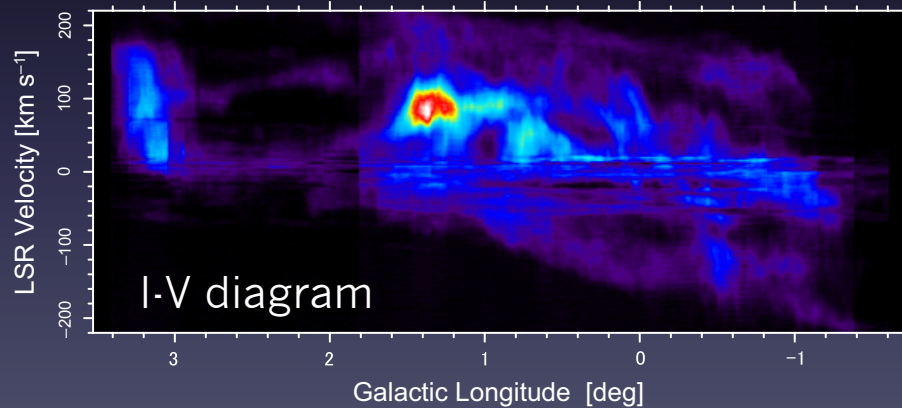
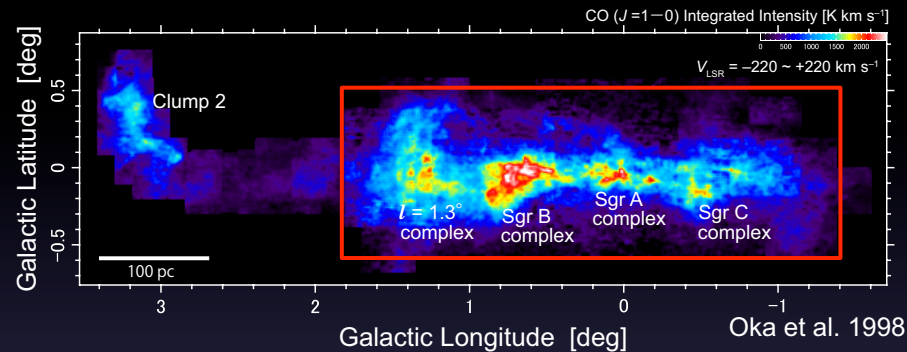


# 銀河系中心分子層と 銀河系核周円盤

竹川俊也, 岡 朋治, 田中邦彦  
(慶應義塾大学)

# Central Molecular Zone (CMZ)



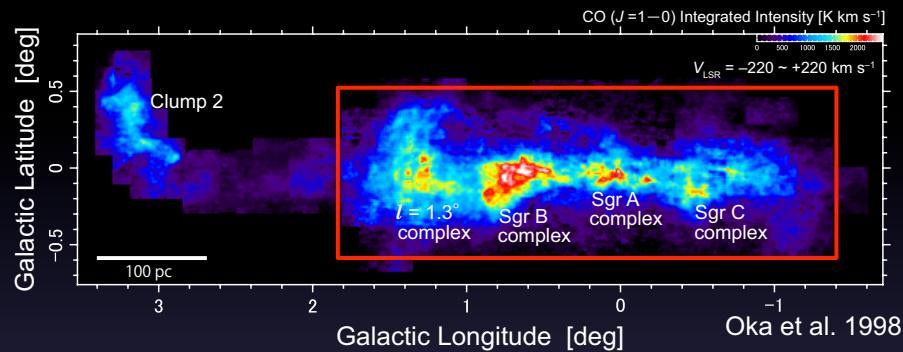
The nearest galactic center  
( $\sim 8.3$  kpc from the Sun)

- $M_{\text{CMZ}} : \sim 5 \times 10^7 M_{\text{sun}}$
- $n(\text{H}_2) > 10^4 \text{ cm}^{-3}$
- $T > 30 \text{ K}$
- $\Delta V > 30 \text{ km/s}$

## Difficulties

- 円盤部が邪魔
- 前後関係がわかりにくい
- 見えすぎて困る

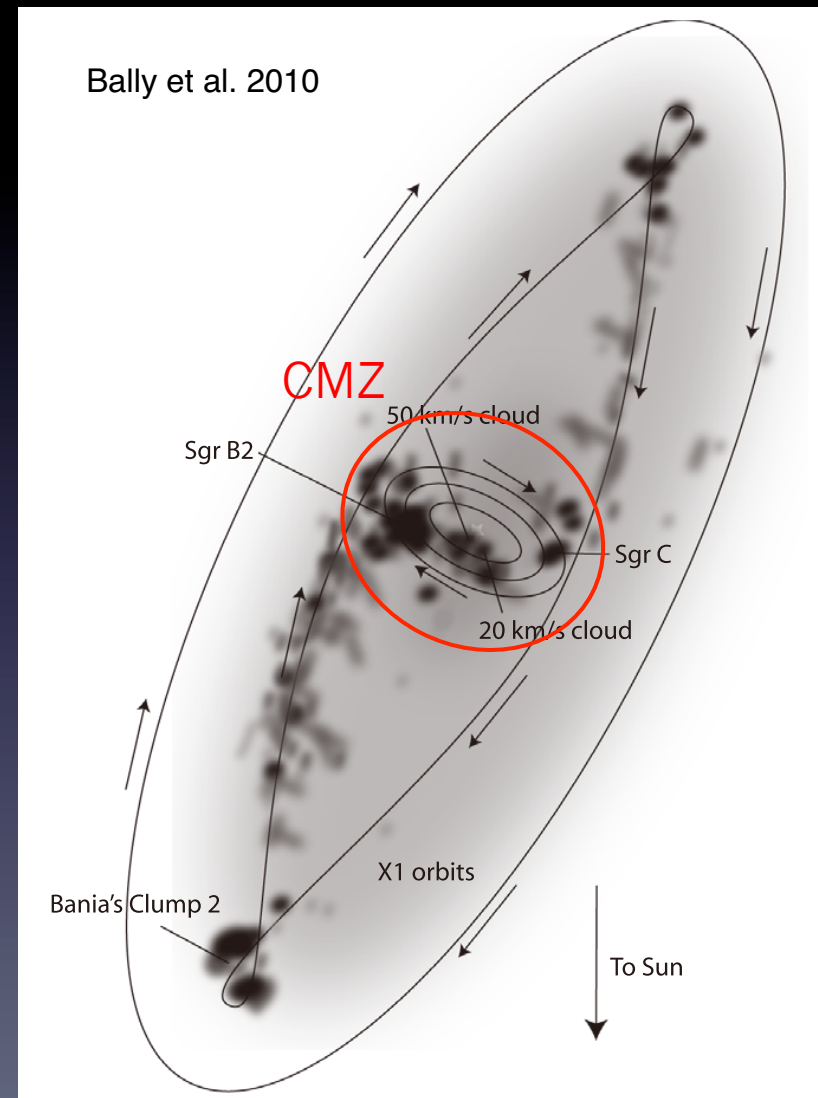
# Central Molecular Zone (CMZ)



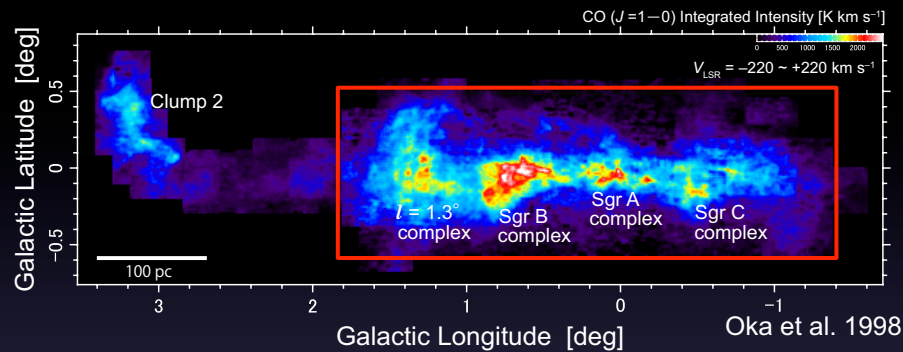
Schematic face-on view  
of the central 500 pc →

Galactic barに沿った長軸  
を持つX1軌道群

それに垂直な長軸を持つ内  
側のX2軌道群



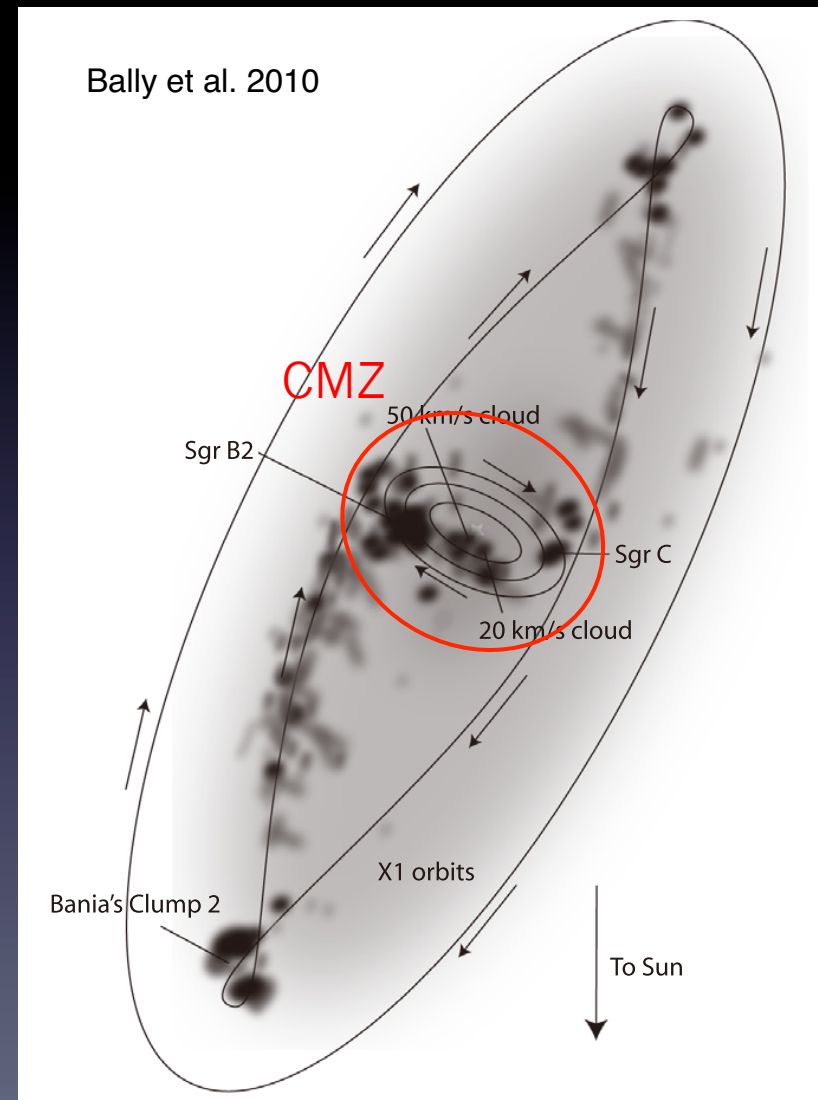
# Central Molecular Zone (CMZ)



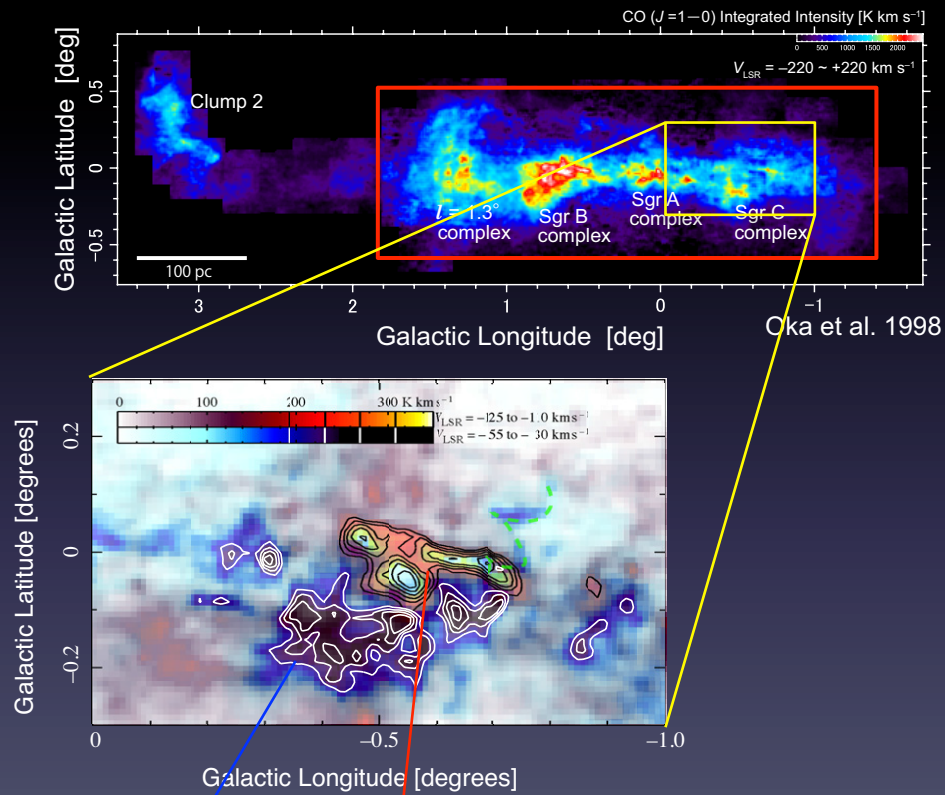
Schematic face-on view  
of the central 500 pc →

軌道同士の接触により  
角運動量を失う

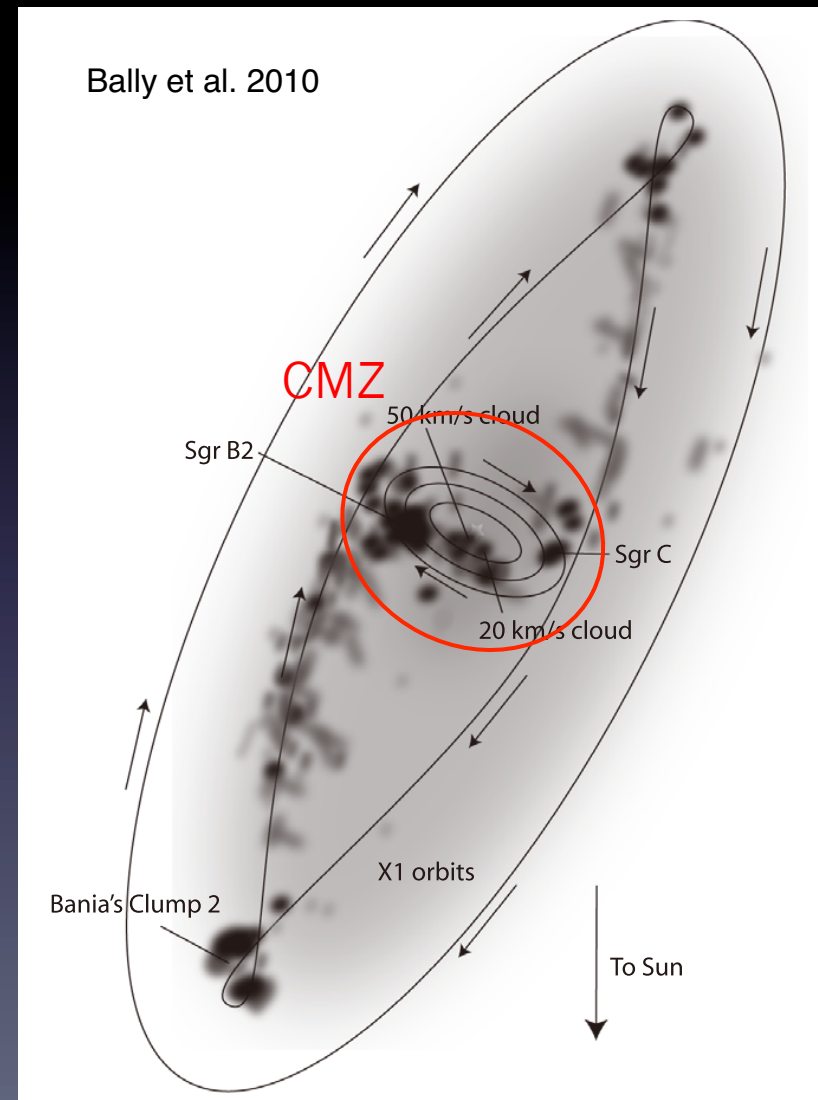
Galactic bar → CMZ



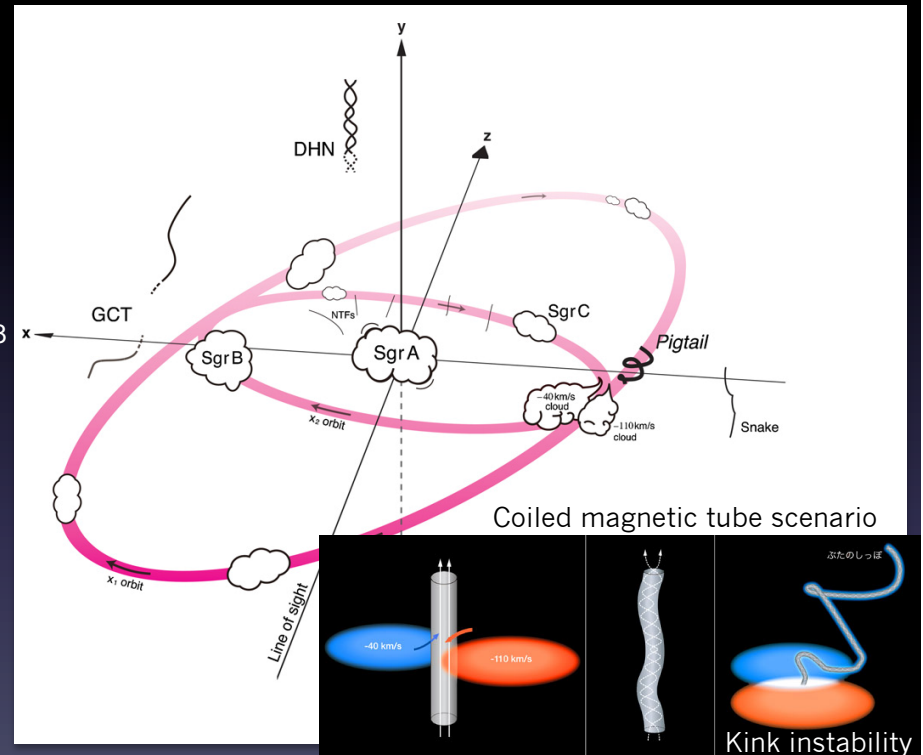
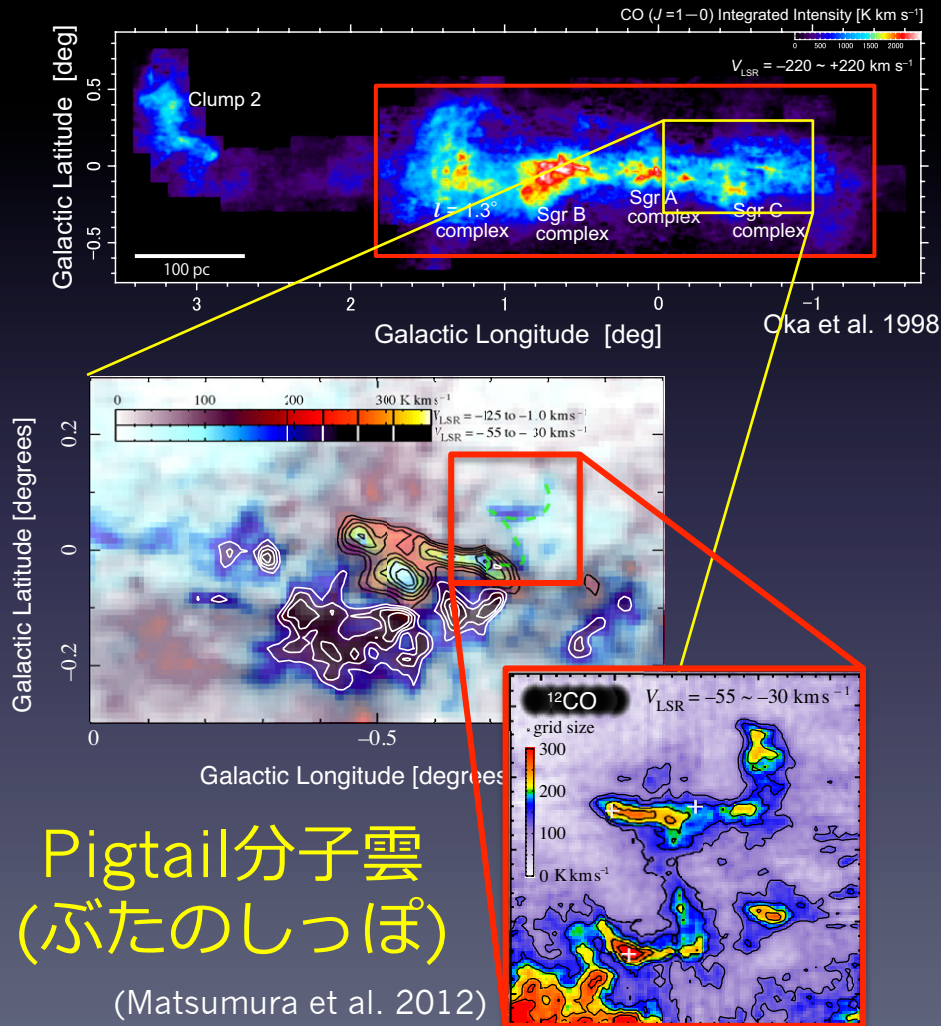
# Discovery of the Pigtail



-110  $\text{km s}^{-1}$  cloud on the inner X1  
-40  $\text{km s}^{-1}$  cloud on the outer X2  
(Matsumura et al. 2012)

