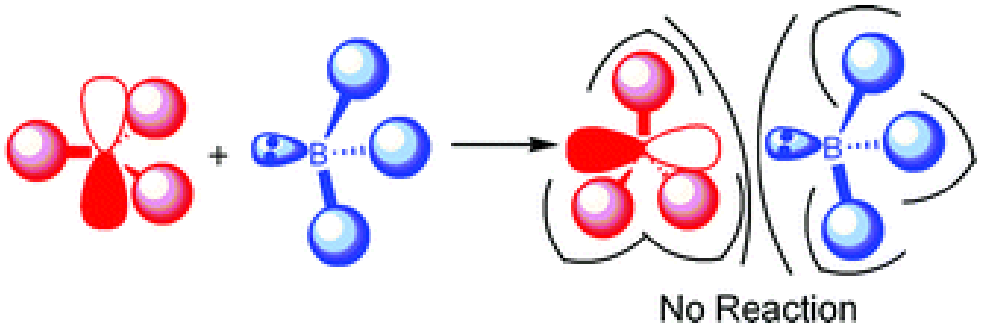
“Frustrated Lewis Pairs”: A Concept for New Reactivity and Catalysis

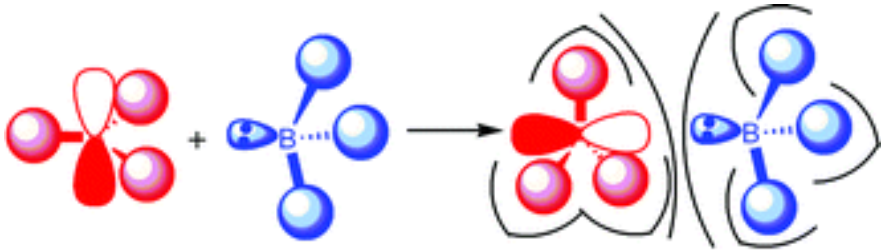


Olivier Baslé

November 25, 2010

Stephan, D. W. *Org. Biomol. Chem.* **2008**, *6,*1535.
Stephan et al. Angew. Chem. Int. Ed. 2010, 49, 46

The Concept



Lewis acid: Electron pair acceptor

Lewis base: Electron pair donor

“Frustrated lewis pair” (FLP)

Donor Acceptor Adduct:

$NH_3.BH_3$: classical Lewis acid/Lewis base adduct

Metal-Ligand (ML) ineherent concept of transition metal coordination chemistry

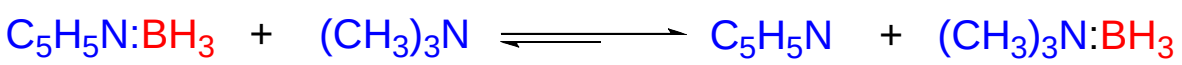
Molecular orbital rationale

Relative stability of some coordination Compound of Boron

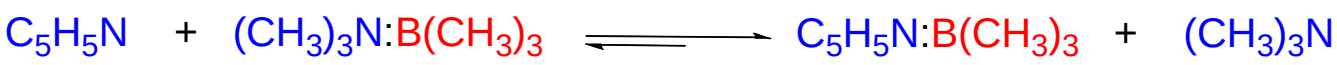
Brown et al. *J Am Chem. Soc.* **1942**, *64*, 325.

NMe_3 is a stronger base than Pyridine

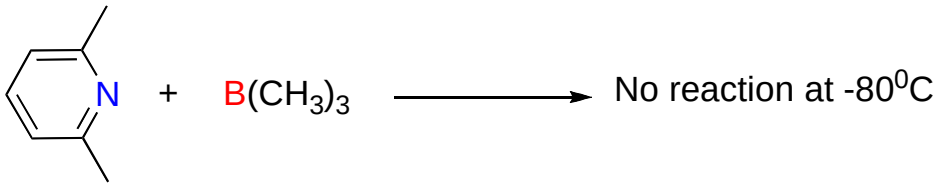
With borine; pyridine is diplaced from the coordination compound



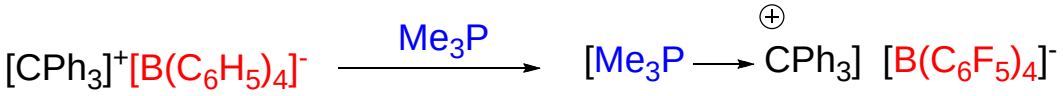
Results obtained In presence of triethylborone, stands in contradition

