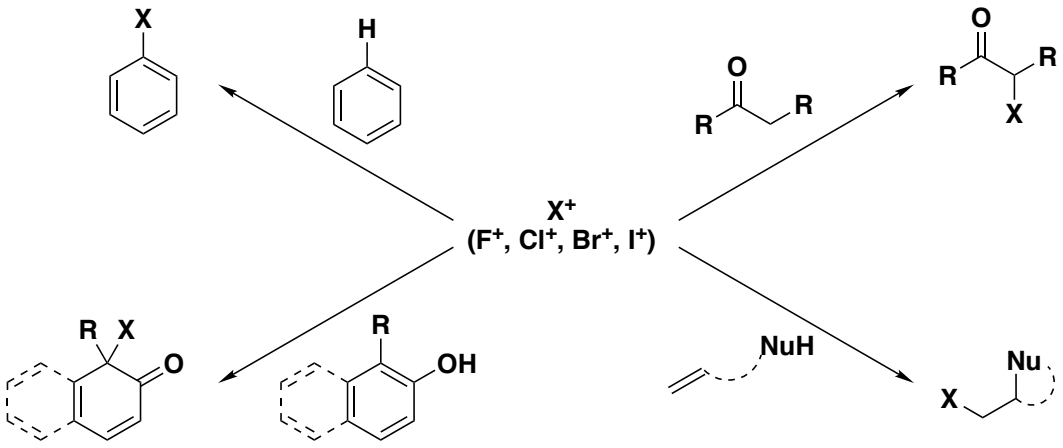
Electrophilic halogenation



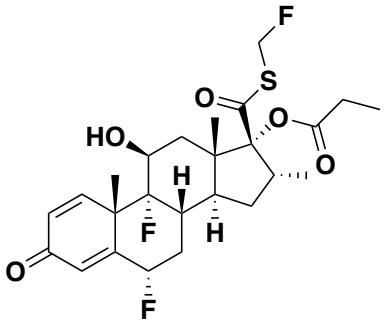
2023/11/25
Yuto Fujii

Contents

1. Introduction

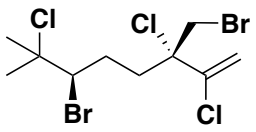
1-1. Organohalogen compounds

1-1-1. Artificial or Natural compounds



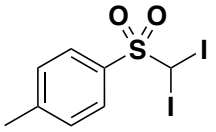
Fluticasone
(anti-inflammatory)

Artificial



Halomon
(antiumor agent)

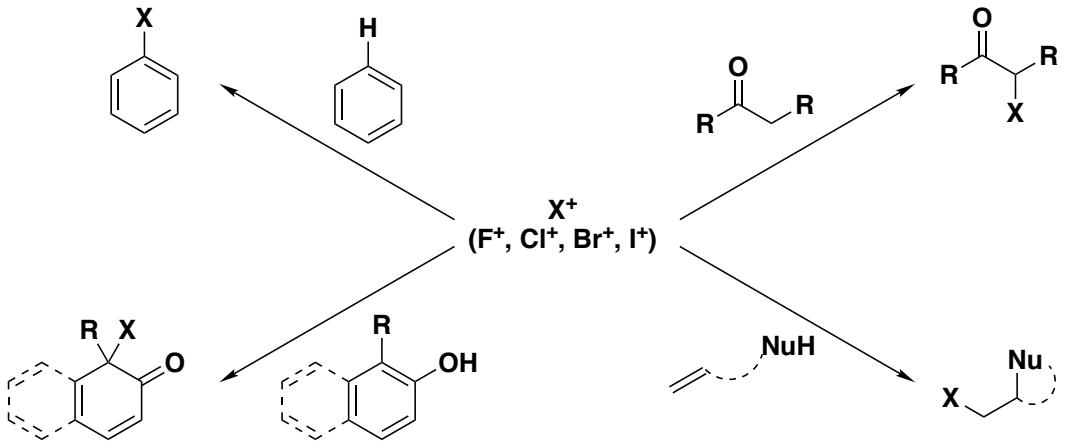
Natural



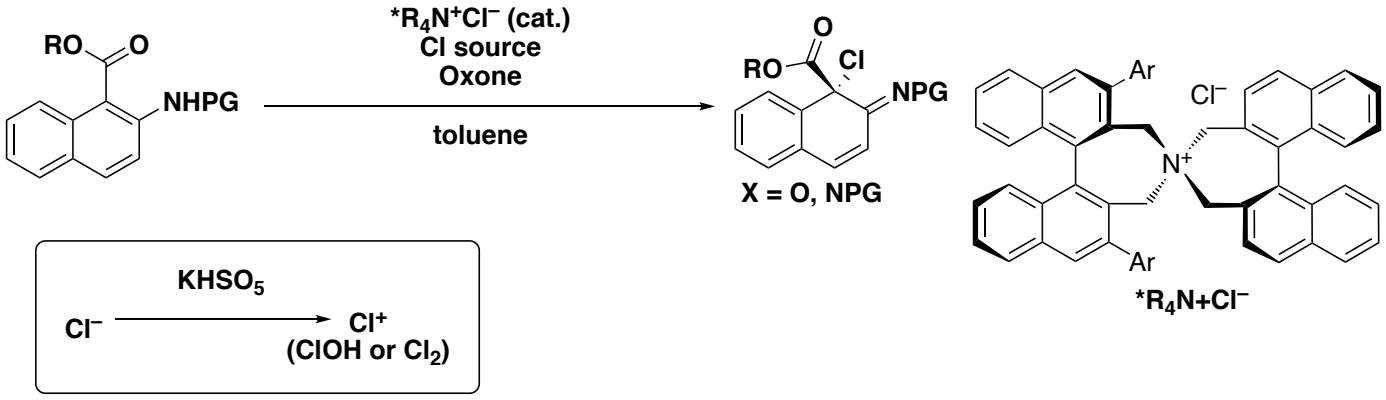
DMTS
(antifungal agent)

Artificial

1-1-2. Electrophilic Halogenation Reactions



1-2. My Work

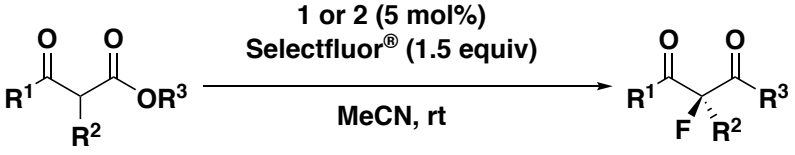


2. EnantioselectiveHalogenation using Metal Cat.

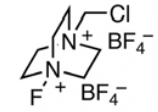
2-1. First Catalytic EnantioselectiveHalogenation

Enantioselective Halogenation of β-Keto Esters (2000 Togni)