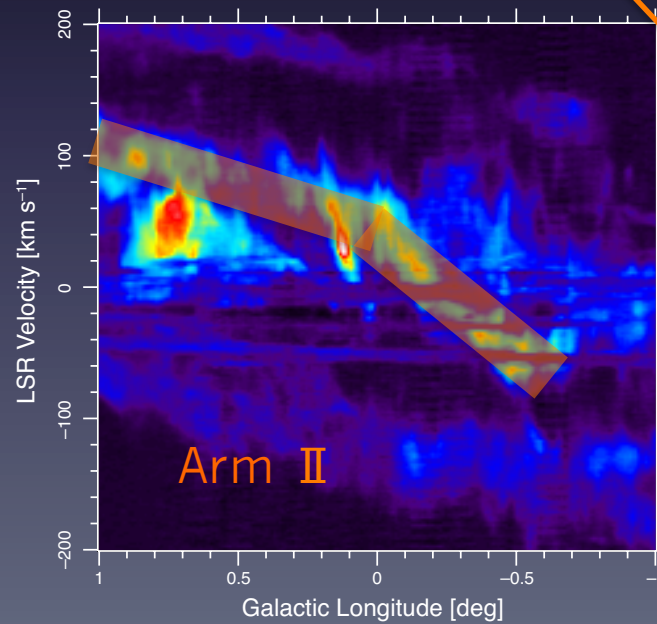
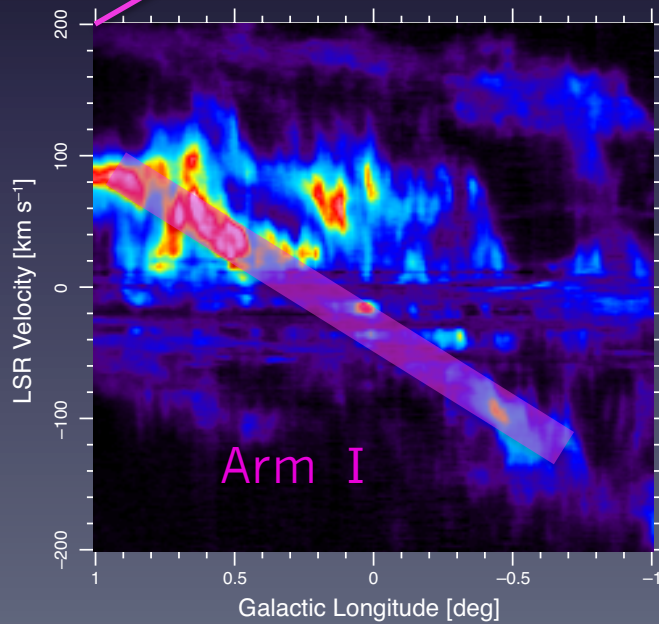
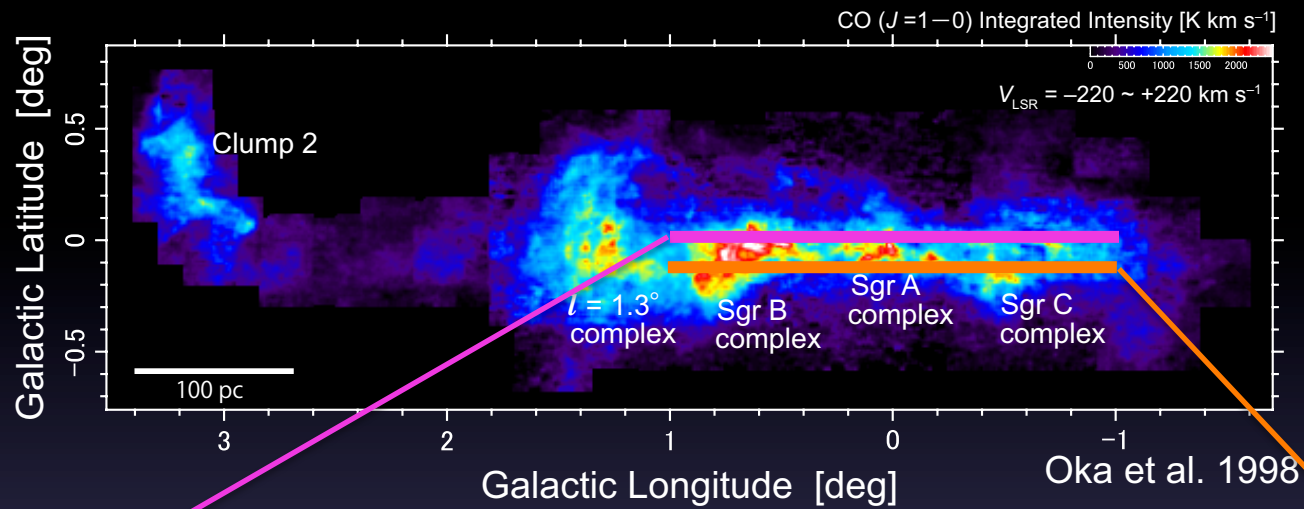


# Discovery of the Pigtail

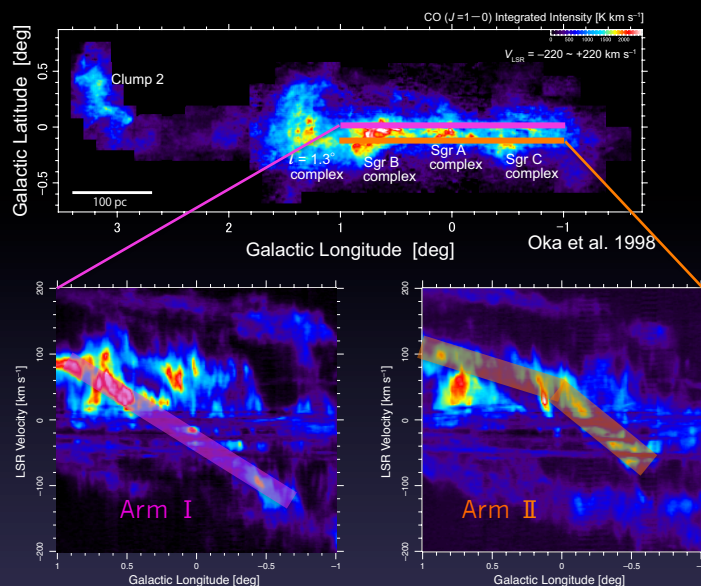


軌道間相互作用の証拠

# Galactic Center Arms and the 120 pc ring

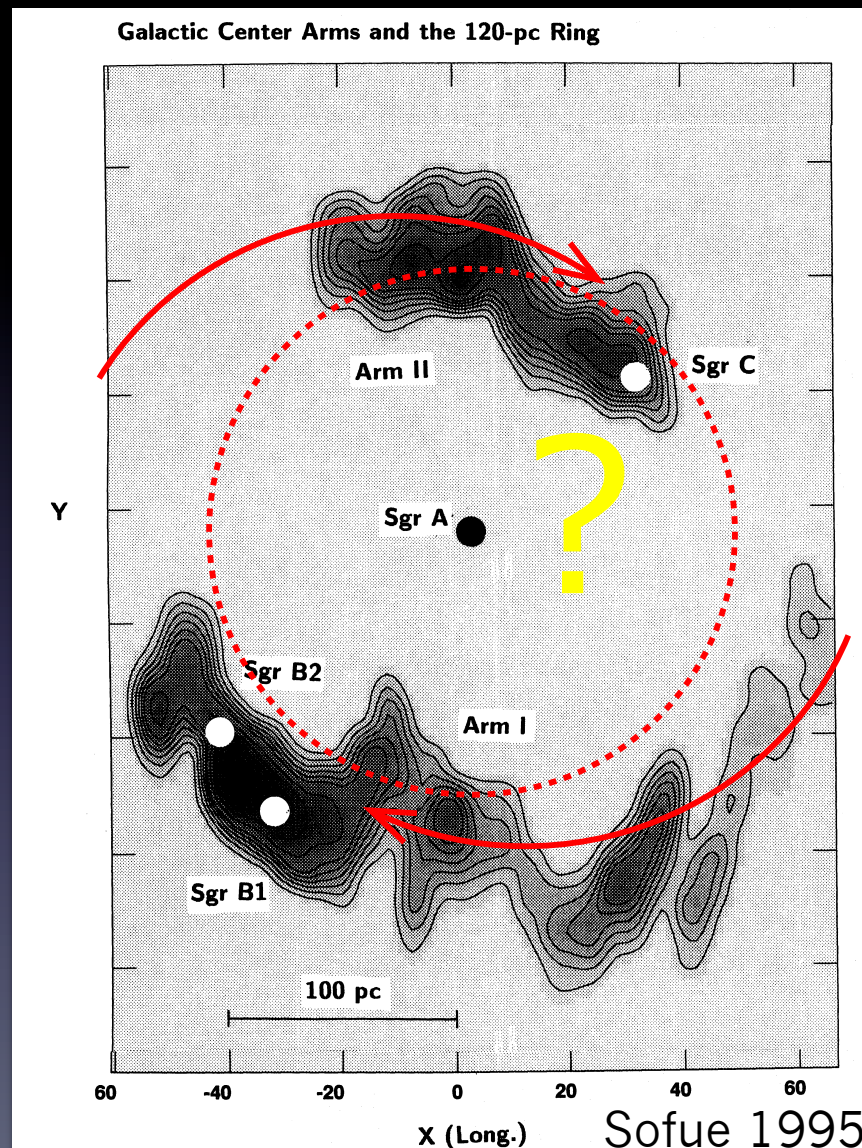


# Galactic Center Arms and the 120 pc ring



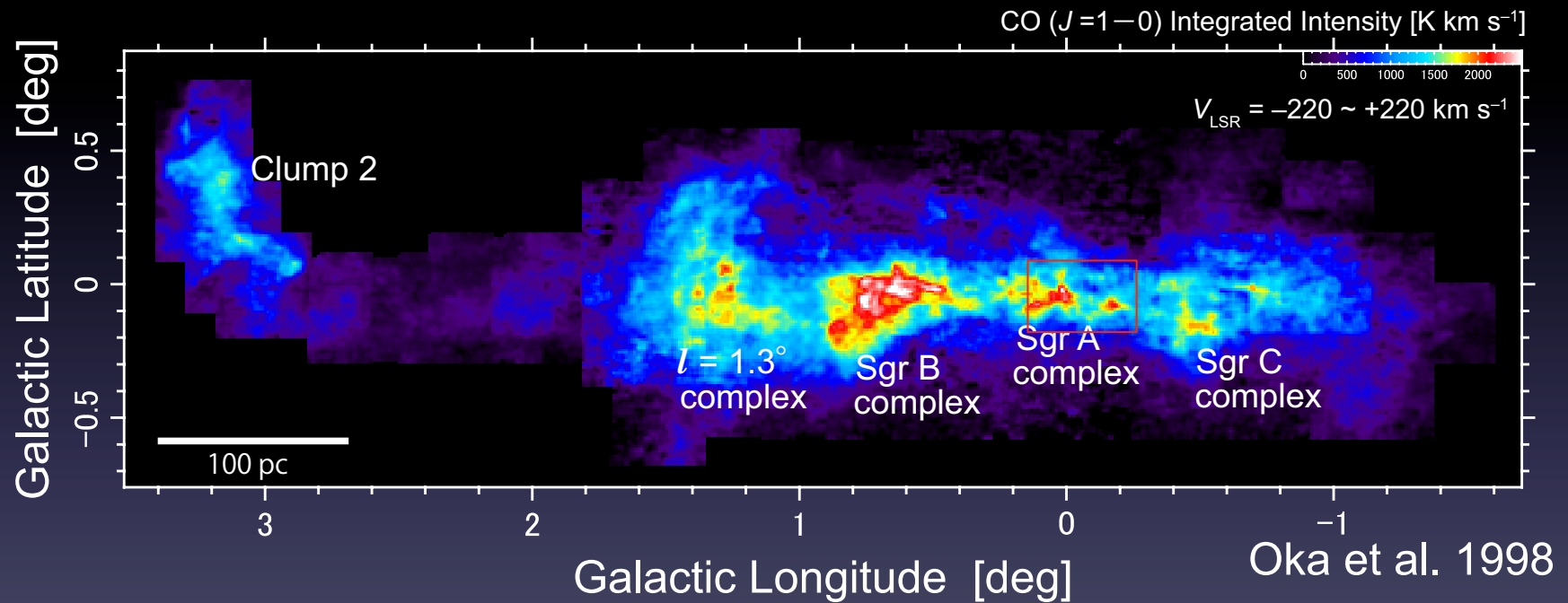
円運動を仮定し、  
 視線速度から  
 中心からの距離を推定

$$y = \pm |x| \sqrt{\left(\frac{V_{\text{rot}}}{v_{\text{los}}}\right)^2 - 1}$$

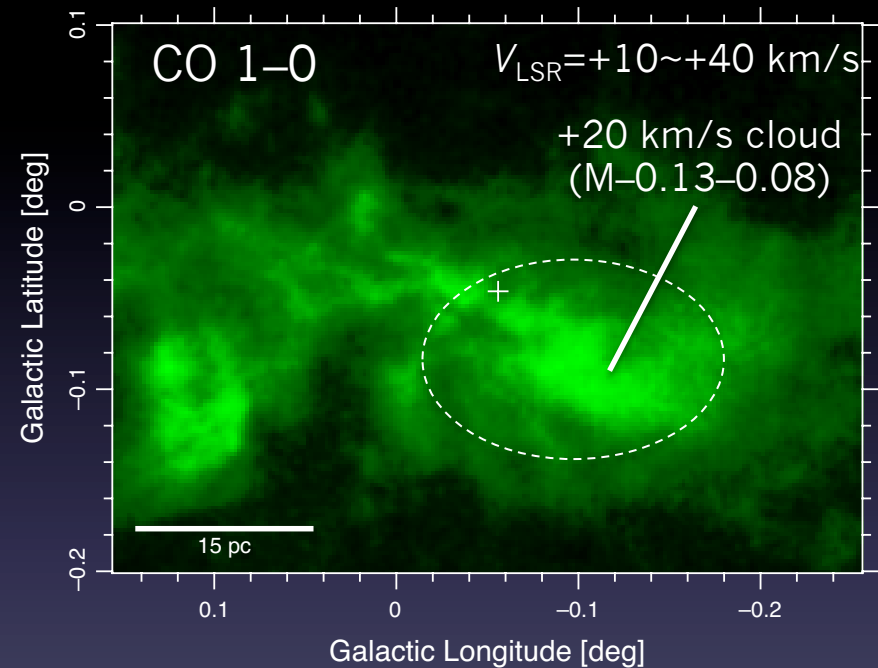
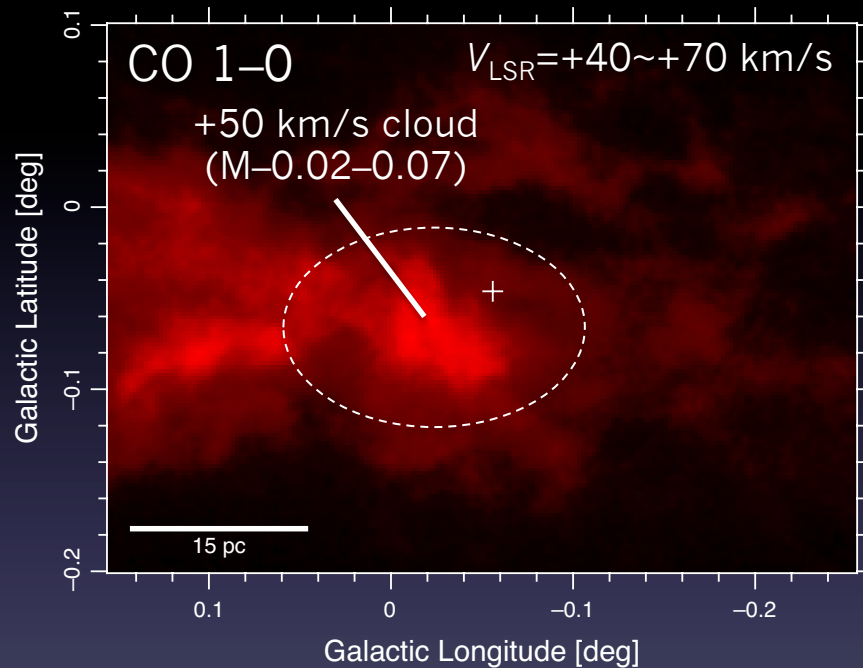




# Two GMCs in the Central 30 pc



# Two GMCs in the Central 30 pc

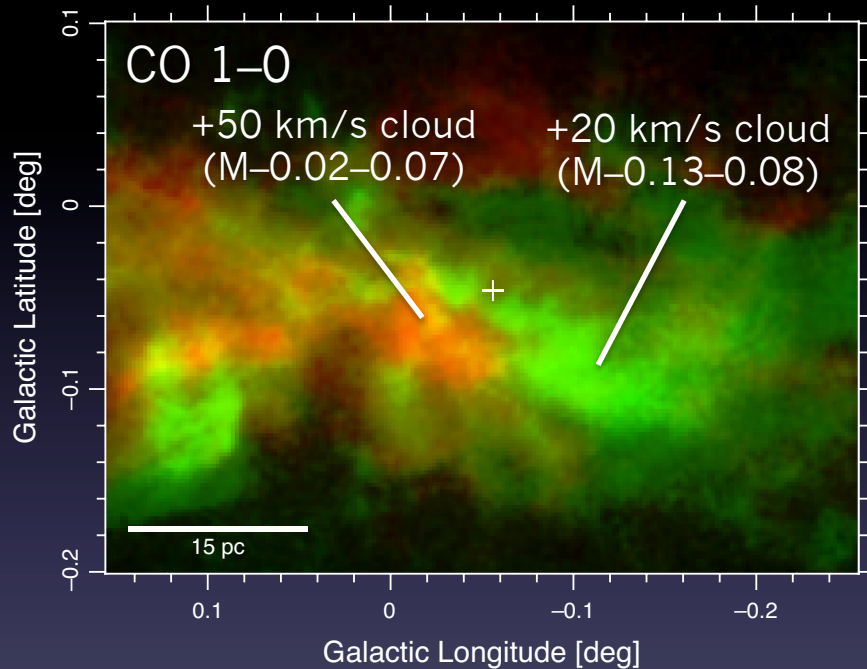


+50 km/s cloud

+20 km/s cloud

中心核(Sgr A\*)方向には2つの巨大分子雲

# Two GMCs in the Central 30 pc

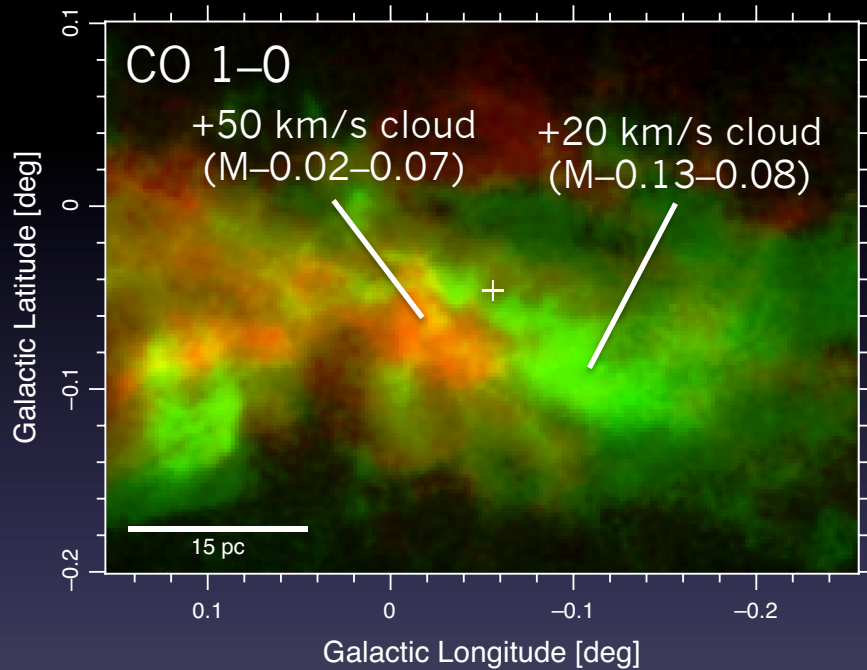


GMCs

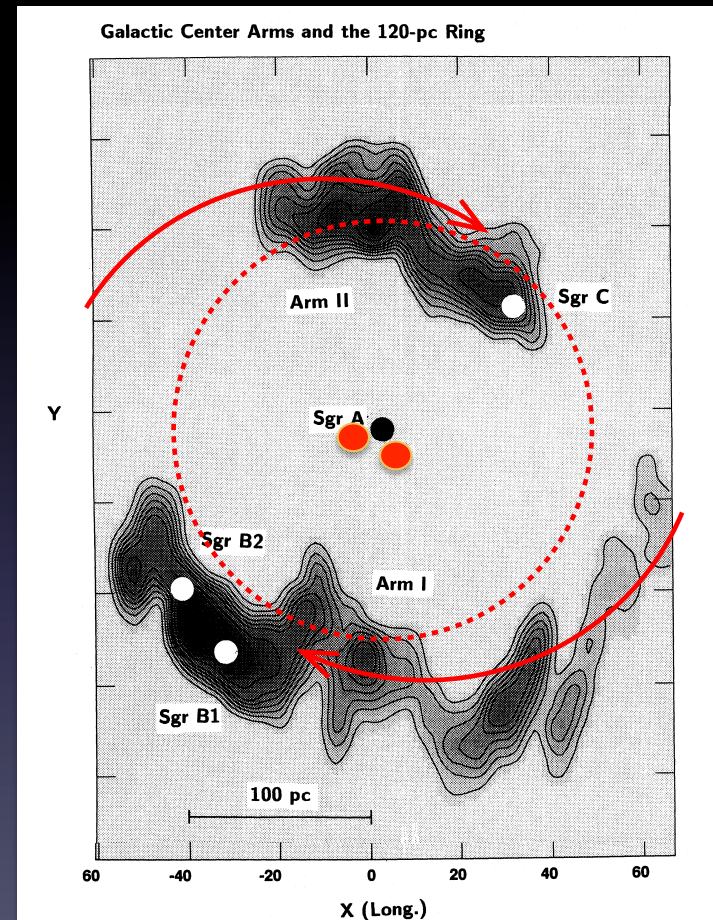
- $M_{50k} : (1-5) \times 10^5 M_{\text{sun}}$
- $M_{20k} : (2-8) \times 10^5 M_{\text{sun}}$
- $n(\text{H}_2) \sim 10^4 \text{ cm}^{-3}$
- $T \sim 30-50 \text{ K}$
- Interacting with the nuclear region(?)

