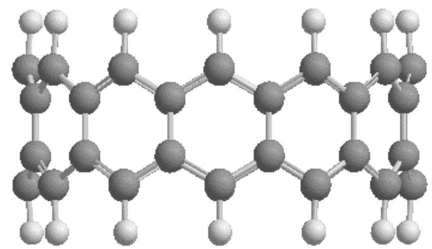
Studies into the Synthesis of [12]Cyclacene



Zhuoran Zhang
Douglas Research Group

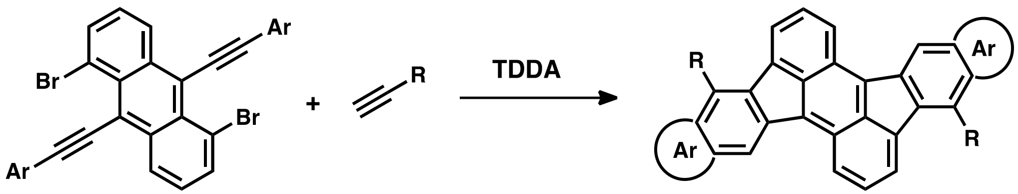
Graduate Student Research Symposium

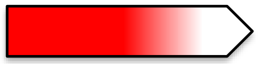
06/07/2016

Research Projects

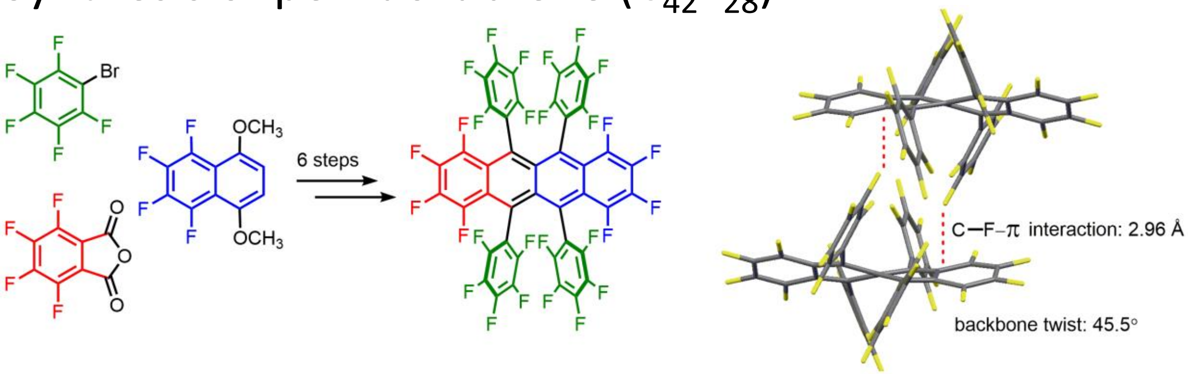
Completeness

I. Synthesis of dibenzorubicenes



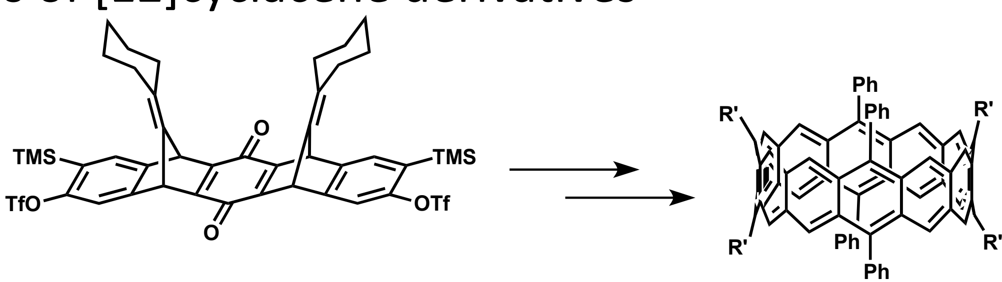


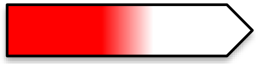
II. Synthesis of perfluorubrene ($C_{42}F_{28}$)



Zhuoran Zhang, William A. Ogden, Victor Young, Jr. and Christopher J. Douglas
Chem. Commun. 2016, Accepted Manuscript, DOI: 10.1039/C6CC03259A

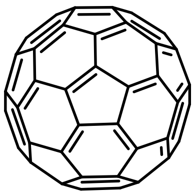
III. Synthesis of [12]cyclacene derivatives



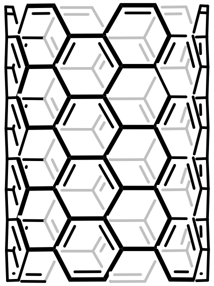


Interesting Theoretical Molecules

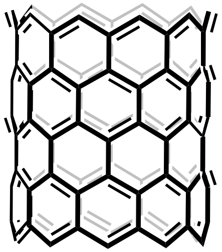
- Fullerenes and carbon nanotubes



C_{60}



Armchair CNT

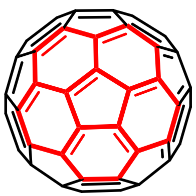


Zig-zag CNT

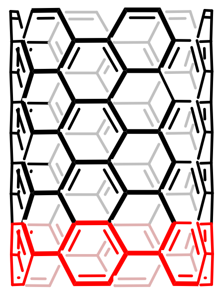
❖ Sphere vs tube
❖ Materials science applications
❖ Curved conjugation

Interesting Theoretical Molecules

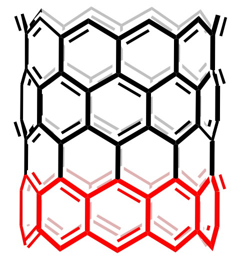
- Fullerenes and carbon nanotubes



C_{60}



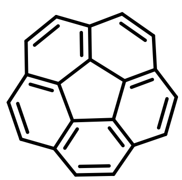
Armchair CNT



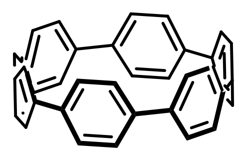
Zig-zag CNT

❖ Sphere vs tube
❖ Materials science applications
❖ Curved conjugation

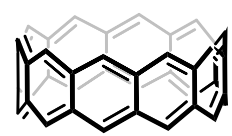
- Fragment structures: buckybowls and molecular belts



Corannulene



Cycloparaphenylene
CPP



Cyclacene

❖ Curved *aromatic* surface
❖ Unique electronics
❖ Host-guest chemistry

❖ Template synthesis for C_{60} or CNT
❖ *Finite* model for property studies
❖ *Support or refine* chemical theories

Syntheses of [n]CPPs: A Recent Accomplishment

- *Challenge*: cyclic structure & ring strain
- *Strategy*: sequentially build up strain

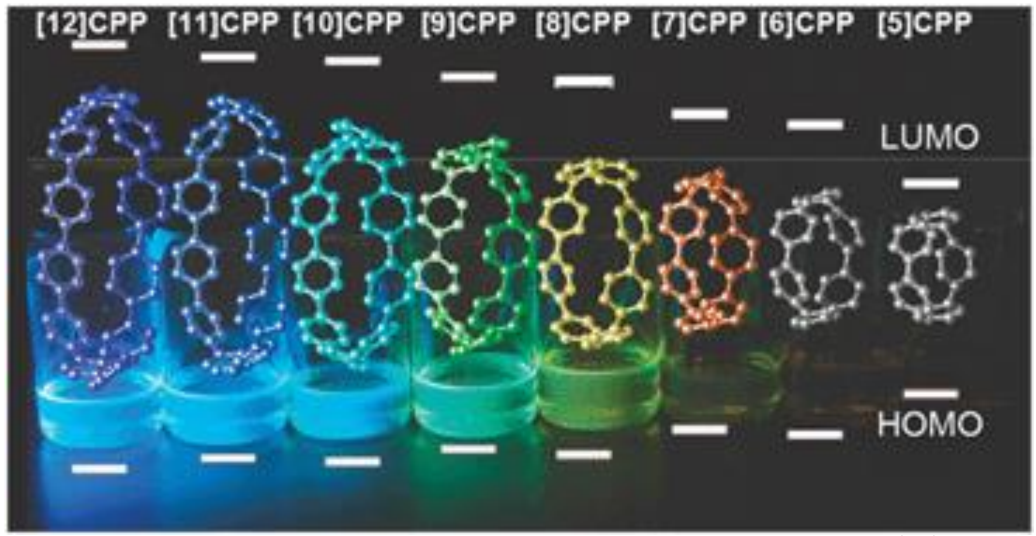
Curved precursor

↓

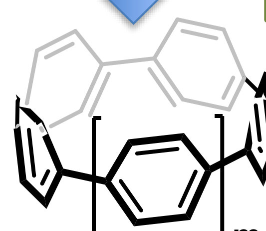
Macrocycle

↓

End-game (aromatization)



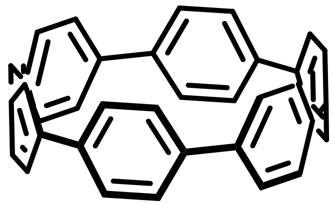
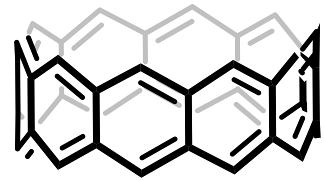
↓ Reductive aromatization

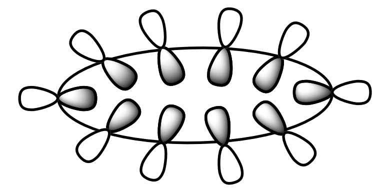


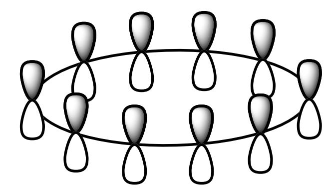
m = 5, 8, 14

Darzi, E. R.; Jasti, R. *Chem. Soc. Rev.*, **2015**, *44*, 6401-6410.
Jasti, R.; Bhattacharjee, J.; Neaton, J. B.; Bertozzi, C. R. *J. Am. Chem. Soc.* **2008**, *130*, 17646-17647.

Cyclacene vs. CPP — A More Challenging Target?

