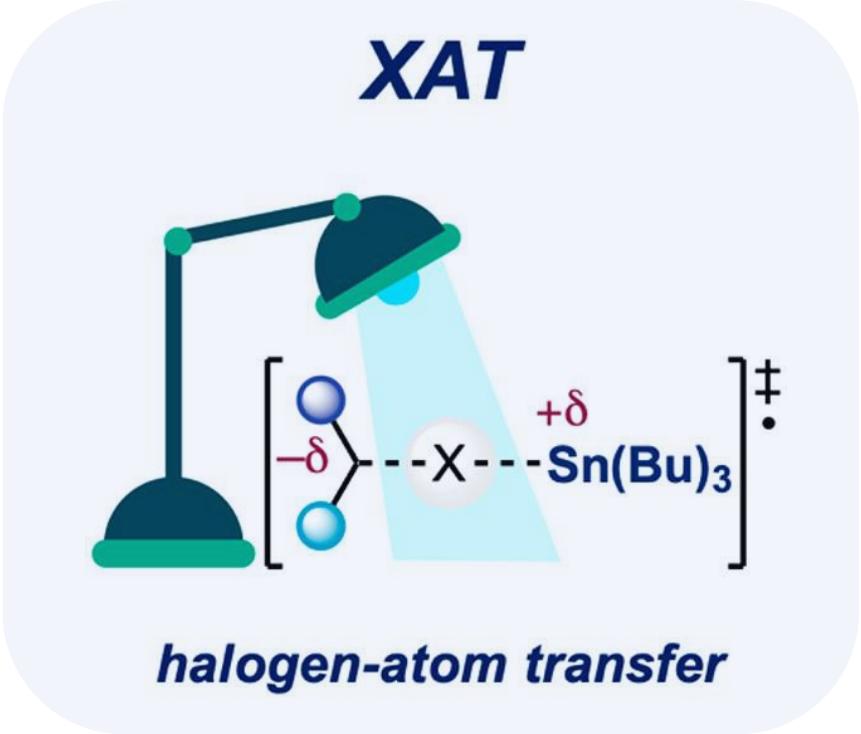
Generation of Carbon-Centered Radical: Merging XAT and Photo(redox)chemistry



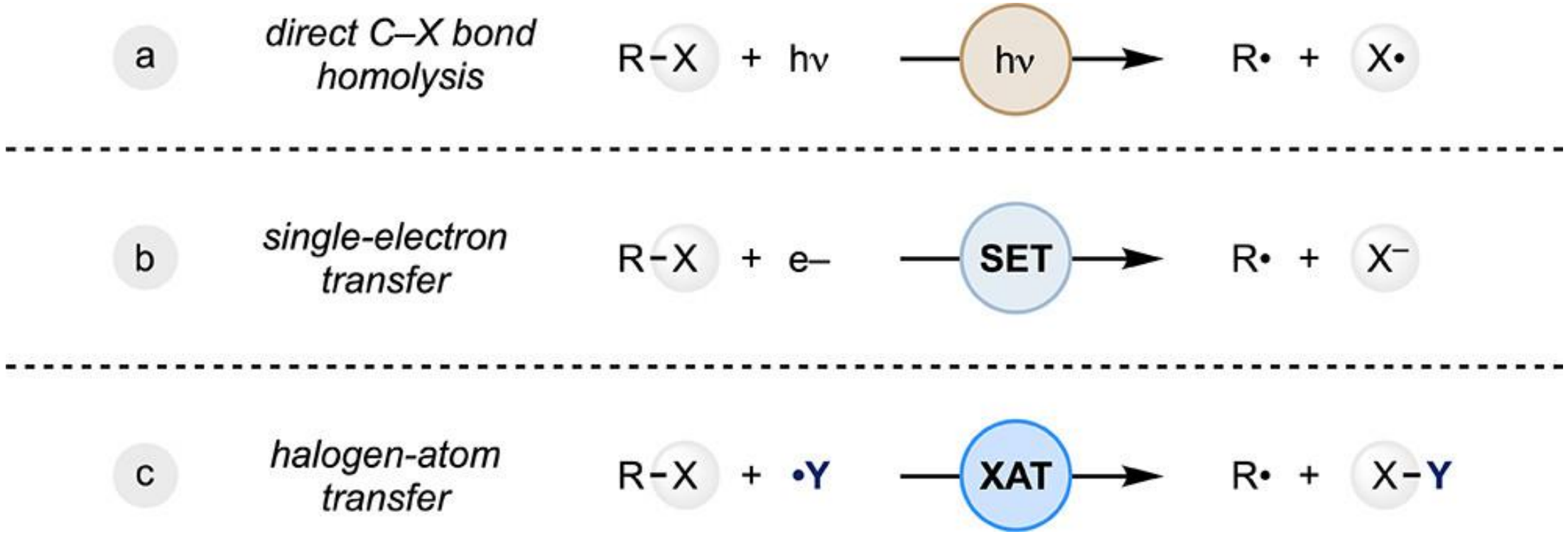
Garry (Lande) Hu

Literature Group Meeting

Jan. 10th, 2024

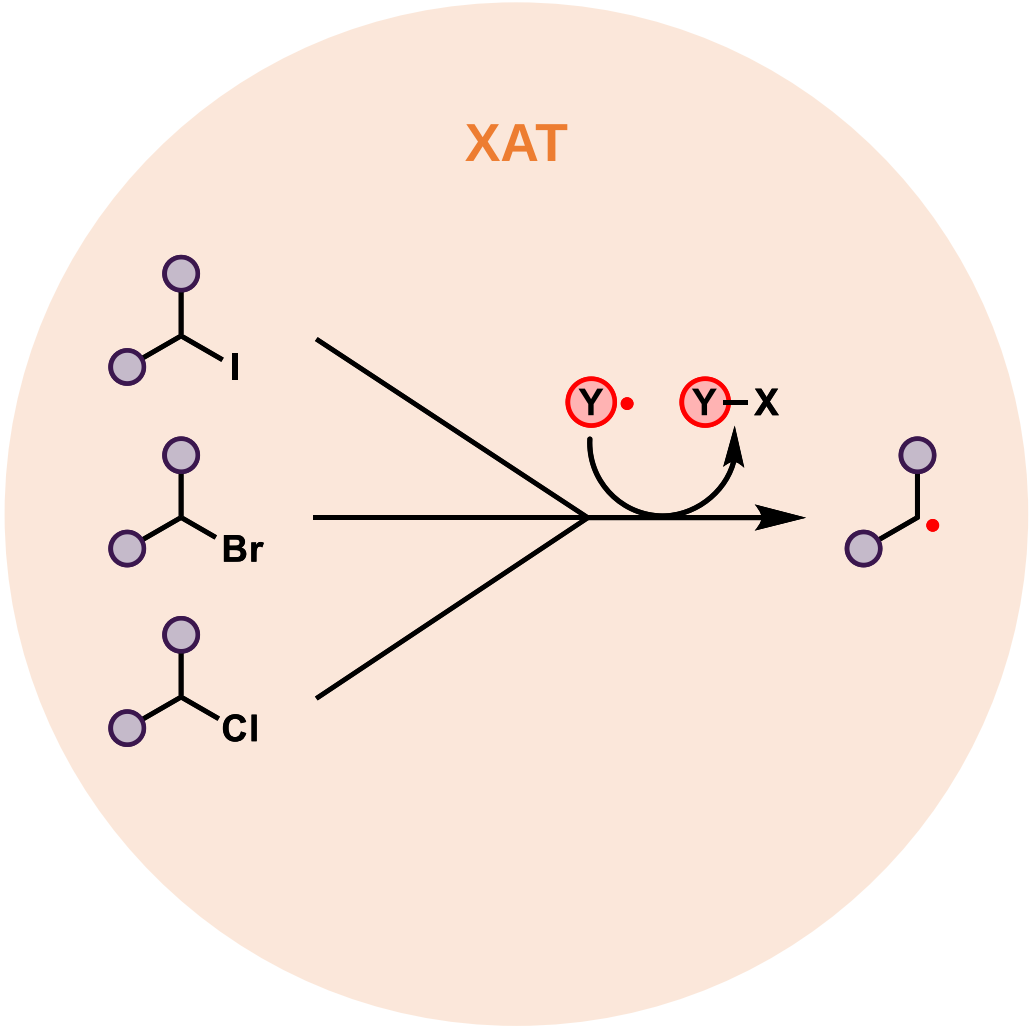
Juliá, F.; Constantin, T.; Leonori, D. *Chem. Rev.* **2022**, *122*, 2292.

Introduction

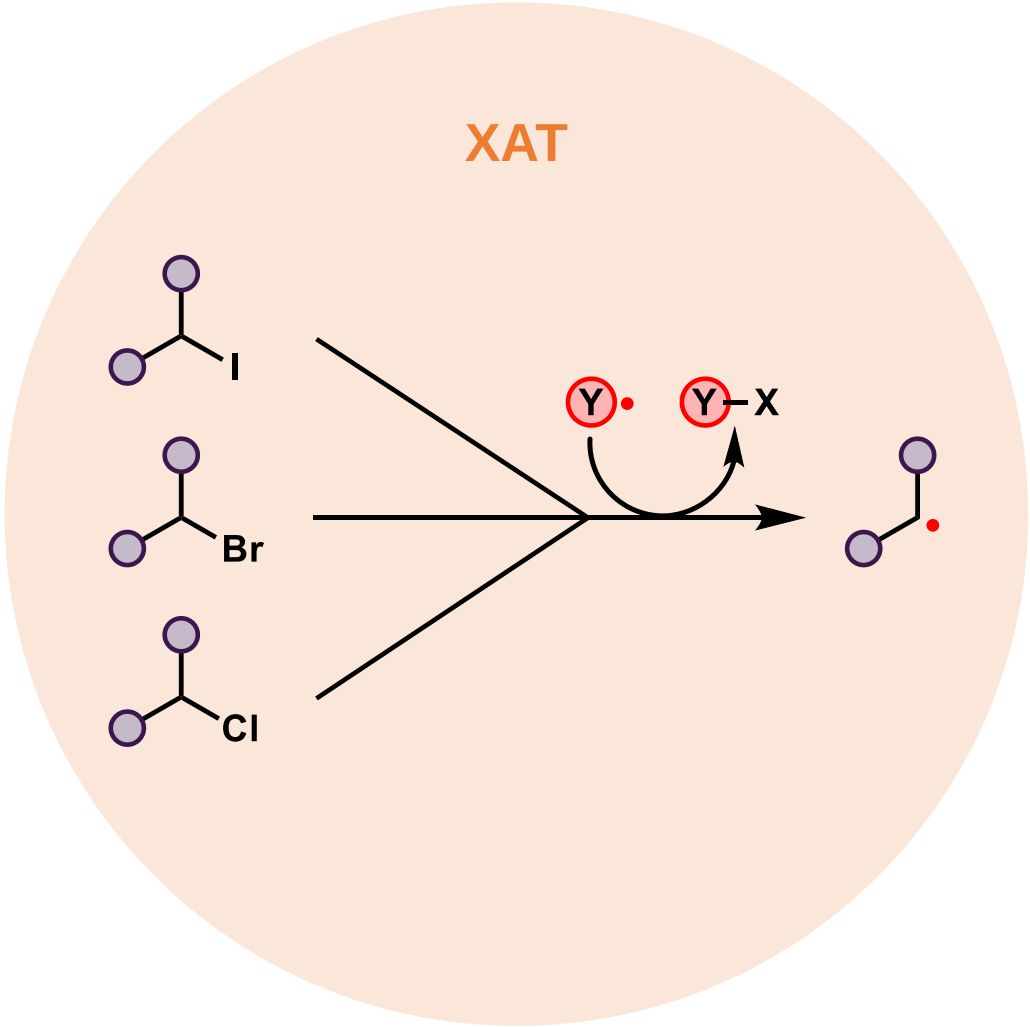


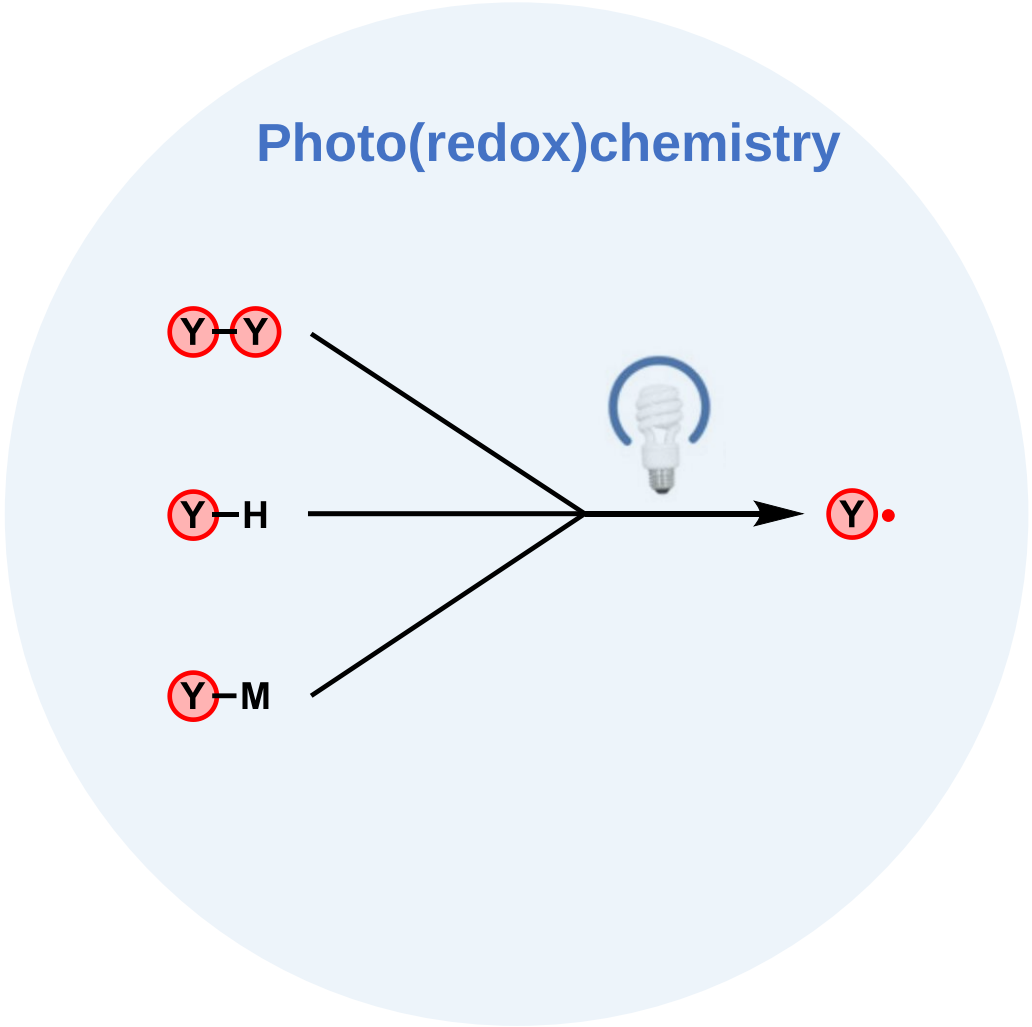
Juliá, F.; Constantin, T.; Leonori, D. *Chem. Rev.* **2022**, *122*, 2292.

Introduction



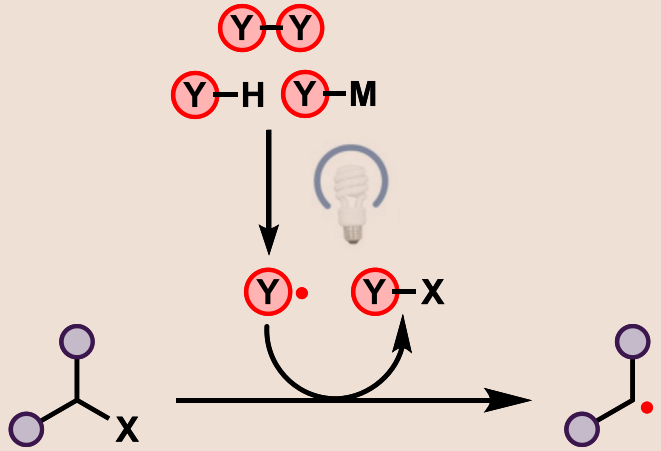
Introduction



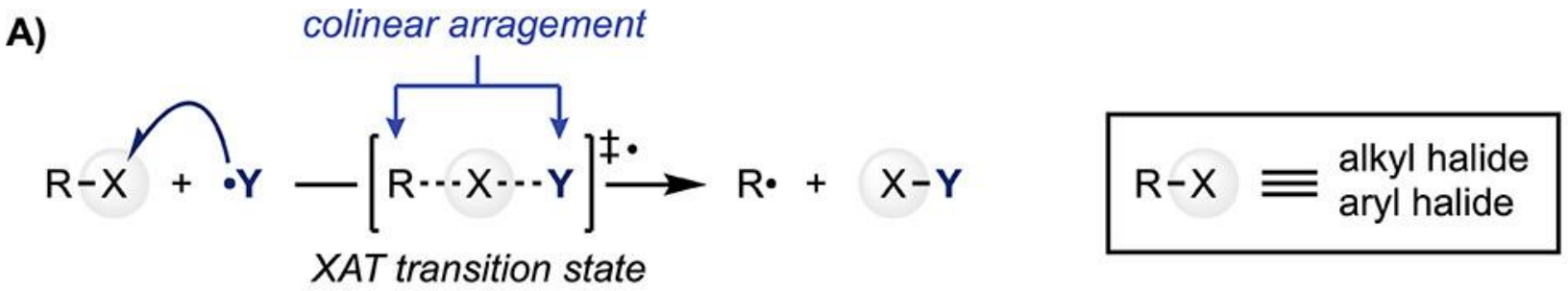


Introduction

Generation of C• via XAT
in Photo(redox)chemistry

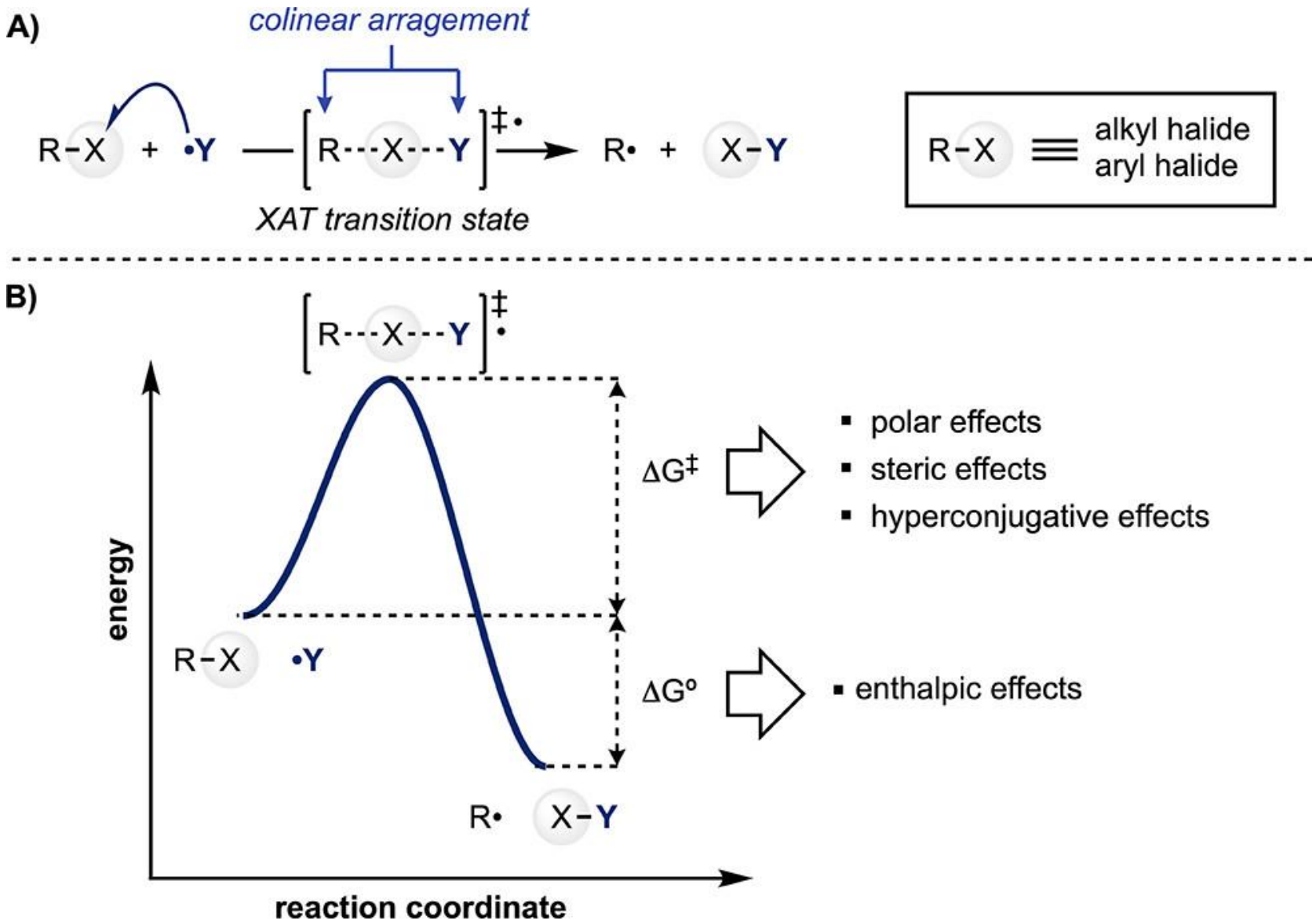


Mechanistic Aspects of XAT



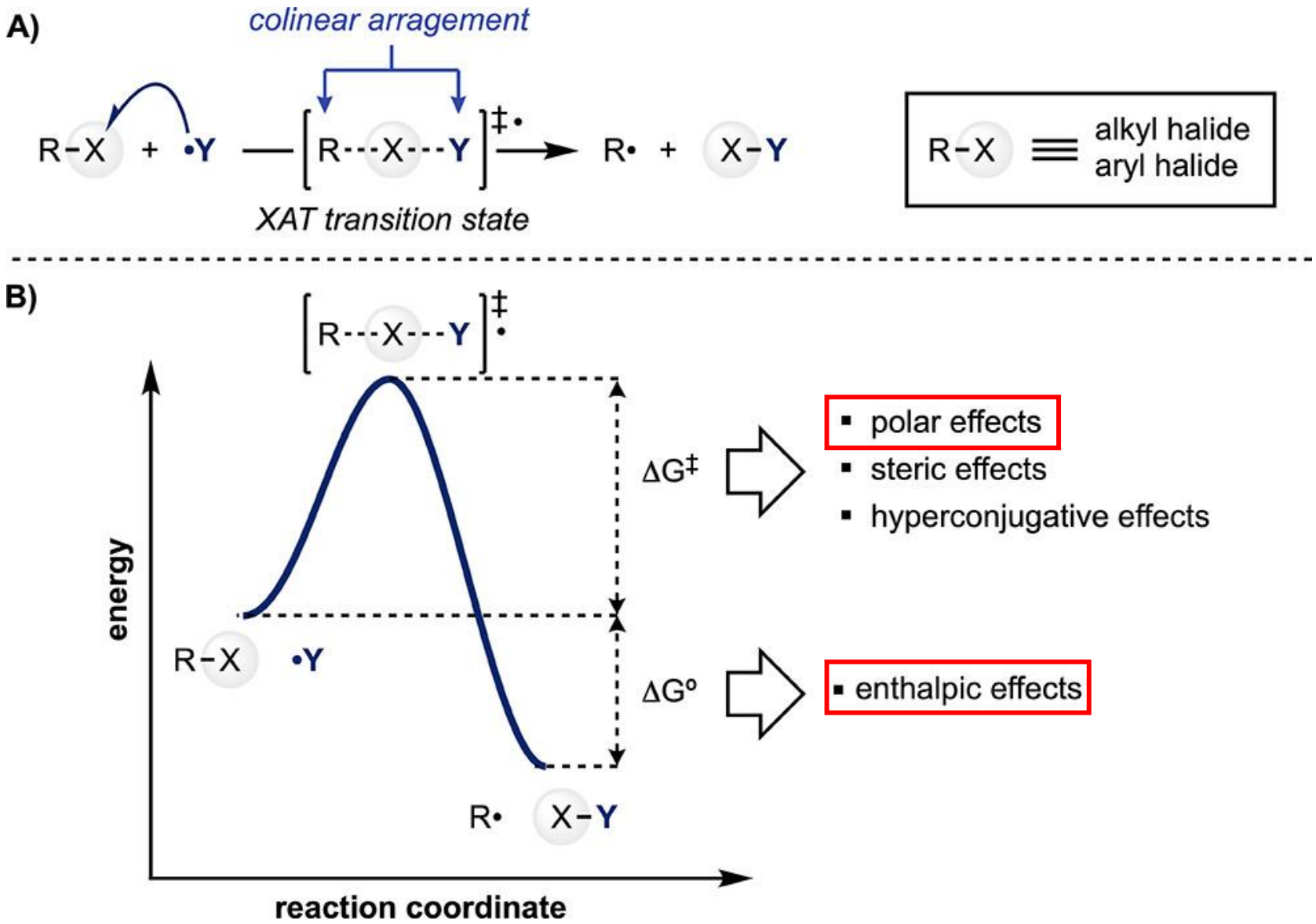
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Itsenko, O.; Norberg, D.; Rasmussen, T.; Långström, B.; Chatgilialoglu, C. *J. Am. Chem. Soc.* **2007**, *129*, 9020.

Mechanistic Aspects of XAT



Schiesser, C. H.; Smart, B. A.; Tran, T.-A. *Tetrahedron* **1995**, *51*, 3327. Schiesser, C. H.; Wild, L. M. *J. Org. Chem.* **1998**, *63*, 670.
Itsenko, O.; Norberg, D.; Rasmussen, T.; Långström, B.; Chatgilialoglu, C. *J. Am. Chem. Soc.* **2007**, *129*, 9020.

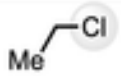
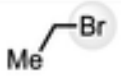
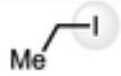
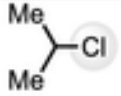
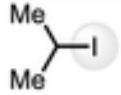
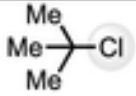
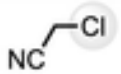
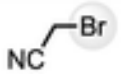
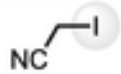
Mechanistic Aspects of XAT



Schiesser, C. H.; Smart, B. A.; Tran, T.-A. *Tetrahedron* **1995**, *51*, 3327. Schiesser, C. H.; Wild, L. M. *J. Org. Chem.* **1998**, *63*, 670.
Itsenko, O.; Norberg, D.; Rasmussen, T.; Långström, B.; Chatgilialoglu, C. *J. Am. Chem. Soc.* **2007**, *129*, 9020.

Enthalpic Effects

Like all types of radical abstractions, enthalpic effects dictate the overall energetic feasibility (ΔG°) of XAT reactions. For XAT processes to be exergonic, the Y−halogen bond needs to be stronger than the C−halogen bond in the starting materials (i.e., $BDE_{X-Y} > BDE_{R-X}$).

Bond	BDE (kcal mol^{-1})	Bond	BDE (kcal mol^{-1})	Bond	BDE (kcal mol^{-1})
Me–Cl	83.7	Me–Br	70.3	Me–I	57.1
	84.2		70.0		55.8
	84.6		71.5		56.1
	84.1		70.0		54.3
	66.4		56.8		44.7
Cl_3C–Cl	70.9	Cl_3C–Br	52.3	Cl_3C–I	40.1
Ph–Cl	96.5	Ph–Br	80.4	Ph–I	65.0
Me_3Sn–Cl	101.6	Me_3Sn–Br	91.3	Me_3Sn–I	76.5
Me_3Si–Cl	117.0	Me_3Si–Br	101.4	Me_3Si–I	82.1



Luo, Y.-R. *Handbook of bond dissociation energies in organic compounds*; CRC Press, **2002**.

Enthalpic Effects

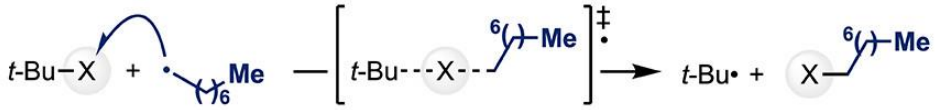
General trend of relative rates: I > Br > Cl
consistent with XAT having early TSs predicted by Hammond postulate

A)



	Ph–I	Ph–Br	Ph–Cl
k_{XAT} (M^{-1} s^{-1}) at r.t.	1×10^9	1×10^8	2.5×10^6

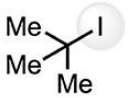
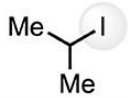
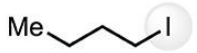
B)



	t-Bu–I	*t*-Bu–Br	*t*-Bu–Cl
k_{XAT} (M^{-1} s^{-1}) at r.t.	3×10^6	4.5×10^3	6×10^2

C)



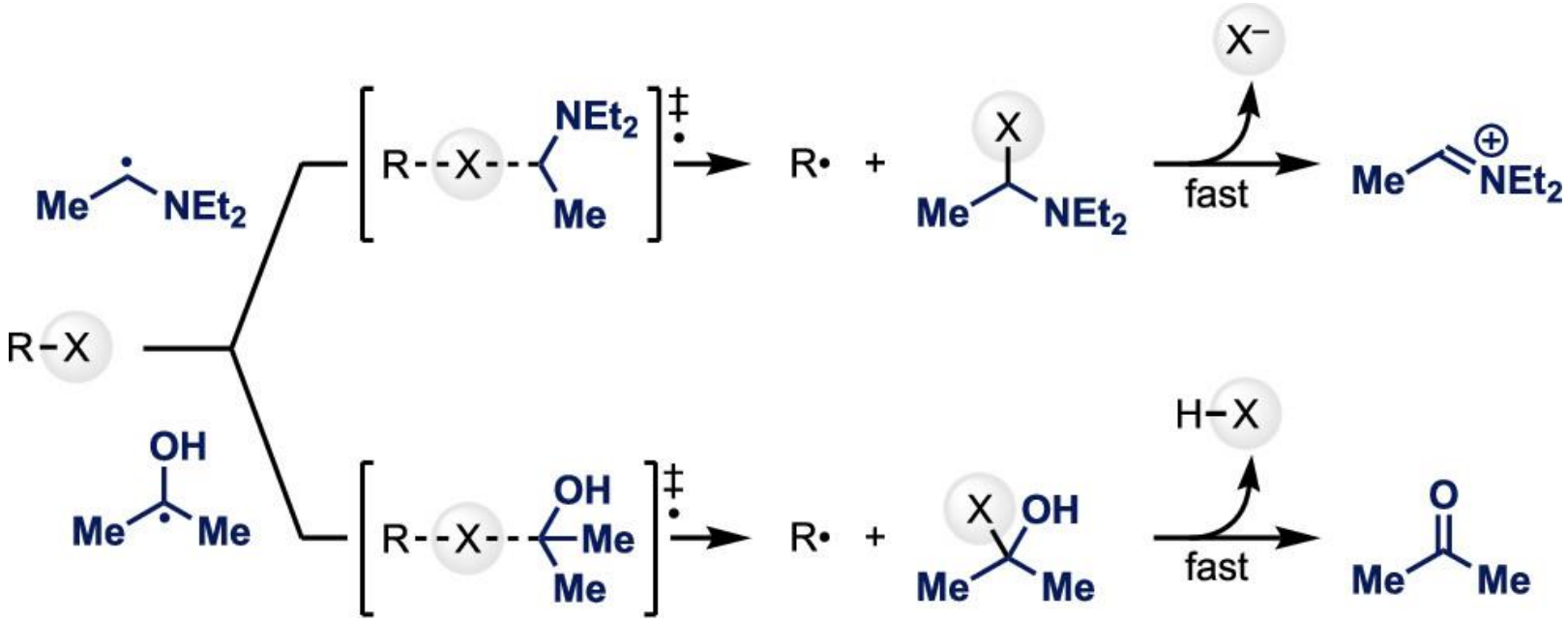
				
k_{XAT} (M^{-1} s^{-1}) at r.t.	1×10^9	1×10^8	5×10^7	2×10^7

Ingold, K. U.; Lusztyk, J.; Scaiano, J. C. *J. Am. Chem. Soc.* **1984**, *106*, 343. Newcomb, M.; Sanchez, R. M.; Kaplan, J. *J. Am. Chem. Soc.* **1987**, *109*, 1195. Curran, D. P.; Bosch, E.; Kaplan, J.; Newcomb, M. *J. Org. Chem.* **1989**, *54*, 1826. Galli, C.; Pau, T. *Tetrahedron* **1998**, *54*, 2893. Tehfe, M.-A.; Makhlouf Brahmi, M.; Fouassier, J.-P.; Curran, D. P.; Malacria, M.; Fensterbank, L.; Lacôte, E.; Lalevée, J. *Macromolecules* **2010**, *43*, 2261.



