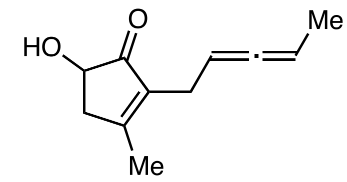
Allenes

Hai Dao
11/03/2012

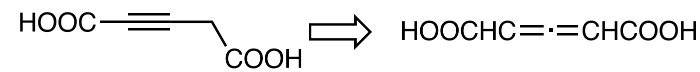
Part 1. Introduction

A brief history

1828: Synthesis of urea = the starting point of modern organic chemistry.
1875: Prediction of the correct structure, Van't Hoff, *La Chimie dans l'Espace*, Bazendijk, P.M., Rotterdam **1875**, 29.
1887: First synthesis of an allene (glutinic acid), Burton and Pechmann, *Chem. Ber.* **1887**, 145.
Confirmation of the structure of "glutinic acid", Jones *et al.*, *J. Chem. Soc.* **1954**, 3208.
1924: Isolation and characterization of first natural allene, pyrethrolone, Staudinger and Ruzicka, *Helv. Chim. Acta* **1924**, 177.
1928: First review on allenes, Bouis, *Ann. Chim. (Paris)* **1928**, 402.
1935: Synthesis of first chiral allene, Maitland and Mills, *Nature* **1935**, 994.
Last decade (2002-2012): Shengming Ma (148 publications); Norbert Krause (42 publications), Benito Alcaide and Pedro Almendros (33 publications). Scifinder, key word: allenes. Google gave 184000 (*vs.* alkyne 999000) (Nov **2012).**

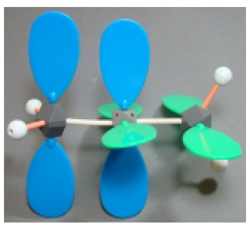


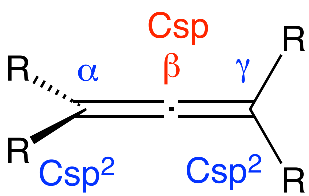
pyrethrolone



initial proposal (1887) revised structure (1954)
"glutinic acid"

Structure and physical properties



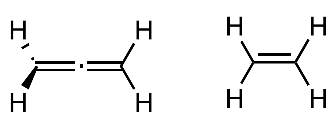


$\chi(Csp^3) = 2.63$
$\chi(Csp^2) = 2.86$
$\chi(Csp) = 2.96$

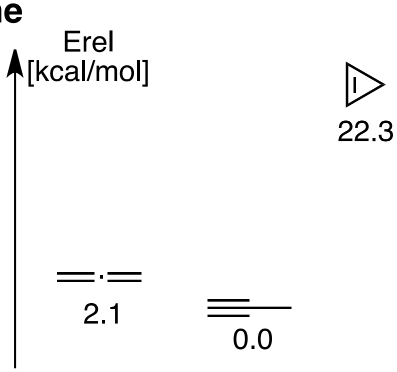
Brown, *J. Chem. Phys.* **1960**, 1881.

IR: antisymetrical streching vibration 1950-1960 cm^{-1}
(*vs.* alkene: 1680 cm^{-1}, alkyne 2200 cm^{-1})
^{1}H NMR: δ = 4.9-4.4 ppm
^{13}C NMR: $\delta_{C\alpha,\ C\gamma}$ = 120-73 ppm; $\delta_{C\beta}$ = 220-200 ppm.

The most simple allene vs. ethylene



	allene	ethylene
d_{C-H} (Å)	1.061	1.086
d_{C-C} (Å)	1.309	1.337
IP	10.07 eV 10.64 eV	10.51 eV



isomers of smallest allene and their relative energies

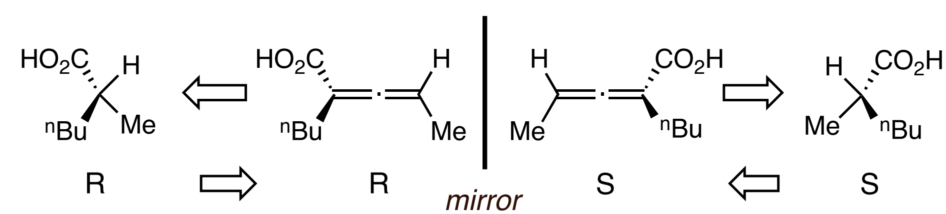
many substituted allenes are thermodynamically more stable than the corresponding alkynes.

Classification

R = alkyl, alkenyl, aryl, alkynyl
EWG = CO_2R, CN, SO_2R...
EDG = OR, SR, NR_2, Hal, ...
Met = Li, Mg, B, Si, Sn, Zn, In, Ti, Cu, Pd

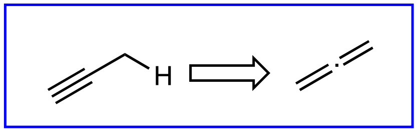
- allenes can react as both nucleophiles and electrophiles
- changing the substituents can alter the reactivity preferences

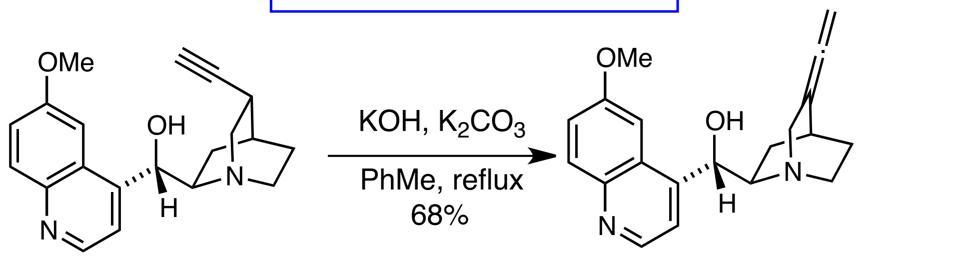
Determination the configuration of chiral allenes



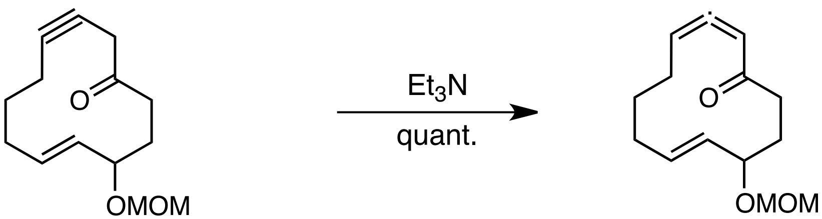
Part 2. Synthesis of Allenes

Prototropic Rearrangements

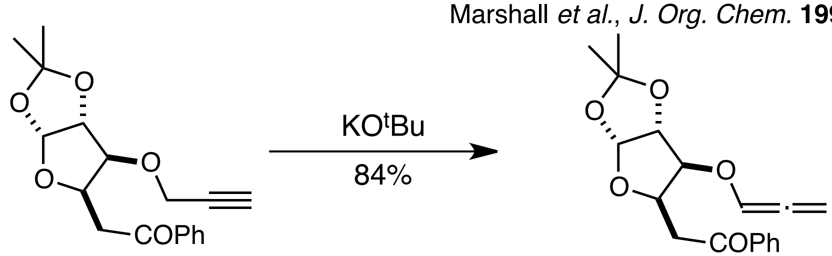




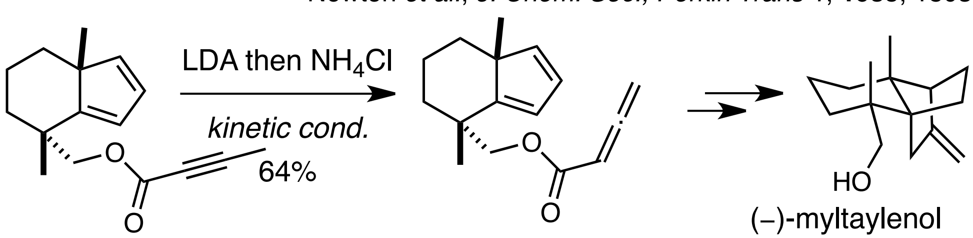
Hoffmann *et al.*, *Helv. Chim. Acta* **2000**, 777



Marshall *et al.*, *J. Org. Chem.* **1991**, 6264.