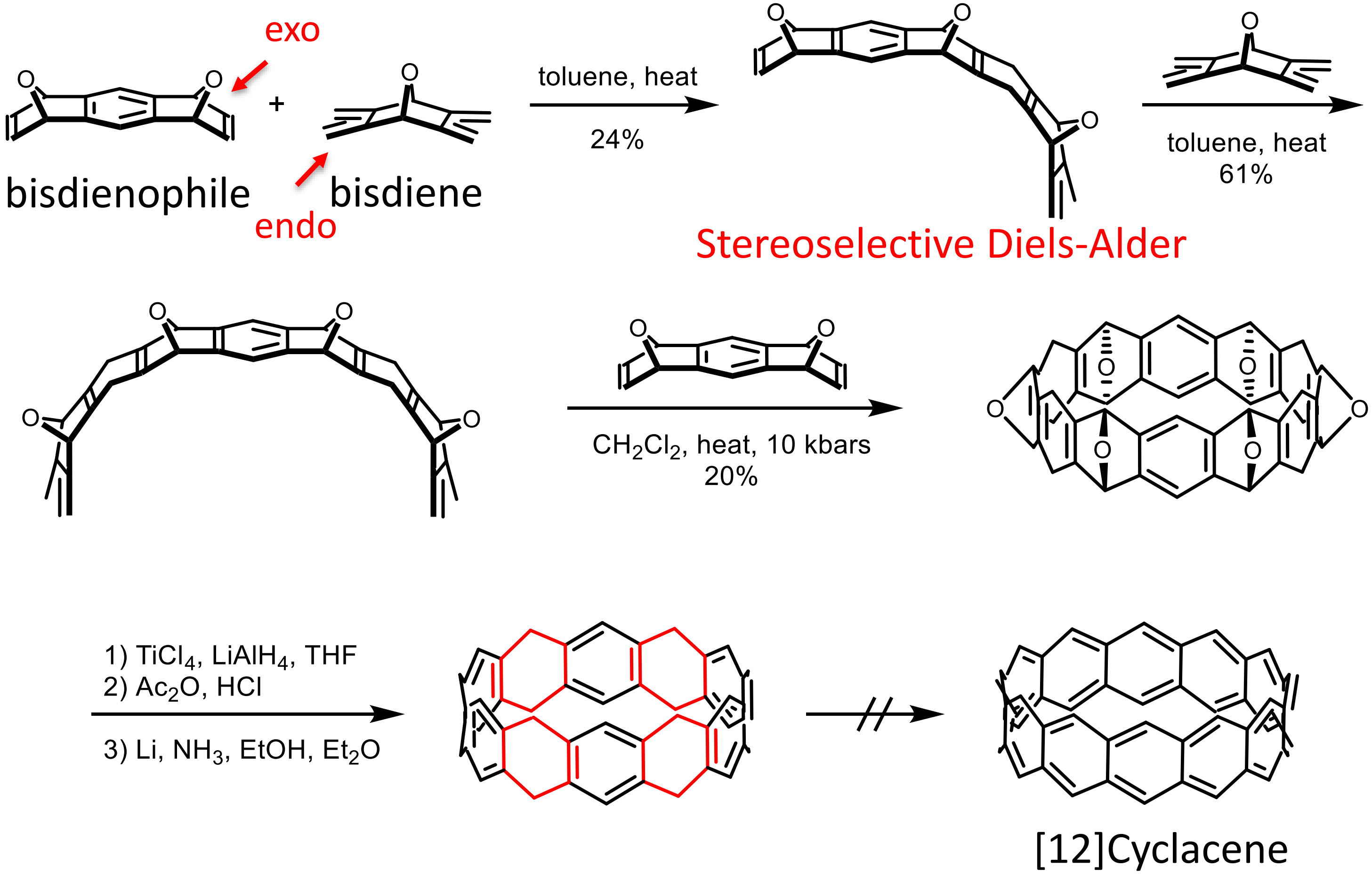
	[n]CPP 	[n]Cyclacene 
Shape	Molecular hoops with radially oriented p orbitals	
Cavity	Yes	Yes
Structure unit	linear phenylene	linear benzenoid
π Electrons	4n or 4n+2	4n
Electronic property	Armchair CNT *metallic*	Zig-zag CNT *Semiconductive*
Known Synthesis	Yes	No





Synthetic precedence to [n]Cyclacene derivatives

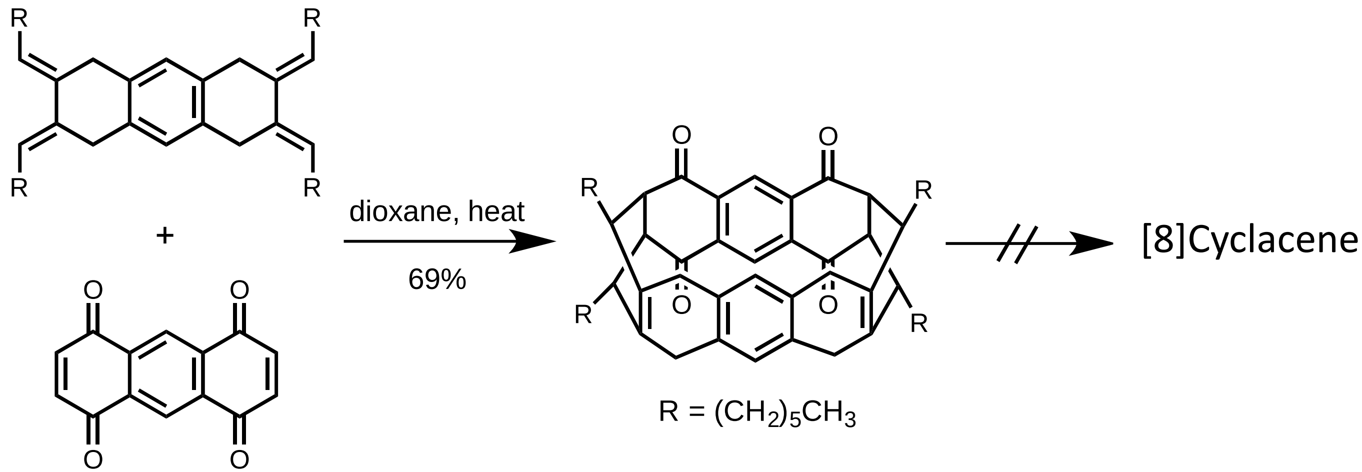
- The Stoddart approach



Kohnke, F. H.; Slawin, A. M. Z.; Stoddart, J. F.; Williams, D. J. *Angew. Chem. Int. Ed.* **1987**, *26*, 892-894.
Ashton, P. R. et al. *J. Am. Chem. Soc.* **1992**, *114*, 6330-6353.

Synthesis Precedence to [n]Cyclacene Derivatives

- Cory's approach to [8]cyclacene



Cory, R. M.; McPhail, C. L.; Dikmans, A. J.; Vittal, J. J. *Tetrahedron Lett.* **1996**, *37*, 1983-1986.

The Strategy for Macrocycle Synthesis

Strategy

Curved precursor

↓ Stereoselective Diels–Alder reaction

Macrocycle

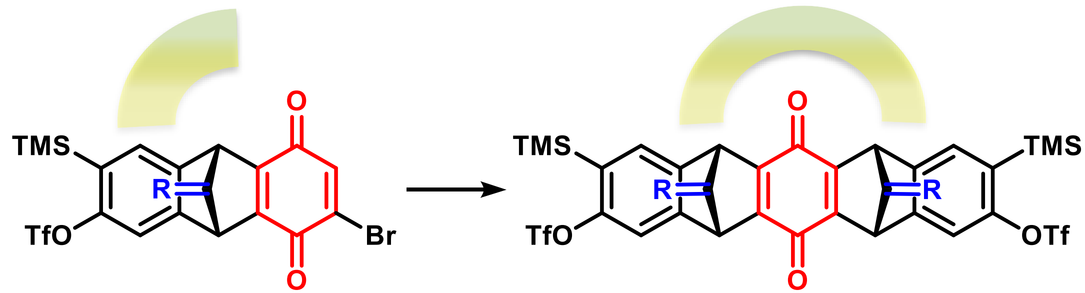
↓ dehydrogenation/oxidation
quinone functionalization
decarbonylation

End-game
(Aromatization)