Enthalpic Effects

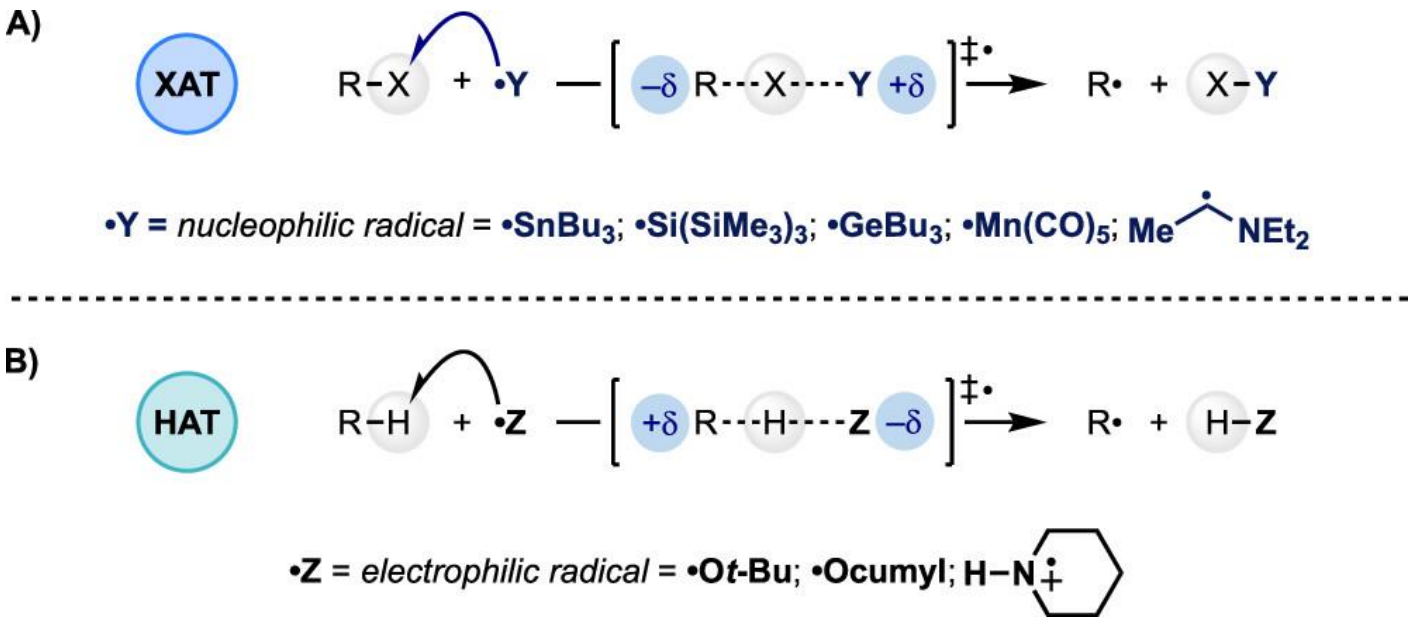
It is important to note that favorable enthalpic effects are not essential to drive halogen abstractions. In the case of systems where the product's Y−halogen bond has a similar (or even slightly weaker) strength than the substrate's C−halogen bond (i.e., $BDE_{X-Y} \leq BDE_{R-X}$), the abstraction can occur if there is a subsequent fast and irreversible reaction taking place.



Constantin, T.; Zanini, M.; Regni, A.; Sheikh, N. S.; Juliá, F.; Leonori, D. *Science* **2020**, *367*, 1021.
Itsenko, O.; Norberg, D.; Rasmussen, T.; Långström, B.; Chatgilialoglu, C. *J. Am. Chem. Soc.* **2007**, *129*, 9020.

Polar Effects

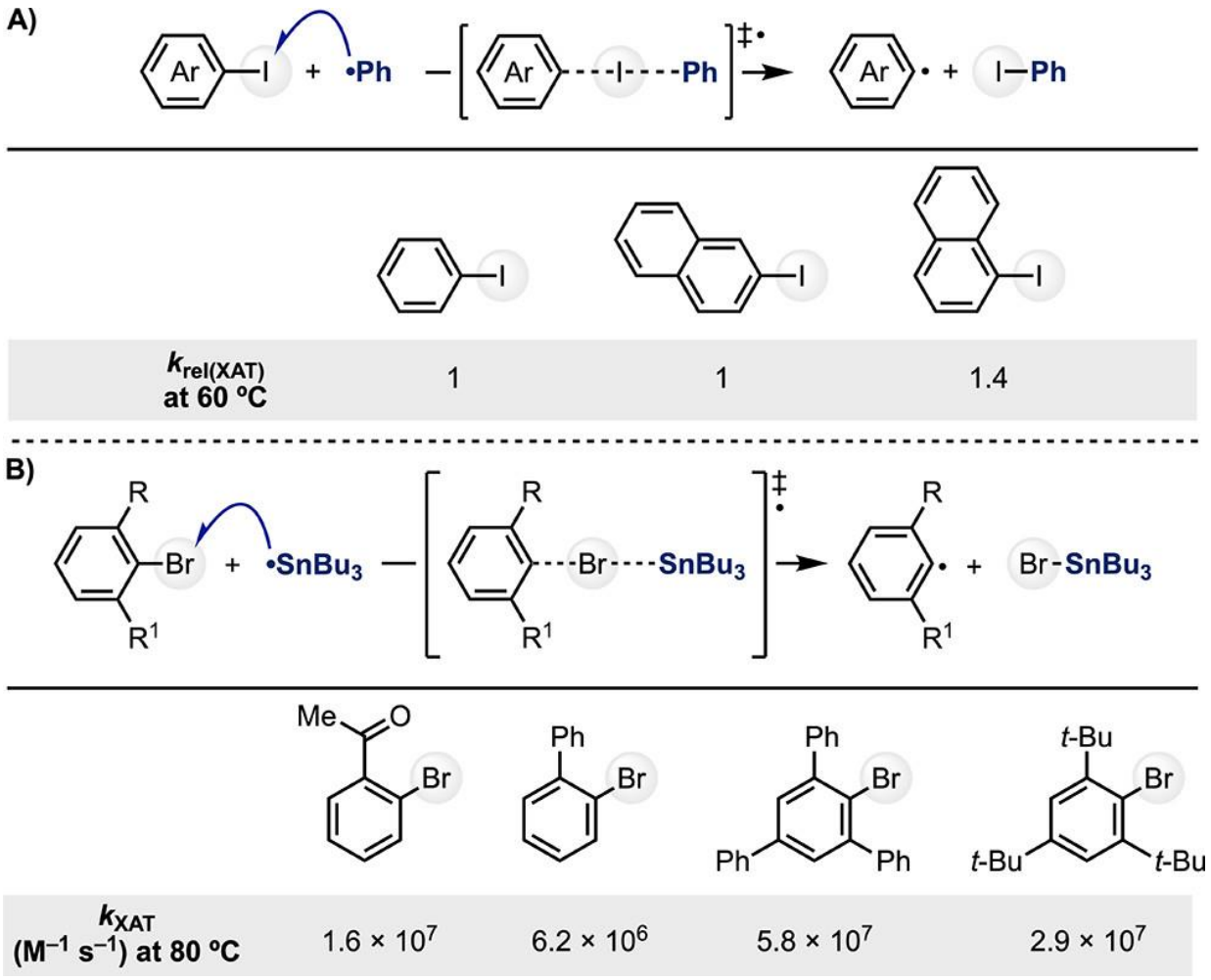
Mechanistic studies using Hammett plot analysis have demonstrated that XAT reactions build a partial negative charge on the halocarbon (R) while a partial positive charge is accumulated on the halogen-abstracting atom (Y). This means that nucleophilic radicals maximize charge transfer in the TS, which facilitates the abstraction. This finding is opposed to the HAT processes where strongly electrophilic radicals (e.g., t-BuO•) are usually employed, mainly due to the difference in electronegativity of halogen- vs H-atoms and the polarizability of the corresponding C−X vs C−H bonds.



Danen, W. C.; Saunders, D. G. *J. Am. Chem. Soc.* **1969**, *91*, 5924. Danen, W. C.; Winter, R. L. *J. Am. Chem. Soc.* **1971**, *93*, 716.
Davis, W. H.; Gleaton, J. H.; Pryor, W. A. *J. Org. Chem.* **1977**, *42*, 7. Chatgilialoglu, C.; Ingold, K. U.; Scaiano, J. C. *J. Org. Chem.* **1987**, *52*, 938.

Steric Effects

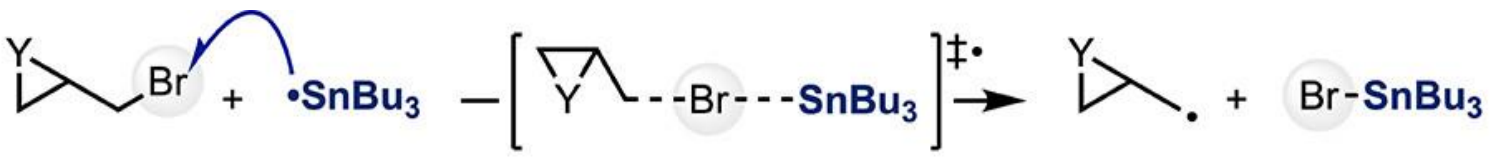
Steric effects have been observed in XAT reactions and were employed to rationalize the increased rate for abstraction on ortho-substituted aryl halides by both aryl and alkyl radicals.



Danen, W. C.; Saunders, D. G.; Rose, K. A. *J. Am. Chem. Soc.* **1974**, *96*, 4558.
Crich, D.; Hwang, J.-T.; Gastaldi, S.; Recupero, F.; Wink, D. J. *J. Org. Chem.* **1999**, *64*, 2877.

Hyperconjugative Effects

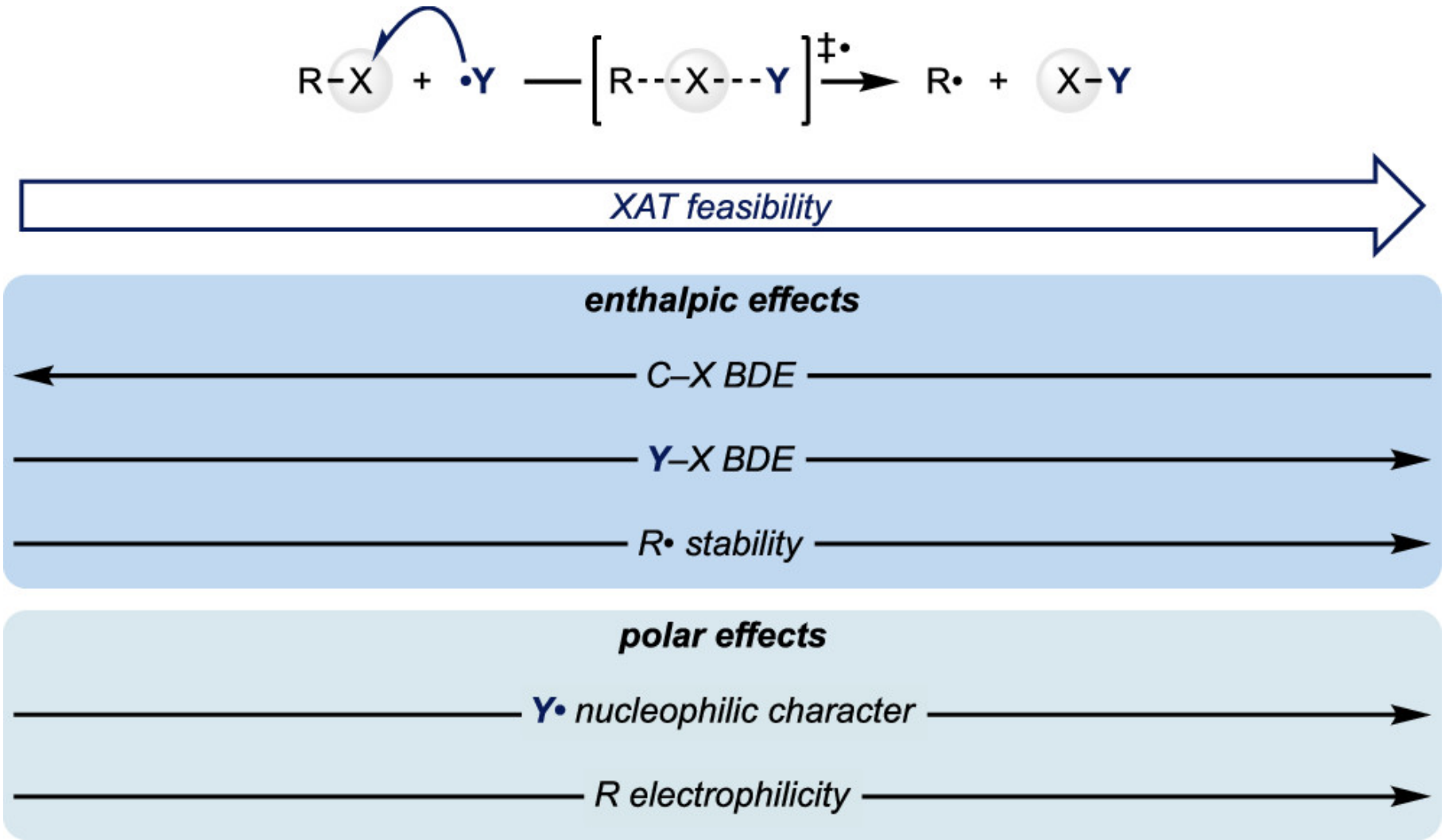
Hyperconjugative assistance was observed in XAT between α-cyclopropyl-, α-oxirane, and α-thiirane alkyl bromides and $Bu_3Sn•$.



	Ph–Br	cyclopropyl–Br	O (oxirane)–Br	S (thiirane)–Br
k_{XAT} (M^{-1} s^{-1}) at 80 °C	7×10^7	8×10^7	2×10^8	4×10^8

Franz, J. A.; Shaw, W. J.; Lamb, C. N.; Autrey, T.; Kolwaite, D. S.; Camaioni, D. M.; Alnajjar, M. S. *J. Org. Chem.* **2004**, *69*, 1020.

Key Aspects Affecting XAT Reactivity

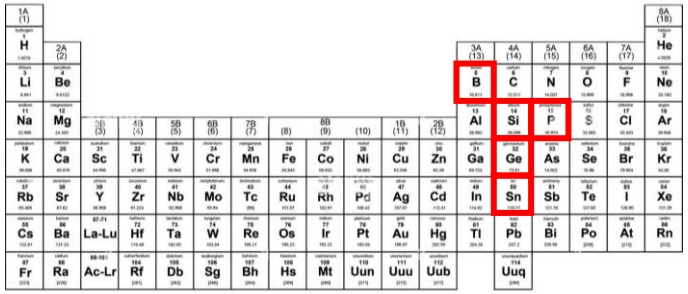


Juliá, F.; Constantin, T.; Leonori, D. *Chem. Rev.* **2022**, *122*, 2292.

Applications of XAT Reactivity in Synthetic Photocatalysis

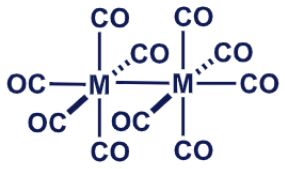
Heteroatom-Based

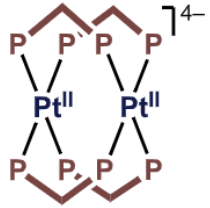
- **Tin Radicals (Sn•)**
- **Silicon Radicals (Si•)**
- **Germanium Radicals (Ge•)**
- **Boron Radicals (B•)**
- **Phosphorus Radicals (P•)**



Metal-Based

- **Dimeric Carbonyl Complexes Displaying Photocleavable Metal–Metal Bonds**
- **Dimeric Complexes Without Formal Metal–Metal Bonds**
- **Metalloradicals Generated From Monomeric Species**





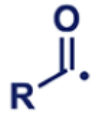


Carbon-Based

- **α-Aminoalkyl Radicals**
- **Methyl Radical**
- **Acyl Radicals**



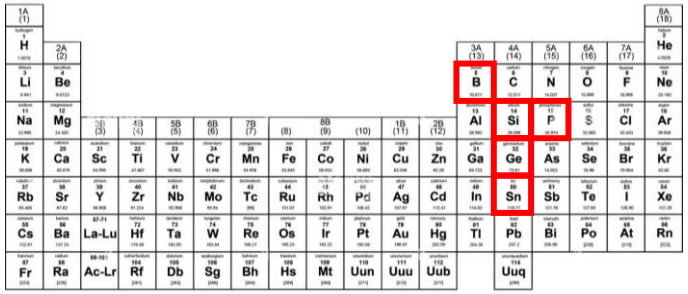




Applications of XAT Reactivity in Synthetic Photocatalysis

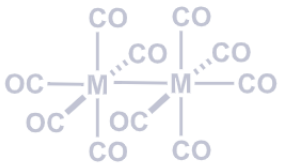
Heteroatom-Based

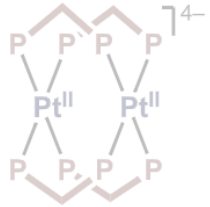
- **Tin Radicals (Sn•)**
- **Silicon Radicals (Si•)**
- **Germanium Radicals (Ge•)**
- **Boron Radicals (B•)**
- **Phosphorus Radicals (P•)**



Metal-Based

- Dimeric Carbonyl Complexes Displaying Photocleavable Metal–Metal Bonds
- Dimeric Complexes Without Formal Metal–Metal Bonds
- Metalloradicals Generated From Monomeric Species





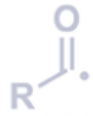


Carbon-Based

- *α*-Aminoalkyl Radicals
- Methyl Radical
- Acyl Radicals

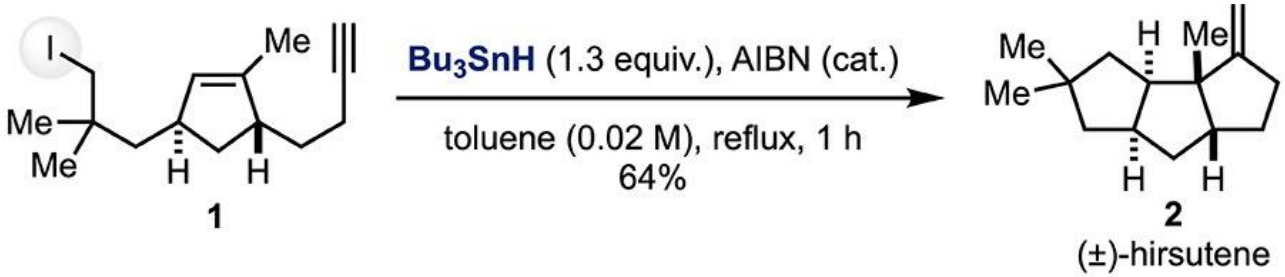


Me•



Heteroatom-Based XAT Reagents: Tin Radicals (Sn•)

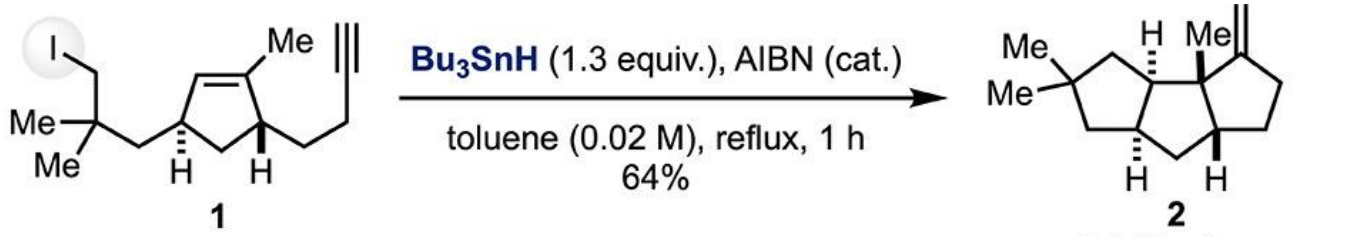
Classical Sn-mediated radical cyclization cascade

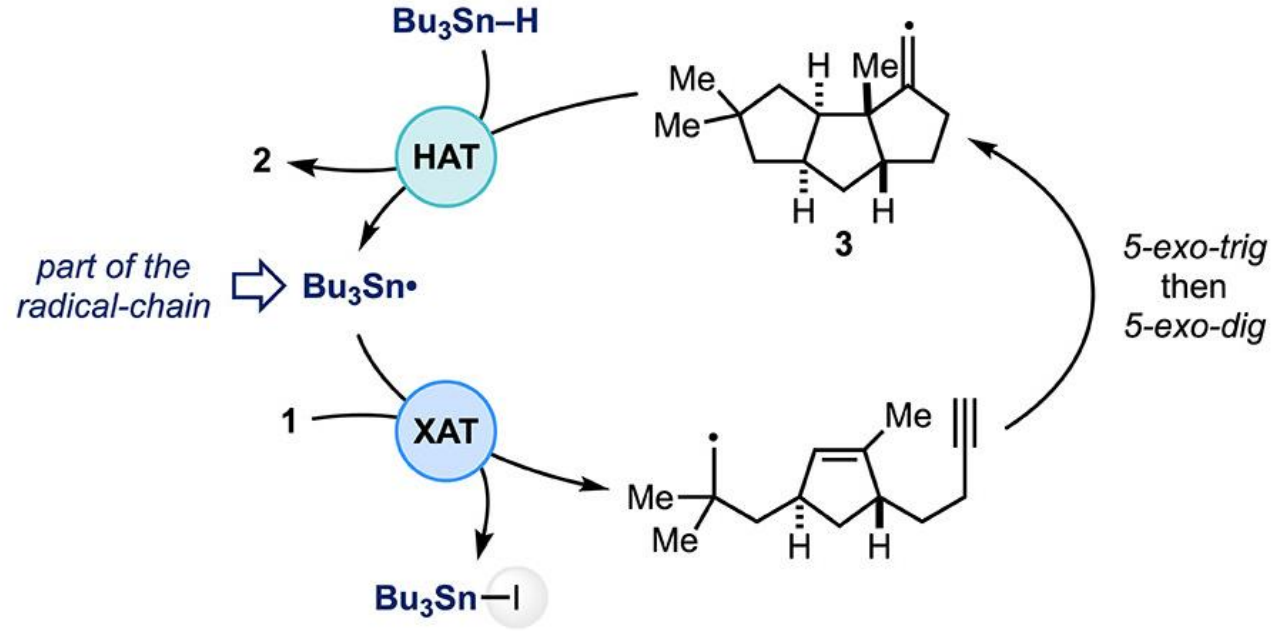


Curran, D. P.; Rakiewicz, D. M. *J. Am. Chem. Soc.* **1985**, *107*, 1448. Curran, D. P.; Rakiewicz, D. M. *J. Am. Chem. Soc.* **1985**, *107*, 1448.

Heteroatom-Based XAT Reagents: Tin Radicals (Sn•)

Classical Sn-mediated radical cyclization cascade

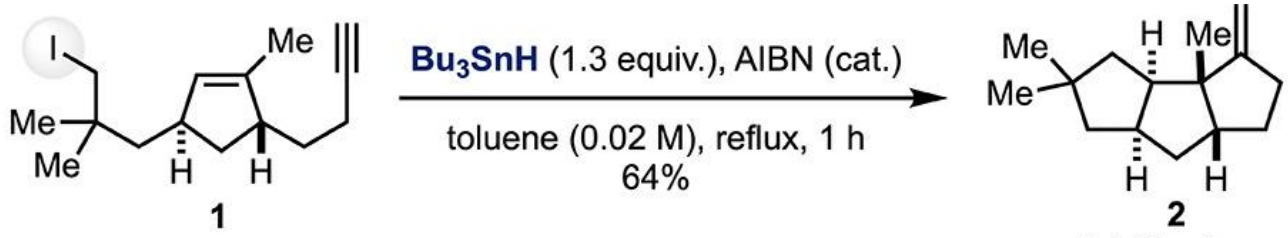


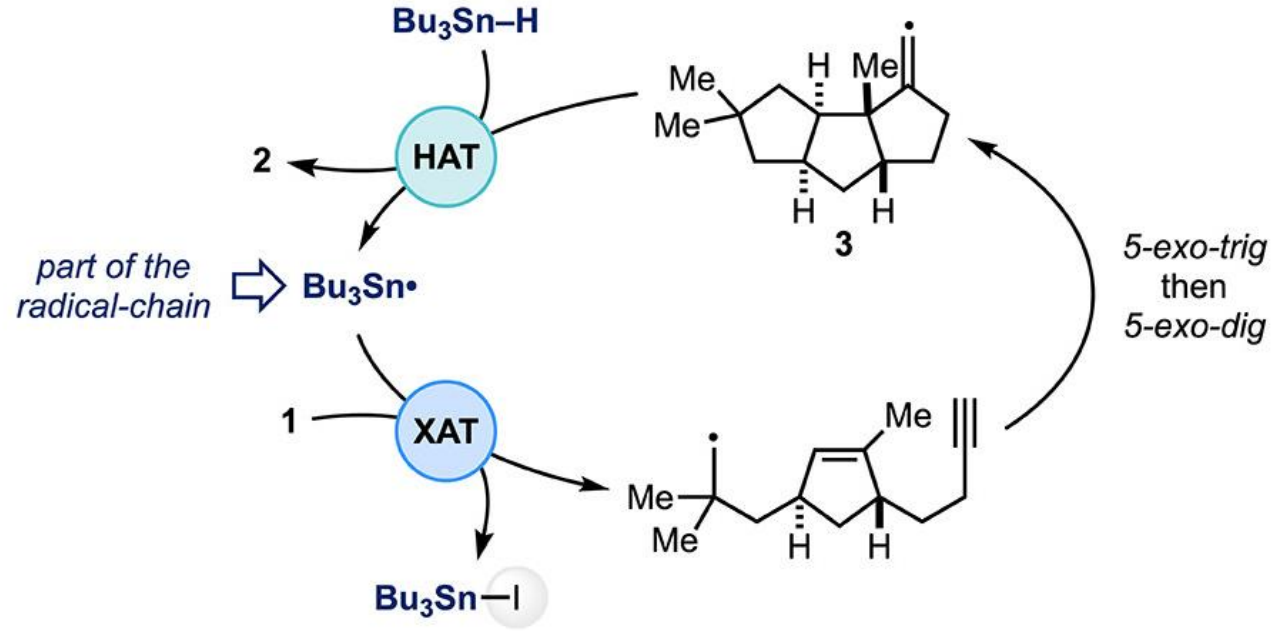


Curran, D. P.; Rakiewicz, D. M. *J. Am. Chem. Soc.* **1985**, *107*, 1448. Curran, D. P.; Rakiewicz, D. M. *J. Am. Chem. Soc.* **1985**, *107*, 1448.

Heteroatom-Based XAT Reagents: Tin Radicals (Sn•)

Classical Sn-mediated radical cyclization cascade



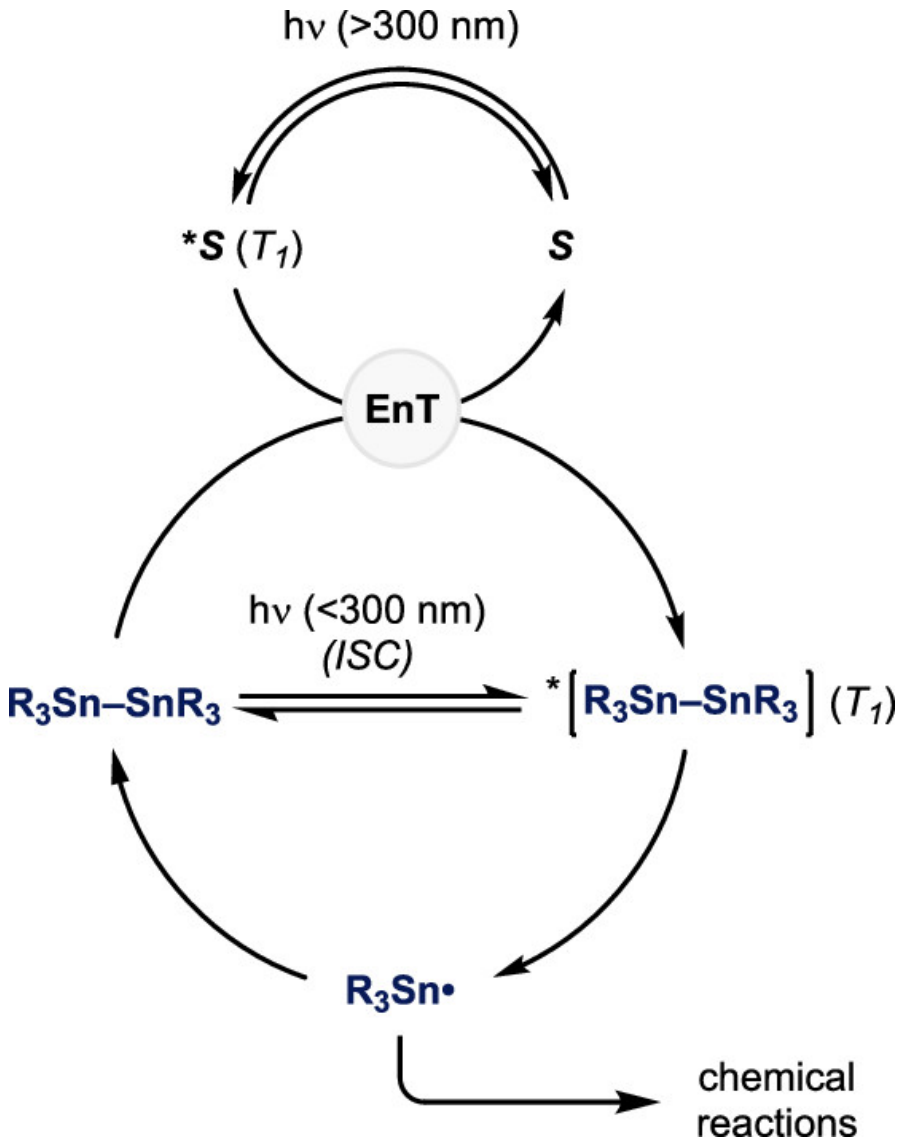


The weak Sn−H bond often causes unwanted radical reduction reactions

Curran, D. P.; Rakiewicz, D. M. *J. Am. Chem. Soc.* **1985**, *107*, 1448. Curran, D. P.; Rakiewicz, D. M. *J. Am. Chem. Soc.* **1985**, *107*, 1448.

