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COMMUNICATION

Visible Light Photocatalytic Asymmetric Synthesis of Pyrrolo[1,2-*a*]indoles via Intermolecular [3+2] Cycloaddition

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The intermolecular diastereoselective and enantioselective synthesis of pyrrolo[1,2-*a*]indoles is developed through a [3+2] cycloaddition between silyl-indole derivatives and α,β-unsaturated *N*-acyl oxazolidinones by merging photocatalysis and Lewis acid catalysis.

Pyrrolo[1,2-*a*]indole represents a molecular scaffold found in a large number of drugs and natural products (Figure 1).[1] Among them, Mitomycin A and JTT-010 should be highlighted as important anti-cancer agent and protein kinase C (PKC) inhibitor, respectively.[1c,e] The importance of these tricyclic structures makes the search for efficient synthetic methods a subject of great interest in organic chemistry.[2] An important strategy for the synthesis of pyrrolo[1,2-*a*]indoles was reported by Padwa in 1989,[3] forming *in situ* the corresponding azomethine ylides, which reacted with alkenes to afford pyrrolo[1,2-*a*]indoles via 1,3-dipolar cycloaddition. Following a different approach, transition metal catalysis has also been employed for the synthesis of these structures.[4] In this context, Van der Eycken reported the rhodium-catalyzed intermolecular cascade C–H functionalization/annulation to obtain pyrrolo[1,2-*a*]indoles in a diastereoselective manner.[4g]

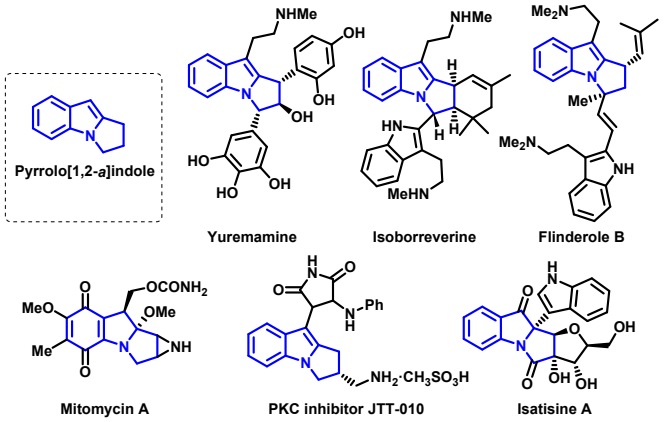
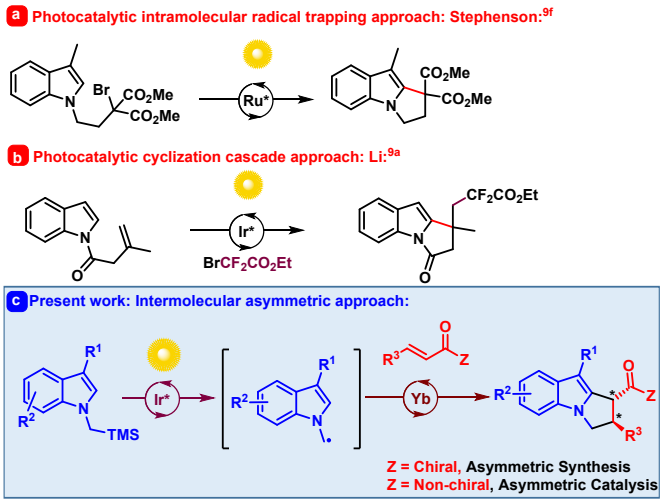


Figure 1. Different natural products and biologically active products featuring pyrrolo[1,2-*a*]indole core.

