Contra-Thermodynamic, Photocatalytic *E*→*Z* Isomerization of Styrenyl Boron Species: Vectors to Facilitate Exploration of 2D Chemical Space

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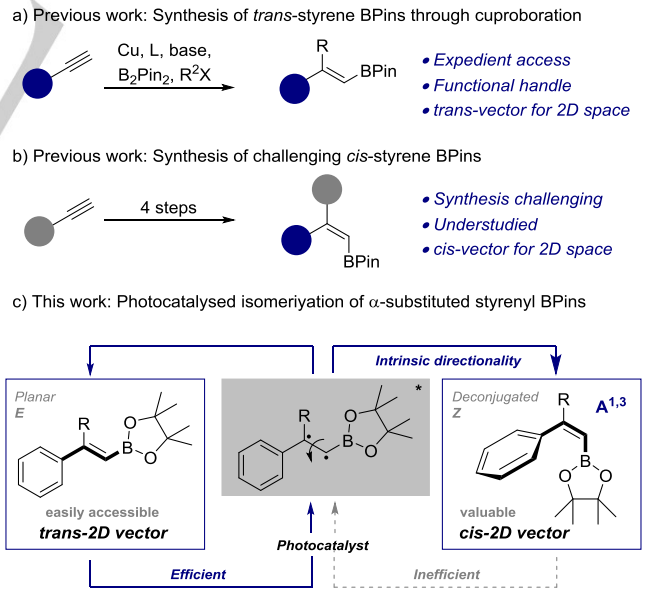
Dedicated to Prof. Dr. Jack D. Dunitz FRS on the occasion of his 95th birthday

Abstract: *The high efficiency and stereospecificity of cross-coupling technologies utilizing olefinic organoboron nucleophiles has been a key development in the interrogation of 2D and, following stereoselective elaboration, 3D chemical space. Accordingly, designing strategies to access stereodefined olefinic organoboron species is an important synthetic challenge. Despite significant advances, there is a striking paucity of routes to Z-α-substituted styrenyl organoborons. Herein, we redress this strategic imbalance by exploiting the polarity of the C(sp^2)-B bond to activate the neighboring π-system: This enables a mild, traceless photocatalytic isomerization of readily accessible E-α-substituted styrenyl BPins to generate the corresponding Z-isomers with high fidelity. Preliminary validation of this contra-thermodynamic E→Z isomerization is demonstrated via a series of stereoretentive transformations to generate Z-configured tri-substituted alkenes, as well as in a concise synthesis of the anti-tumor agent Combretastatin A-4.*

The C(sp^2)-B bond is an inimitable vector for the exploration of chemical space.[1] This prominence is particularly evident in the pharmaceutical industry, where organoboron species retain a privileged position in drug discovery. The strategic importance of this bond is a consequence of stability, simplicity of installation, and versatility in subsequent transformations.[1,2] Of the multitude of transition-based platforms that embrace organoboron species for cross-coupling, the Suzuki-Miyaura reaction may be credited with having had the greatest impact on reshaping the pharmaceutical landscape. Indeed, over 40% of all C-C bond forming reactions in medicinal chemistry can be attributed to this process.[3] The unique blend of reproducibility, scalability and structural tolerance has inspired numerous laboratories to rigorously investigate the mechanistic intricacies of this remarkable transformation.[1,2] The last decade has witnessed key breakthroughs:[4] In particular, seminal investigations by Denmark and coworkers have uncovered the elusive pre-transmetalation intermediate, which is a key event in the oxo-palladium pathway. [4d,4e]