Heteroatom-Based XAT Reagents: Tin Radicals (Sn•)

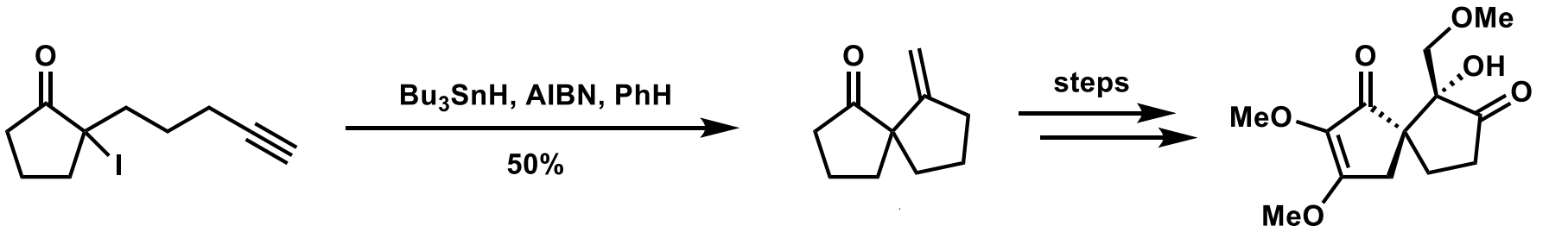
Photoactivation of Sn–Sn bond



Juliá, F.; Constantin, T.; Leonori, D. *Chem. Rev.* **2022**, *122*, 2292.

Heteroatom-Based XAT Reagents: Tin Radicals (Sn•)

Atom Transfer Radical Cyclization

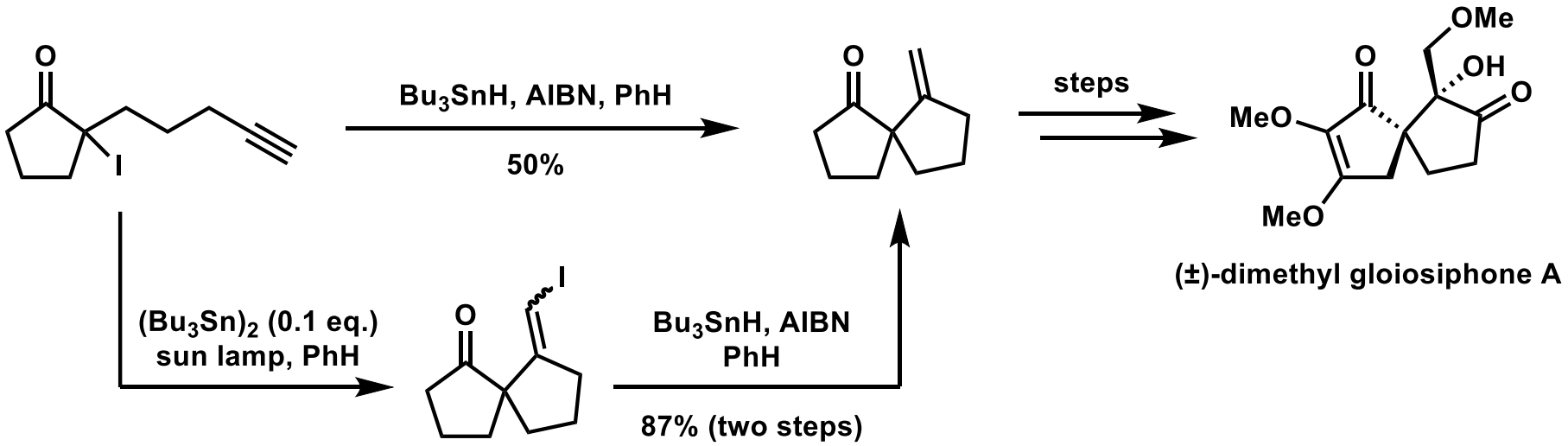


(±)-dimethyl gloiosiphone A

Sha, C.-K.; Ho, W.-Y. *Chem. Commun.* **1998**, 2709. Chen, C.-H.; Chen, Y.-K.; Sha, C.-K. *Org. Lett.* **2010**, *12*, 1377.

Heteroatom-Based XAT Reagents: Tin Radicals (Sn•)

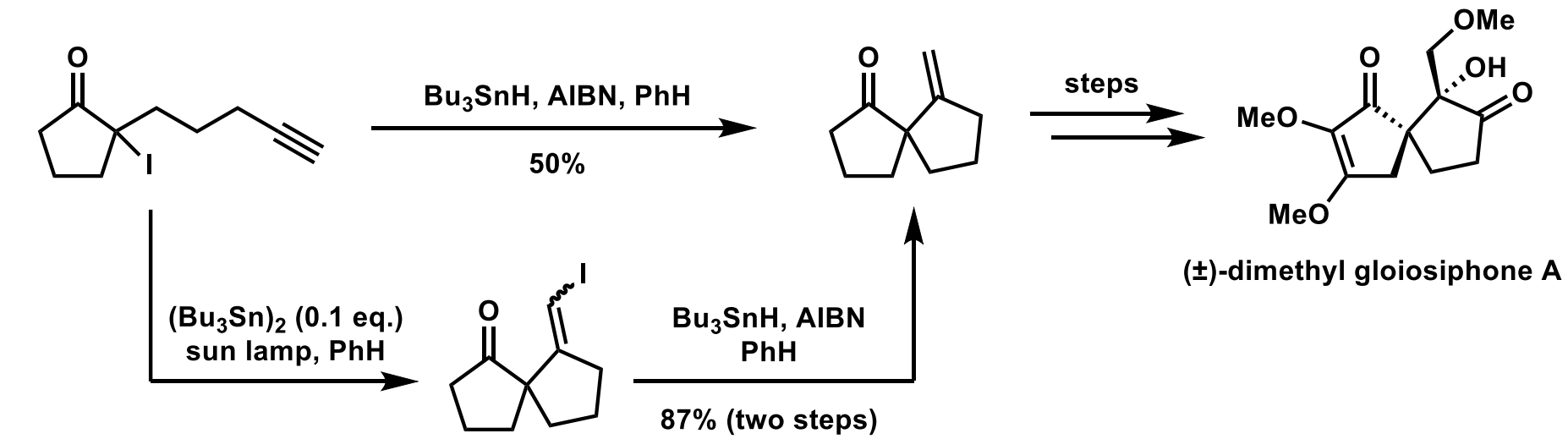
Atom Transfer Radical Cyclization

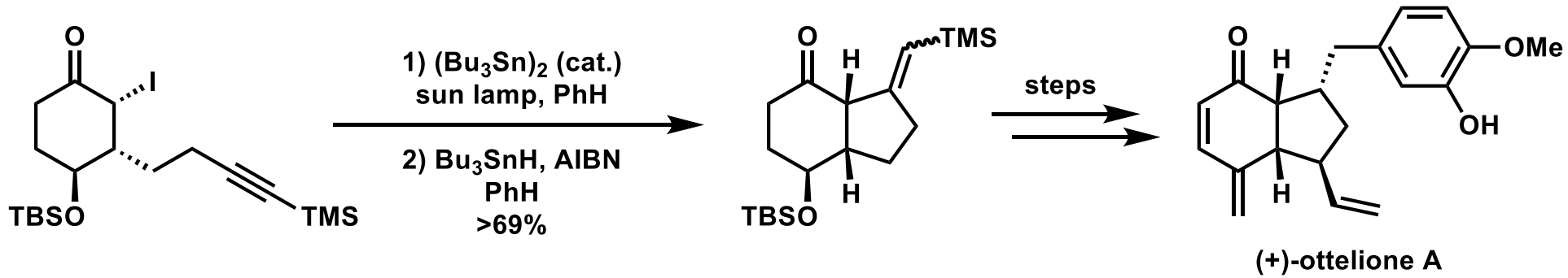


Sha, C.-K.; Ho, W.-Y. *Chem. Commun.* **1998**, 2709. Chen, C.-H.; Chen, Y.-K.; Sha, C.-K. *Org. Lett.* **2010**, *12*, 1377.

Heteroatom-Based XAT Reagents: Tin Radicals (Sn•)

Atom Transfer Radical Cyclization

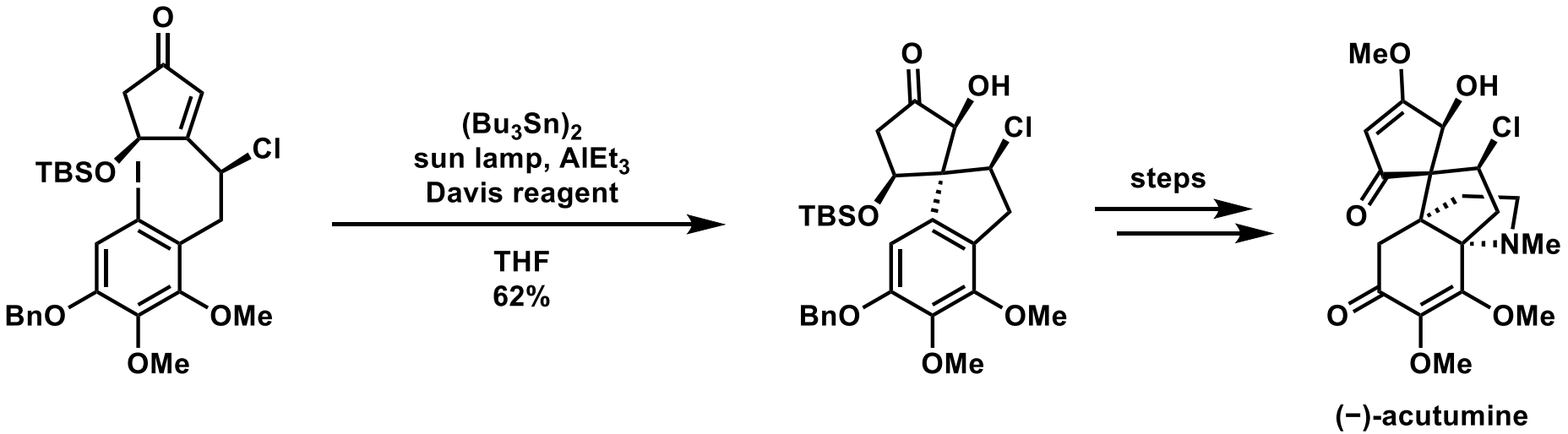




Sha, C.-K.; Ho, W.-Y. *Chem. Commun.* **1998**, 2709. Chen, C.-H.; Chen, Y.-K.; Sha, C.-K. *Org. Lett.* **2010**, *12*, 1377.

Heteroatom-Based XAT Reagents: Tin Radicals (Sn•)

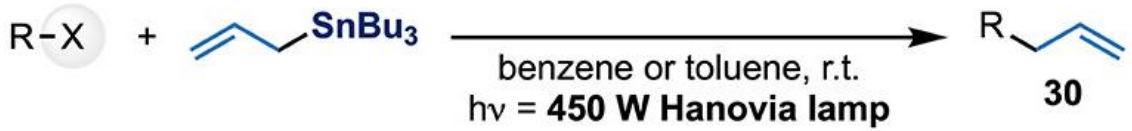
Radical-Polar Crossover



Li, F.; Tartakoff, S. S.; Castle, S. L. *J. Org. Chem.* **2009**, *74*, 9082.

Heteroatom-Based XAT Reagents: Tin Radicals (Sn•)

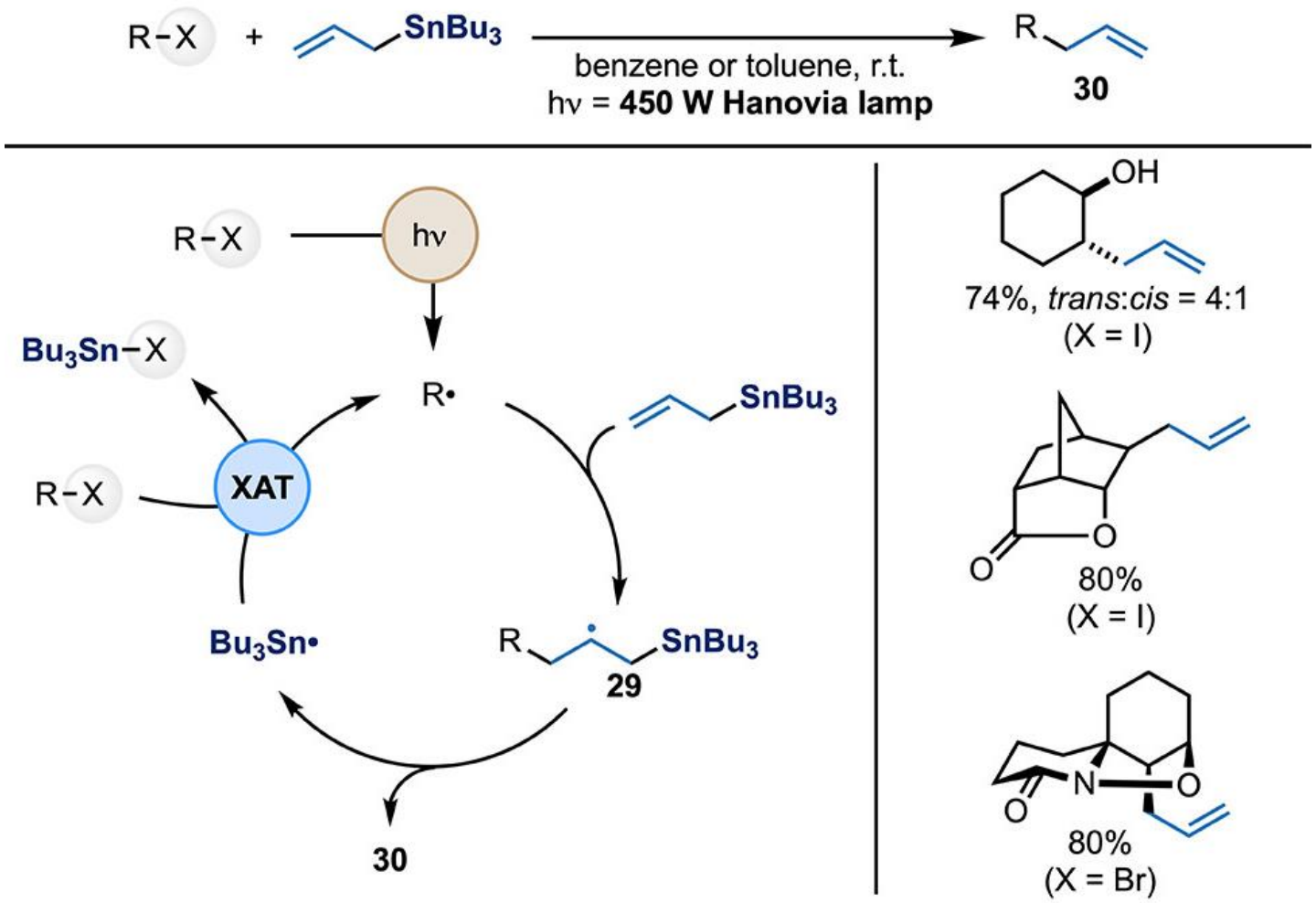
Keck Allylation



Keck, G. E.; Enholm, E. J.; Yates, J. B.; Wiley, M. R. *Tetrahedron* **1985**, *41*, 4079.

Heteroatom-Based XAT Reagents: Tin Radicals (Sn•)

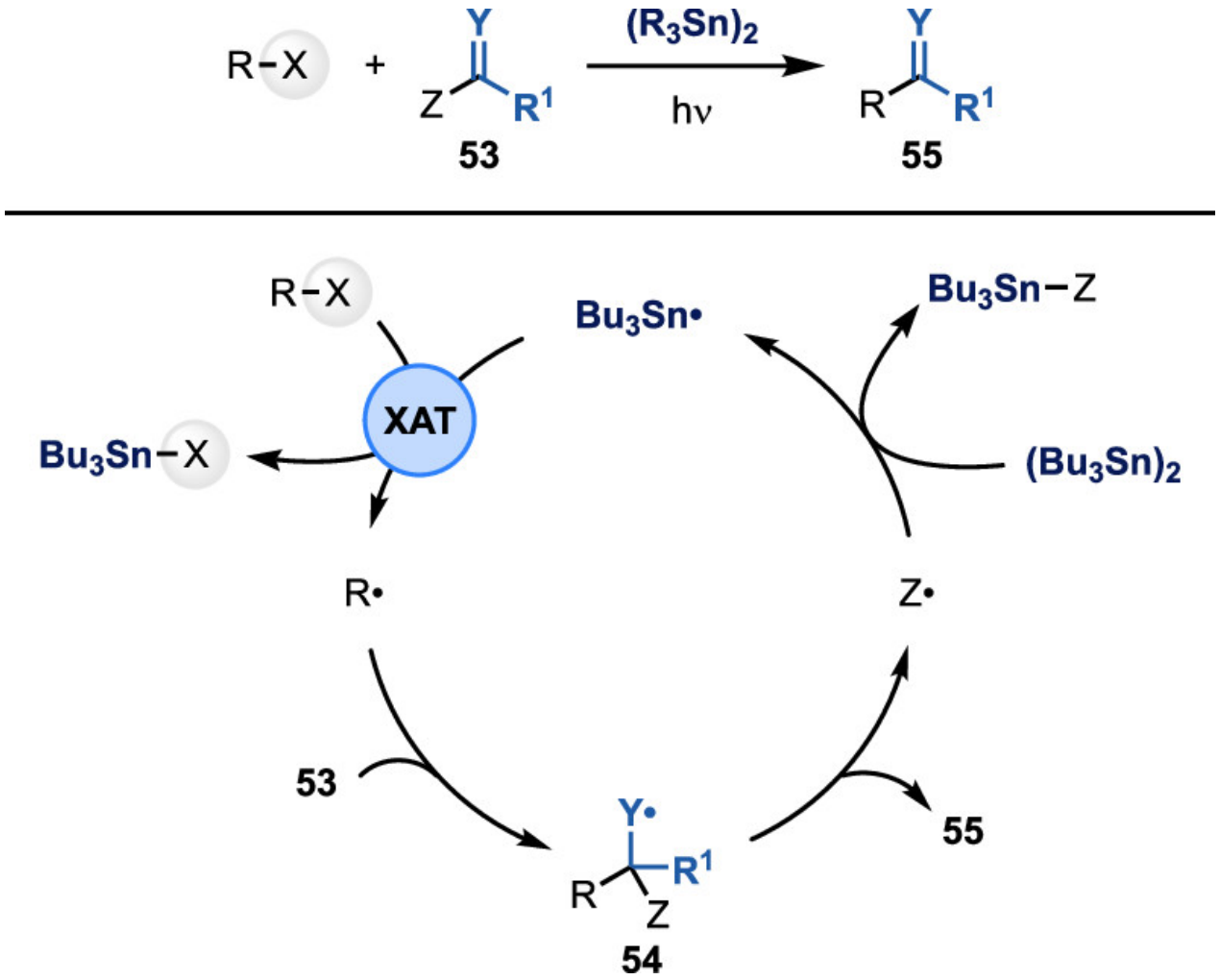
Keck Allylation



Keck, G. E.; Enholm, E. J.; Yates, J. B.; Wiley, M. R. *Tetrahedron* **1985**, *41*, 4079.

Heteroatom-Based XAT Reagents: Tin Radicals (Sn•)

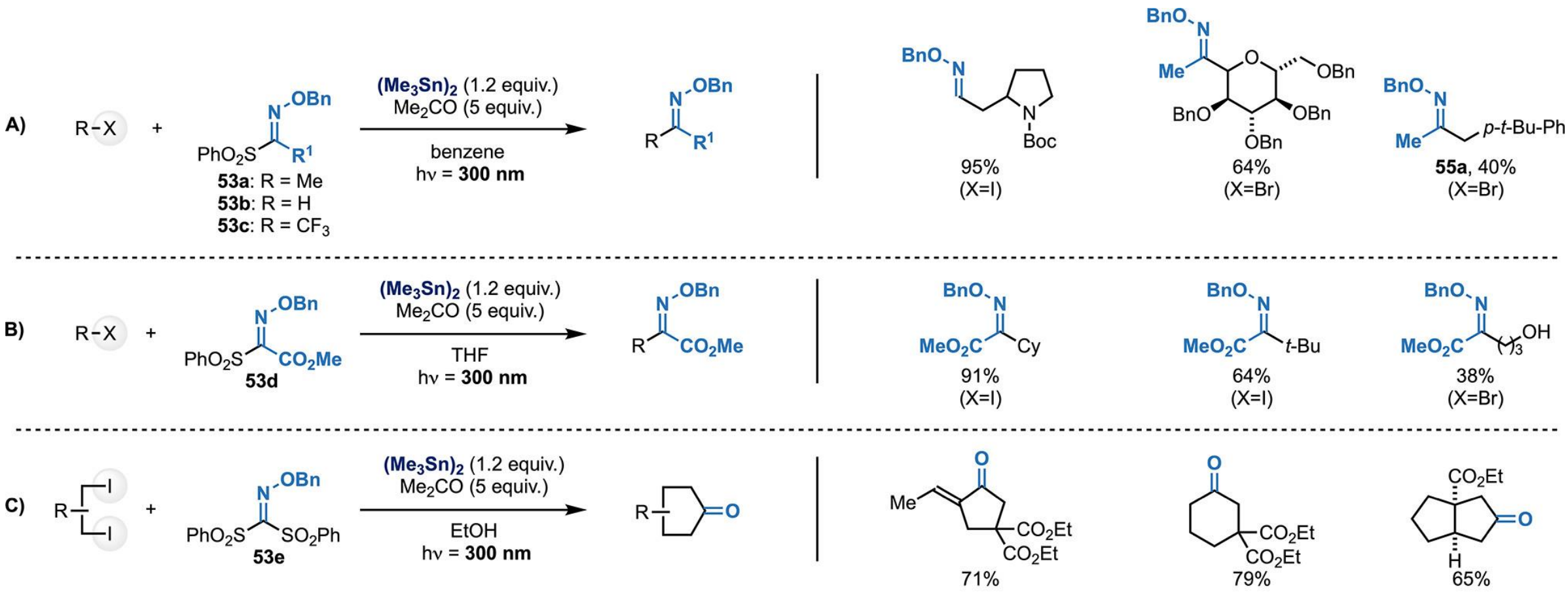
Carbonylation



Juliá, F.; Constantin, T.; Leonori, D. *Chem. Rev.* **2022**, *122*, 2292.

Heteroatom-Based XAT Reagents: Tin Radicals (Sn•)

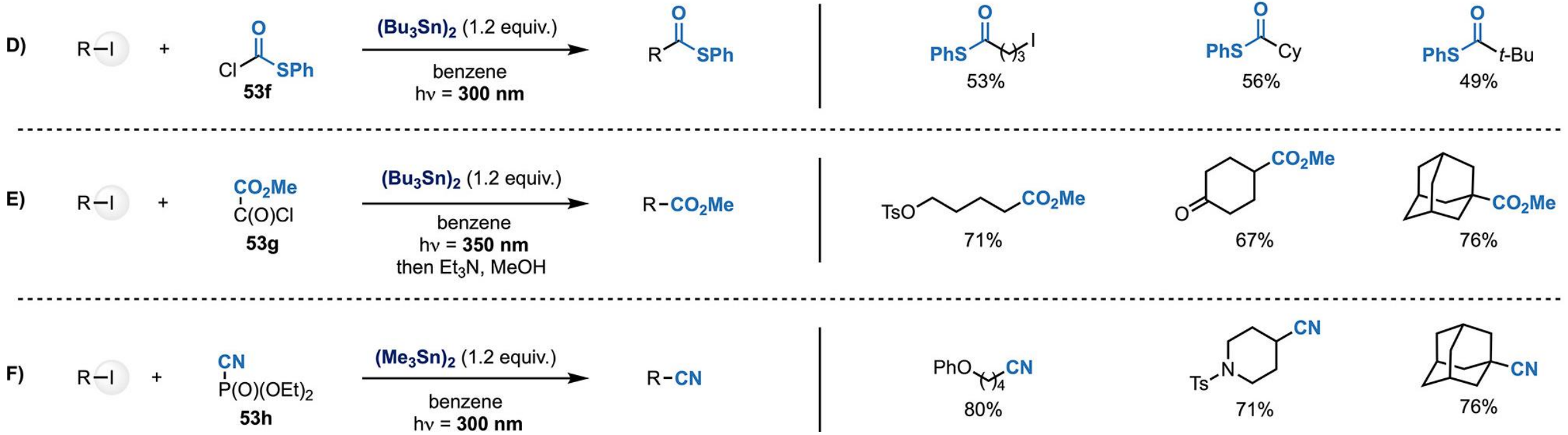
Carbonylation



Kim, S.; Lee, I. Y.; Yoon, J.-Y.; Oh, D. H. *J. Am. Chem. Soc.* **1996**, *118*, 5138. Kim, S.; Yoon, J.-Y.; Lee, I. *Synlett* **1997**, *1997*, 475. Kim, S.; Yoon, J.-Y. *J. Am. Chem. Soc.* **1997**, *119*, 5982. Kim, S. *Chem. Commun.* **1998**, 815. Kim, S.; Jon, S. Y. *Tetrahedron Lett.* **1998**, *39*, 7317. Cho, C.; Lee, J.; Kim, S. *Synlett* **2008**, *2009*, 81.

Heteroatom-Based XAT Reagents: Tin Radicals (Sn•)

Carbonylation

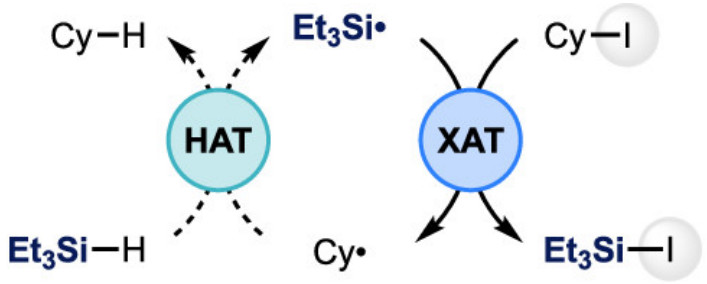


Kim, S.; Lee, I. Y.; Yoon, J.-Y.; Oh, D. H. *J. Am. Chem. Soc.* **1996**, *118*, 5138. Kim, S.; Yoon, J.-Y.; Lee, I. *Synlett* **1997**, *1997*, 475. Kim, S.; Yoon, J.-Y. *J. Am. Chem. Soc.* **1997**, *119*, 5982. Kim, S. *Chem. Commun.* **1998**, 815. Kim, S.; Jon, S. Y. *Tetrahedron Lett.* **1998**, *39*, 7317. Cho, C.; Lee, J.; Kim, S. *Synlett* **2008**, *2009*, 81.



Heteroatom-Based XAT Reagents: Silicon Radicals (Si•)

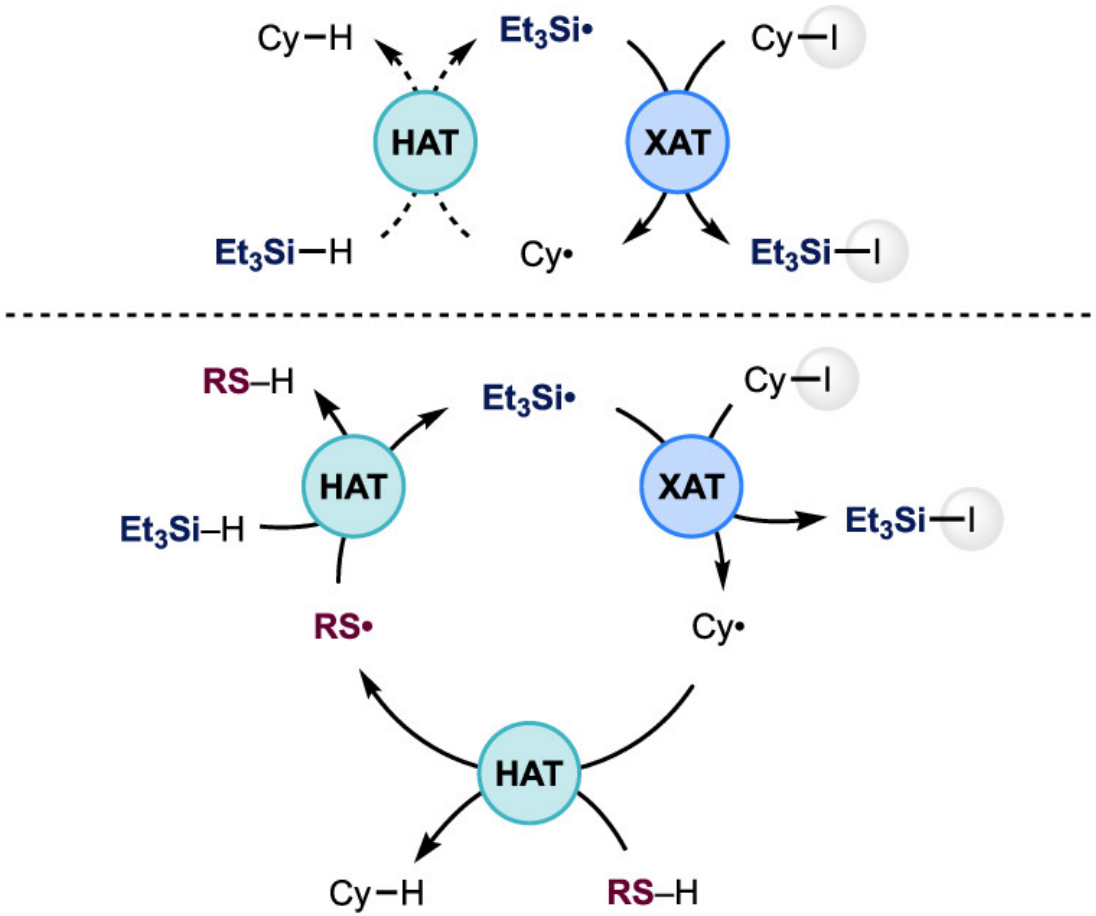
Strategies of Et_3Si• in XAT



Roberts, B. P. *Chem. Soc. Rev* **1999**, *28*, 25. Baguley, P. A.; Walton, J. C. *Angewandte Chemie International Edition* **1998**. Chatgilialoglu, C. *Acc. Chem. Res.* **1992**, *25*, 188.