In the last decades, photocatalysis has emerged as a powerful tool to avoid the harsh conditions involved by the use of the radical initiators.[6,7,8] Nevertheless, the formation of these radical-mediated processes by means of visible light photocatalysis has hardly been explored in the synthesis of these pyrrolo derivatives.[9] In 2010, Stephenson's group reported the synthesis of racemic pyrrolo[1,2-*a*]indoles through an intramolecular cyclization photocatalyzed by $Ru(bpy)_3^{2+}$, starting from highly deactivated carbon-bromine bonds (Scheme 1a).[9f] Last year, Li published the synthesis of difluoroalkylated pyrrolo[1,2-*a*]indoles using the complex *fac*-$Ir(ppy)_3$ as photocatalyst (Scheme 1b).[9a] All those photocatalytic processes afforded racemic pyrrolo[1,2-*a*] indoles, and the photocatalytic asymmetric synthesis of those structures remains an elusive process. In this regard, we envisaged that an intermolecular approach for the construction of pyrrolo[1,2-*a*]indoles would be more versatile since it allow the synthesis of scaffolds with higher structural diversity.

Based on these precedents, we thought that a [3+2] cycloaddition between silyl-indole derivatives, used as radical precursors,[10] and Michael acceptors[11] could provide



Scheme 1. Previous and present works for the synthesis of pyrrolo[1,2-*a*]indoles.

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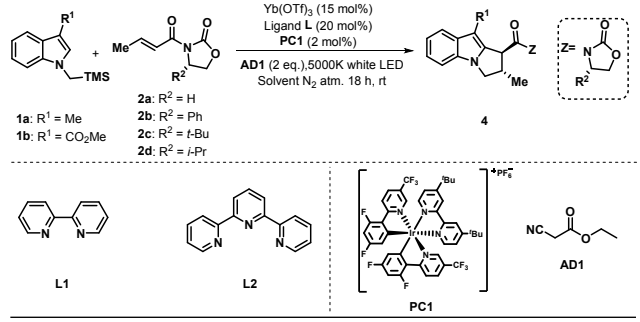
pyrrolo[1,2-*a*]indole structures in a stereoselective manner (Scheme 1c). Therefore, in this work, we have developed the photocatalytic asymmetric intermolecular [3+2] cycloaddition for the synthesis of pyrrolo[1,2-*a*]indole derivatives, combining a photocatalyst – for the formation of the α-amino radical from the silyl-indole derivative **1** – with a Lewis acid for the activation of the Michael acceptor **2**.

Evans-type oxazolidinones have been one of the best synthetic platforms used in asymmetric synthesis as chiral auxiliaries, and in asymmetric catalysis in combination with chiral Lewis acids.[12] Thus, we chose α,β-unsaturated *N*-acyl oxazolidinones **2** to accomplish the [3+2] cycloaddition in a stereoselective approach. First, we explored the cycloaddition between indoles **1** and chiral Michael acceptors **2** to develop the asymmetric synthesis of pyrrolo[1,2-*a*]indoles **4** (Table 1). We began the optimization studies by using indole **1a** and non-chiral Michael acceptor **2a**. After conducting a screening of photocatalysts, Lewis acids and additives, the combination of iridium-based photocatalyst **PC1**, $Yb(OTf)_3$ and ethyl cyanoacetate (**AD1**) gave the best results (see S.I. for the full optimization studies). Under this set of conditions, pyrrolo[1,2-*a*]indole **4** was obtained in 70% yield with complete diastereoselectivity (entry 1). The cycloaddition of the methyl ester indole derivative **1b** furnished higher yield (76%, entry 2), preserving the high diastereoselectivity. However, indole with R^1 = H provided very low yield (5%) and diastereoselectivity (50:50), showing that the presence of substituent at C3 position of the indole is strictly necessary (see E.S.I.). In order to carry out the asymmetric synthesis of this [3+2] cycloaddition, we chose a Michael acceptor bearing a chiral oxazolidinone to reach a single pyrrolo[1,2-*a*]indole enantiomer (entries 3-9). It is well known that substituents at the 4-position of the oxazolidinone is able to block one face of the Michael acceptor.[12b,d] Therefore, we tried chiral Michael acceptors **2b**, **2c** and **2d**, bearing phenyl, *tert*-butyl and *iso*-propyl groups (entries 3, 4 and 5, respectively) to evaluate the influence of the substitution at the 4-position of the oxazolidinone in the cycloaddition reaction. By using **2b** (R^2 = Ph), the reaction proceeded with moderate yield (17% yield) and diastereoselectivity (entry 3). Nonetheless, Michael acceptors **2c** and **2d**, bearing bulky alkyl substituents, afforded the corresponding pyrrolo[1,2-*a*]indoles in high diastereo-selectivity, being the 4-*iso*-propyl *N*-acyloxazolidinone derivative **2d** the one which provided higher yield (57%, entry 5). Next, we performed the reaction using a tridentate ligand (terpyridine, **L2**) instead of bipyridine, but the yield was not improved (entry 6). To conclude the optimization study, we tested from polar to non-polar solvents (entries 3, 7, 8 and 9) and acetonitrile was the best choice (entry 5). Finally, the use of Lewis acid, ligand **L**, additive **AD1**, photocatalyst, light and the absence of oxygen were found to be crucial for the reaction to succeed (entries 10, 11 and 12, and Table S1). It is worth mentioning, that pyrrolo[1,2-*a*]indole **4** was obtained as single diastereoisomer and unique enantiomer (determined by SFC using chiral columns, see S.I. compound **4a**).