Enantioselective Fluorination of β-Keto Esters (2000 Togni)

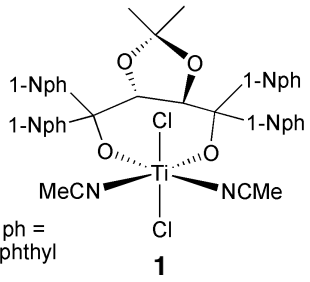


8 examples
up to 89% yield
up to 91 % ee

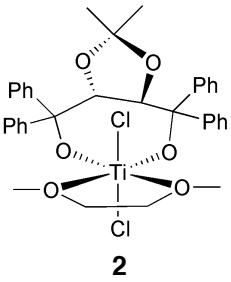


Selectfluor®

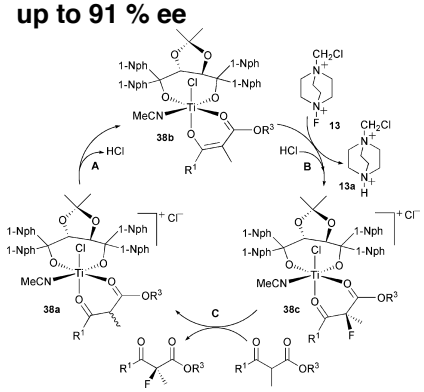
A. Togni
(1956-)

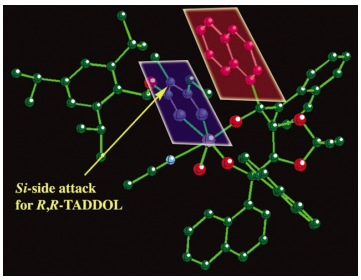


1

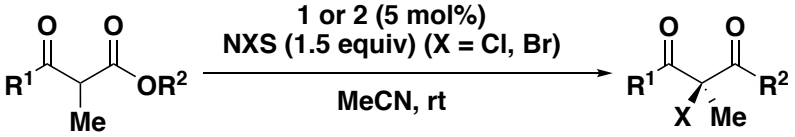


2





Enantioselective Chlorination and Bromination of β-Keto Esters (2000 Togni)

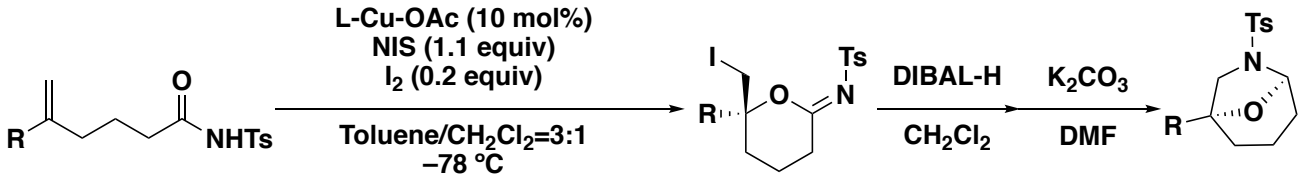


X = Cl
up to 97% yield
up to 88 % ee

X = Br
up to 90% yield
up to 23 % ee

2-2. Recent Catalytic Enantioselective Halogenation

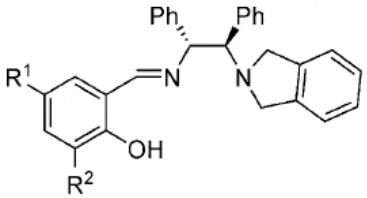
Enantioselective Iodocyclization of *N*-Tosyl Alkenamides (2015 Yamanaka)



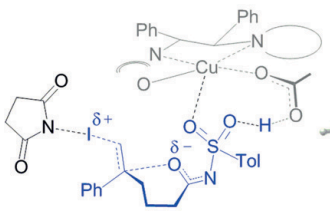
R = Ar, $(CH_2)_7CH_3$, Cy

12 examples
up to 98% yield
up to 94% ee

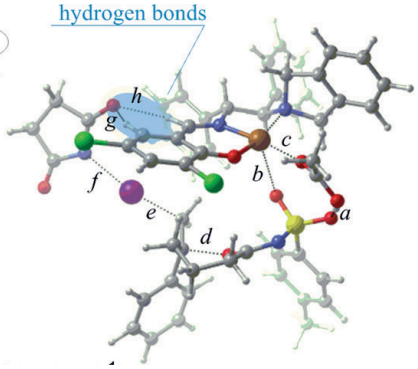
w/o loss of ee



Ligand
R^1 = Br, R^2 = Br



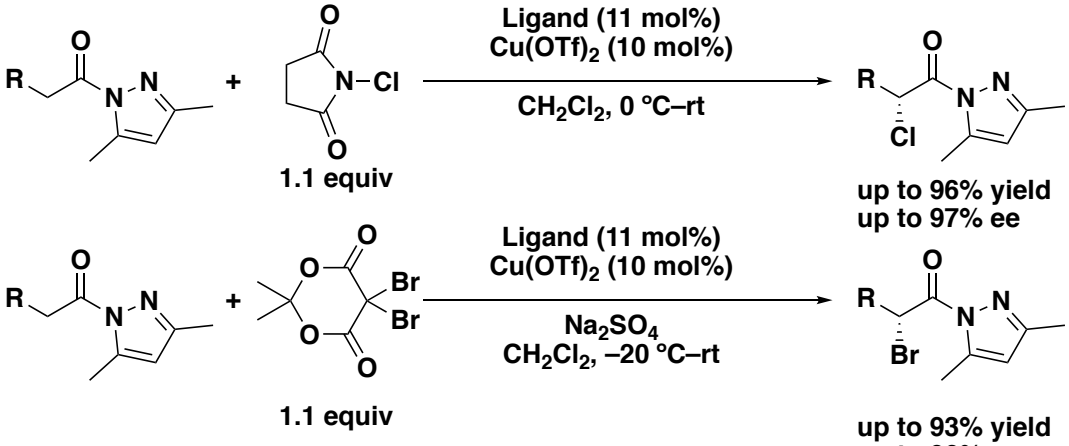
a : 1.683 *f* : 2.452
b : 3.098 *g* : 2.163
c : 1.986 *h* : 2.313
d : 1.889
e : 2.326



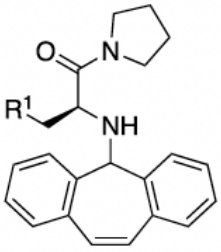
1) Togni. *et. al. Angew. Chem. Int. Ed.* **2000**, *39*, No. 23.
2) Togni. *et. al. Helv. Chim. Acta.* **2000**, *83*, 2425–2435.
3) Togni. *et. al. Chem. Comm.* **2004**, 1147–1155.
4) Yamanaka. *et. al. Angew. Chem. Int. Ed.* **2015**, *54*, 12767–12771.