Heteroatom-Based XAT Reagents: Silicon Radicals (Si•)

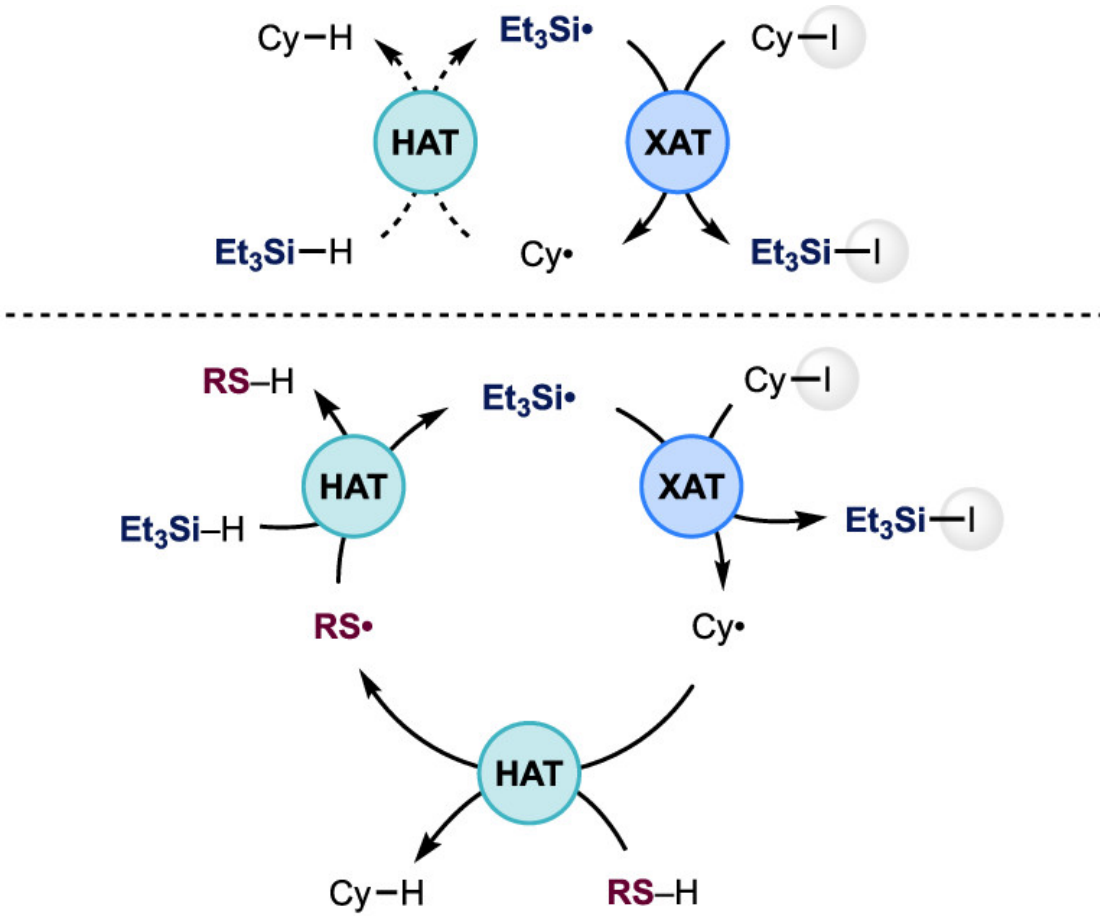
Strategies of Et_3Si• in XAT

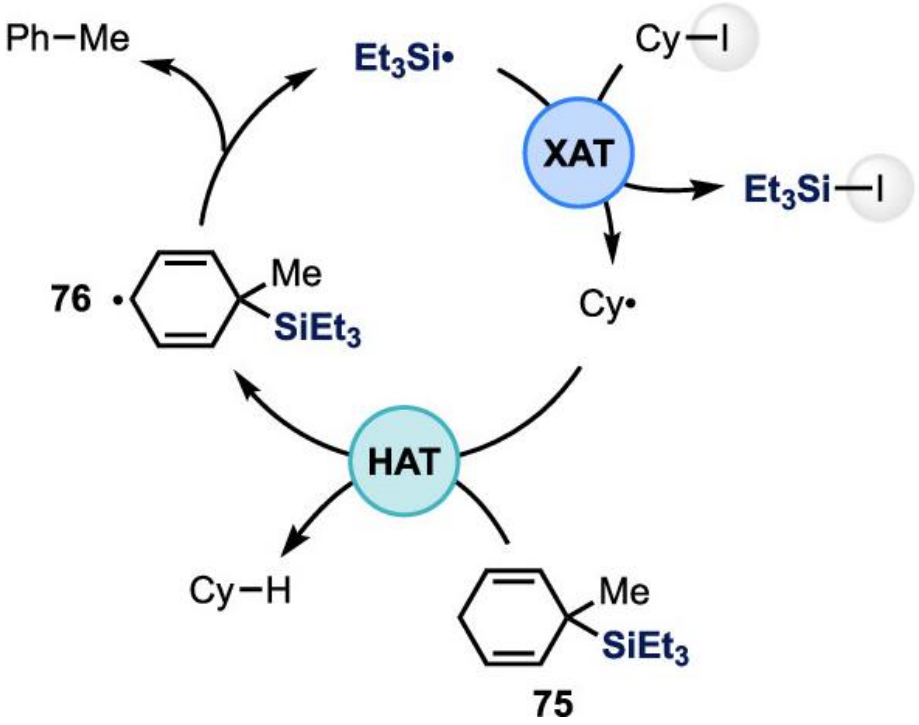


Roberts, B. P. *Chem. Soc. Rev* **1999**, *28*, 25. Baguley, P. A.; Walton, J. C. *Angewandte Chemie International Edition* **1998**. Chatgilialoglu, C. *Acc. Chem. Res.* **1992**, *25*, 188.

Heteroatom-Based XAT Reagents: Silicon Radicals (Si•)

Strategies of Et_3Si• in XAT

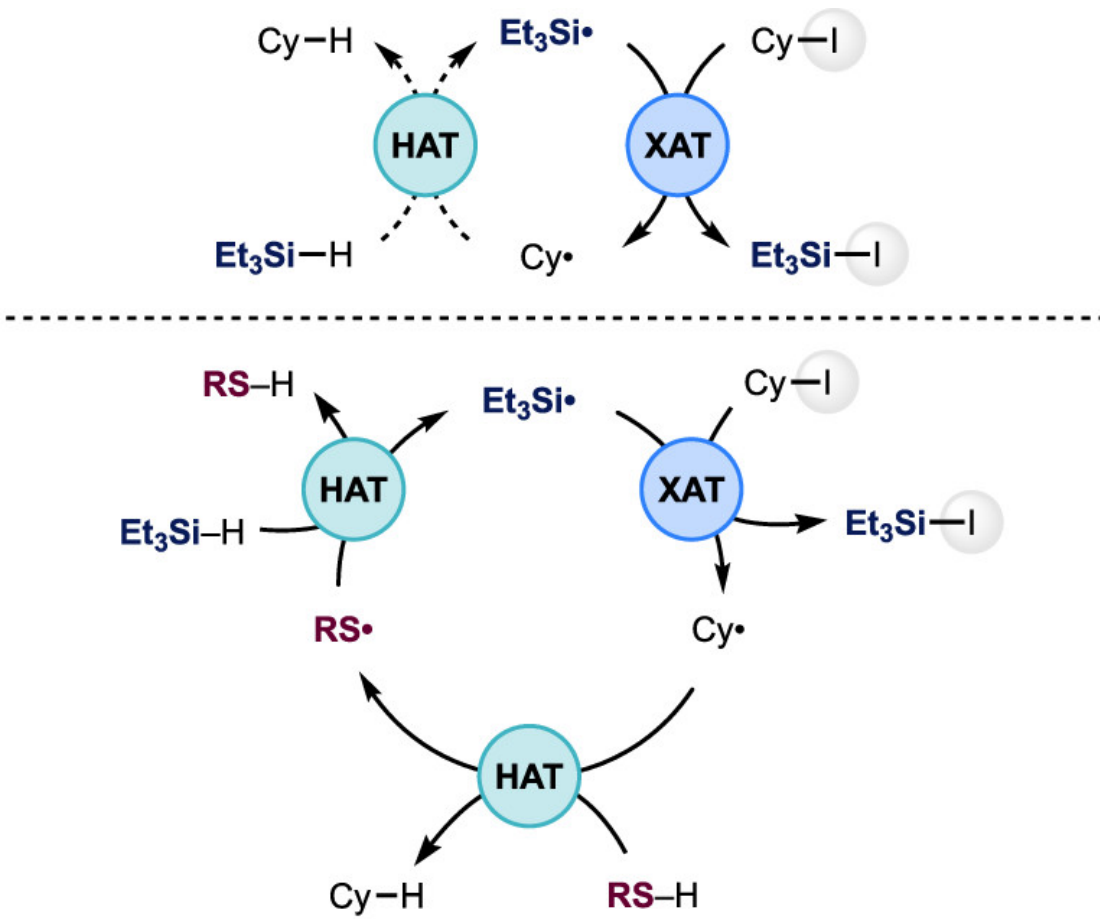


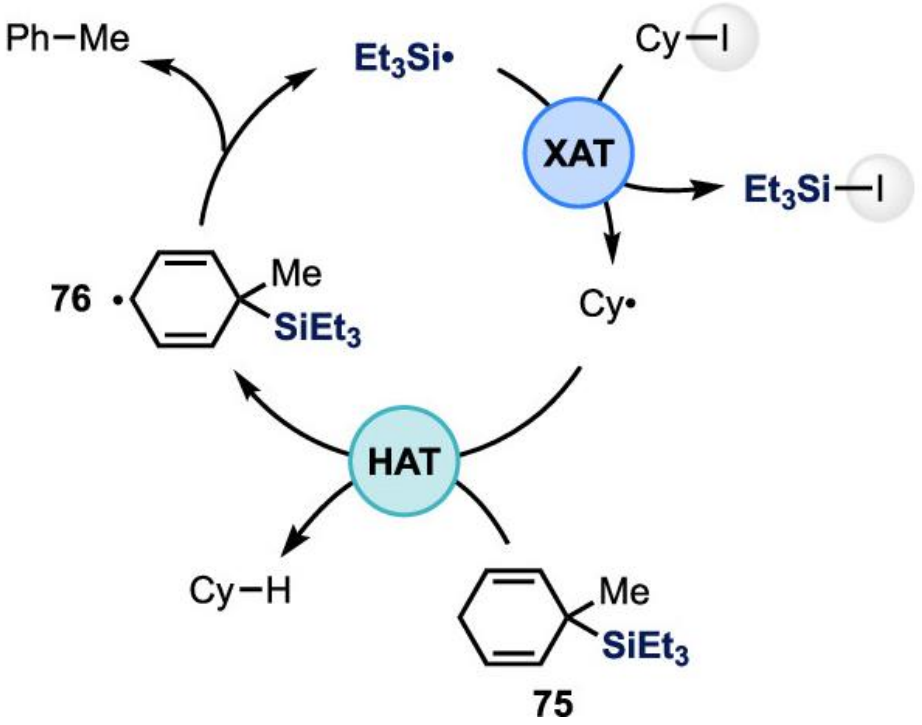


Roberts, B. P. *Chem. Soc. Rev* **1999**, *28*, 25. Baguley, P. A.; Walton, J. C. *Angewandte Chemie International Edition* **1998**. Chatgilialoglu, C. *Acc. Chem. Res.* **1992**, *25*, 188.

Heteroatom-Based XAT Reagents: Silicon Radicals (Si•)

Strategies of Et_3Si• in XAT



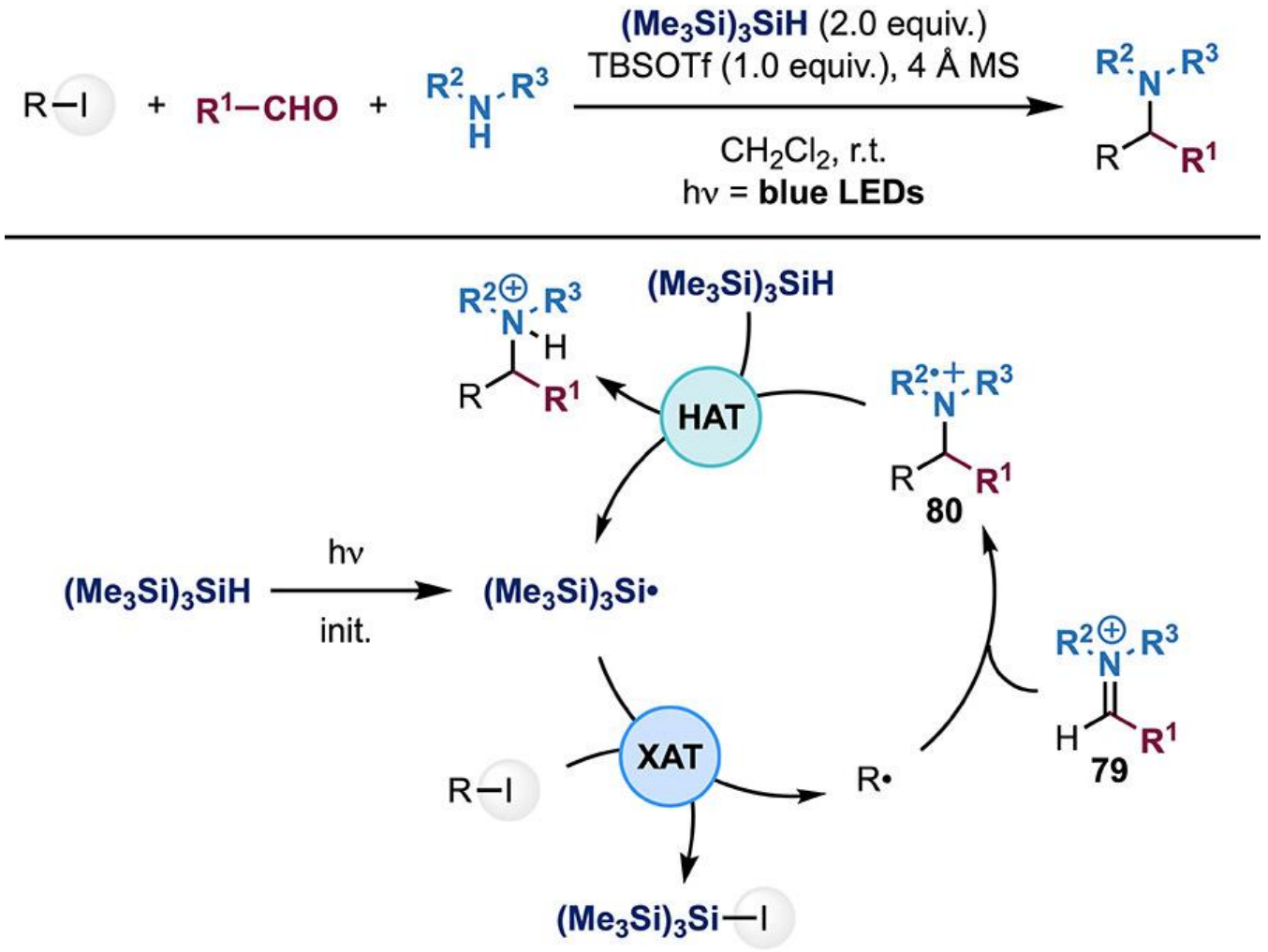


silane	Si–H BDE (kcal mol^{-1})	silane	Si–H BDE (kcal mol^{-1})
$H_3Si–H$	91.7	$Me_3Si–H$	94.7
$Et_3Si–H$	94.6	$(Me_3Si)_3Si–H$	83.7
$(MeS)_3Si–H$	87.0	$Bu_3Sn–H$	78.0

Roberts, B. P. *Chem. Soc. Rev* **1999**, *28*, 25. Baguley, P. A.; Walton, J. C. *Angewandte Chemie International Edition* **1998**. Chatgilialoglu, C. *Acc. Chem. Res.* **1992**, *25*, 188.

Heteroatom-Based XAT Reagents: Silicon Radicals (Si•)

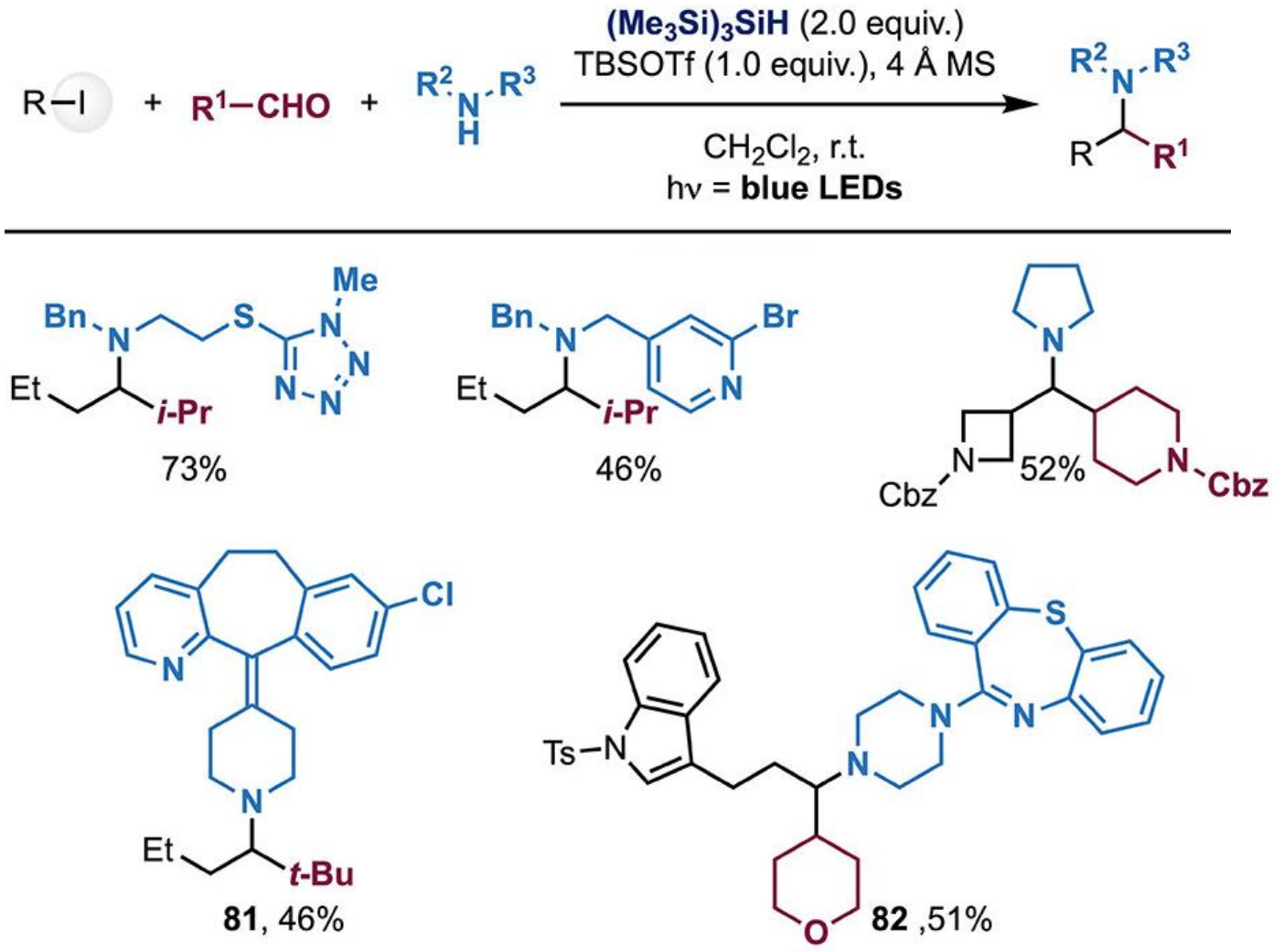
Supersilane



Kumar, R.; Flodén, N. J.; Whitehurst, W. G.; Gaunt, M. J. *Nature* **2020**, *581*, 415.

Heteroatom-Based XAT Reagents: Silicon Radicals (Si•)

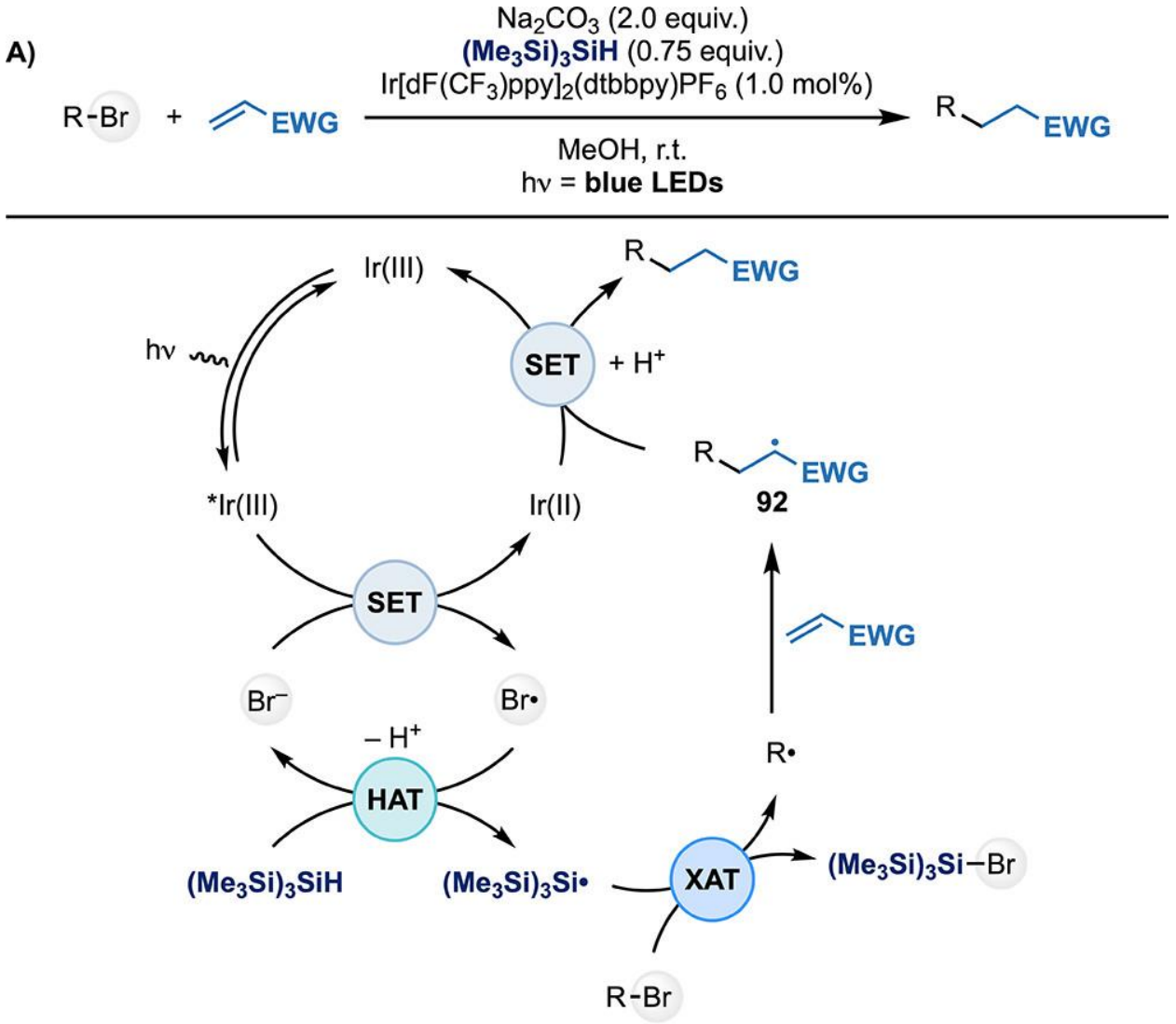
Supersilane



Kumar, R.; Flodén, N. J.; Whitehurst, W. G.; Gaunt, M. J. *Nature* **2020**, *581*, 415.

Heteroatom-Based XAT Reagents: Silicon Radicals (Si•)

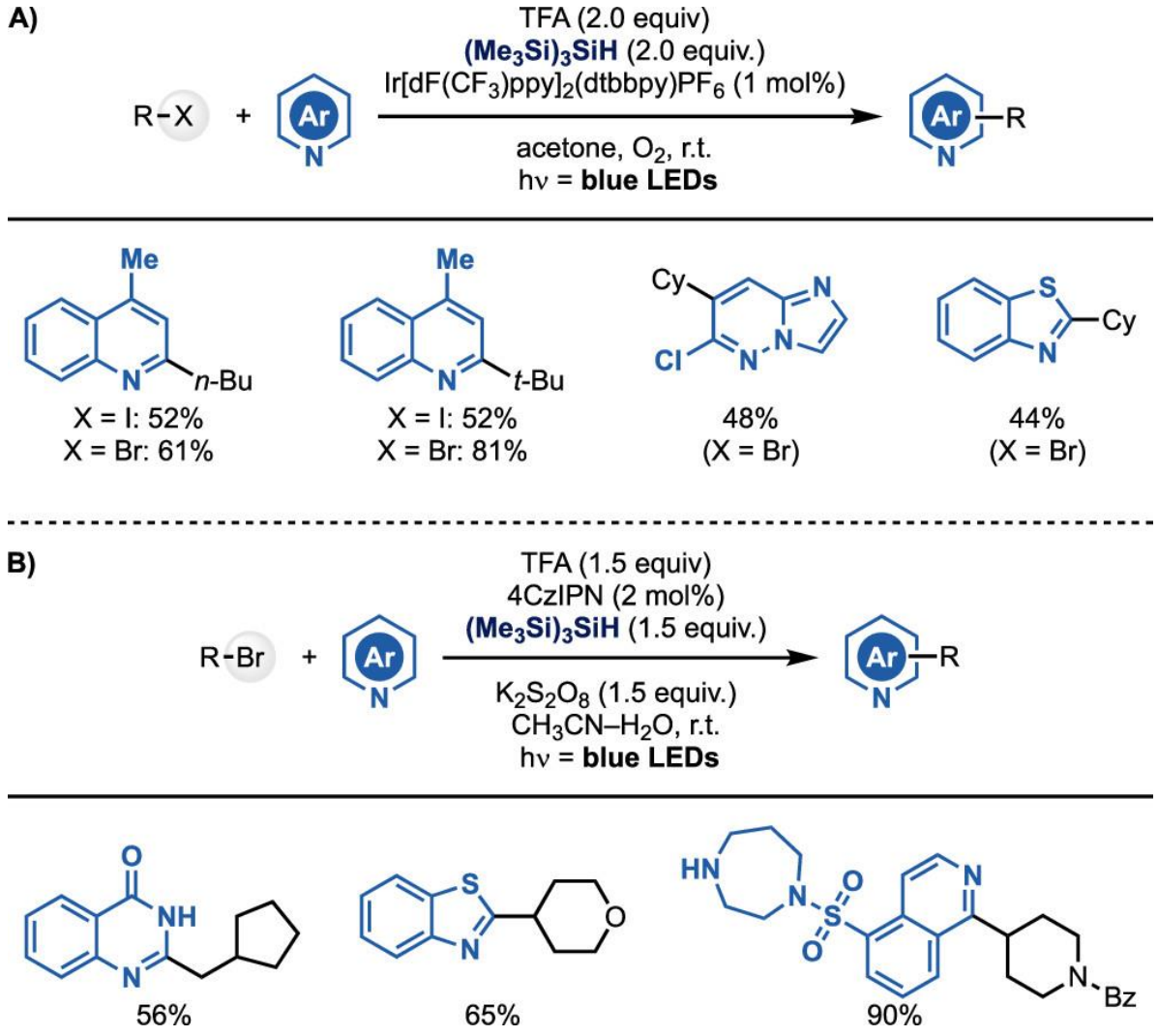
Supersilane – photoredox catalysis



Le, C. C.; Wismer, M. K.; Shi, Z.-C.; Zhang, R.; Conway, D. V.; Li, G.; Vachal, P.; Davies, I. W.; MacMillan, D. W. C. *ACS Cent. Sci.* **2017**, *3*, 647.
ElMarrouni, A.; Ritts, C. B.; Balsells, J. *Chem. Sci.* **2018**, *9*, 6639.

Heteroatom-Based XAT Reagents: Silicon Radicals (Si•)

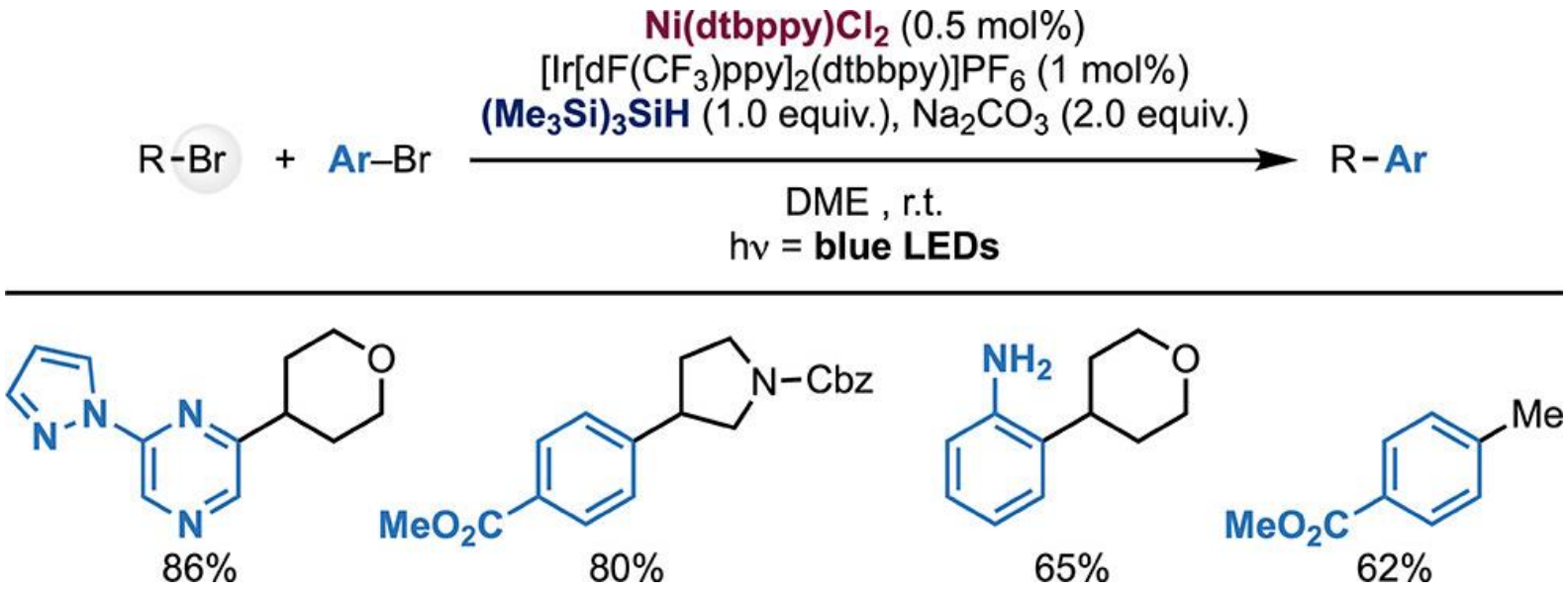
Supersilane – photoredox catalysis



Dong, J.; Lyu, X.; Wang, Z.; Wang, X.; Song, H.; Liu, Y.; Wang, Q. *Chem. Sci.* **2019**, *10*, 976-982.
Perkins, J. J.; Schubert, J. W.; Streckfuss, E. C.; Balsells, J.; ElMarrouni, A. *European J. Org. Chem.* **2020**, *10*, 1515.