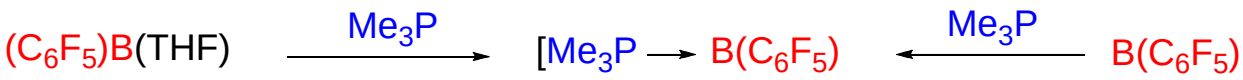


$Et_3N:B(CH_3)_3$ Stable only at low temperatures

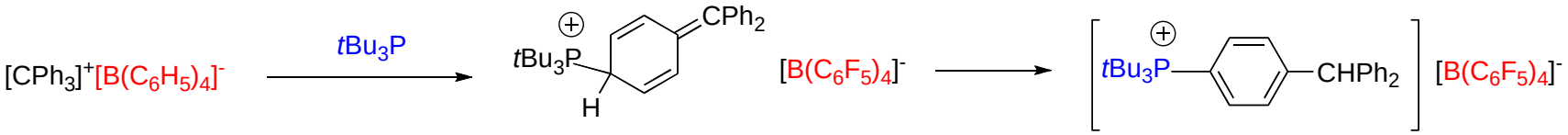


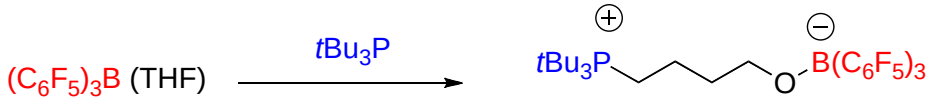
Classical Lewis Adducts

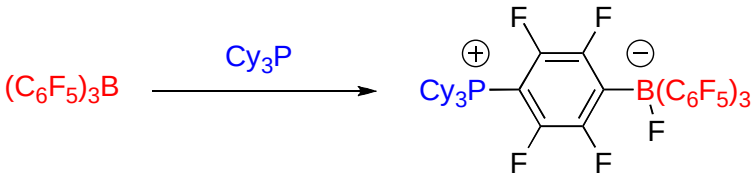




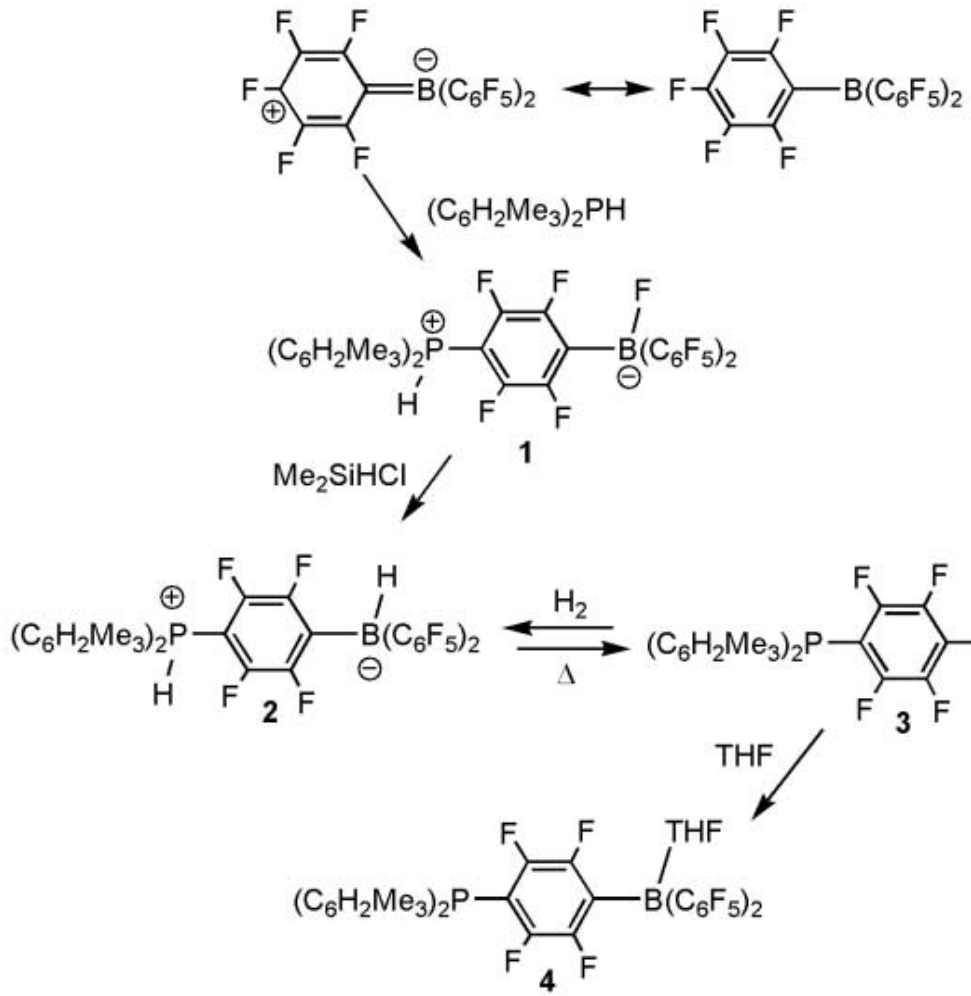
Frustrated Lewis Pair Products







Activation of small Molecules by FLPs



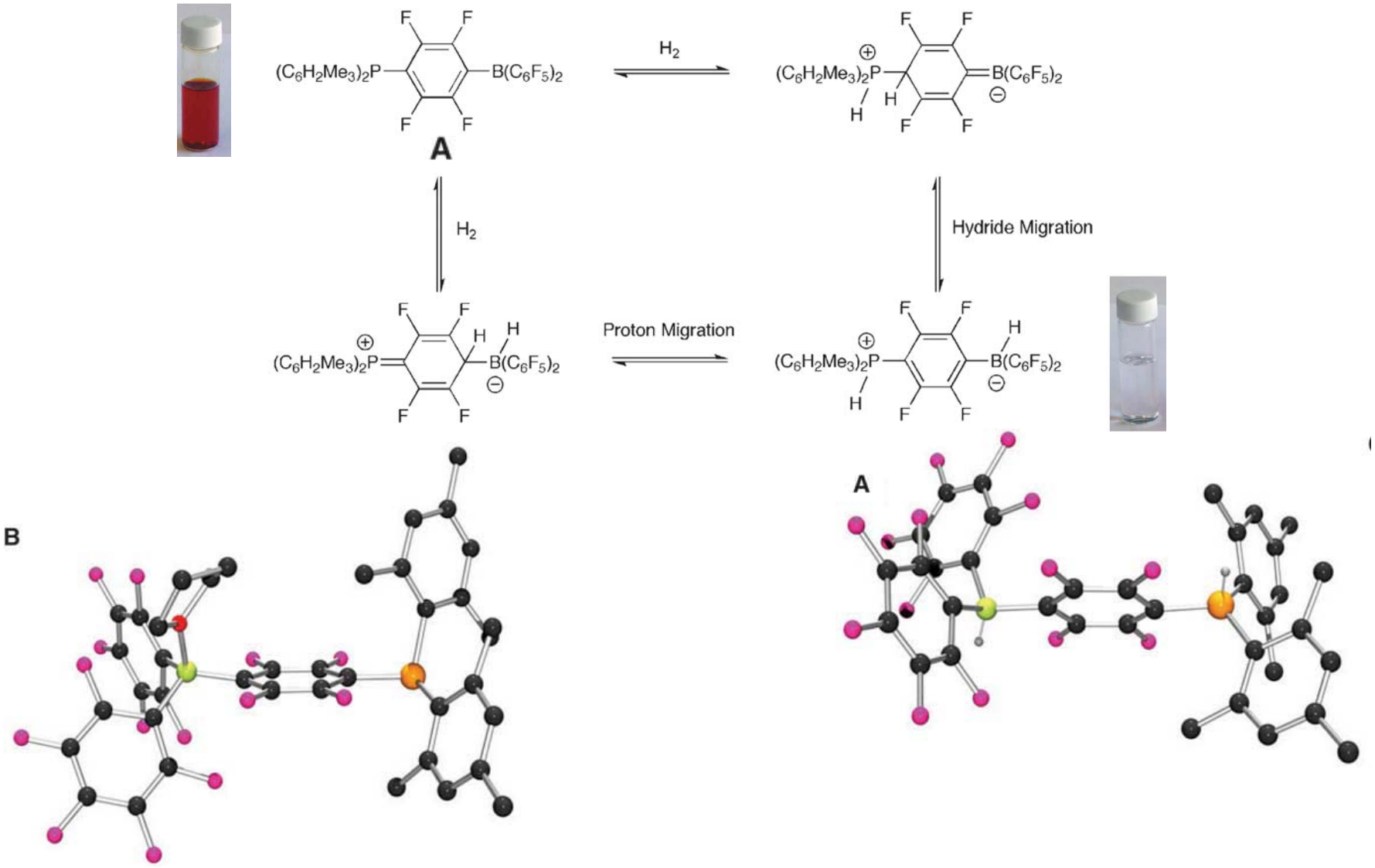
Monomeric in solution

ense color related to:

$_2PC{\equiv}CB(C_6H_2Me_3)_2$

Stephan et al. Science, **2006**, *314*, 1124.

Crystallographic studies



Stephan et al. Science, **2006**, *314*, 1124.