中心核(Sgr A\*)方向には2つの巨大分子雲

# Two GMCs in the Central 30 pc



GMCs



中心核(Sgr A\*)方向には2つの巨大分子雲

# Twisted ring?

Herschel 250  $\mu\text{m}$  (Molinari et al. 2011)

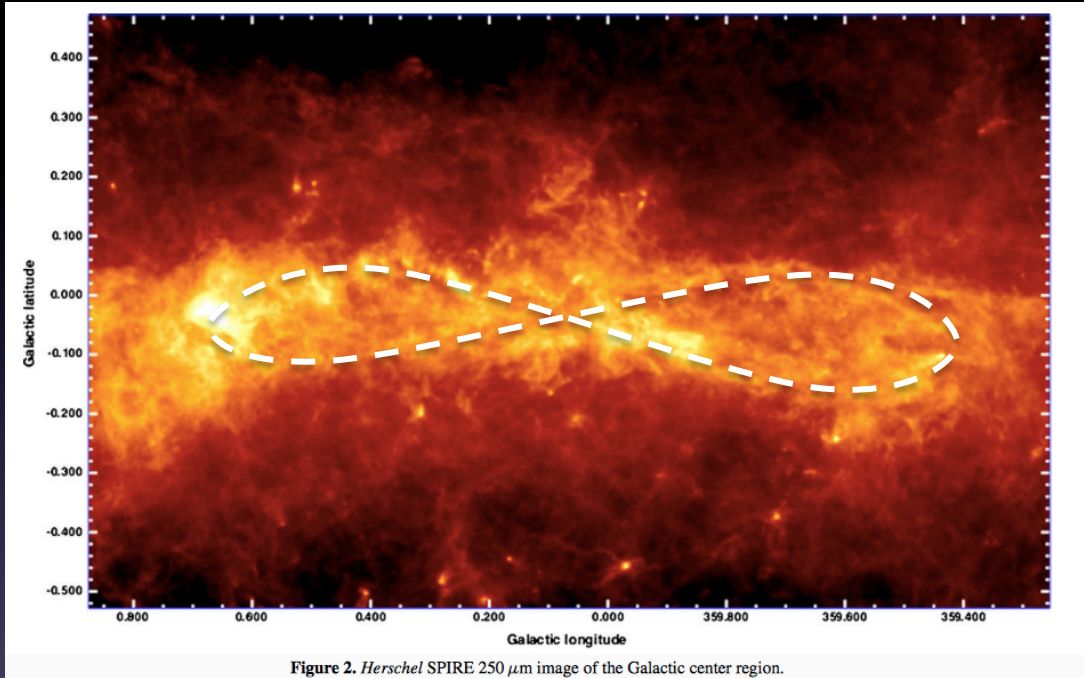
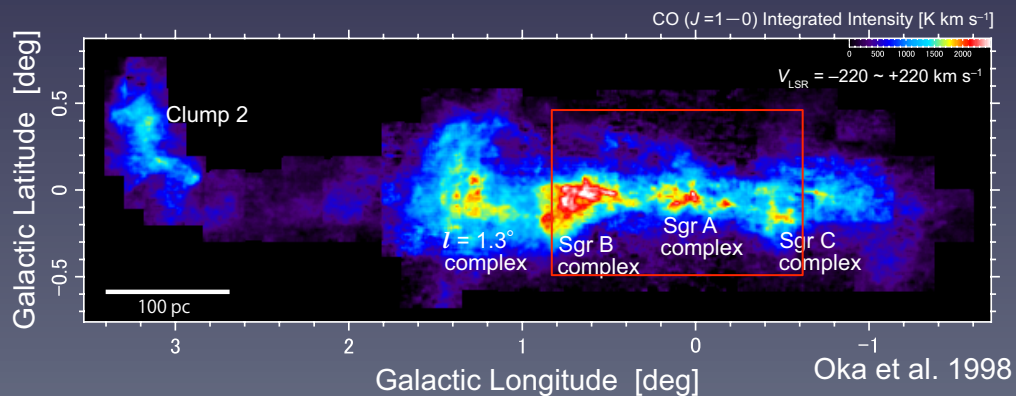
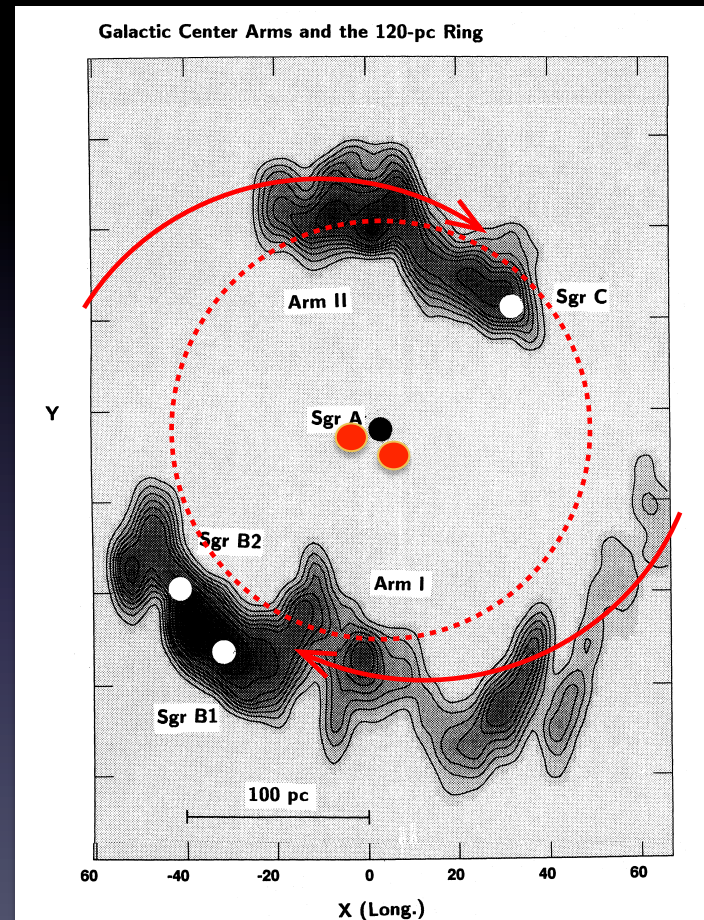


Figure 2. *Herschel* SPIRE 250  $\mu\text{m}$  image of the Galactic center region.



# Twisted ring?

Temperature map (Molinari et al. 2011)

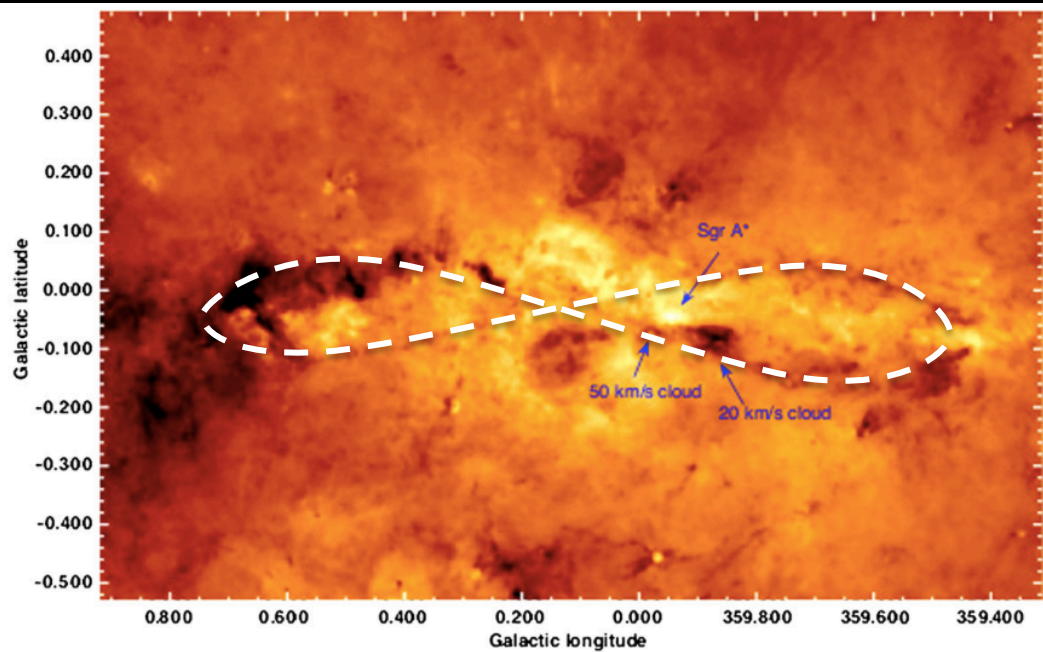
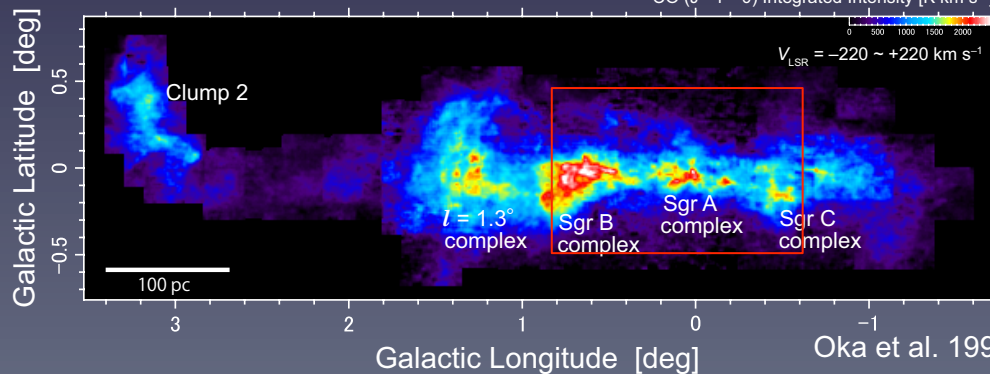
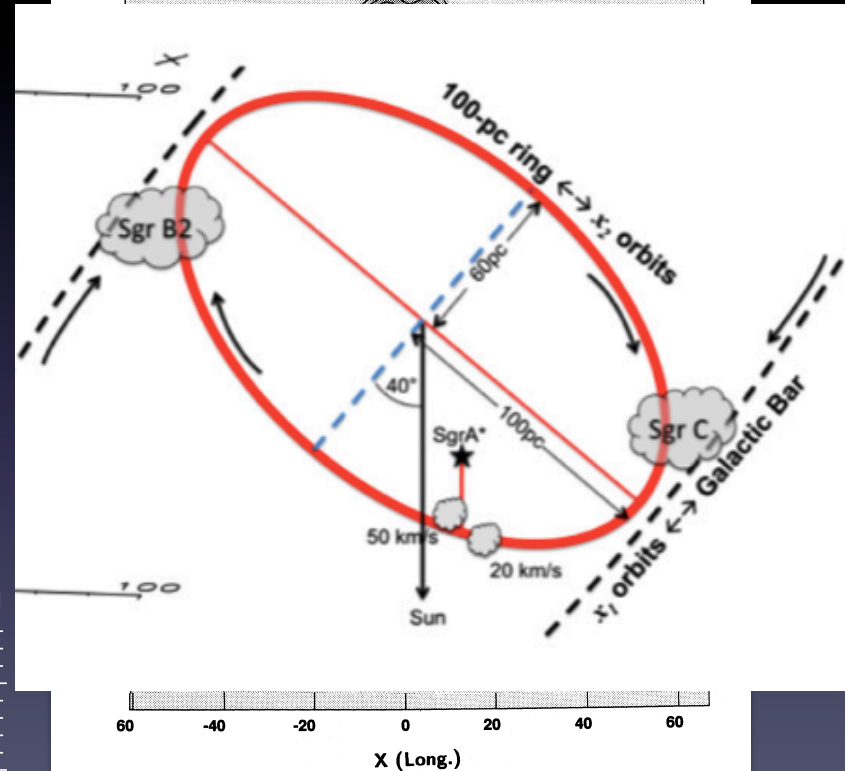
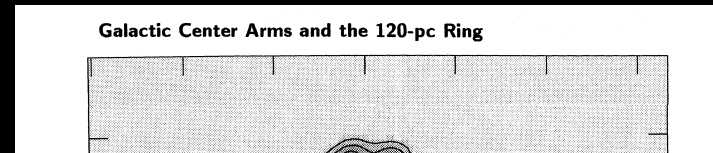


Figure 3. Temperature map of the Galactic center region. The log-color stretch extends from 15 K to 40 K on Sgr A\*.

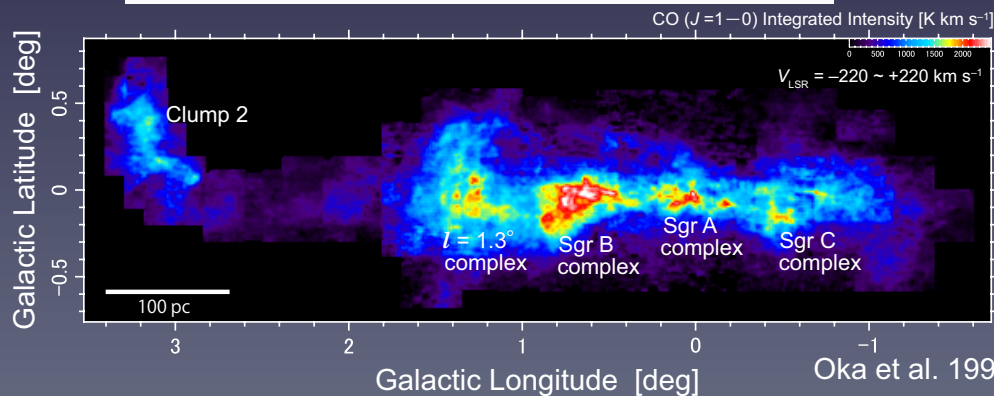
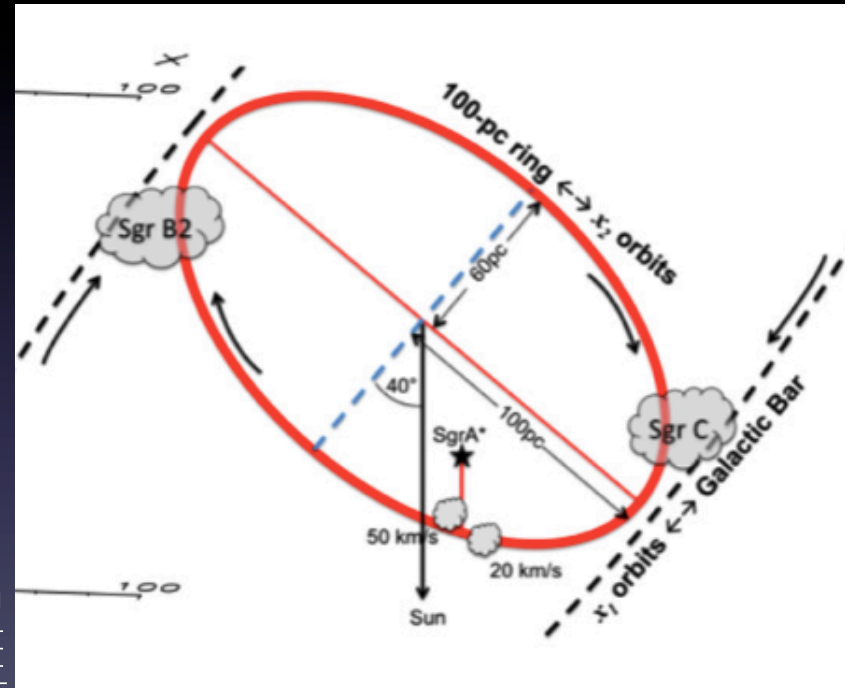
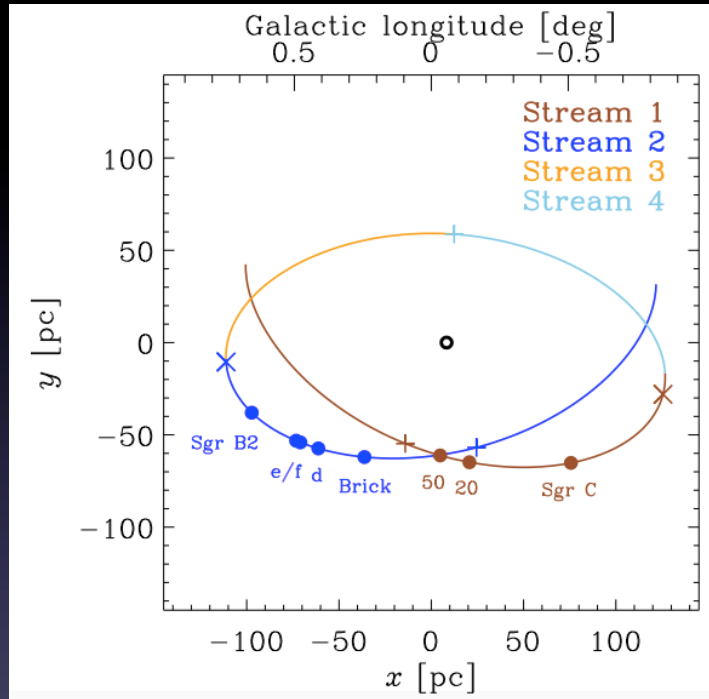


中心核が中心にない?!

Oka et al. 1998

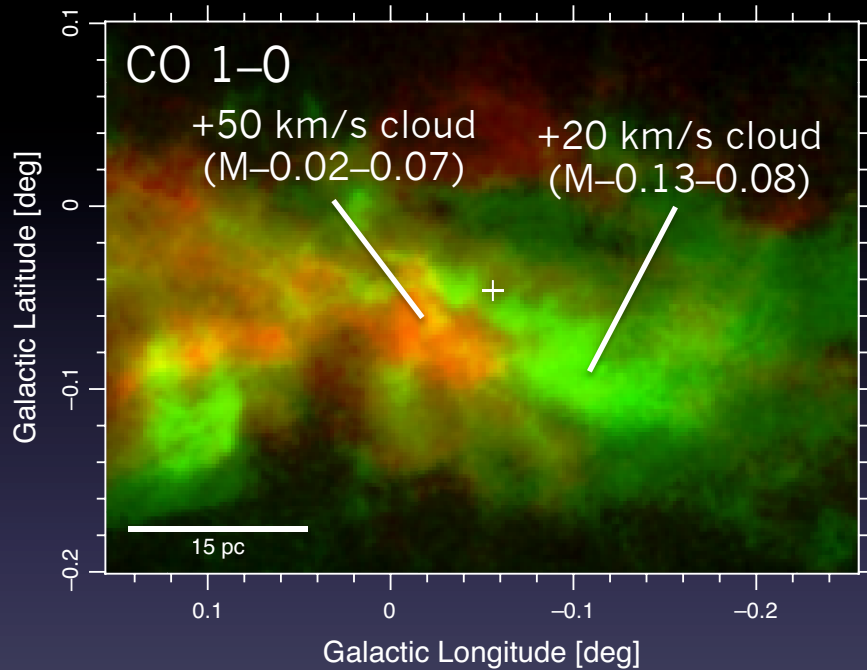
# Four streams?

Kruijssen et al. 2015

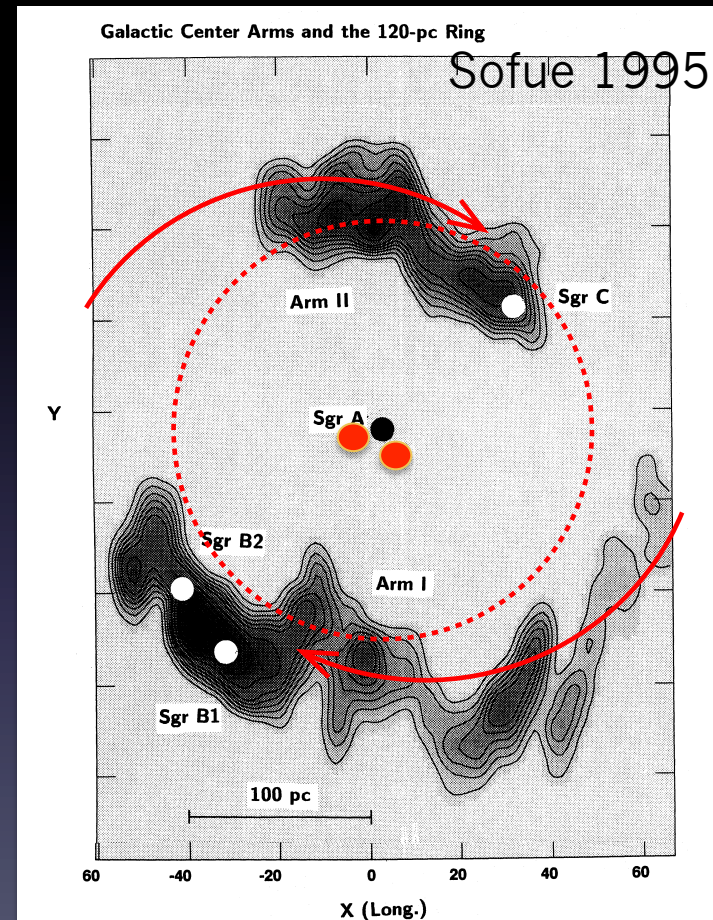


リングですらない?!

