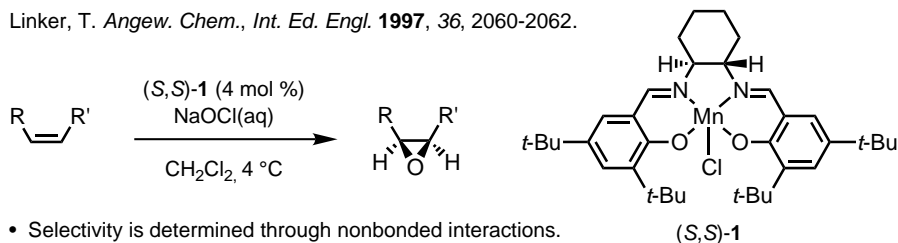


## Reviews:

Jacobsen, E. N. In *Catalytic Asymmetric Synthesis*, Ojima, I., Ed.; VCH: New York, **1993**; pp. 159-202.

Linker, T. *Angew. Chem., Int. Ed. Engl.* **1997**, 36, 2060-2062.



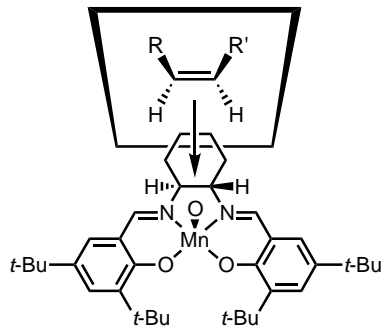
- Selectivity is determined through nonbonded interactions.
- In general, R is aryl, alkenyl or alkynyl and R' is a bulky group.
- *cis*-Disubstituted conjugated olefins are epoxidized with high levels of enantioselectivity.
- *trans*-Disubstituted olefins react more slowly and with diminished selectivity.

olefin	epoxide	yield, %	ee, %	equiv (S,S)-1
		96	97	0.03
		63	94	0.15
		79	84	0.006 <sup>a</sup>

<sup>a</sup>Reaction carried out in the presence of 4-phenylpyridine *N*-oxide.

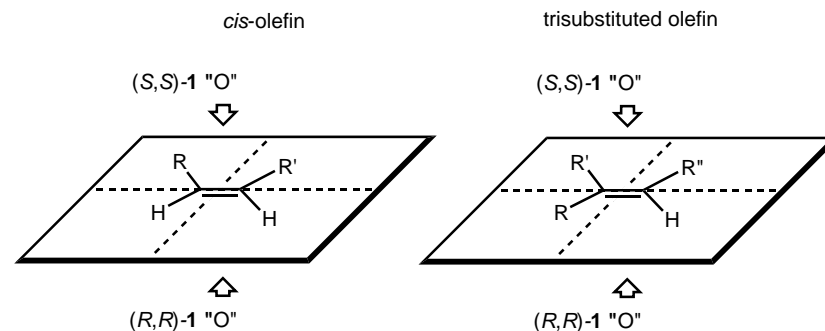
From: Jacobsen, E. N.; Zhang, W.; Muci, A. R.; Ecker, J. R.; Deng, L. *J. Am. Chem. Soc.* **1991**, 113, 7063-7064.

- The observed selectivities have been explained by a side-on approach of olefin:



- Terminal olefins are poor substrates.
- Addition of substoichiometric amounts of 4-phenylpyridine *N*-oxide improves both catalyst selectivity and turnover numbers.

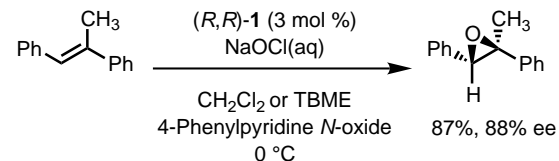
## Mnemonics for the observed selectivities:



- *cis*-Olefins: Place Aryl, alkenyl or alkynyl substituent in upper-left quadrant (R) and the corresponding trans hydrogen atom in the lower-right quadrant.
- *trans*-Olefins are poor substrates.
- Trisubstituted olefins: Place the hydrogen atom in the lower-right quadrant.