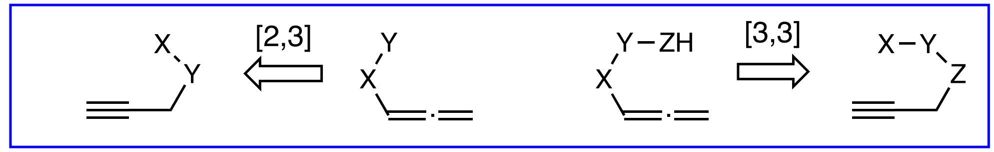


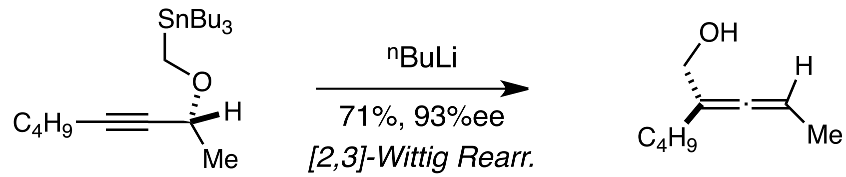
Newton *et al.*, *J. Chem. Soc., Perkin Trans 1*, **1985**, 1803.



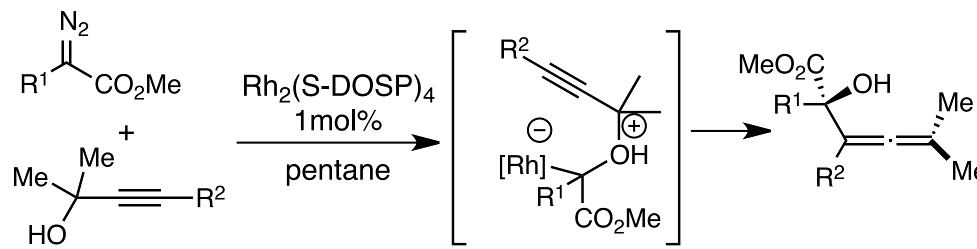
Winterfeldt *et al.*, Chem. Eur. J. . **1998**, 1480.

Sigmatropic Rearrangements

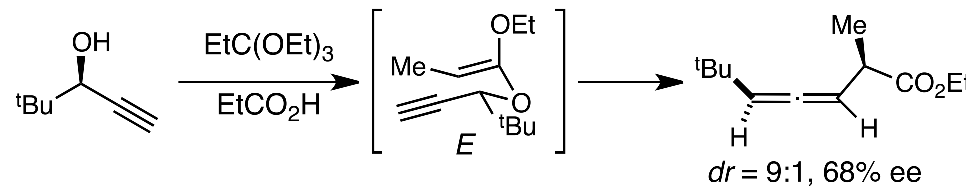




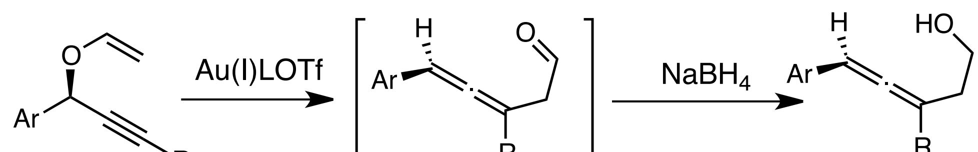
Marshall *et al.*, *J. Org. Chem.* **1989**, 5854.



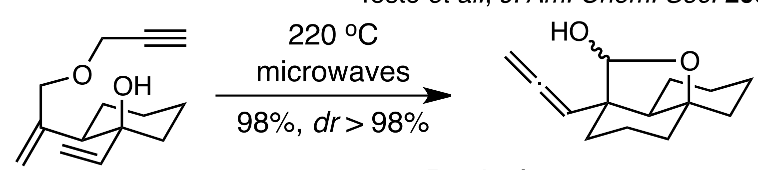
Davies *et al.*, *J. Am. Chem. Soc.* **2012**, 15497.



Heathcock *et al.*, J. *Org. Chem.* **1988**, 4736.



Shi *et al.*, *Org. Lett.* **2011**, 2618.
Toste *et al.*, *J. Am. Chem. Soc.* **2004** 15978.



Barriault *et al.*, *Org. Lett.* **2002**, 1371.

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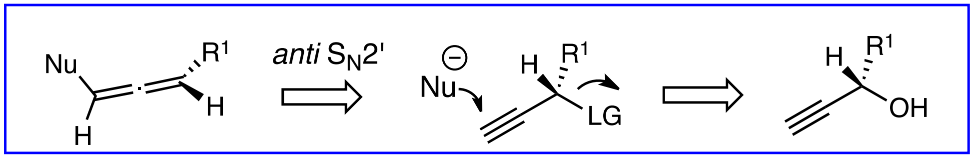
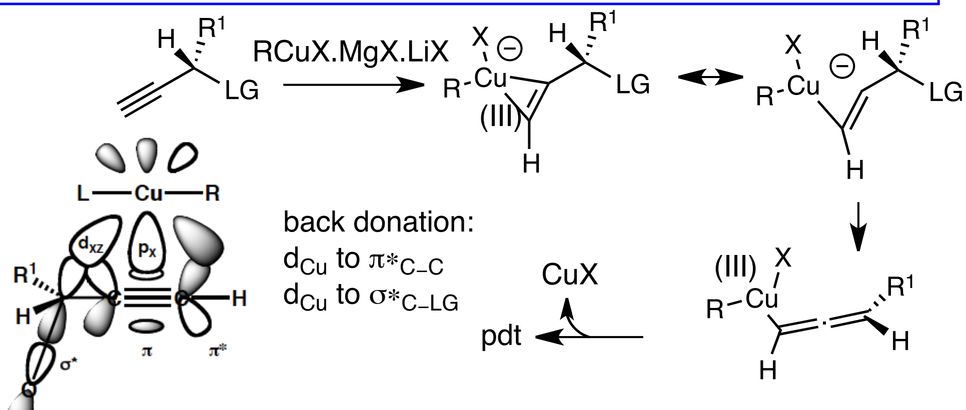
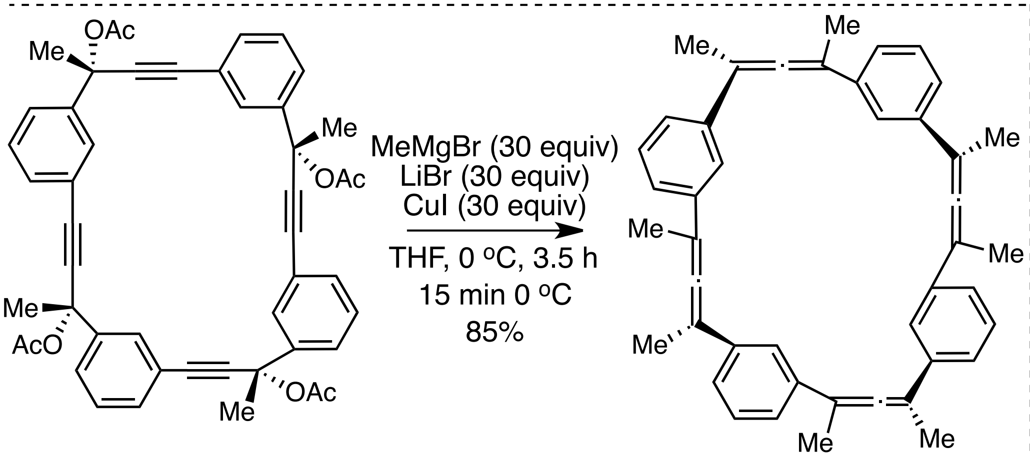
Nucleophilic Substitution

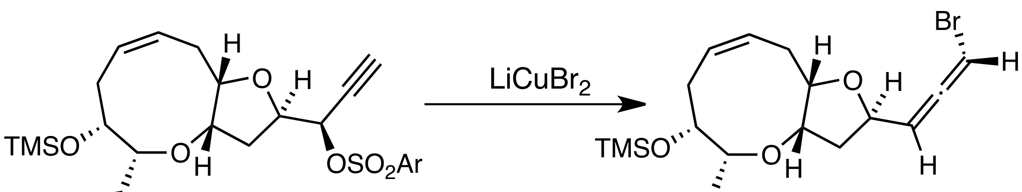




mechanism of organocopper-mediated stereospecific substitution

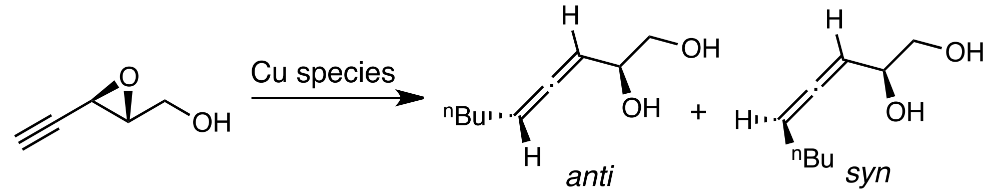


Fallis *et al.*, *Angew. Chem. Int. Ed.* **2008**, 568.