Simple Combination of Phosphines and Boranes

$B(C_6F_5)_3 + Cy_3P \xrightarrow[1\ atm,\ 25^oC]{H_2} [Cy_3PH][HB(C_6F_5)_3]$

$BPh_3 + tBu_3P \xrightarrow[1\ atm,\ 25^oC]{H_2} [tBu_3PH][HBPh_3]$

33 % yield

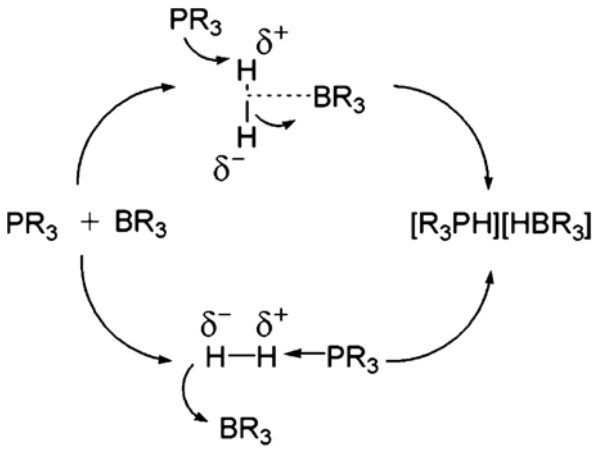
$B(C_6F_5)_3 + (C_6F_5)_3P \xrightarrow[1\ atm,\ 25^oC]{H_2}$ No reaction

$BMes_3 + tBu_3P \xrightarrow[1\ atm,\ 25^oC]{H_2}$ No reaction

$B(C_6F_5)_3 + R_3P \xrightarrow[1\ atm,\ 25^oC]{H_2} [R_3P][B(C_6F_5)_3]$

R = Me, Ph

Possible Mechanism for Heterolytic Cleavage of H_2 by Phosphine and Borane.

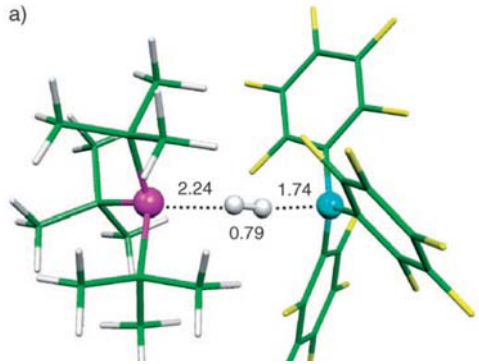


Stephan et Al. *J. Am. Chem. Soc.* **2007**, *129*, 1880

See also mechanism of H_2 activation by carbenes:

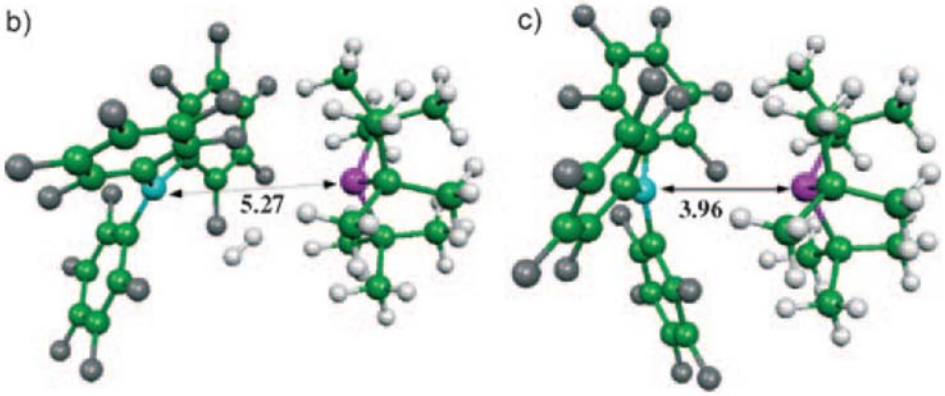
Bertrand et Al. *Science*, **2007**, *316*, 439.

Computational models of phosphine-borane activation of H_2



a) $t\mathrm{Bu_3P}$ ------ H --- H ----- $\mathrm{B(C_6F_5)_3}$

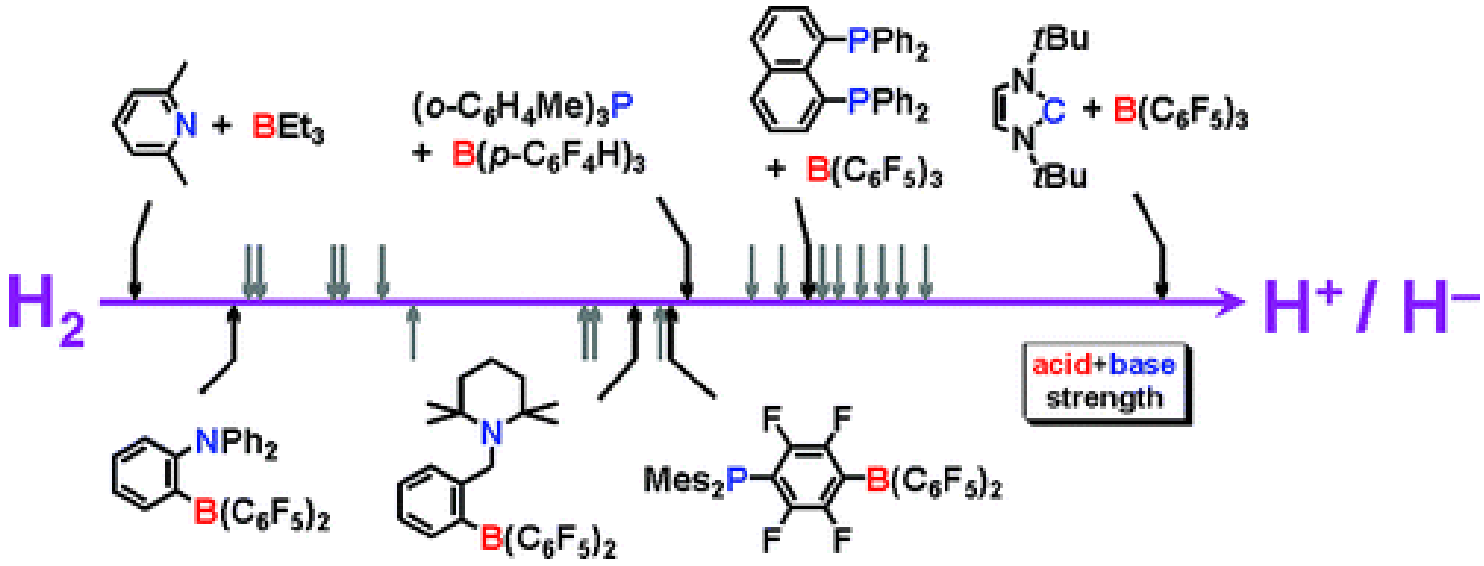
2.24 Å, 1.74 Å, 0.79 Å



a) Papai et al. *J. Am. Chem. Soc.* **2009**, *131*, 2029. *Angew Chem Int. Ed.* **2008,** 47, 2435.