Heteroatom-Based XAT Reagents: Silicon Radicals (Si•)

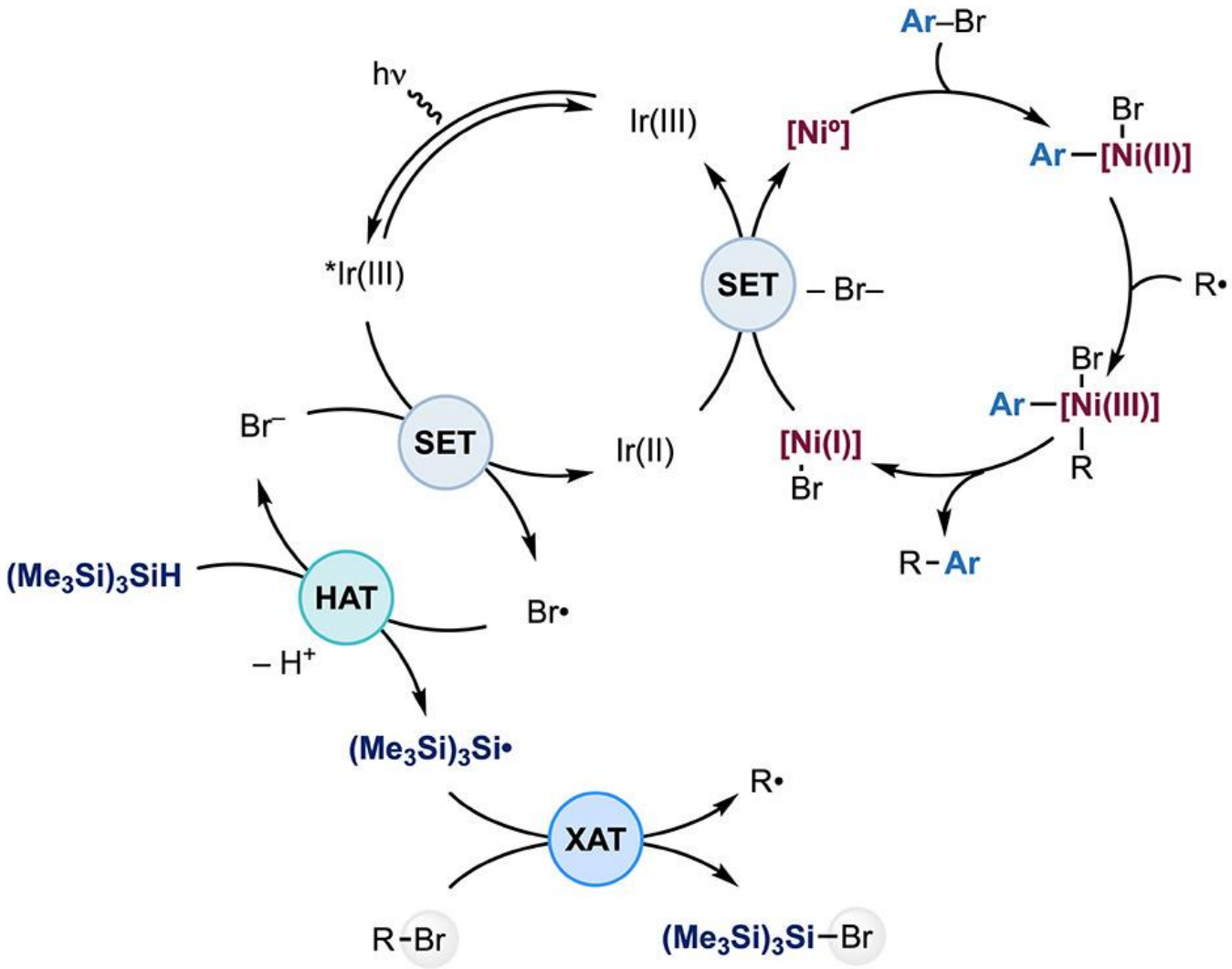
Supersilane – Metallaphotoredox



Zhang, P.; Le, C. C.; MacMillan, D. W. C. *J. Am. Chem. Soc.* **2016**, *138*, 8084.

Heteroatom-Based XAT Reagents: Silicon Radicals (Si•)

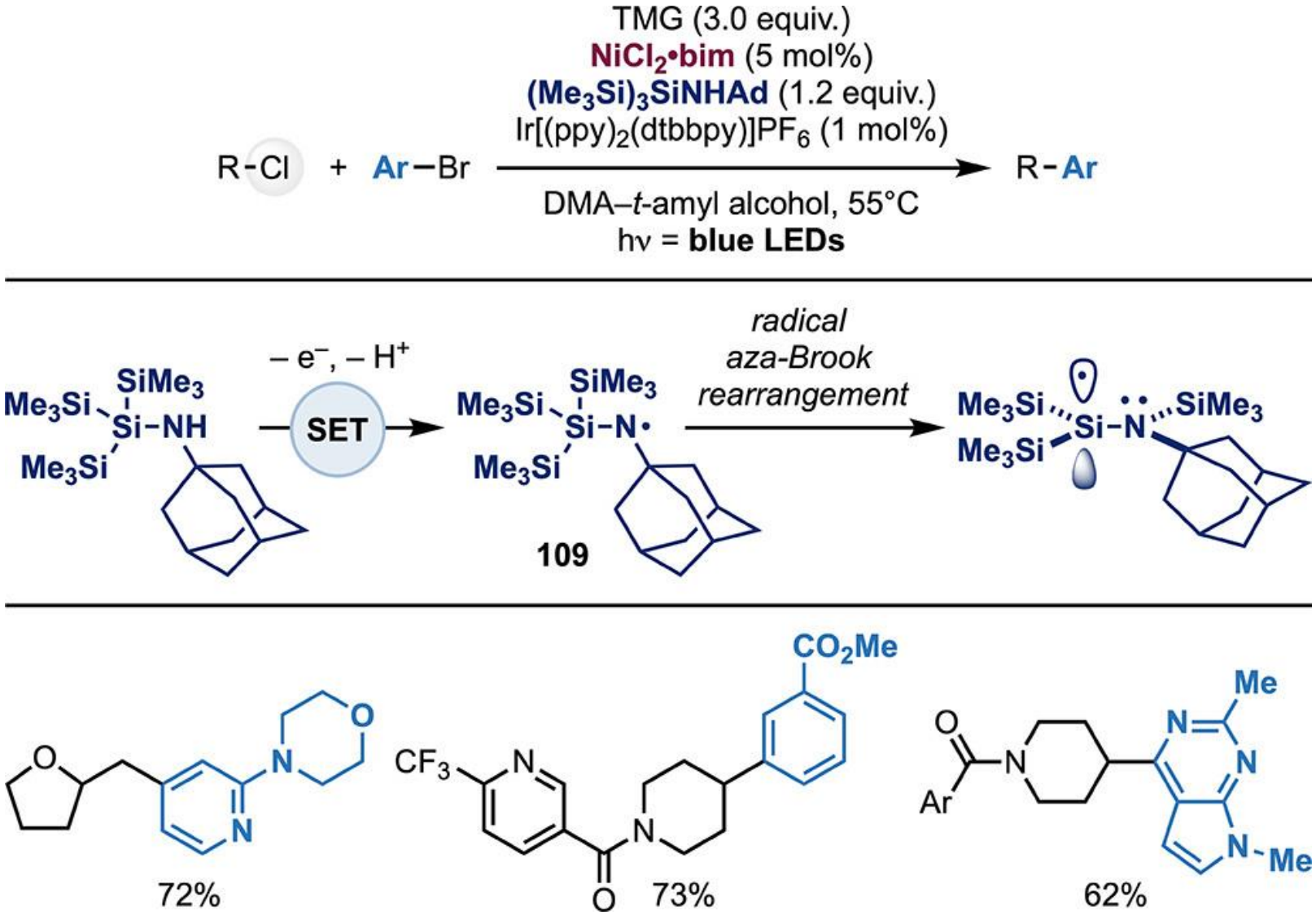
Supersilane – Metallaphotoredox



Zhang, P.; Le, C. C.; MacMillan, D. W. C. *J. Am. Chem. Soc.* **2016**, *138*, 8084.

Heteroatom-Based XAT Reagents: Silicon Radicals (Si•)

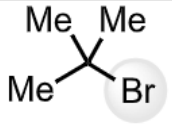
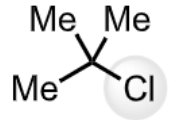
Supersilane – Metallaphotoredox



Sakai, H. A.; Liu, W.; Le, C. C.; MacMillan, D. W. C. *J. Am. Chem. Soc.* **2020**.

Heteroatom-Based XAT Reagents: Germanium Radicals (Ge•)

Comparable XAT reactivity with Sn•

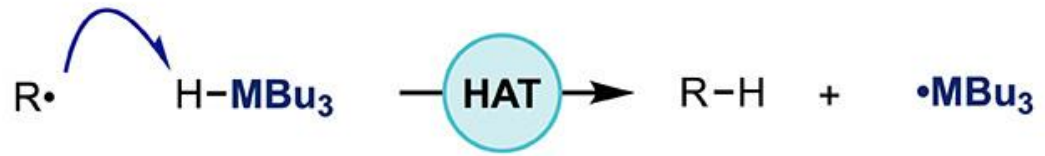
	k_{XAT} (M^{-1} s^{-1})		
Substrate	**Bu_3Ge•**	**Bu_3Sn•**	**Et_3Si•**
Cl_3C-Cl	3×10^8		5×10^9
Ph-Cl	2×10^6	1×10^6	2×10^7
Ph-Br	8×10^8	1×10^9	2×10^9
Me-I	$>3 \times 10^7$		4×10^9
Me-Br	5×10^7	3×10^7	5×10^8
	9×10^7	1×10^8	1×10^9
	$<5 \times 10^4$	3×10^4	3×10^6

Ingold, K. U.; Lusztyk, J.; Scaiano, J. C. *J. Am. Chem. Soc.* **1984**, *106*, 343.

Heteroatom-Based XAT Reagents: Germanium Radicals (Ge•)

Slower HAT than R_3SnH

A)

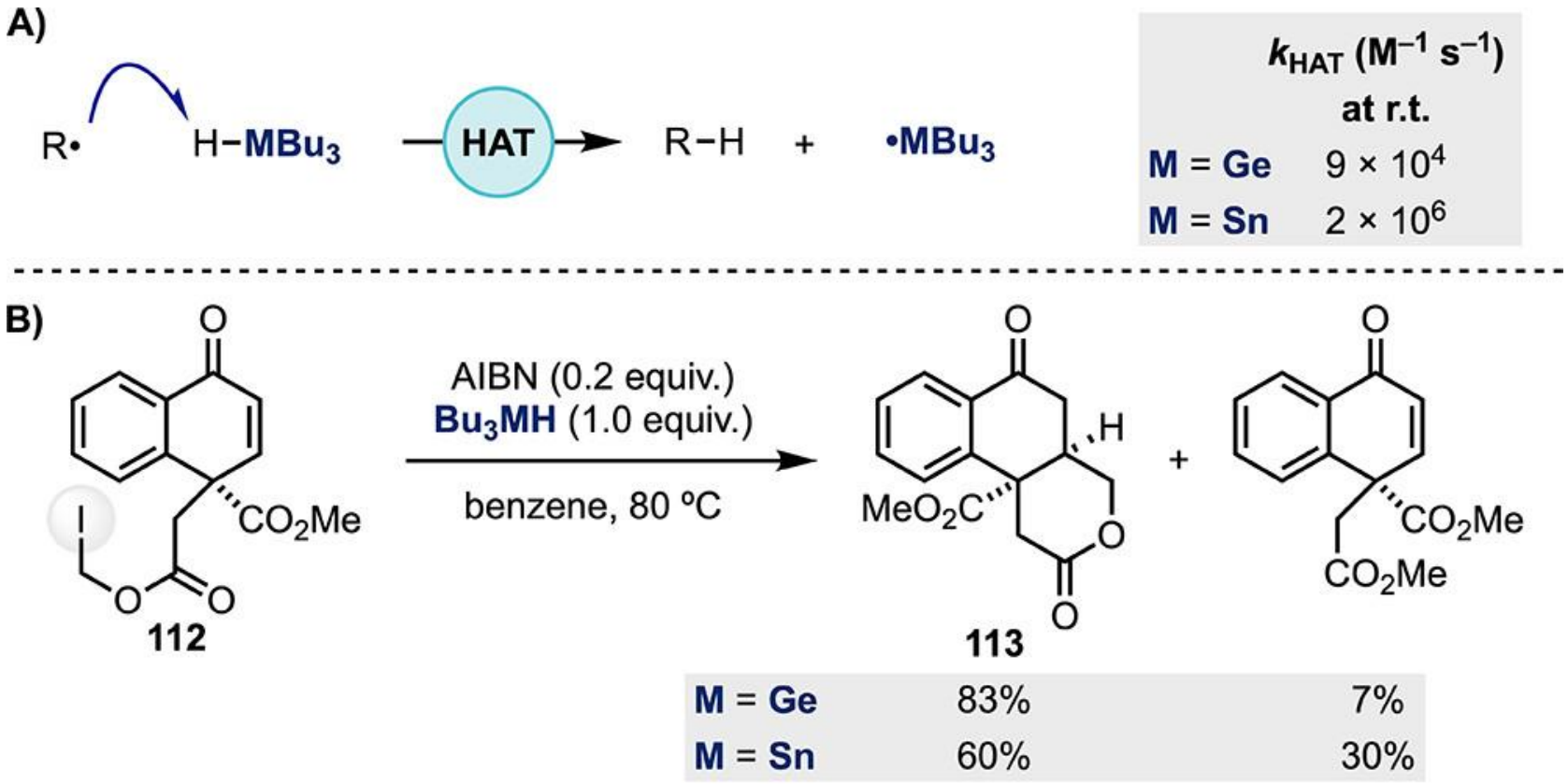


	k_{HAT} (M^{-1} s^{-1}) at r.t.
M = Ge	9×10^4
M = Sn	2×10^6

Lusztyk, J.; Maillard, B.; Lindsay, D. A.; Ingold, K. U. *J. Am. Chem. Soc.* **1983**, *105*, 3578. Beckwith, A. L. J.; Pigou, P. E. *J. Chem. Soc., Chem. Commun.* **1986**, 85.

Heteroatom-Based XAT Reagents: Germanium Radicals (Ge•)

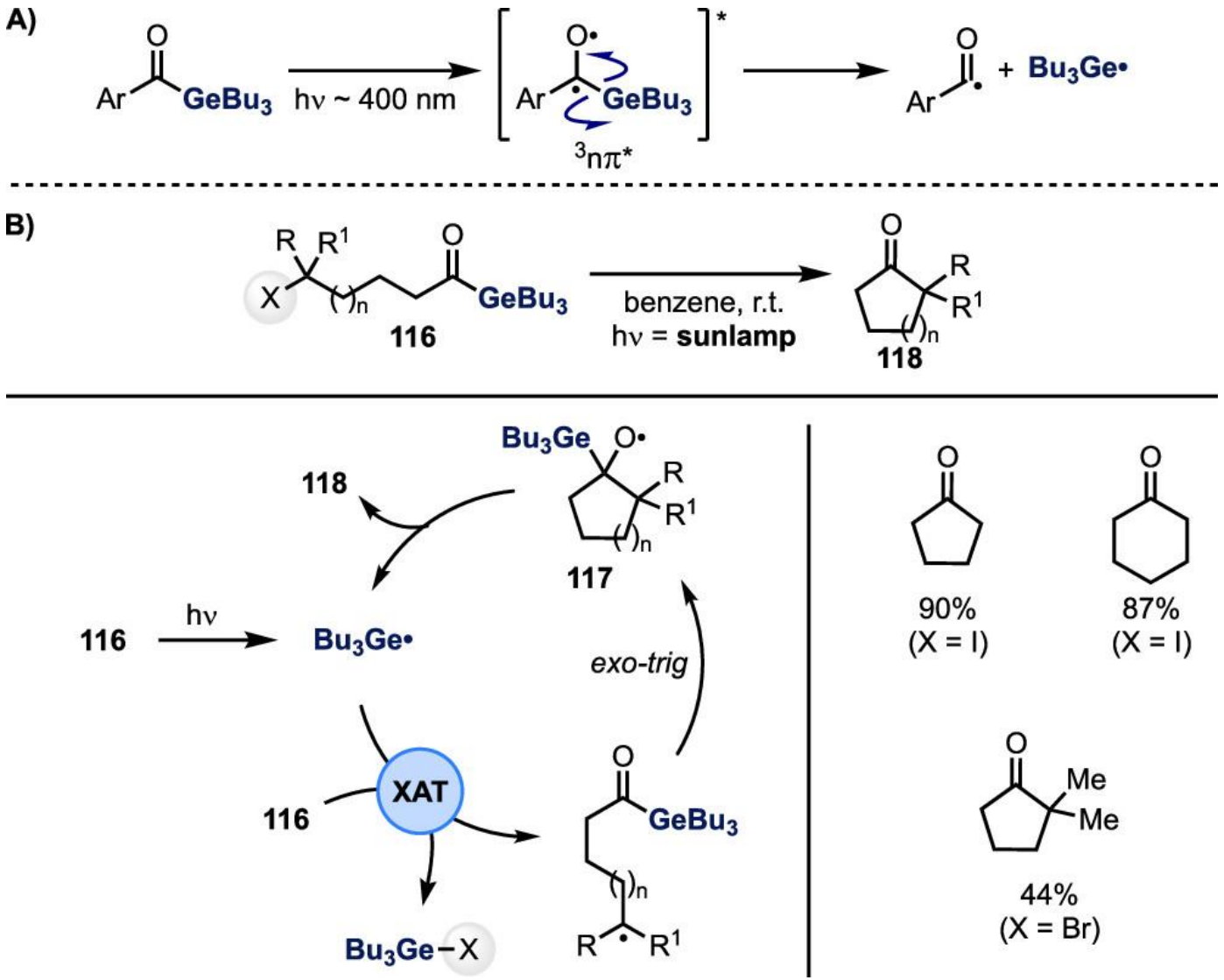
Slower HAT than R_3SnH



Lusztyk, J.; Maillard, B.; Lindsay, D. A.; Ingold, K. U. *J. Am. Chem. Soc.* **1983**, *105*, 3578. Beckwith, A. L. J.; Pigou, P. E. *J. Chem. Soc., Chem. Commun.* **1986**, 85.

Heteroatom-Based XAT Reagents: Germanium Radicals (Ge•)

Photochemistry of Acyl Germanium



Doi, T.; Takahashi, T. *J. Org. Chem.* **1991**, *56*, 3465.

Heteroatom-Based XAT Reagents: Boron Radicals (B•)

Comparable XAT reactivity with Si•

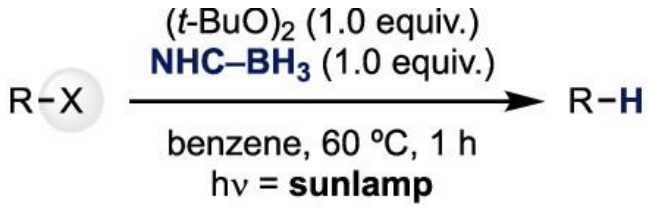
	k_{XAT} (M^{-1} s^{-1})			
Substrate	**Et_3Si•**	**Me_3N–BH_2•**	**H_3B•**	**NHC–BH_2•**
Cl_3C-Cl	5×10^9	5×10^9	2×10^9	2×10^7
Ph Br	2×10^9	2×10^9	5×10^8	
Me Br	5×10^8	1×10^8	1×10^8	
Ph Cl	2×10^7	1×10^7	3×10^7	

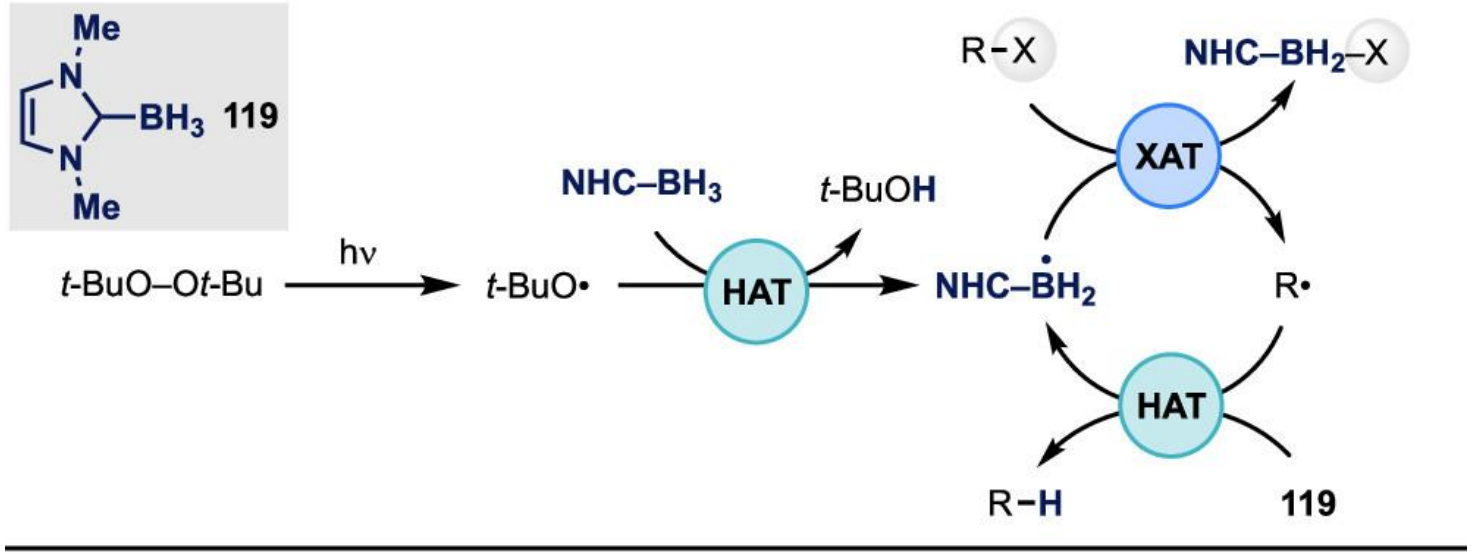
Tehfe, M.-A.; Makhlouf Brahmi, M.; Fouassier, J.-P.; Curran, D. P.; Malacria, M.; Fensterbank, L.; Lacôte, E.; Lalevée, J. *Macromolecules* **2010**, *43*, 2261.
Sheeller, B.; Ingold, K. U. *J. Chem. Soc., Perkin Trans. 2* **2001**, 480.



Heteroatom-Based XAT Reagents: Boron Radicals (B•)

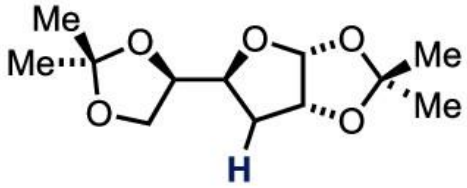
NHC–BH_3 dehalogenation



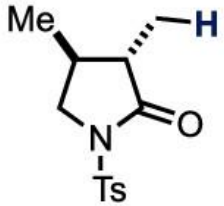




71%



63%

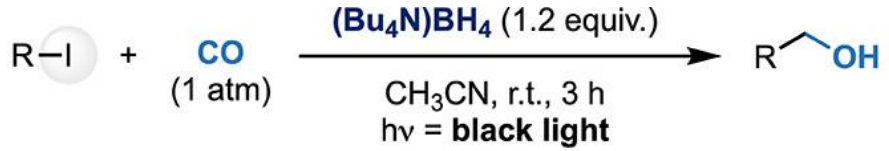


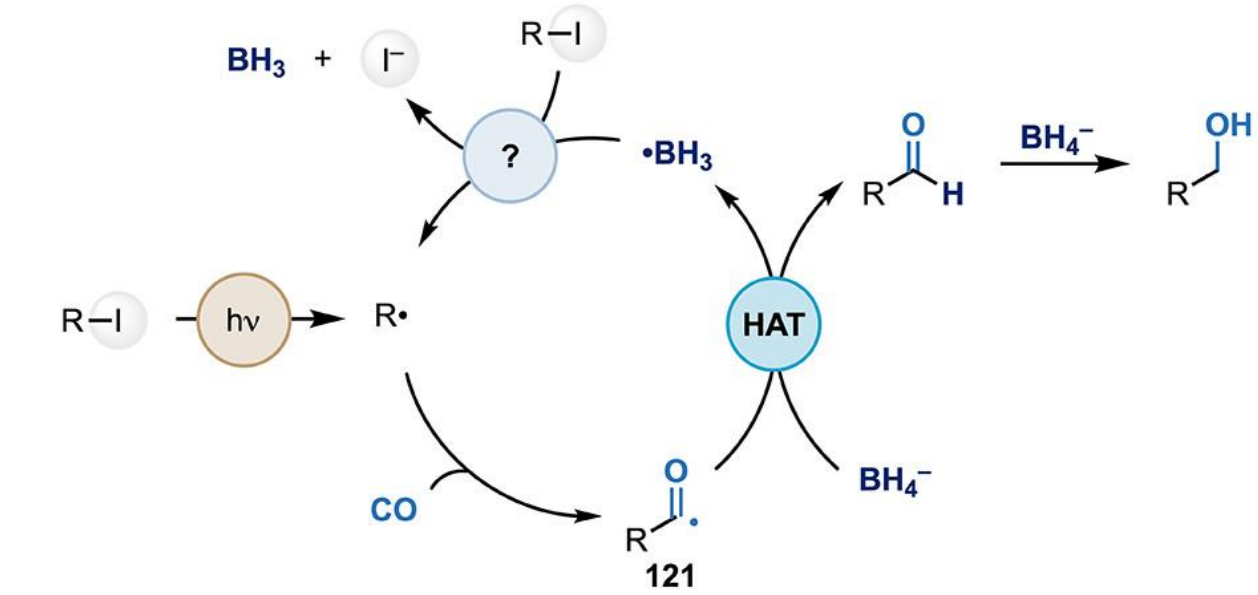
120, 56%
trans:*cis* = 4.5:1

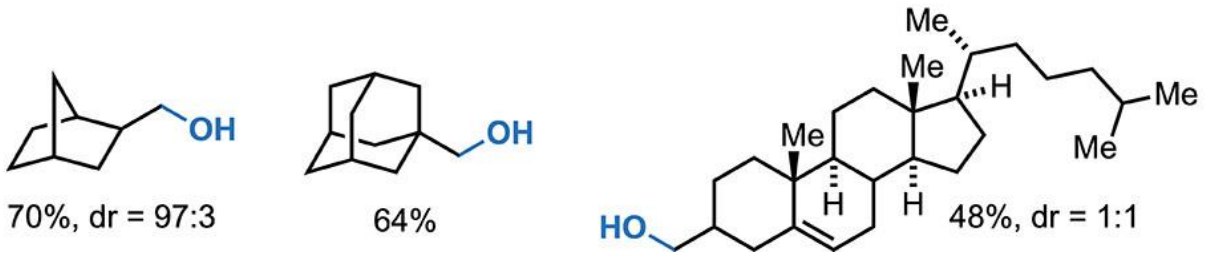
Ueng, S.-H.; Fensterbank, L.; Lacôte, E.; Malacria, M.; Curran, D. P. *Org. Biomol. Chem.* **2011**, *9*, 3415.

Heteroatom-Based XAT Reagents: Boron Radicals (B•)

Carbonylation



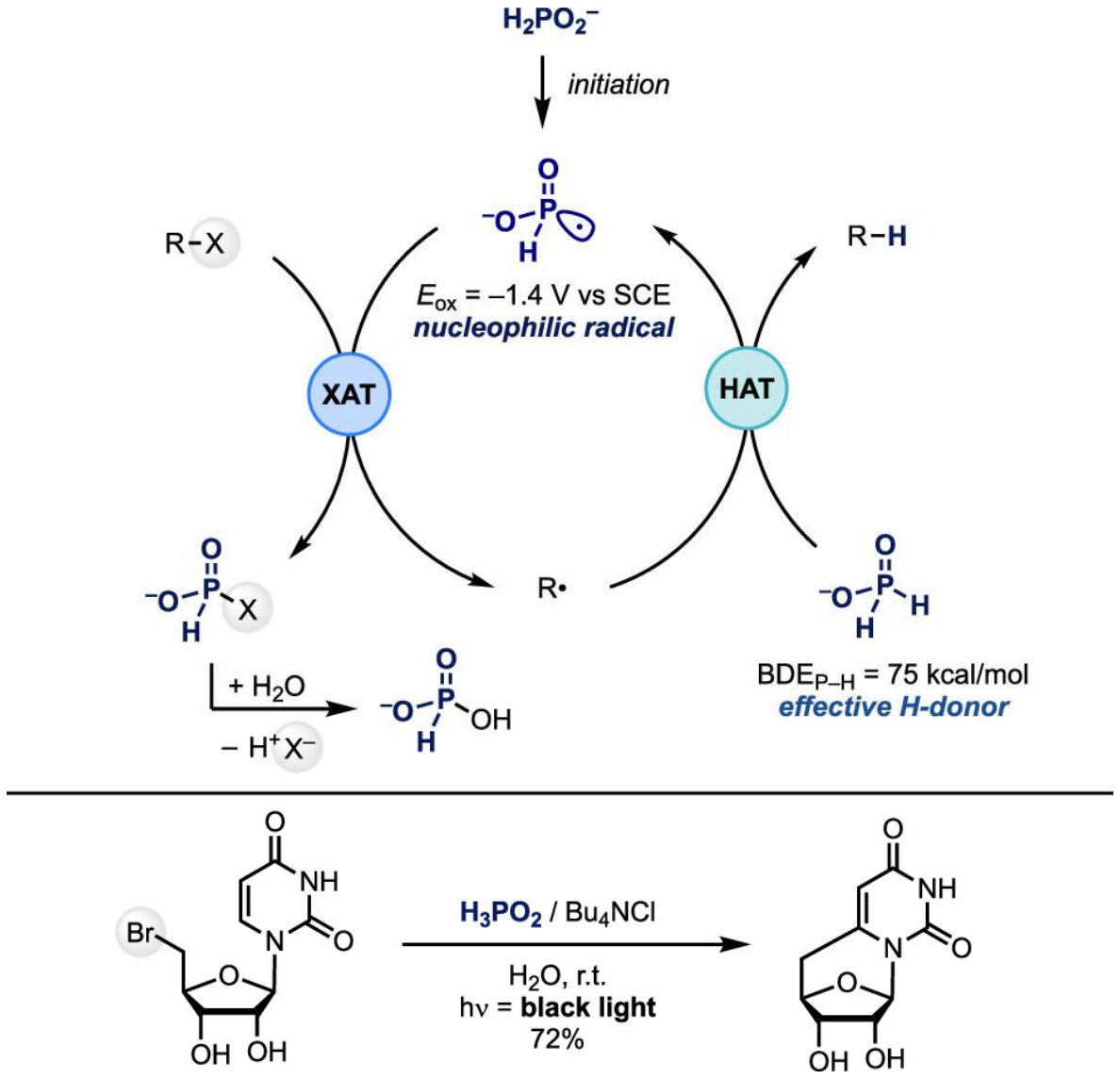




Kobayashi, S.; Kawamoto, T.; Uehara, S.; Fukuyama, T.; Ryu, I. *Org. Lett.* **2010**, *12*, 1548.
Kobayashi, S.; Kinoshita, T.; Kawamoto, T.; Wada, M.; Kuroda, H.; Masuyama, A.; Ryu, I. *J. Org. Chem.* **2011**, *76*, 7096.