# Two GMCs in the Central 30 pc



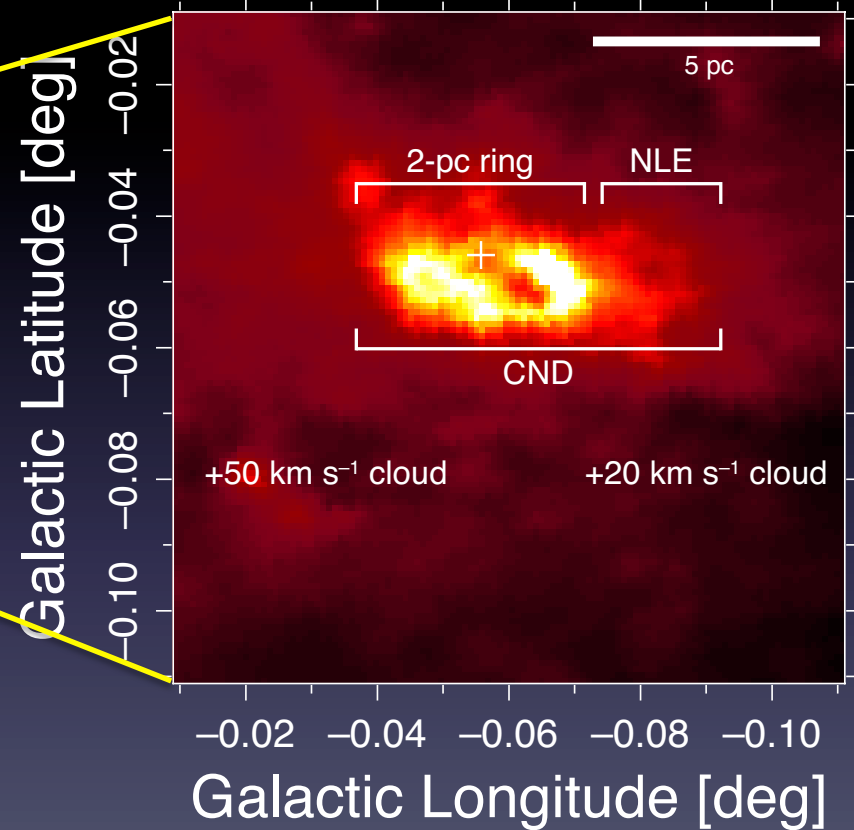
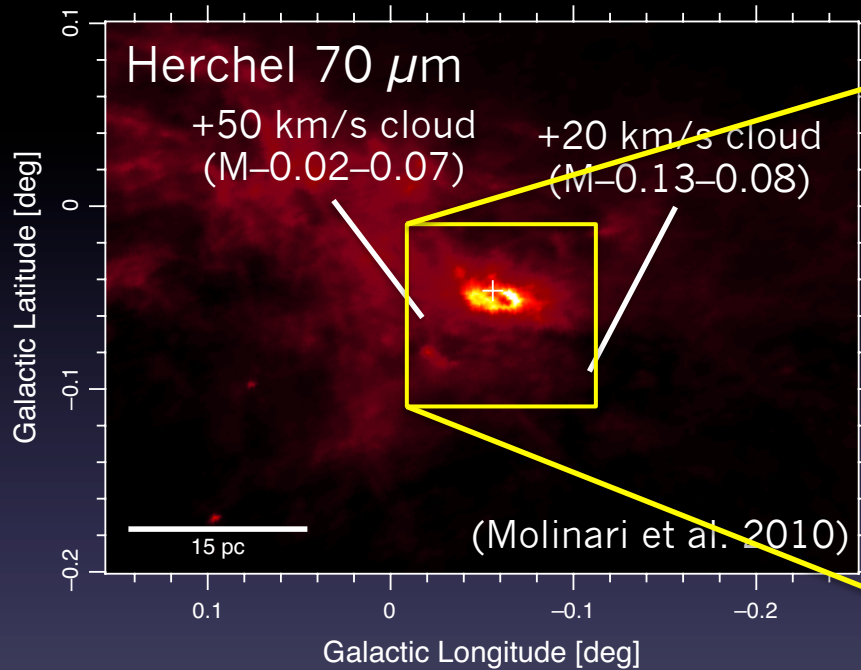
GMCs



中心核(Sgr A\*)近傍には2つの巨大分子雲



# Circumnuclear Disk

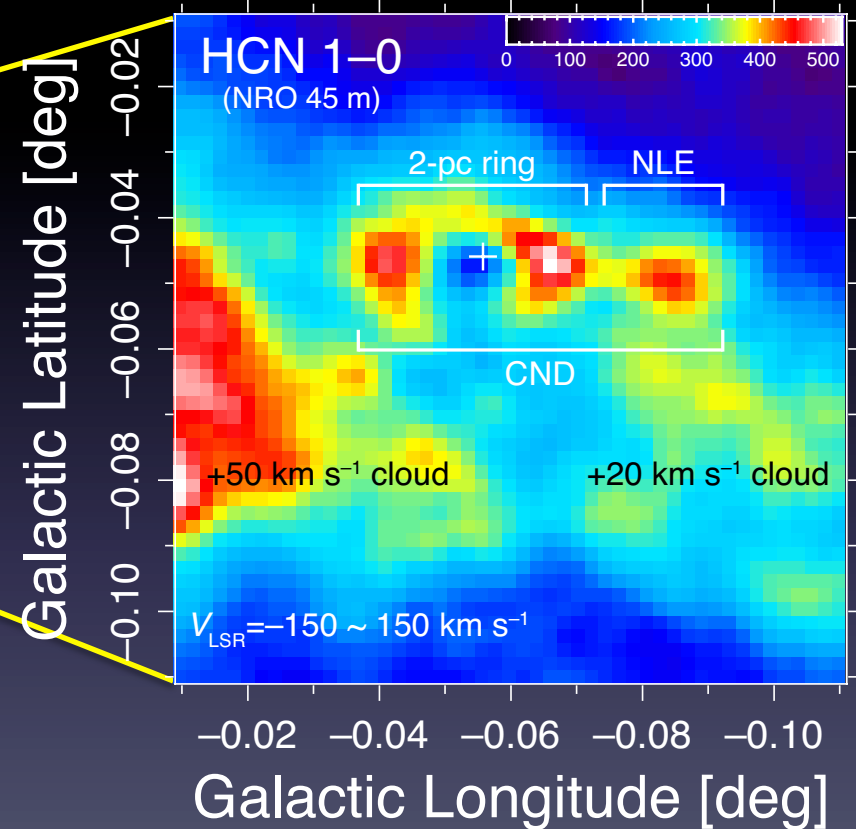
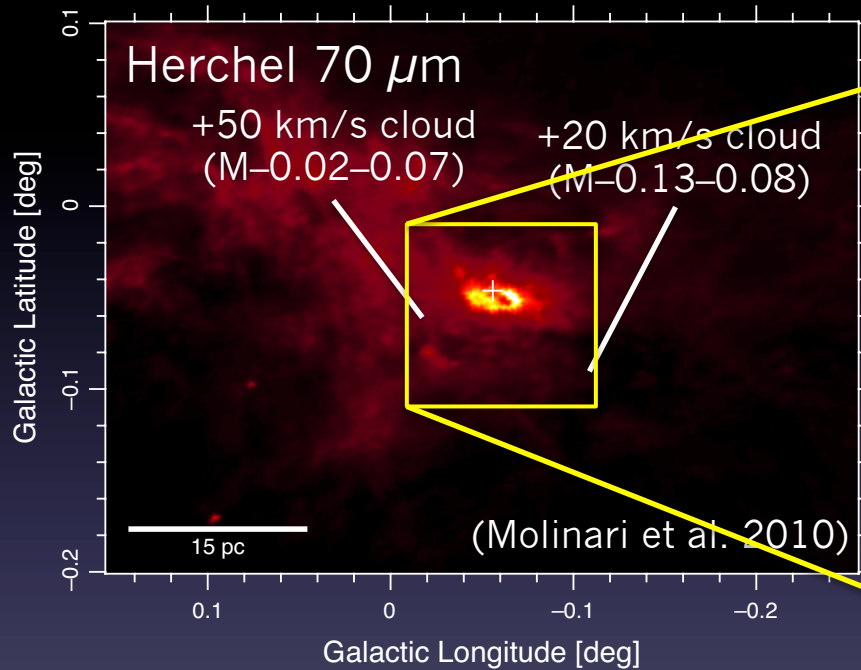


CND

Dust torus of our Galaxy

# Circumnuclear Disk

(Takekawa et al. 2016 in prep.)



CND=2-pc ring+NLE  
(NLE: Negative longitude extension)

Asymmetric disk/ring

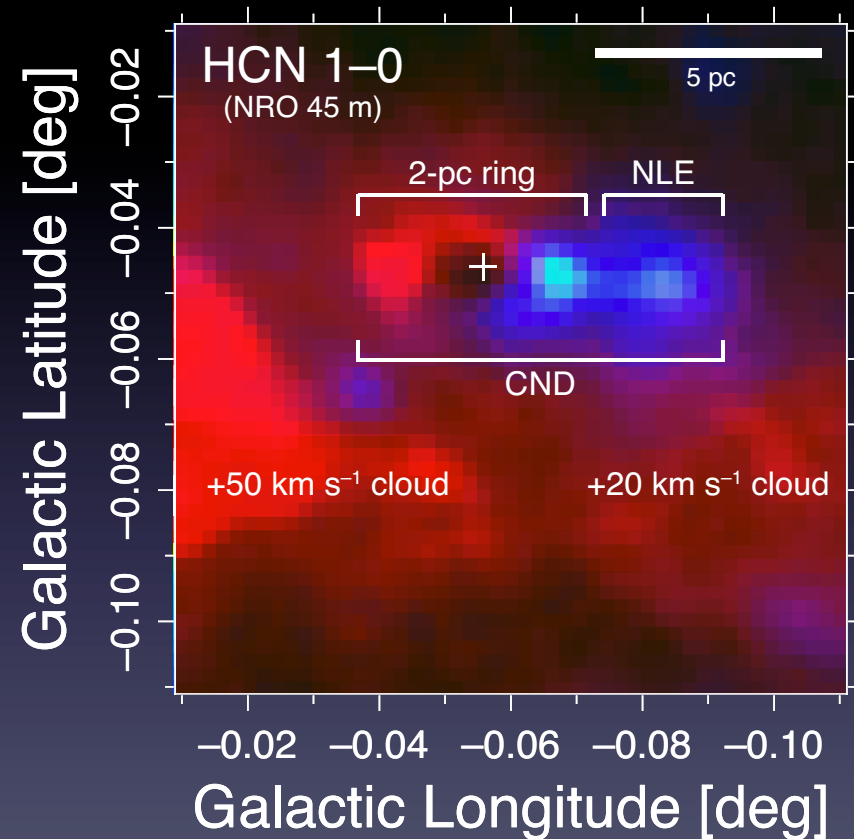
# Circumnuclear Disk

- $M_{\text{CND}} \sim 10^5 M_{\text{sun}}$
- $n(\text{H}_2) \sim 10^5 \text{ cm}^{-3}$
- $T_k > \sim 100 \text{ K}$
- $V_{\text{rot}} \sim 110 \text{ km/s}$

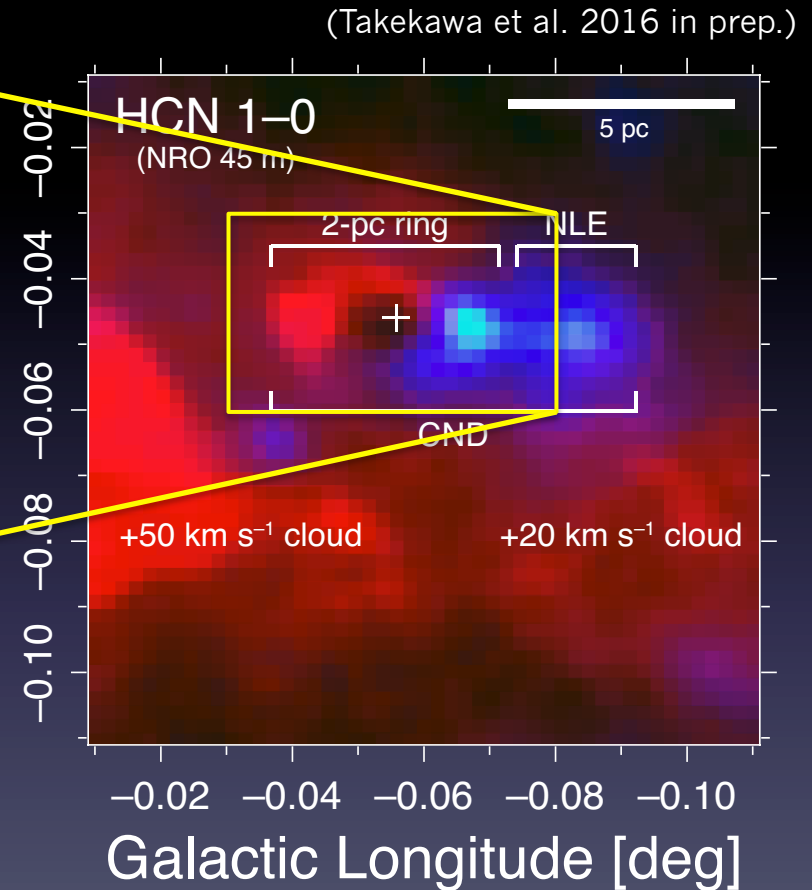
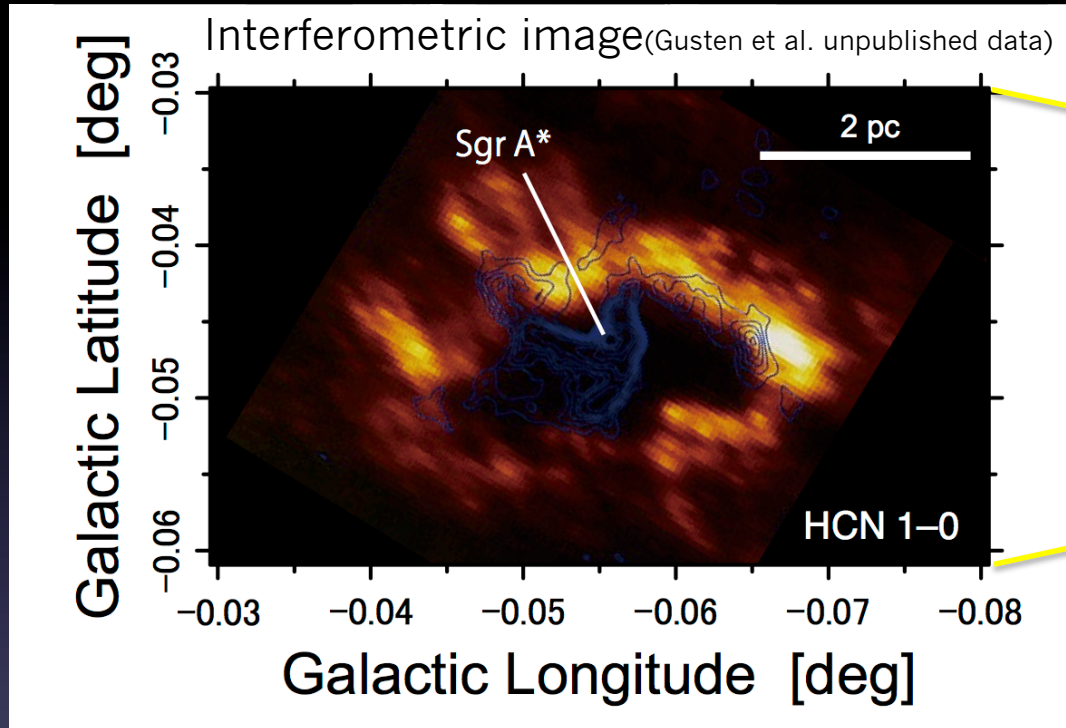
**CND=2-pc ring+NLE**  
(NLE: Negative longitude extension)

Key object for feeding and feedback

(Takekawa et al. 2016 in prep.)



# Circumnuclear Disk

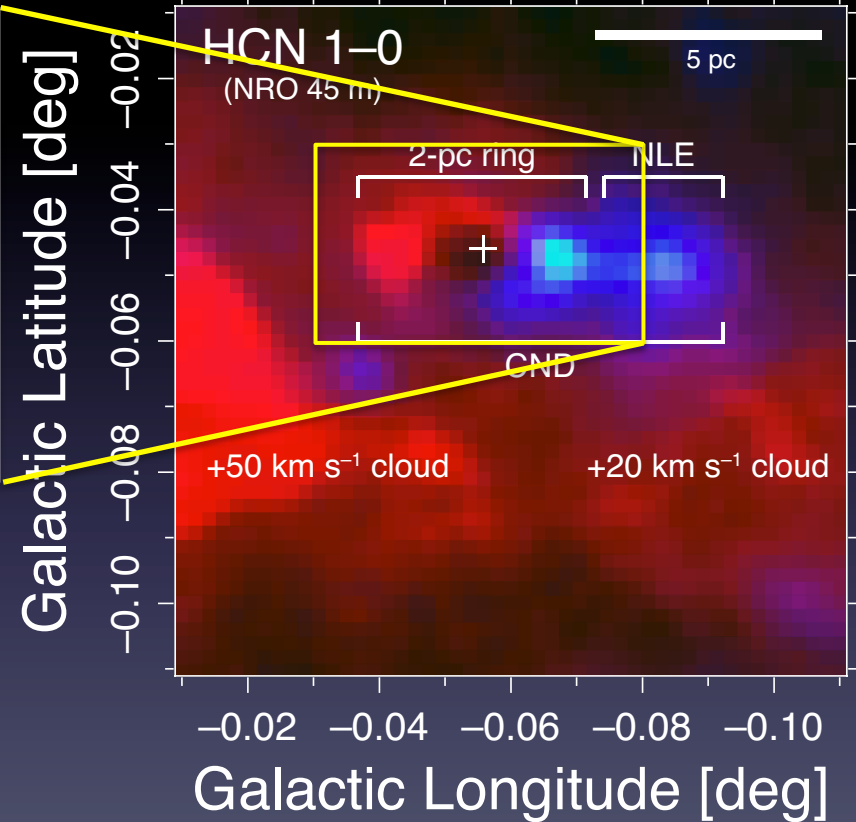
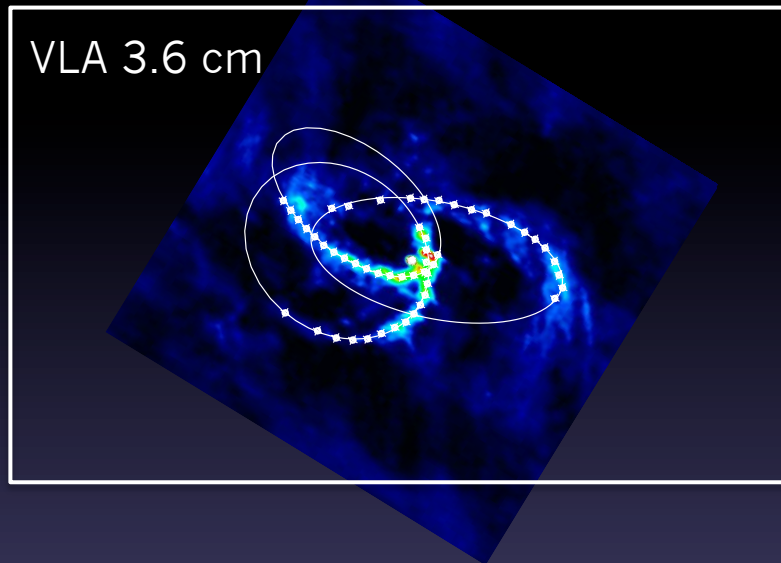


CND=2-pc ring+NLE  
(NLE: Negative longitude extension)

Key object for feeding and feedback

# Minispiral

(Takekawa et al. 2016 in prep.)

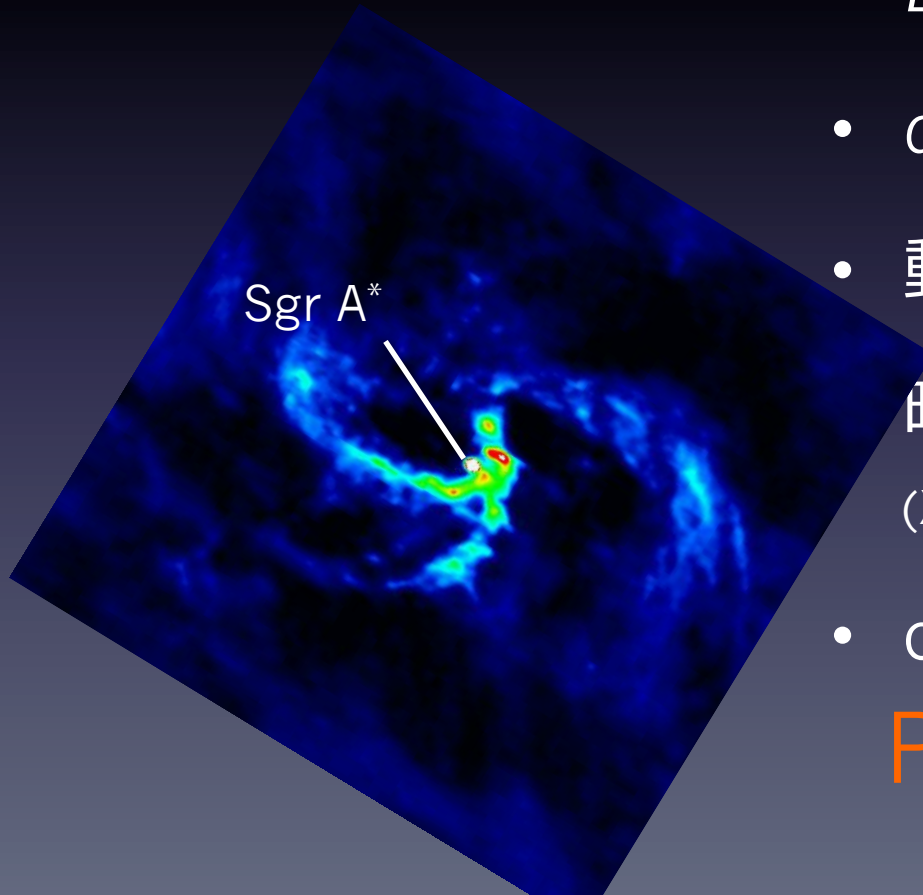


2-pc ringの内側を埋める  
ように電離ガスが分布

3つのケプラー軌道に沿って運動 (Zhao et al. 2009)

# Our Galactic Nucleus

The nearest  
galactic nucleus



- $M_{\text{Sgr A}^*} \sim 4 \times 10^6 M_{\text{sun}}$
- $L_{\text{bol}} \sim 10^{36} \text{ erg/s}$
- $dM_{\text{BH}}/dt < 10^{-7} M_{\text{sun}}/\text{yr}$
- 動かない

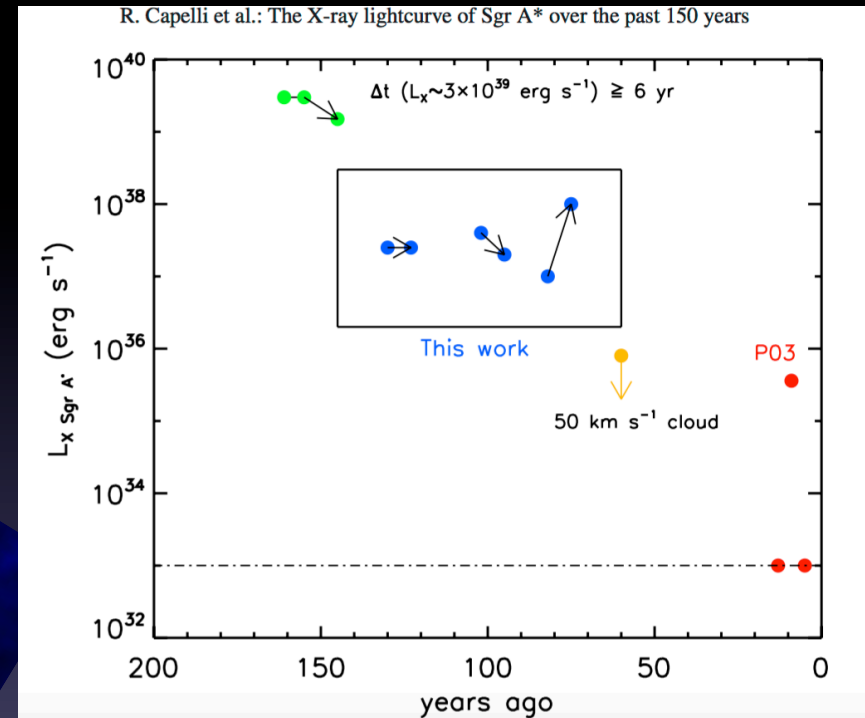
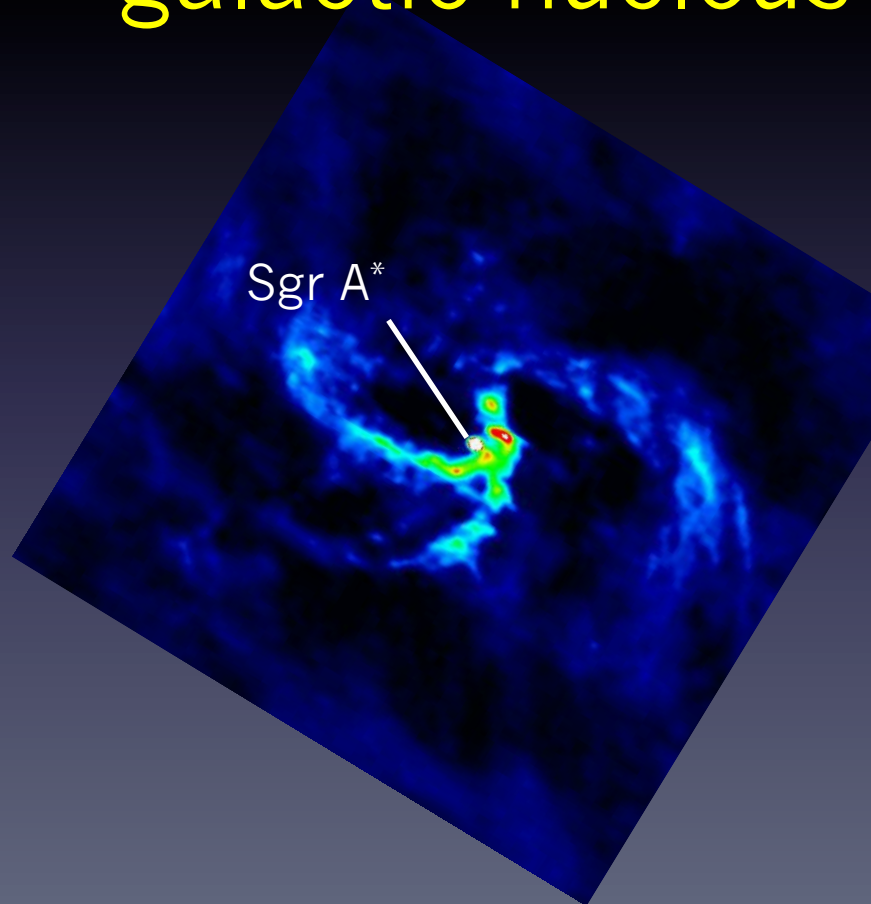
時々 flare up

(X-ray/IR/sub-mm/mm)

- cm波では変動しない
- Past activities?