From a molecular design perspective, a notable advantage of this venerable transformation is the associated stereospecificity observed when using substituted alkenyl organoboron species or alkenyl halides/*pseudo*-halides.[5] This conservation of stereochemical information allows the outcome of the reaction to be predicted *a priori* such that the alkenyl species can be considered as a masked vector to explore the desired 2D space. Naturally, this feature has the caveat that the chemical space exploration is directly linked to the geometry of the starting material and the ease with which it can be prepared: Advances in the hydro- and cupro-boration of alkynes continues to provide expedient access to *trans*[6] and *trans*-α-substituted[7] styrenyl boron species, respectively (Scheme 1a). This directly identifies *cis*-α-substituted styrenyl systems as a strategic limitation. Whilst elegant strategies do exist to prepare unsubstituted styrenes,[8] installation of the α-substituent can be laborious (Scheme 1b).[9] Consequently, a method that would allow access to the *cis* isomer from the more readily accessible *trans* isomer would address this limitation, simplify access, and permit divergence from a common and easily accessed intermediate. Herein, we disclose an operationally simple, photocatalytic isomerization of *trans*-α-substituted styrenyl boronic acid, pinacol esters (BPins) to the corresponding *cis* isomers with high fidelity (Scheme 1c). The synthetic utility of the method is demonstrated in a range of subsequent transformations to generate *Z*-configured alkenes, as well as in a concise synthesis of anti-tumor agent combretastatin A_4.[10]



Scheme 1. Formation of styrenyl BPins. a) Cuproboration to form *trans*-α-substituted styrenyl BPins; b) Synthesis of *cis*-α-styrenyl BPins; c) Proposed photocatalytic *E*→*Z* isomerization of *trans*-α-substituted styrenyl BPins (BPins = boronic acid, pinacol esters).

Spatio-temporal control of pre-existing alkene geometry remains a multifaceted challenge in synthesis.[11] Consequently, the contra-thermodynamic *E*→*Z* isomerization of alkenes continues to lack

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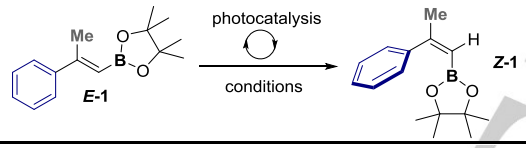
generality. This is noteworthy given the prominence of vinyl C(sp^2)-X precursors in stereospecific cross-coupling chemistry. Fortunately, constraints such as microscopic reversibility can be circumvented by photochemical activation. Seminal studies by Hammond, Arai, and others[12] provide a platform for selective geometric isomerization by photosensitization.[13] In recent years, this concept has translated to more challenging substrate classes. Pertinent examples include the *E*→*Z* isomerization of allylic alcohols and amines by Weaver,[14] and the application of (–)-riboflavin to invoke *E*→*Z* isomerization of polarized olefins.[15] In this latter scenario, a conjugated π-system can be activated by the excited state of the photocatalyst via an energy transfer manifold (E_T). Subsequent rotation of the central bond in the transient intermediate can give rise to both the *trans* and *cis* isomers. However, developing allylic strain in the *cis* form deconjugates the π-systems and thus reactivation is inefficient. This process thereby induces an intrinsic directionality in favor of the *contra*-thermodynamic process (*E*→*Z,* Scheme 1c). Since, trigonal planar boron molecules contain an empty Lewis acidic *p*-orbital, thereby increasing electron deficiency, we reasoned that a photocatalytic isomerization via an energy transfer enabled by a suitable sensitizer would constitute a simple and elegant solution this problem. Based on this working hypothesis, we sought to explore several photocatalysts in a benchmark transformation. To that end, the geometric isomerization of ***E*-1** to ***Z*-1** was explored (Table 1).

Table 1. Optimization of the isomerization ***E*-1** → ***Z*-1**.