isolaurallene precursor

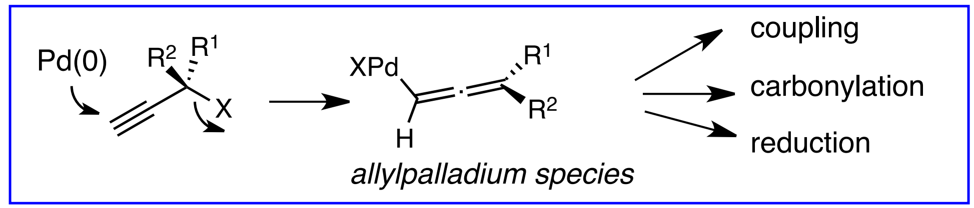
Crimmins *et al.*, *J. Am. Chem. Soc.* **2001**, 1533.

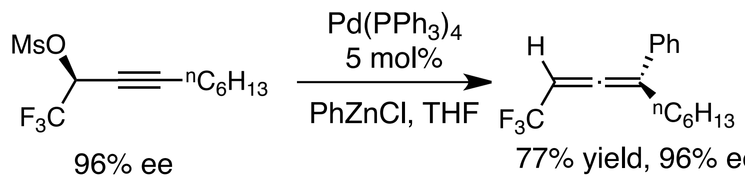


syn: anti: $^nBu_2CuLi$ = 60:40; $^nBu_2CuLi.Me_2S$ = 6:94; $^nBu_2CuMgBr.Me_2S$ = 1:99

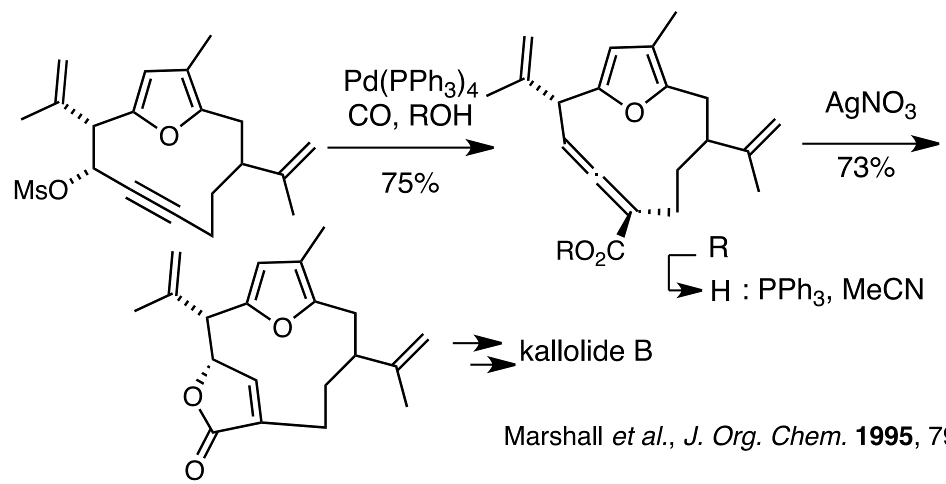
Cu-promoted racemization of allenes through SET
Me_2S stablizes Cu species

Oehlschlager and Czyzewska , *Tetrahedron Lett.* **1983**, 5587.



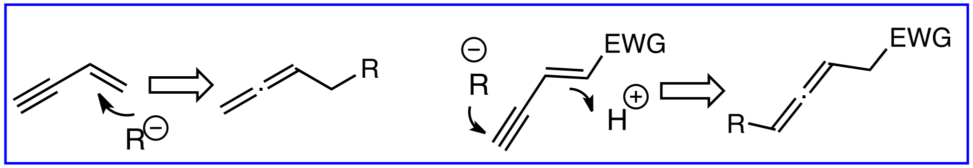


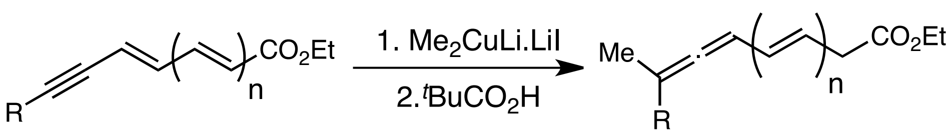
Kono and Yamanaka *et al.*, *Chem. Lett.* **2000**, 1360.



Marshall *et al.*, *J. Org. Chem.* **1995**, 796.

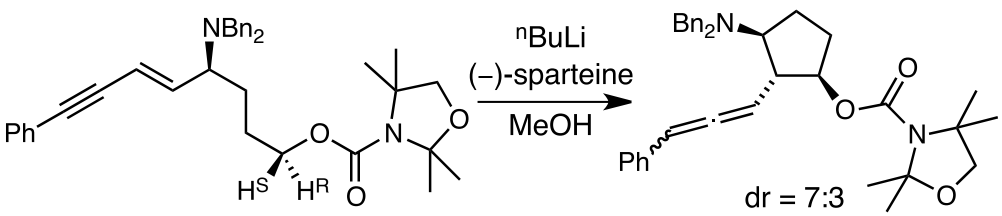
Additions to Enynes Systems



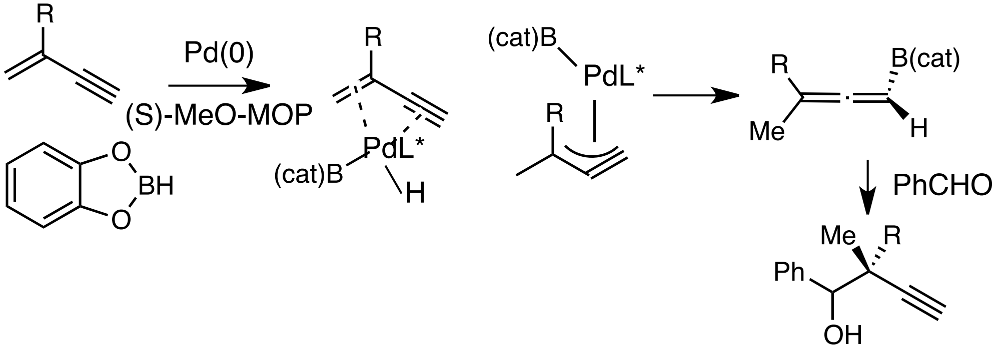


R = ^{t}Bu, n = 1, 90% (1,8 addition); R = Me, n = 2, 68% (1,10 addtion);
R = Me, n = 3, 26% (1,12 addtion)

Krause, *Liebigs Ann. Chem.* **1996**, 1487.



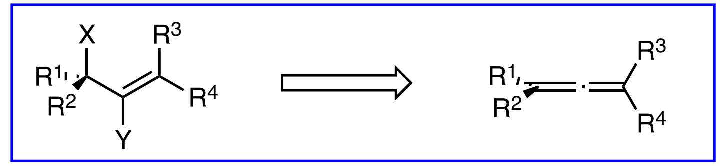
Oestreich and Hoppe, *Tetrahedron Lett.* **1999**, 1881.

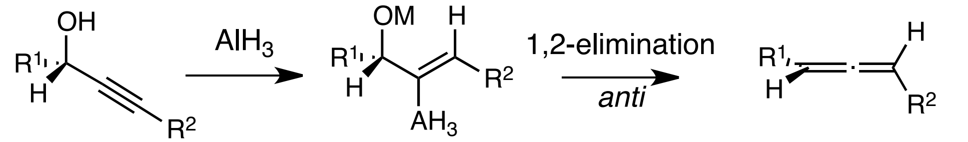


up to 63% ee

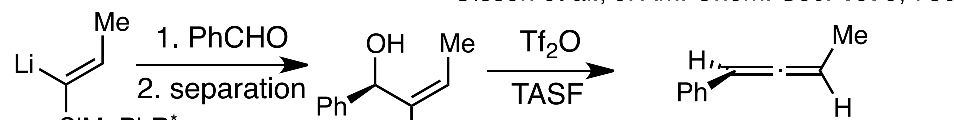
Hayashi, *J. Chem. Soc., Chem. Commun* **1993**, 1468.