# Our Galactic Nucleus

The nearest  
galactic nucleus

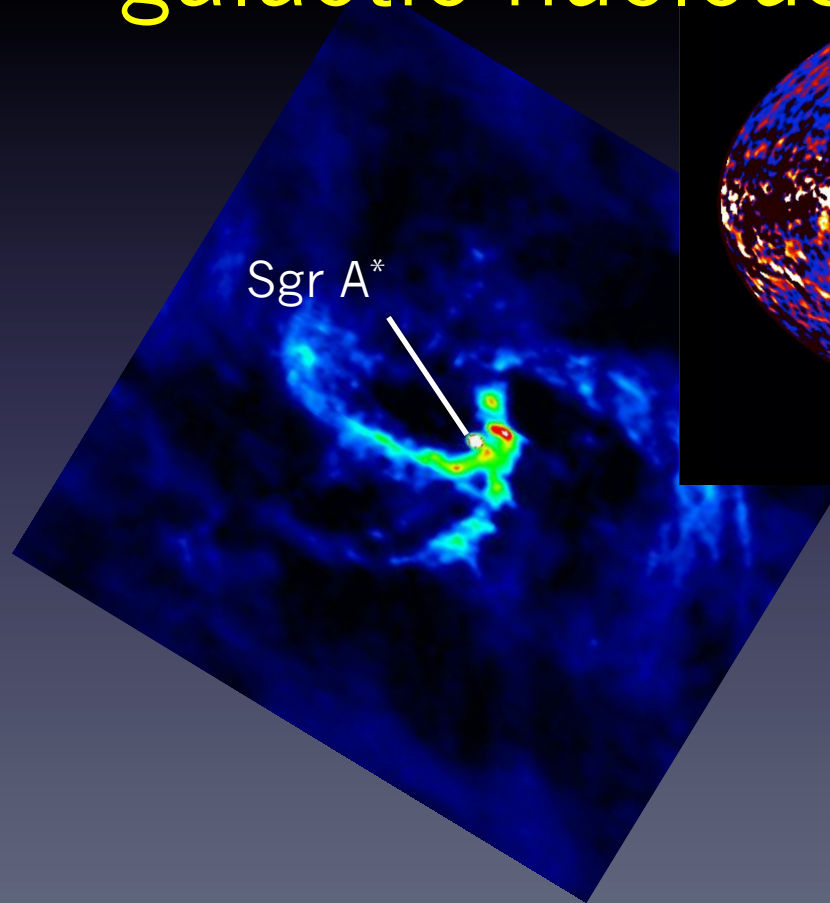


by X-ray reflection nebulae  
(e.g. Koyama et al. 1995)

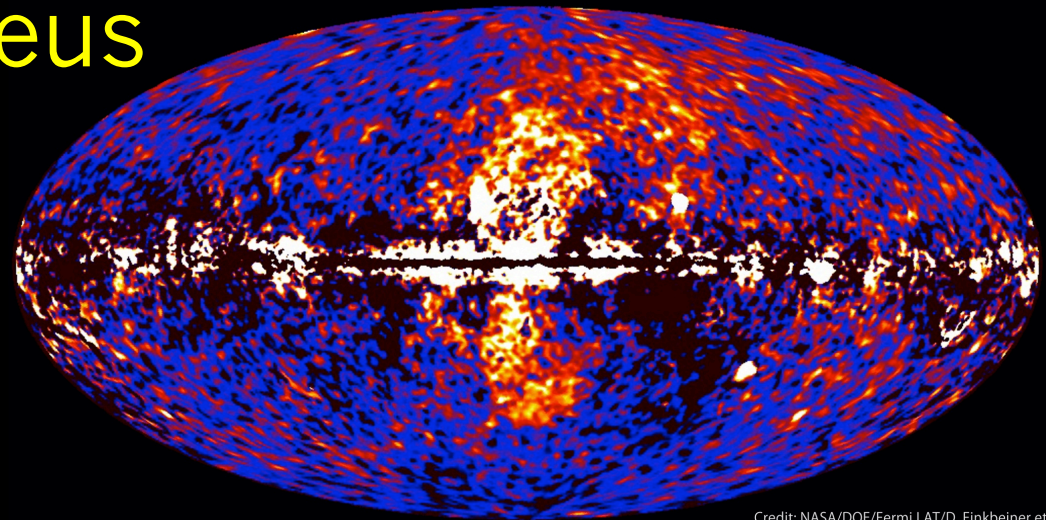
Past activities?

# Our Galactic Nucleus

The nearest  
galactic nucleus



Fermi data reveal giant gamma-ray bubbles



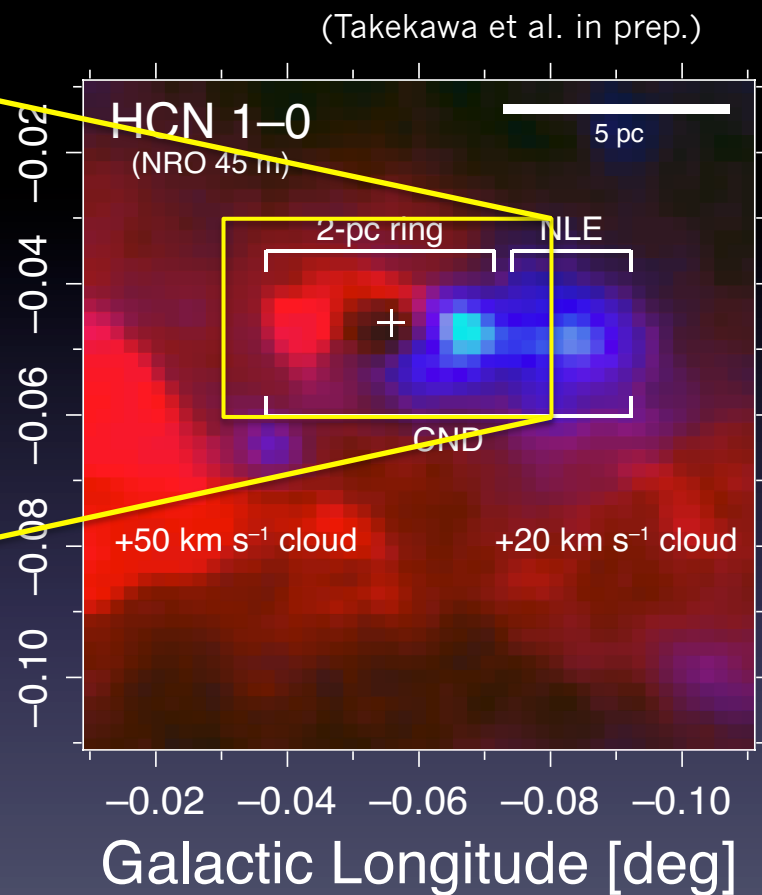
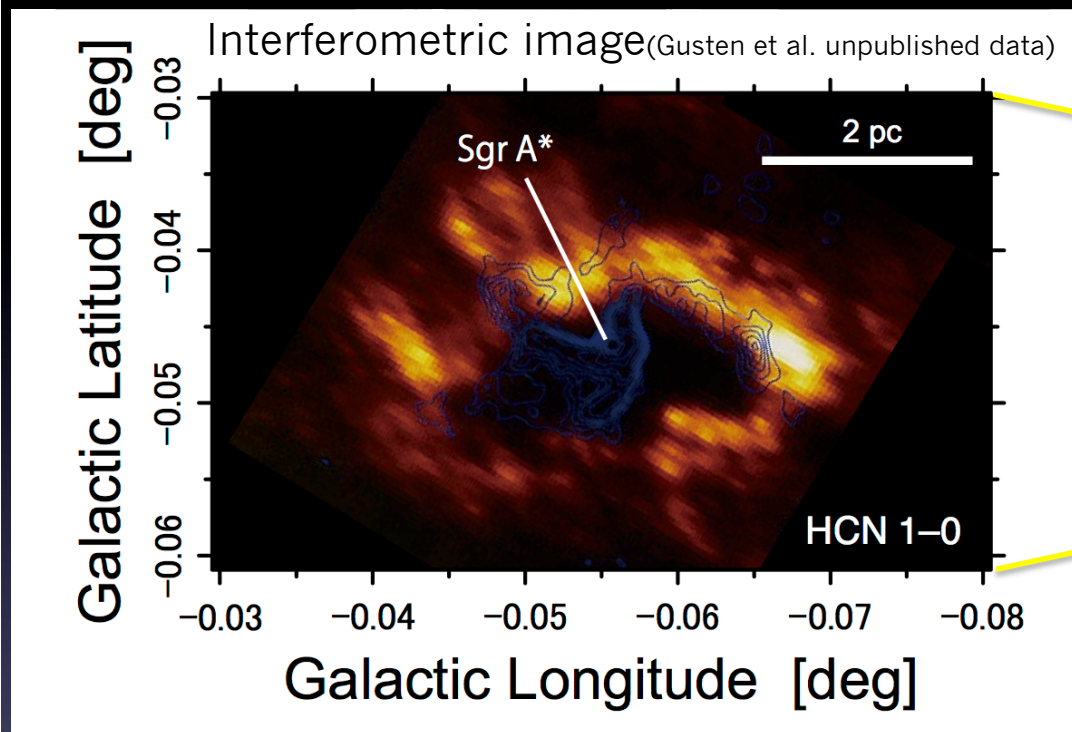
Fermi bubbles  
(e.g. Su et al. 2010)

Past activities?



Our recent studies

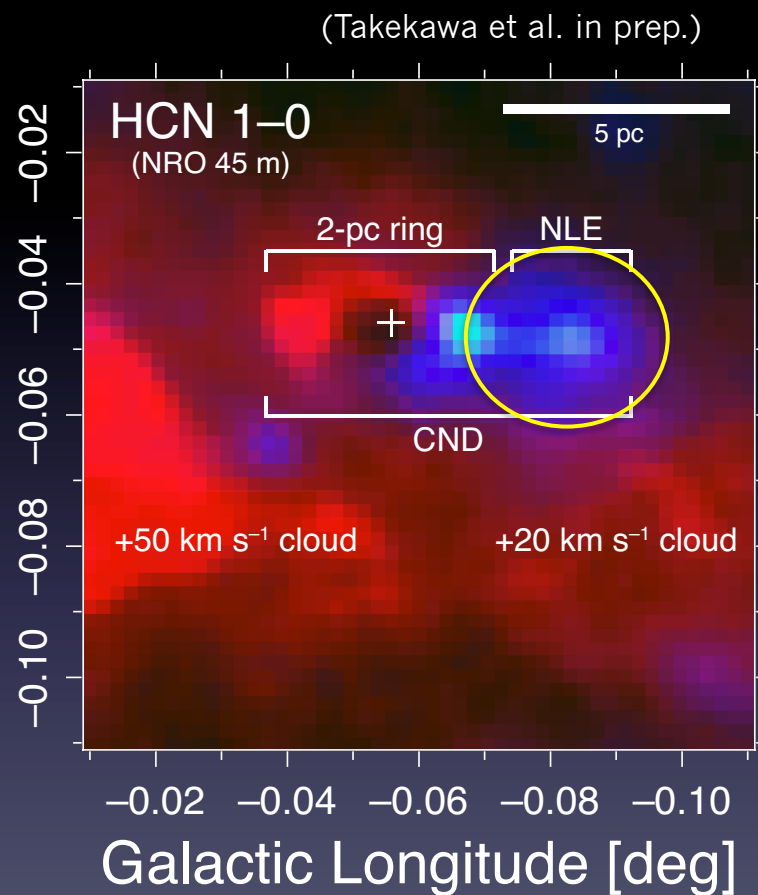
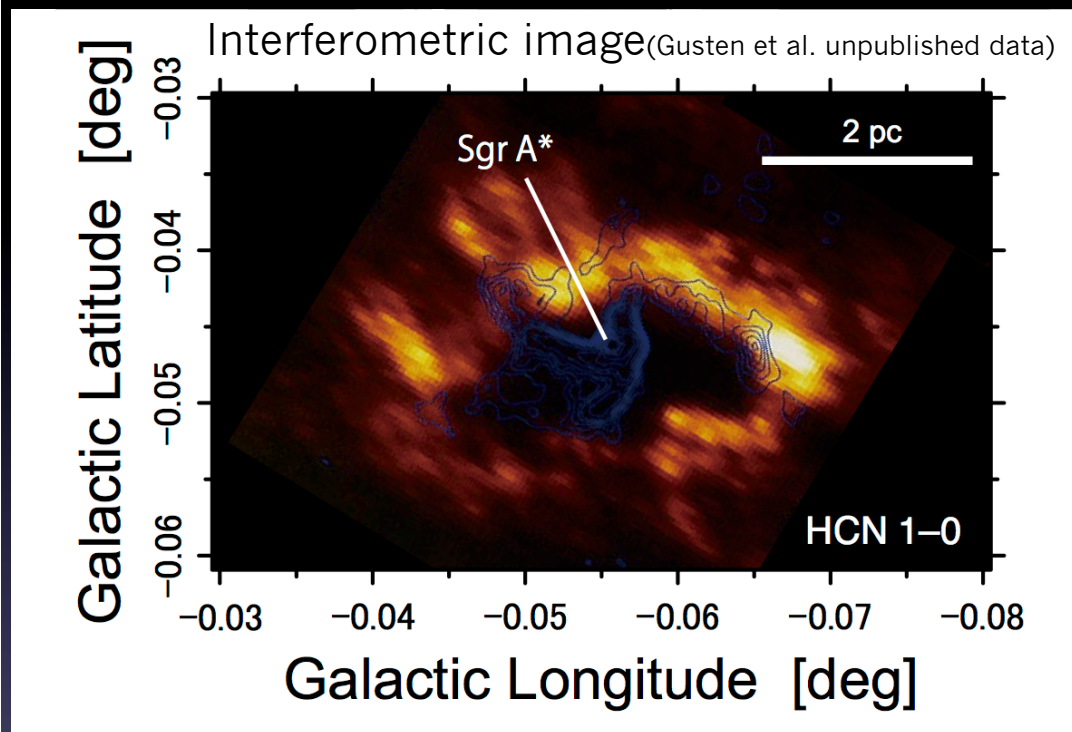
# Circumnuclear Disk



CND=2-pc ring+NLE  
(NLE: Negative longitude extension)

Key object for feeding and feedback

# Circumnuclear Disk



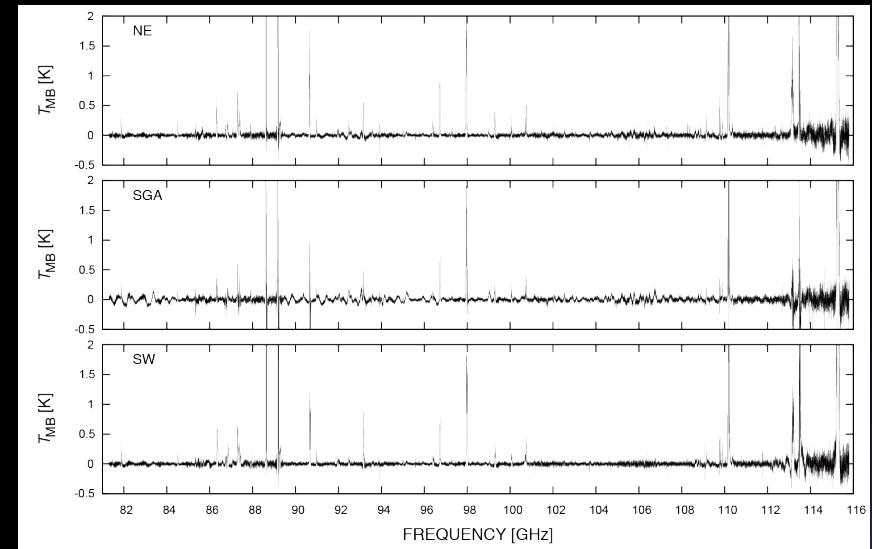
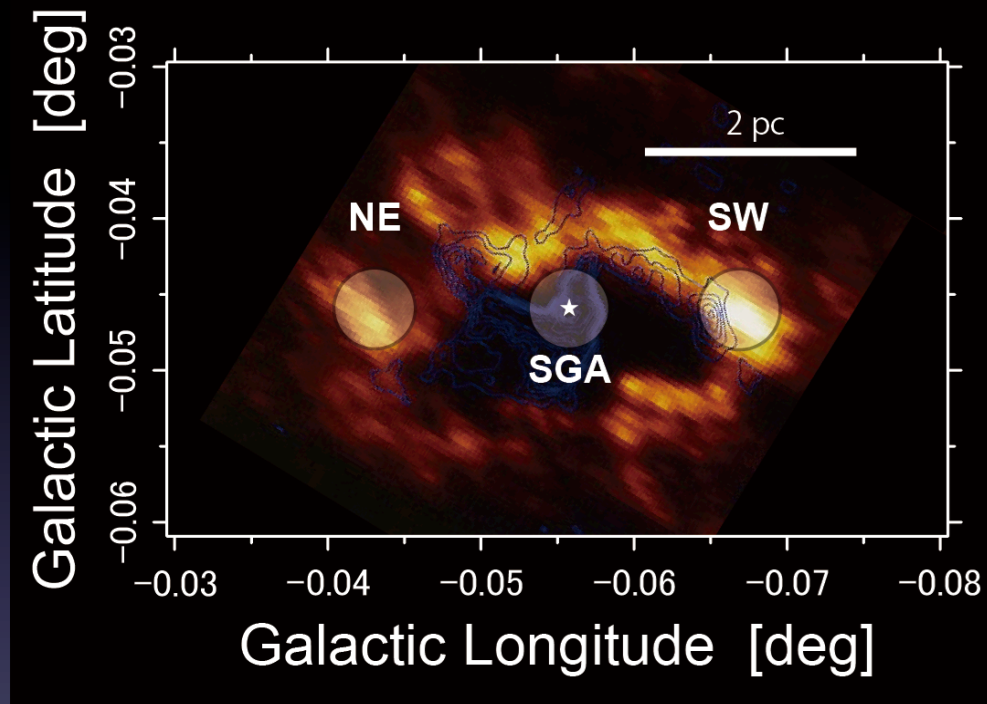
CND=2-pc ring+NLE

(NLE: Negative longitude extension)

NLEはほとんど無視されている  
(missing flux故)

# Line surveys toward the CND

(Takekawa et al. 2014)



3 mm band (81–116 GHz)  
with NRO 45 m

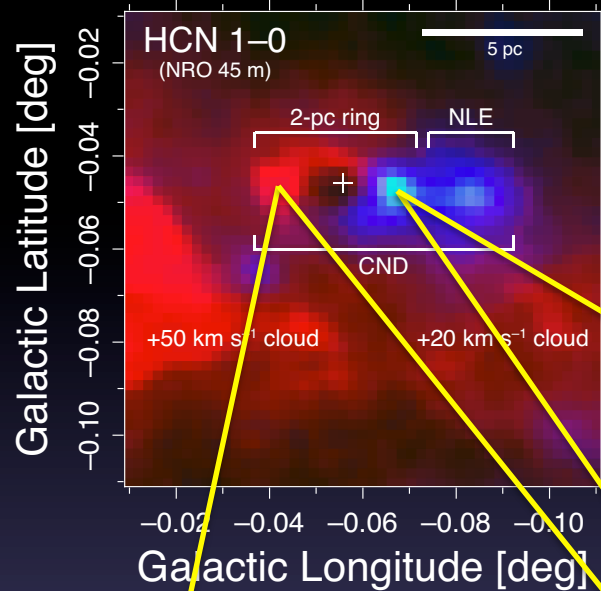
- CNDの化学組成を調べる  
(CND tracer を探す)