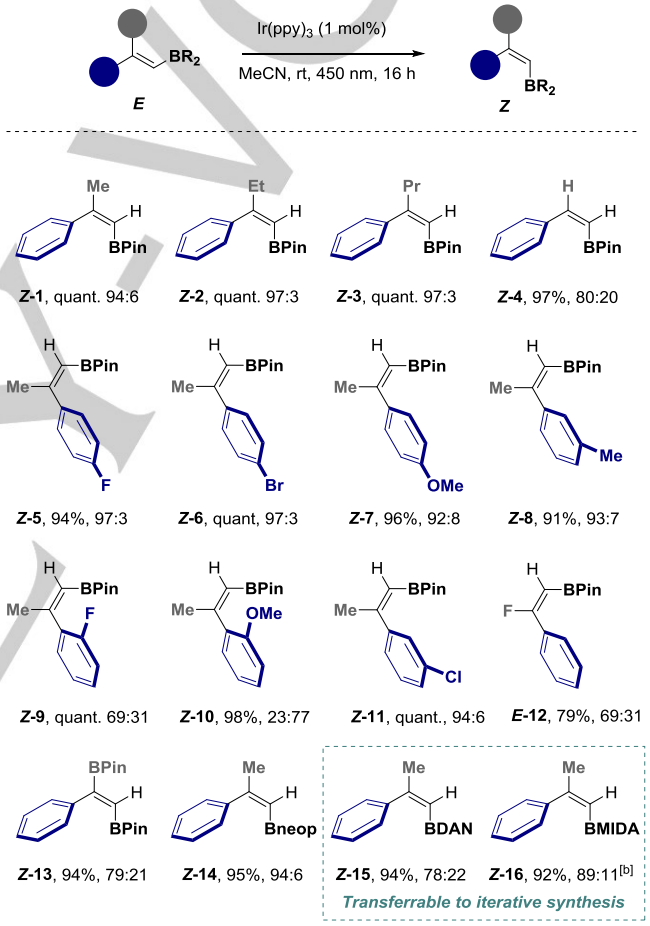
Entry	Catalyst	Catalyst loading (mol%)	Reaction Time (h)	Irradiation wavelength (nm)	*Z*/*E* ratio[a]
1	-	-	24	450	12:88
2	(–)-riboflavin	5	24	400	75:25
3	Anthracene	5	24	365	73:27
4	Fluorenone	5	24	400	48:52
5	Benzophenone	5	24	365	75:25
6	Ir(ppy)$_3$	5	24	450	90:10
7	Ir(ppy)$_3$	1	24	450	86:14
8	Ir(ppy)$_3$	1	16	450	79:21
9	**Ir(ppy)$_3$**	**1**	**16**	450	**94:6**[b]
10	Ir(ppy)$_3$	1	16	450	39:61[c]

[a] Reactions were performed in MeCN on a 0.1 mmol scale at ambient temperature. *Z*:*E* selectivity was determined by ^{1}H NMR spectroscopy. [b] Reaction was performed under an argon atmosphere.[c] Reaction was performed under an oxygen atmosphere.

Whilst common organic sensitizers provided proof of principle (entries 2-5 *cf* entry 1) at 5 mol% catalyst loadings, unsatisfactory levels of selectivity were observed after 24 h irradiation (up to *Z*:*E* 75:25). Consequently, the triplet sensitizer Ir(ppy)$_3$ that had been reported by Weaver[14] proved to be highly effective for this process. Indeed, with a significantly reduced catalyst loading (1 mol%) and a shorter reaction time of 16 h (entries 6-8). Performing the reaction under an inert atmosphere of argon not only increased reaction efficiency, but it implicates a triplet energy transfer manifold (E_T) as being operational (Entry 9).[16] Additional support for this proposal derived from an experiment performed under an oxygen atmosphere in which the selectivity was notably diminished (entry 10, *Z*:*E* 39:61).

Having established a set of general conditions to achieve the efficient *E*→*Z* isomerization of styrenyl BPins, scope and limitations were established (Table 2).