1,2-Elimination



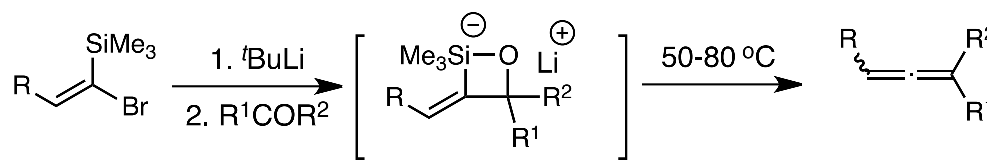


Olsson *et al.*, *J. Am. Chem. Soc.* **1979**, 7302.



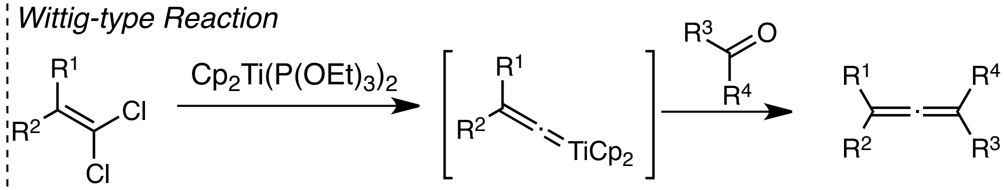
50% yield, 18% ee

McGarvey, *Tetrahedron Lett.* **1988**, 1355.

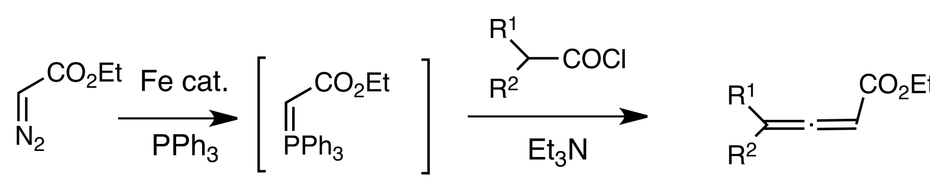


Takeda, *Synthesis* **2006**, 2577.

Wittig-type Reaction



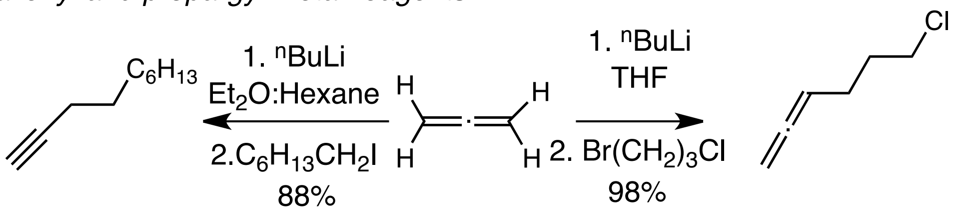
Takeda, *Org. Biomol. Chem.*, **2005**, 2914.



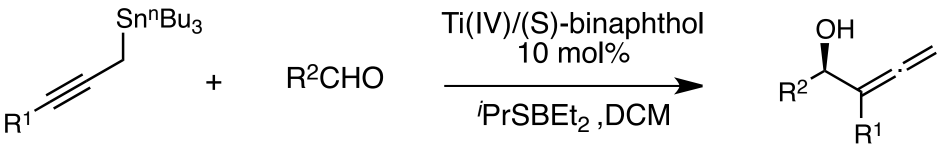
Dai *et al.*, *J. Am. Chem. Soc.* **2007**, 1494.

Other Methods

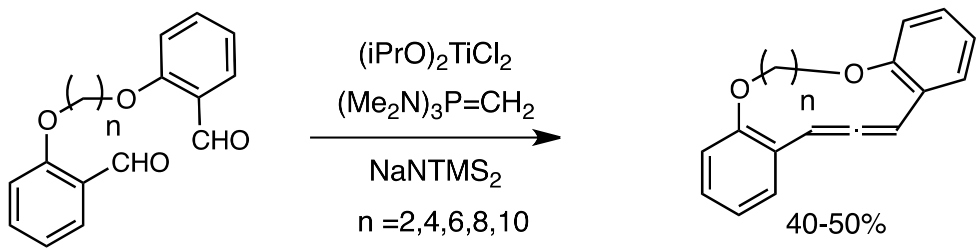
allenyl and propargyl metal reagents



Hooz *et al.*, *Tetrahedron. Lett.* **1985**, 271.
Arseniyadis *et al.*, *Tetrahedron* **1979**, 353

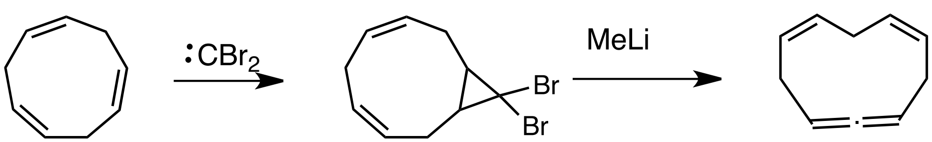


titanium-phosphorus ylides



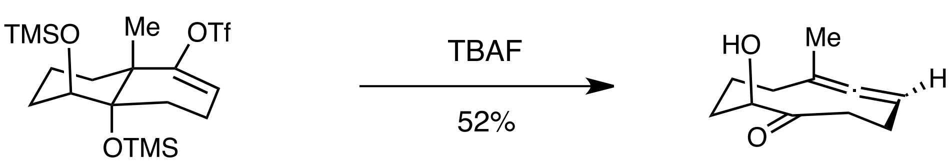
Finn *et al.*, *J. Am. Chem. Soc.* **1997**, 3429.

carbene approach



Thies *et al.*, *J. Org. Chem.* **1975**, 585.

fragmentation

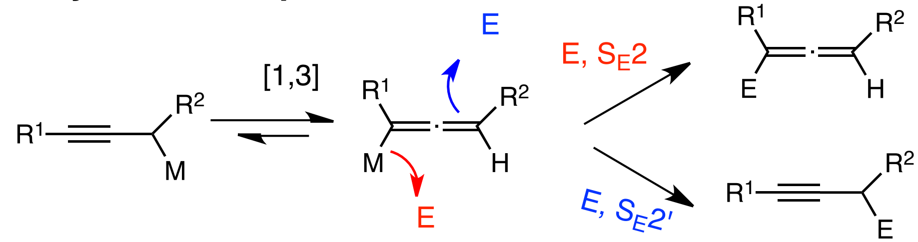


Lawrence *et al.*, *J. Am. Chem. Soc.* **2012**, 12970.

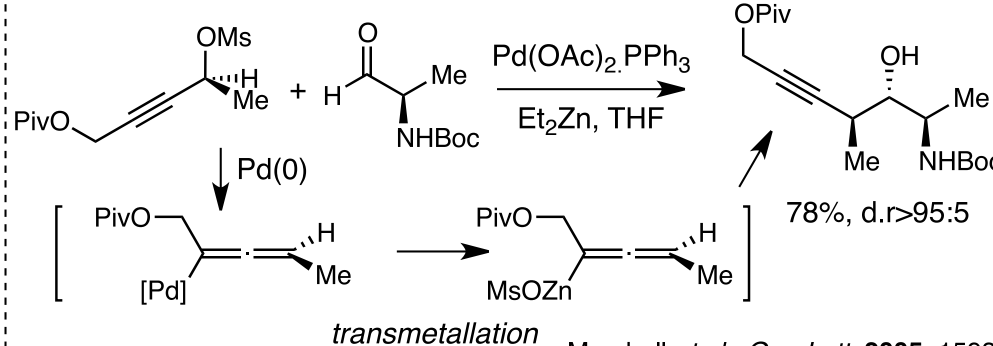
Part 3. Reactions of Allenes

NOT to be covered:
- allenes as an alkenes (eg: Diels-Alder reaction, coupling)
- allenes as enones, unsaturated esters...(eg. 1,4-addition inEWG substituted allenes)

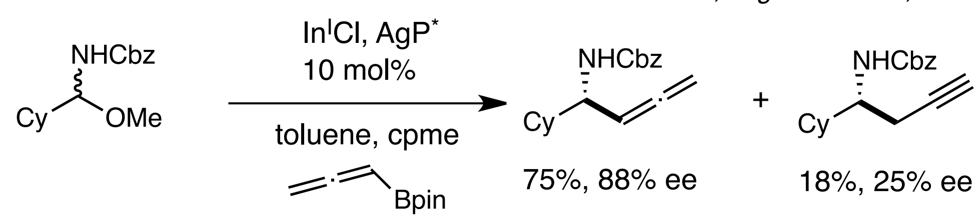
Allenylmetal Compounds



General rule (can be altered depend on R^1, R^2 and/or metals, electrophiles):
- allenic isomer is more table than propagylic one
- reaction in both S_E2 (Li, Mg...) and S_E2' (Sn, B, In, Zn...) manners
- syntheses: metal-halogen exchange/propargylic deprotonation (Li), Babier type oxidative addition (Mg, Zn, In...), transmetallation (Li, Mg to Cu, Sn, B, Si, Zn, Ti...), or palladium catalyzed hydrogenation (B, Si)
- some allenic and propargylic metals can be isolated (M=B, Si, Sn)



Marshall *et al.*, *Org. Lett.* **2005**, 1593.