2. EnantioselectiveHalogenation using Metal Cat.

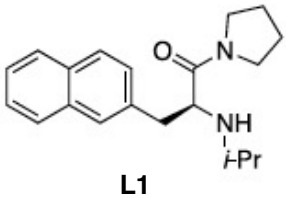
Enantioselective α-Halogenation of *N*-Acyl-3,5-dimethylpyrazoles (2022 Ishihara)



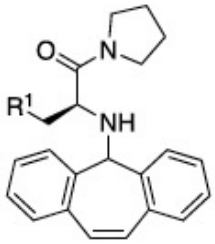
K. Ishihara
(1963-)



Ligand
R^1 = 2-naphthyl

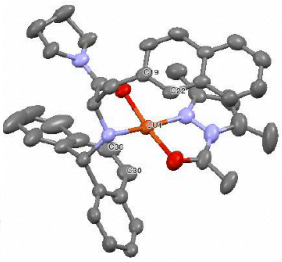


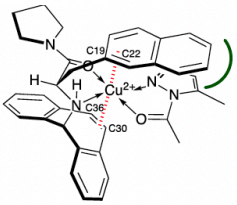
L1



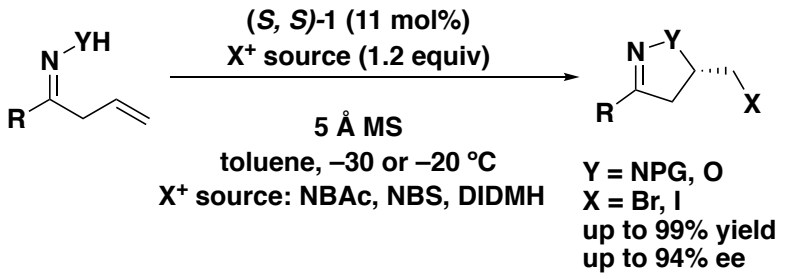
L2

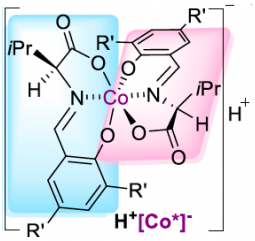
entry	ligand (R^1)	2b yield (%)[b]	2b ee (%)[c]
1[d]	L1 w/2,6-lutidine	8	38
2	L1 w/o base	54	32
5	L2 (2-naphthyl) w/o base	90 (71)[g]	96 (94)[g]



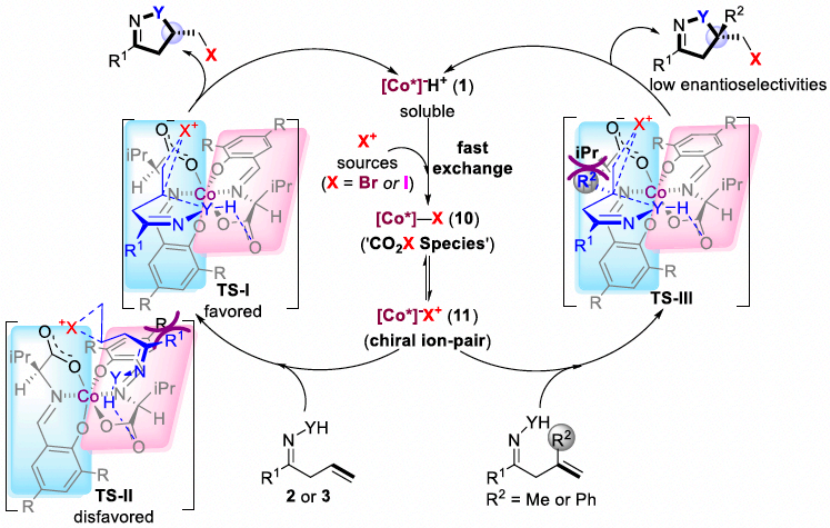


Anionic Chiral CO(III) Complexes Mediated Asymmrtric Halocyclization (2021 Yu)





(*S, S*)-1

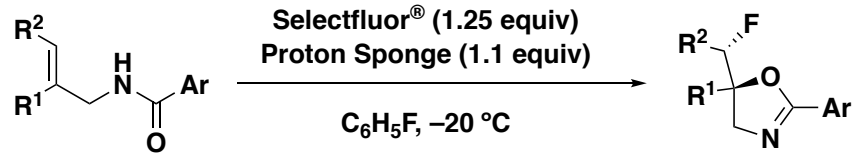


1) Ishihara. *et. al. Acs. Catal.* **2022**, *12*, 1012–1017.
2) Yu. *et. al. Org. Lett.* **2021**, *23*, 9134–9139.

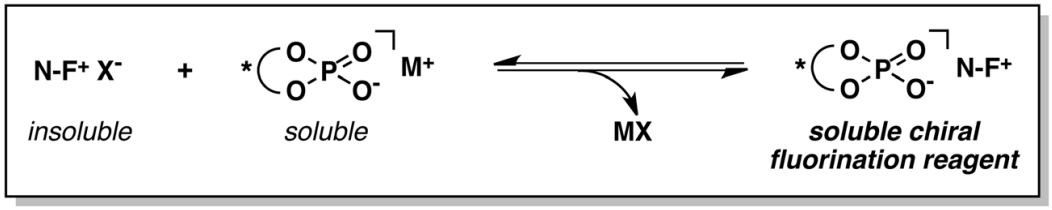
3. Enantioselective halogenation using Organocatalyst

3-1. Enantioselective halogenation using Anionic PTC

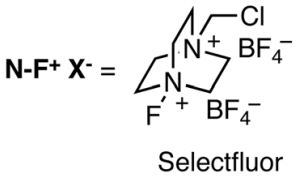
3-1-1. First Example of Asymmetric Fluorination using Anionic PTC (2011 Toste)

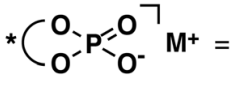


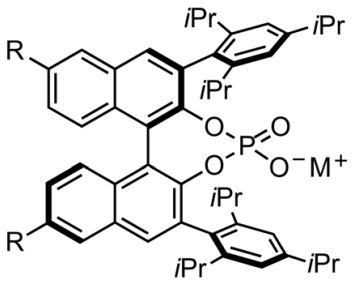
F. Dean Toste (1971-)