Table 2. Establishing Substrate Scope.[a]

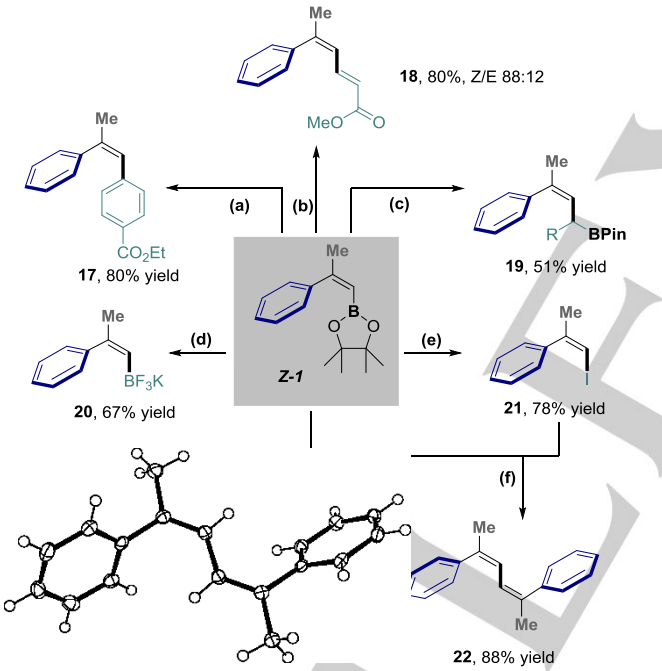


[a] Reactions were performed in MeCN on a 0.1 mmol scale at ambient temperature under an argon atmosphere. *Z*:*E* ratio was determined by ^{1}H NMR spectroscopy. [b] Anthracene (5 mol%) and UV-light (365 nm) were required for isomerization. N.B. The isomerized product **12** is *E*-configured, reflecting the higher IUPAC priority of F than C. CCDC-1815285 contains the supplementary crystallographic data for ***E*-16**. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.

Pleasingly, the protocol was transferable to a range of substrates including extended α-substituents such as ethyl and propyl units, ***Z*-2** and ***Z*-3** respectively. The importance of the α-substituent is reflected in ***Z*-4**, where a reduction in selectivity is observed. Moreover, varied functionalities on each position of the aryl ring were well tolerated,

including electron deficient halides (***Z*-5**, ***Z*-6**, ***Z*-9**, and ***Z*-11**) and electron rich motifs (***Z*-7** and ***Z*-8**) with all of the aforementioned examples proceeding with high levels of selectivity favouring the *Z*-isomer. Interestingly, a reduction in selectivity was observed with *ortho*-substituents: This may be attributable to the deconjugation of the starting material ($A^{1,3}$-strain) that compromises the efficiency of the initial excitation of the *trans* styenyl BPin (***Z*-9** and ***Z*-10**).[15] Electron deficient α-substituents proved to be more challenging (***Z*-12** and ***Z*-13**), although the *bis*-BPin species ***Z*-13** does provide a platform for subsequent bidirectional coupling.[17] A particular strength identified during this investigation was the tolerance to variation in the organoboron residue itself (***Z*-14**, ***Z*-15**, and ***Z*-16**). Cognisant of the fact that boron protecting group orthogonality is essential to ensure chemoselectivity in subsequent transformations, the BDAN[18] (***Z*-15**) and BMIDA[19] (***Z*-16**) systems were also subjected to our general conditions. Recent application of these motifs in the iterative synthesis of important polyketides further exemplifies the synthetic value of these building blocks.[18,19]

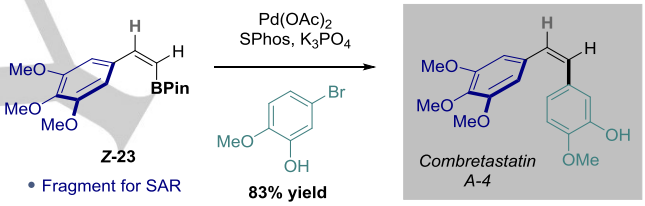
Finally, to provide preliminary validation of the synthetic value of this protocol in accessing new areas of 2D space, vector ***Z*-1** was exposed to a selection of stereospecific transformations (Scheme 2).