The Strategy for Macrocycle Synthesis– The Douglas Approach

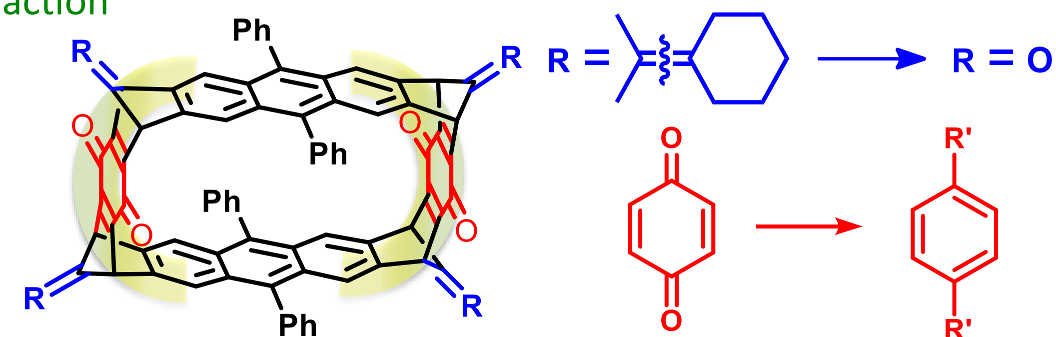
Strategy

Curved precursor



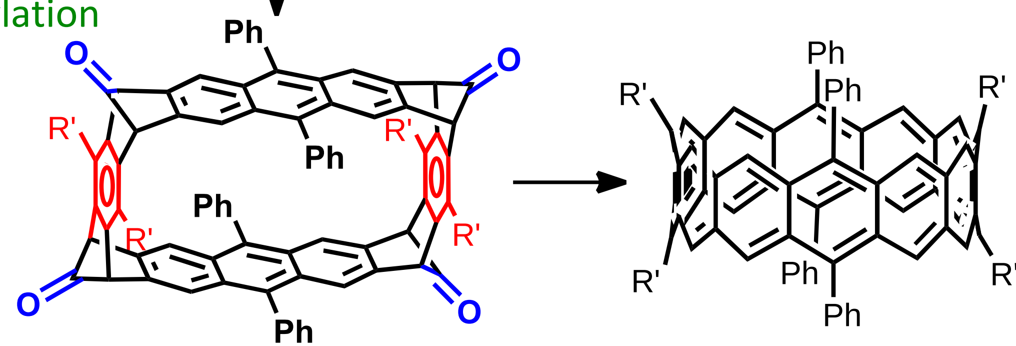
Stereoselective
Diels–Alder reaction

Macrocycle



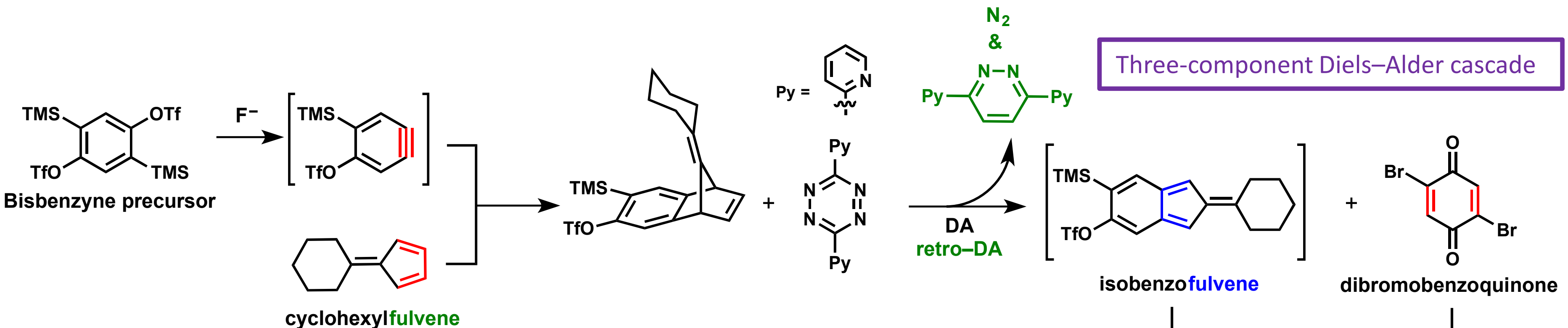
dehydrogenation/oxidation
quinone functionalization
decarbonylation

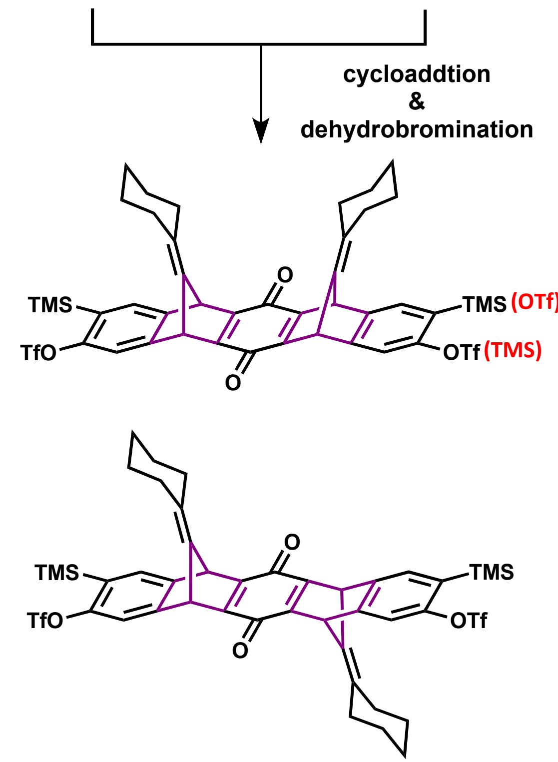
End-game
(Aromatization)

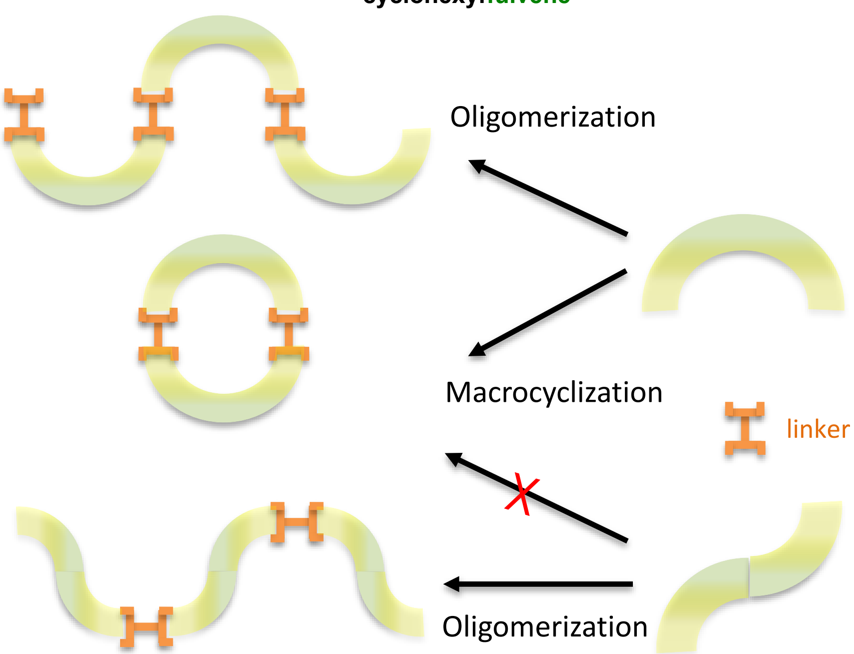


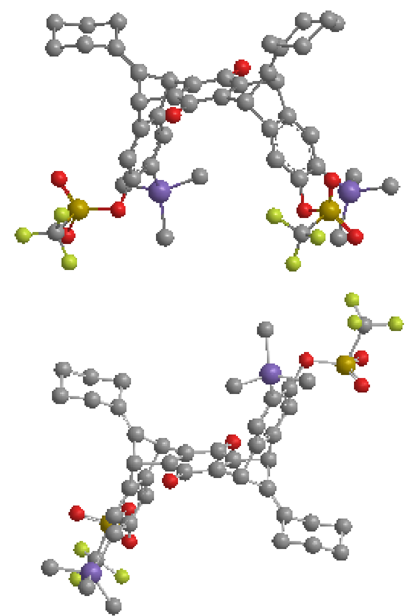
Proposed Synthesis and Predicted Challenges

- Challenge I: Stereoselective synthesis of cyclization precursor (half cycle)