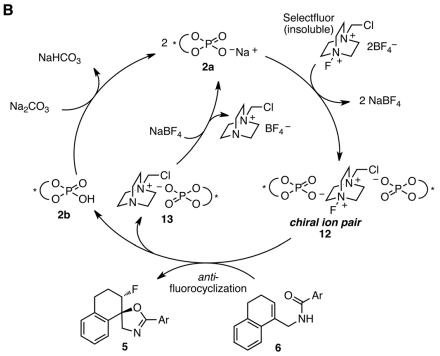


B

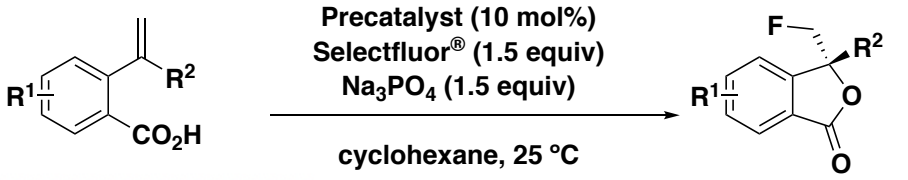




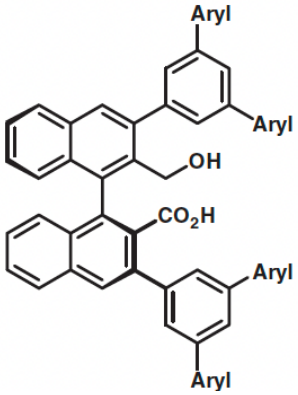




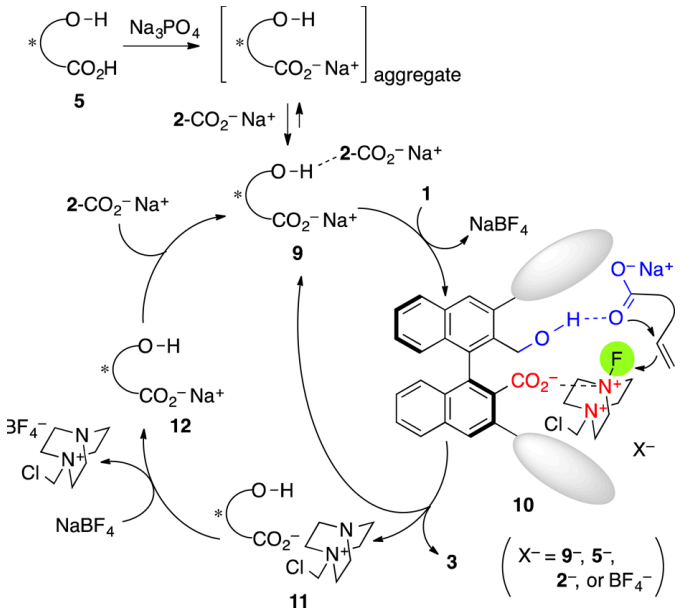
3-1-2. Asymmetric Fluorolactonization with a Bifuctional Hydroxyl Carboxylate Catalyst (2015 Hamashima)



Y. Hamashima (1974-)



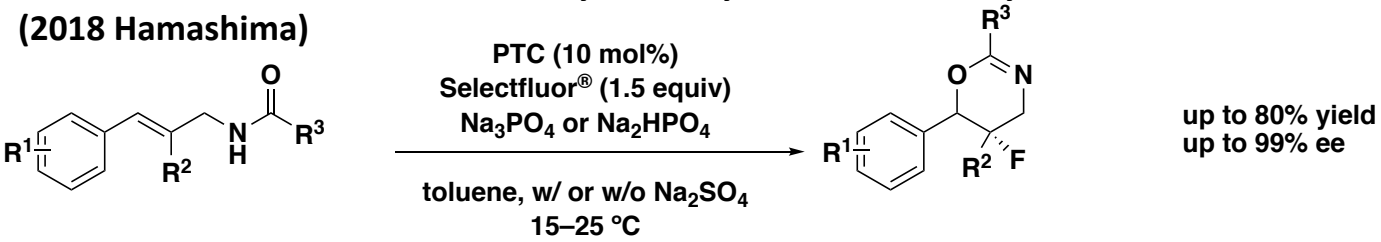
Aryl = 3,5-*t*-Bu2-C6H3



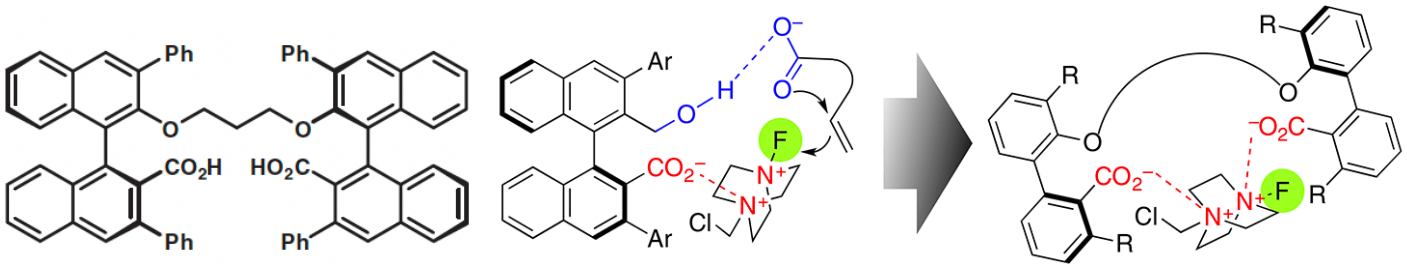
1) Toste. *et. al. Science.* **2011**, *334*, 1681.
2) Hamashima. *et. al. J. Am. Chem. Soc.* **2015**, *137*, 10132–10135.

3. Enantioselective halogenation using Organocatalyst

3-1-3.Dianionic Phase-Transfer Catalyst for Asymmetric Fluoro-cyclization (2018 Hamashima)