Table 1. Screening of reaction conditions for the [3+2] cycloaddition.[a]

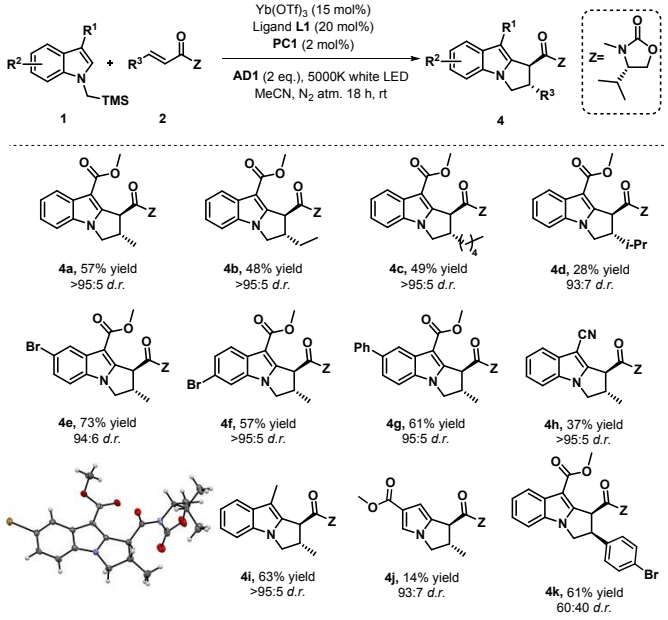


Entry	1	2	solvent	ligand	*d.r.* (%)[b]	Yield (%)[c]
1	**1a**	**2a**	MeCN	**L1**	>95:5	70[d]
2	**1b**	**2a**	MeCN	**L1**	>95:5	76
3	**1b**	**2b**	MeCN	**L1**	79:21	17
4	**1b**	**2c**	MeCN	**L1**	>95:5	20
5	**1b**	**2d**	MeCN	**L1**	>95:5	57
6	**1b**	**2d**	MeCN	**L2**	>95:5	43
7	**1b**	**2d**	DMF	**L1**	>95:5	10
8	**1b**	**2d**	DCE	**L1**	92:8	50
9	**1b**	**2d**	THF	**L1**	88:12	38
10[e]	**1a**	**2a**	MeCN	**L1**	-	<5%
11[f]	**1a**	**2a**	MeCN	**L1**	-	<5%
12[g]	**1a**	**2a**	MeCN	**-**	-	10%

[a] **1** (0.1 mmol, 1.0 eq.), **2** (0.2 mmol, 2.0 eq.), **PC1** (2 mol%), Yb $(OTf)_3$ (15 mol%), ligand **L** (20 mol%), additive **AD1** (0.2 mmol, 2.0 eq.) in 2 mL of the solvent were irradiated under a 5000 K white LED. [b] *d. r.* by ^{1}H NMR. [c] Isolated yield after purification by FC. [d] NMR-yield using 9-bromophenanthrene as internal standard. [e] No photocatalyst. [f] No light. [g] No Lewis acid.