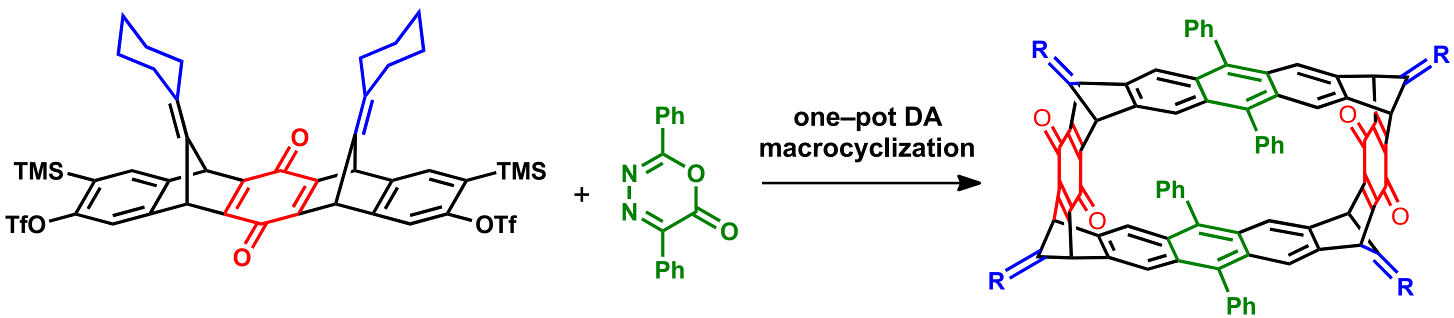




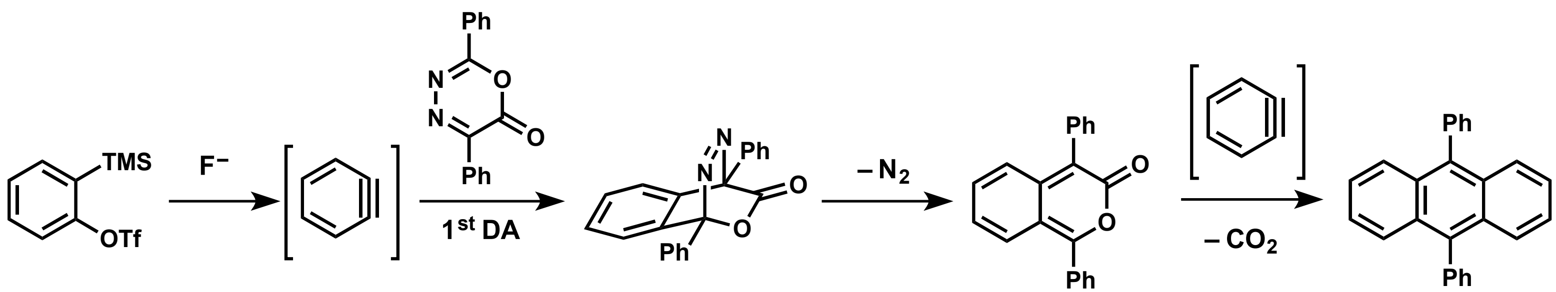


Proposed Synthesis and Predicted Challenges

- Challenge II: macrocyclization and late-stage functionalization



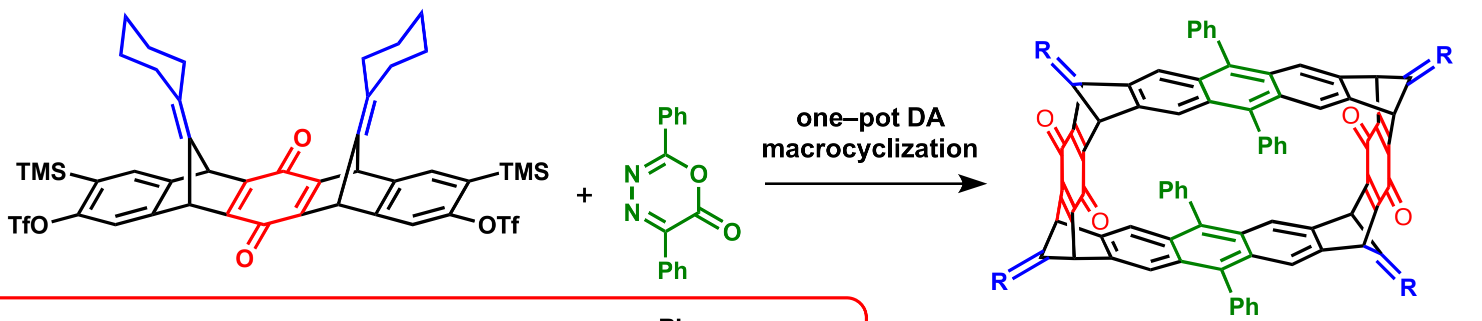
Literature precedence

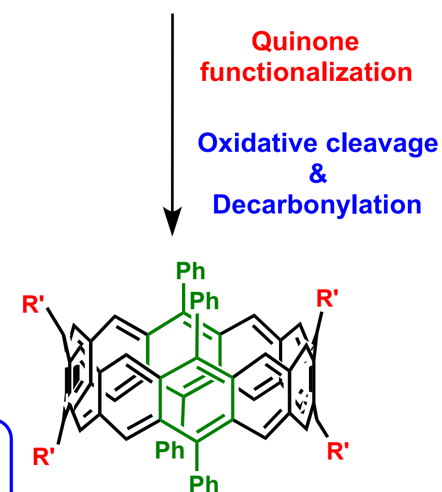


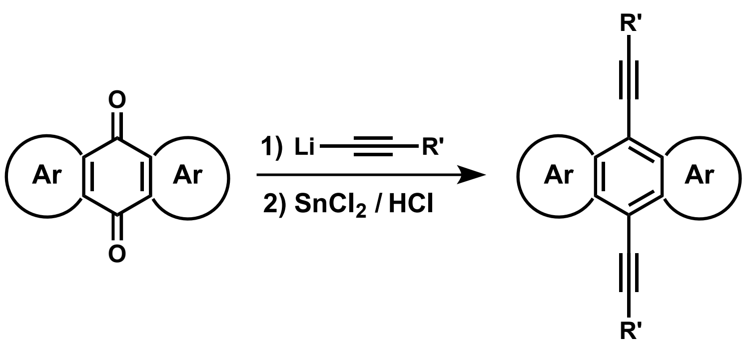
Steglich, W.; Buschmann, E.; Gansen, G.; Wilschowitz, L. *Synthesis* **1977**, 1977(*4)*, 252-253.

Proposed Synthesis and Predicted Challenges

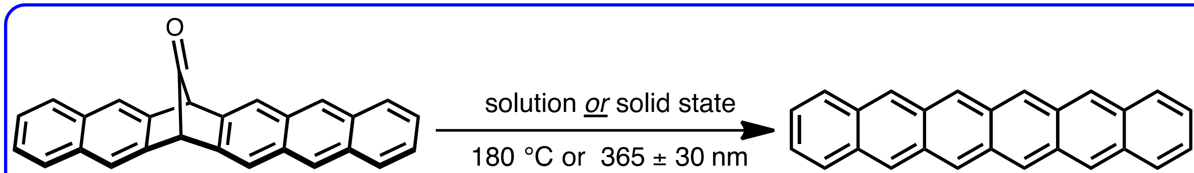
➢ Challenge II: macrocyclization and late-stage functionalization







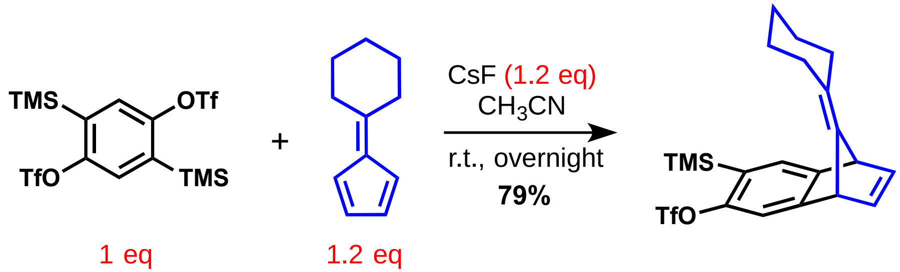
Anthony, J. E.; Eaton, D. L.; Parkin, S. R. *Org. Lett.* **2002**, *4(1)*, 15-18.

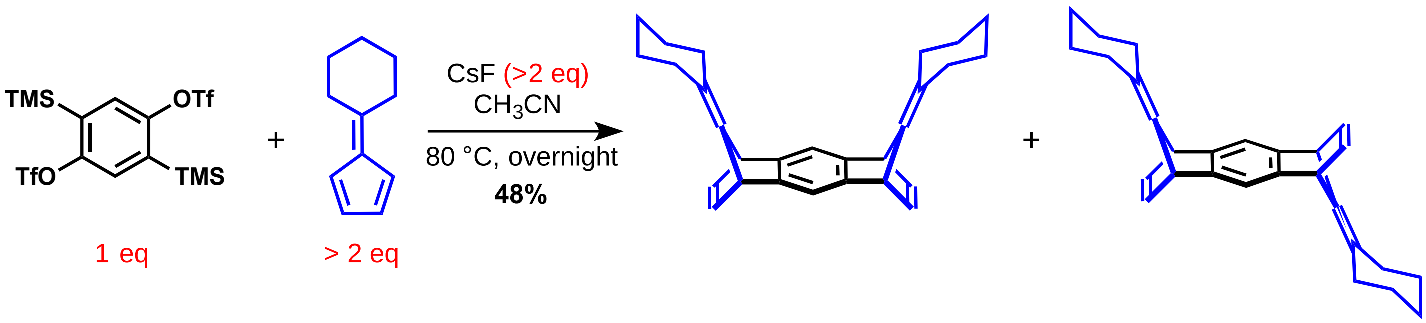


Watanabe, M. et al. *Nat. Chem.* **2012**, *4*, 574-578.

Synthesis of Mono-bridged Precursor (1/4 cycle)

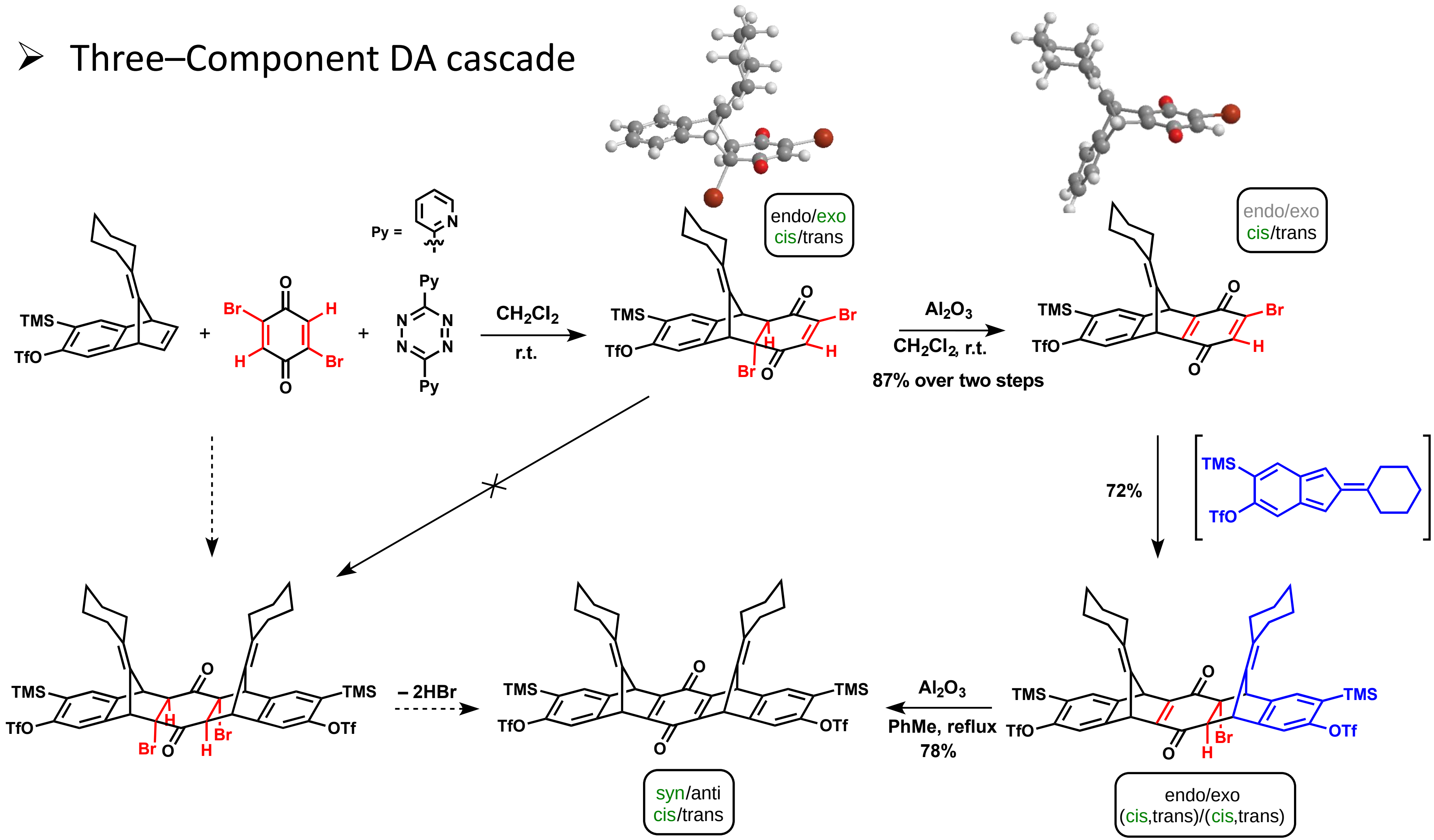
- Controlled benzyne Diels–Alder reaction