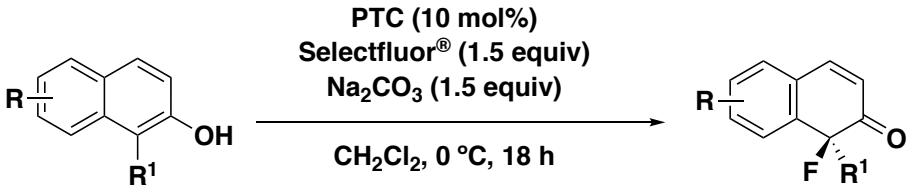
up to 80% yield
up to 99% ee



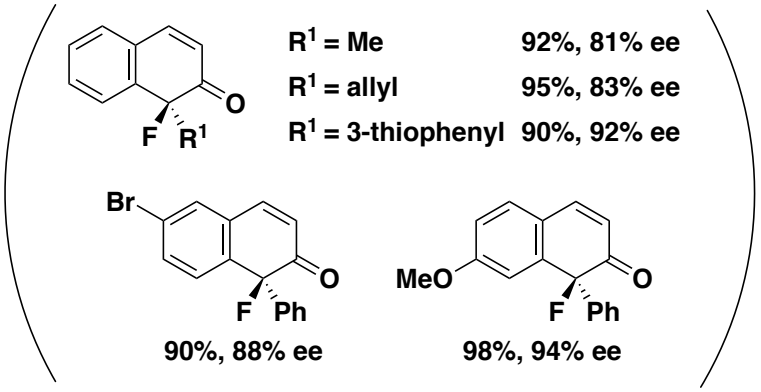
PTC

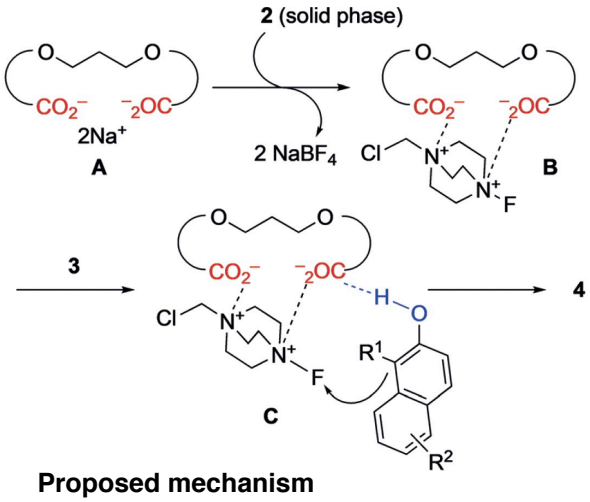
Phase-transfer activity
mono-anion < formal di-anion

3-1-4. Enantioselective reactions of 2-naphthols (2020 Hamashima)



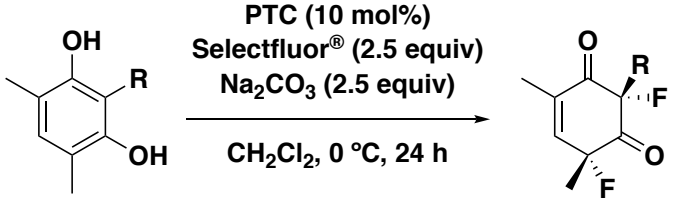
21 examples
up to >99% yield
up to 94 % ee





Proposed mechanism

3-1-5. Enantioselective reactions of resorcinols (2021 Hamashima)



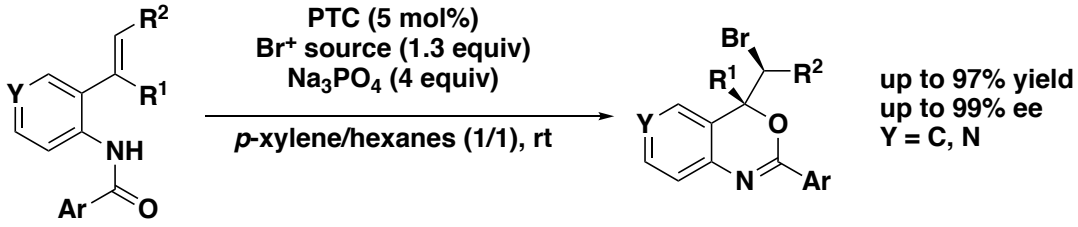
7 examples
up to >99% yield
up to 16:1 dr
up to 95 % ee

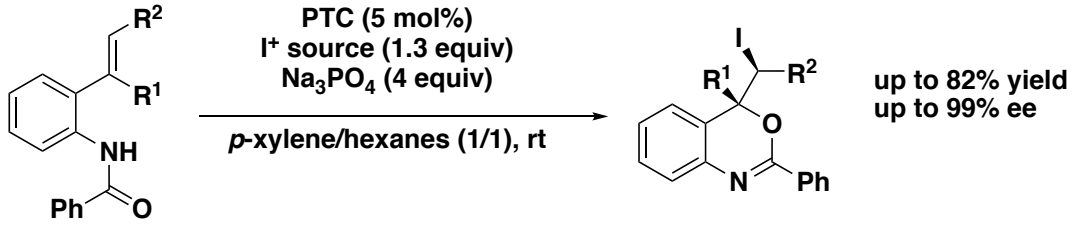
1) Hamashima. *et. al. J. Am. Chem. Soc.* **2015**, *137*, 10132–10135.
2) Hamashima. *et. al. Angew. Chem. Int. Ed.* **2020**, *59*, 14101.
3) Hamashima. *et. al. Tetrahedron.* **2021**, *96*, 132355.

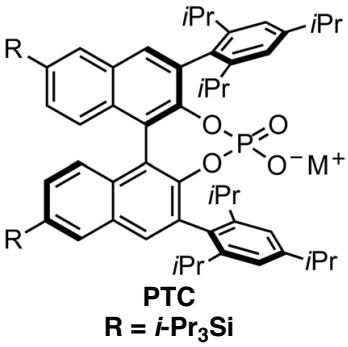
3. Enantioselective halogenation using Organocatalyst

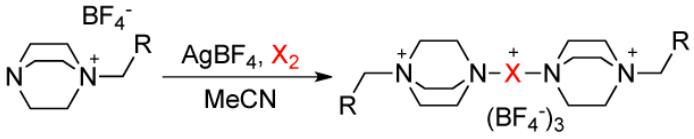
Asymmetric Electrophililic Bromination/Iodination Using an Anionic Chiral PTC

3-1-6. Enantioselective Halocyclization Using Reagents Tailored for Chiral Anion PTC (2012 Toste)



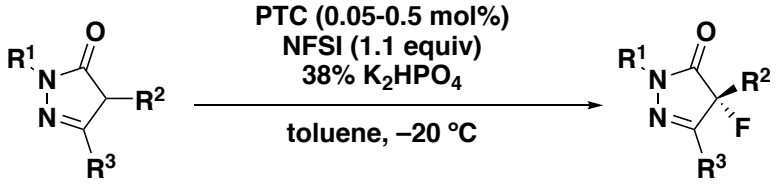


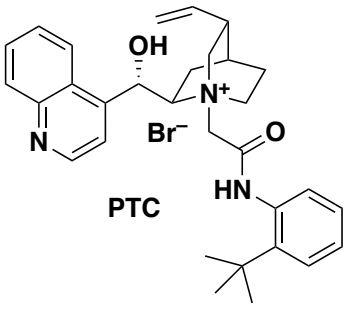


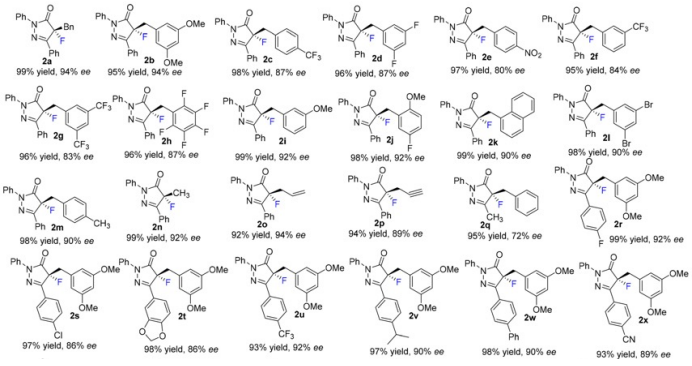


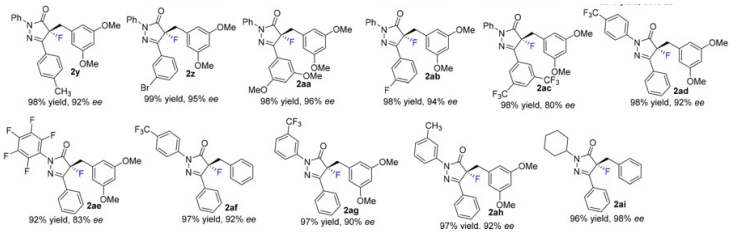
3-2. Enantioselective halogenation using Cationic PTC