## Trisubstituted olefins:

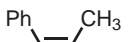

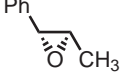

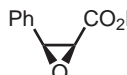
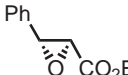
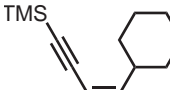
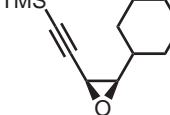
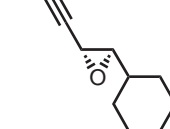
- The following trisubstituted alkenes are epoxidized with high levels of enantioselectivity:



olefin	epoxide <sup>a</sup>	yield, %	ee, %
		69	93
		91	95
		97	92

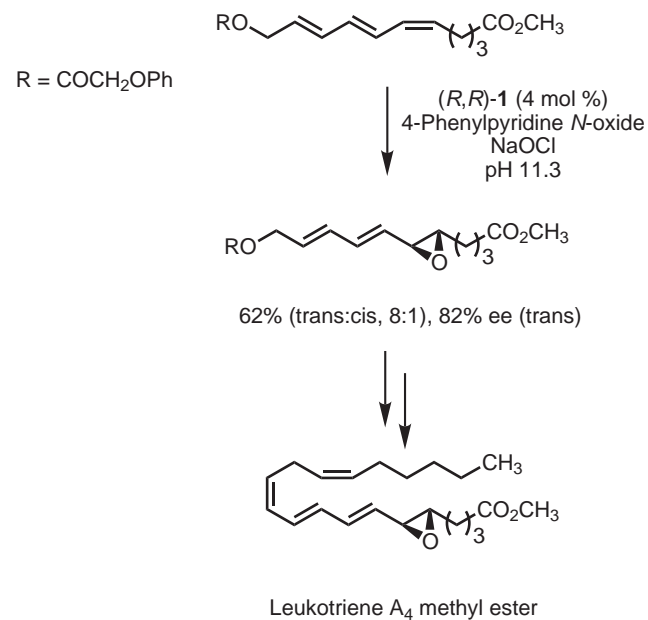
From: Brandes, B. D.; Jacobsen, E. N. *J. Org. Chem.* **1994**, 59, 4378-4380.

- cis*- $\beta$ -Substituted styrene derivatives afford *cis*-epoxides as major products while *cis*-enynes and *cis*-dienes produce *trans*-epoxides.

olefin	equiv (S,S)-1	<i>cis</i> -epoxide	yield (%), ee (%)	<i>trans</i> -epoxide	yield (%), ee (%)
	0.04		77, 92		6.7, 83
	0.08		52, 97		15, 78
	0.04		10, 64		55, 98

From: Jacobsen, E. N. In *Catalytic Asymmetric Synthesis*, Ojima, I., Ed.; VCH: New York, **1993**; pp. 159-202 and Jacobsen, E. N.; Zhang, W.; Muci, A. R.; Ecker, J. R.; Deng, L. *J. Am. Chem. Soc.* **1991**, *113*, 7063-7064.

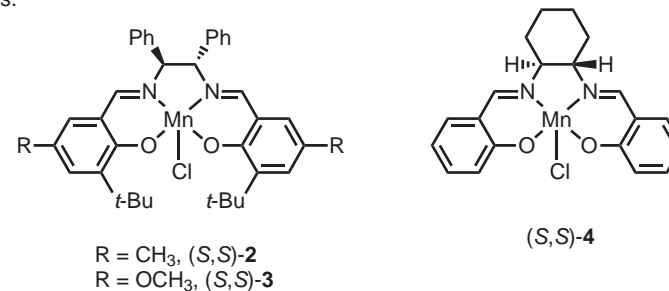
- Rotation of a radical intermediate is proposed to account for the *cis*  $\rightarrow$  *trans* isomerization.

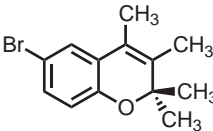
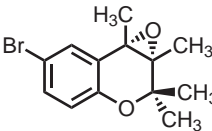
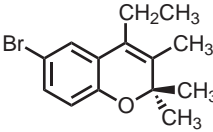
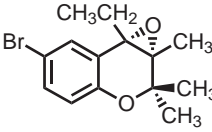
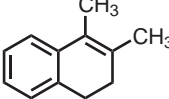
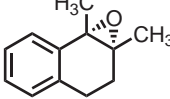
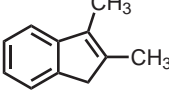
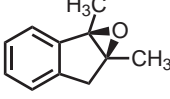
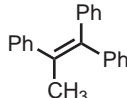
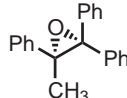


Chang, S.; Lee, N. H.; Jacobsen, E. N. *J. Org. Chem.* **1993**, *58*, 6939-6941.

#### Tetrasubstituted Olefins:

- High enantioselectivities are not yet general but may be attained in certain cases with catalysts shown.
- Chromene derivatives undergo epoxidation with higher enantioselectivity as compared to indene derivatives.



olefin	catalyst	epoxide	epoxide yield, %	ee, %
	( <i>S,S</i> )-2		84	96
	( <i>S,S</i> )-2		81	97
	( <i>S,S</i> )-3		45	65
	( <i>R,R</i> )-3		37	35
	( <i>S,S</i> )-4		12	46

From: Brandes, B. D.; Jacobsen, E. N. *Tetrahedron Lett.* **1995**, *36*, 5123-5126.