30分子種  
50輝線検出

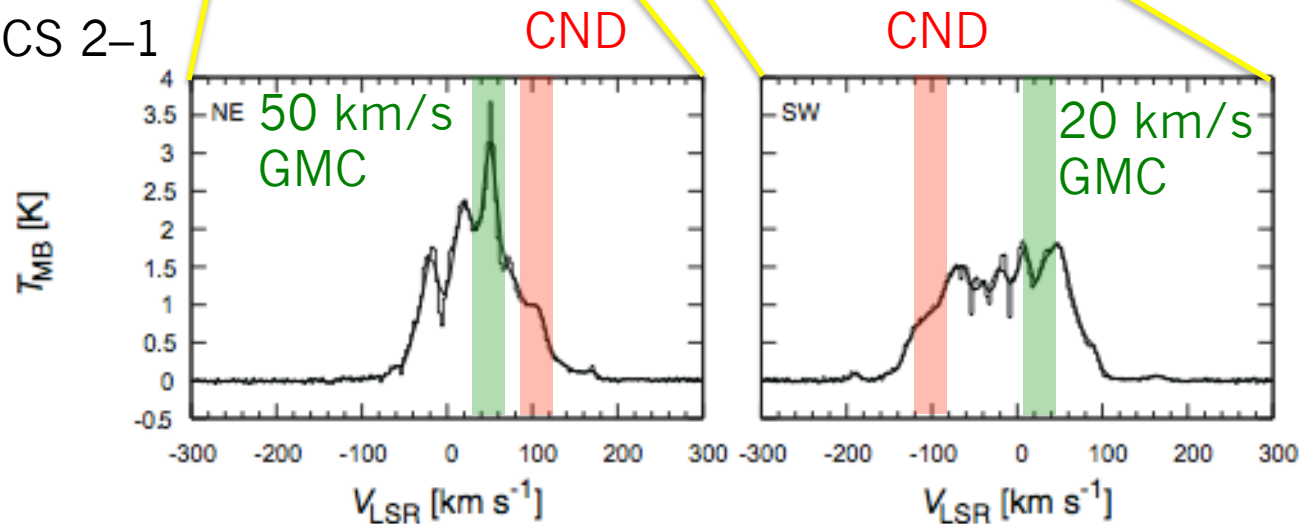
# Line Classification

(Takekawa et al. 2014)

GMCに対するCNDの相対強度  
によりlineを3タイプに分類



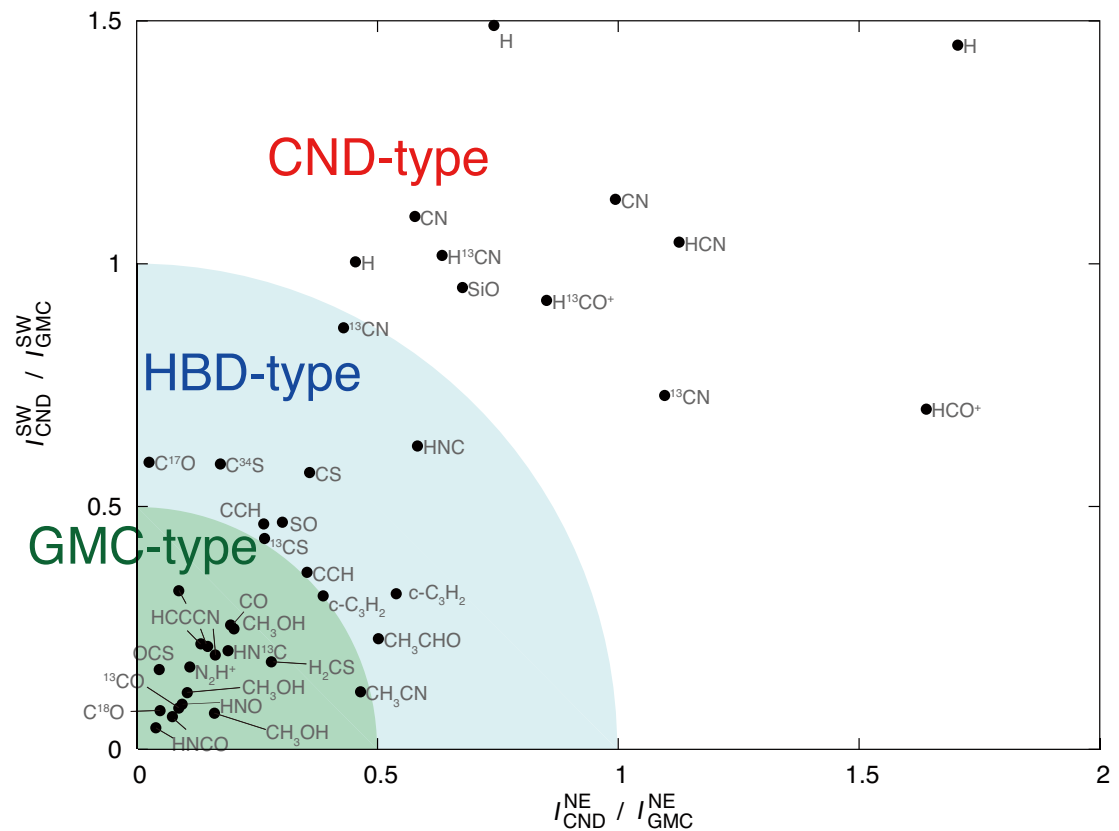
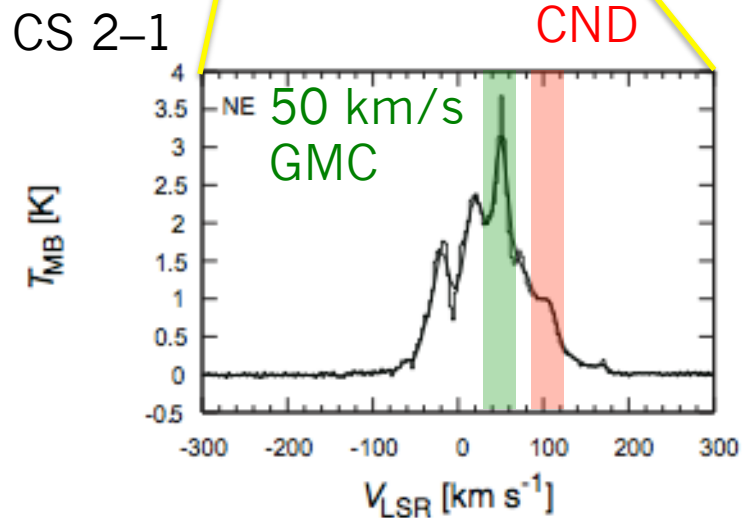
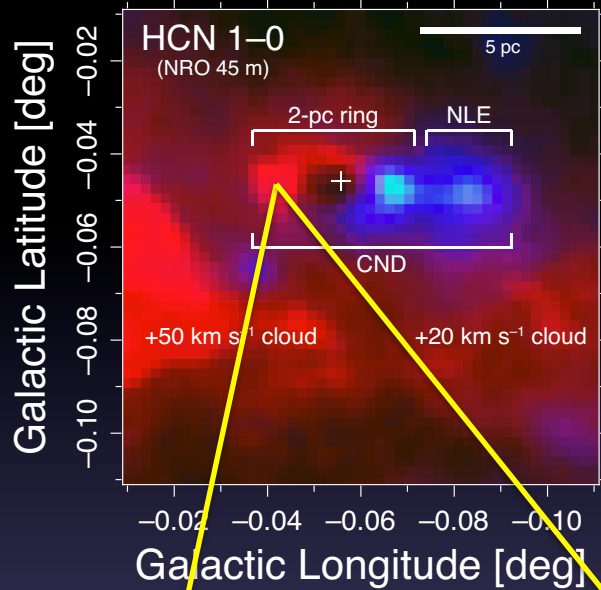
CS 2-1



# Line Classification

(Takekawa et al. 2014)

## GMCに対するCNDの相対強度によりlineを3タイプに分類



# Line Classification

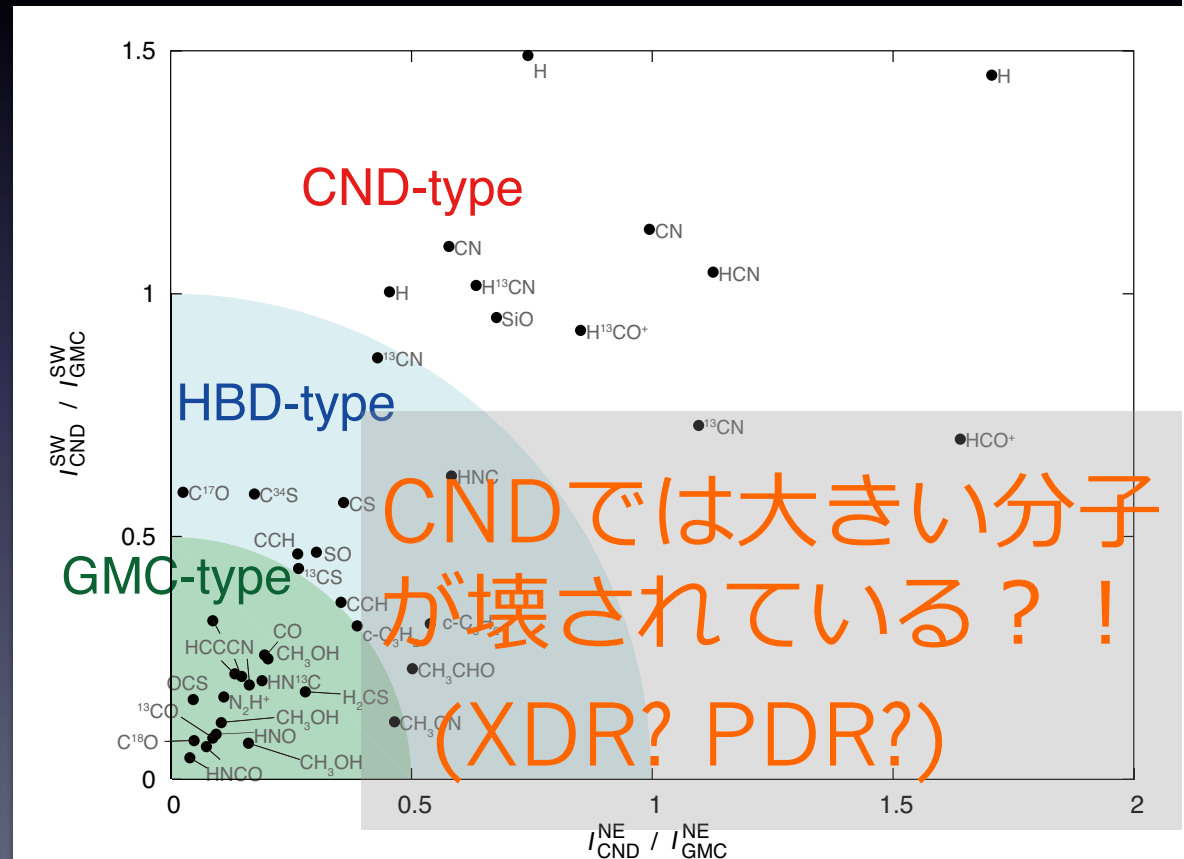
(Takekawa et al. 2014)

**CND-type**  
HCN, HCO<sup>+</sup>  
SiO, CN

**Hybrid-type**  
CS, CCH  
SO, HNC

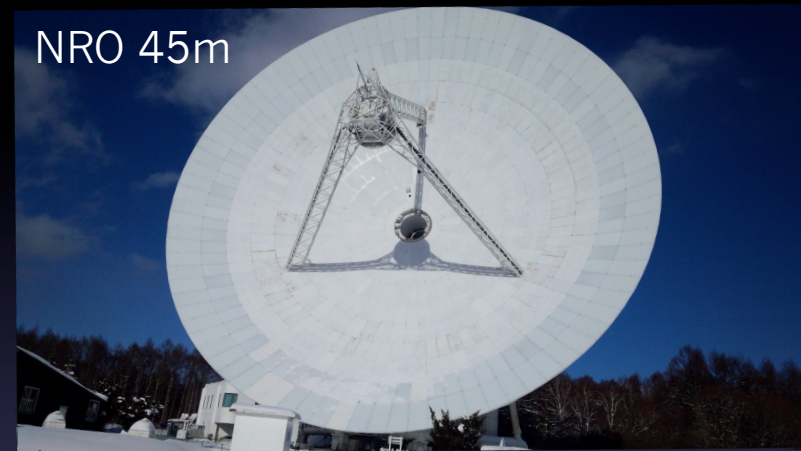
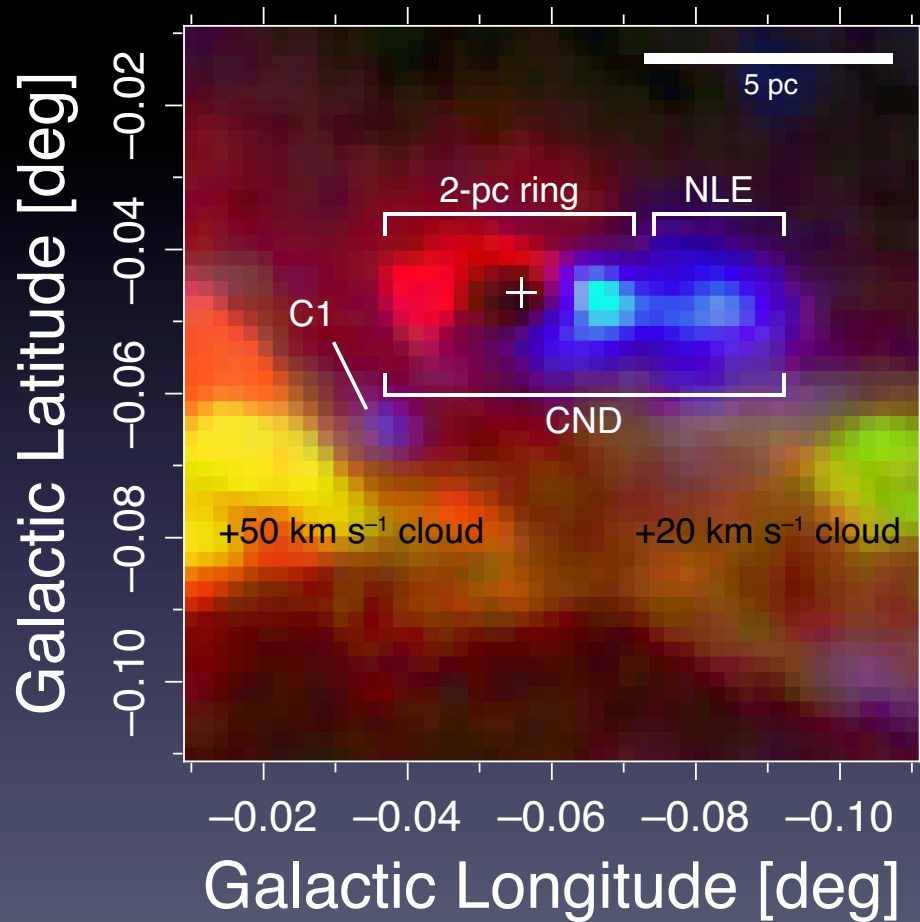
**GMC-type**  
HCCCN  
CH<sub>3</sub>OH, HNCO

GMCに対するCNDの相対強度  
によりlineを3タイプに分類



# OTF mapping of the CND

(Takekawa et al. in prep.)



Target lines

HCN 1-0, HCO<sup>+</sup> 1-0, SiO 2-1  
CS 2-1, HC<sub>3</sub>N 11-10 etc...

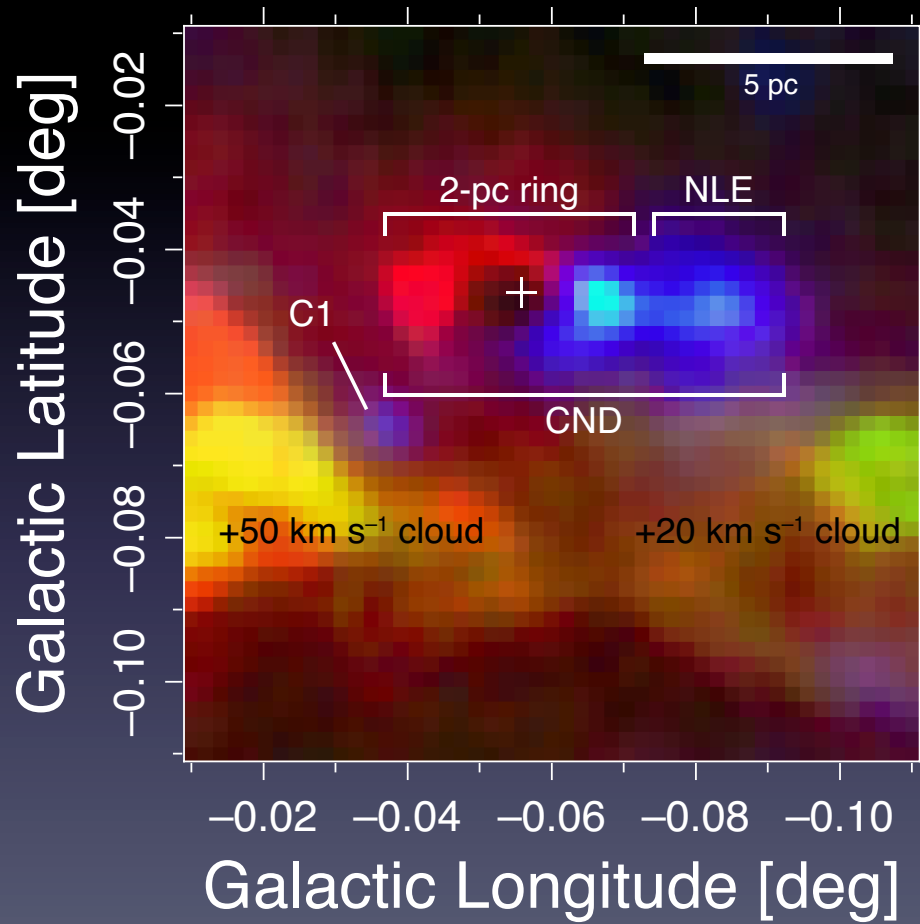
Mapping range = 6' × 6'  
Beamsize ~20'' (~0.8 pc)

赤: HCN 1-0 redshift  
青: HCN 1-0 blueshift  
緑: HC<sub>3</sub>N 11-10 (GMC-type)

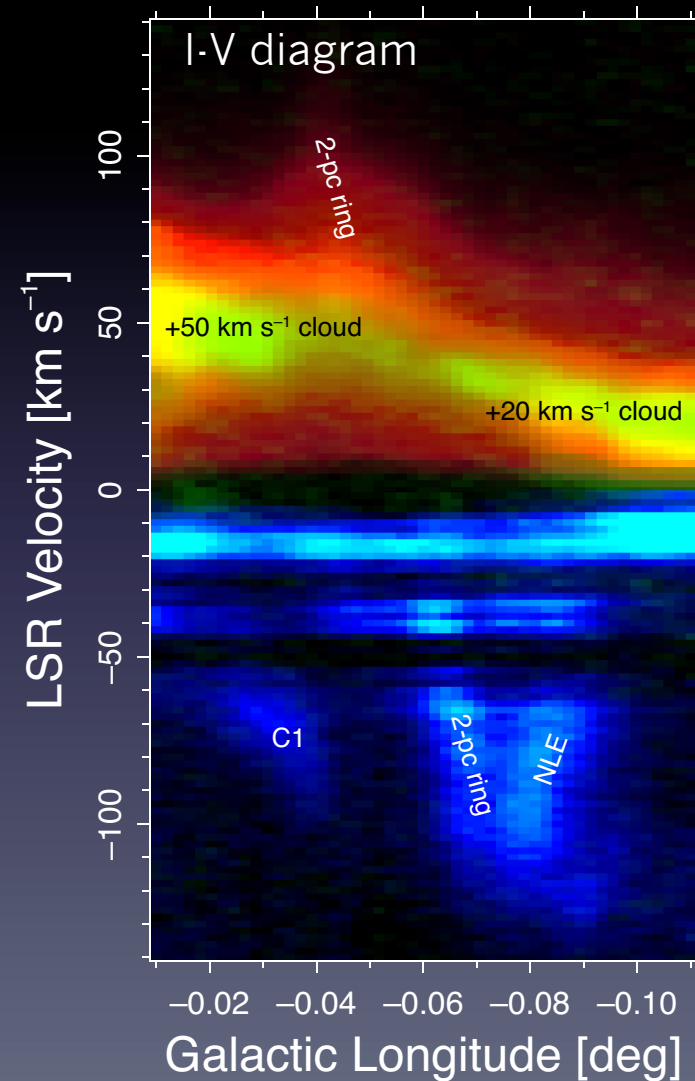


# OTF mapping of the CND

(Takekawa et al. in prep.)