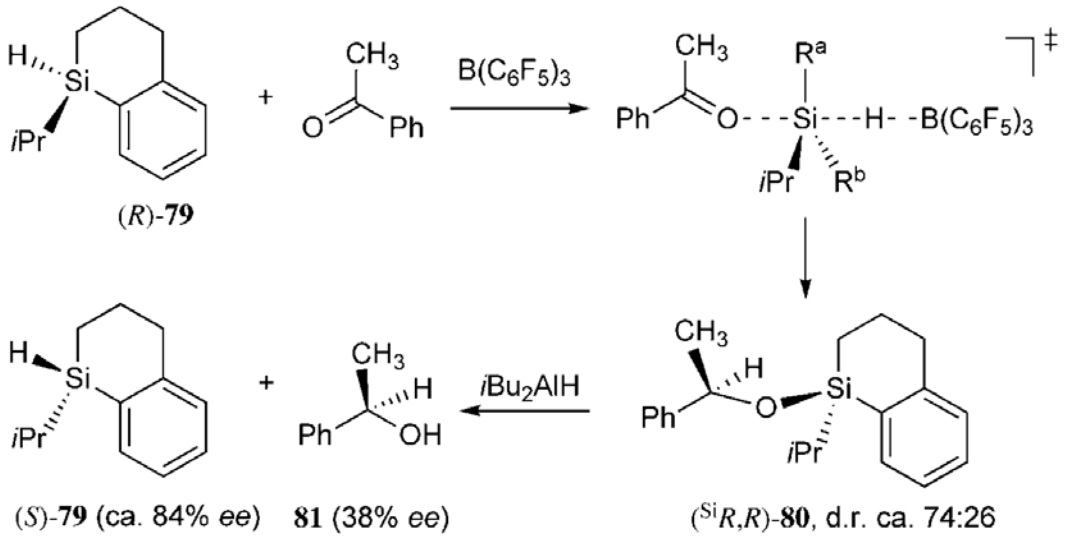
b) c) Grimme et Al. *Angew. Chem. Int. Ed.* **2009,** ; *J. Comput. Chem.* **2006,** *27,* 1787.

Rationalizing the Reactivity of Frustrated Lewis Pairs: Thermodynamics of H_2 Activation and the Role of Acid-Base Properties



Papai et al. *J. Am. Chem. Soc.* **2009**, *131*, 10701.

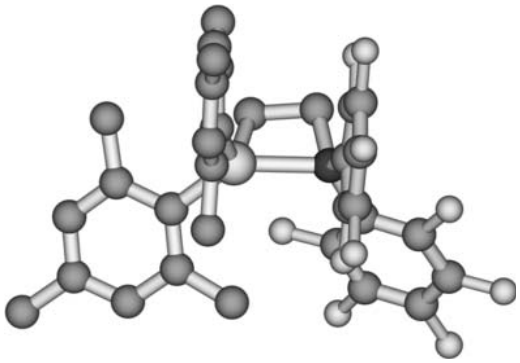
Stereochemical analysis using the “Oestreich silane”

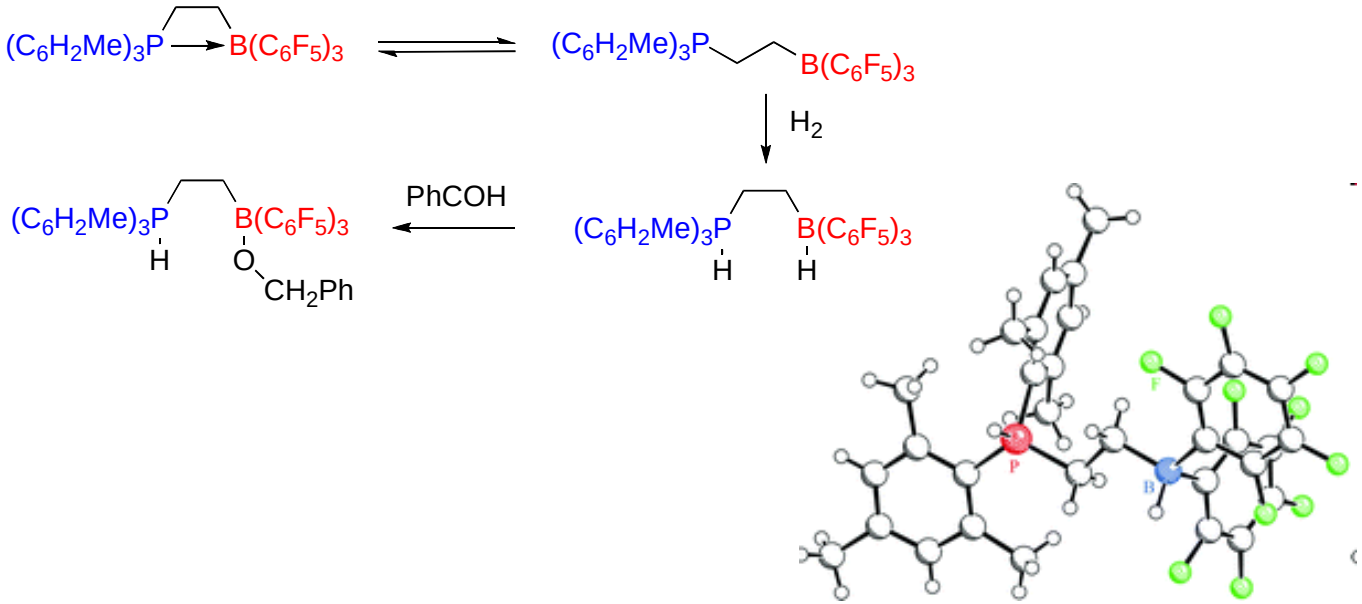


S_N2-type process with an inversion at the silicone atom.

Oestreich et al. *angew. Chem. Int. Ed.* **2008**, *47,* 5997. And references therein.

Systems as Reducing Agent



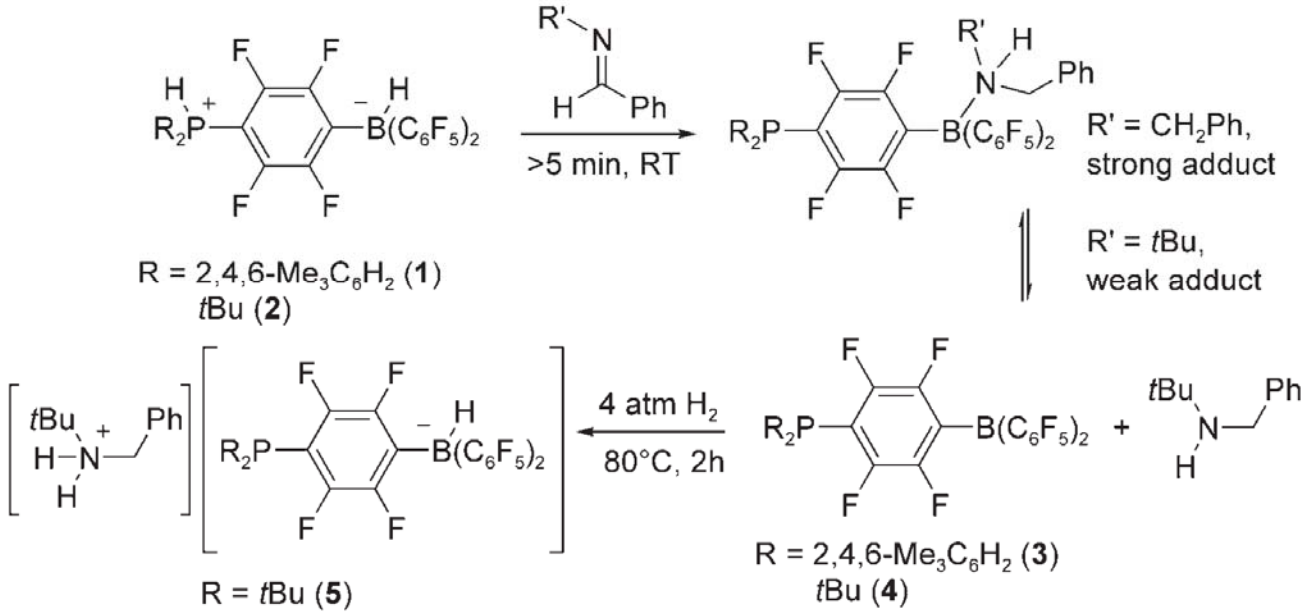


Erker et Al. *Chem. Commun.* **2007**, 5072

Stoichiometric reduction of imines

[redacted]