Scheme 2. Stereospecific transformations employing vector ***Z*-1**: (a) Ethyl 4-bromobenzoate (1.2 eq.), $Pd(OAc)_2$ (5 mol%), SPhos (10 mol%), K_3PO_4 (3.0 eq.), H_2O (5.0 eq.), 1,4-dioxane, 80 °C; (b) methyl acrylate (6.0 eq.), $Pd(OAc)_2$ (5 mol%), O_2, DMA, 50 °C; c) (3-Phenylpropyl) diisopropylcarbamate (1 eq.), (+)-sparteine (1.2 eq.), *s*BuLi (1.1 eq.), $MgBr_2$•OEt_2 (2.0 eq.), Et_2O, -78 °C; d) Aq. KHF_2 (4.5 M, 5 eq.), MeOH, rt; e) Aq. NaOH (3 M, 3.0 eq.), iodine (2.0 eq.), THF, rt; f) **21** (1 eq.), $Pd(OAc)_2$ (5 mol%), SPhos (10 mol%), K_3PO_4 (3.0 eq.), H_2O (5.0 eq.), 1,4-dioxane, 80 °C. CCDC-1815286 contains the supplementary crystallographic data for **22**. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.

Significant quantities of ***Z*-1** were required and so the photocatalytic isomerization ***E*-1** → ***Z*-1** was performed on a 1 mmol scale. Since this study was inspired by the importance of the Suzuki-Miyaura coupling in medicinal chemistry, ***Z*-1** was processed to the *cis*-stilbene **17** 80% yield as a single geometric isomer. The reaction with methyl acrylate under oxidative Heck conditions also proceeded smoothly to generate the retinal mimic **18** in 80% yield. The *cis* vector was also utilised in the elegant homologation developed by Aggarwal and co-workers[21] to generate the *Z*-configured allylic BPin **19**. Ligand exchange on boron also proved facile to deliver the corresponding BF_3K species **20**.[22] Reversing the nucleophilic character of the *cis* vector ***Z*-1** to an electrophilic species was also enabled through iodination of the boron residue (**21**).[23] This simple polarity reversal enabled a union of ***Z*-1** and **21** to generate the *Z,Z*-diene **22** in 88% yield. Gratifyingly, it was possible to isolate crystals that were suitable for X-ray analysis (Scheme 2, lower left, CCDC 1815286). This valuable structural insight clearly demonstrates the importance of 1,3-allylic strain in deconjugating the aryl ring from the π-system. This destabilising, non-covalent interaction is a critical feature in placing the high *Z*-selectivities observed in this transformation on a structural basis.

Finally, encouraged by the efficient conversion of ***Z*-1** to the *cis*-stilbene **17** via Suzuki-Miyaura coupling, the synthesis of the anti-tumour natural product combretastatin A-4 was realized (Scheme 3, 83% yield).[8,24] Fragment ***Z*-23** not only provides a direct access to the natural product in a single step, but also allows for the rapid generation of libraries and complements the existing metathesis.[8]



Scheme 3. Concise synthesis of Combretastatin A-4 utilising fragment ***Z*-23**.

In summary, we have developed an efficient and operationally simple method for the preparation of *cis*-α-substituted styrenyl BPins. A straightforward photocatalytic isomerization of the readily available *trans*-isomer allows direct access to the significantly more challenging *cis*-isomer with high stereoselectivity. As valuable fragments for the exploration of 2D space, and for the subsequent elaboration into 3D space, this method now allows the facile investigation of vectors that were previously troublesome to interrogate. A series of representative, stereospecific transformations constitute preliminary validation of this strategy in the synthesis of *Z*-configured trisubstituted olefins, and underscore the value of vectors such as ***Z*-1** in molecular design.

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Keywords: alkenes • catalysis • conformation • geometric isomerization • medicinal chemistry

[1] A. J. J. Lennox, G. C. Lloyd-Jones, *Chem. Soc. Rev.* **2014**, *43*, 412 – 443.

