Letter

Tris(pentafluorophenyl)borane-Catalyzed Cyclopropanation of Styrenes with Aryldiazoacetates

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Tris(pentafluorophenyl)borane-Catalyzed Cyclopropanation of Styrenes with Aryldiazoacetates.

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Supporting Information Placeholder

ABSTRACT: Methods for the synthesis of cyclopropanes are critical for drug discovery, chemical biology, total synthesis and other fields. Herein, we report the use of the strong sterically encumbered Lewis acid tris(pentafluorophenyl)borane as a catalyst for the cyclopropanation of unactivated alkenes using aryldiazoacetates. The cyclopropane products are synthesized using 10 mol % of the catalyst under mild conditions in up to 90% yield (8:1 to >20:1 dr). We propose that the reaction proceeds via a Lewis acid-activated carbene.

Cyclopropanes are dissonant carbocycles which are typically synthesized using [2+1] cycloaddition strategies and are used in a variety of applications.[1–7] Consequently, reactions to build these motifs are enabling for a number of subdisciplines. To date, some of the most efficient methods for the synthesis of cyclopropanes rely on the activation of a carbene precursor, such as a diazo acetate, with a transition-metal catalyst[8] generating transient metal carbene species. These transformations have been optimized extensively and, in most cases, provide cyclopropanes with high enantioselectivity and diastereoselectivity and regiocontrol. Alternatively, stoichiometric transformations utilizing zinc carbenoids have been developed.[9] These transformations, however, are not without limitations. The use of expensive transition-metal catalysts can be a deterrent for their use on large scale. Furthermore, the use of zinc carbenoids requires 1,1-dihaloalkane precursors, work best when transferring methylene units, and produces stoichiometric amounts of zinc waste. Thus, *transition-metal-free* variants of [2+1] cycloaddition reactions are valuable.[10–12]

Harnessing the electrophilic reactivity of diazocarbonyl compounds catalytically without transition-metals is conspicuously absent despite the extensive studies on the stoichiometric reactivity of these compounds with both Brønsted and Lewis acids.[13–15] Early mechanistic studies demonstrated these species are capable of generating both diazonium ketones, when activated with an acid on carbon, or an alkenediazonium intermediate when activated on oxygen instead.[16] Interactions of acids with diazo compounds on nitrogen are also common.[17] Typically, the putative diazonium species are then trapped with a variety of nucleophiles such as pendant heteroatoms,[18] nitriles,[19] arenes[20] or activated olefins to give substitution products.[21] However, these transformations are limited in scope and often produce substitution products in low yields and as a mixture of isomers (Figure 1, A). Organocatalytic transformations using diazocarbonyls as ylides have only recently been achieved using enaldehyde Michael acceptors activated by highly electrophilic chiral oxazaborolidinium catalysts due to the low nucleophilicity of diazoacetates.[22] At the outset of these studies, *there were no reports of isolating cyclopropanes when unactivated alkenes were used as a reaction partner in the presence of Lewis acids*. However, during the preparation of this manuscript, a report by Melen and coworkers appeared disclosing such reactivity.[23]

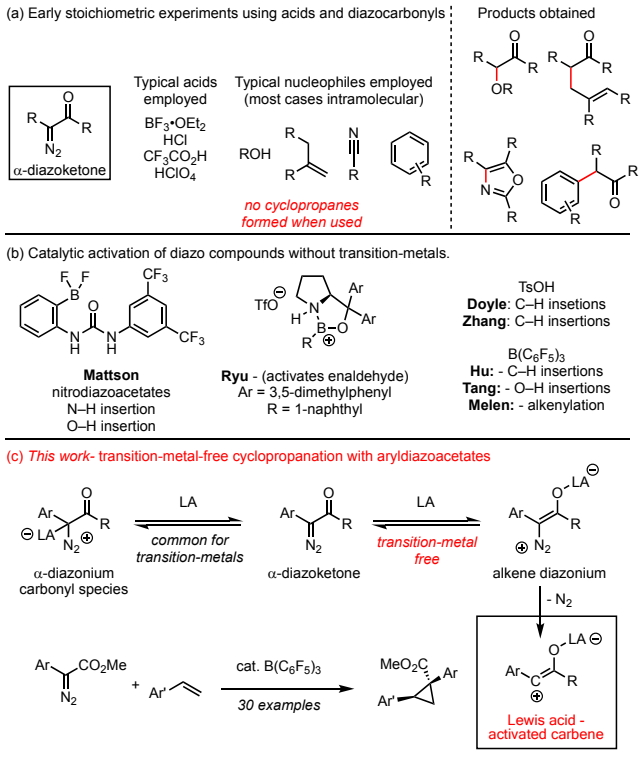


Figure 1: Summary of the reactivity of Brønsted and Lewis acids with diazocarbonyl compounds.