Mechanism:

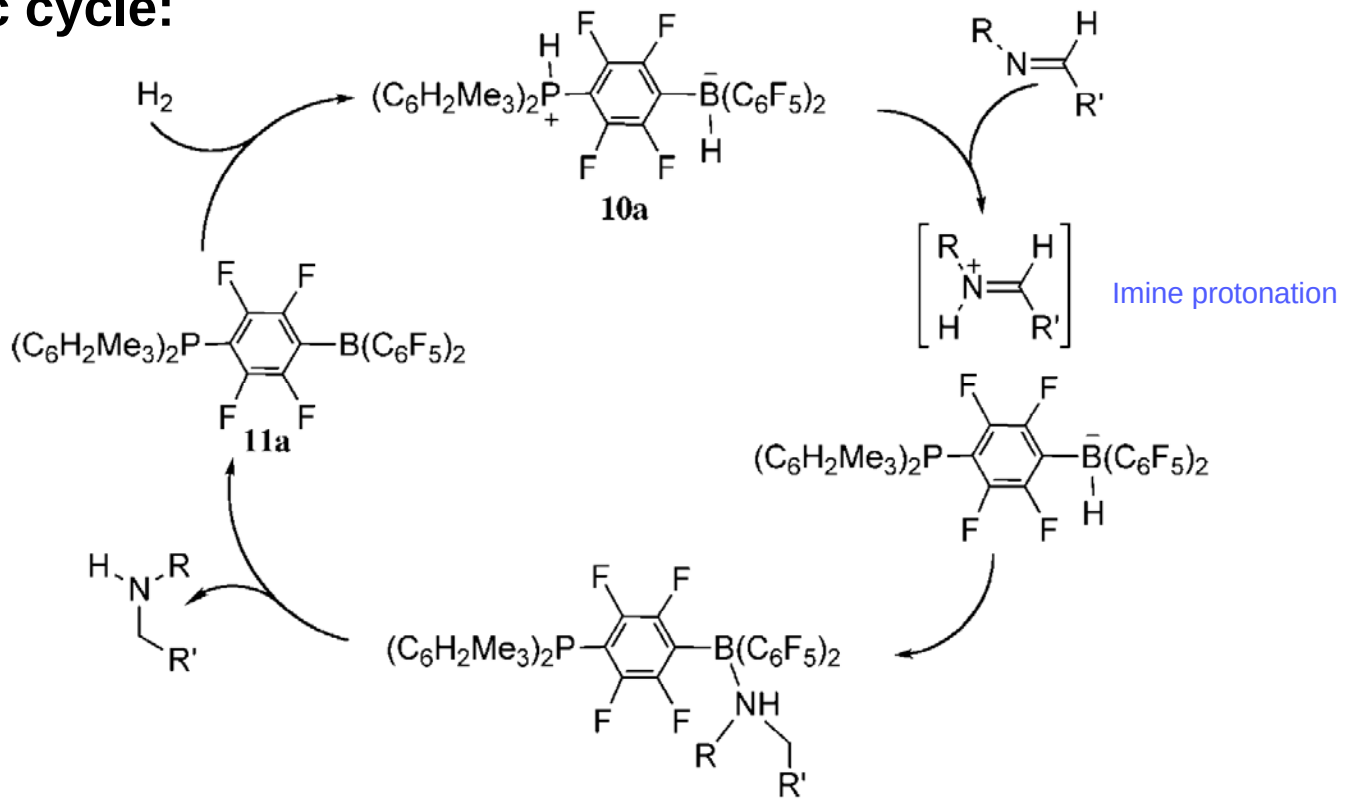


Stephen et al. *Angew Int. Ed*. **2007**, *46*, 4968.

Catalytic reduction of imines with FLP

[redacted]

Catalytic cycle:

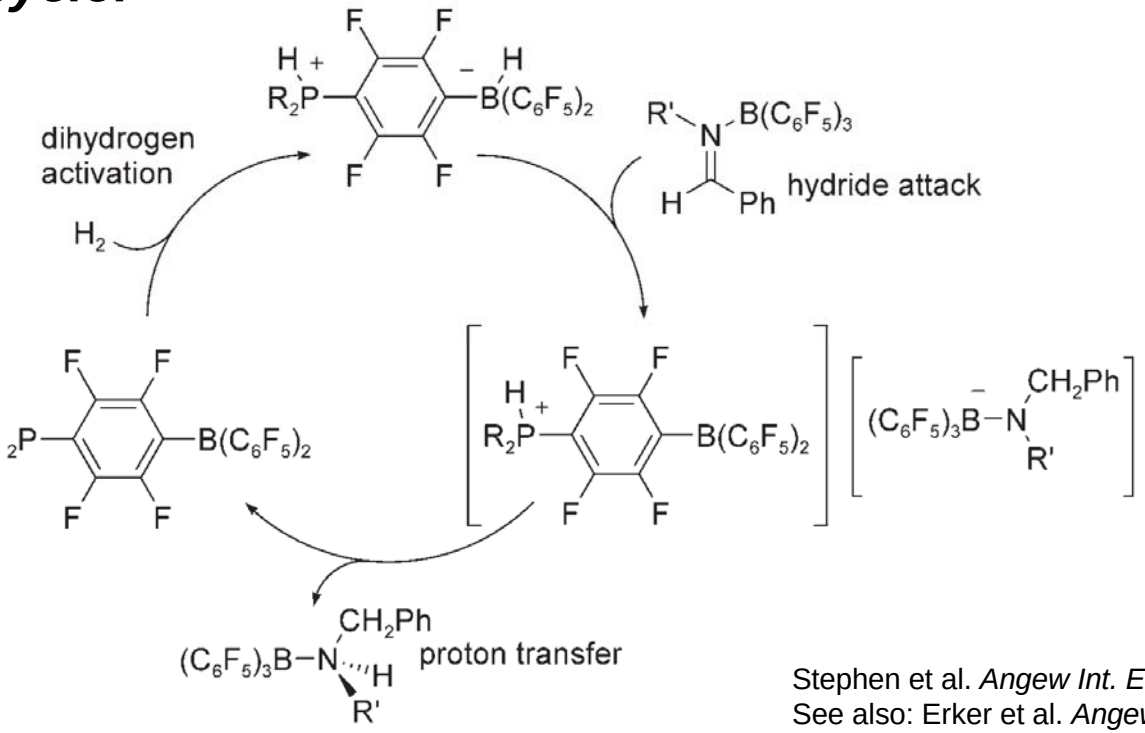


Stephan et al. *Chem. Commun*. **2008,**1701.