Kobayashi and Schneider *et al.*, *Angew. Chem. Int. Ed.* **2011**, 11121.

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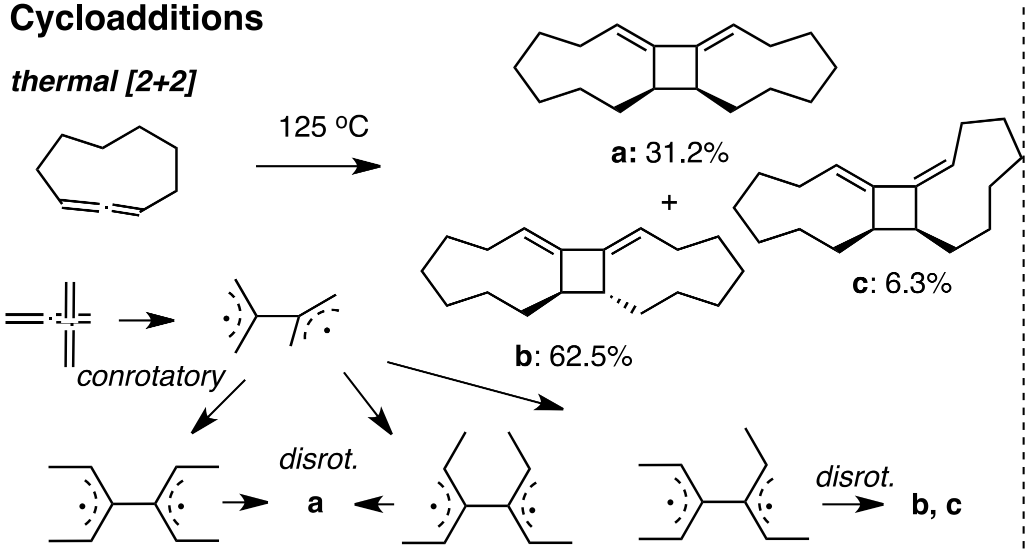
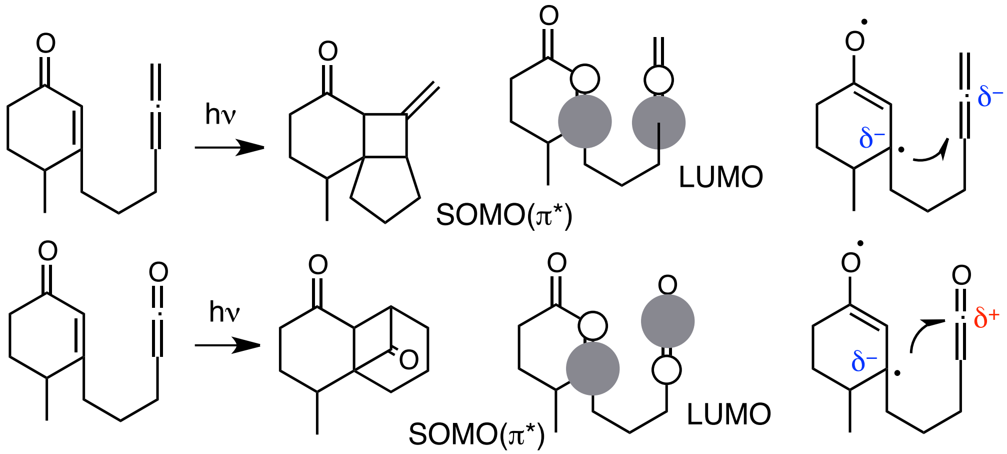
Cycloadditions

thermal [2+2]

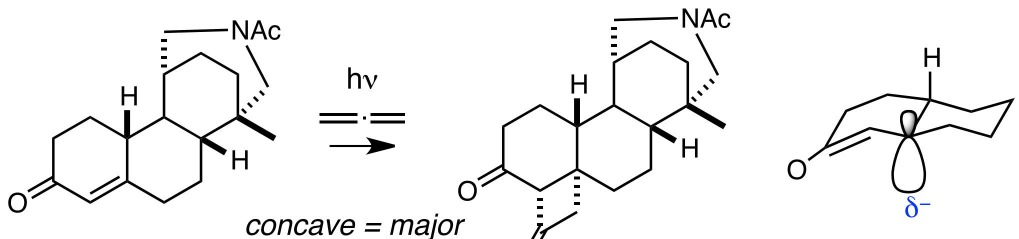


biradical as intermediate

photochemial [2+2]



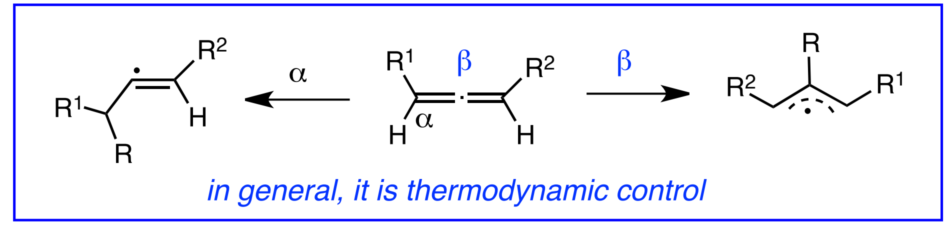
Becker *et al.*, *Chem. Commun.* **1975**, 277.

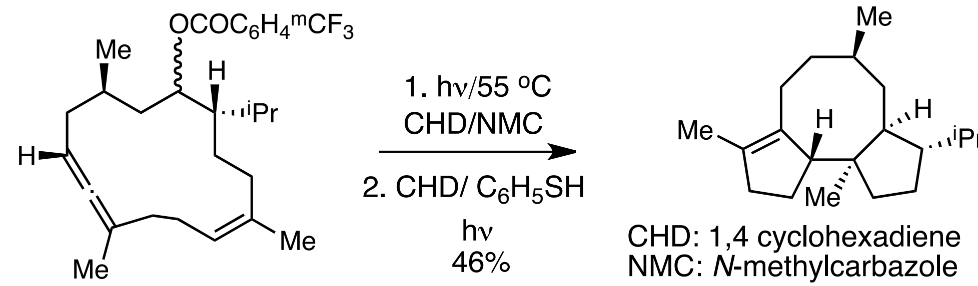


concave = major

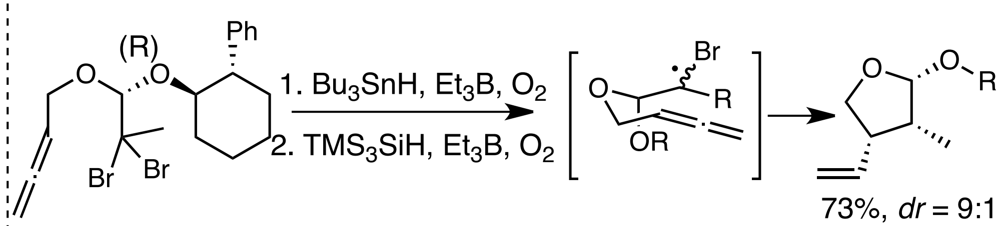
Weisner, *Tetrahedron* **1975**, 1655.