Heteroatom-Based XAT Reagents: Phosphorus Radicals (P•)

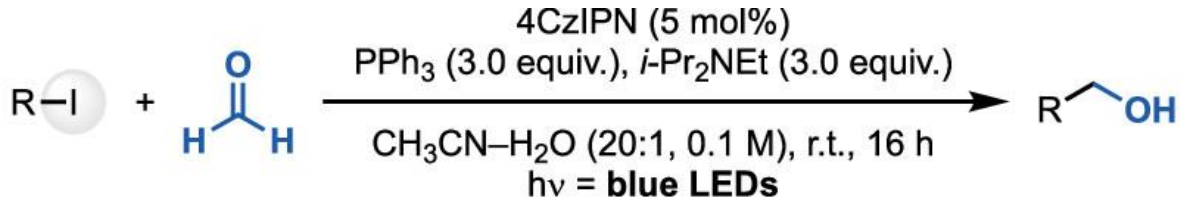
Nucleophilic radical/effective H-donor

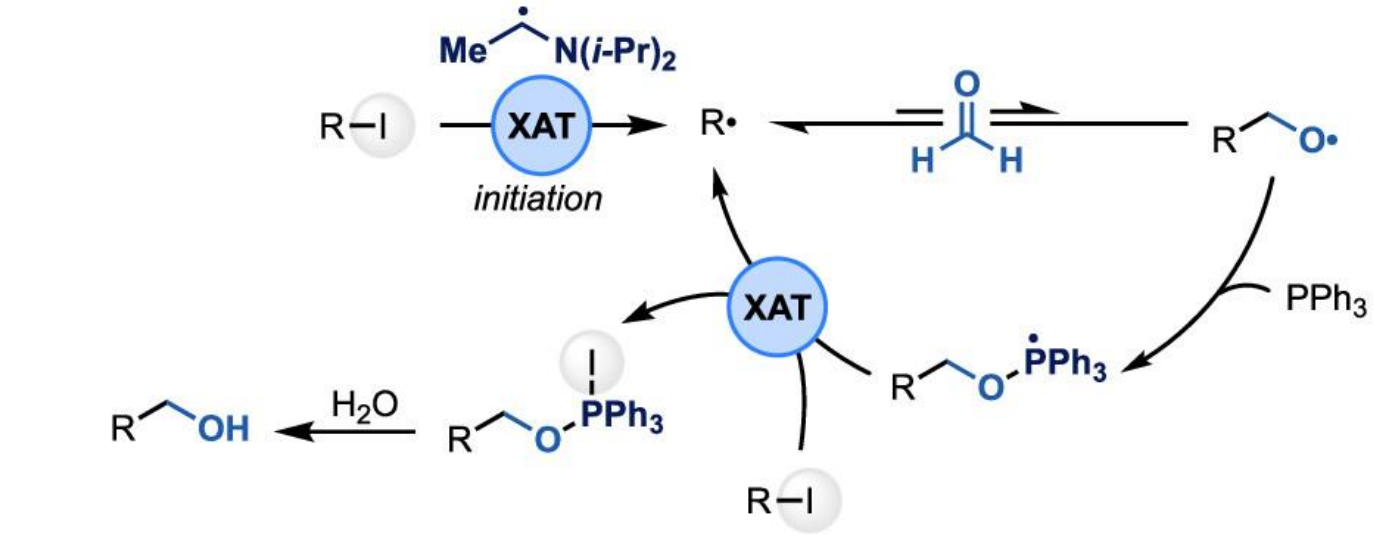


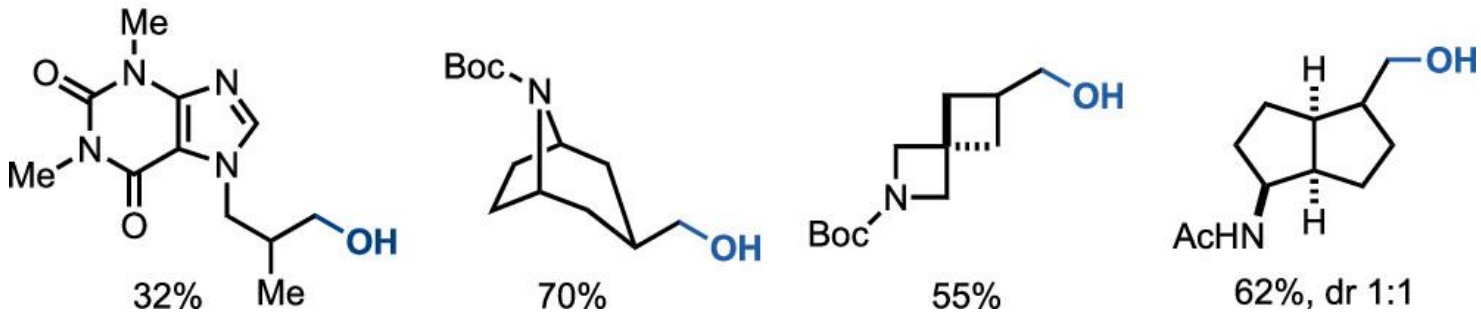
Shastri, L. V.; Huie, R. E.; Neta, P. *J. Phys. Chem.* **1990**, *94*, 1895. Lin, C. Y.; Peh, J.; Coote, M. L. *J. Org. Chem.* **2011**, *76*, 1715. T. Perchyonok, V. *Lett. Org. Chem.* **2011**, *8*, 337.

Heteroatom-Based XAT Reagents: Phosphorus Radicals (P•)

Hydroxymethylation





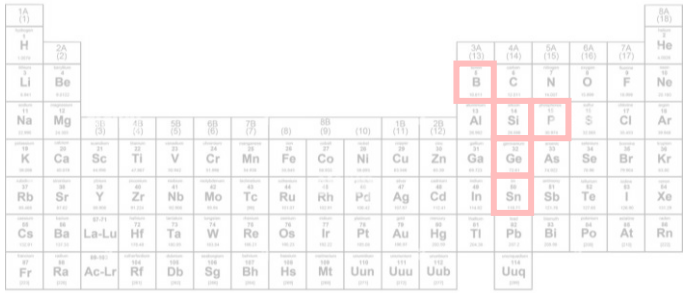


Caiger, L.; Sinton, C.; Constantin, T.; Douglas, J. J.; Sheikh, N. S.; Juliá, F.; Leonori, D. *Chem. Sci.* **2021**, *12*, 10448.

Applications of XAT Reactivity in Synthetic Photocatalysis

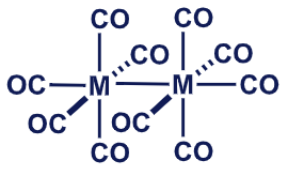
Heteroatom-Based

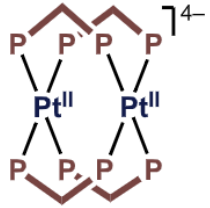
- Tin Radicals (Sn•)
- Silicon Radicals (Si•)
- Germanium Radicals (Ge•)
- Boron Radicals (B•)
- Phosphorus Radicals (P•)



Metal-Based

- **Dimeric Carbonyl Complexes Displaying Photocleavable Metal–Metal Bonds**
- **Dimeric Complexes Without Formal Metal–Metal Bonds**
- **Metalloradicals Generated From Monomeric Species**







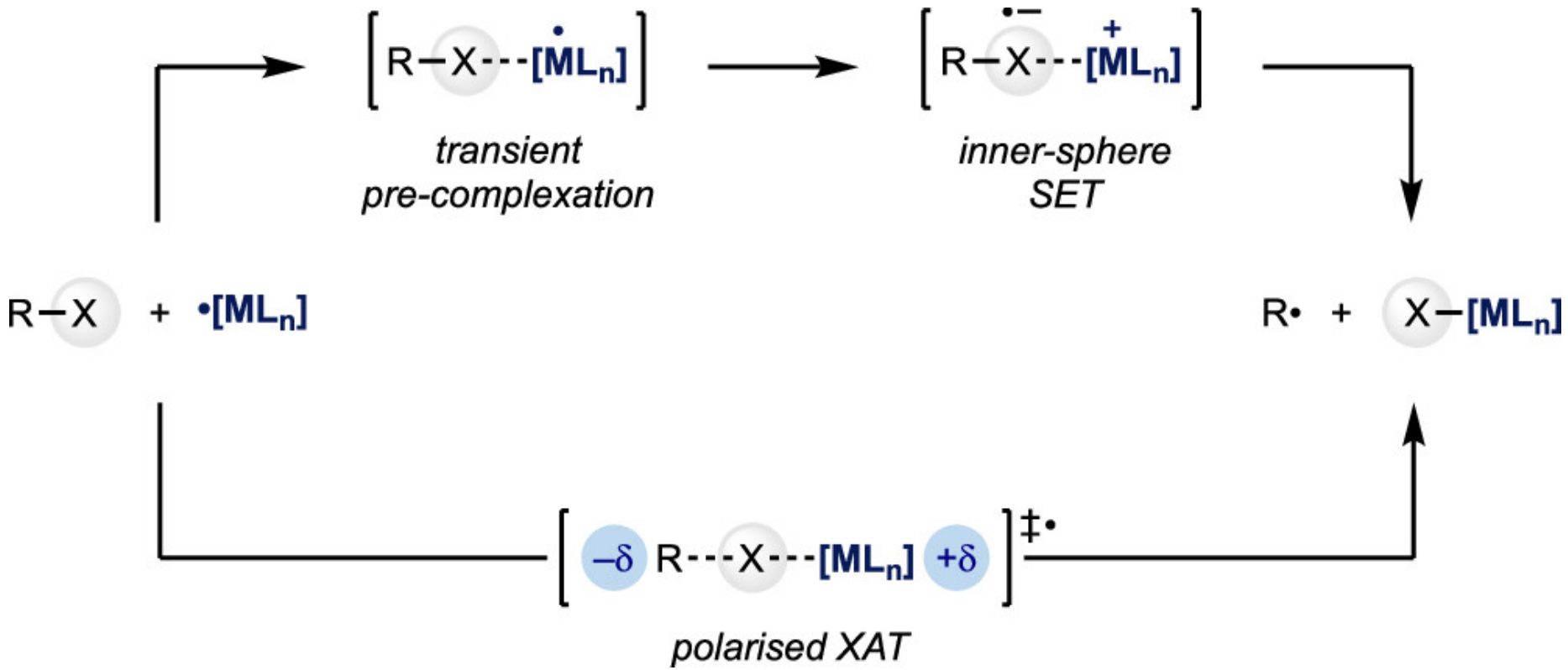
Carbon-Based

- α-Aminoalkyl Radicals
- Methyl Radical
- Acyl Radicals

Me•

Metal-Based XAT Reagents

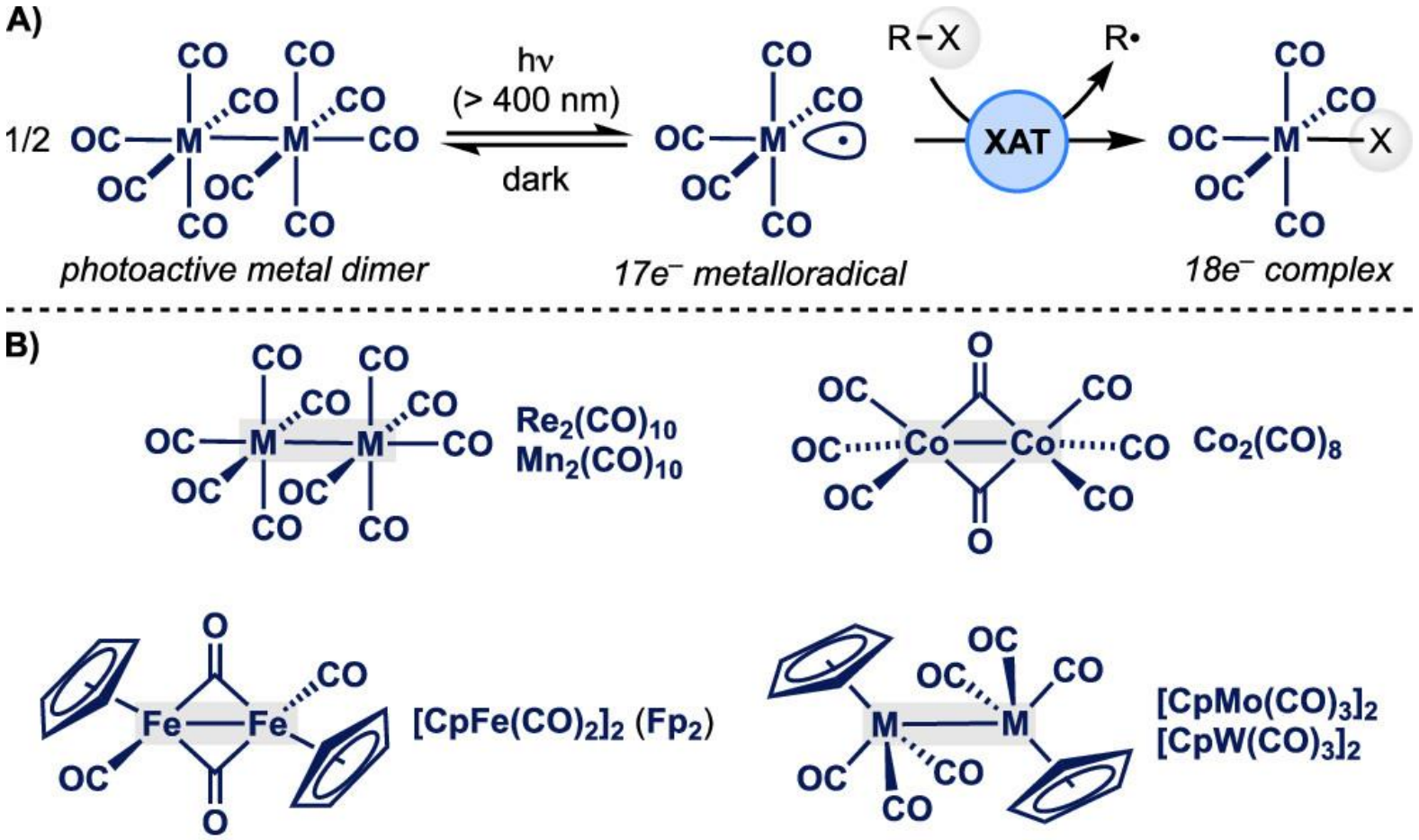
Mechanistic pathways for XAT reactions involving metal complexes



Juliá, F.; Constantin, T.; Leonori, D. *Chem. Rev.* **2022**, *122*, 2292.

Metal-Based XAT Reagents: Dimeric Carbonyl Complexes Displaying Photocleavable Metal−Metal Bonds

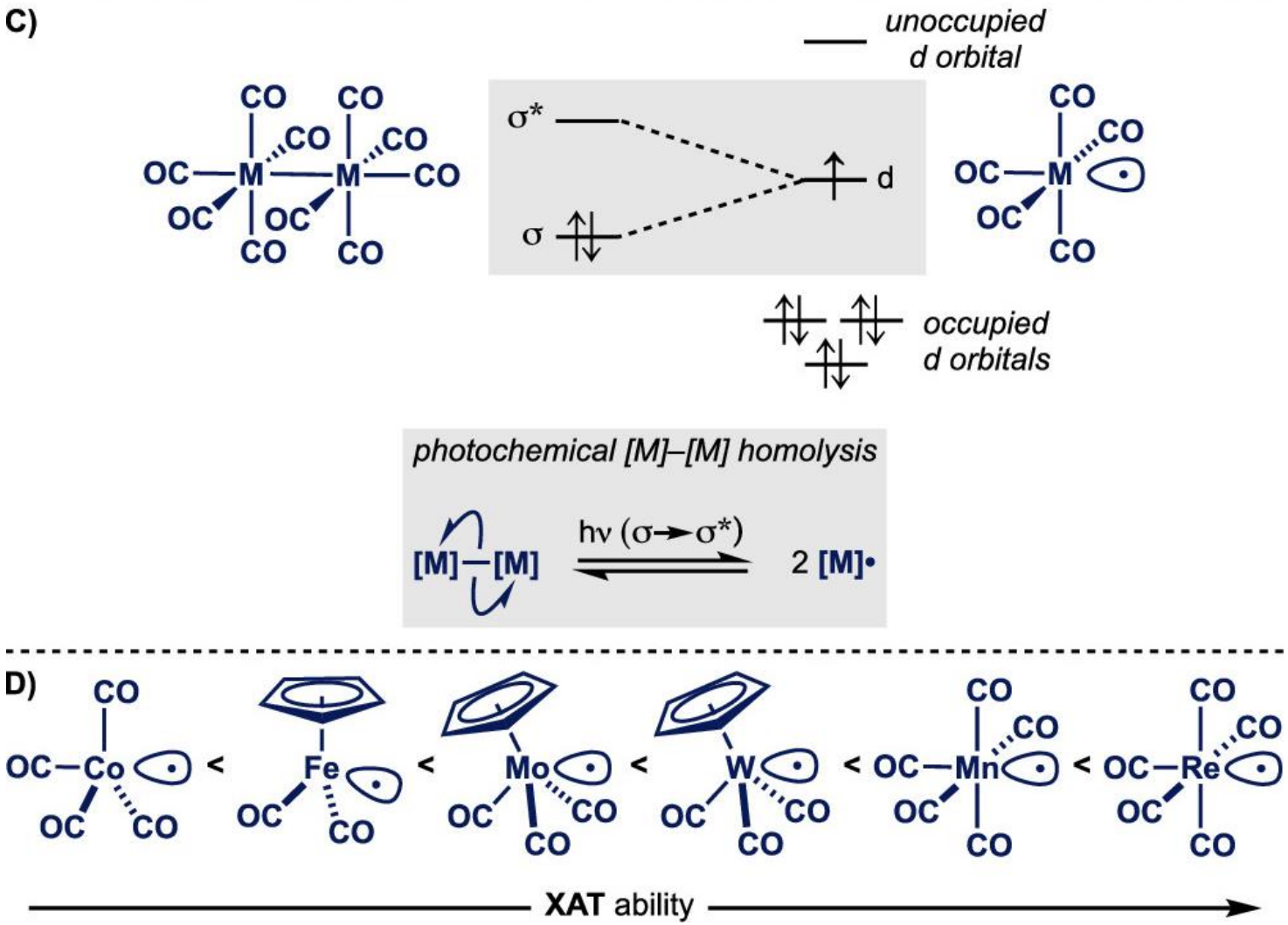
Representative examples of carbonyl dimers containing [M−M] bonds



Meyer, T. J.; Caspar, J. V. *Chem. Rev.* **1985**, *85*, 187.

Metal-Based XAT Reagents: Dimeric Carbonyl Complexes Displaying Photocleavable Metal−Metal Bonds

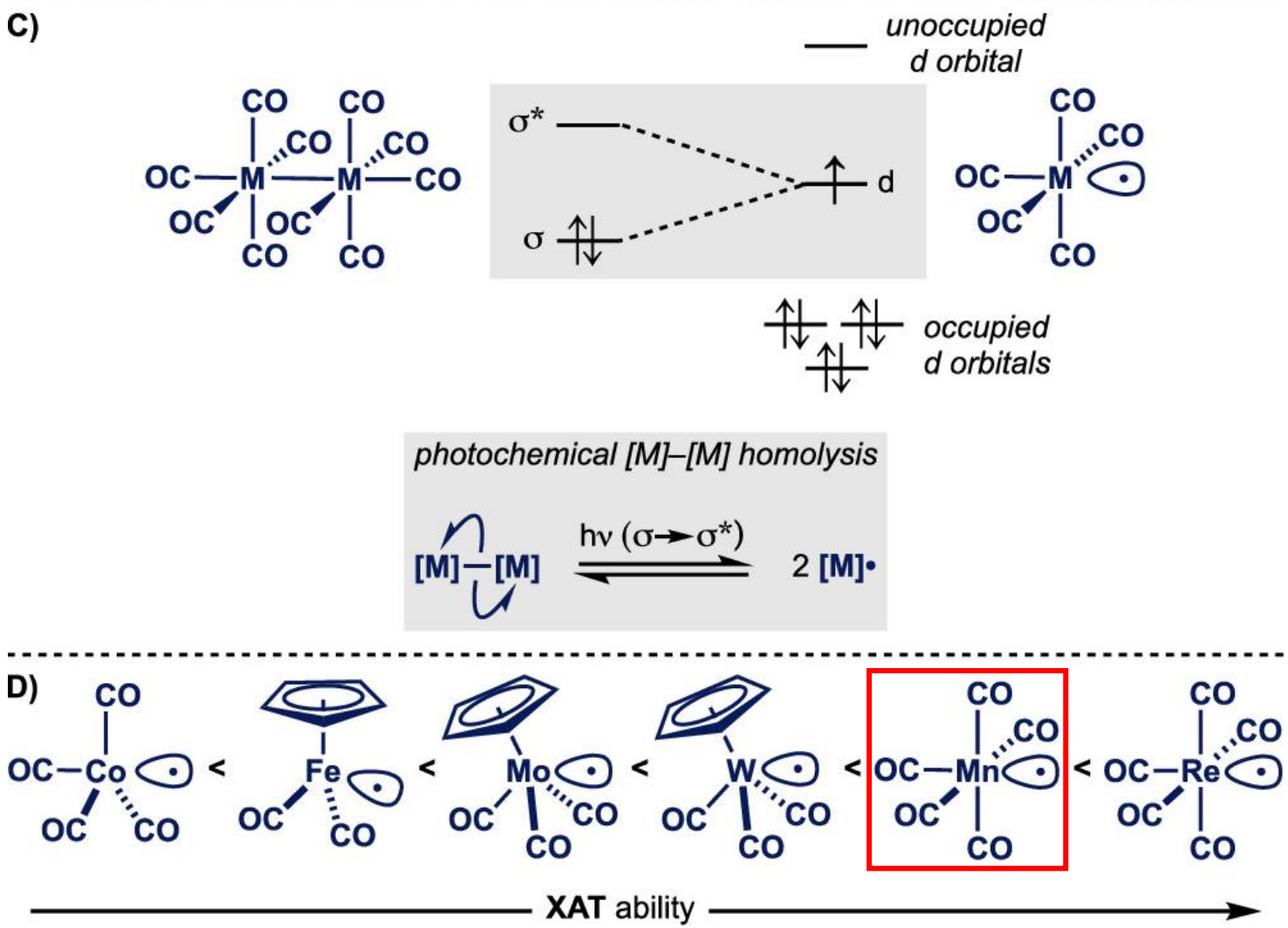
Reactivity scale of metalloradicals in XAT



Abrahamson, H. B.; Wrighton, M. S. *Inorg. Chem.* **1978**, *17*, 1003. Abrahamson, H. B.; Wrighton, M. S. *J. Am. Chem. Soc.* **1977**, *99*, 5510.

Metal-Based XAT Reagents: Dimeric Carbonyl Complexes Displaying Photocleavable Metal−Metal Bonds

Reactivity scale of metalloradicals in XAT

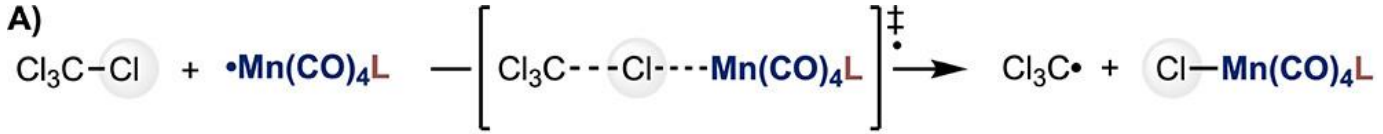


Abrahamson, H. B.; Wrighton, M. S. *Inorg. Chem.* **1978**, *17*, 1003. Abrahamson, H. B.; Wrighton, M. S. *J. Am. Chem. Soc.* **1977**, *99*, 5510.

Metal-Based XAT Reagents: Dimeric Carbonyl Complexes Displaying Photocleavable Metal−Metal Bonds

Tunable rate of XAT with ligand

A)

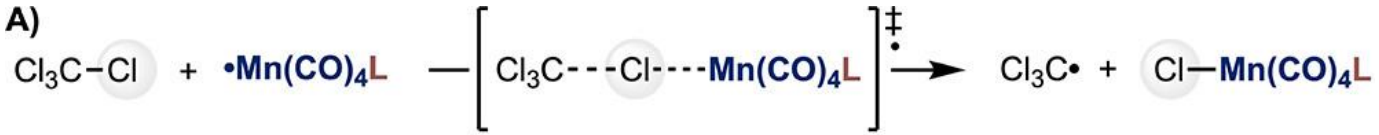


L =	$P(^nBu)_3$	$P(O^iPr)_3$	$P(^iBu)_3$	$P(Cy)_3$
θ (degrees)	132	130	143	170
k_{XAT} (M^{-1} s^{-1}) at 24 °C	2×10^6	2×10^4	9×10^4	2×10^4

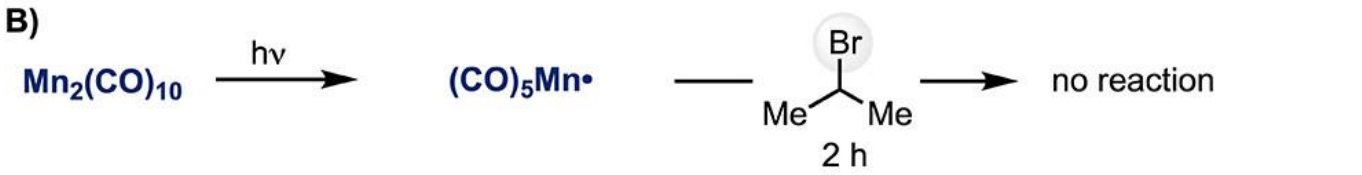
Herrick, R. S.; Herrinton, T. R.; Walker, H. W.; Brown, T. L. *Organometallics* **1985**, *4*, 42. Tyler, D. R.; Goldman, A. S. *J. Organomet. Chem* **1986**, *311*, 349.

Metal-Based XAT Reagents: Dimeric Carbonyl Complexes Displaying Photocleavable Metal−Metal Bonds

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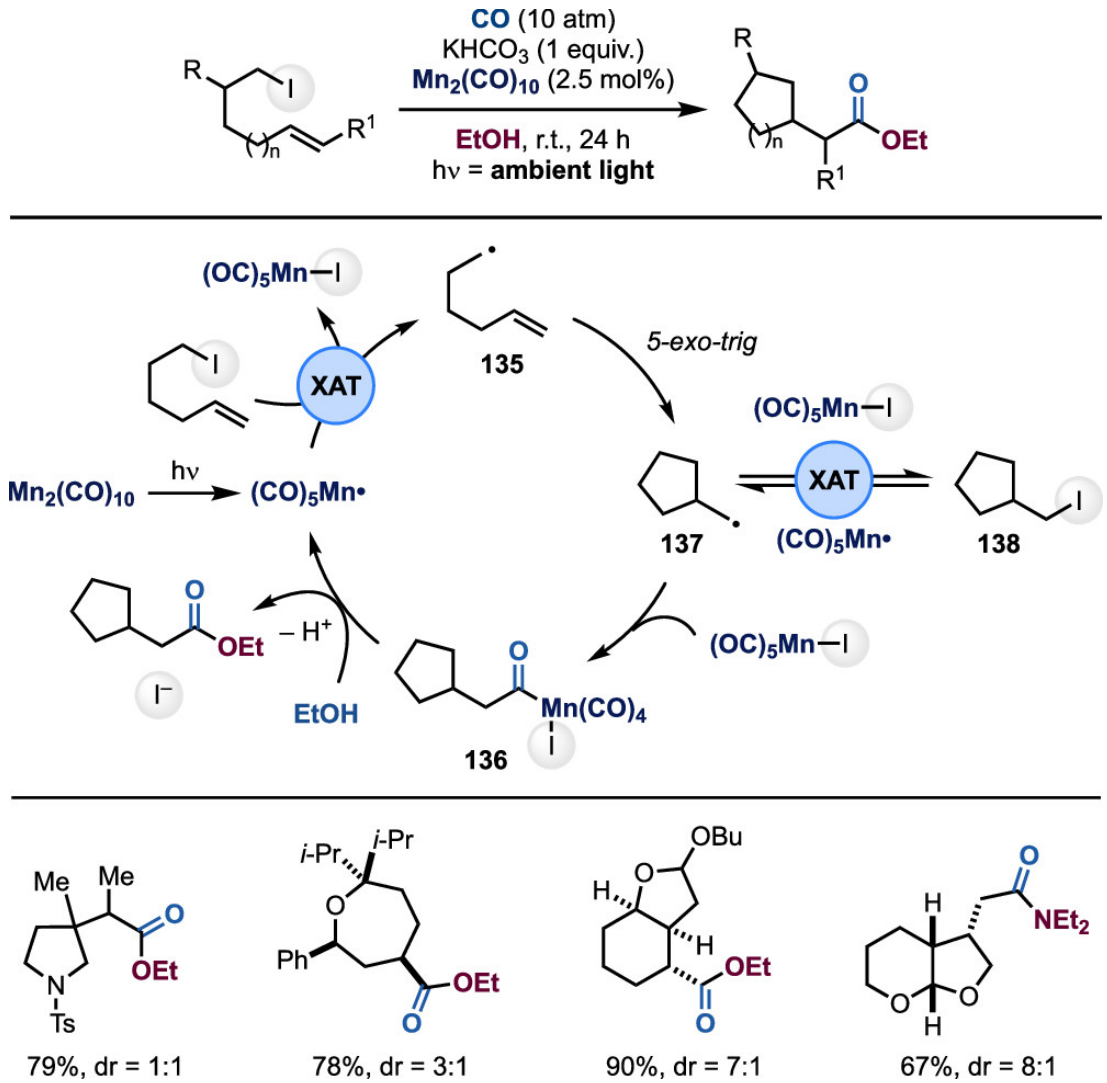




Herrick, R. S.; Herrinton, T. R.; Walker, H. W.; Brown, T. L. *Organometallics* **1985**, *4*, 42. Tyler, D. R.; Goldman, A. S. *J. Organomet. Chem* **1986**, *311*, 349.

Metal-Based XAT Reagents: Dimeric Carbonyl Complexes Displaying Photocleavable Metal−Metal Bonds

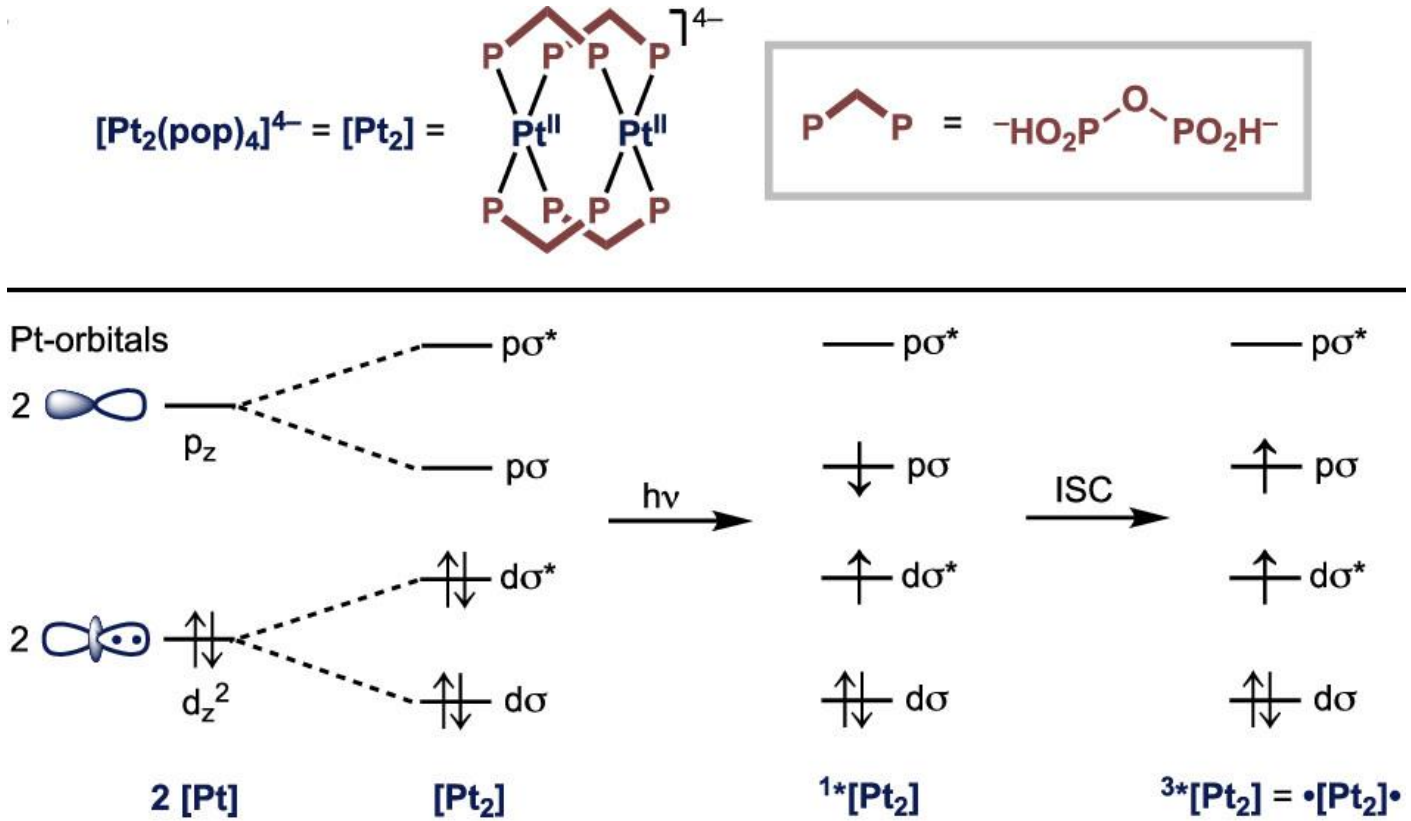
$Mn_2(CO)_{10}$ catalyzed photochemical cyclization−carbonylation



McMahon, C. M.; Renn, M. S.; Alexanian, E. J. *Org. Lett.* **2016**, *18*, 4148.