Catalytic reduction of $B(C_6F_5)_3$-protected imine.

[redacted]

Catalytic cycle:

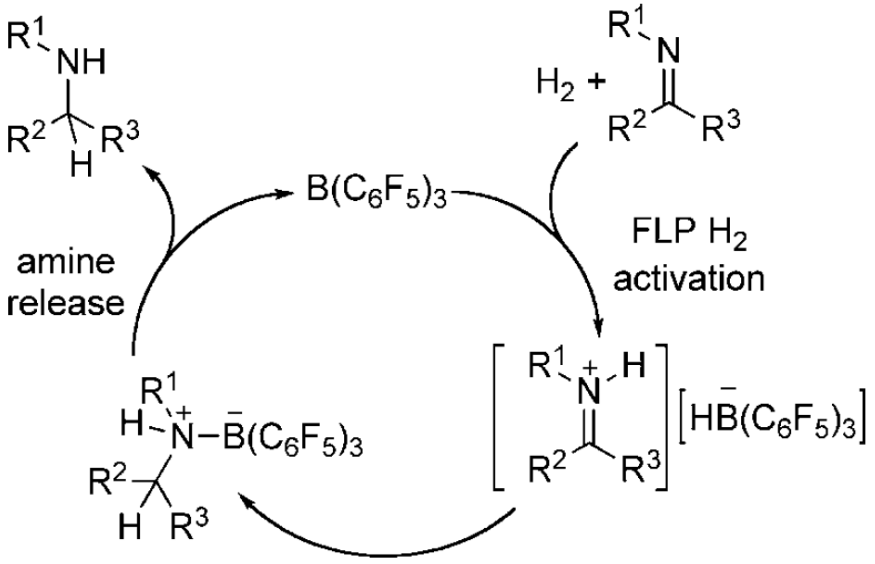


Stephen et al. *Angew Int. Ed*. **2007**, *46*, 4968.
See also: Erker et al. *Angew. Chem. Int. Ed.* **2008,** *47*, 7543

Catalytic reduction of imines by $B(C_6F_5)$

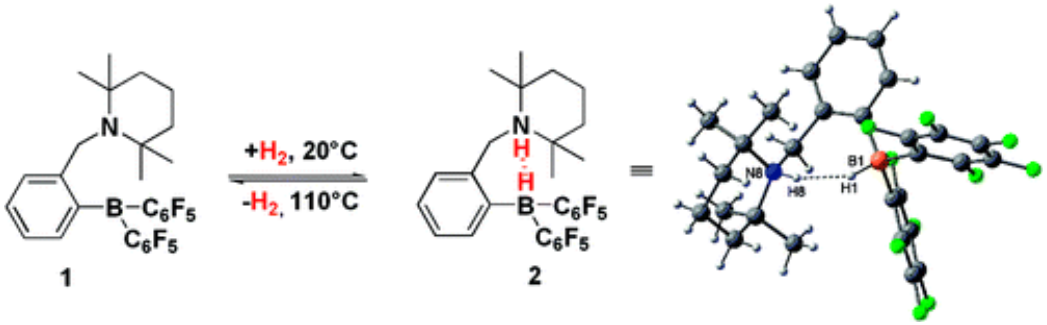
[redacted]

Catalytic cycle:



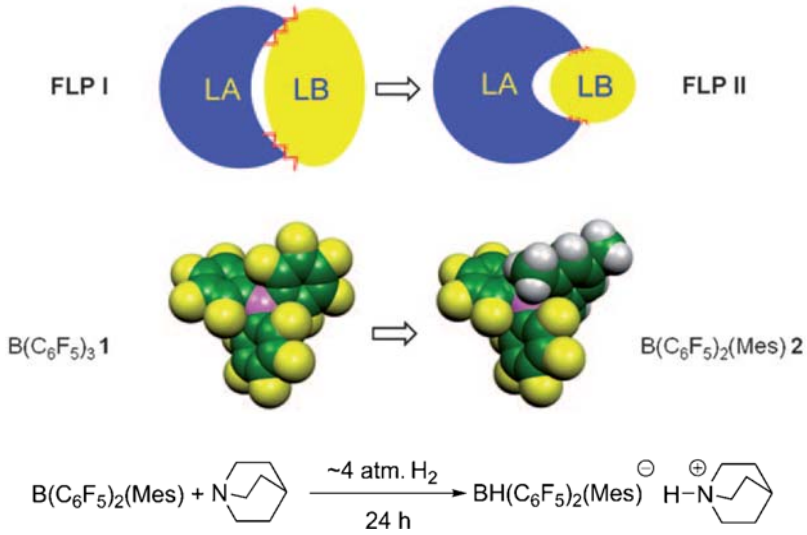
Stephen et al. *Chem. Commun.* **2008**, 1701.

H_2 activation by amine-borane FLP: Catalytic reduction of simple imines



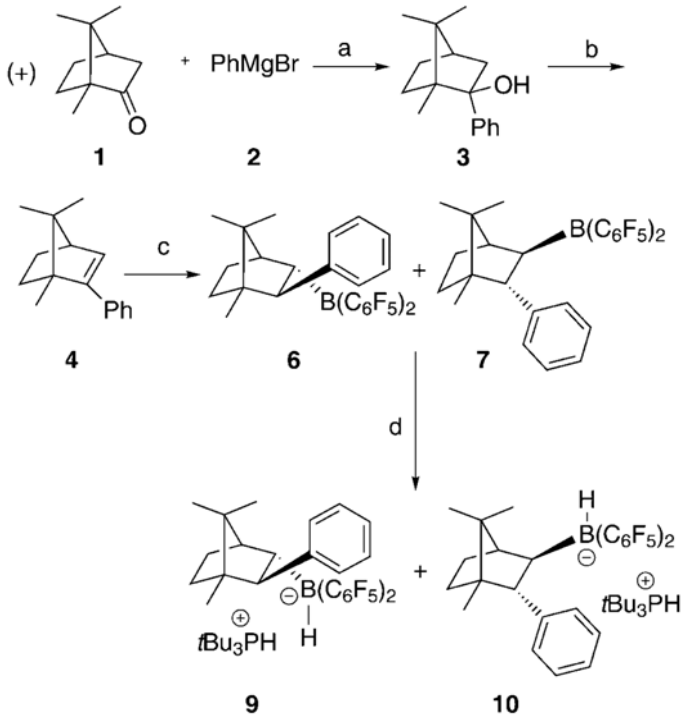
Catalytic reduction of simple imines.

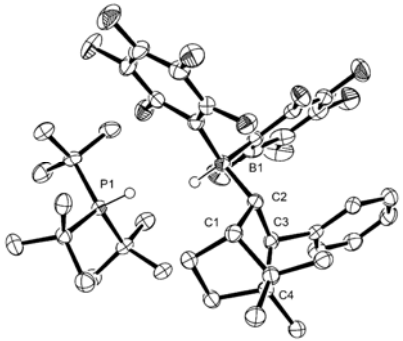
Repo and Rieger, *J. Am. Chem. Soc.* **2008**, *130*, 14117.