Free Radical Addition





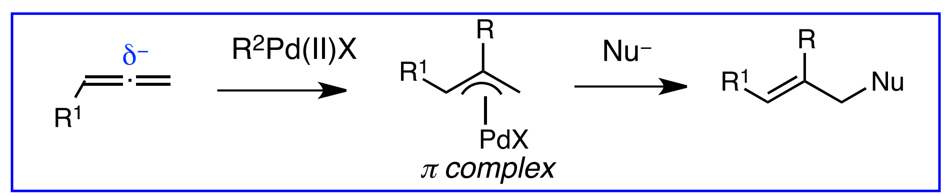
Mayers *et al.*, *J. Am. Chem. Soc.* **1993**, 7926.



Nauguier and Renaud *et al.*, *Tetrahedron asymmetry* **2003**, 3005.

Palladium-catalyzed Addition to Allenes

carbopalladation



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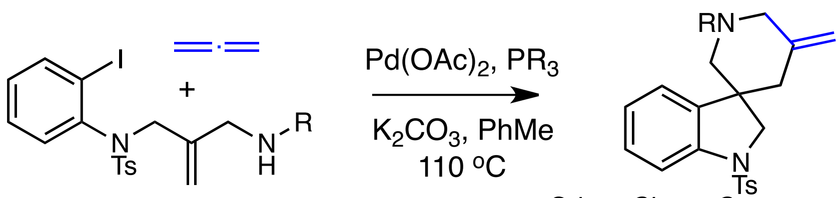
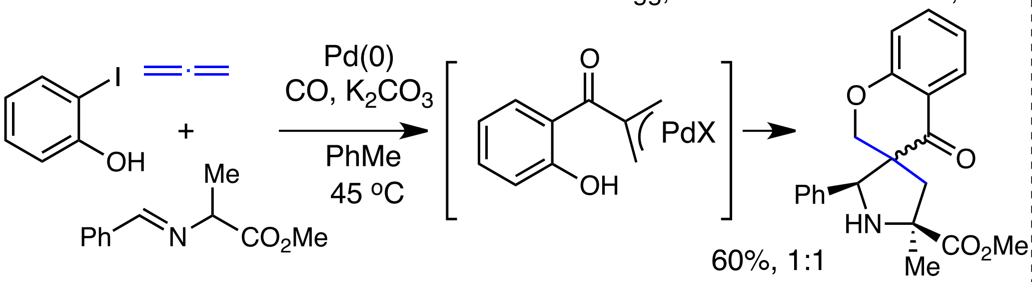
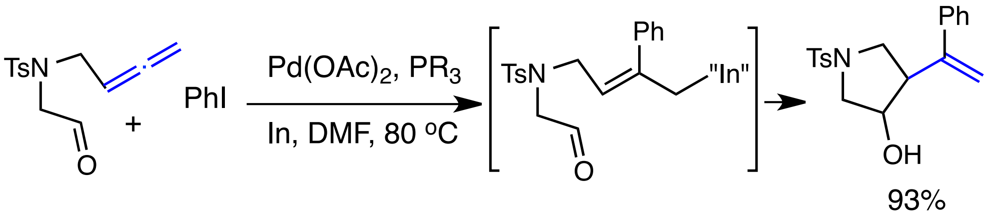


Grigg, *Chem. Commun.* **2001**, 964.

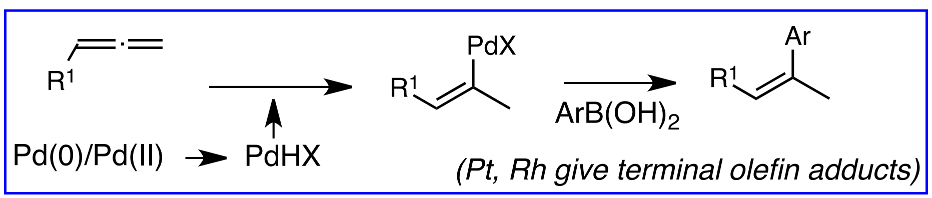


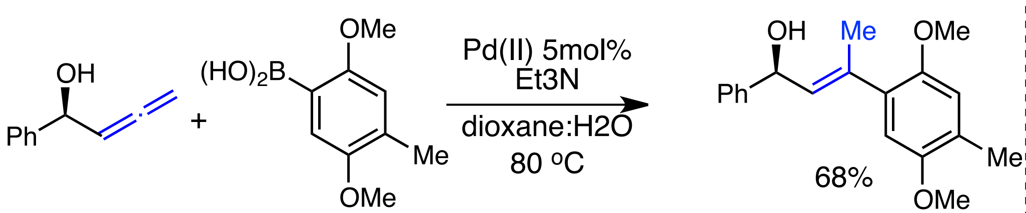
Grigg, *Tetrahedron Lett.* **2000**, 7129.



Kang *et al.*, *J. Org. Chem.* **2002,** 4376.

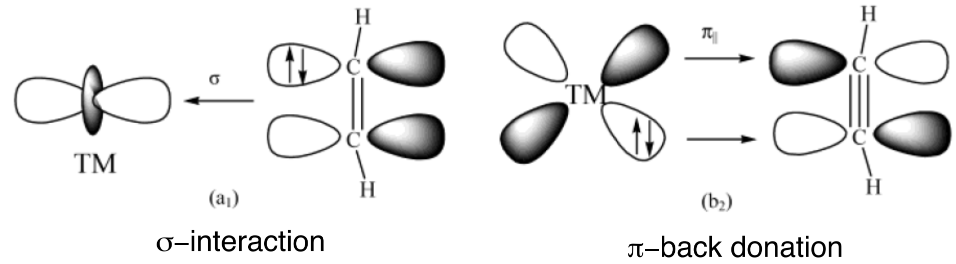
additions of arylboronic acid to allenes





Yoshida *et al.*, *Org. Lett.* **2009**, 1441.

Carbophylic Activation by *Solf* Lewis Acids



2 most important orbital interaction in TM-alkyne

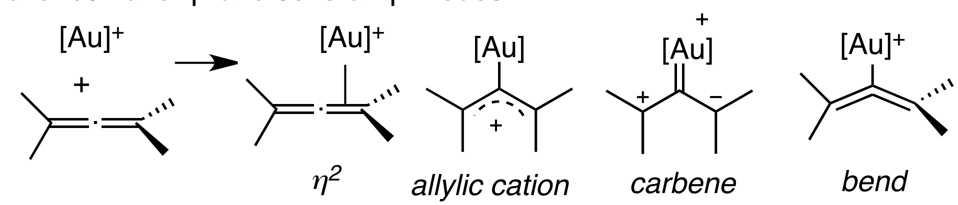
Rayon and Frenking et al., J. *Phy. Chem. A* **2004**, 3134.

calculated data (Cu^I, Ag^I, Au^I):
- ethylene ligand is slightly stronger bonded to TM$^+$
- σ–interaction contributed to about 55-70%, π–back donation contributed to about 20-33% of covalent bonds.

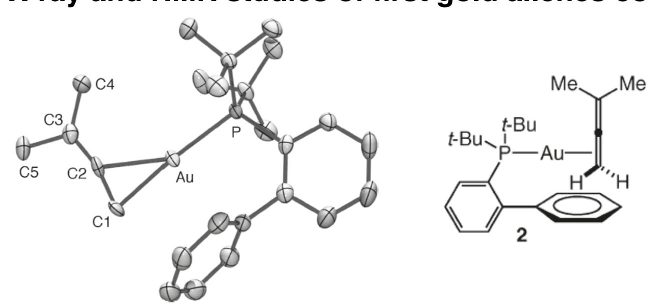
that means:
- reactions at the alkyne (allenes) *vs.* olefin sites are kinetic in origin (steric?)
- TM interacted multiple bonds become more electrophilic

Furstner and Davies, *Angew. Chem. Int. Ed.* **2007**, 3410.