Metal-Based XAT Reagents: Dimeric Complexes Without Formal Metal−Metal Bonds

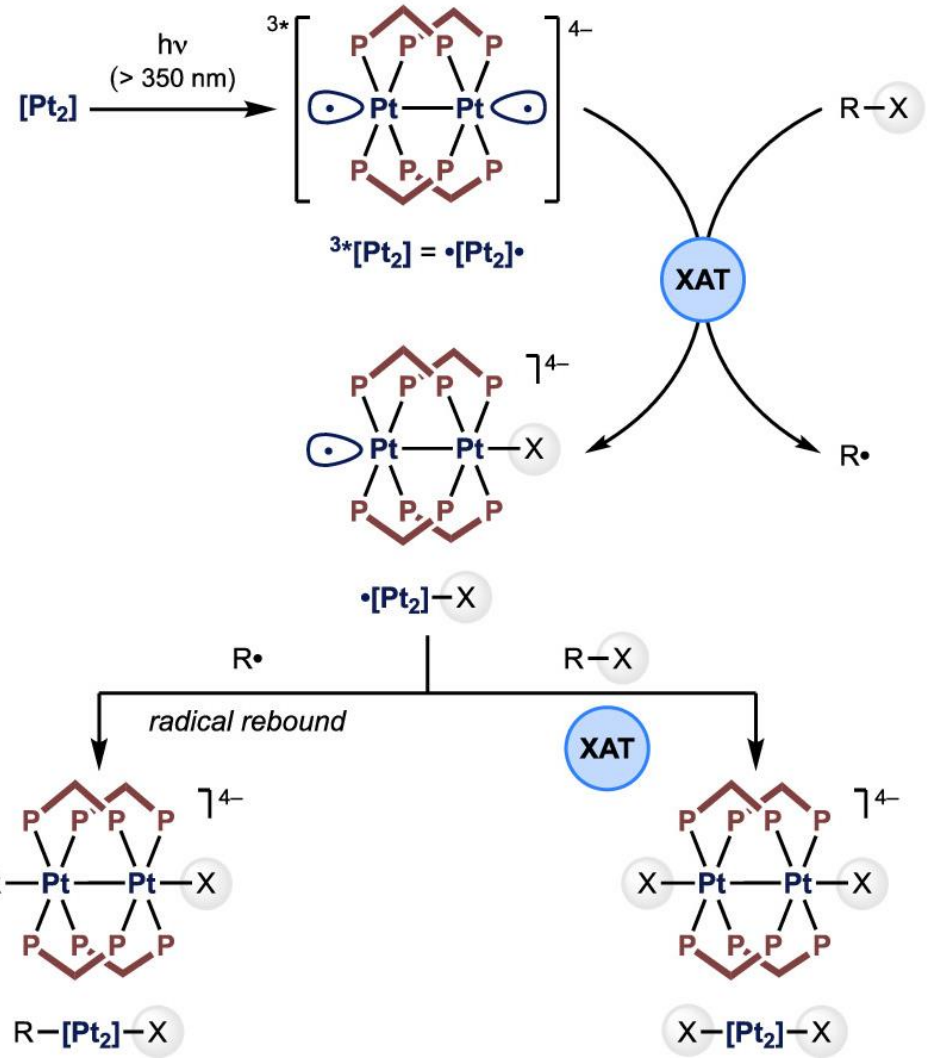
Pt(II) dimer



Che, C. M.; Butler, L. G.; Gray, H. B. *J. Am. Chem. Soc.* **1981**, *103*, 7796.

Metal-Based XAT Reagents: Dimeric Complexes Without Formal Metal−Metal Bonds

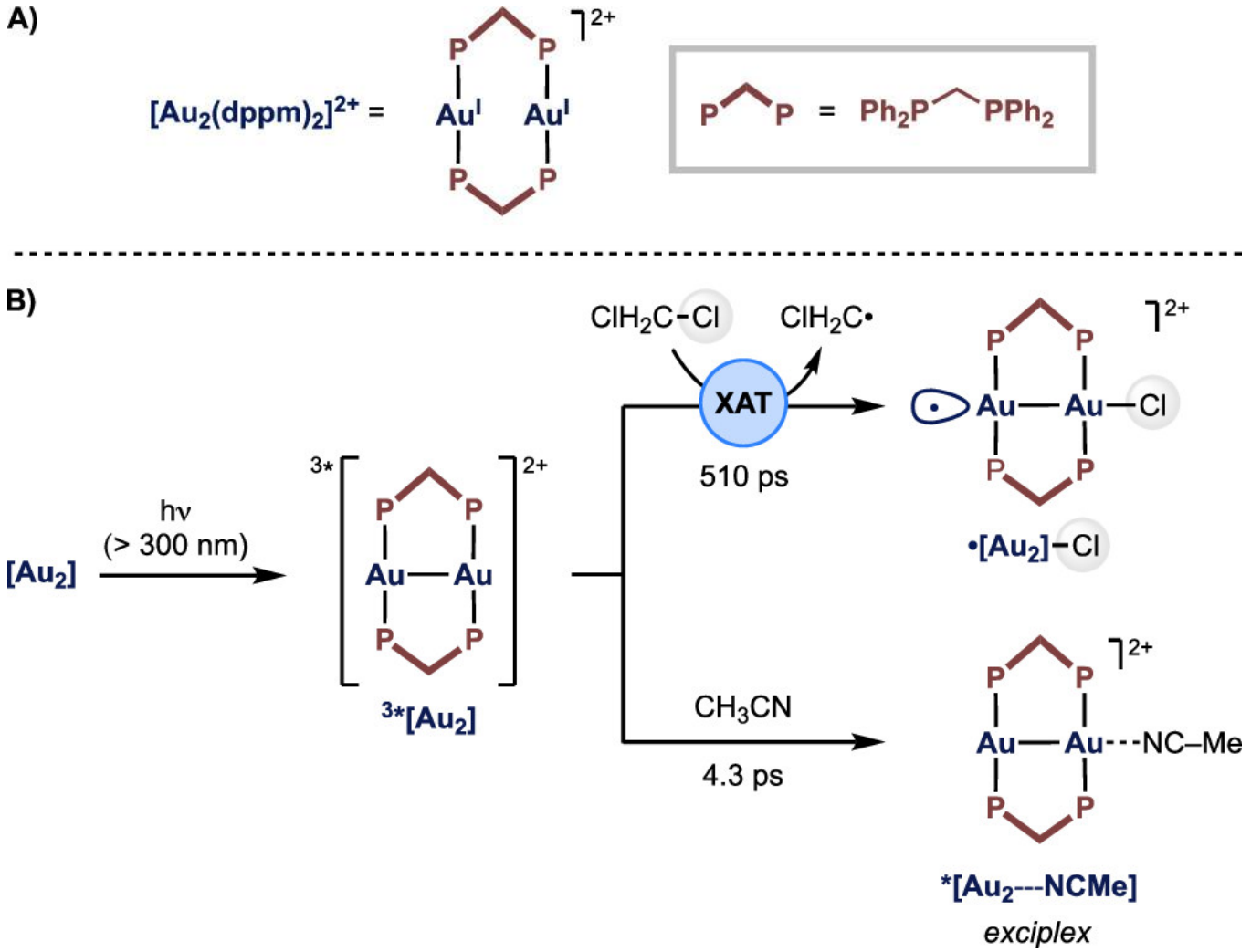
Pt(II) dimer



Roundhill, D. M.; Dickson, M. K.; Atherton, S. J. *J. Organomet. Chem* **1987**, *335*, 413.

Metal-Based XAT Reagents: Dimeric Complexes Without Formal Metal−Metal Bonds

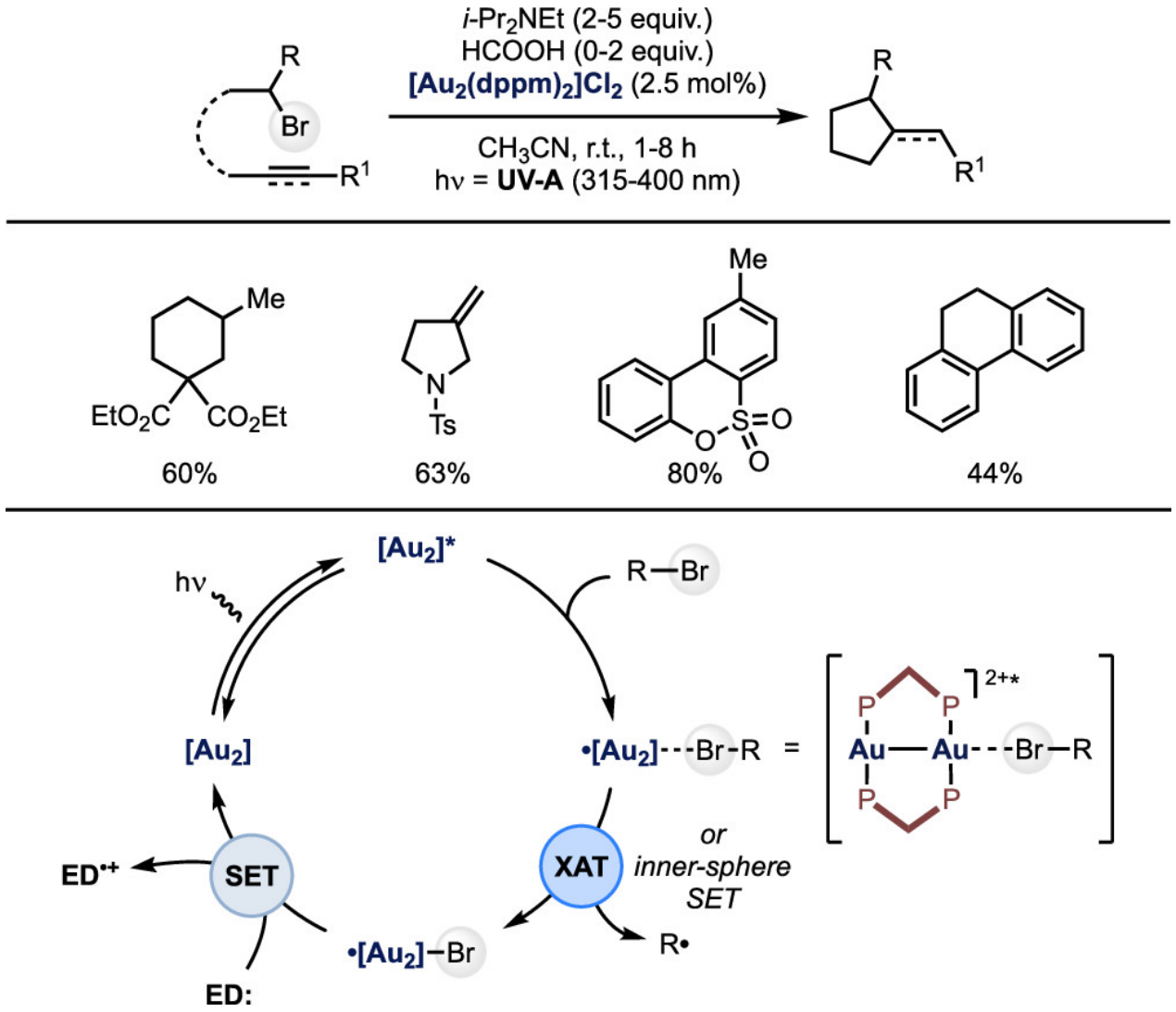
Au(I) dimer



Fu, W.-F.; Chan, K.-C.; Miskowski, V. M.; Che, C.-M. *Angewandte Chemie International Edition* **1999**.
Ma, C.; Chan, C. T.-L.; To, W.-P.; Kwok, W.-M.; Che, C.-M. *Chem. Eur. J* **2015**, *21*, 13888.

Metal-Based XAT Reagents: Dimeric Complexes Without Formal Metal−Metal Bonds

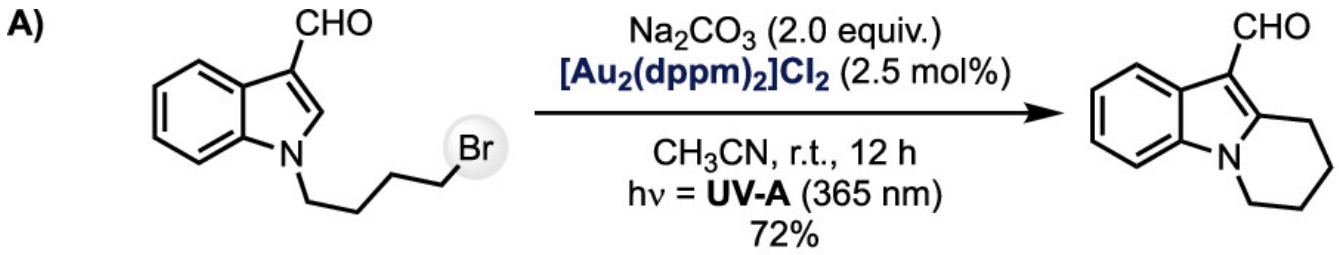
Au(I) dimer: Photochemical dehalogenative cyclization of alkyl bromides



Revol, G.; McCallum, T.; Morin, M.; Gagosz, F.; Barriault, L. *Angew. Chem. Int. Ed* **2013**, *52*, 13342.

Metal-Based XAT Reagents: Dimeric Complexes Without Formal Metal−Metal Bonds

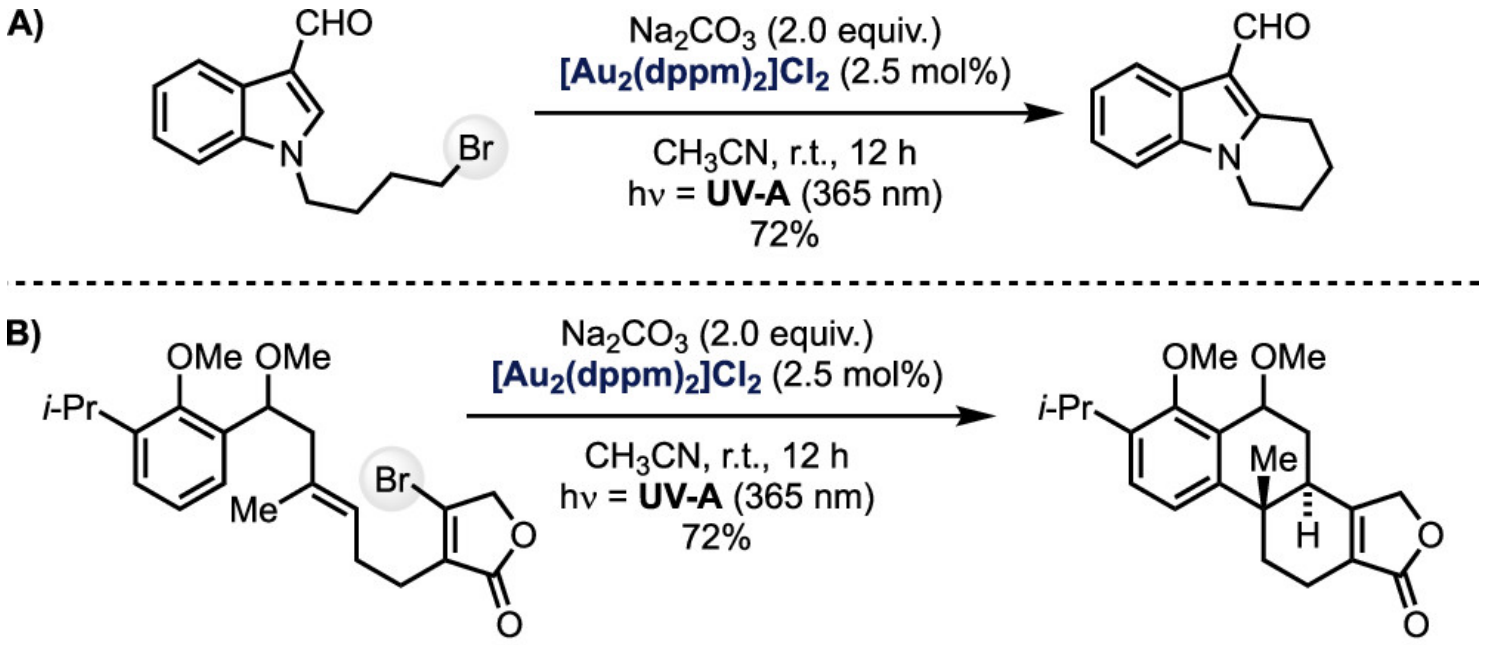
Au(I) dimer: application in total synthesis



Kaldas, S. J.; Cannillo, A.; McCallum, T.; Barriault, L. *Org. Lett.* **2015**, *17*, 2864. Cannillo, A.; Schwantje, T. R.; Bégin, M.; Barabé, F.; Barriault, L. *Org. Lett.* **2016**, *18*, 2592. Miloserdov, F. M.; Kirillova, M. S.; Muratore, M. E.; Echavarren, A. M. *J. Am. Chem. Soc.* **2018**, *140*, 5393.

Metal-Based XAT Reagents: Dimeric Complexes Without Formal Metal−Metal Bonds

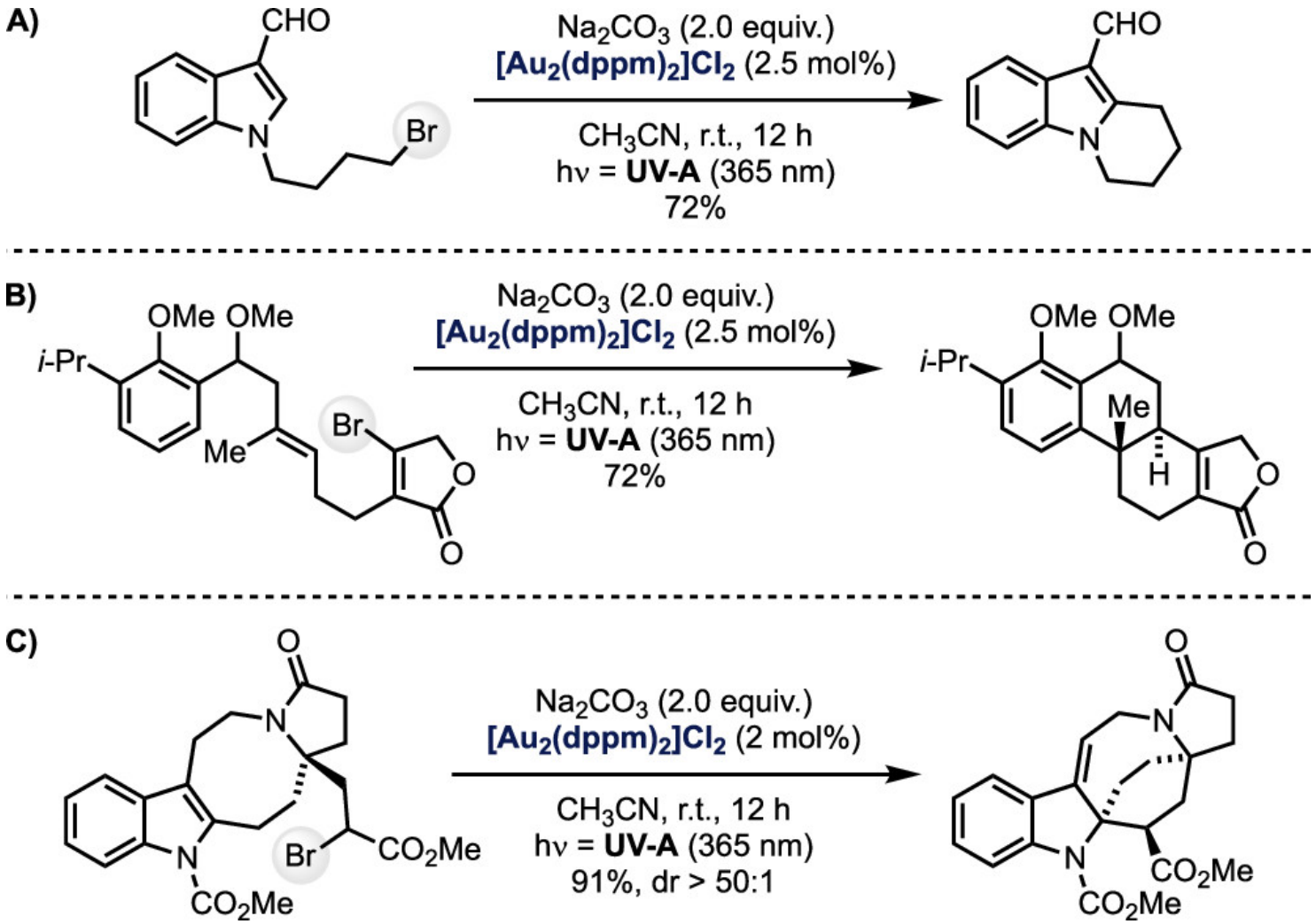
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Metal-Based XAT Reagents: Dimeric Complexes Without Formal Metal−Metal Bonds

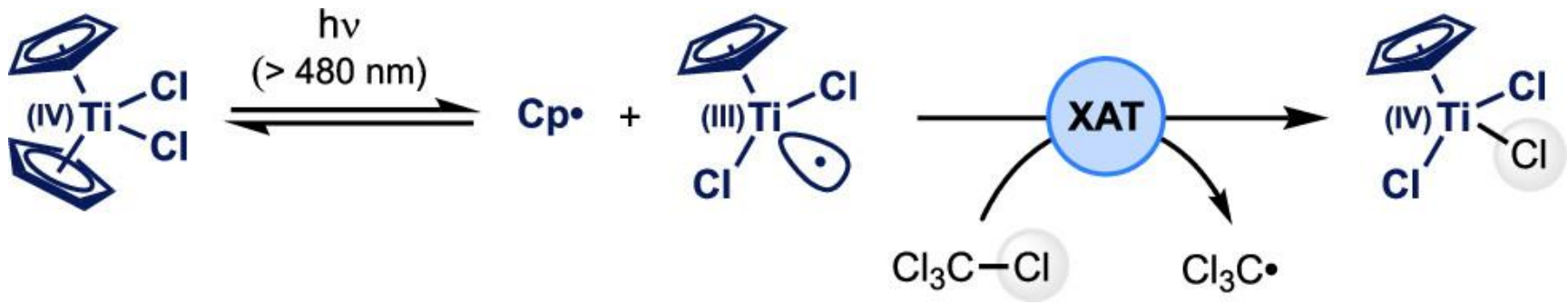
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Kaldas, S. J.; Cannillo, A.; McCallum, T.; Barriault, L. *Org. Lett.* **2015**, *17*, 2864. Cannillo, A.; Schwantje, T. R.; Bégin, M.; Barabé, F.; Barriault, L. *Org. Lett.* **2016**, *18*, 2592. Miloserdov, F. M.; Kirillova, M. S.; Muratore, M. E.; Echavarren, A. M. *J. Am. Chem. Soc.* **2018**, *140*, 5393.

Metal-Based XAT Reagents: Metalloradicals Generated From Monomeric Species

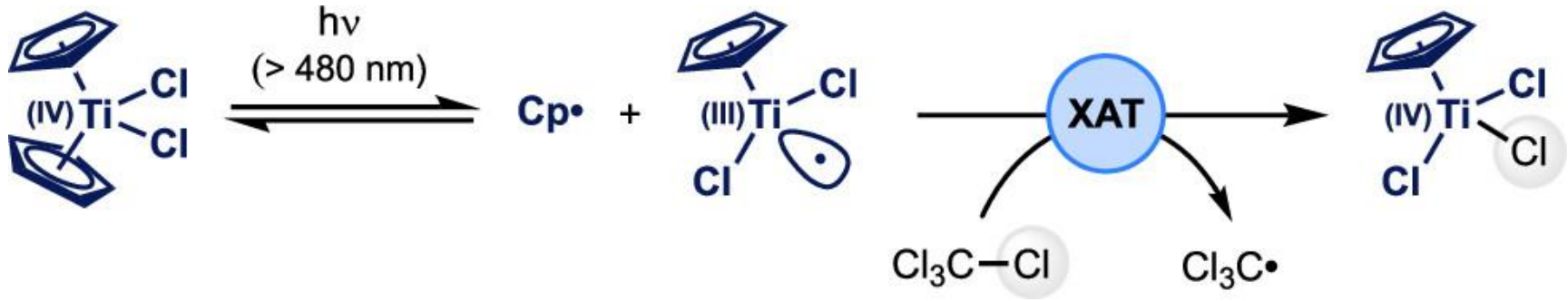
Ti(III) XAT

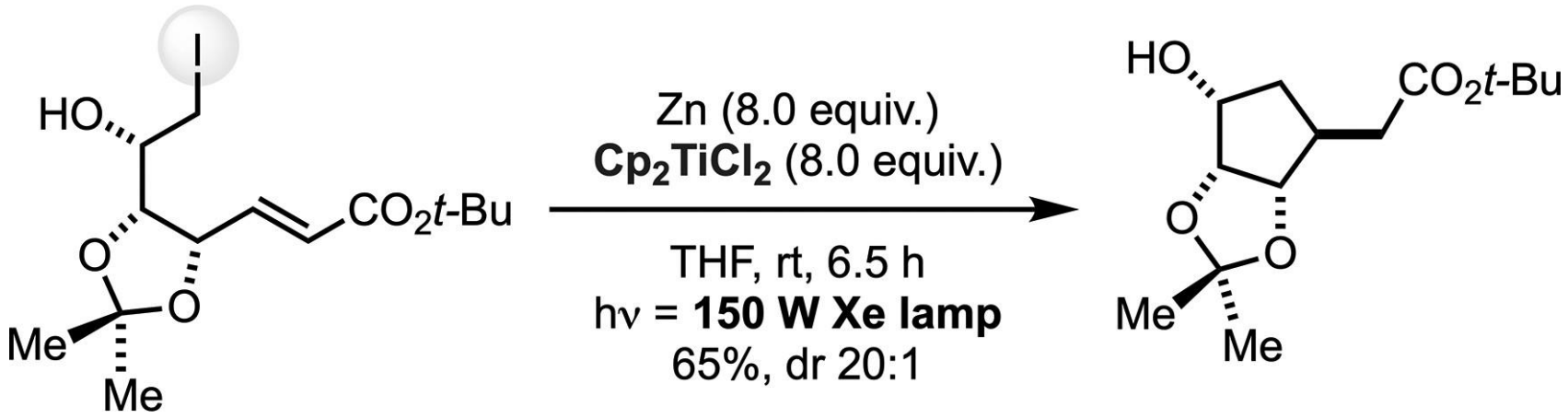


Tsai, Z.-T.; Brubaker, C. H. *J. Organomet. Chem* **1979**, *166*, 199. Hersant, G.; Sadok Ferjani, M. B.; Bennett, S. M. *Tetrahedron Lett.* **2004**, *45*, 8123.

Metal-Based XAT Reagents: Metalloradicals Generated From Monomeric Species

Ti(III) XAT

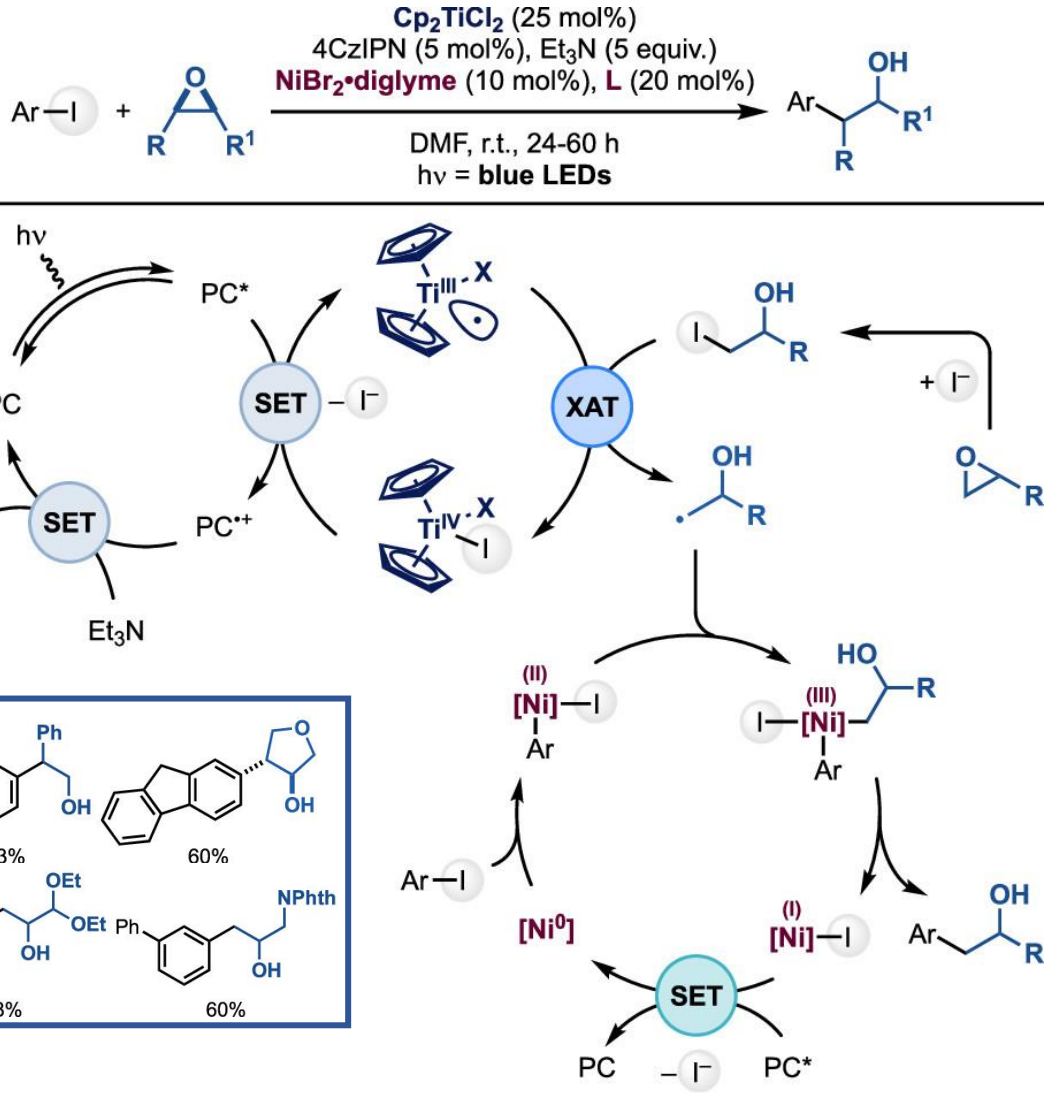




Tsai, Z.-T.; Brubaker, C. H. *J. Organomet. Chem* **1979**, *166*, 199. Hersant, G.; Sadok Ferjani, M. B.; Bennett, S. M. *Tetrahedron Lett.* **2004**, *45*, 8123.

