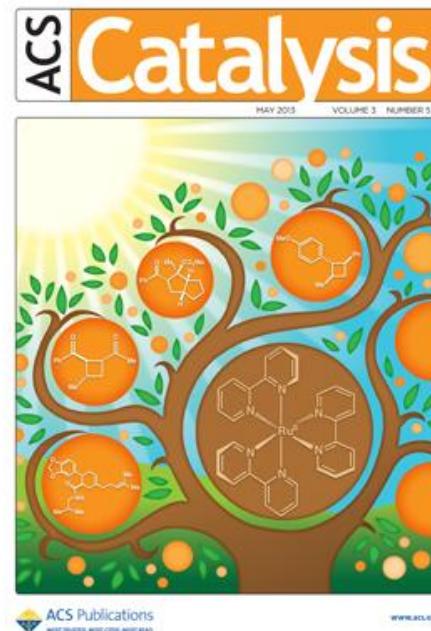
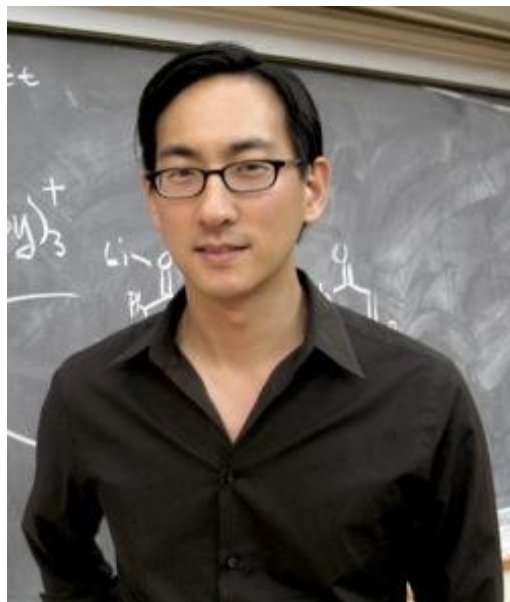

Tehshik Peter Yoon – Visible Light Photocatalysis

Magnus Pfaffenbach
Gaich Group Seminar
October 14, 2013



Curriculum Vitae – Tehshik Peter Yoon

Education and Training

- A.B., Harvard University (Evans), 1996
- M.S., Caltech (Carreira), 1998
- Ph.D., Caltech (MacMillan), 2002
- Postdoc, Harvard (Jacobsen), 2002-2005

Professional

University of Wisconsin-Madison

- Assistant Professor of Chemistry 2005-2011
- Associate Professor of Chemistry 2011-present

Publications

33 papers from Wisconsin

- 10x J. Am. Chem. Soc.
- 3x Angew. Chem. Int. Ed.
- 1x Nature Chem.

Awards and Honors

- Eli Lilly Grantee
- Camille Dreyfus Teacher-Scholar Award
- Amgen Young Investigator Award
- Alfred P. Sloan Research Fellowship
- Thieme Chemistry Journal Award
- Cottrell Scholar Award
- Beckman Young Investigator Award
- UW–Madison Research-Service Award
- NSF Career Award
- Eli Lilly New Faculty Award

Visible Light as Reagent

Pro

- Inexpensive
- Abundant
- Renewable
- Non-polluting
- Green chemistry
- Distinctive synthetic utility

Contra

- Inability of most common organic molecules to absorb wavelengths of visible light

Contra UV Light

- Requirement for specialized equipment (photoreactor, quartz glassware)
- Undesired decomposition processes

Convenient Sources of Visible Light

- ambient light (laboratory window)
- 23 W fluorescent light bulb
- 200 W tungsten filament light bulb
- 275 W floodlight



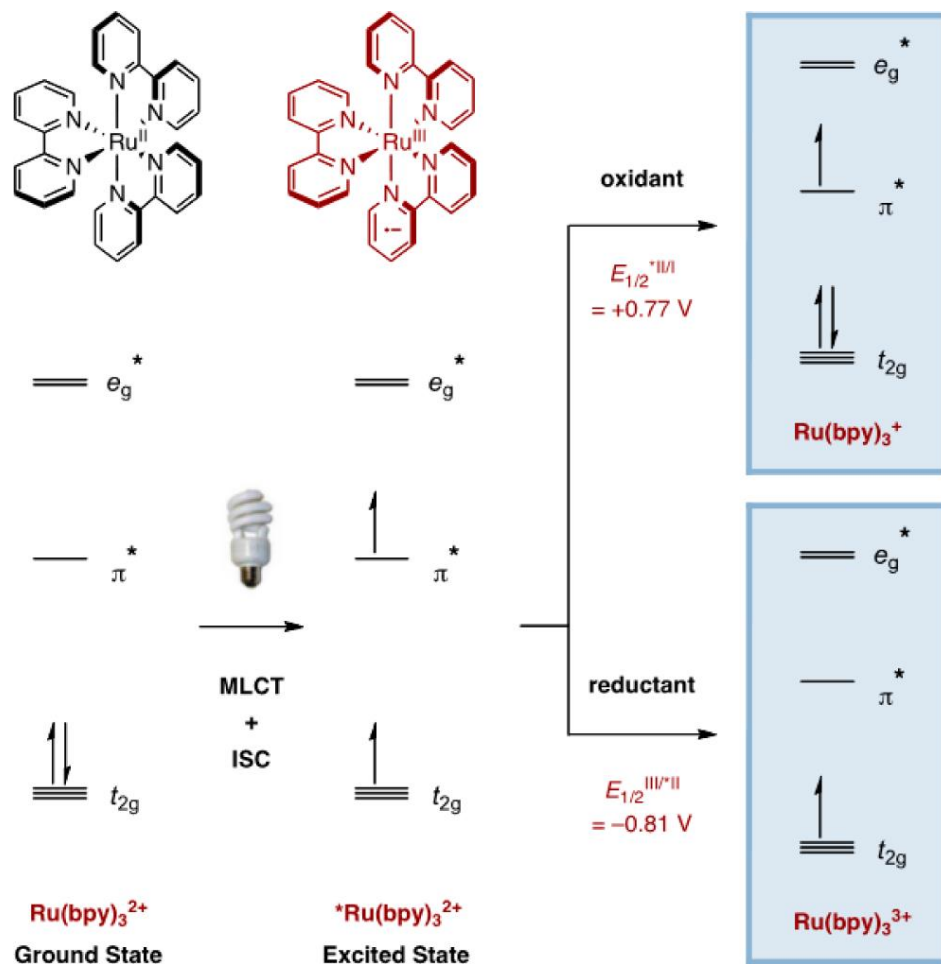
Photoredox Catalyst Complexes

Ruthenium polypyridyl photocatalysts:

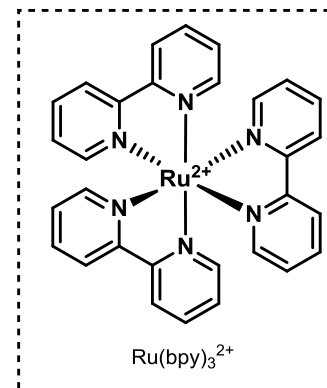
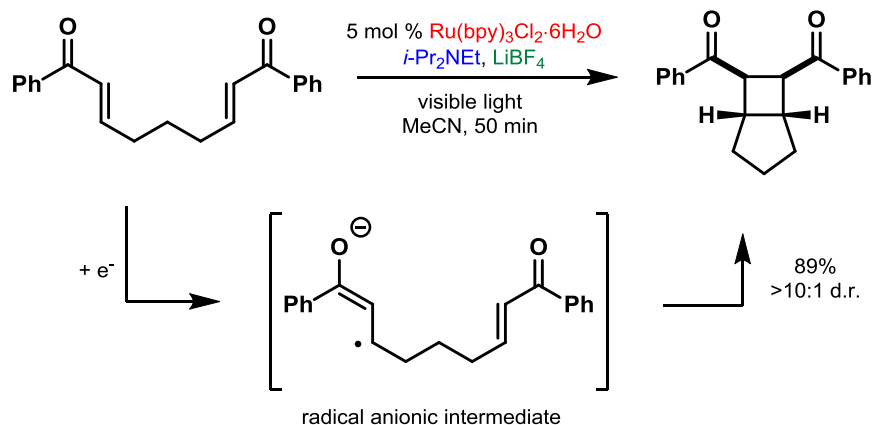
- $\text{Ru}(\text{bpy})_3^{2+}$
- Absorption at 452 nm (visible light)
- Stable, long-lived excited states ($t = 1100 \text{ ns}$)
- Single electron transfer catalyst
- Effective excited state oxidant and reductant

→ Photon energy to electrochemical potential

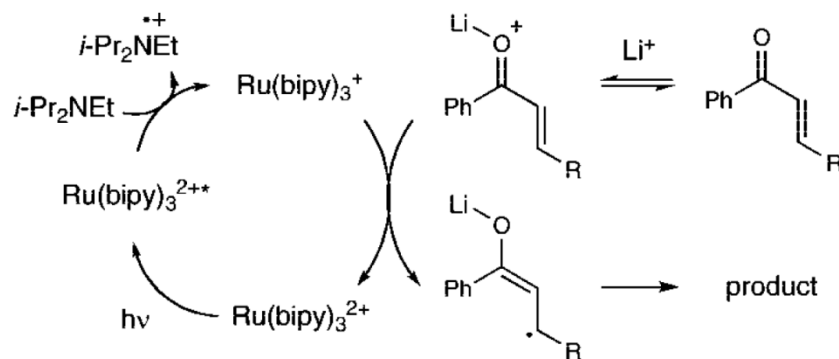
MLCT = metal to ligand charge transfer
ISC = intersystem crossing



Visible Light Photocatalysis of [2+2] Enone Cycloadditions



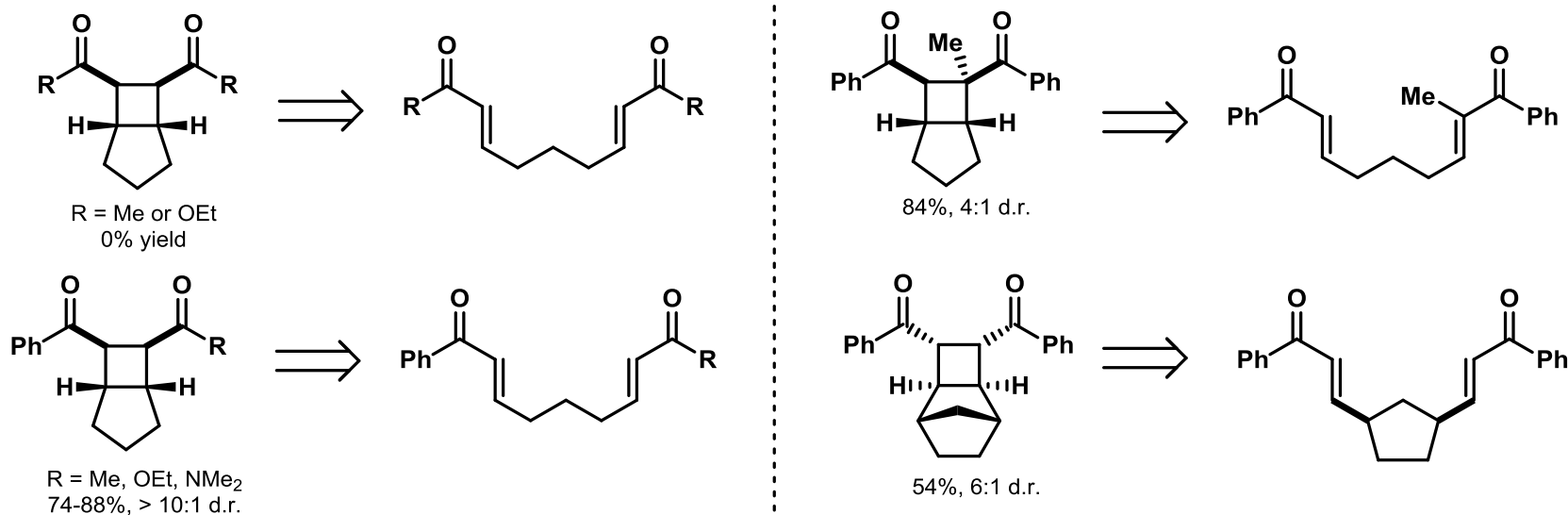
Mechanism



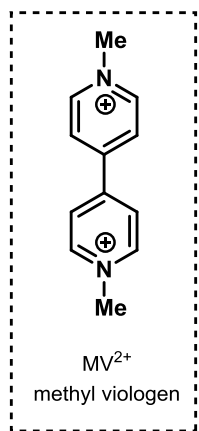
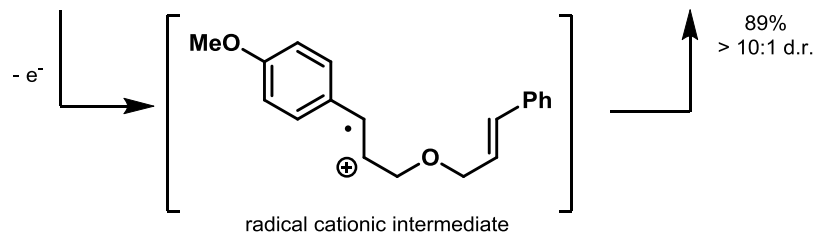
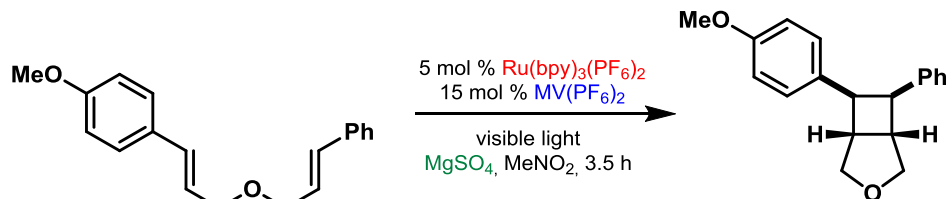
Multicomponent Photocatalytic System:

- (1) $\text{Ru}(\text{bpy})_3^{2+}$: Sensitizer for photoinduced electron transfer
- (2) $i\text{-Pr}_2\text{NEt}$: Reductive quencher; reacts with the excited state
- (3) LiBF_4 : Lewis-acid activates the enone toward reduction and stabilizes the resulting radical anion

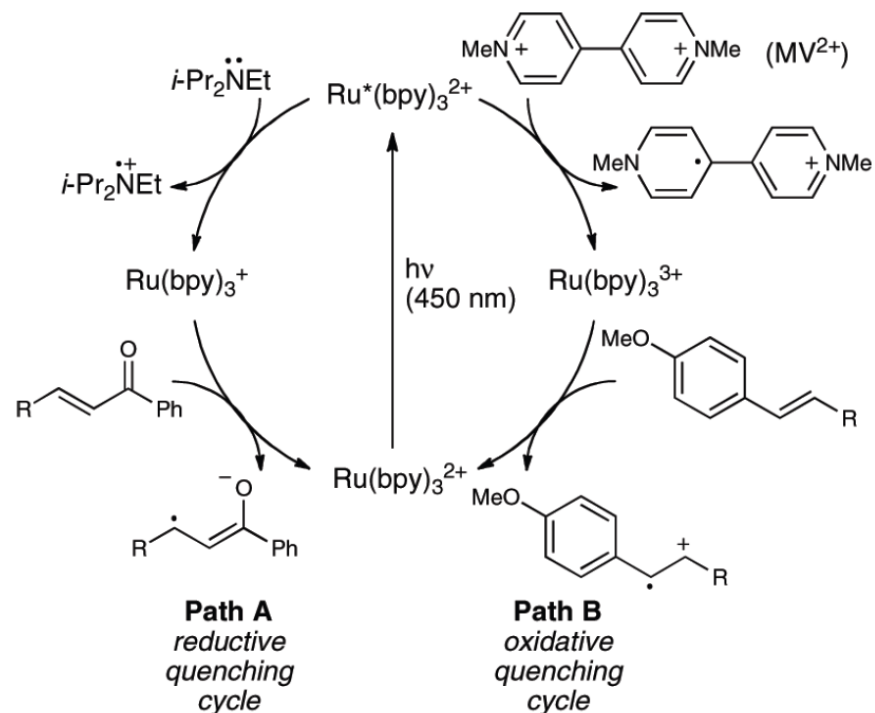
Scope [2+2] Enone Cycloaddition



[2+2] by Oxidative Visible Light Photocatalysis

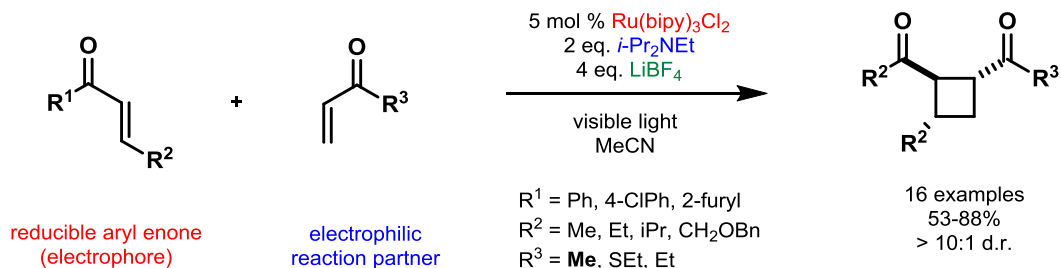


Ru-catalyst access either photooxidative or photoreductive reactivity by choosing the appropriate oxidative or reductive quencher!