3-2-1. Enantioselective Fluorination of 4-Substituted Pyrazolones (2023 Wang)





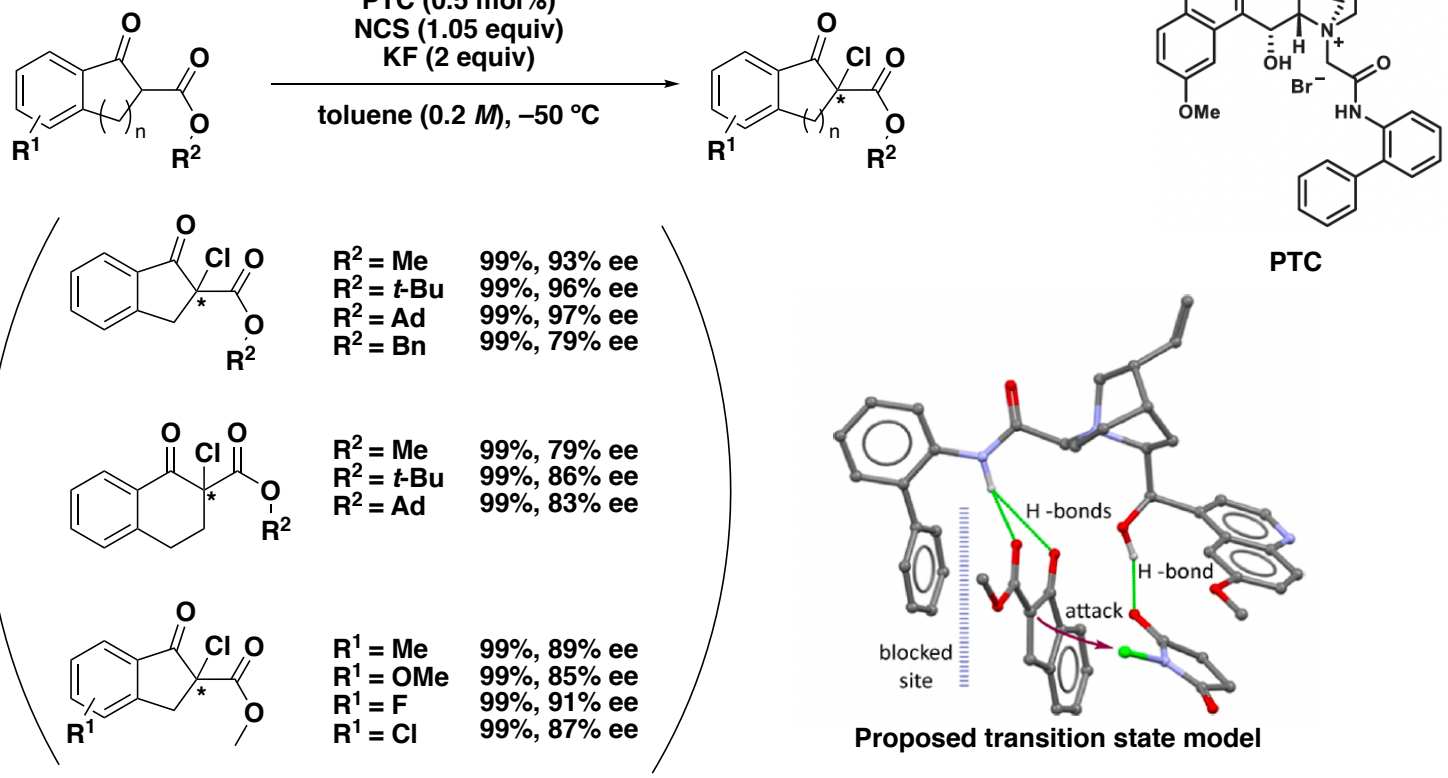




1) Toste. *et. al. J. Am. Chem. Soc.* **2012**, *134*, 12928–12931.
2) Wang. *et. al. Org. Chem. Front.* **2023**, *10*, 2226–2233.

3. Enantioselective halogenation using Organocatalyst

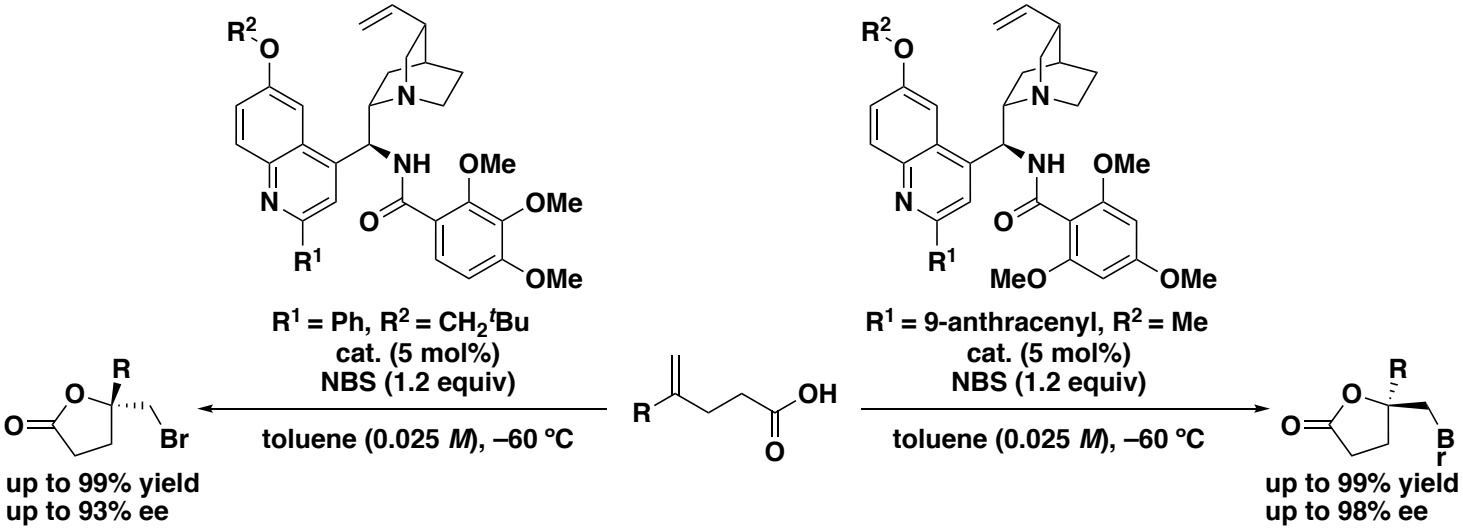
3-2-2. Enantioselective α-Chlorination of β-Keto Esters (2021 Jurczak)