[2] For selected reviews on the Suzuki-Miyaura reaction , see: a) N. Miyaura, A. Suzuki, *Chem. Rev*. **1995**, *95*, 2457 – 2483; b) L. Xu, S. Zhang, P. Li, *Chem. Soc. Rev.* **2015**, *44*, 8848 – 8858; c) J. W. B. Fyfe, A. J. B. Watson, *Chem* **2017**, *3*, 31 – 55; d) J. P. G. Rygus, C. M. Crudden, *J. Am. Chem. Soc.* **2017**, *139*, 18124 – 18137.

[3] S. D. Roughley, A. M. Jordan, *J. Med. Chem.* **2011**, *54*, 3451 – 3479.

[4] For studies on the oxo-palladium pathway, see: a) B. P. Carrow, J. F. Hartwig, *J. Am. Chem. Soc.* **2011**, *133*, 2116 – 2119; b) C. Amatore, A. Jutand, G. Le Duc, *Chem. Eur. J.* **2011**, *17*, 2492 – 2503; c) A. F. Schmidt, A. A. Kurokhtina, E. V. Larina, *Russ. J. Gen. Chem.* **2011**, *81*, 1573 – 1574; d) A. A. Thomas, S. E. Denmark, *Science* **2016**, *352*, 329 – 332; e) A. A. Thomas, H. Wang, A. F. Zahrt, S. E. Denmark, *J. Am. Chem. Soc.* **2017**, *139* 3805 – 3821.

[5] G. A. Molander, L. A. Felix, *J. Am. Chem. Soc.* **2005**, *70*, 3950 – 3956.

[6] For selected examples of hydroboration of terminal alkynes, see: a) S. Pereira, M. Srebnik, *Organometallics* **1995**, *14*, 3127 – 3128; b) K. Shirakawa, A. Arase, M. Hoshi, *Synthesis* **2004**, 1814 – 1820.

[7] For selected examples of copper-catalysed borylation, see: a) R. Alfaro, A. Parra, J. Alemán, J. L. G. Ruano, M. Tortosa, *J. Am. Chem. Soc.* **2012**, *134*, 15165 − 15168; b) C. -C. Tai, M. -S. Yu, Y. -L. Chen, W. -H Chuang, T. -H. Lin, G. P. A. Yap, T. -G. Ong, *Chem. Commun.* **2014**, *50*, 4344 – 4346; c) B. Mun, S. Kim, H. Yoon, K. H. Kim, Y. Lee, *J. Org. Chem.* **2017**, *82*, 6349 − 6357.

[8] a) E. T. Kiesewetter, R. V. O'Brien, E. C. Yu, S. J. Meek, R. R. Schrock, A. H. Hoveyda, *J. Am. Chem. Soc.* **2013**, *135*, 6026 – 6029; b) T. Ohmura, Y. Yamamoto, N. Miyaura, *J. Am. Chem. Soc.* **2000**, *122*, 4990 – 4991.

[9] a) C. Wang, T. Tobrman, Z. Xu, E. Negishi, *Org. Lett.* **2009**, *11*, 4092 – 4095; b) T. -J. Hu, G. Zhang, Y. -H. Chen, C. -G. Feng, G. -Q. Lin, *J. Am. Chem. Soc.* **2016**, *138*, 2897 – 2900.

[10] For the isolation of Combretastatin A-4, see: G. R. Pettit, S. B. Singh, M. R. Boyd, E. Hamel, R. K. Pettit, J. M. Schmidt, F. Hogan, *J. Med. Chem.* **1995**, *38*, 1666 – 1672.

[11] C. M. Pearson, T. N. Snaddon, *ACS Cent. Sci*. **2017**, *3*, 922-924.