With the optimal conditions in hand, we investigated the versatility of the methodology by reacting different indole derivatives **1** and chiral Michael acceptors **2** (Table 2). First, we tested the reaction between indole **1b** (with a methyl ester group at C3 position) and Michael acceptors **2** with different alkyl chains (R^3 = Me, Et, *n*-pent, *i*-Pr). The cycloaddition proceeded efficiently for the Michael acceptors **2** bearing linear alkyl chains, affording the corresponding products (**4a**-**4c**) in good yields (48-57%) and complete diastereoselectivities. In the case of the branched *iso*-propyl group at the α,β-unsaturated system, the high diastereoselectivity was maintained, but the yield decreased to 28% (**4d**). The reaction of 5- and 6-bromo substituted indoles **1e** and **1f** with **2d** afforded the corresponding pyrrolo[1,2-*a*]indoles **4e** and **4f** in high yields and diastereomeric ratio. In addition, these examples are particularly interesting since they can be easily post-functionalized to obtain more complex structures. The reaction also allowed the use of indoles with aromatic substitution at the six-member ring, affording **4g** in good yields and excellent diastereoselectivity. The reaction tolerates the use of indole derivatives **1** with a cyano or a methyl group at C3 position (products **4h** and **4i**, respectively), displaying the versatility of the method regarding the electronic nature of the R^1 substituent. Finally, we also tried the cycloaddition of pyrrole derivative **1i,** instead of the indole substrate, that afford pyrrolizine scaffold, commonly found in drugs and natural products (e.g. Licofelone). We were pleased to obtain diastereoselectively the corresponding pyrrolizine **4j**. Although **4j** is isolated in low yield, it should be noted that Padwa's 1,3-

Table 2. Scope of the [3+2] cycloaddition between **1** and Michael acceptors **2**.[a]

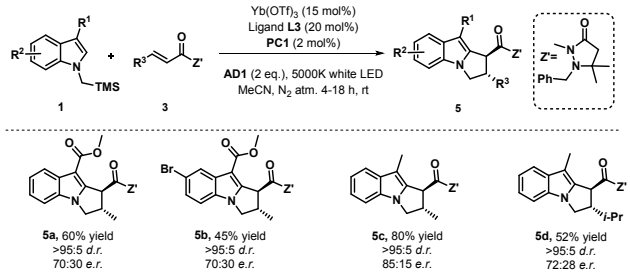


[a] **1** (0.2 mmol, 2.0 eq.), **2** (0.1 mmol, 1.0 eq.), **PC1** (2 mol%), $Yb(OTf)_3$ (15 mol%), **L1** (20 mol%), **AD1** (0.2 mmol, 2.0 eq.) in 2 mL of dry MeCN were irradiated under a 5000 K white LED. *d. r.* determined by ^1H NMR. Isolated yield after purification by FC.

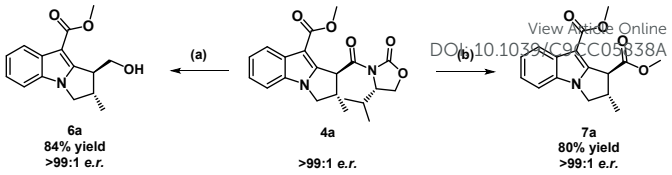
dipolar cycloaddition protocol could not afford this product,[3] showing the versatility of the presented approach. Finally, aromatic groups at R^3 substitution of the Michael acceptor **2** gave pyrrolo[1,2-*a*]indole **4k** in good yields but low diastereoisomeric ratio (60:40).[13] The absolute configuration of the pyrrolo[1,2-*a*]indole **4e** was unequivocally assigned by X-ray crystallographic analysis of a single-crystal (see Table 2 and S.I.).[14] The same stereochemical outcome was assumed for the rest of compounds **4**.