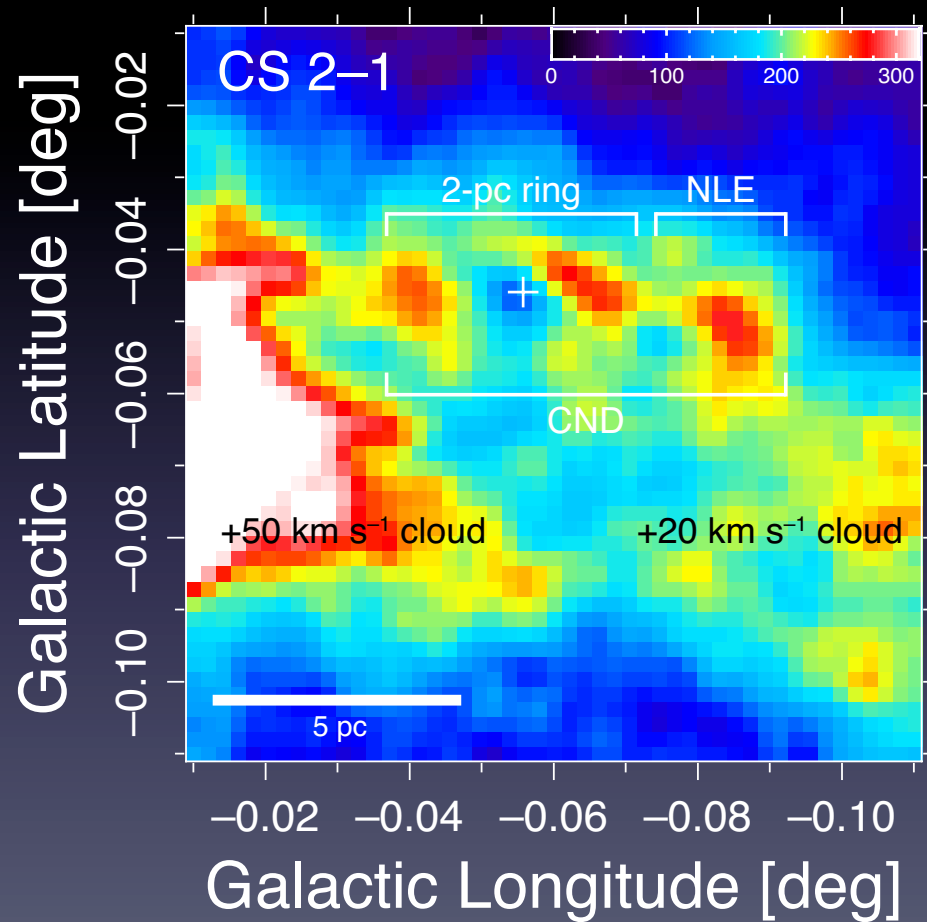


赤: HCN 1-0 redshift  
青: HCN 1-0 blueshift  
緑: HC<sub>3</sub>N 11-10 (GMC-type)

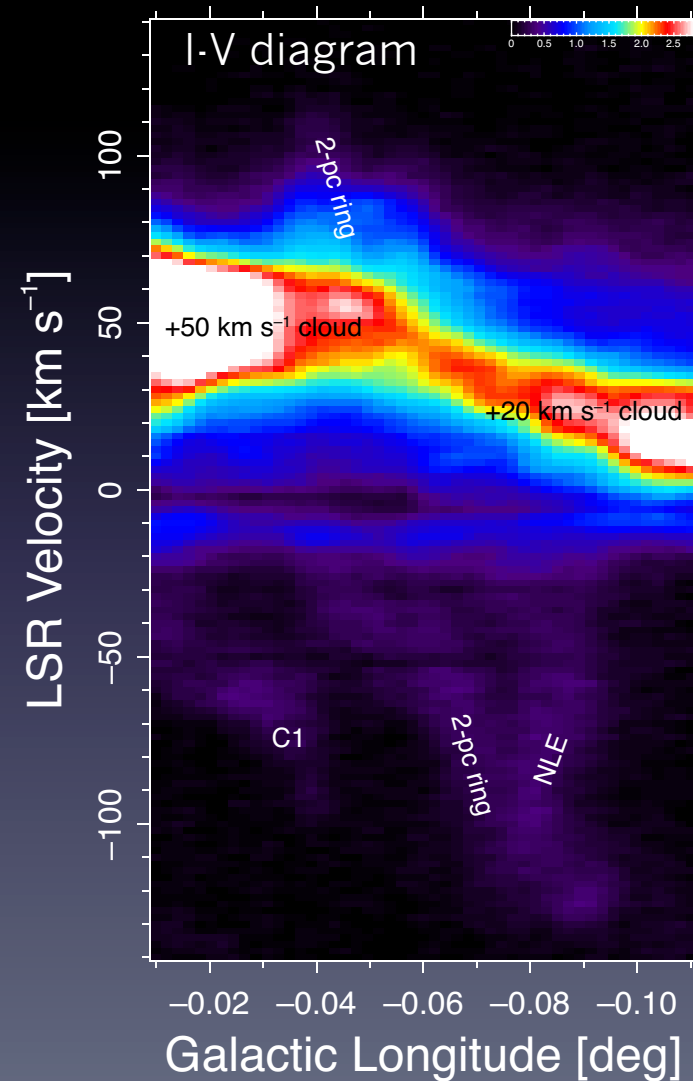


# OTF mapping of the CND

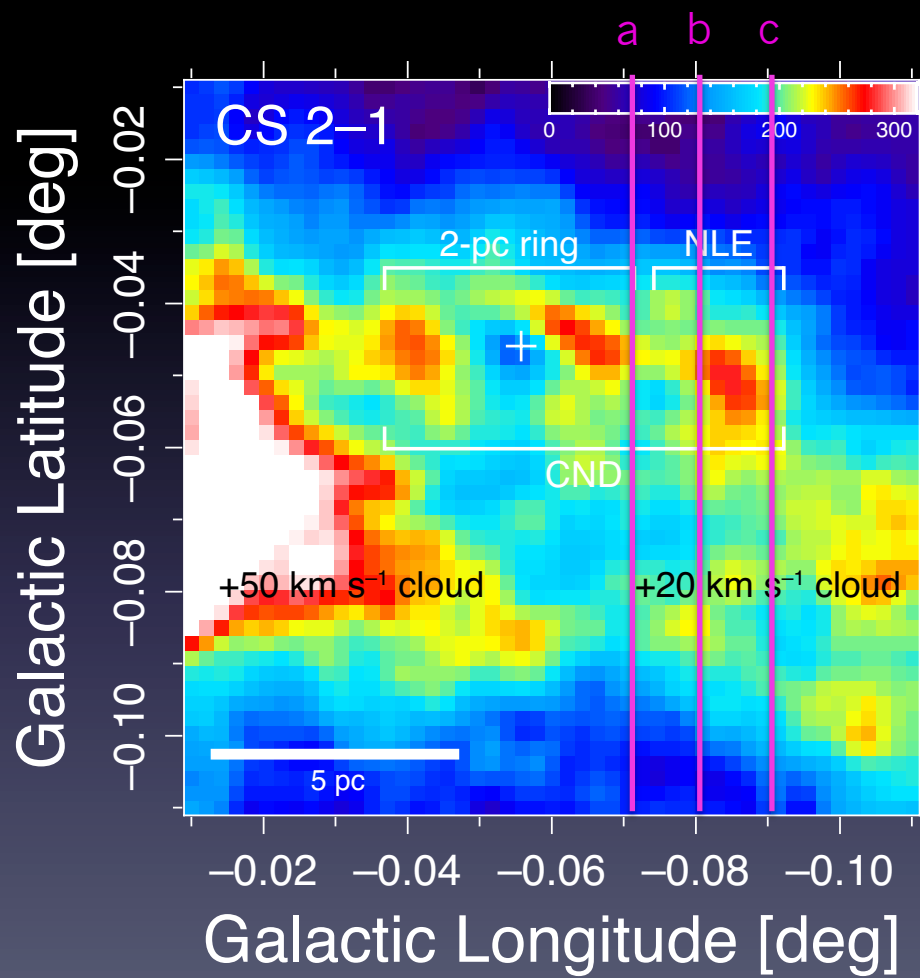
(Takekawa et al. in prep.)



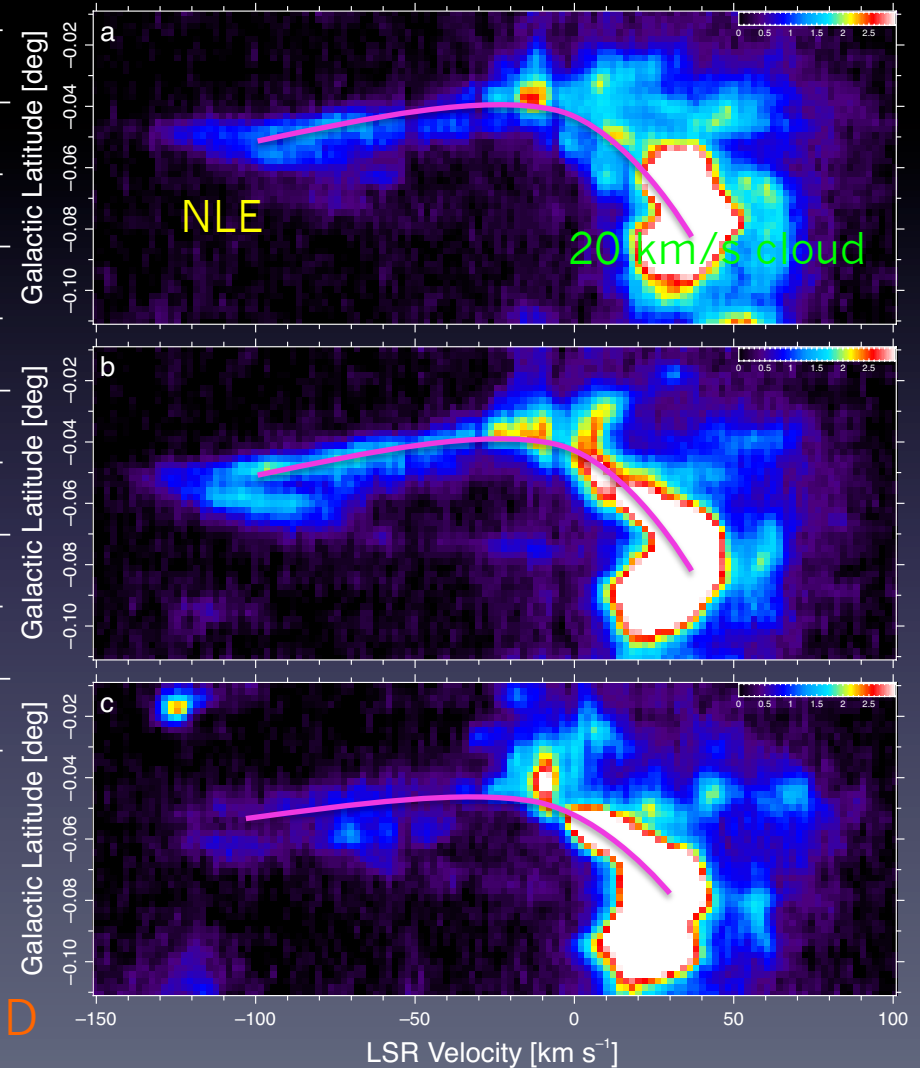
CSはHCN, HCO<sup>+</sup>に比べて円盤部の吸収を受けにくい



# Discovery of the bridge

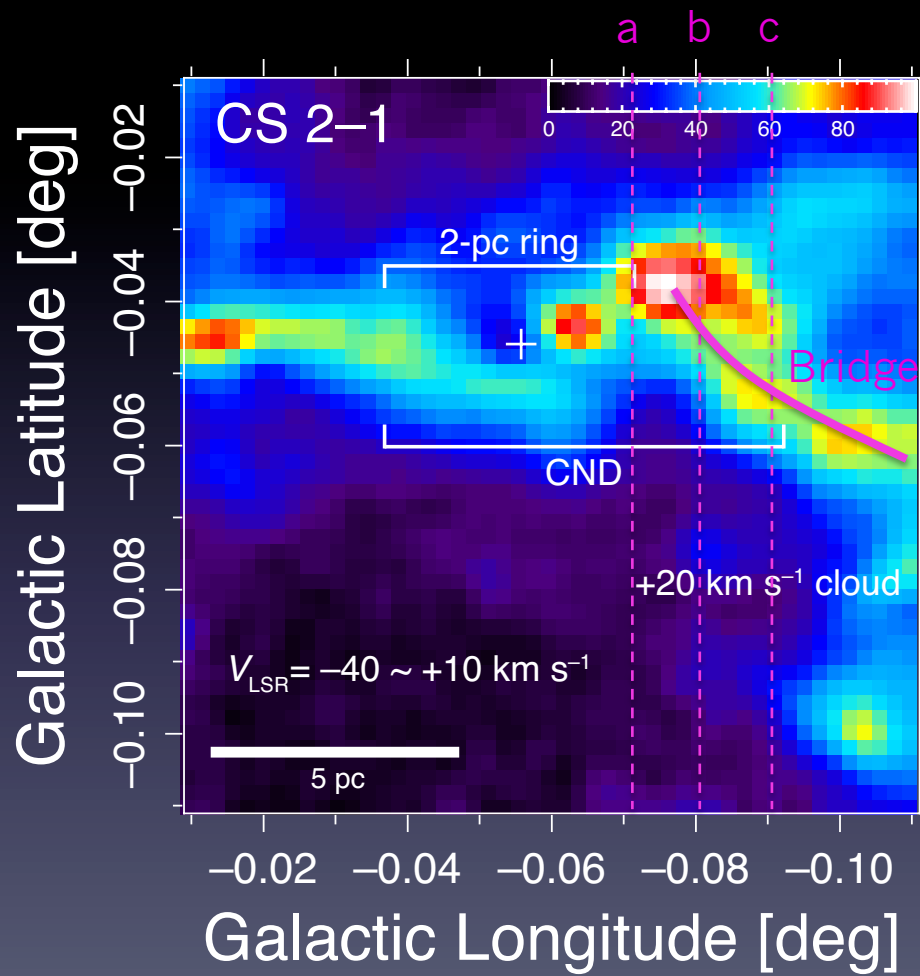


b-V diagrams (Takekawa et al. in prep.)

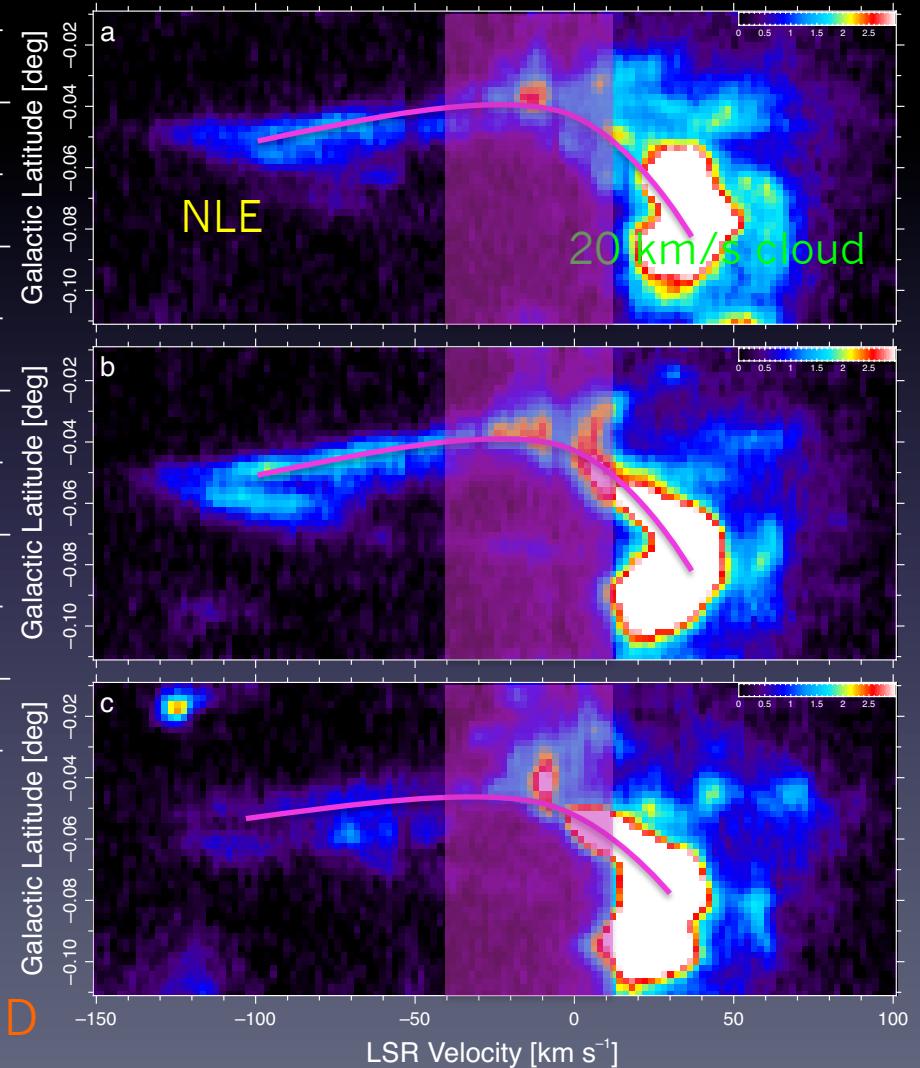


Bridge between the 20k cloud and the CND

# Discovery of the bridge



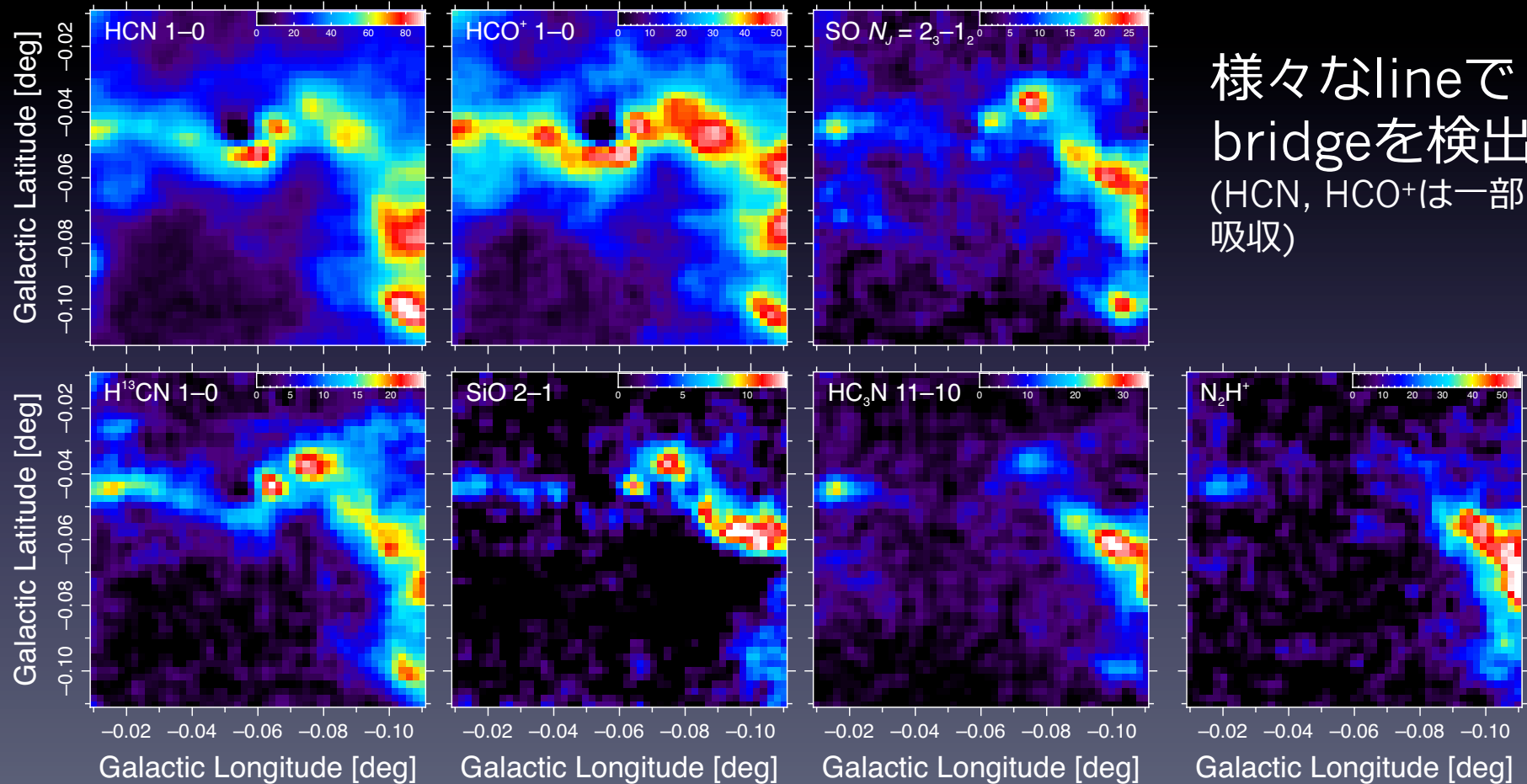
b-V diagrams (Takekawa et al. in prep.)



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# Discovery of the bridge

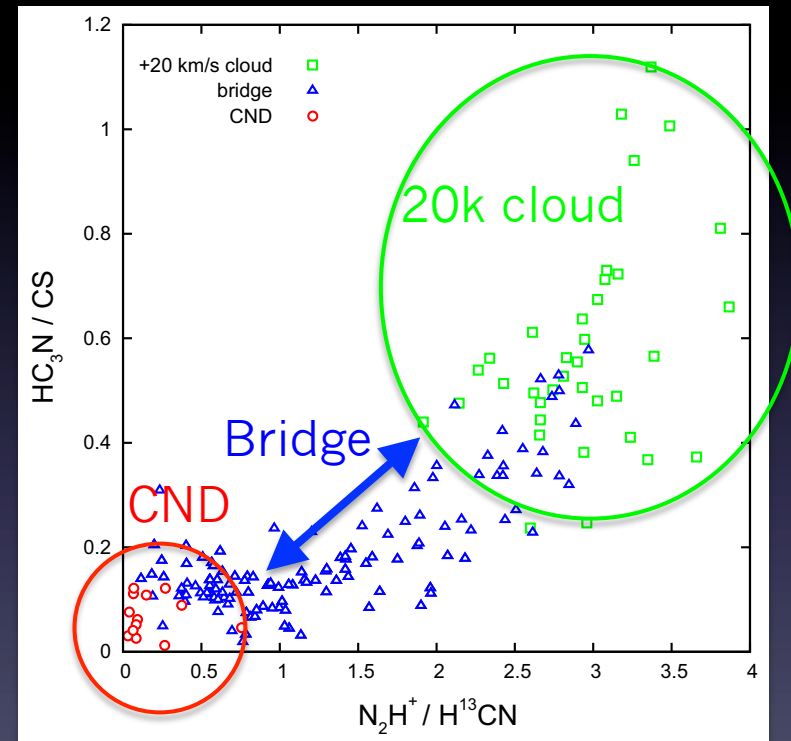
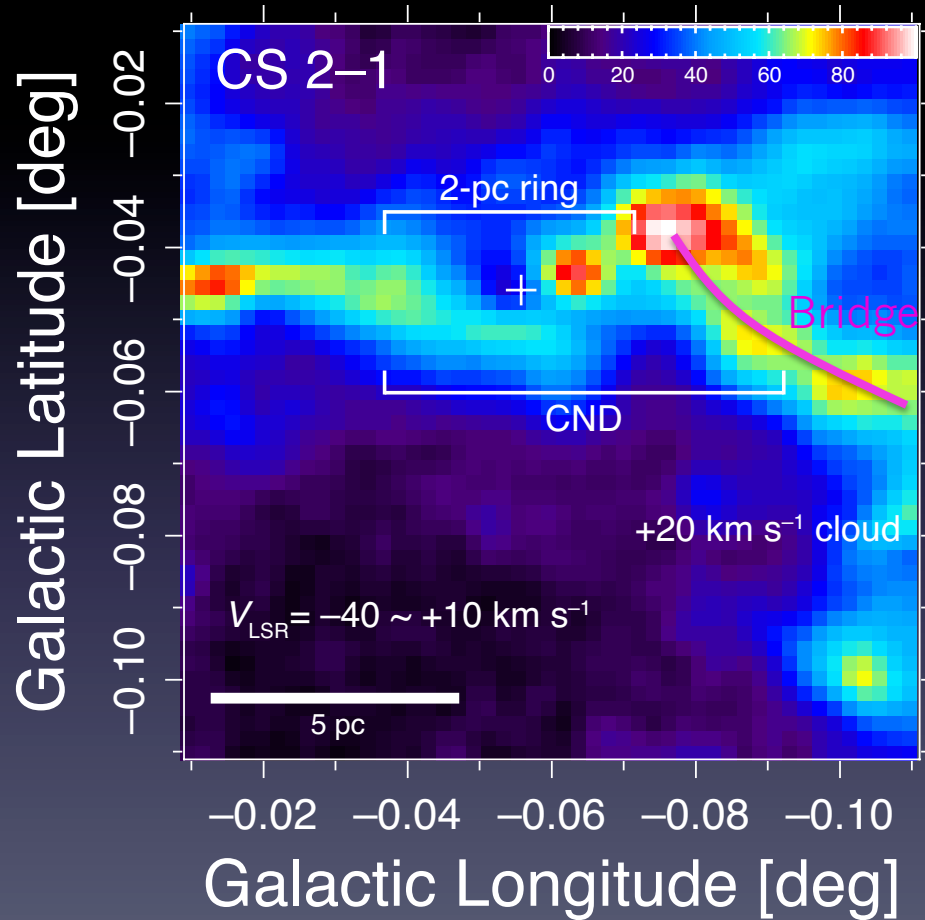
(Takekawa et al. in prep.)