Synthesis Attempts toward Syn-isomer

➢ Three–Component DA cascade



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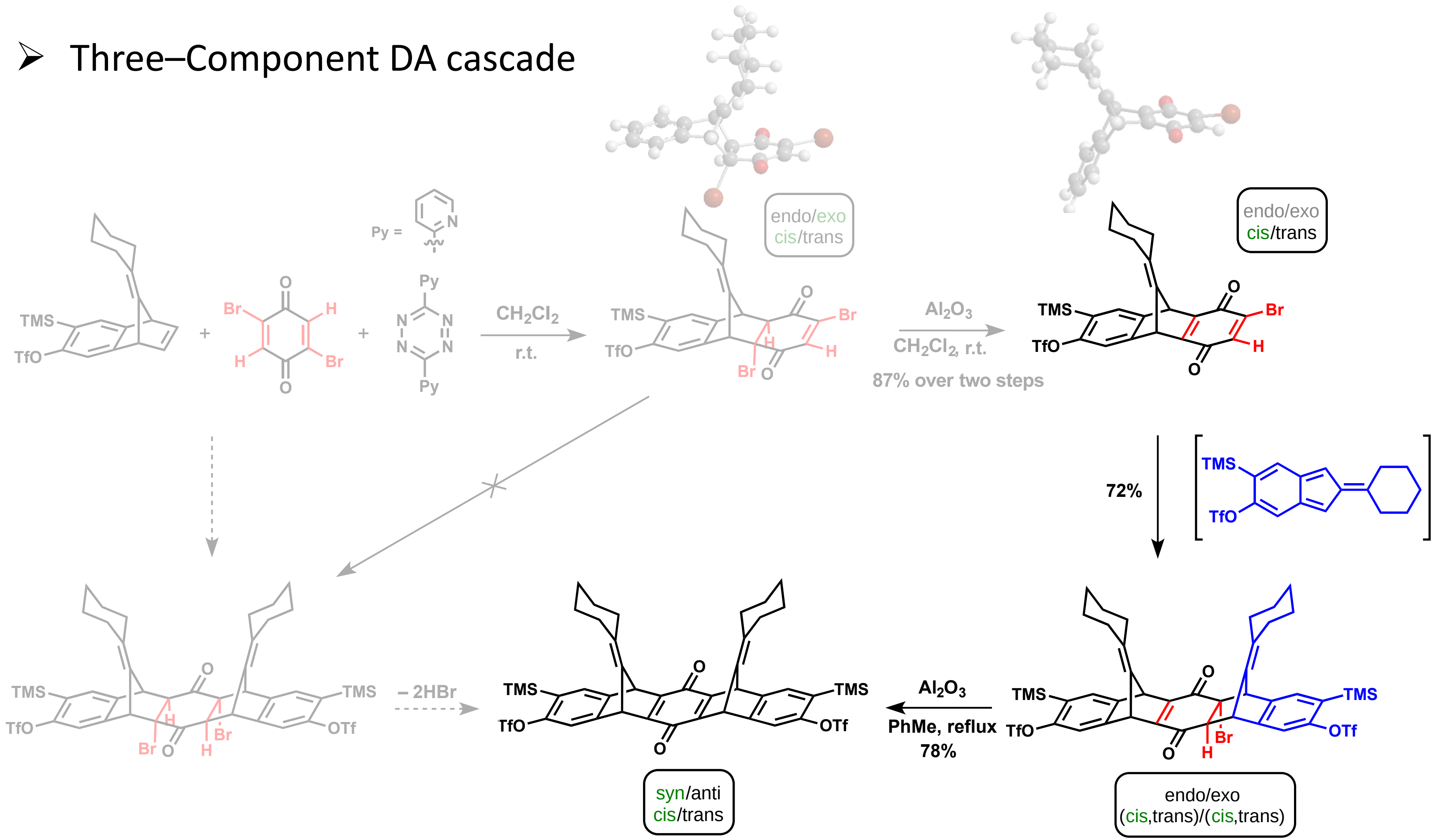
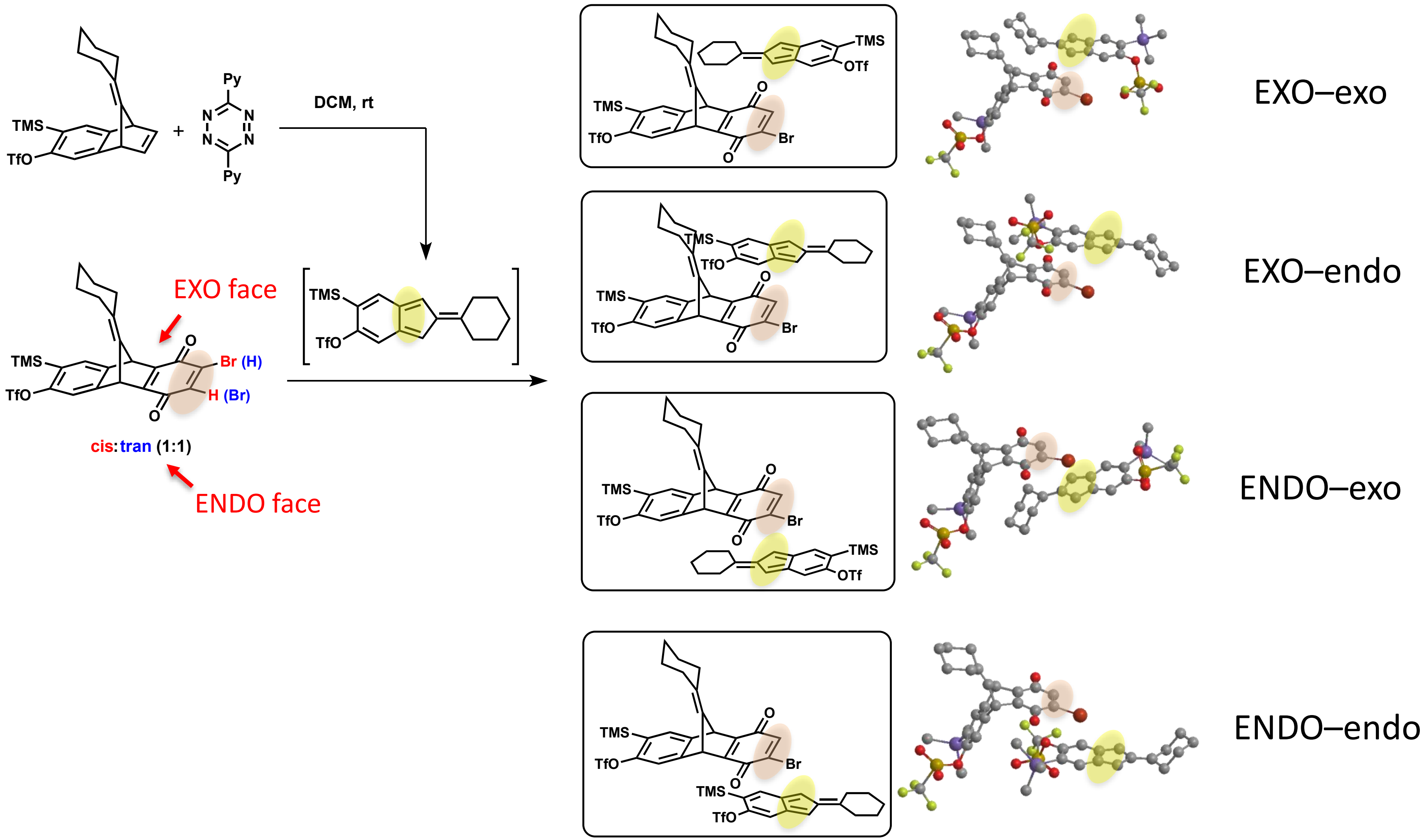


Steric Analysis

- Stereoselective Diels–Alder reactions — "*EXO–exo* selectivity"