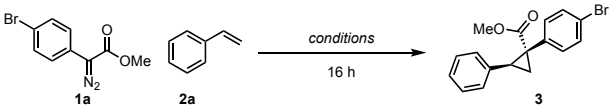
Recently, researchers have focused attention on catalytic activation of diazocarbonyl compounds with Brønsted (including H–bonding) and Lewis acids. However, these transformations are mainly limited to X–H insertions (X = C, N, or O).[24] For example, studies by the Mattson group showed that anilines undergo N–H insertions with α-nitrodiazoesters activated by thioureas as catalyst.[25] In 2014, Hu found that treating 3-diazooxindoles with TfOH results in formal C–H insertion products which arise through a Friedel–Crafts alkylation of electron-rich arenes (Figure 1, B).[26]

Later in 2016, Zhang showed that tris(pentafluorophenyl)borane ($B(C_6F_5)_3$),[27] activates aryldiazoacetates to effect an *ortho*-selective C–H insertion reaction on phenols, and O–H insertions into water.[28]

As a part of a research program centered on main-group catalysis, we became interested in the reactivity of strong sterically encumbered Lewis acids with aryldiazoacetates. We sought to use the carbonyl group of aryldiazoacetates as a Lewis base handle for activation and hypothesized that a strong, but sterically encumbered, Lewis acids, such as tris(pentafluorophenyl)borane, would facilitate catalysts turnover. Furthermore, we envisioned a Lewis-acid activated carbene intermediate (see inset box in Scheme 1, C) would confer high levels of diasterocontrol. Herein, we report an additional study on the use of $B(C_6F_5)_3$ to activate donor/acceptor diazo compounds for the catalytic diastereoselective cyclopropanation of styrene derivatives.

We began by studying the reaction of ethyl 4-bromophenyldiazoacetate with styrene in the presence of catalytic (5 mol%) tris(pentafluorophenyl)borane.[29] We found that increasing the catalyst loading from 5 to 10 mol % was moderately beneficial (Table 1, Entries 1–2), but further increases (15 mol % were deleterious to the reaction efficiency. A control study of the reaction in the absence of catalyst revealed no conversion to cyclopropane by ^{1}H NMR. Next, the effect of solvent on the system was investigated. We observed that non-coordinating solvents such as benzene gave the best initial results (Table 1, Entry 8), and that 1,2-dichloroethane was optimal (63% yield, Table 1, Entry 9). Other more coordinating solvents such as tetrahydrofuran and acetonitrile significantly diminished the yields of cyclopropane products (< 5%) presumably due to competitive inhibition of the catalyst by the solvent. Reducing the equivalents of styrene relative to diazo (2 equiv **1a**) gave the best results 83% yield (75% isolated) of compound **3**. We observed increased amounts of poly(styrene) in the crude reaction mixture when increased amounts of styrene we used. The reaction was amenable to large batches, providing **3** on gram scale (70% isolated yield with 1.00 mmol styrene). Notably, BPh_3 and other Lewis acid catalyst gave diminished yields of the cyclopropane product (Table 1, Entries 13–16). The temperature of the reaction was also investigated and 50 °C was optimal. Cooling the reaction mixture to room temperature resulted in slower conversion to product over days while heating the mixture to 90 ºC resulted in premature thermal decomposition of the aryldiazoacetate, in accord with previous studies.[30]

Table 1. Optimization Studies.