In addition, we investigated the possibility of performing the [3+2] cycloaddition under asymmetric catalysis starting from prochiral Michael acceptor and using chiral Lewis acid catalysis (15 chiral ligands, see S.I. for further details). Thus, we changed the type of Michael acceptor from chiral oxazolidinone **2** to pyrazolidinone **3** and switched the ligand of the Lewis acid from bipyridine to chiral ligands. We performed a broad screening of the reaction conditions (see E.S.I. for the full optimization studies), being pyrazolidinone Michael acceptor **3a** (R^3 = Me) the best substrate. A combination of $Yb(OTf)_3$ and (*R,R*)-*iso*-Pr-

Table 3. Scope of the enantioselective synthesis of **5**.[a]



a **1** (0.2 mmol, 2.0 eq.), **3** (0.1 mmol, 1.0 eq.), **PC1** (2 mol%), $Yb(OTf)_3$ (15 mol%), (*R,R*)-i-Pr-PyBOX ligand L3 (20 mol%), ethyl cyanoacetate **AD1** (0.2 mmol, 2.0 eq.) in 2 mL of dry MeCN were irradiated under a 5000 K white LED. Isolated yield after purification by FC. d. r. determined by ^1H NMR. Enantiomeric ratio determined by SFC using chiral columns.



Scheme 2. Derivatization of **4a**. (a) $NaBH_4$ (4 eq.), 4:1 THF/H_2O mixture, 20 h, rt; (b) $Er(OTf)_3$ (1 eq.), 1:1 $MeOH/CH_2Cl_2$ mixture, 20 h, 60 ºC.

catalyst, photocatalyst **PC1**, ethyl cyanoacetate (**AD1**) as additive, MeCN as solvent were determined to be the optimal reaction conditions. Under these conditions, we evaluated a brief scope for this approach (Table 3). Different indoles **1** and Michael acceptors **3** were tested in this process. In all the cases,pyrrolo[1,2-*a*]indoles **5a-d** were obtained in good yields and complete diastereoselectivity. Regarding the enantioselectivity, the *e.r.* ranged from 70:30 to 85:15 regardless of the substitution at the C3 position (R^1) of indole **1** or the steric hindrance at the R^3 group of the Michael acceptor **3**. The absolute configuration of compounds **5** was established by comparison of the optical rotation value of **5a** and **4a** after derivatization into their corresponding alcohols (see Scheme 2 below, and S.I. for more details). Both [3+2] cycloaddition approaches, asymmetric synthesis and asymmetric catalysis, provide pyrrolo[1,2-*a*]indole structures with the same (*R*,*R*) configuration at the stereogenic centers C1 and C2.

To demonstrate the synthetic utility of this methodology, pyrrolo[1,2-*a*]indole **4a** was easily derivatized to generate key intermediates (Scheme 2). Under reductive conditions, the alcohol **6a** was isolated in 84% yield.[15] On the other hand, the treatment of **4a** with $Er(OTf)_3$ in a refluxing mixture of CH_2Cl_2/MeOH afforded the methyl ester **7a** in high yield (80%).[16] In both cases, the enantiomeric purity of **4a** was maintained in the corresponding derivatized products **6a** and **7a**.

Lastly, we performed fluorescence quenching experiments of the photocatalyst **PC1** to gain mechanistic insights. In those experiments, indole **1a**, Michael acceptor **2a** and ethyl cyanoacetate additive (**AD1**) were studied as quenchers (Figure 2A). First, no quenching of the excited state of **PC1** was observed upon addition of Michael acceptor **2a** or **AD1.** However, indole **1a** (E^p_{ox} = 1.16 vs Ag/AgCl) efficiently quenched the excited state of **PC1** (E^*_{red} = 1.21 vs Ag/AgCl), with a Stern-Volmer quenching constant (K_{SV}) of 1.06 mM^{-1}. This means that the first step of the photocatalytic cycle is the oxidation of the indole derivative **1** by the excited mechanism outlined in Figure 2B. Once the photocatalyst reaches its excited state after visible light irradiation, it is able to oxidize indole derivative **1**, generating the reduced photocatalyst (Ir^{II}) and the α-amino radical intermediate **A**. The Ir(II) photocatalyst is then oxidized by **AD1** or other species presence in the media, regenerating the initial Ir(III) photocatalyst. On the other hand, nucleophilic α-amino radical **A** is added intermolecularly to the β-position of Michael acceptor **2** (or **3**). Next, the resulting α-carbonyl radical intermediate **B** undergoes a cyclization to the C2 position of the indole, forming the tricyclic core of the final product. The oxidation of benzyl radical **C** and, subsequent deprotonation of **D**, afford the final aromatized compound **4** (or **5**).[17] The stereo-