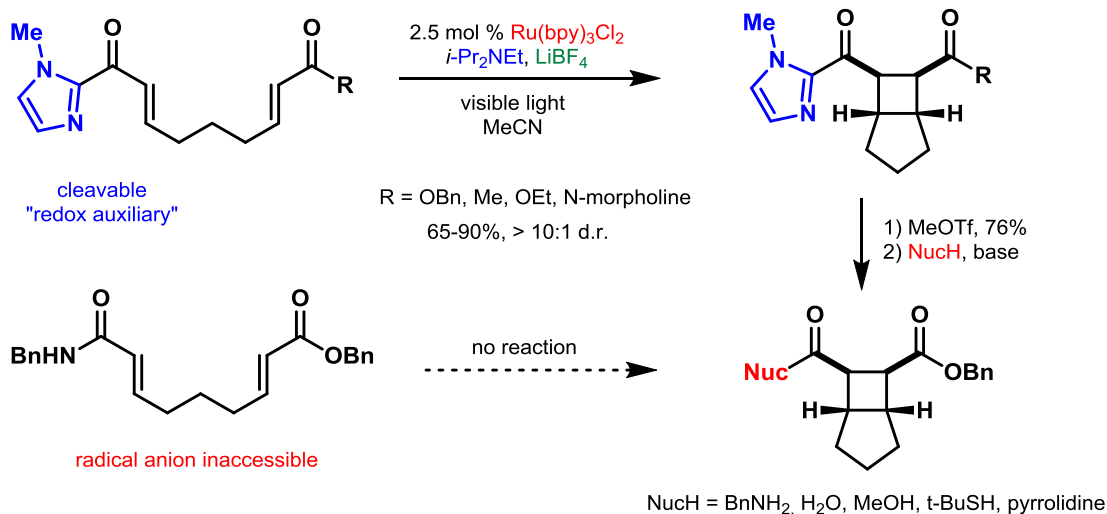


More [2+2] Enone Cycloaddition Chemistry

Crossed intermolecular [2+2] heterodimerization of acyclic enones

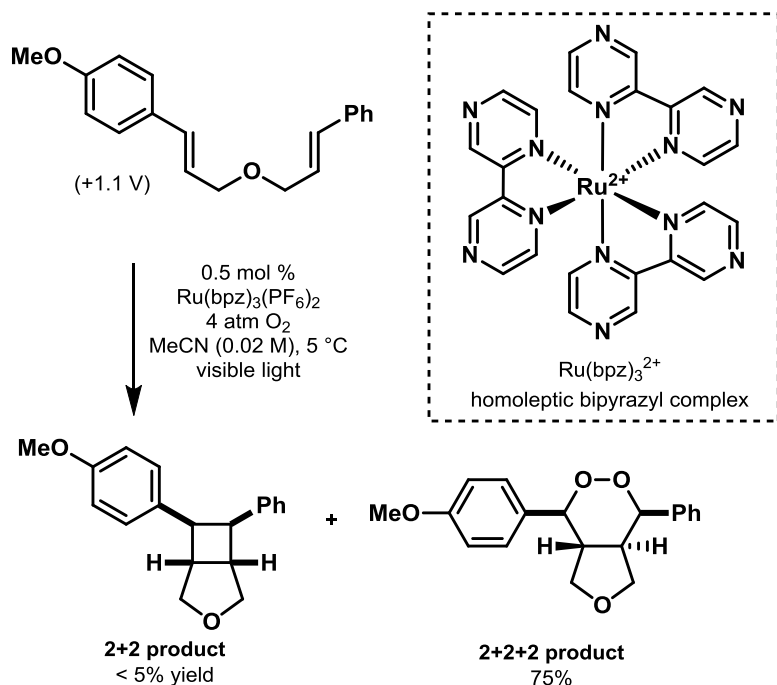


Photocatalytic [2+2] Cycloadditions of Enones with Cleavable Redox Auxiliaries



Endoperoxides by Aerobic [2+2+2] Cycloadditions

- Endoperoxide moiety is key pharmacophore of anti-malarial, anti-viral and anti-cancer agents

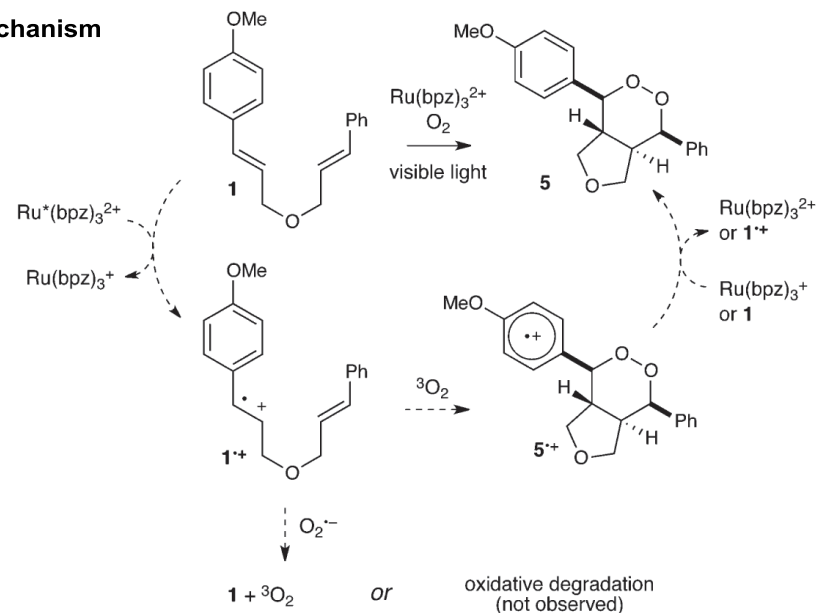


photoexcited states (vs. SCE)

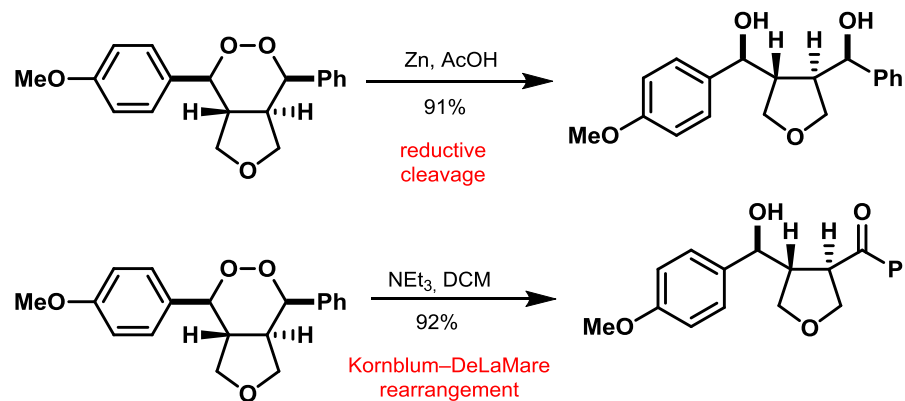
$$Ru^*(bpz)_3^{2+} = +1.4 \text{ V vs. } Ru^*(bpy)_3^{2+} = +0.8 \text{ V}$$