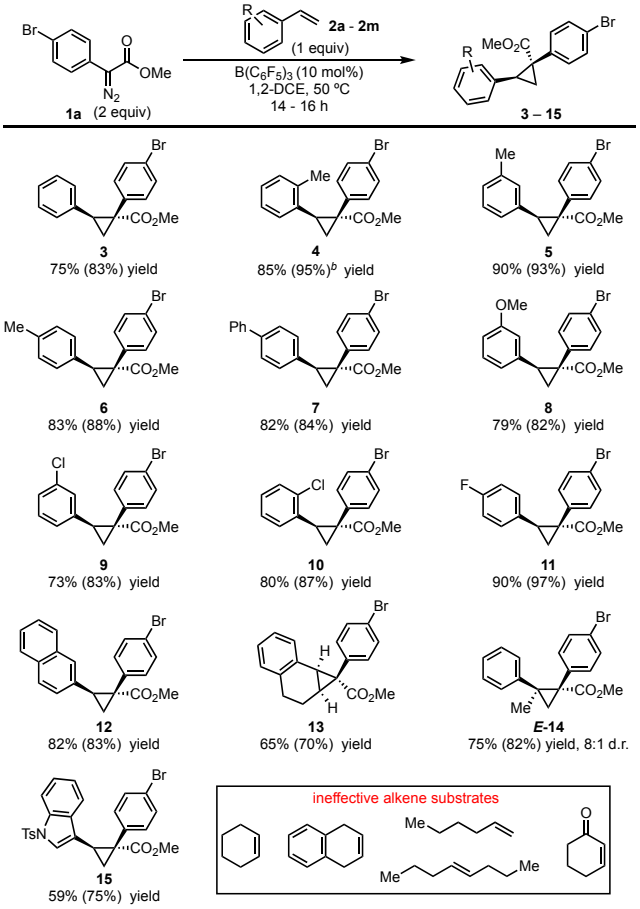
1a 2a 3

Entry	catalyst	loading (mol %)	2a (equiv)	solvent	temp. (°C)	yield (%) 3a[a]	
1	$B(C_6F_5)_3$	5	5	PhMe	50	27	Loading
2	$B(C_6F_5)_3$	10	5	PhMe	50	33	
3	$B(C_6F_5)_3$	15	5	PhMe	50	21	
4	$B(C_6F_5)_3$	5	5	Et_2O	50	37	Solvent
5	$B(C_6F_5)_3$	5	5	THF	50	<5	
6	$B(C_6F_5)_3$	5	5	MeCN	50	<5	
7	$B(C_6F_5)_3$	5	5	CH_2Cl_2	50	16	
8	$B(C_6F_5)_3$	5	5	PhH	50	57	
9	$B(C_6F_5)_3$	5	5	1,2-DCE	50	63	Stoich.
10	$B(C_6F_5)_3$	5	1	1,2-DCE	50	70	
11	$B(C_6F_5)_3$	10	1	1,2-DCE	50	64	
12	**$B(C_6F_5)_3$**	**10**	**1**	**1,2-DCE**	**50**	**83[b] (75)**	
13	BPh_3	10	1	1,2-DCE	50	< 5	Lewis acid
14	$SnCl_4$	10	1	1,2-DCE	-78 to 25	21	
15	BF_3•OEt_2	10	1	1,2-DCE	-78 to 25	21	
16	$TiCl_4$	10	1	1,2-DCE	-78 to 25	decomp.	

Standard conditions: 0.10 M, 16 h. [a]Yields are based on ^{1}H NMR analysis of the crude reaction mixture using 150 µmol mesitylene or hexamethyldisiloxane as an internal standard. [b]150 µmol styrene **2a**, 300 µmol (2 equiv) diazo **1a**.

With our optimized conditions in hand, we explored the scope of this transformation, beginning first with substitution on the styrene. The transformation was amenable to several electron-rich styrene derivatives producing **4**–**8** and electron deficient styrene derivatives producing **9**–**11** (Chart 1) including those with Lewis basic functionality that could hinder the reaction by coordinating with the Lewis acid catalyst (e.g., **8**). In all cases we observe a single diastereomer with the aryl rings *cis* to each other, except in the case of α-methyl styrene, where an 8:1 mixture of diastereomers was observed by proton ^{1}H NMR (***E*-14**).[29] Indole groups were also tolerated giving compound **15** in good yield, and no products arising from cyclopropanation of the 2,3-bond of the indole unit were observed. We also tested several unactivated alkenes (Chart 1, inset box) and found these substrates performed poorly with our optimized conditions producing the desired cyclopropanes in low yields (< 15%).

Chart 1. Reaction Scope with Styrene Derivatives

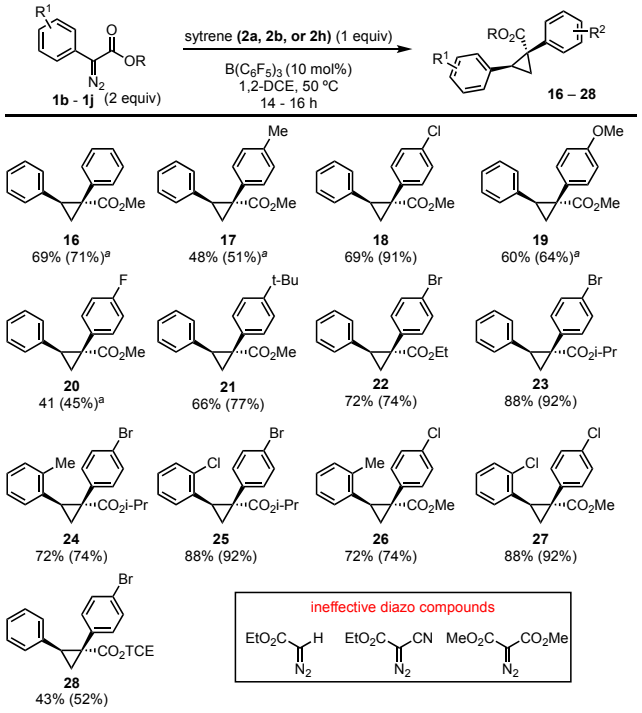


[a] Yields determined by ^{1}H NMR of the crude reaction mixture in parenthesis. Product **3** is included for comparison purposes. Conditions: All reactions were performed on 150 µmol **2a**–**2m** (0.10 M) in a reaction tube. [b]2-methyl styrene 75.0 µmol scale.