Steric Analysis

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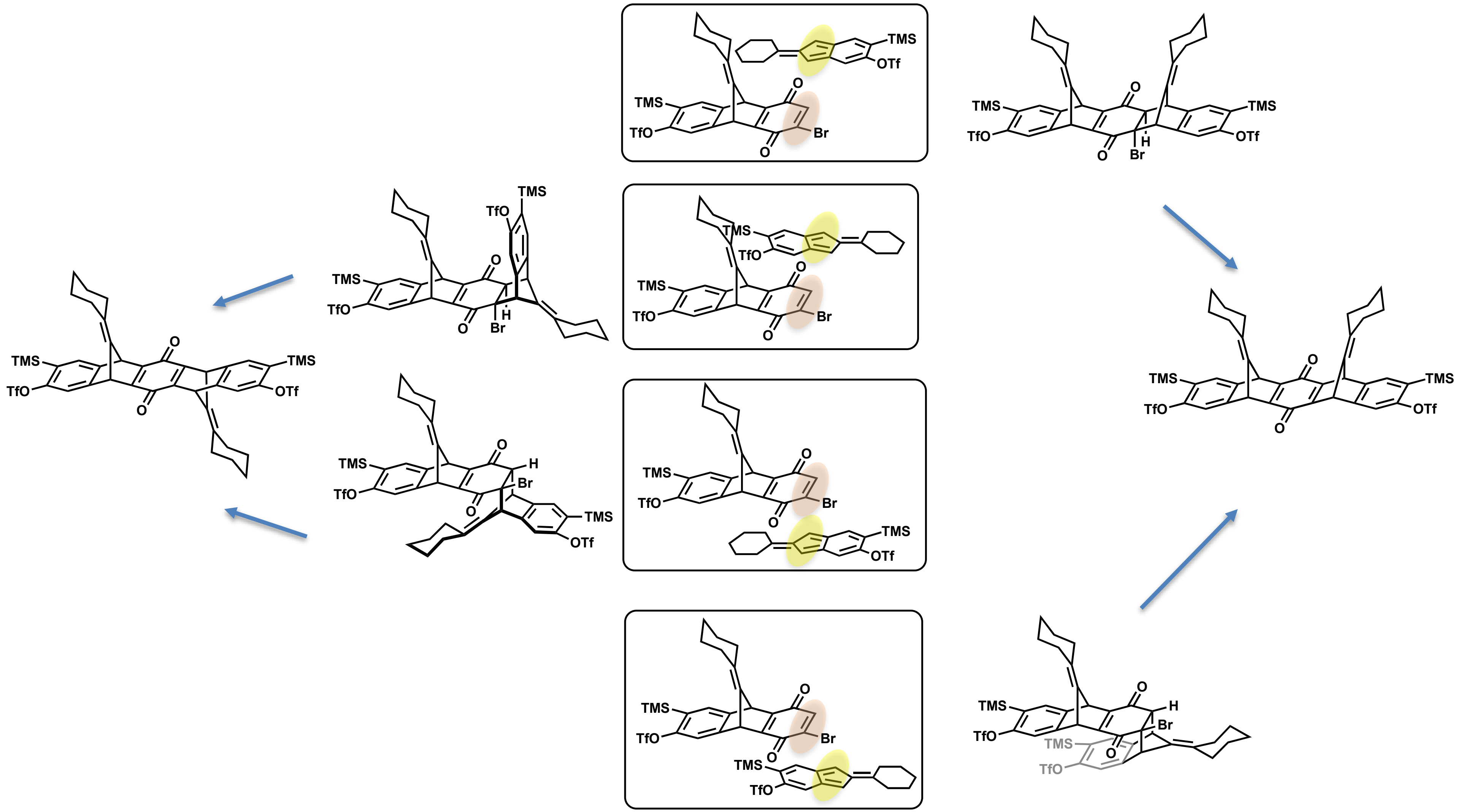
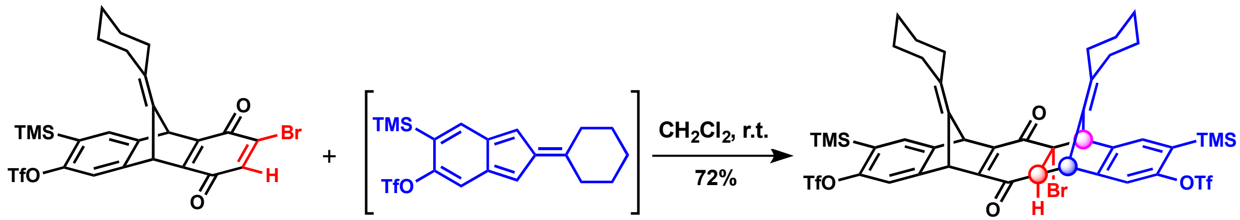
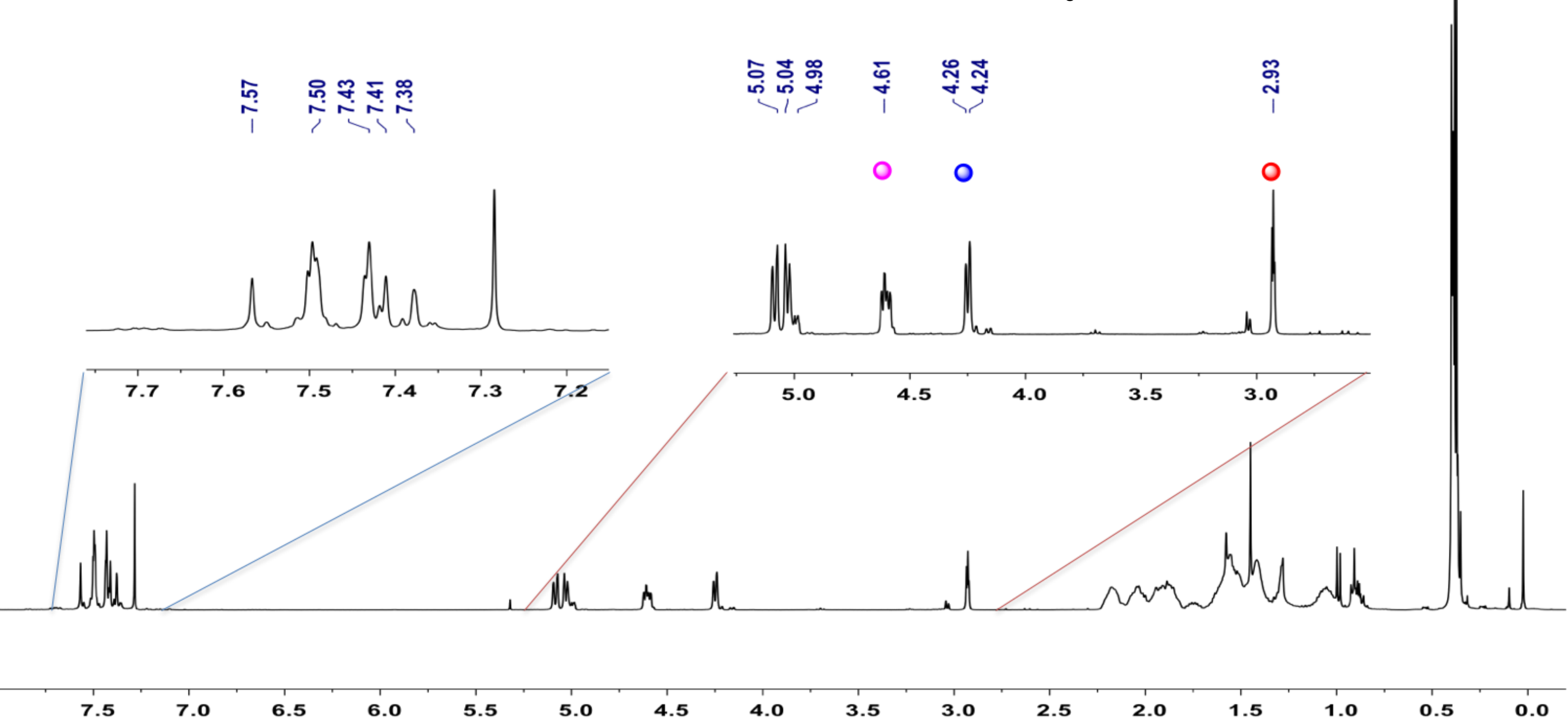


Stereoselective Diels–Alder Reaction

➢ Stereoselectivity observed in [1]H–NMR spectrum!