SCE = Saturated calomel electrode

Mechanism

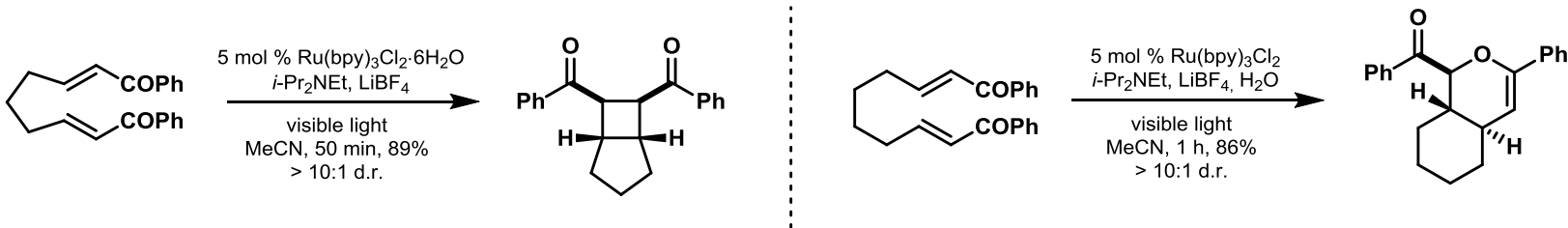


1,2-Dioxanes provide access to 1,4-diols and γ -hydroxyketones

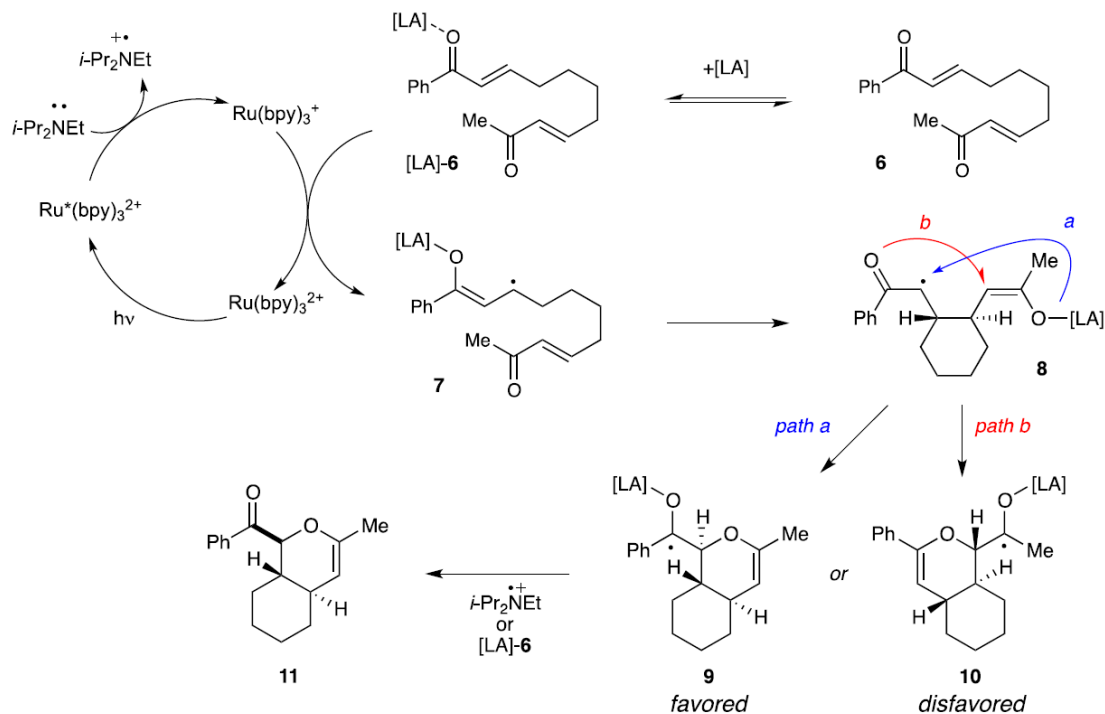


Radical Anion Hetero-Diels-Alder Cycloadditions

Tether length crucial for the product outcome

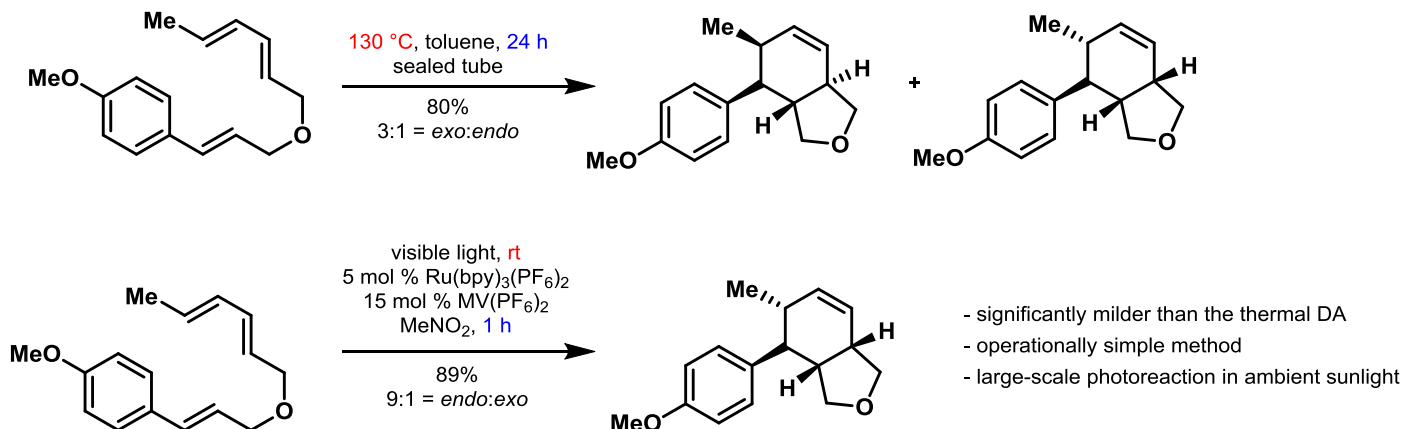


Unsymmetrical (bis)enones react with high level of regioselectivity

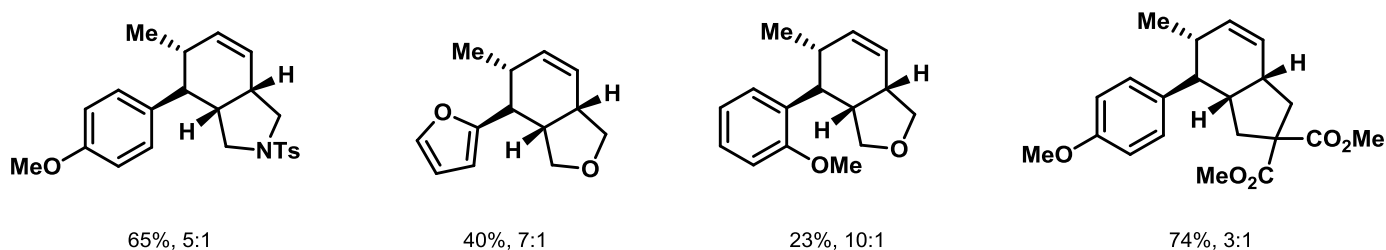


Radical Cation Diels-Alder Cycloadditions

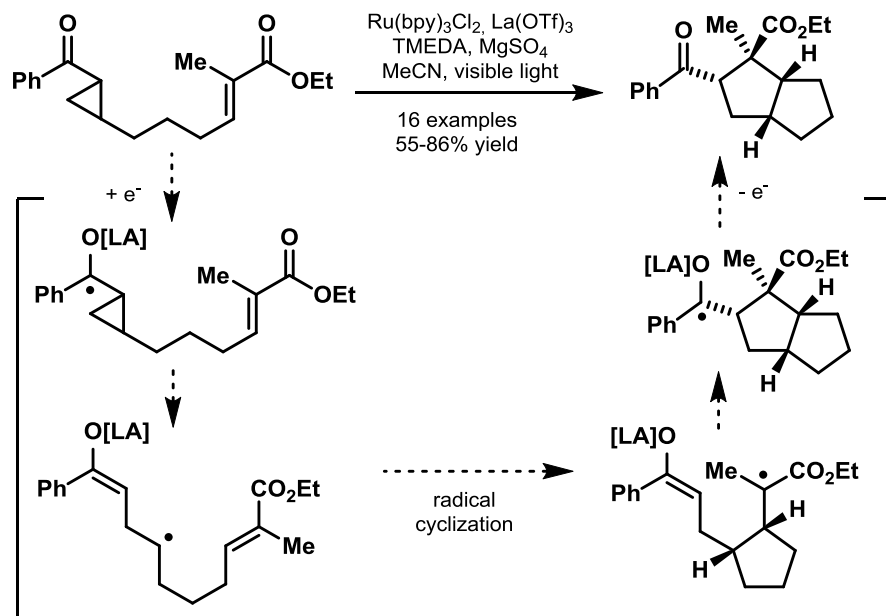
Thermal vs. photocatalyzed radical cation cycloaddition of electronically mismatched Diels-Alder substrate