We next explored the scope of the donor/acceptor diazo compounds. We found that aryl diazoacetates with various functionalities were reactive using the optimized reaction conditions (Chart 2). Changing the identity of the ester did not hinder the reaction, as methyl ester **1b** ethyl ester **1h** and even the more sterically encumbered isopropyl ester **1i** proved tolerant of the reaction conditions giving products **16**, **22** and **23** respectively. More deactivated diazo compounds, such as the *para*-fluoro derivative **1f**, required longer reaction times, giving diminished yields of cyclopropane **20**. The more activated *para*-methoxy diazo **1e** also gave **19** in reasonable yield (60% yield). Diazocarbonyl

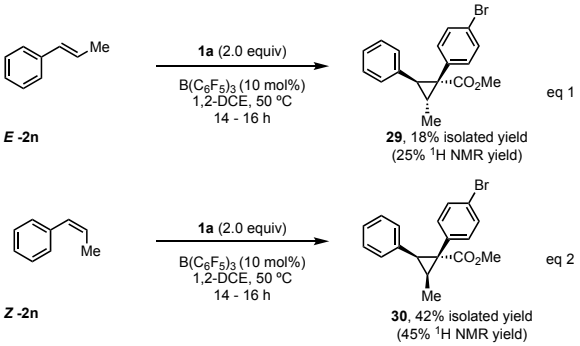
compounds without aryl substitution or with two electron withdrawing groups (e.g., ethyl diazoacetate, ethyl diazocyanoacetate, or dimethyl diazomalonate) were ineffective using the optimized conditions giving less than 5% conversion to product by ^{1}H NMR analysis (Chart 2, inset box).

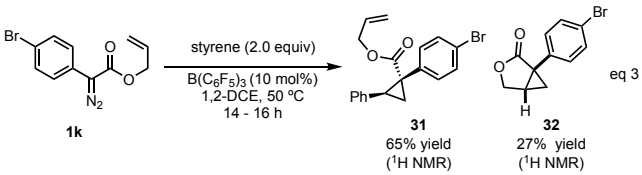
Chart 2. Cyclopropanation Scope with Diazocarbonyl Compounds

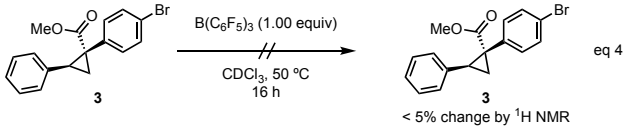


Conditions: All reactions were performed on 150 μmol **2a** (0.10 M). [a] 24 h reaction time. TCE = 2,2,2-trichloroethyl.

Preliminary investigations into the mechanism for this transformation are outlined in eq 1–2. Reacting diazo **1a** with *E*-β-methyl styrene (*E*-**2n**) and *Z*-β-methyl styrene (*Z*-**2n**) gave products **29** and **30** as single diastereomers by ^{1}H NMR, indicating the reaction is both stereospecific and stereoselective. The reaction is not limited to *Z*-alkenes; *E*-alkenes, which typically react with diazo carbonyl compounds only using Ag catalysis, also react in our system, albeit slower.[31] When allyl 4-bromophenyldiazoacetate **1k** was subjected to the optimized reaction conditions, products **31** and **32** were formed 65% and 27% yield, respectively, by crude ^{1}H NMR analysis (eq 3). Thus, alkene groups on the diazoester are allowed during the cyclopropanation reaction. The stereospecific nature and high levels of diastereoselectivity are in accord with a concerted cycloaddition process. As shown in eq 4, when purified cyclopropane product **3** was subjected to the Lewis acid catalyst at 50 ºC, no changes were observed by ^{1}H NMR spectroscopy.

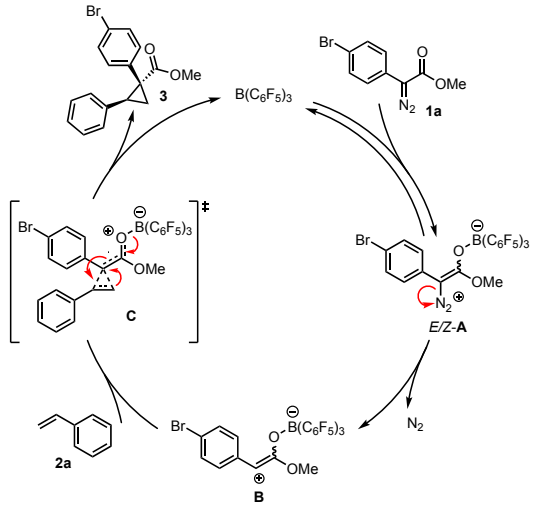






With these data, the tentatively proposed mechanism for this transformation is shown in Scheme 1. First, $B(C_6F_5)_3$ coordinates reversibly to the Lewis basic ester on diazo compound **1a**, generating the alkene diazonium species **A** which exists as a mixture of *E*- and *Z*- isomers. The proposed *O*-bound enol diazonium ion is in accord with known values for the equilibrium of C- versus O-bound boron enolates, and is predicted to be ~25 kcal/mol lower in energy than the *C*-bound isomers.[32] Loss of dinitrogen affords a resonance stabilized Lewis acid-activated carbene intermediate **B**, which then undergoes a concerted [2+1] cycloaddition reaction with the vinyl group on styrene derivative **2a** and regenerates the Lewis acid catalyst. Intermediates such as **C** have been studied using DFT calculations.[27b] The concerted nature of the cycloaddition reaction is suggested by eq 1 and 2. We hypothesize that the high diastereoselectivity results from steric interference between the styrene aryl group and the bulky tris(pentafluorophenyl)borane, however we cannot rule out favorable π-stacking interactions at this point. Lastly, $B(C_6F_5)_3$ is known to have a Lewis acidity intermediate of BF_3 and BCl_3.[33] We surmise this is an important feature of our catalytic reaction that prevents ring-opening of the cyclopropane products and facilitates catalysts turnover suggested by eq 4.