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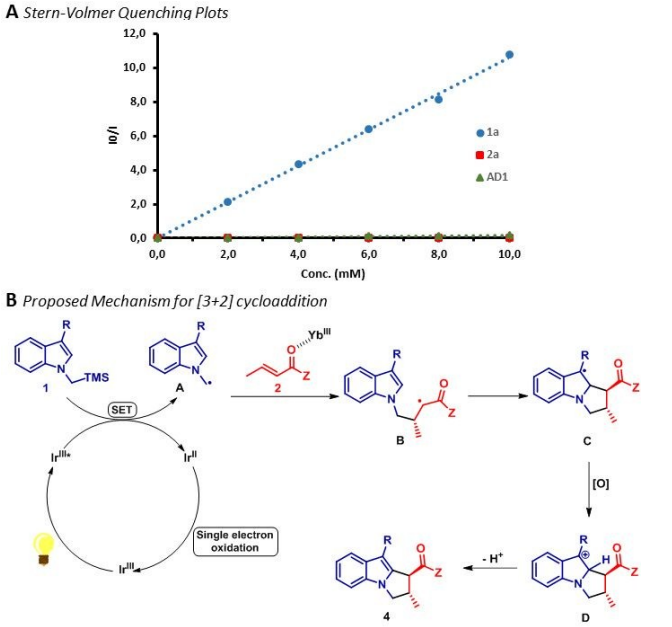

Figure 2. (A) Stern-Volmer plot of the emission quenching of **PC1** by adding indole **1a**, **2a** and **AD1**. (B) Proposed mechanism for the [3+2] cycloaddition.

chemical outcome can be justified following a monocoordinated Yb complex (see E.S.I.).[12e]

In summary, the intermolecular asymmetric synthesis of pyrrolo[1,2-*a*]indoles has been accomplished via [3+2] cycloaddition between silyl-indole derivatives and α,β-unsaturated *N*-acyl oxazolidinones using a dual catalytic system that combines an Ir(III) photocatalyst and a Lewis acid.

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Conflicts of interest

The authors declare no conflict of interest.

Notes and references

1 (*a*) P. D. Bass, D. A. Gubler, T. C. Judd and R. M. Williams, *Chem. Rev.*, 2013, **113**, 6816; (*b*) L. S. Fernandez, M. S. Buchanan, A. R. Carroll, Y. J. Feng, R. J. Quinn and V. M. Avery, *Org. Lett.,* 2009, **11**, 329; (*c*) T. Sasase, H. Morinaga, T. Abe, K. Miyajima, T. Ohta, M. Shinohara, M. Matsushita and A. Kakehashi, *Diabetes Obes. Metab.,* 2009, **11**, 1084; (*d*) J. F. Liu, Z. Y. Jiang, R. R. Wang, Y. T. Zheng, J. J. Chen, X. M. Zhang and Y. B. Ma, *Org. Lett.,* 2007, **9**, 4127; (*e*) U. Galm, M. H. Hager, S. G. Lanen, J. Ju and J. S. Thorson and B. Shen, *Chem. Rev.,* 2005, **105**, 739.