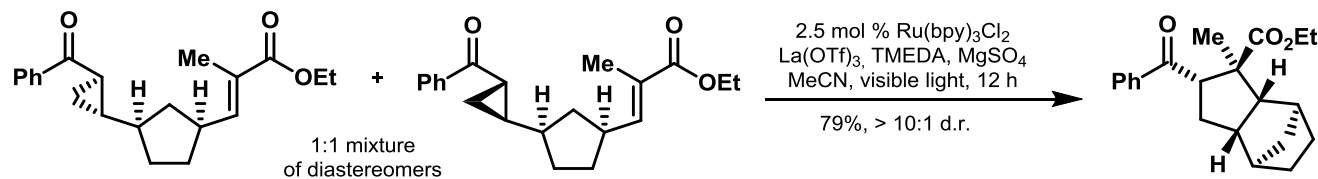
Scope of the intramolecular [4+2] cycloaddition



[3+2] Cycloadditions of Aryl Cyclopropyl Ketones

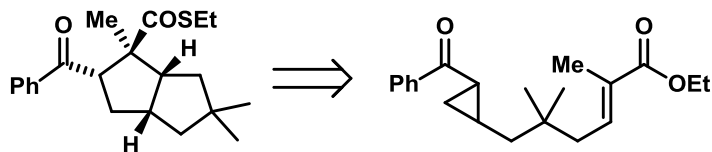


Support for a non-stereogenic ring-opened distonic radical anion

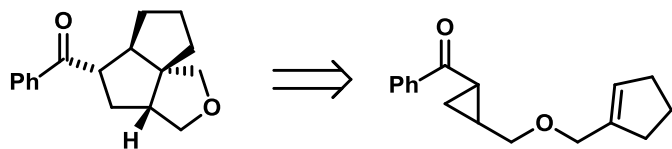


[3+2] Cycloadditions of Aryl Cyclopropyl Ketones

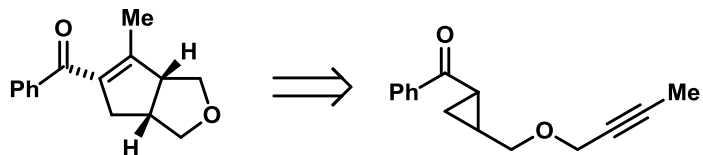
Scope of Intramolecular [3+2] Cycloaddition



82%, > 10:1 d.r.

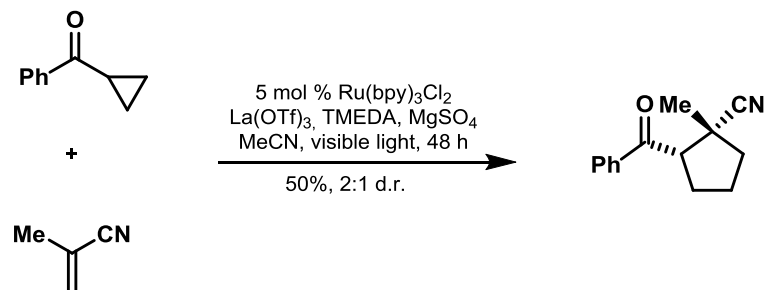


69%, 2:1 d.r.



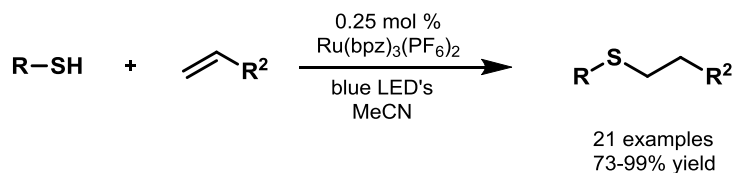
73%, > 10:1 d.r.