Scheme 1. Proposed Mechanism for the Transformation



In conclusion, we have shown that aryldiazoacetates can be activated with catalytic amounts of $B(C_6F_5)_3$ to cyclopropanate olefins. The reaction is tolerant of a wide variety of styrene derivatives and diazo compounds with yields comparable to those reported with transition-metal complexes. Further investigations into the mechanism of this transformation, extension of the scope of this transformation to unactivated alkenes, as well as methods for rendering the transformation enantioselective are currently underway.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website.

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Notes

The authors declare no competing financial interests.

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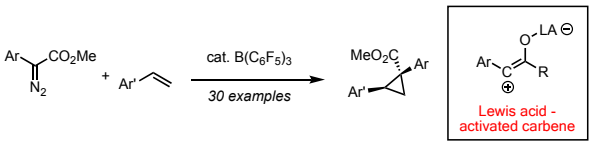
REFERENCES

1. a) Kulinkovich, O. G. *Cyclopropanes in organic synthesis*; Wiley: New Jersey, 2015.; b) Rappoport, Z. *The Chemistry of the Cyclopropyl Group*; Wiley: Chinchester, 1987.; c) Pellissier, H.; Lattanzi, A.; Dalpozzo, R. *Asymmetric synthesis of three-membered rings*; Wiley: Weinheim, 2017.; d) Small Ring Compounds in Organic Synthesis, VI in *Topics in Current Chemistry*; de Meijere, A.; Ed.; Vol. 207; Springer: Berlin, 2000.
2. a) For the use of cyclopropanes as radical clocks, see: Griller, D.; Ingold, K. U. Free-radical clocks. *Acc. Chem. Res.* **1980**, *13*, 317–323.; b) Kumar, D.; de Visser, S. P.; Sharma, P. K.; Cohen, S.; Shaik, S. Radical clock substrates, their C–H hydroxylation mechanism by cytochrome P450, and other reactivity patterns: What Does Theory Reveal about the Clocks' Behavior? *J. Am. Chem. Soc.* **2004**, *126*, 1907–1920.; c) Ortiz de Montellano, P. R.; Substrate oxidation by cytochrome P450 Enzymes. In *Cytochrome p450: Structure, Mechanism, and Biochemistry*, 4th ed.; Ortiz de Montellano, P. R., Ed.; Springer: Switzerland, 2015; Vol. *1*, Ch 4.; d) Ortiz de Montellano, P. R. Hydrocarbon hydroxylation by cytochrome P450 enzymes. *Chem. Rev* **2010**, *110*, 932–948 .
3. a) Boche, G.; Walborsky, H. M. *Cyclopropane Derived Reactive Intermediates*; Rappaport, Z., Ed.; Wiley: New York, 1990.; b) Schneider, T. F.; Kaschel, J.; Werz, D. B. A new golden age for donor-acceptor cyclopropanes. *Angew. Chem. Int. Ed.* **2014**, *53*, 5504–5523.; c) Grover, H. K.; Emmet, M. R.; Kerr, M. A. Carbocycles from donor-acceptor cyclopropanes. *Org. Biomol. Chem.* **2015**, *13*, 655–671.; d) Cavitt, M. A.; Phun, L. H.; France, S. Intramolecular donor-acceptor cyclopropane ring-opening cyclizations. *Chem. Soc. Rev.* **2014**, *43*, 804–818.
4. Talele, T. T. The 'cyclopropyl fragment' is a versatile player that frequently appears in preclinical/clinical drug molecules. *J. Med. Chem.* **2016**, *59*, 8712–8756.
5. a) Rubin, M.; Rubina, M.; Gevorgyan, V. Transition metal chemistry of cyclopropenes and cyclopropanes. *Chem. Rev.* **2007**, *107*, 3117–3179.; b) Chen, Y.; Fields, K. B.; Zhang, X. P. "Bromoporphyrins as Versatile Synthons for Modular construction of chiral porphyrins: Cobalt-catalyzed highly enantioselective and diastereoselective cyclopropanation. *J. Am. Chem. Soc.* **2004**, *126*, 14718–14719.; c) Qin, C.; Boyarskikh, V.; Hansen, J. H.; Hardcastle, K. I.; Musaev, D. G.; Davies, H. M. L. D_2-Symmetric Dirhodium catalysts derived from a 1,2,2,-triarylcyclopropanecarboxylate ligand: Design, Synthesis and application. *J. Am. Chem. Soc.* **2011**, *133*, 47, 19198–19204.