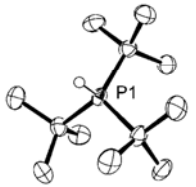


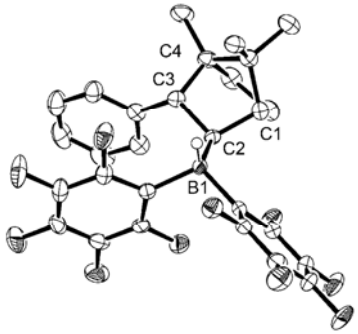
Soos et al. *Angew Int. Ed*. **2010**, *49*, 4968.

Asymmetric Hydrogenation: Chiral FLP





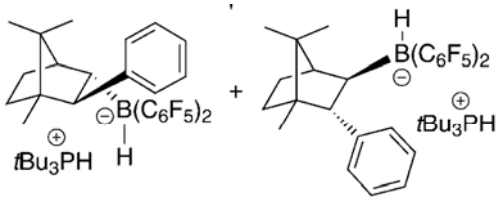




Scheme 1. Synthesis of chiral boranes and subsequent reaction of the FLPs with hydrogen. a) THF, 66 °C, 12 h; b) pyridine, $SOCl_2$, −10 °C, 1 h, 78 %; c) $(C_6F_5)_2BH$ (**5**), *n*-pentane, RT, 1 h, 99 %, d) *t*Bu_3P (**8**), H_2, *n*-pentane, RT, 30 h, 53 %.

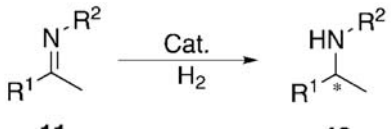
Klankermayer et al. *Angew Int. Ed*. **2010**, *49*, early view.

Enantioselective Hydrogenation with FLP



9 **10**

Table 1: Hydrogenation catalyzed by chiral FLP salts.

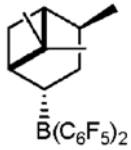


11 **12**

11a: R^1 = Ph, R^2 = Ph
11b: R^1 = Ph, R^2 = 2-Me-C_6H_4
11c: R^1 = Ph, R^2 = 2,6(Me_2CH)C_6H_3
11d: R^1 = 4-MeO-C_6H_4, R^2 = Ph
11e: R^1 = Ph, R^2 = 4-MeO-C_6H_4
11f: R^1 = 2-Naphthyl, R^2 = Ph
11g: R^1 = 2-Naphthyl, R^2 = 4-MeO-C_6H_4

Entry[a]	Substrate	Catalyst	Yield [%][c]	*ee* [%][d]
1	**11a**	**9/10** = 1:1	> 99	20 (*S*)
2	**11a**	**9**	> 99	48 (*S*)
3	**11a**	**10**	95	79 (*R*)
4[b]	**11b**	**10**	37	74 (−)
5[b]	**11c**	**10**	0	–
6	**11d**	**10**	96	81 (−)
7	**11e**	**10**	> 99	81 (*R*)
8	**11f**	**10**	93	80 (−)
9	**11g**	**10**	96	83 (+)

[a] Reaction conditions: Catalyst (10 µmol), imine (0.2 mmol), H_2 (25 bar), T = 65 °C, 15 h. [b] Reaction time: 20 h. [c] Yield was determined by ^{1}H NMR analysis. [d] Determined by HPLC or GC methods using a chiral column; absolute configurations assigned by comparison of retention times and optical rotations with literature values.

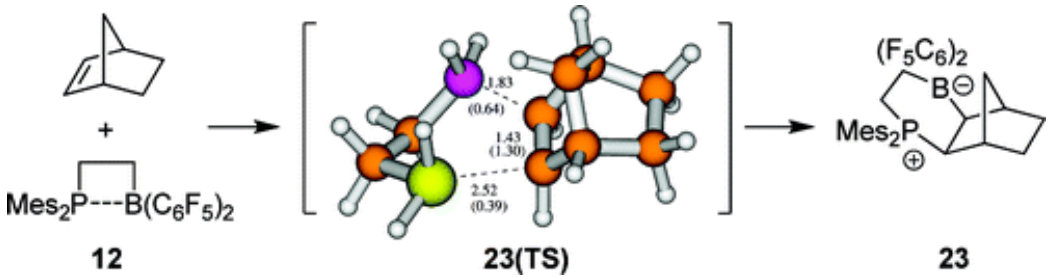


α-pinene borane : 16 % ee

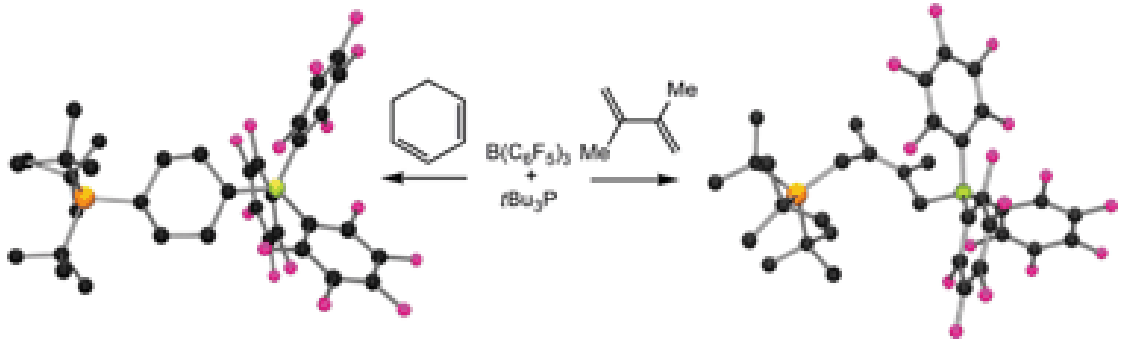
Klankermayer et al. *chem. Commun.* **2008**, *49*,2130

Klankermayer et al. *Angew Int. Ed*. **2010**, *49*, early view.