Intermolecular [3+2] Cycloaddition

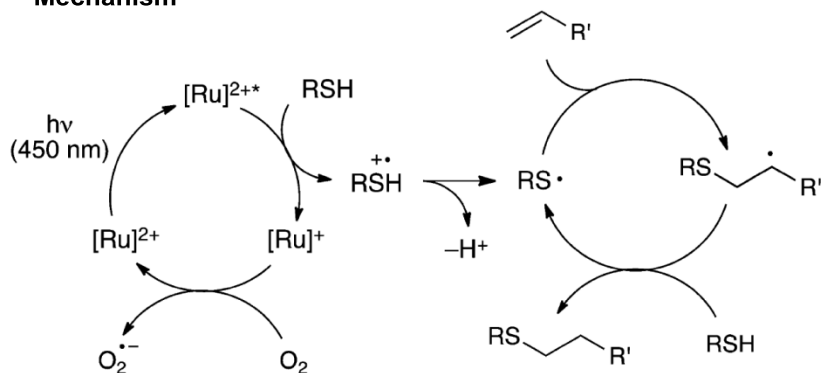


Photoredox Catalysis of Radical Thiol-Ene Reactions

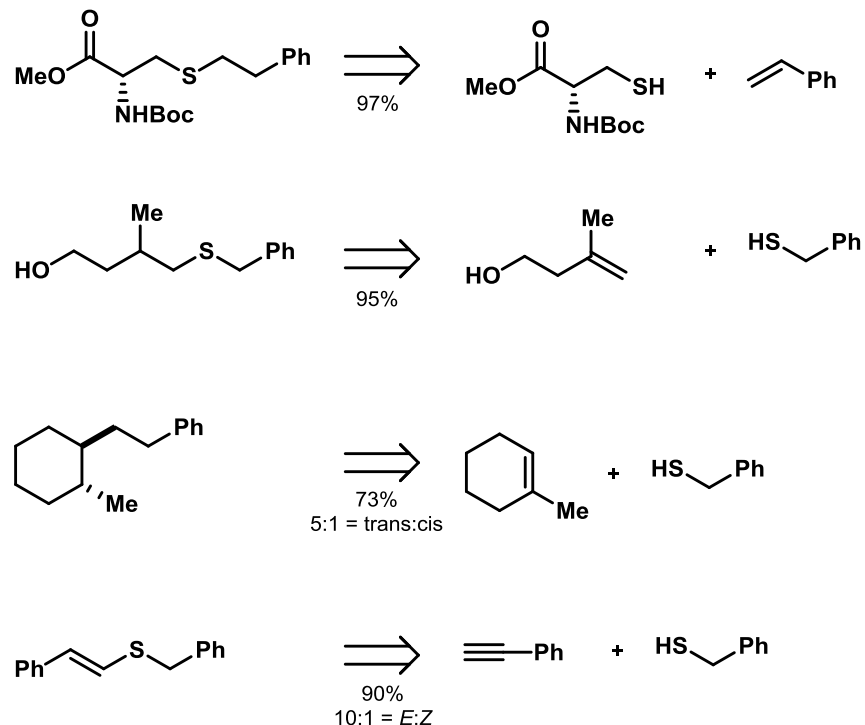
Anti-Markovnikov hydrothiolation



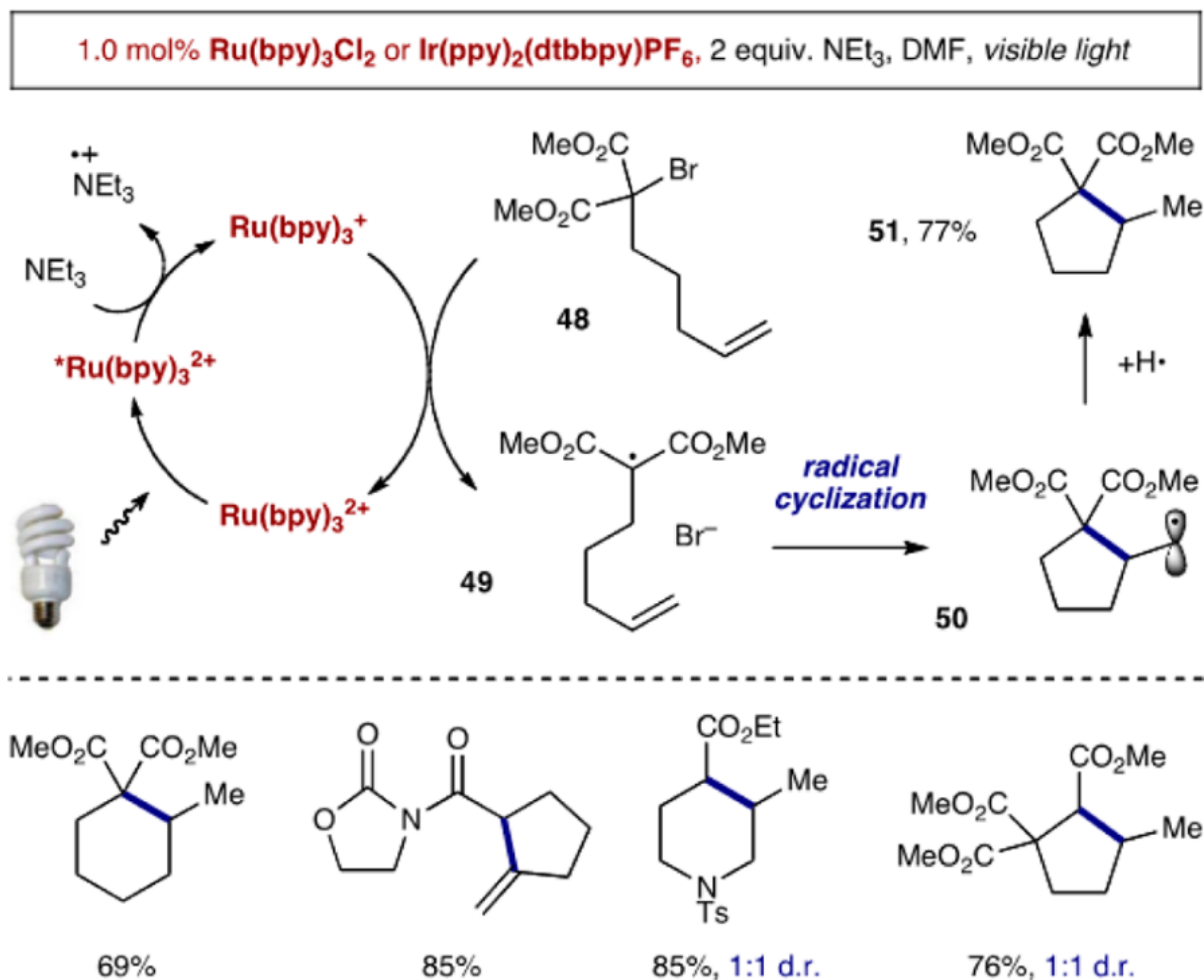
Mechanism



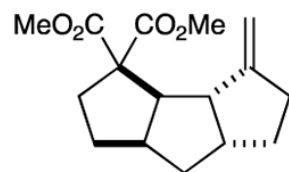
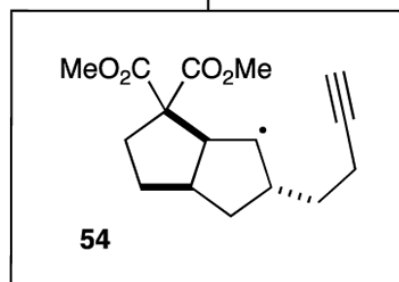
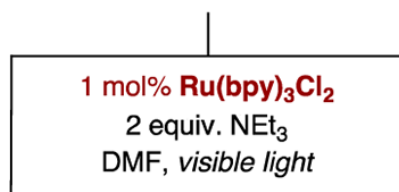
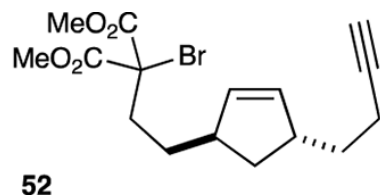
Generality for a variety of alkenes and thiols



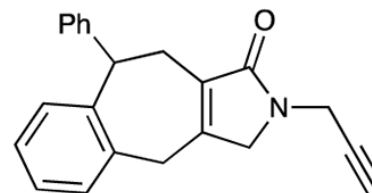
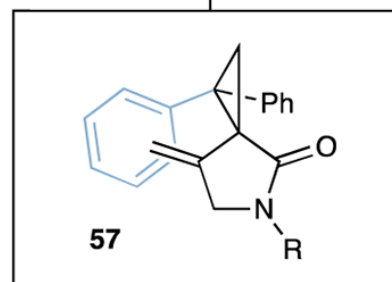
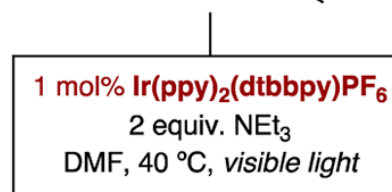
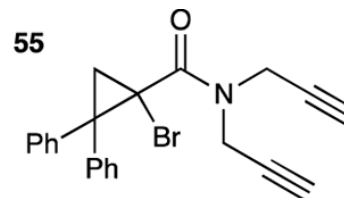
Building Molecular Complexity I