6. Ebner, C.; Carreira, E. M. Cyclopropanation strategies in recent total synthesis. *Chem. Rev.* **2017**, *117*, 11651–11679.; b) Chen, D. Y.-K.; Pouwer, R. H.; Richard, J.-A. Recent advances in the total synthesis of cyclopropane-containing natural products. *Chem. Soc. Rev.* **2012**, *41*, 4631–4642.
7. Thibodeaux, C. J.; Chang, W.; Liu, H. Enzymatic chemistry of cyclopropane, epoxide, and aziridine biosynthesis. *Chem. Rev.* **2012**, *112*, 1681–1709.
8. a) Doyle, M. P.; McKervey, M. A.; Ye, T. *Modern Catalytic Methods for Organic Synthesis with Diazo Compounds: From Cyclopropanes to Ylides.* Wiley: New York, 1998.; b) Diaz-Requejo, M. M.; Perez, P. J. Copper, silver and gold-based cactalyts for carbene addition or insertion reactions. *J. Organomet. Chem.* **2005**, *690*, 5441–5450. c) For Ru-catalyzed reactions, see: Chanthamath, S.; Iwasa, S. Enantioselective cyclopropanation of a wide variety of olefins catalyzed by Ru(II)-phenox complexes. *Acc. Chem. Res*. **2016**, *49*, 2080–2090.; d) Pellissier, H. Recent developments in asymmetric cyclopropanation. *Tetrahedron*, **2008**, *64*, 7041–7095.
9. Lebel, H.; Marcoux, J.-F.; Molinaro, C.; Charette, A. B. Stereoselective cyclopropanation reactions. *Chem. Rev.* **2003**, *103*, 977–1050.
10. Li, A.-H.; Dai, L.-X.; Aggarwal, V. K. Asymmetric ylide reactions: epoxidations, cyclopropanation, aziridination, olefination, and rearrangement. *Chem. Rev.* **1997**, *97*, 2341–2372.; b) Aggarwal, V. K.; Smith, H. W.; Jones, R. V. H.; Fieldhouse, R. Catalytic asymmetric cyclopropanation of electron deficient alkenes mediated by chiral sulfides. *J. Chem. Soc., Chem. Commun.* **1997**, 1785–1786.; c) Aggarwal, V. K.; Alonso, E.; Fang, G.; Ferrara, M.; Hynd, G.; Porcelloni, M. Application of chiral sulfides to catalytic asymmetric aziridination and cyclopropanation with in situ generation of the diazo compound. *Angew. Chem. Int. Ed.* **2001**, *41*, 1430–1433.
11. Papageorgiou, C. D.; de Dios, M. A. C.; Ley, S. V.; Gaunt, M. J. Enantioselective organocatalytic cyclopropane via ammonium ylides. *Angew. Chem. Int. Ed.* **2004**, *43*, 4641–4644.
12. Liao, W.-W.; Li, K.; Tang, Y. Controllable diastereoselective cyclopropanation. Enantioselective synthesis of vinylcyclopropanes via chiral telluronium ylides *J. Am. Chem. Soc.* **2003**, *125*, 13030–13031.
13. For the activation of α-hydroxydiazo compounds using Lewis acids to ionize pendant hydroxyl groups, see: a) Pellicciari, R.; Natalini, B., Sadeghpour, B. M., Marinozzi, M., Snyder, J. P., Williamson, B. L., Kuethe, J. T., Padwa, A. The reaction of α-diazo-β-hydroxy esters with boron trifluoride etherate: generation and rearrangement of destabilized vinyl cations. A detailed experimental and theoretical study. *J. Am. Chem. Soc.* **1996**, *118*, 1–12.; b) Draghici, C., Brewer, M. Lewis acid promoted carbon-carbon bond cleavage of γ-silyloxy-β-hydroxy-α-diazoesters. *J. Am. Chem. Soc*. **2008**, *130*, 3766–3767.; c) Bayir, A., Brewer, M. Fragmentation of bicyclic γ-silyloxy-β-hydroxy-α-diazolactones as an approach to ynolides *J. Org. Chem*. **2014**, *79*, 6037–6046.; d) Cleary, S., Hensinger, M., Brewer, M. Remote C–H insertion of vinyl cations leading to cyclopentenones. *Chem. Sci.* **2017**, *8*, 6810-6814.; e) Fang, J., Brewer, M. Intramolecular vinylation of aryl rings by vinyl cations *Org. Lett.* **2018**, *20*, 7384–7387.; f) Hensinger, M.J., Dodge, N.J., Brewer, M. Substituted α-alkylidene cyclopentenones via the intramolecular reaction of vinyl cations with alkenes. *Org. Lett*. **2020**, *22*, 497–500.
14. For reviews on the reactivity of diazocarbonyl compounds with acids, see; Smith, III., A. B., Dieter, R. K. The acid promoted decomposition of α-diazoketones. *Tetrahedron* **1981**, *37*, 2407–2439.