[12] For examples of *cis−trans* isomerizations of stilbenes, see: a) G. S. Hammond, J. Saltiel, *J. Am. Chem. Soc.* **1962**, *84*, 4983 − 4984. b) J. Saltiel, G. S. Hammond, *J. Am. Chem. Soc.* **1963**, *85*, 2515 − 2516. c) G. S. Hammond, J. Saltiel, A. A. Lamola, N. J. Turro, J. S. Bradshaw, D. O. Cowan, R. C. Counsell, V. Vogt, C. Dalton, *J. Am. Chem. Soc.* **1964**, *86*, 3197 − 3217; d) For examples of *cis−trans* isomerizations of styrenes, see: d) T. Arai, H. Sakuragi, K. Tokumaru, *Chem. Lett.* **1980**, 261 − 264. e) T. Arai, H. Sakuragi, K. Tokumaru, *Bull. Chem. Soc. Jpn.* **1982**, *55*, 2204 − 2207.

[13] For examples of photocatalysis using sensitizers, see: a) A. Bauer, F. Westkamper, S. Grimme, T. Bach, *Nature* **2005**, *436*, 1139 – 1140; b) C. Müller, A. Bauer, T. Bach, *Angew. Chem., Int. Ed.* **2009**, *48*, 6640 − 6642; *Angew. Chem.* **2009**, *121*, 6767 – 6769; c) C. Müller, A. Bauer, M. M. Maturi, M. C. Cuquerella, M. A. Miranda, T. Bach, *J. Am. Chem. Soc.* **2011**, *133*, 16689 – 16697; d) M. M. Maturi, M. Wenninger, R. Alonso, A. Bauer, A. Pöthig, E. Riedle, T. Bach, *Chem. Eur. J.* **2013**, *19*, 7461 − 7472. e) R. Alonso, T. Bach, *Angew. Chem., Int. Ed.* **2014**, *53*, 4368 − 4371; *Angew. Chem.* **2014**, *126*, 4457 – 4460; f) M. M. Maturi, T. Bach, *Angew. Chem., Int. Ed.* **2014**, *53*, 7661 − 7664; *Angew. Chem.* **2014**, *126*, 7793 – 7796; g) For recent reviews on photocatalysis, see: D. A. Nicewicz, T. M. Nguyen, *ACS Catal.* **2014**, *4*, 355 − 360. h) R. Brimioulle, D. Lenhart, M. M. Maturi, T. Bach, *Angew. Chem., Int. Ed.* **2015**, *54*, 3872 − 3890; *Angew. Chem.* **2015**, *127*, 3944−3963.

[14] a) S. M. Senaweera, A. Singh, J. D. Weaver, *J. Am. Chem. Soc.* **2014**, *136*, 3002 – 3005; b) A.Singh, J. J. Kubik, J. D.Weaver, *Chem. Sci.* **2015**, *6*, 7206 – 7212; c) Teegardin, K.; Day, J. I.; Chan, J.; Weaver, J. *Org. Process Res. Dev.* **2016**, *20*, 1156–1163.

[15] a) J. B. Metternich R. Gilmour, *J. Am. Chem. Soc.* **2015**, *137*, 11254 − 11257; b) J. B. Metternich R. Gilmour, *J. Am. Chem. Soc.* **2016**, *138*, 1040 – 1045; c) J. B. Metternich, D. G. Artiukhin, M. C. Holland, M. von Bremen-Kühne, J. Neugebauer, R. Gilmour, *J. Org. Chem.* **2017**, *82*, 9955 – 9977; d) For a recent review see: J. B. Metternich, R. Gilmour, *Synlett* **2016**, *27*, 2541 – 2552; e) W. Cai, H. Fan, D. Ding, Y. Zhang, W. Wang, *Chem. Commun.* **2017**, *53*, 12918–12921; f) K. Zhan, Y. Li, *Catalysts* **2017**, *7*, 337; f) S. Faßbender, J. B. Metternich, R. Gilmour, *Org. Lett.* **2018**, DOI 10.1021/acs.orglett.7b03859.