Metal-Based XAT Reagents: Metalloradicals Generated From Monomeric Species

Ti(III) XAT in metallaphotoredox

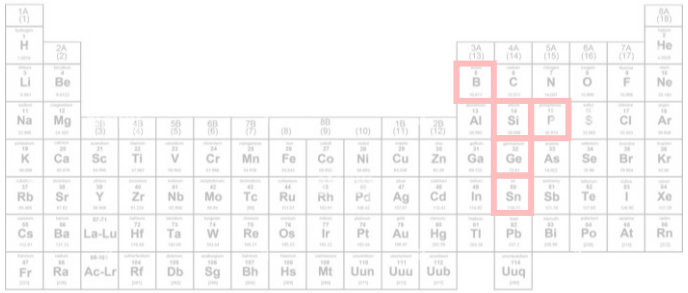


Parasram, M.; Shields, B. J.; Ahmad, O.; Knauber, T.; Doyle, A. G. *ACS Catal.* **2020**, *10*, 5821.

Applications of XAT Reactivity in Synthetic Photocatalysis

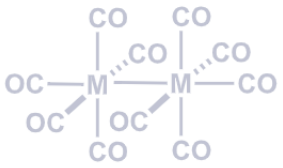
Heteroatom-Based

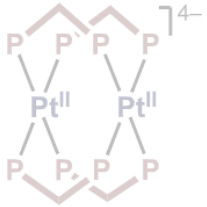
- Tin Radicals (Sn•)
- Silicon Radicals (Si•)
- Germanium Radicals (Ge•)
- Boron Radicals (B•)
- Phosphorus Radicals (P•)



Metal-Based

- Dimeric Carbonyl Complexes Displaying Photocleavable Metal–Metal Bonds
- Dimeric Complexes Without Formal Metal–Metal Bonds
- Metalloradicals Generated From Monomeric Species





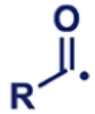


Carbon-Based

- **α-Aminoalkyl Radicals**
- **Methyl Radical**
- **Acyl Radicals**

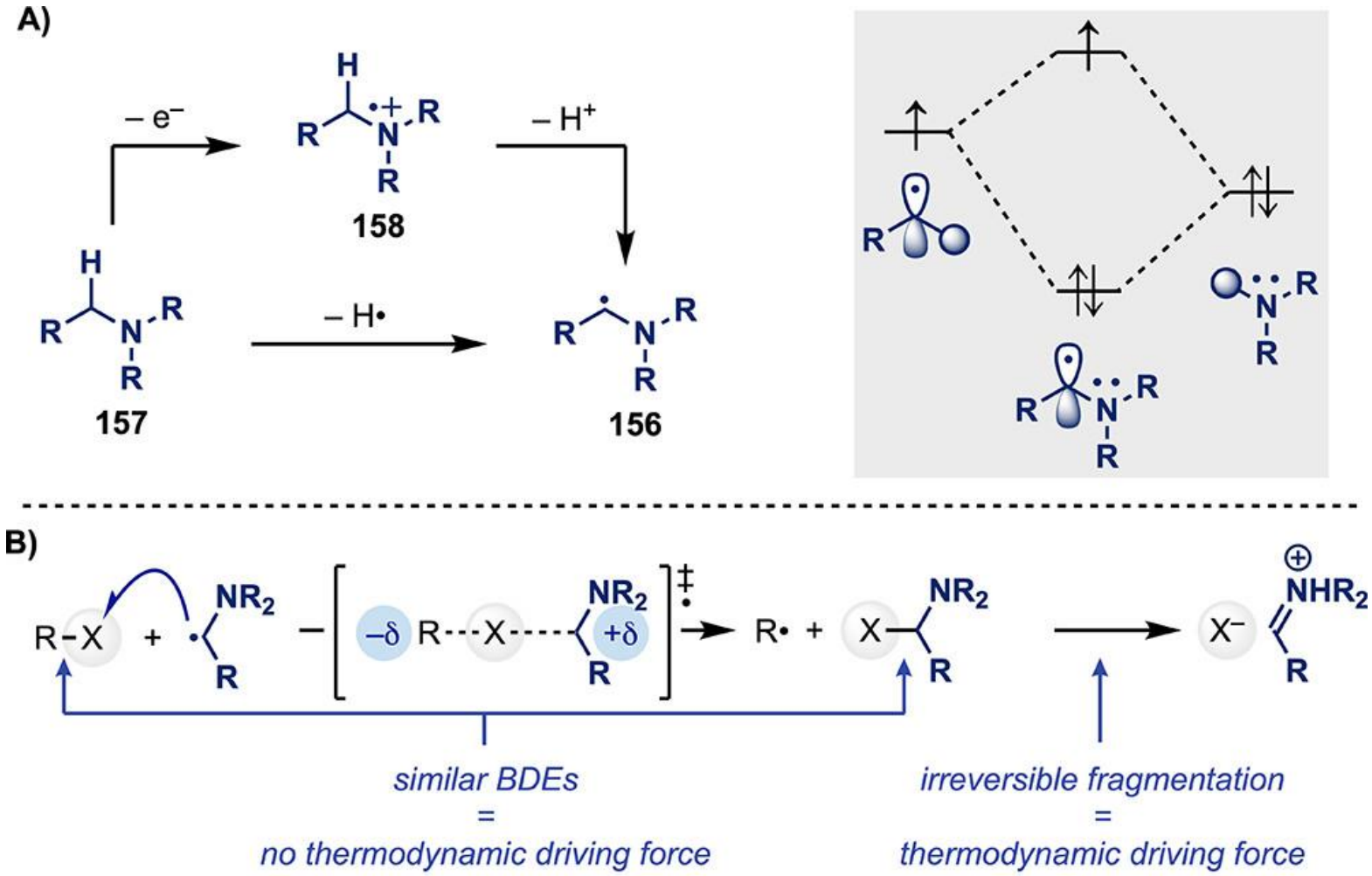






Carbon-Based XAT Reagents: α-Aminoalkyl Radicals

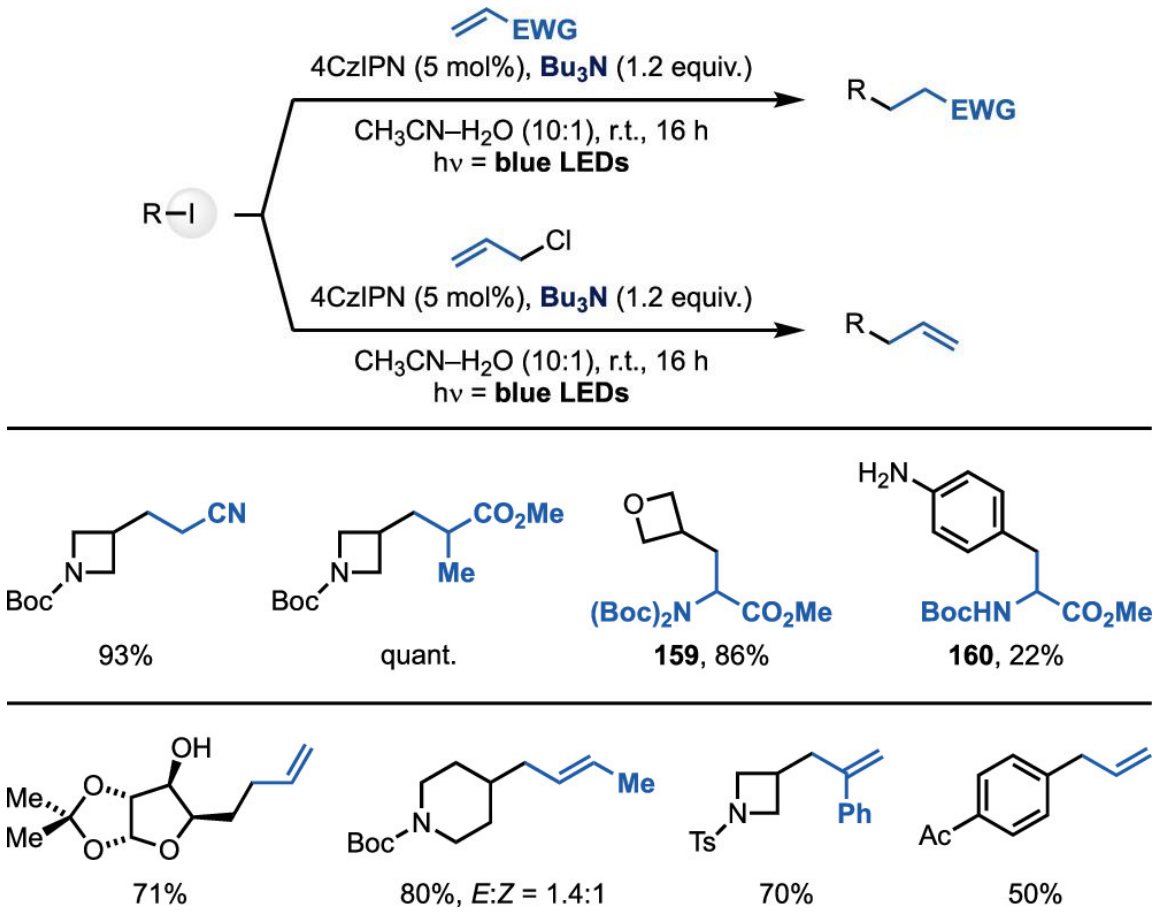
Irreversible fragmentation as driving force

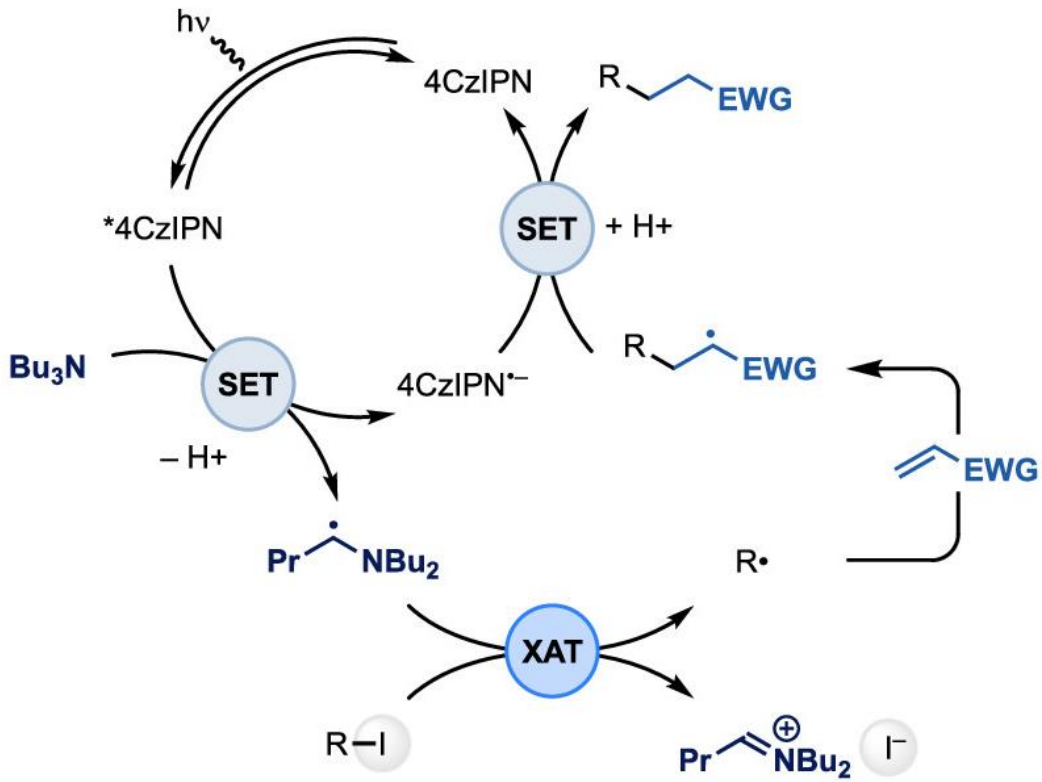


Cohen, S. G.; Parola, A.; Parsons, G. H. *Chem. Rev.* **1973**, *73*, 141. DeLaive, P. J.; Foreman, T. K.; Giannotti, C.; Whitten, D. G. *J. Am. Chem. Soc.* **1980**, *102*, 5627. Constantin, T.; Zanini, M.; Regni, A.; Sheikh, N. S.; Juliá, F.; Leonori, D. *Science* **2020**, *367*, 1021.

Carbon-Based XAT Reagents: α-Aminoalkyl Radicals

Giese addition/radical allylation

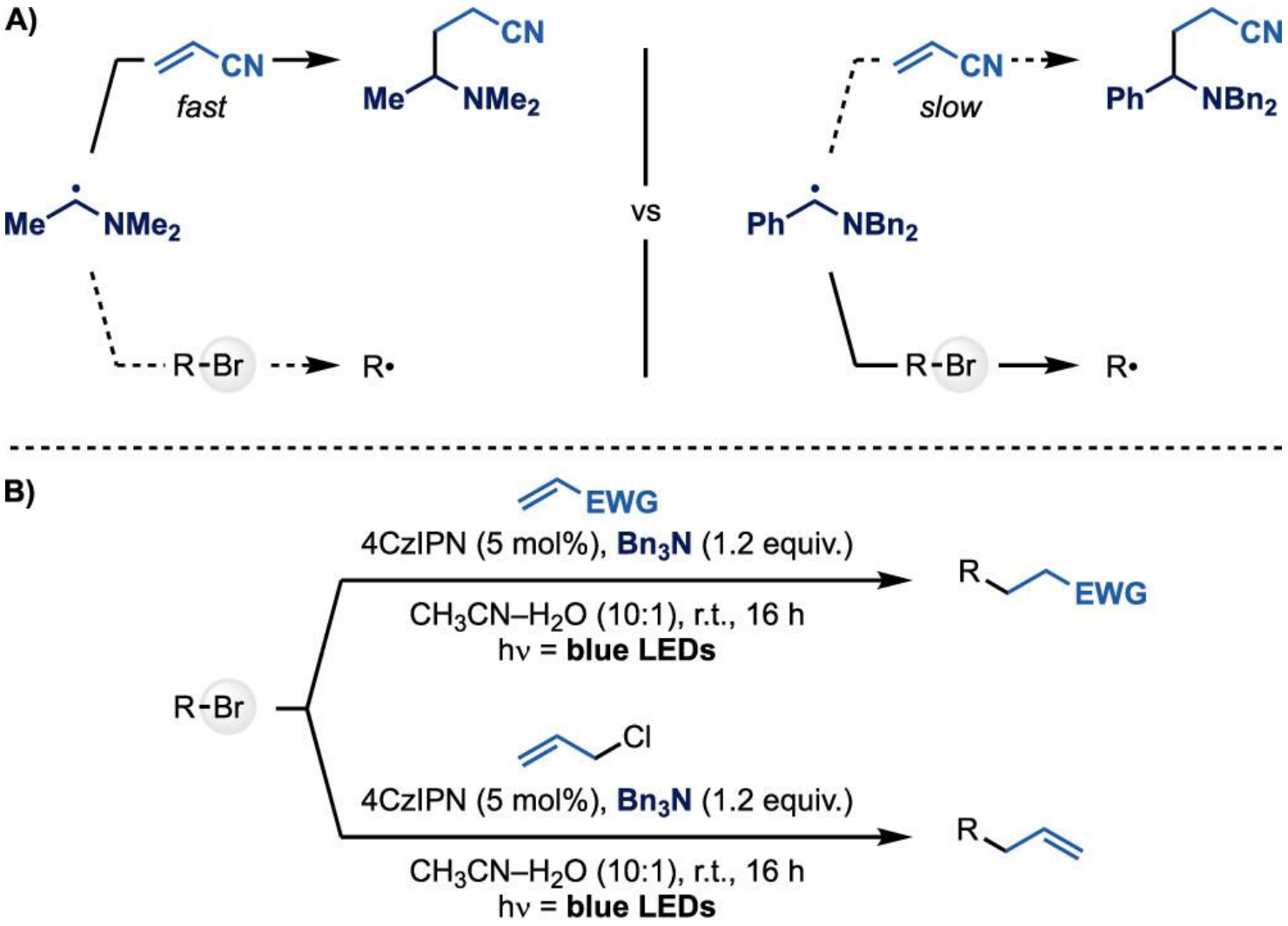




Constantin, T.; Zanini, M.; Regni, A.; Sheikh, N. S.; Juliá, F.; Leonori, D. *Science* **2020**, *367*, 1021.

Carbon-Based XAT Reagents: α-Aminoalkyl Radicals

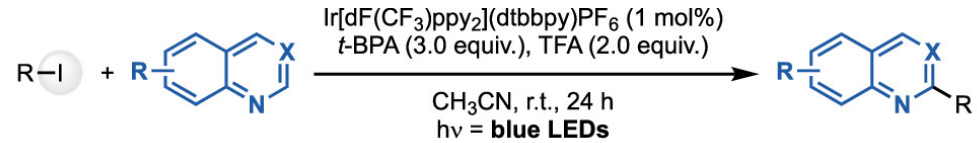
Giese addition/radical allylation

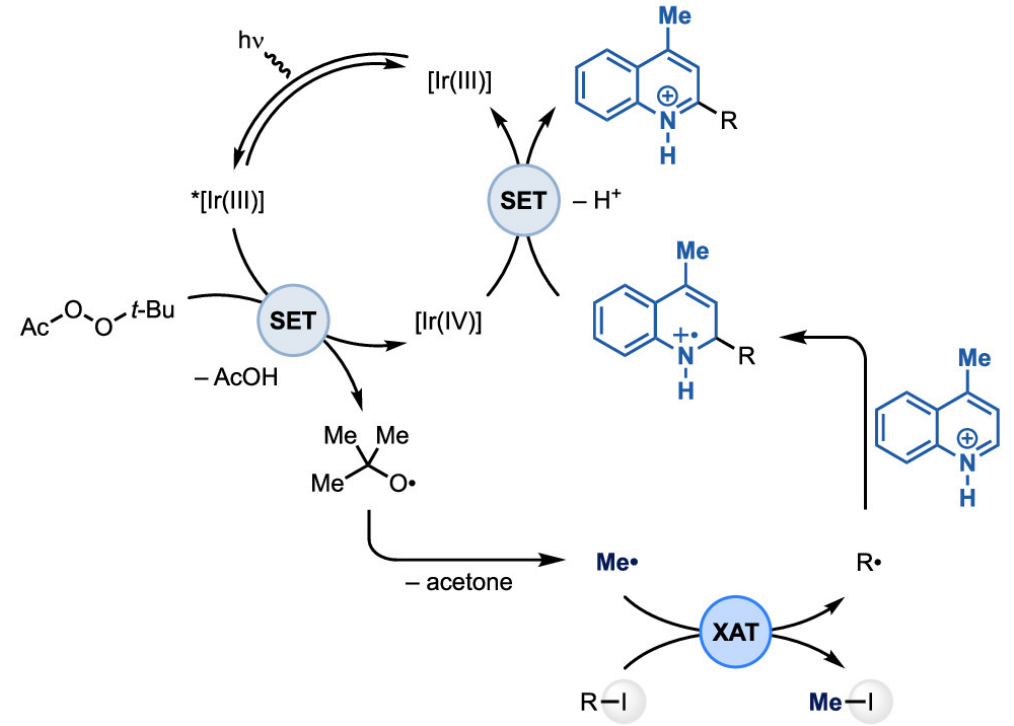


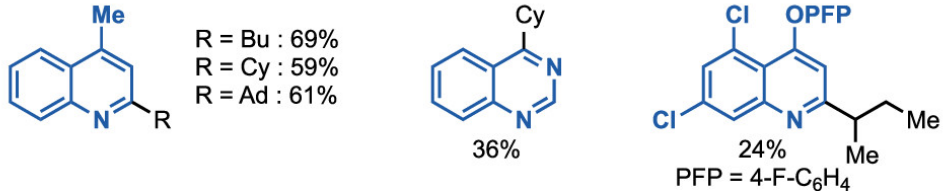
Lalevée, J.; Graff, B.; Allonas, X.; Fouassier, J. P. *J. Phys. Chem. A* **2007**, *111*, 6991. Constantin, T.; Zanini, M.; Regni, A.; Sheikh, N. S.; Juliá, F.; Leonori, D. *Science* **2020**, *367*, 1021.

Carbon-Based XAT Reagents: Methyl Radical

Me• mediated Minisci reaction



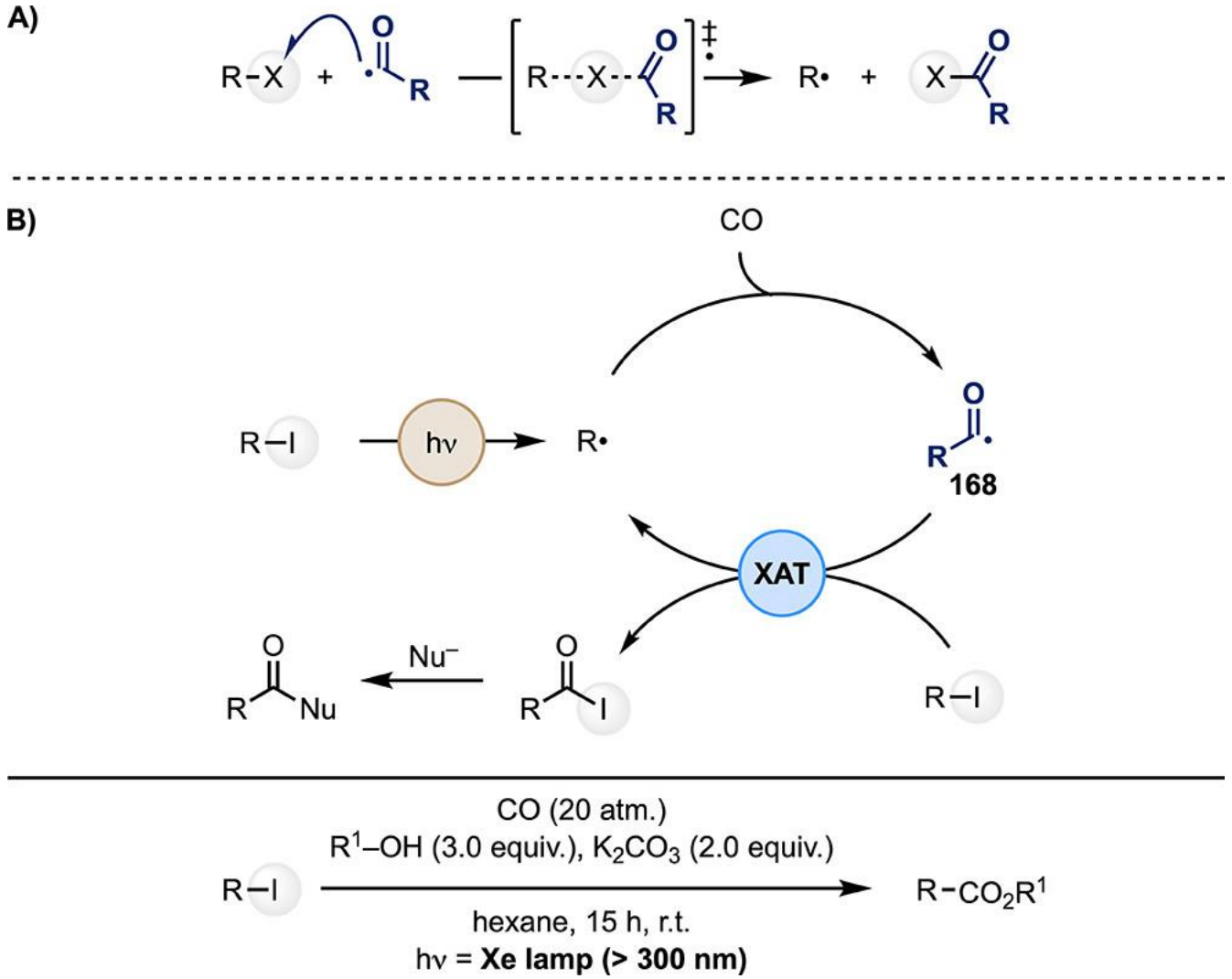




Wang, Z.; Dong, J.; Hao, Y.; Li, Y.; Liu, Y.; Song, H.; Wang, Q. *J. Org. Chem.* **2019**.

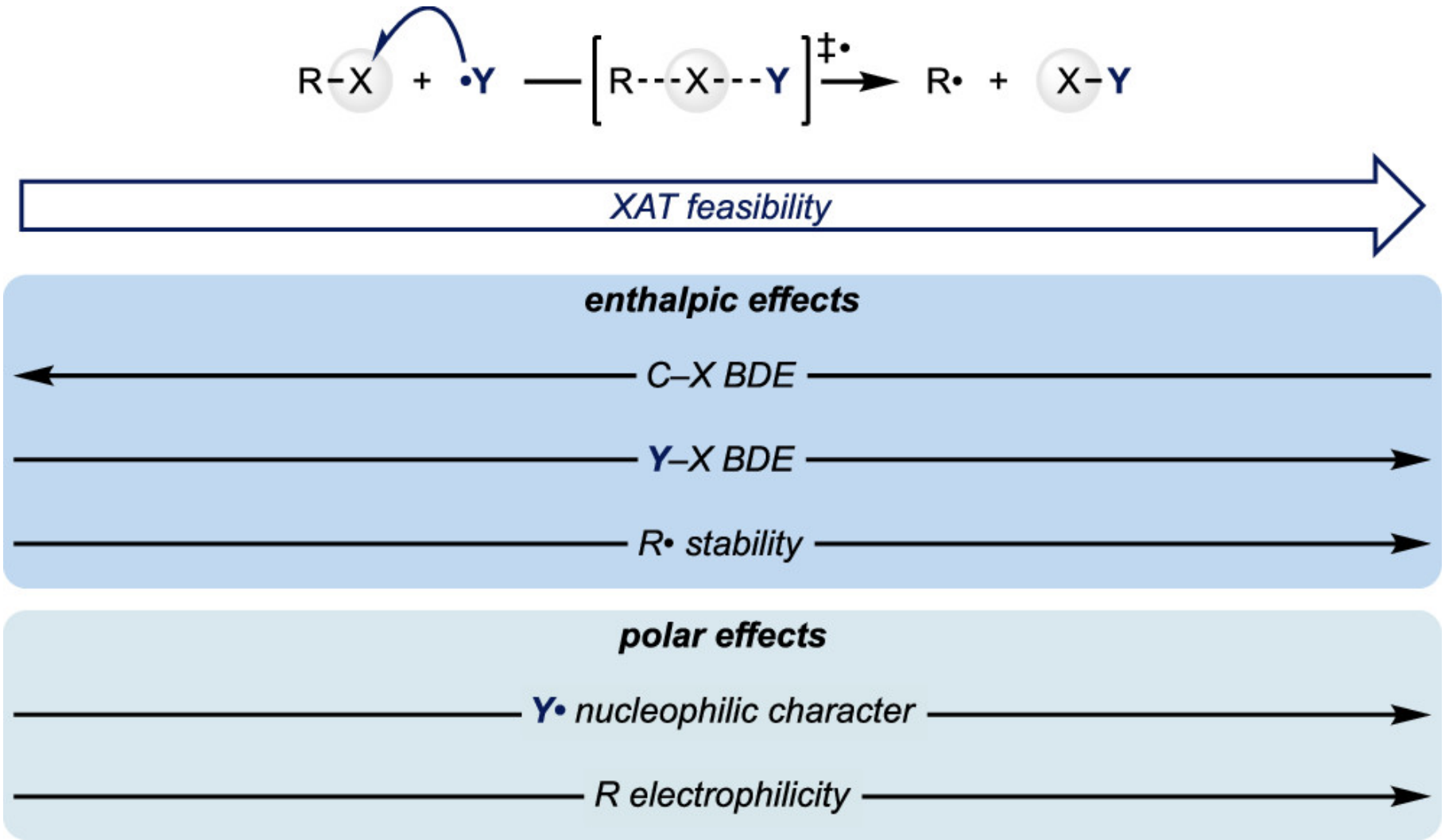
Carbon-Based XAT Reagents: Acyl Radicals

Carbonylation



Matsubara, H.; Ryu, I.; Schiesser, C. H. *Org. Biomol. Chem.* **2007**, *5*, 3320. Nagahara, K.; Ryu, I.; Komatsu, M.; Sonoda, N. *J. Am. Chem. Soc.* **1997**, *119*, 5465. Fukuyama, T.; Nishitani, S.; Inouye T.; Morimoto, K.; Ryu, I. Org. Lett. **2006**, *8*, (7), 1383-1386

Key Aspects Affecting XAT Reactivity

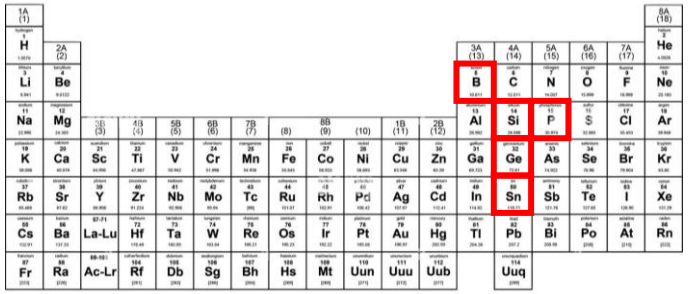


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Applications of XAT Reactivity in Synthetic Photocatalysis

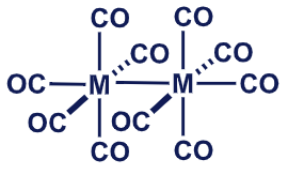
Heteroatom-Based

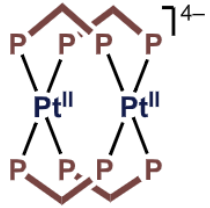
- **Tin Radicals (Sn•)**
- **Silicon Radicals (Si•)**
- **Germanium Radicals (Ge•)**
- **Boron Radicals (B•)**
- **Phosphorus Radicals (P•)**



Metal-Based

- **Dimeric Carbonyl Complexes Displaying Photocleavable Metal–Metal Bonds**
- **Dimeric Complexes Without Formal Metal–Metal Bonds**
- **Metalloradicals Generated From Monomeric Species**







Carbon-Based

- **α-Aminoalkyl Radicals**
- **Methyl Radical**
- **Acyl Radicals**