15. Dumitrescu, L.; Azzouzi-Zriba, K.; Bonnet-Deplon, D.; Crousse, B. Non-metal catalyzed insertion reactions of diazocarbonyls to acid derivatives in fluorinated alcohols. *Org. Lett.* **2011**, *13*, 692–695.
16. Bott, K. Alkenediazonium salts: A new chapter of classical organic chemistry. *Angew. Chem. Int. Ed. Engl.* **1979**, *18*, 259–265.
17. a) For X-ray crystallographic studies, see: Tang, C.; Liang, Q.; Jupp, A. R.; Johnstone, T. C.; Neu, R. C.; Song, D.; Grimme, S.; Stephan, D. W. 1,1-Hydroboration and a boron adduct of diphenyldiazomethane: A Potential prelude to FLP-N_2 chemistry.*Angew. Chem. Int. Ed.* **2017**, *129*, 16815–16819.; b) Neu, R. C.; Jiang, C.; Stephan, D. W. Bulky derivatives of boranes, boronic acids and boronate esters via reaction with diazomethanes. *Dalton Trans.* **2013**, *42*, 726–736.
18. a) For reviews, see: Miller, D. J.; Moody, C. J. Synthetic applications of the O–H insertion reactions of carbenes and carbenoids derived from diazocarbonyl and related diazo compounds. *Tetrahedron*, **1995**, *51*, 10811–10843.; b) Gillingham, D.; Fei, N.; Catalytic X–H insertion reactions based on carbenoids. *Chem. Soc. Rev.* **2013**, *42*, 4918–4931.; c) Marshall, E. R.; Kuck, J. A.; Elderfield, R. C. Studies on lactones related to the cardiac aglycones X. Synthesis of simple hydroxylated β-substituted $\Delta^{\alpha,\beta}$-butenoldies. *J. Org. Chem.* **1942**, *7*, 444–456.; d) Bose, A. K.; Yates, P. The conversion of α-diazo-*o*-methoxyacetophenone to coumaranone. *J. Am. Chem. Soc.* **1952**, *74*, 4703–4704.
19. Doyle, M. P., Buhro, W.E., Davidson, J. G., Elliot, R. C., Hoekstra, J. W., Oppenhuizen, M. Lewis acid promoted reactions of diazocarbonyl compounds. 3. Synthesis of oxazoles from nitriles through intermediate β-imidatoalkenediazonium salts. *J. Org. Chem.* **1980**, *45*, 3657–3664.
20. a) Hutt, O. E.; Mander, L. N.; Willis, A. C. Ring fragmentation process resulting from acid catalyzed diazo ketone cyclisations. *Tetrahedron Lett.* **2005**, *46*, 4569–4572.; b) Morris, J. C.; Mander, L. N.; Hockless, D. C. R. Norcaradienes from the intramolecular cyclopropanation reactions of diazomethyl ketones. Valuable intermediates for the synthesis of polycyclic diterpenes. *Synthesis* **1998**, 455–467.; c) Beames, D. J.; Mander, L. N. Studies on intramolecular alkylation I: the preparation of tricyclic intermediates for the synthesis of diterpene alkaloids. *Aust. J. Chem.* **1971**, *24*, 343–351.; d) Mander, L. N.; Pyne, S. G. A New Strategy for Gibberillin Synthesis. *J. Am. Chem. Soc.* **1979**, *101*, 3373–3375.; d) Pour, M.; King, G. R.; Monck, N. J. T.; Morris, J. C.; Zhang, H.; Mander, L. N. Synthetic and structural studies of novel gibberellins. *Pure and App. Chem.* **1998**, *70*, 351–354.
21. a) Smith III, A. B., Toder, B. H., Branca, S. J., Dieter, R. K. Lewis acid promoted decomposition of unsaturated α-diazo ketones. 1. An Efficient approach to simple annulated cyclopentenones. *J. Am. Chem. Soc.* **1981**, *103*, 1996–2008. (b) Smith III, A.B., Dieter, R. K. Lewis acid promoted decomposition of unsaturated α-diazoketones. 2. A new initiator for polyolefinic cationic cyclization. *J. Am. Chem. Soc.* **1981**, *103*, 2009-2016. (c) Smith III, A.B., Dieter, R. K. Lewis acid promoted decomposition of unsaturated a-diazoketones. 3. Stereochemical consequences of polyolefinic cyclizations initiated by the α-diazoketone functionality *J. Am. Chem. Soc.* **1981**, *103*, 2017-2022.
22. Shim, S. Y.; Ryu, D. H. Enantioselective carbonyl 1,2- or 1,4-addition reactions of nucleophilic silyl and diazo compounds catalyzed by the chiral oxazaborolidinium ion. *Acc. Chem. Res.* **2019**, *52*, 2349–2360.