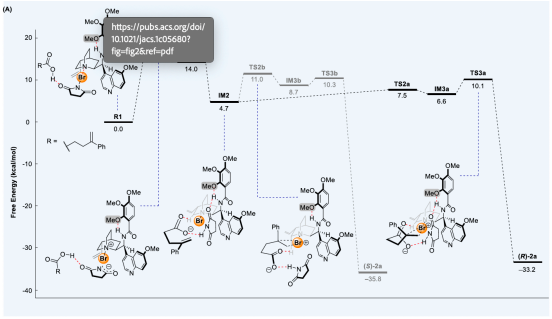


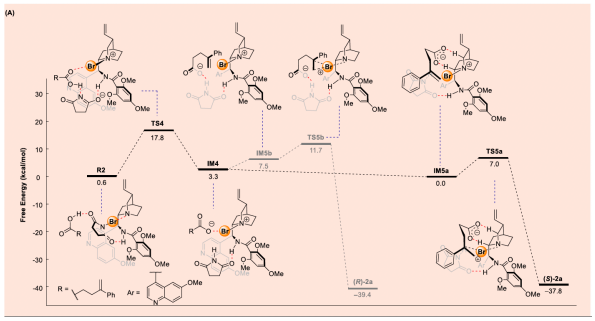
Proposed transition state model

3-3. Enantioselective halogenation using Organocatalyst

3-3-1. Enantiodivergent Bromolactonization (2021 Yeung)





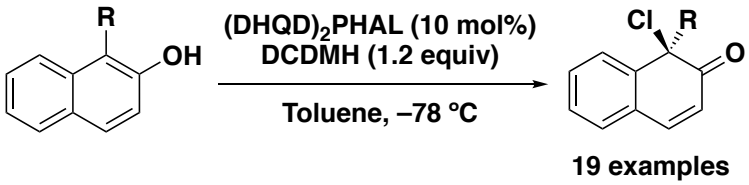


1) Jurczak. *et. al. J. Org. Chem.* **2021**, *86*, 995–1001.
2) Yeung. *et. al. J. Am. Chem. Soc.* **2021**, *143*, 12745–12754.

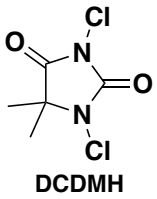
3. Enantioselective halogenation using Organocatalyst

3-3-2. Enantioselective reactions of naphthols (2015 You)

Scope of 2-naphthols

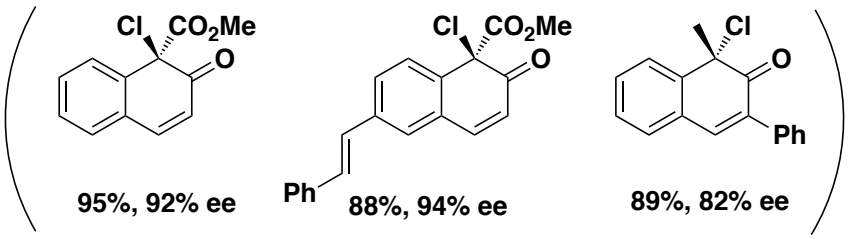


19 examples

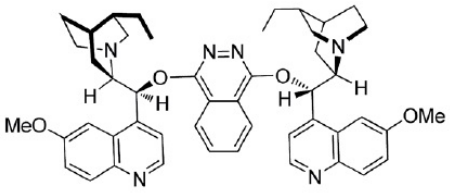


DCDMH

Shu-Li You (1975-)

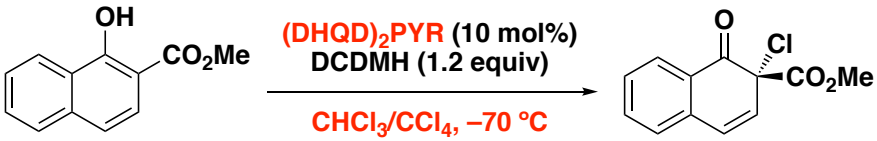


95%, 92% ee | 88%, 94% ee | 89%, 82% ee

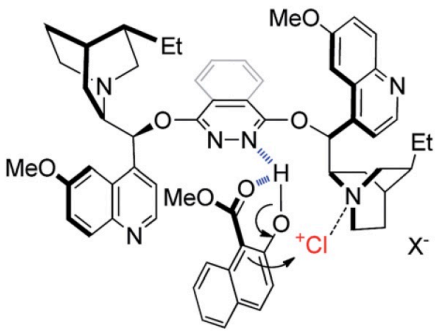


$(DHQD)_2PHAL$

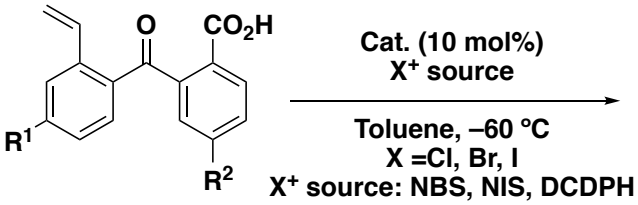
Investigation of 1-naphthols

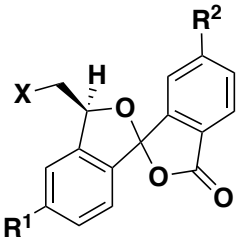


94%, 90% ee

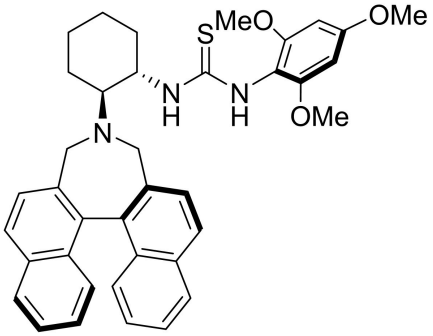


3-3-3. Enantio- and Diastereoselective Domino Halocyclization (2020 Yeung)



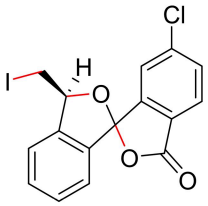


up to 93% yield
up to > 99:1 dr
up to 99% ee

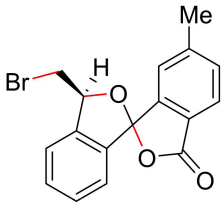


Cat.