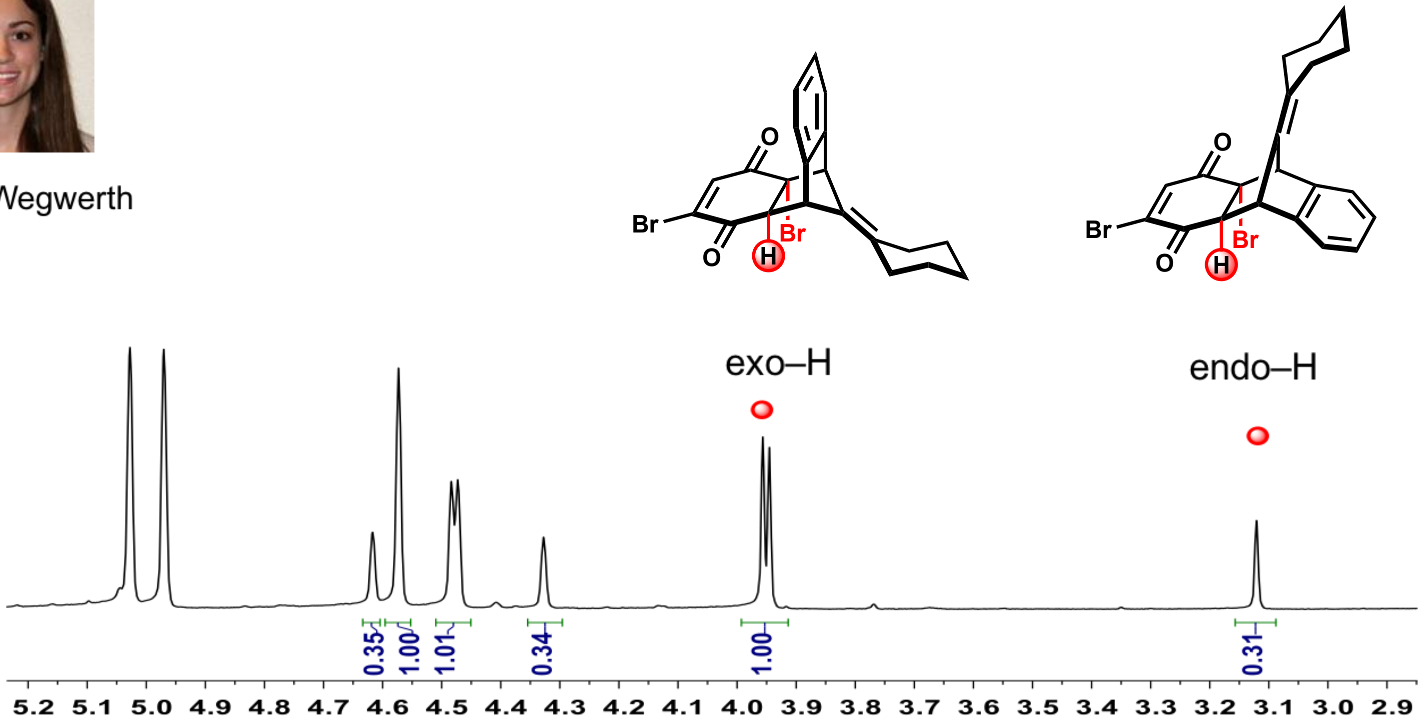




Stereoselective Diels–Alder Reaction

- Model study

Sarah Wegwerth



Stereoselective Diels–Alder Reaction

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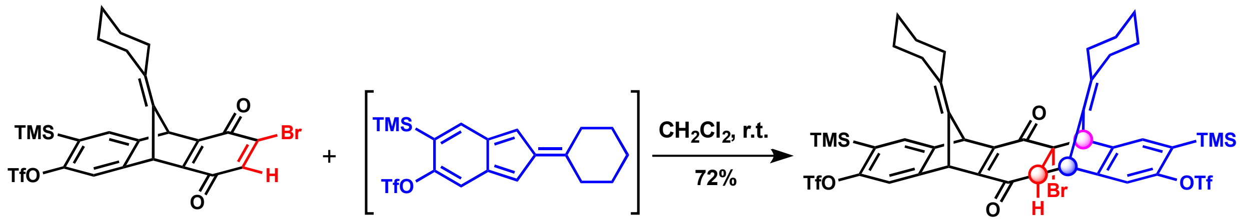
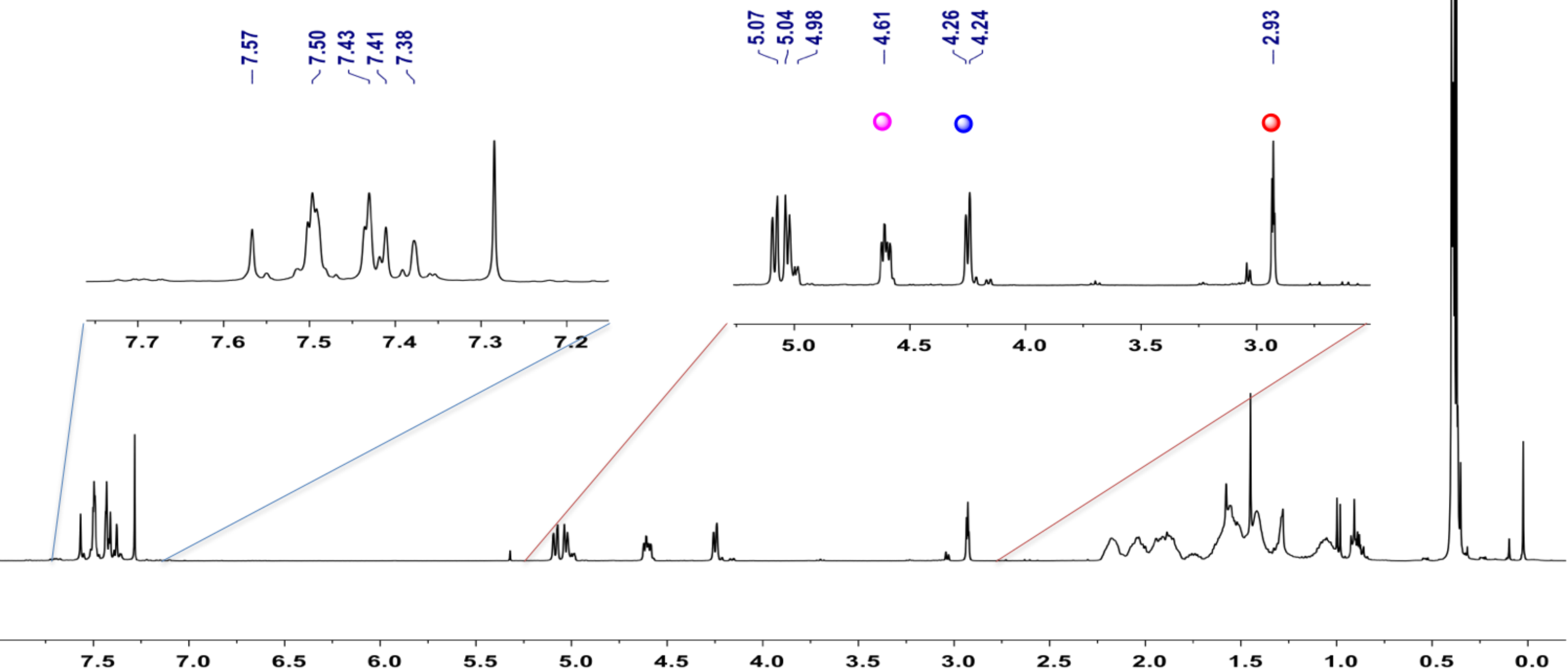
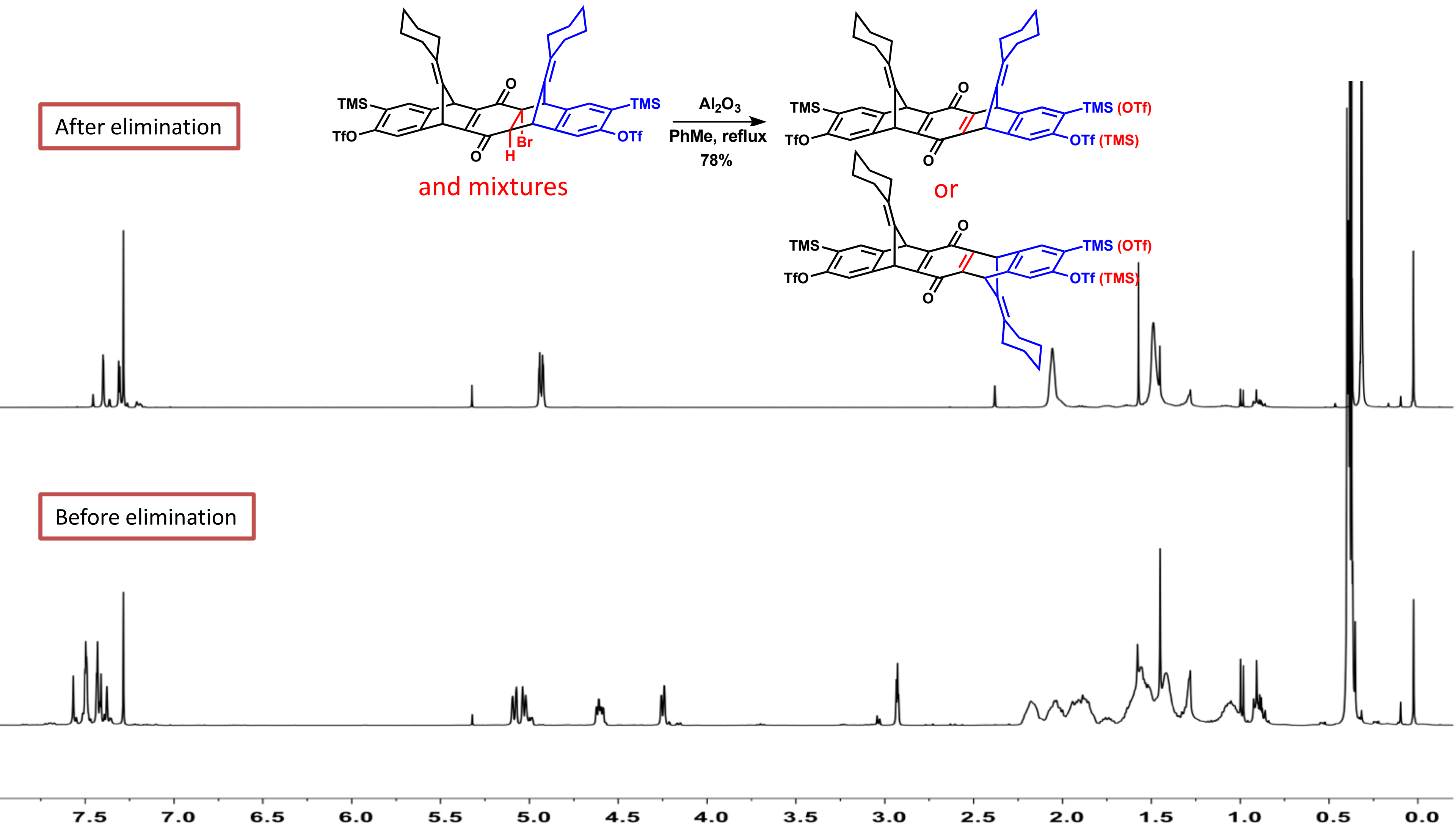