2 For selected examples see: (*a*) N. Monakhova, S. Ryabova and V. Makarov, *J. Heterocyclic Chem.*, 2016, **53**, 685; (*b*) R. Vallakati and J. A. May, *J. Am. Chem. Soc.,* 2012, **134**, 6936; (*c*) T. O. Schrader, B. R. Johnson, L. Lopez, M. Kasem, T. Gharbaoui, D. Sengupta, D. Buzard, C. Basmadjian and R. M. Jones, *Org. Lett*. 2012, **14**, 6306; (*d*) R. M. Zeldin and F. D. Toste, *Chem. Sci.,* 2011, **2**, 1706; (*e*) D. H. Dethe, R. D. Erande and A. Ranjan, *J. Am. Chem. Soc.,* 2011, **133**, 2864.

3 A. Padwa, G. E. Fryxell, J. R. Gasdaska, M. K. Venkatramanan and G. S. K. Wong, *J. Org. Chem*., 1989, **54**, 644.

4 For selected examples see: (*a*) X. Xie, P. Li, L. Wang, *Eur. J. Org. Chem*., 2019, 221; (*b*) C. Shen, N. Zeidan, Q. Wu, C. B. J. Breuers, R. R. Liu, Y. X. Jia and M. Lautens, *Chem. Sci*., 2019, **10**, 3118; (*c*) T. Li, P. Yang, *J. Org. Chem*., 2018, **83**, 14751; (*d*) J. Xu, X. Yu and Q. Song, *Org. Lett*., 2017, **19**, 980; (*e*) S. J. Jin, J. M. Guo, Y. S. Zhu, Q. L. Wang and Z. W. Bu, *Org. Biomol. Chem*., 2017, **15**, 8729; (*f*) H. Zhang, W. Li and C. Zhu, *J. Org. Chem*., 2017, **82**, 2199; (*g*) S. Singh, H. H. Butani, D. D. Vachhani, A. Shah and E. V. Van der Eycken, *Chem. Commun*., 2017, **53**, 10812.

5 For the synthesis of racemic pyrrolo[1,2-a] indole using SmI_2, see: (a) C. Beemelmanns and H. U. Reissig, *Chem. Soc. Rev*. 2011, **40**, 2199; (b) S. C. Lin, F. D. Yang, J. S. Shiue, S. M. Yang and J. M. Fand, *J. Org. Chem*., 1998, **63**, 2909; (c) J. S. Shiue and J. M. Fang, *J. Chem. Soc. Chem. Commun*., 1993, 1277.

6 For the synthesis of racemic pyrrolo[1,2-*a*] indole using $HSnBu_3$ and AIBN, see: (*a*) A. Fiumana and K. Jones, *Tetrahedron Lett.,* 2000, **41**, 4209; (*b*) A. P. Dobbs, K. Jones and K. T. Veal, *Tetrahedron*, 1998, **54**, 2149; (*c*) A. P. Dobbs, K. Jones and K. T. Veal, *Tetrahedron Lett*., 1995, **36**, 4857.

7 R. Coyle, P. McArdle and F. Aldabbagh, *J. Org. Chem*., 2014, **79**, 5903-5907.

8 For selected reviews, see: (*a*) A. A. Festa, L. G. Voskressenky and E. V. Van der Eycken, *Chem. Soc. Rev*., 2019. DOI: 10.1039/c8cs00790j; (*b*) J. J. Douglas, M. J. Sevrin and C. R. J. Stephenson, *Org. Process Res. Dev*., 2016, **20**, 1134; (*c*) N. A. Romero and D. A. Nicewicz, *Chem. Rev*., 2016, **116**, 10075; (*d*) K. L. Skubi, T. R. Blum and T. P. Yoon, *Chem. Rev.,* 2016, **116**, 10035; (*e*) C. K. Prier, D. A. Rankic and D. W. C. MacMillan, *Chem. Rev*., 2013, **113**, 5322.