23. Dasgupta, A.; Bambaahmadi, R.; Slater, B.; Yates, B. F.; Ariafard, A.; Melen, R. L. *Chem.* **2020**, doi.org/10.1016/j.chempr.2020.06.035.
24. Doyle, M. P.; Zheng, H.; Dong, K.; Wherritt, D.; Arman, H. Brønsted acid catalyzed Friedel–Crafts-type coupling and dedinitrogenation reactions of vinyl diazo compounds *Angew. Chem. Int. Ed.* **2020**, 59, 1–6.
25. a) So, S. S.; Mattson, A. E. Urea activation of α-nitrodiazoesters: an organocatalytic approach to N–H insertion reactions *J. Am. Chem. Soc.* **2012**, *134*, 8798–8801.; b) Auvil, T. J.; So, S. S.; Mattson, A. E. Double arylation of nitrodiazoesters via a transient N–H insertion organocascade. *Angew. Chem. Int. Ed.* **2013**, *52*, 11317–11320.; c) So, S. S.; Mattson, A. E. Enantioselective N–H insertion/Arylation reactions of nitrodiazoesters. *Asian J. Org. Chem.* **2014**, *3*, 425–428.; d) So. S. S.; Oottikkal, S.; Badjic, J.; Hadad, C. M.; Mattson, A. E. Urea-catalyzed N–H insertion-arylation reactions of nitrodiazoesters. *J. Org. Chem.* **2014**, *20*, 8283–8287. e) Fisher, T. J.; Mattson, A. E. Synthesis of α-peroxyesters via organocatalyzed O–H insertion of hydroperoxides and aryl diazoesters. *Org. Lett.* **2014**, *20*, 5316–5319.
26. Zhai, C.; Xing, D.; Jun Zhou, C. J.; Wang, C.; Wang, D.; Hu, W. Facile synthesis of 3-aryloxindoles via Brønsted acid catalyzed Friedel-Crafts Alkylation of Electron-Rich Arenes with 3-Diazooxindoles. *Org Lett.* **2014**, *16*, 2934–2937.
27. a) Yu, Z.; Li, Y.; Shi, J.; Ma, B.; Liu, L.; Zhang, J. $(C_6F_5)_3B$ catalyzed chemoselective and *ortho*-selective substitution of phenols with α-aryl α-diazoesters. *Angew. Chem. Int. Ed.* **2016**, *55*, 14807–14811.; b) For computational studies, see: Zhang, Q.; Zhang, X.-F.; Li, M.; Li, C.; Liu, J.-Q.; Jiang, Y.-Y.; Ji, X.; Liu, L.; Wu, Y.-C. Mechanistic insights into the chemo- and regioselective $B(C_6F_5)_3$ catalyzed C–H functionalization of phenols with diazoesters. *J. Org. Chem.* **2019**, *84*, 14508–14519.
28. San, H. H.; Wang, S.-J.; Jian, M.; Tang, W.-Y. Boron-Catalyzed O–H Insertion of α-Aryl α-Diazo Esters in Water. *Org. Lett.* **2018**, *20*, 4672–4676.
29. See the Supporting Information for further details.
30. Ovalles, S. R.; Hansen, J. H.; Davies, H. M. L. Thermally Induced Cycloadditions of Donor/Acceptor Carbenes. *Org. Lett.* **2011**, *13*, 4284–4287.; b) Tortoreto, C.; Rackl, D.; Davies, H. M. L. Metal-Free C–H Functionalization of Alkanes by Aryldiazoacetates. *Org. Lett.* **2017**, *19*, 770–773. c) Hansen, S.; Spangler, J. E.; Hansen, J.; Davies, H. M. L. Metal-Free N–H insertions of donor/acceptor carbenes. *Org. Lett.* **2012**, *14*, 4626–4629.
31. Thompson, J. L.; Davies, H. M. L. Enhancement of cyclopropanation chemistry in the silver-catalyzed reactions of aryldiazo acetates. *J. Am. Chem. Soc.* **2007**, *129*, 6090–6091.
32. For a review, see: He, Z.; Kajdlik, A.; Yudin, A. K. α-Borylcarbonyl compounds: from transient intermediates to robust building blocks. *Dalton. Trans.* **2014**, *43*, 11434–11451.; b) Despite this, a C-bound intermediate has been proposed for a related transformation: see, Rao, S.; Kapanaiah, R.; Prabhu, K. R. Boron-catalyzed C–C functionalization of allylic alcohols. *Adv. Synth. Catal.* **2019**, *361*, 1301–1306.
33. a) Beckett, M. A.; Brassington, D. S.; Coles, S. J.; Hursthouse, M. B. Lewis acidity of tris(pentafluorophenyl)borane: crystal and molecular structure of $B(C_6F_3)_3$•$OPEt_3$. *Inorg. Chem. Commun.* **2000**, *3*, 530–533.; b) Jacobsen, H.; Berke, H.; Doring, S.; Kehr, G.; Erker, G.; Frohlich, R.; Meyer, O. Lewis acid properties of Tris(pentafluorophenyl)borane. Structure and bonding in L-$B(C_6F_5)_3$ complexes *Organometallics* **1999**, *18*, 1724–1735.

TOC Graphic.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