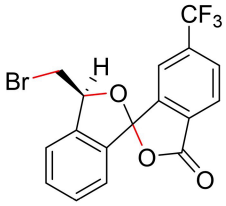
Selected examples



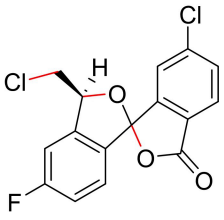
98a
71% yield
99% ee, 44:1 dr



98b
93% yield
99% ee, 44:1 dr



98c
90% yield
>99% ee, 53:1 dr

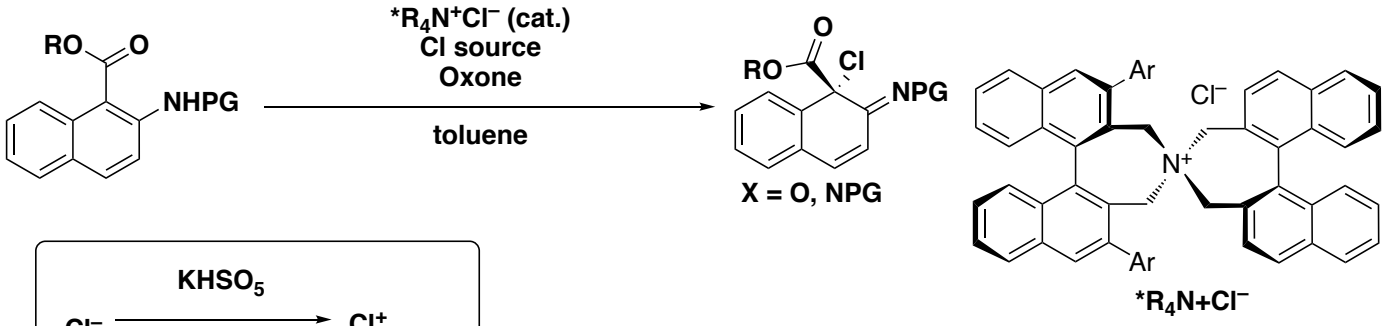


98d
77% yield
96% ee, 44:1 dr

1) You. *et. al. Chem. Sci.* **2015**, *6*, 4179.
2) Yeung. *et. al. Nat. Catal.* **2020**, *3*, 993–1001.

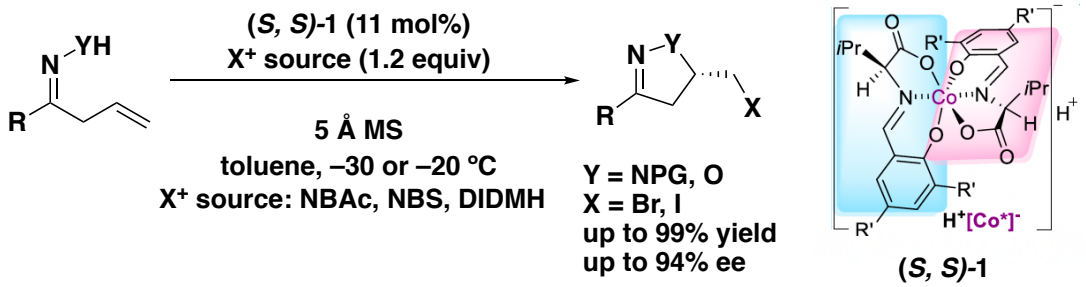
4. Proposal

My Work



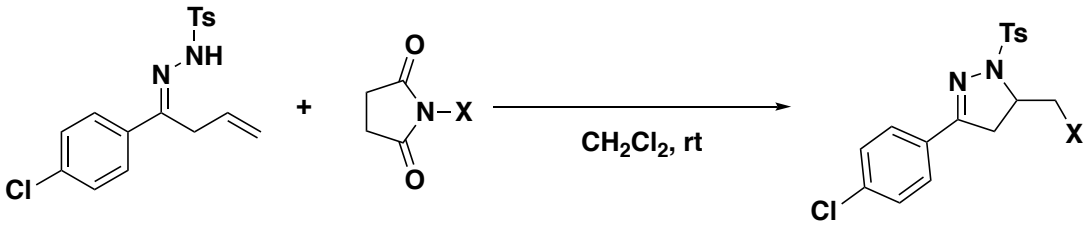
Back Ground

Anionic Chiral CO(III) Complexes Mediated Asymmrtric Halocyclization (2021 Yu)



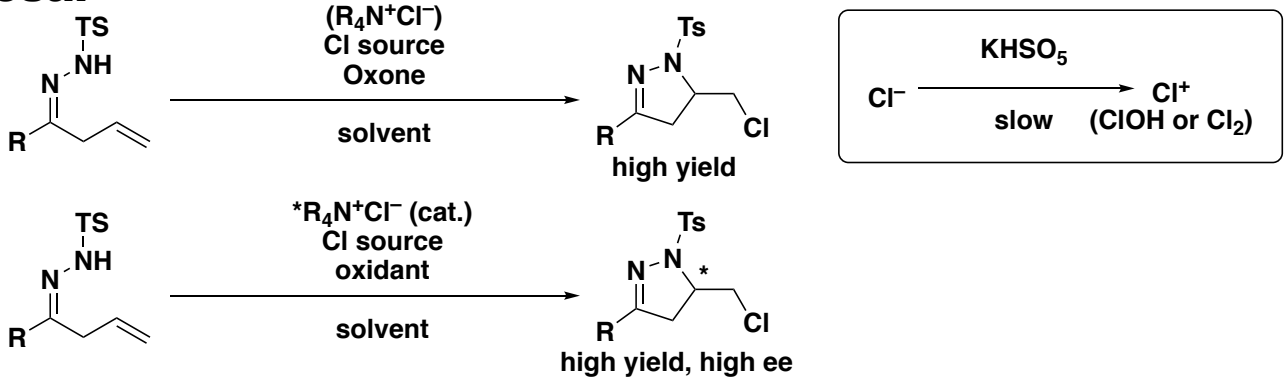
→ Chlorination reaction has not been reported

Halocyclization of β,Γ-Unsaturated Hydrazones (2014 Xiao)



X = Cl	complex mixture
X = Br	96% yield
X = I	83% yield

Proposal



1) Yu. et. al. *Org. Lett.* **2021,** *23,* 9134–9139.
2) Xiao. et. al. *Eur. J. Org. Chem.* **2014,** 3082–3086.