. Sci.* **2012**, *3*, 2899 – 2919; h) A. Marinetti, H. Jullien, A. Voituriez, *Chem. Soc. Rev.* **2012**, *41*, 4884 – 4908; i) A. K. Mourad, C. Czekelius, *Synlett* **2013**, 1459 – 1463; j) M. J. Campbell, F. D. Toste, *Chem. Sci.* **2011**, *2*, 1369 – 1378.

[3] a) Y.-M. Wang, A. D. Lackner, F. D. Toste, *Acc. Chem. Res.* **2014**, DOI: 10.1021/ar400188g; for earlier examples, see: b) M. P. Muñoz, J. Adrio, J. C. Carretero, A. M. Echavarren, *Organometallics* **2005**, *24*, 1293 – 1300; c) M. J. Johansson, D. J. Gorin, S. T. Staben, F. D. Toste, *J. Am. Chem. Soc.* **2005**, *127*, 18002 – 18003; d) Z. Zhang, R. A. Widenhoefer, *Angew. Chem.* **2007**, *119*, 287 – 289; *Angew. Chem. Int. Ed.* **2007**, *46*, 283 – 285; e) R. L. LaLonde, B. D. Sherry, E. J. Kang, F. D. Toste, *J. Am. Chem. Soc.* **2007**, *129*, 2452 – 2453.

[4] a) F. Liu, D. Qian, L. Li, X. Zhao, J. Zhang, *Angew. Chem.* **2010**, *122*, 6819 – 6822; *Angew. Chem. Int. Ed.* **2010**, *49*, 6669 – 6672; b) G. Zhou, F. Liu, J. Zhang, *Chem. Eur. J.* **2011**, *17*, 3101 – 3104; for works from other groups, see: c) S. G. Sethofer, T. Mayer, F. Dean Toste, *J. Am. Chem. Soc.* **2010**, *132*, 8276 – 8277; d) S. A. Gawade, S. Bhunia, R.-S. Liu, *Angew. Chem.* **2012**, *124*, 7955 – 7958; *Angew. Chem. Int. Ed.* **2012**, *51*, 7835 – 7838; e) J. F. Briones, H. M. L. Davies, *J. Am. Chem. Soc.* **2012**, *134*, 11916 – 11919; f) J. F. Briones, H. M. L. Davies, *J. Am. Chem. Soc.* **2013**, *135*, 13314 – 13317; g) Z.-Y. Cao, X. Wang, C. Tan, X.-L. Zhao, J. Zhou, K. Ding, *J. Am. Chem. Soc.* **2013**, *135*, 8197 – 8200.

[5] a) I. Alonso, B. Trillo, F. López, S. Montserrat, G. Ujaque, L. Castedo, A. Lledós, J. L. Mascareñas, *J. Am. Chem. Soc.* **2009**, *131*, 13020 – 13030; b) H. Teller, S. Flügge, R. Goddard, A. Fürstner, *Angew. Chem.* **2010**, *122*, 1993 – 1997; *Angew. Chem. Int. Ed.* **2010**, *49*, 1949 – 1953; c) A. Z. González, D. Benitez, E. Tkatchouk, W. A. Goddard III, F. D. Toste, *J. Am. Chem. Soc.* **2011**, *133*, 5500 – 5507; d) H. Teller, M. Corbet, L. Mantilli, G. Gopakumar, R. Goddard, W. Thiel, A. Fürstne r, *J. Am. Chem. Soc.* **2012**, 134, 15331 – 15342; e) S. Suárez-Pantiga, C. Hernández-Díaz, E. Rubio, J. M. González, *Angew. Chem.* **2012**, *124*, 11720 – 11723; *Angew. Chem. Int. Ed.* **2012**, *51*, 11552 – 11555;

f) B. Liu, K.-N. Li, S.-W. Luo, J.-Z. Huang, H. Pang, L.-Z. Gong, *J. Am. Chem. Soc.* **2013**, *135*, 3323 – 3326.

[6] K. Yavari, P. Aillard, Y. Zhang, F. Nuter, P. Retailleau, A. Voituriez, A. Marinetti, *Angew. Chem.* **2014**, *126*, 880 – 884; *Angew. Chem. Int. Ed.* **2014**, *53*, 861 – 865.

[7] G. L. Hamilton, A. J. Kang, M. Nba, F. D. Toste, *Science* **2007**, *317*, 496 – 499.

[8] For an alternative strategy for enantioselective gold catalysis that employs N-heterocyclic carbenes (NHCs) and acyclic diaminocarbenes (ADCs) as chiral ligands, see: a) Y.-M. Wang, C. N. Kuzniewski, V. Rauniyar, C. Hoong, F. D. Toste, *J. Am. Chem. Soc.* **2011**, *133*, 12972 – 12975; b) S. Handa, L. M. Slaughter, *Angew. Chem.* **2012**, *124*, 2966 – 2969; *Angew. Chem. Int. Ed.* **2012**, *51*, 2912 – 2915; c) J. Francos, F. Grande-Carmona, H. Faustino, J. Iglesias-Sigüenza, E. Díez, I. Alonso, R. Fernández, J. M. Lassaletta, F. López, J. L. Mascareñas, *J. Am. Chem. Soc.* **2012**, *134*, 14322 – 14325.

[9] Chiral *tert*-butanesulfinamide and 2-(diphenylphosphino)benzaldehyde were bought from Shanghai Darui Finechemical Co., Ltd. and the Energy Chemical, respectively. For the synthesis of 2-(diphenylphosphino)benzaldehyde from 2-bromobenzaldehyde and diphenylphosphine, see: S. Laue, L. Greiner, J. Wöltinger, A. Liese, *Adv. Synth. Catal.* **2001**, *343*, 711 – 720.

[10] a) L. B. Schenkel, J. A. Ellman, *Org. Lett.* **2003**, *5*, 545 – 548; b) L. B. Schenkel, J. A. Ellman, *J. Org. Chem.* **2004**, *69*, 1800 – 1802.

[11] D. A. Cogan, G. Liu, J. A. Ellman, *Tetrahedron* **1999**, *55*, 8883 – 8904.

[12] CCDC 984098 ((*R*,R_S)-**M3**), 984099 ((*S*,R_S)-**M5**), and 987973 ([{(R_S)-**M0**}AuCl]) contain the supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.

[13] Y. Zhang, J. Zhang, *Chem. Commun.* **2012**, *48*, 4710 – 4712.