Building Molecular Complexity II



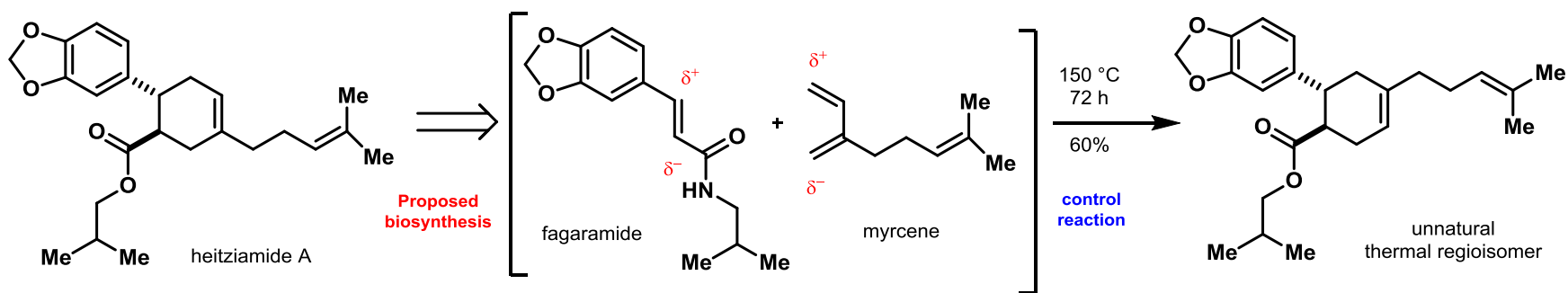
53, 69%



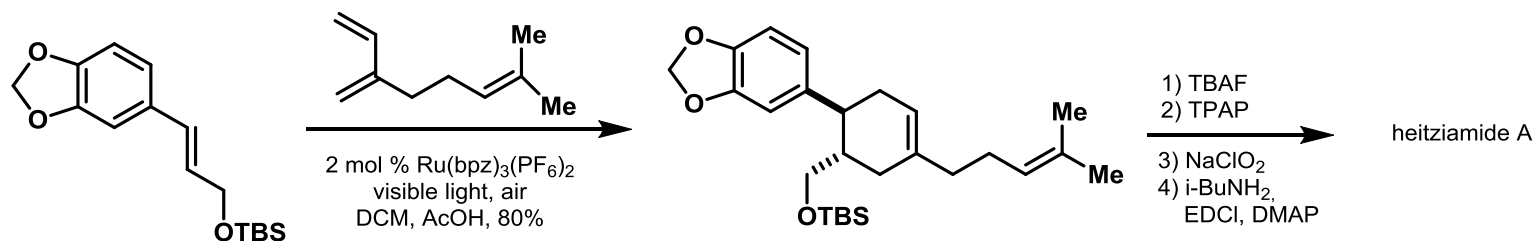
56, 69%

Natural Product Synthesis – Yoon Group

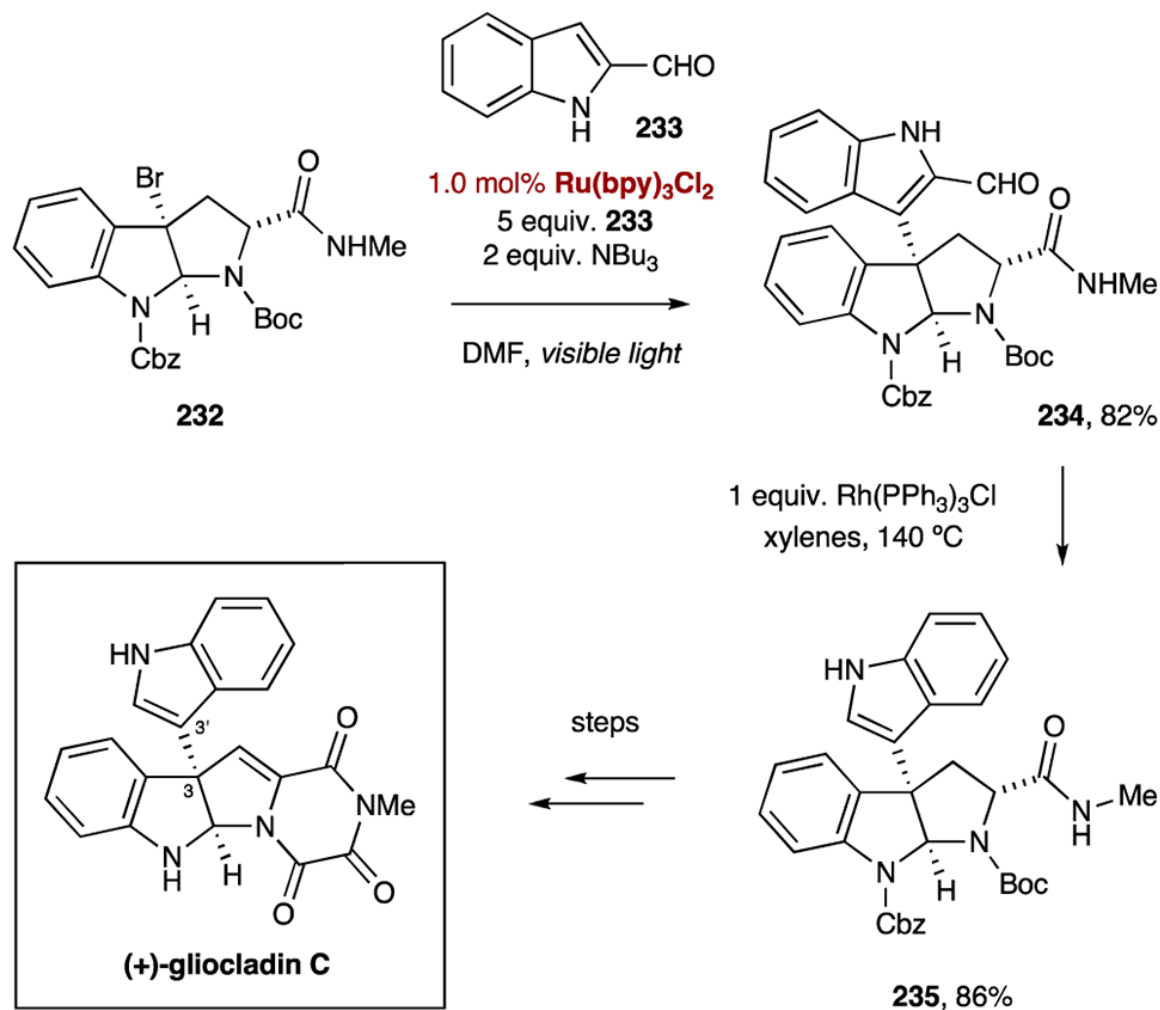
Proposed biosynthetic origin vs. control reaction



Total synthesis enabled by a radical cation Diels-Alder Cycloaddition



Natural Product Synthesis – Stephenson Group



- Reductive dehalogenation
- Tert. Benzylic radical
- Block of C-2 indole position
- Wilkinson decarbonylation
- 10 steps, 30% overall

Natural Product Synthesis – Overman Group