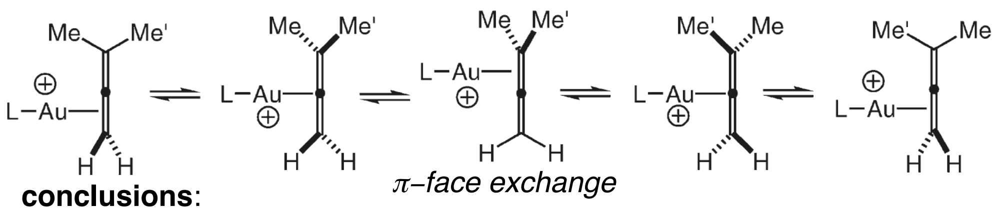
allenes *vs.* alkenes (and alkynes):
- alkynes and alkenes coodinate to TM in η^2 mode,
- allenes have η^2 and several η^1 modes



X-ray and NMR studies of first gold allenes complexes

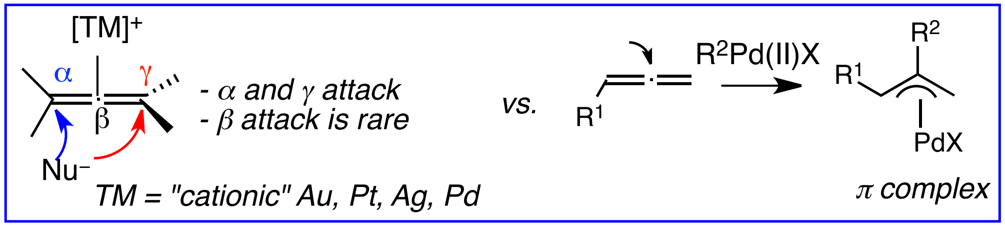


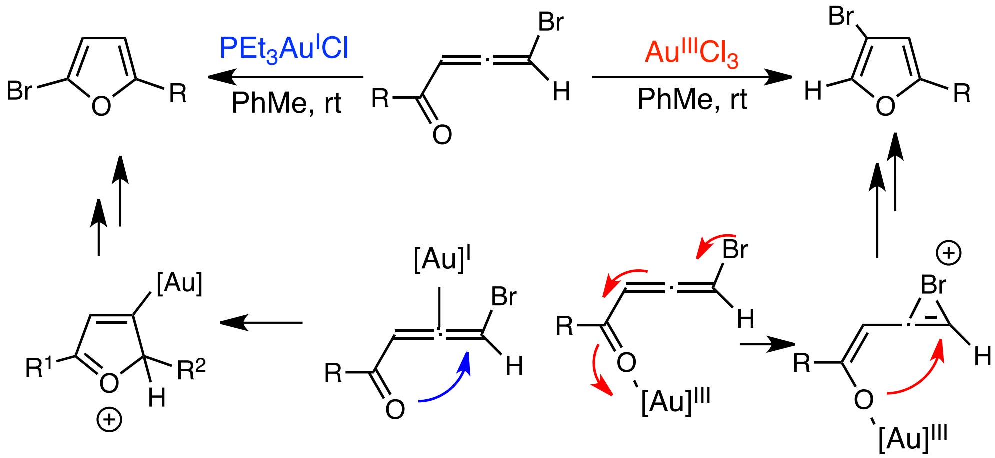
C1-C2: 1.340 Å
C2-C3: 1.311 Å
Au–C1: 2.191 Å
Au–C2: 2.306 Å
C1-C2-C3: 165.0



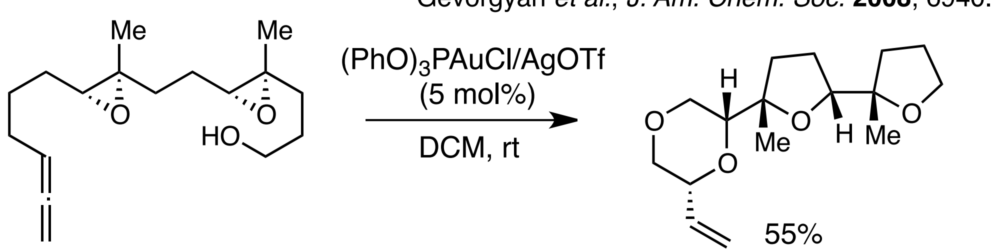
conclusions:
- gold tends to bind to less substituted C=C
- fluxional behavior: π-face exchange *via* η^1 intermediate

Widenhoefer *et al.*, *Organometalic* **2010**,4207.

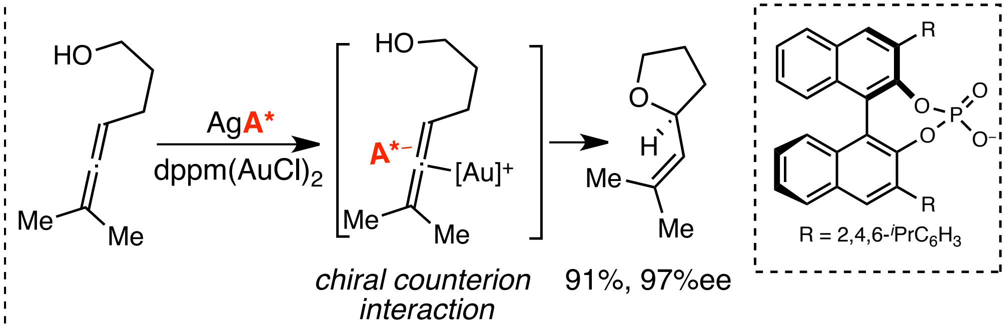




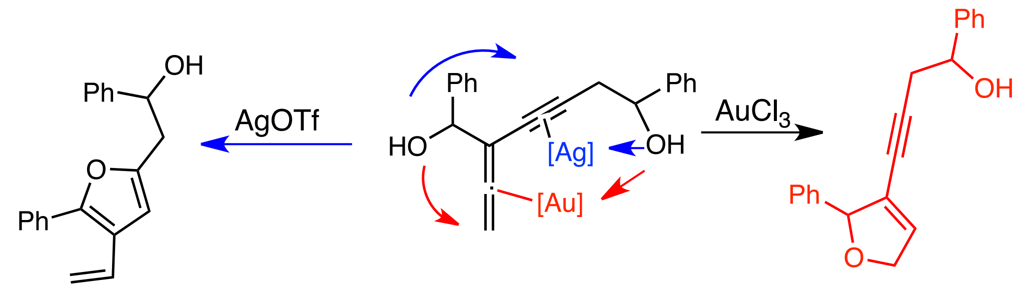
Gevorgyan *et al.*, *J. Am. Chem. Soc.* **2008**, 6940.



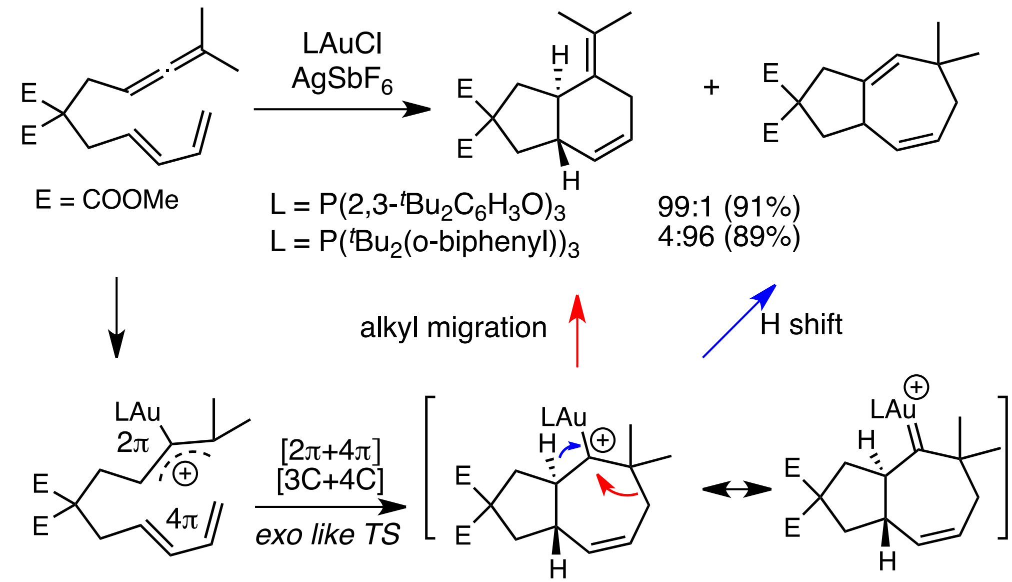
Widenhoefer *et al.*, *J. Am. Chem. Soc.* **2006**, 9066.