9 (a) H. Huang, M. Yu, X. Su, P. Guo, J. Zhao, J. Zhou and Y. Li, *J. Org. Chem.,* 2018, **83**, 2425; (b) O. Boubertakh and J. P. Goddard, *Eur. J. Org. Chem*., 2017, 2072; (c) W. J. Zhou, G. M. Cao, G. Shen, X. Y. Zhu, Y. Y. Gui, J. H. Ye, L. Sun, L. L. Liao, J. Li and D. G. Yu, *Angew. Chem. Int. Ed*., 2017, **56**, 15683; (d) S. J. Kaldas, A. Cannil-lo, T. McCallum and L. Barriault, *Org. Lett*., 2015, **17**, 2864; (e) R. Coyle, K. Fahey and F. Aldabbagh, *Org. Biomol. Chem*., 2013, **11**, 1672; (f) J. W. Tucker, J. M. R. Narayanam, S. W. Krabbe and C. J. R. Stephenson, *Org. Lett*., 2010, **12**, 368.

10 Mariano and coworkers deeply investigated the generation of α-amino radicals from α-sylilamines through a photocatalyzed SET oxidation. See: E. Hasegawa, W. Xu, P. S. Mariano, U. C. Yoon and J. U. Kim, *J. Am. Chem. Soc*., 1988, **110**, 8099.

11 For selected examples see: (a) C. Remeur, C. B. Kelly, N. R. Patel and G. A. Molander, *ACS Catal*., 2017, **7**, 6065; (b) L. R. Espelt, I. S. McPherson, E. M. Wiensch and T. P. Yoon, *J. Am. Chem. Soc*., 2015, **137**, 2452; (c) Y. Miyake, Y. Ashida, K. Nakayima and Y. Nishi-bayashi *Chem. Commun*., 2012, **48**, 6966.

12 See for example: (a) S. Lauzon, M. Li, H. Keipour and T. Ollevier, *Eur. J. Org. Chem*., 2018, 4536; (b) W. Zhi, J. Li, D. Zou, Y. Wu and Y. Wu, *J. Org. Chem*., 2017, **82**, 12286; (c) M. P. Sibi, T. Soeta and C. P. Jasperse, *Org. Lett*., 2009, **11**, 5366; (d) A. M. M. Abe, S. J. K. Sauerland and A. M. P. Koskinen, *J. Org. Chem*., 2007, **72**, 5411; (e) M. P. Sibi, J. Ji, J. B. Sausker and C. P. Jasperse, *J. Am. Chem. Soc*., 1999, **121**, 7517; (f) S. Kanemasa, Y. Oderaotoshi and E. Wada, *J. Am. Chem. Soc*., 1999, **121**, 8675.

13 The Michael acceptor with the aromatic substitution (R^3) seems to be excited to its triplet state via an energy transfer process from the photocatalyst **PC1**. This excitation implies an isomerization of the double bond, which is in accordance to the *cis-trans* mixture of the starting material recovered after the reaction. This fact could also explain the low diastereoisomeric ratio obtained since both isomers are present in the reaction mixture (see compound **4j** in S.I.)

14 CCDC 1939359 contains crystallographic data of compound **4e**.

15 C. Palomo, M. Oiarbide, R. López, P. B. González, E. Gómez-Bengoa, J. M. Saá and A. Linden, *J. Am. Chem. Soc*., 2006, **128**, 15236.

16 W. Zhang, D. Tan, R. Lee, G. Tong, W. Chen, B. Qi, K. W. Huang, C. H. Tan and Z. Jiang, *Angew. Chem. Int. Ed*., 2012, **51**, 10069.

17 The excited state of iridium-based photocatalyst PC1, can perform a single electron oxidation of benzyl radical C. This process would allow the aromatization of pyrrolo[1,2a]indole. See reference 9f.

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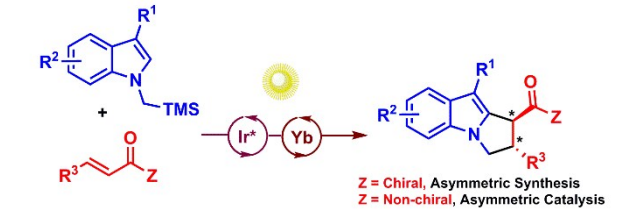
Graphical Abstract



- Dual Catalytic System
- Intermolecular [3+2] cycloaddition
- Structurally diverse approach
- Enantio- and diastereoselective synthesis