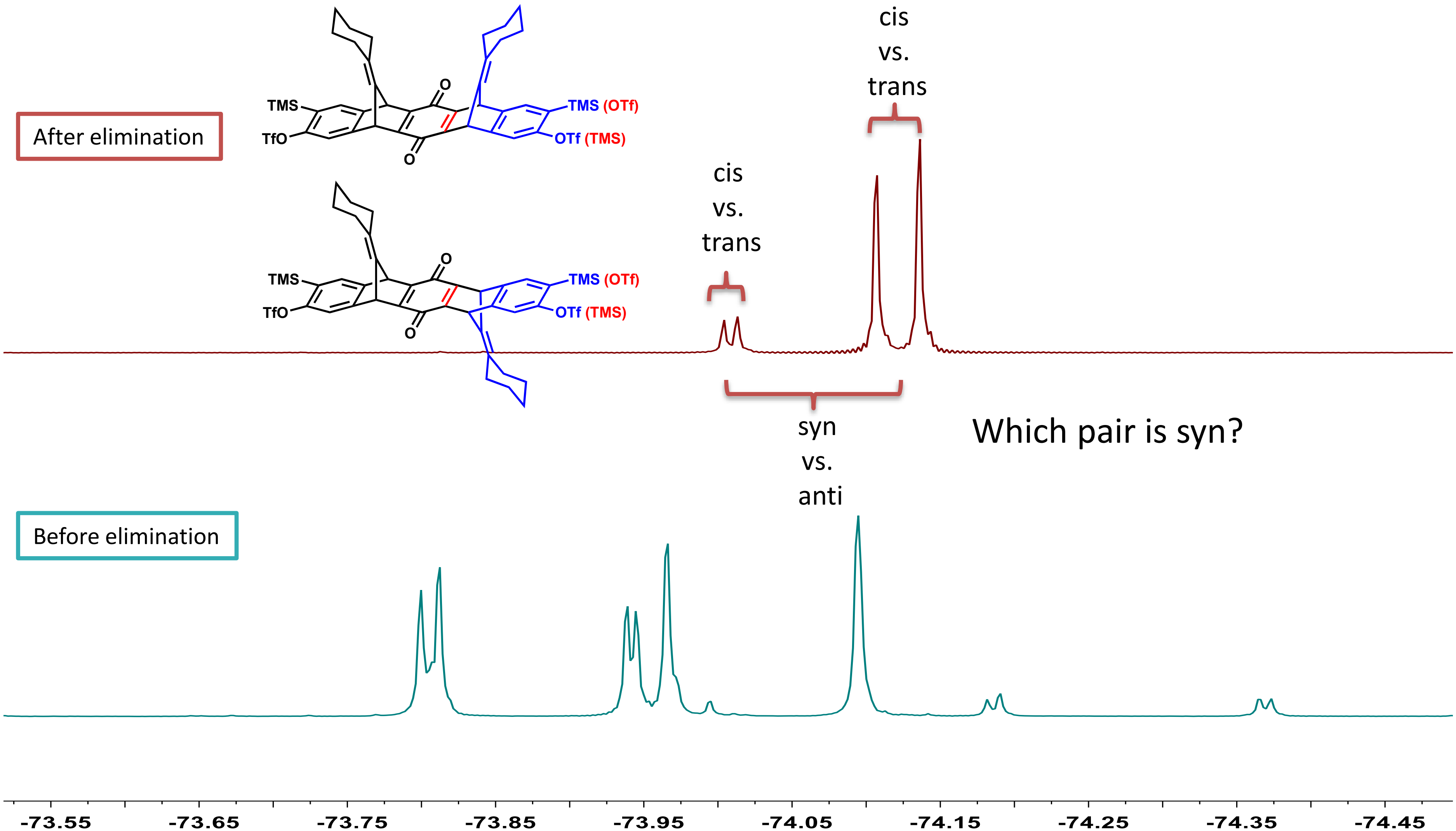
Synthesis Attempts toward Syn-isomer

➢ Dehydrobromination of stereoisomers



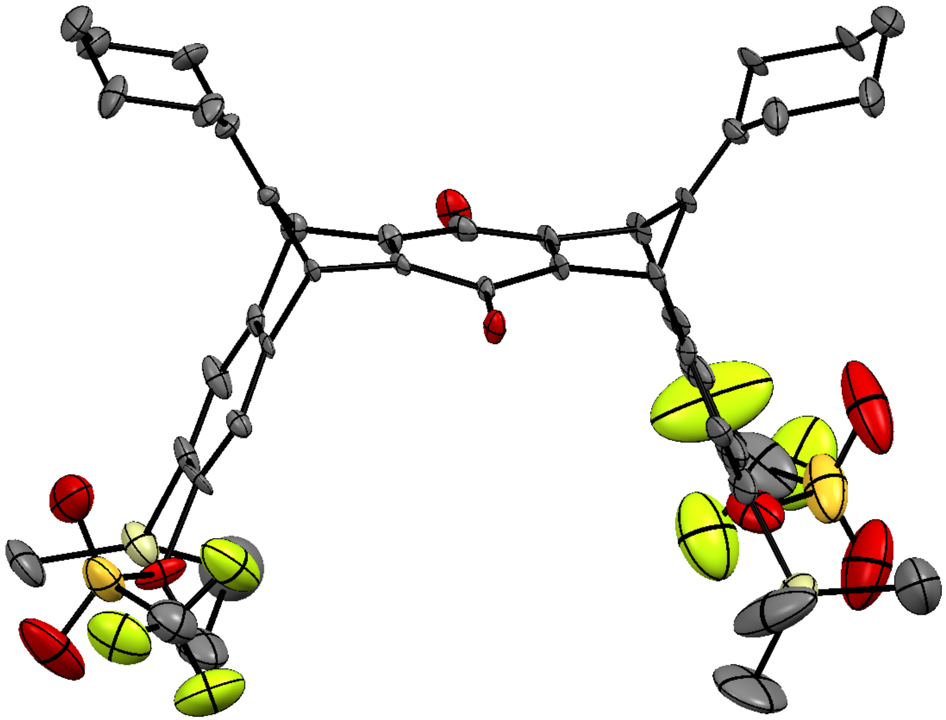
Synthesis Attempts toward Syn-isomer

- Dehydrobromination of stereoisomers by ^{19}F–NMR



Crystal Structure

- Syn-isomer as the major product!

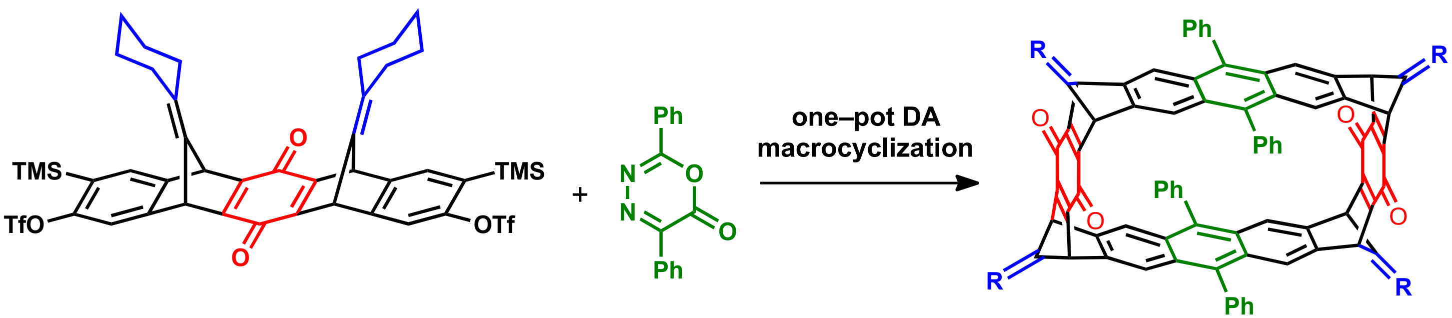


Steven Underwood

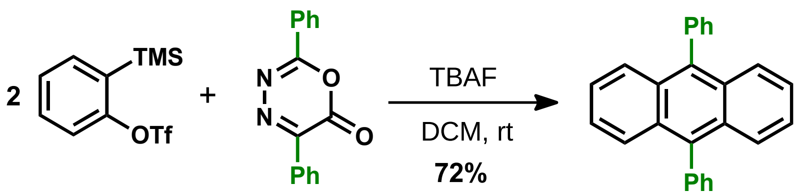
Dr. Victor Young

Future Work

- Macrocyclization and late-stage functionalization

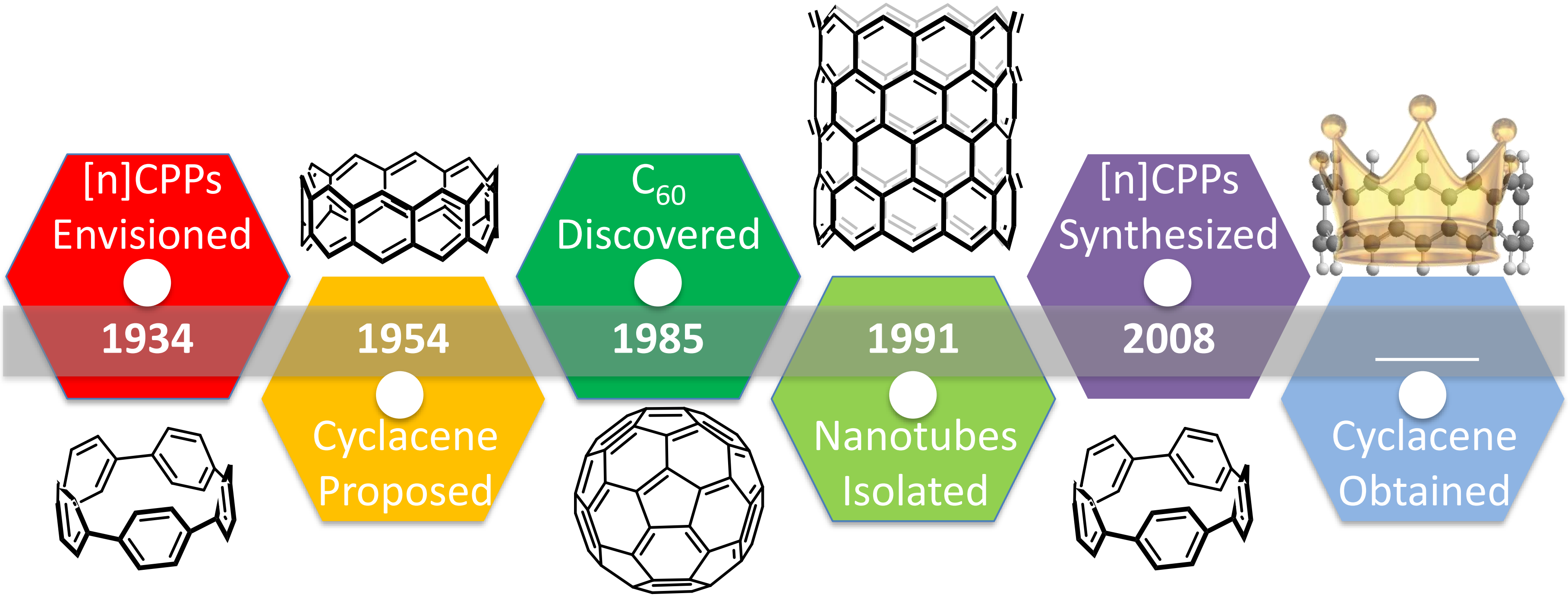


Model study



Steglich, W.; Buschmann, E.; Gansen, G.; Wilschowitz, L. *Synthesis* **1977**, *1977(4)*, 252-253.

Conclusion and Outlook



Unimolecular Architectures

Carbon Nanostructures

Synthesis Applications

Acknowledgements

- Prof. Chris Douglas
- Team Cyclacene (Sarah, Lafe, Steve)
- Douglas group members
- NMR lab and XCL
- Funded by ACS PRF

ACS PRF

Thank you

Future Work

- Macrocyclization and late–stage functionalization