FLP for the activation of small molecules:
Reaction with alkenes

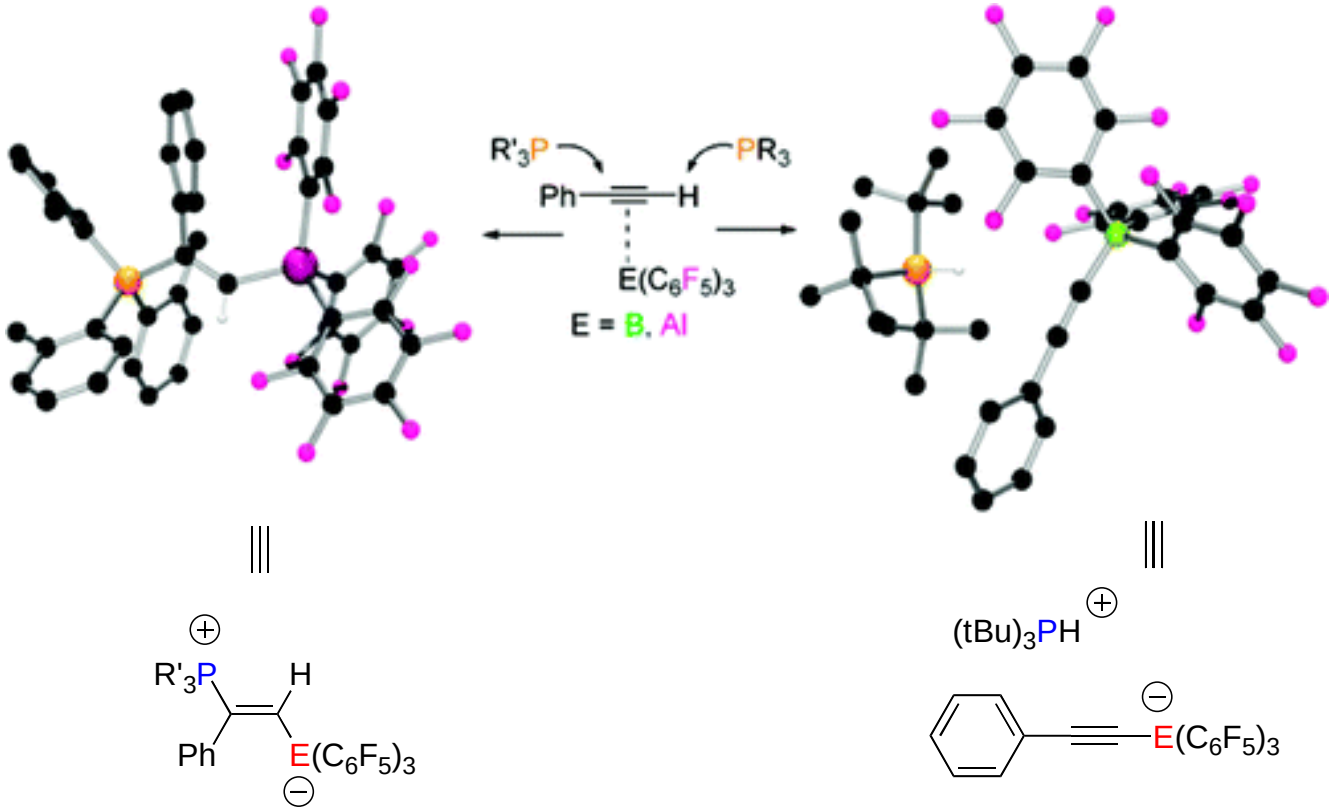


Erker et al. *J. Am. Chem. Soc.* **2009**, *131,* 12280
and references therein



Stephan et al. *Chem. Commun.* **2009**, 2335
and references therein

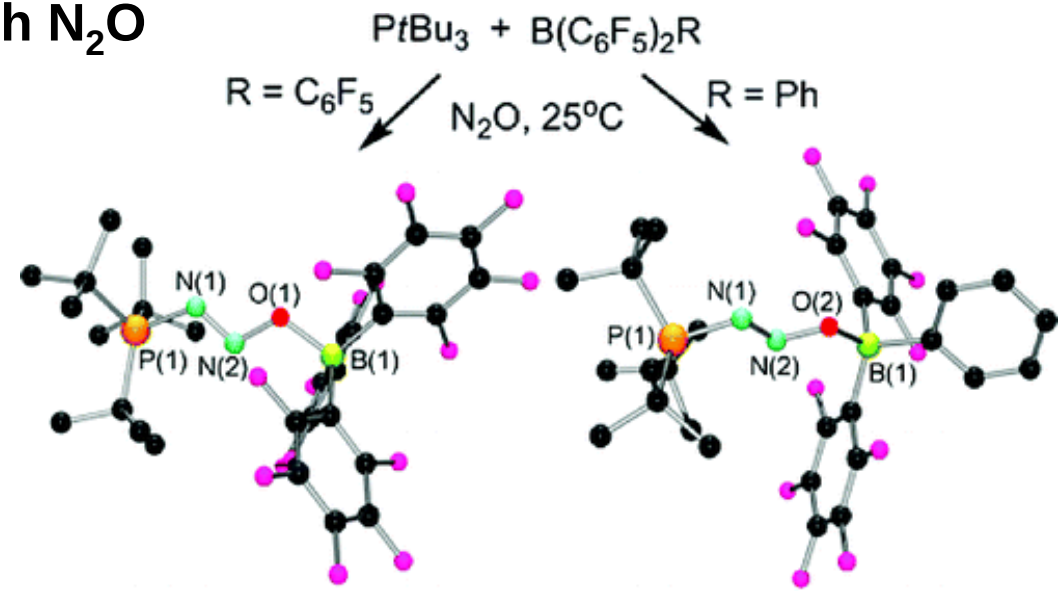
FLP for the activation of small molecules:
Reaction with alkynes



Stephan et al. *J. Am. Chem. Soc*. **2009** *131*, 8396.

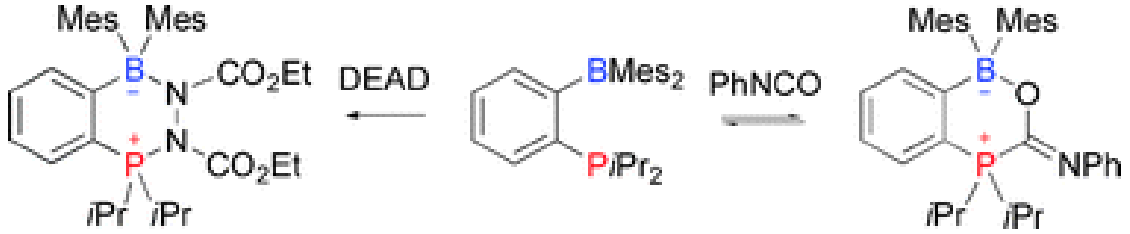
FLP for the activation of small molecules:

Reaction with N_2O



Stephan et al. *J. Am. Chem. Soc.* **2009**, *131*, 9918.

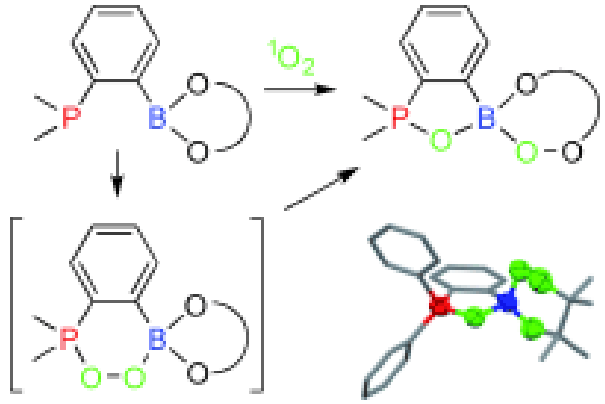
Reaction with PhCNO



Bourissou et al. *Chem. Commun.* **2008**, 3435

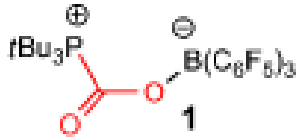
FLP for the activation of small molecules

Reaction with singlet O_2



Bourissou et al. *Angew. Chem. Int. Ed.* **2010**, *49,* 6186.

Reaction with singlet CO_2



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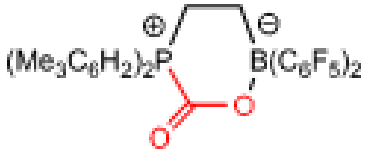

2

Stephan et al. *Angew. Chem. Int. Ed.* **2019** *498,* 66436.