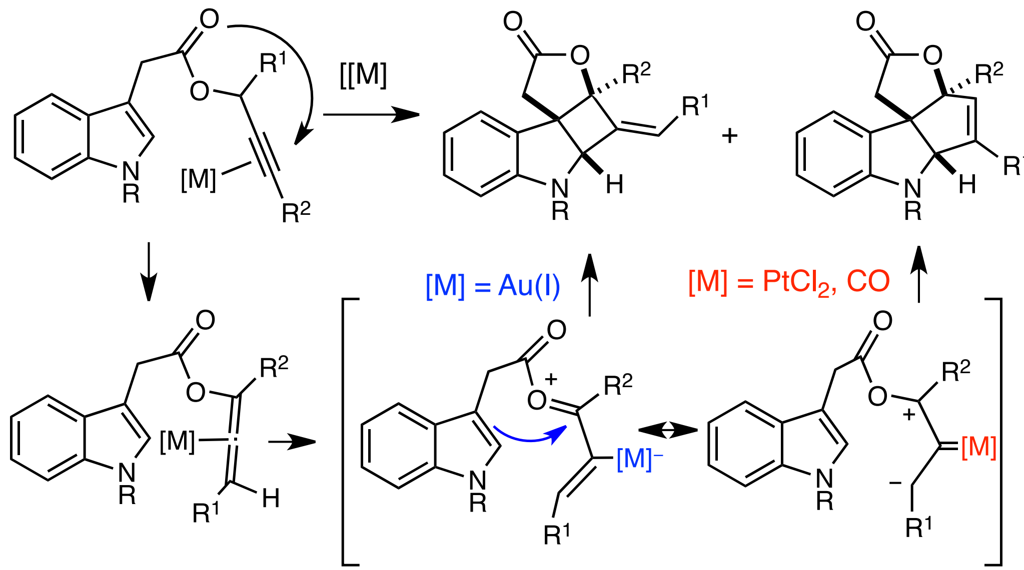
Halminton and Toste *et al.*, *Science* **2007**, 496.



Kim and Lee *et al.*, *Adv. Synth. Catal.* **2008**, 547.



Toste *et al.*, *J. Am. Chem. Soc.* **2009**, 6348.
Montserrat *et al.*, *J. Am. Chem. Soc.* **2009**, 13020.

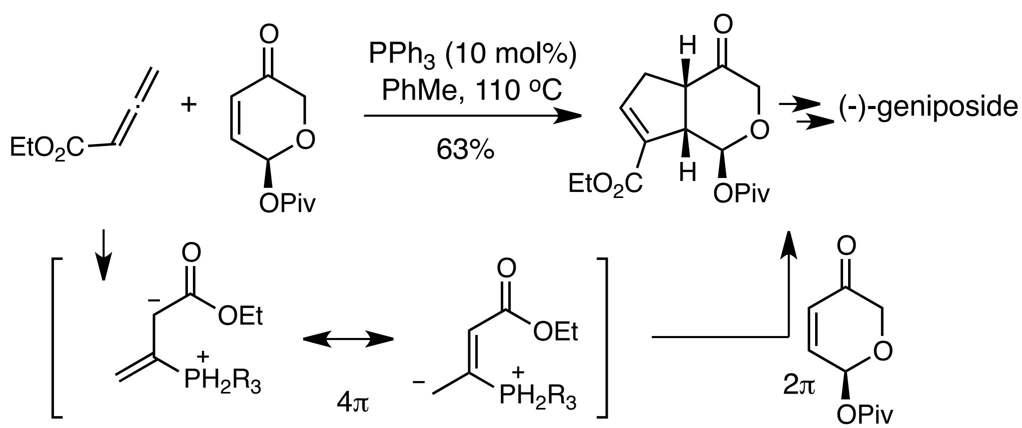


Pt *cat.* favors carbenoid mechanism *vs.* Au *cat.* *via* carbocationic intermediate

General conclutions (noble metals catalyzed reactions of allenes, alkynes):
- "importance of charge in synthetic design: introduction of a charged atom into a molecular skeleton undergoing bond reorganization usually lowers the activation of energy of the process, which leads to milder reaction conditons and greater selectivities"
- effect of noble metals on TS: play important roles in various points of the reaction (not just as solf Lewis acids).

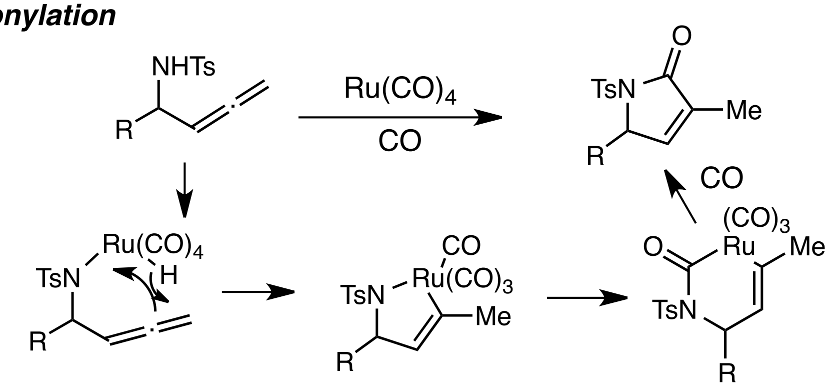
topics in current chemistry, 302, p125-6.

Phosphine-catalyzed Cycloaddition

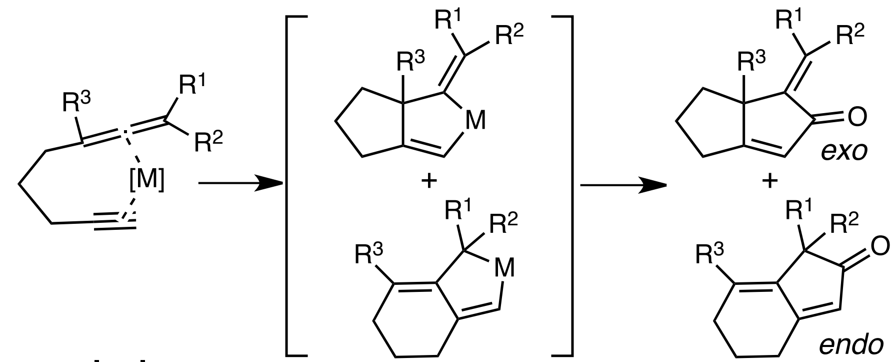


Carbonylation and Pauson-Khand Reaction

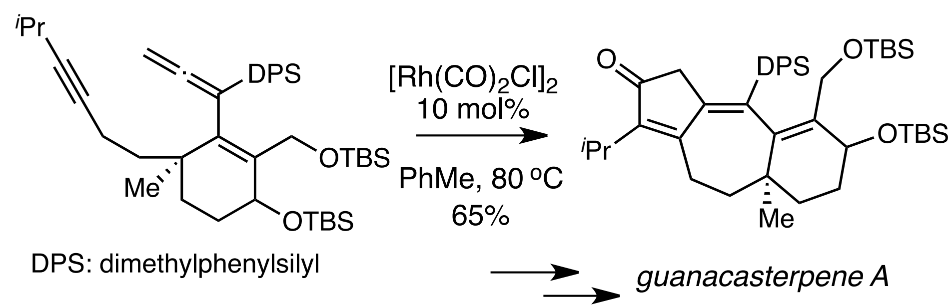
carbonylation



allenic Pauson-Khand reactions



general rules:
- $Co_2(CO)_8$ is not effective, causing polymerization
- $Mo(CO)_6$ favors *exo*-cyclized products
- $[Rh(CO)_2Cl]_2$ favors *endo*-cyclized products
- $R_3 \neq H$: *endo* products are prefered



DPS: dimethylphenylsilyl

Brummond and Gao *et al.*, *Org. Lett.* **2003**, 3491.

other important topics: oxidation (including epoxidation), electrophilic additions...

Part 4. Important References

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2. Computational mechanism of Au and Pt catalyzed reactions, topics in current chemistry, 302, Soriano and Marco-Cotelles, Springer, **2011**.
3. Allenes in organic synthesis, Schuster and Coppola, *Wiley,* **1984**.
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6. Gold-catalyzed nucleophilic cyclization of functionalized allenes: a powerful access to carbo-heterocycle, Krause *et al., Chem Rev.* **2011**, 111.
7. Catalytic carbophilic activation: catalysis by platinum and gold p acids, Furstner and Davies, *Angew. Chem. Int. Ed.* **2007**, 3410.
8. how easy are the synthesis of allenes?, Ma *et al., Chem. Commun.* **2011**, 5384