[16] C. Grewer, H. Brauer, *J. Phys. Chem.* **1994**, *98*, 4230 – 4235.

[17] Chemoselective Suzuki-Miyaura could be achieved using ***E*-13** as seen in: I. Tatsuo, Y. Masafumi, M. Norio, *Chem. Lett.* **1996**, *25*, 1117 – 1118. Selectivity could not be achieved with ***Z*-13** (see SI for details).

[18] H. Noguchi, K. Hojo, M. Suginome, *J. Am. Chem. Soc.* **2007**, *129*, 758 – 759.

[19] J. Li, A. S. Grillo, M. D. Burke, *Acc. Chem. Res.* **2015**, *48*, 2297 – 2307; b) E. P. Gillis, M. D. Burke, *Aldrichimica Acta* **2009**, *42*, 17 – 27; c) J. Li, S. G. Ballmer, E. P. Gillis, S. Fujii, M. J. Schmidt, A. M. E. Palazzolo, J. W. Lehmann, G. F. Morehouse, M. D. Burke, *Science* **2015**, *347*, 1221 – 1226.

[20] K. -S. Yoo, C. H. Yoon, K. W. Jung, *J. Am. Chem. Soc.* **2006**, *128*, 16384 – 16393.

[21] J. L. -Y. Chen, V. K. Aggarwal, *Angew. Chem. Int. Ed.* **2014**, *53*, 10992 – 10996; *Angew. Chem.* **2014**, *126*, 11172 – 11176.

[22] G. A. Molander, N. M. Ellis, *J. Org. Chem.* **2008**, *73*, 6841 – 6844.

[23] C. Wang, T. Tobrman, Z. Xu, E. Negishi, *Org. Lett.* **2009**, *11*, 4092 – 4095.

[24] For previous syntheses of Combretastatin A4, see: a) N. J. Lawrence, F. A. Ghani, L. A. Hadfield, J. A. Hepworth, A. T. McGown, R. G. Pritchard, *Synthesis* **1999**, 1656 – 1660; b) K. Gaukroger, J. A. Hadfield, L. A. Hepworth, N. J. Lawrence, A. T. McGown, *J. Org. Chem.* **2001**, *66*, 8135 – 8138; c) K. Odlo, J. Klaveness, P. Rongved, T. V. Hansen, *Tetrahedron Lett.* **2006**, *47*, 1101 – 1103; d) F. Lara-Ochoa, G. Espinoza-Perez, *Tetrahedron Lett.* **2007**, *48*, 7007 – 7010; e) G. R. Pettit, M. D. Minardi, F. Hogan, P. M. Price, *J. Nat. Prod.* **2010**, *73*, 399 – 403; f) D. J. Wardrop, J. P. Komenda, *Org. Lett.* **2012**, *14*, 1548 – 1551.

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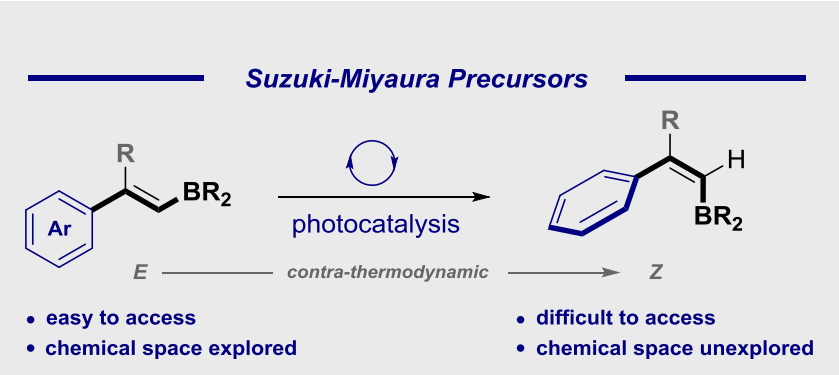

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