様々なlineで  
bridgeを検出  
(HCN, HCO<sup>+</sup>は一部  
吸収)

# Discovery of the bridge

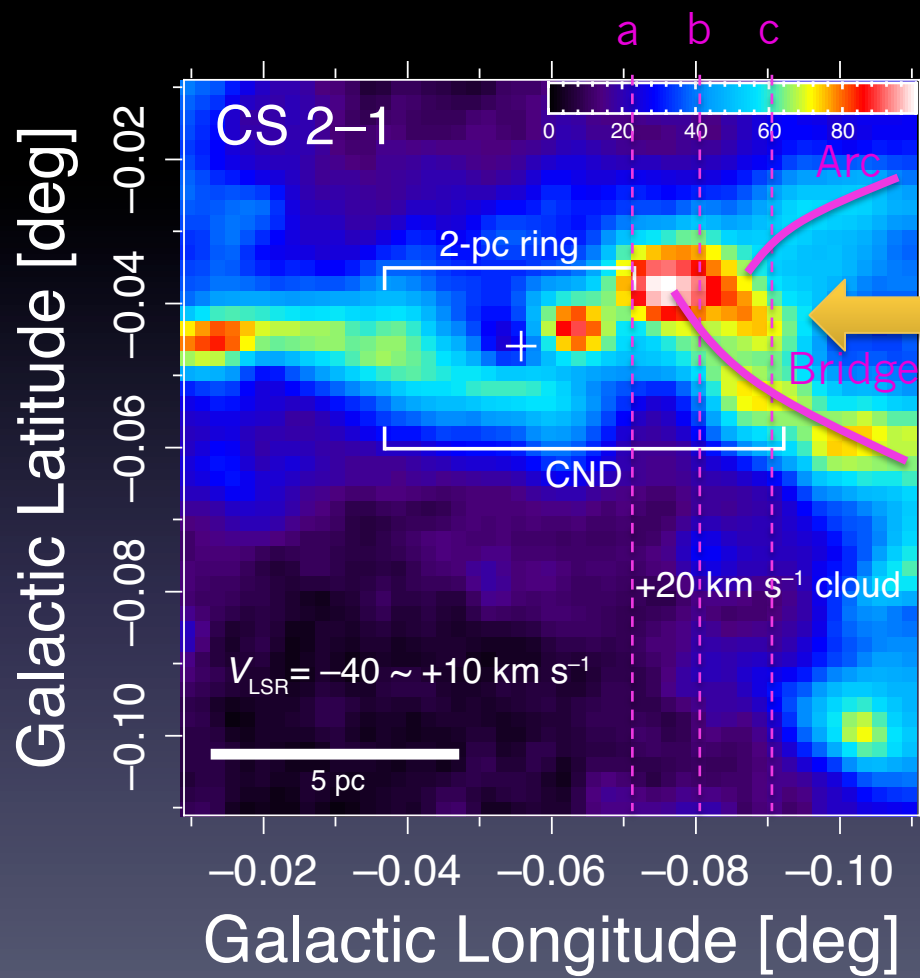
(Takekawa et al. in prep.)



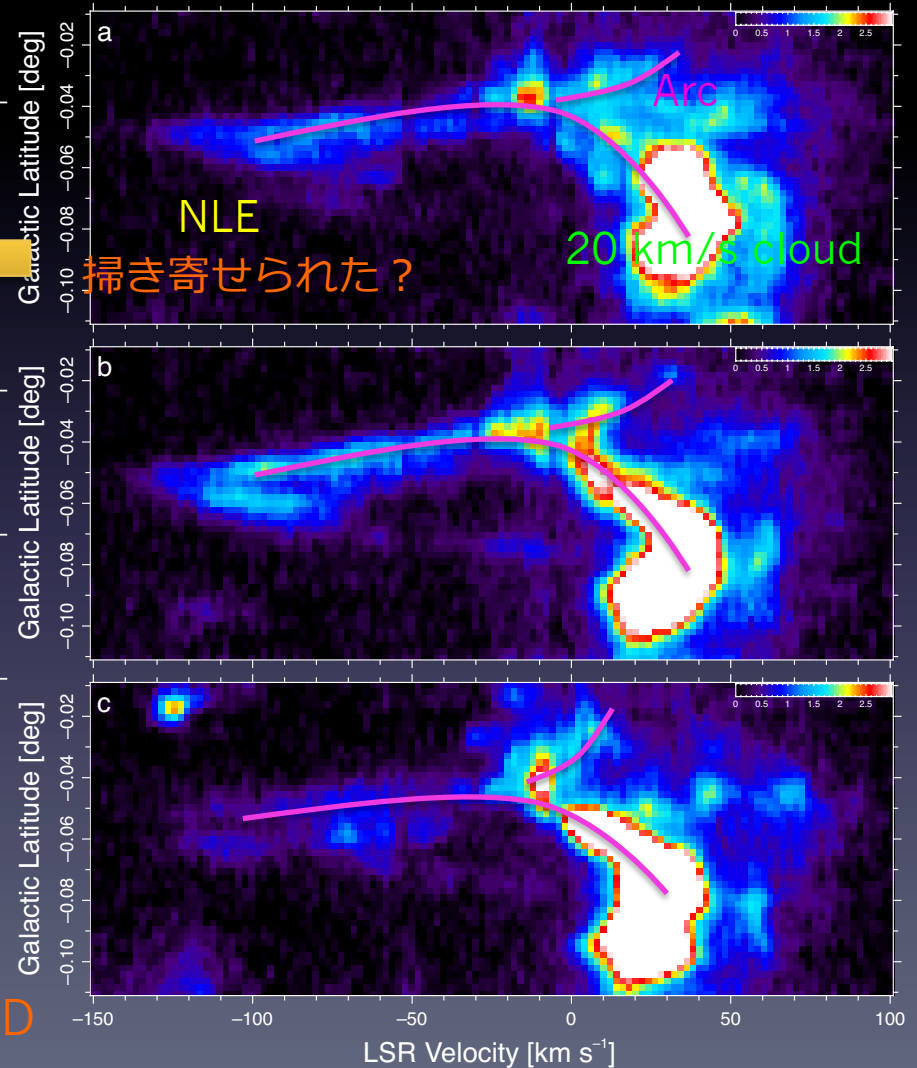
化学組成もCNDと  
20k cloudの中間

Bridge between the 20k cloud and the CND

# Formation scenario of the bridge

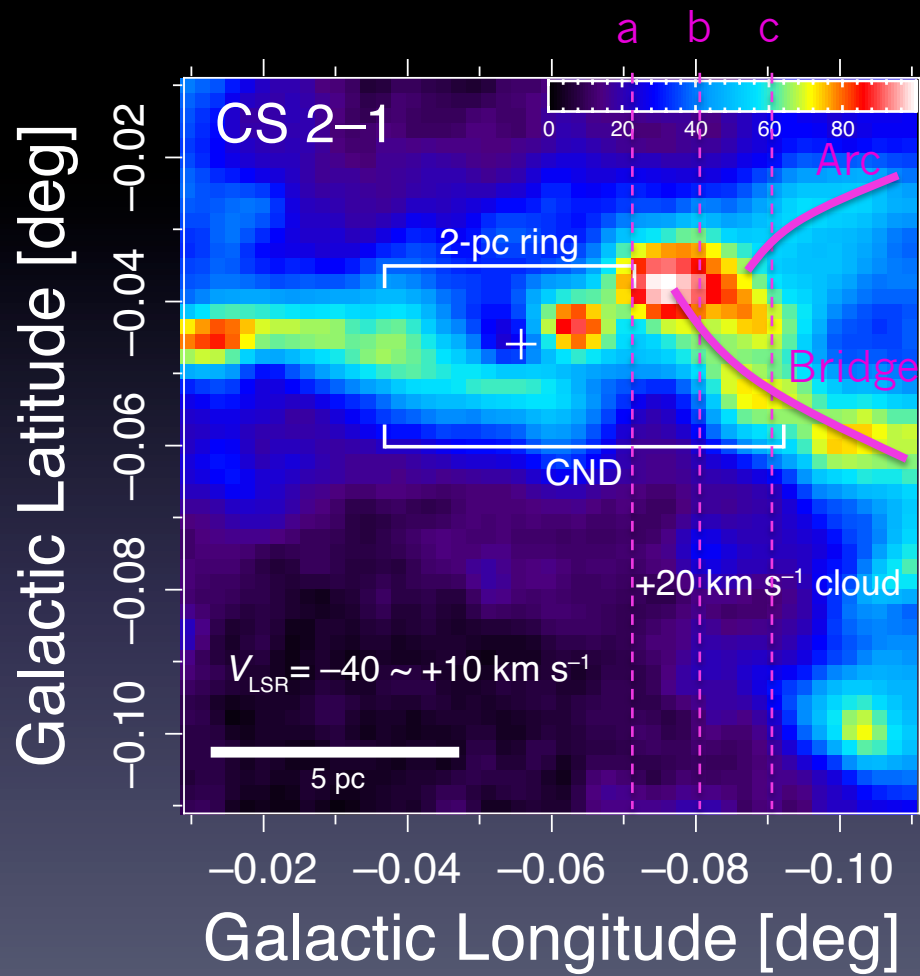


b-V diagrams (Takekawa et al. in prep.)

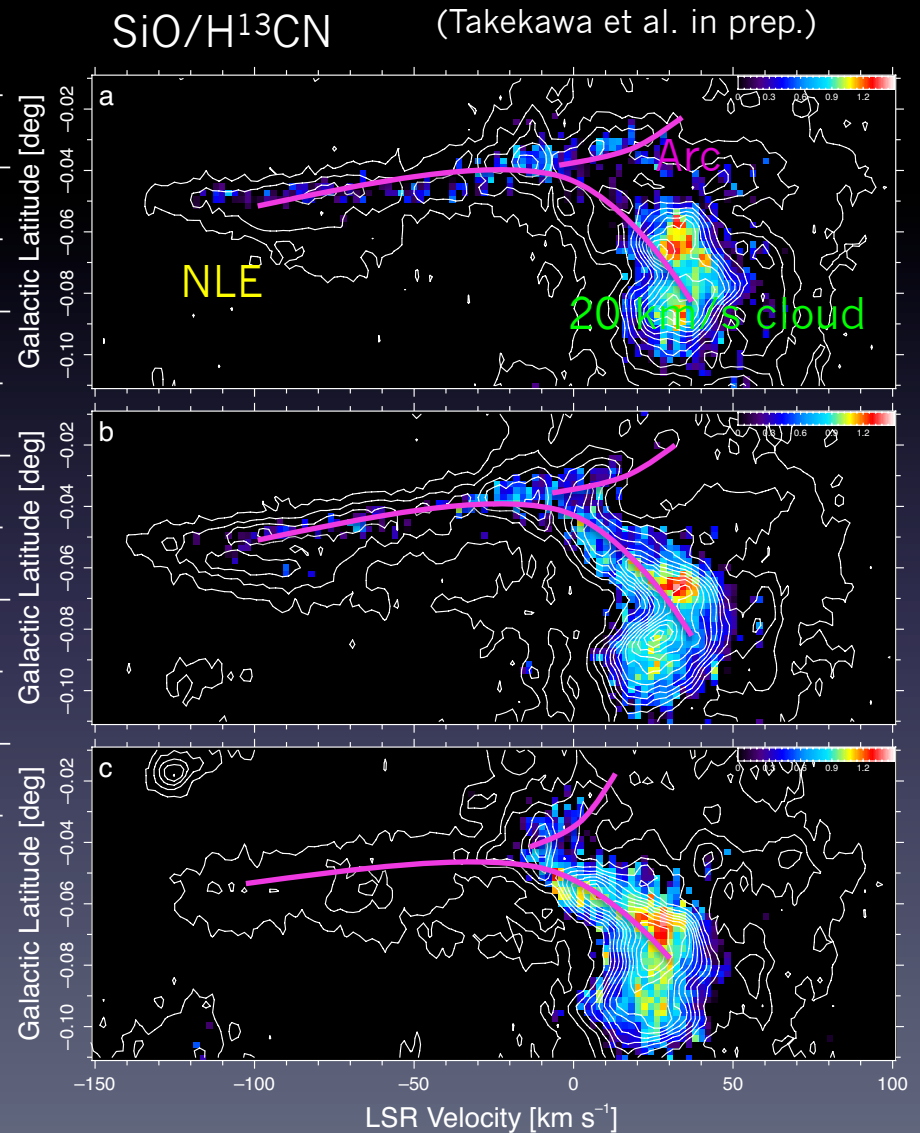


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# Formation scenario of the bridge

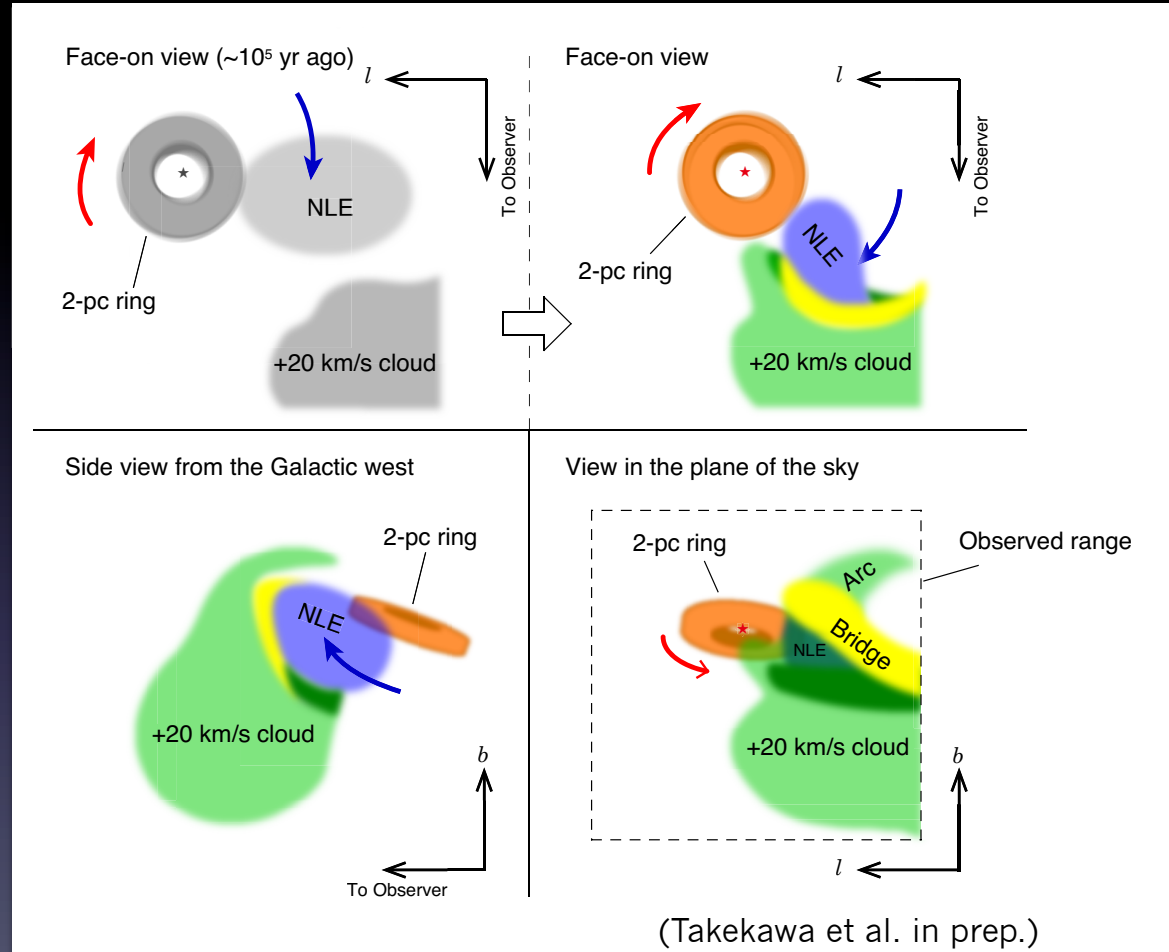
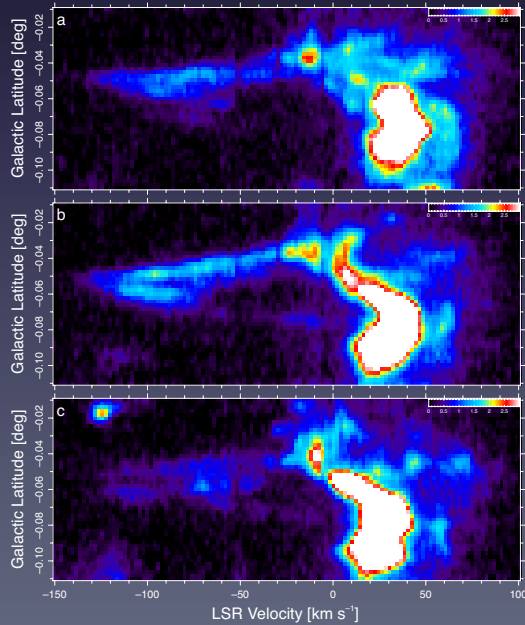
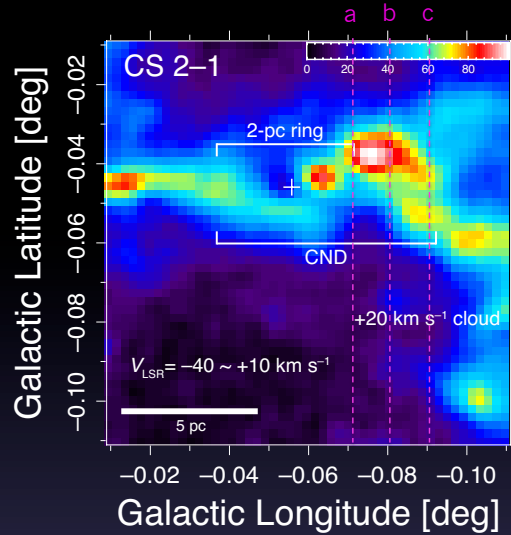


Shock in the root of the bridge?!



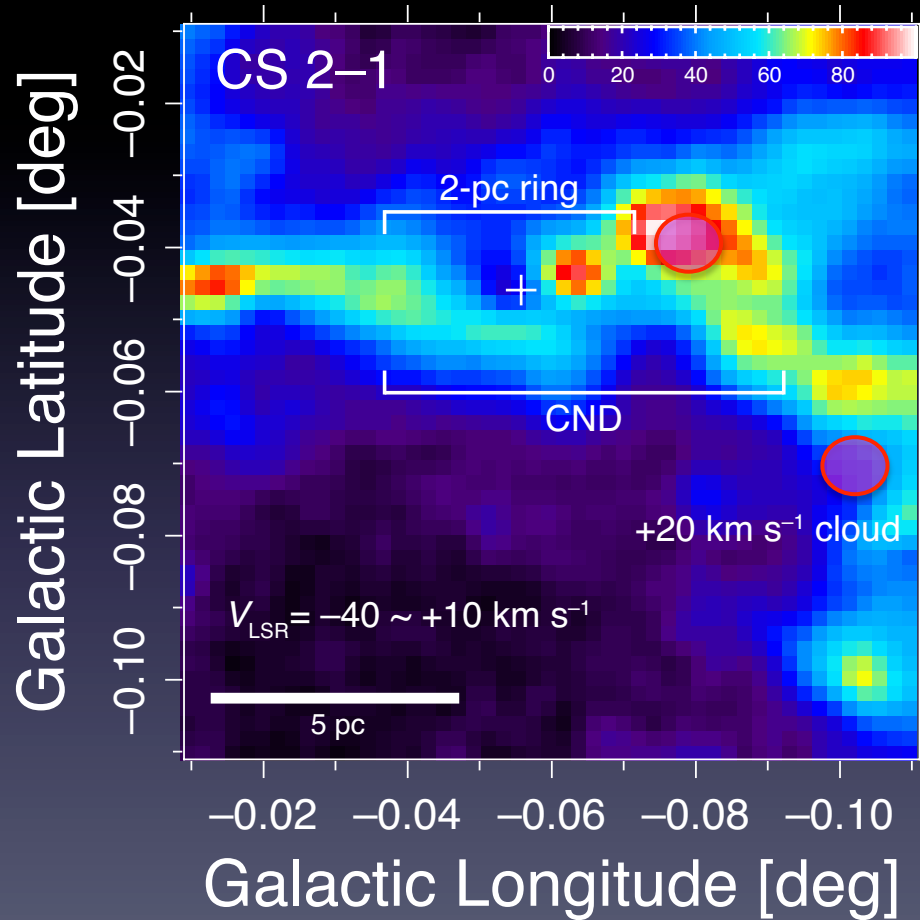


# Formation scenario of the bridge



一部ガスは衝突により  
角運動量を失い中心へ

# LVG analysis



1. HCN 1-0
2. H<sup>13</sup>CN 1-0
3. HCN 4-3
4. HCO<sup>+</sup> 1-0
5. HCO<sup>+</sup> 4-3

5輝線



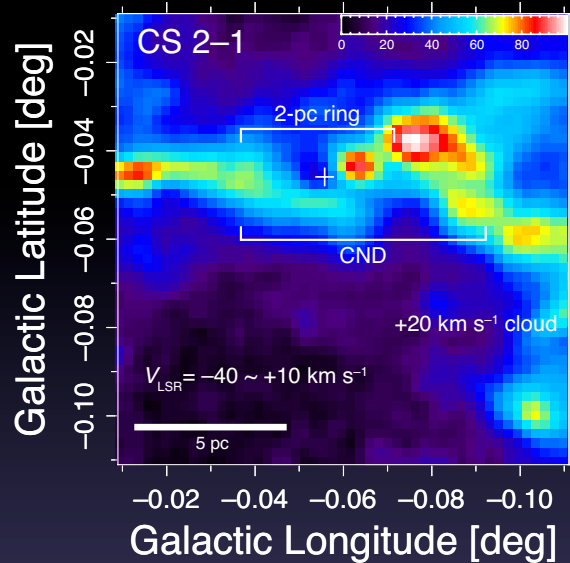
$n(\text{H}_2)$ ,  $T$ ,  $N/dV$ ,  $[\text{HCN}]/[\text{HCO}^+]$

	$n(\text{H}_2)$ [cm <sup>-3</sup> ]	$T$ [K]
20k	$10^{4.9-5.3}$	30-50
bridge	$>10^{5.8}$	60-150
NLE	$10^{4.7-5.0}$	$>100$

温度・密度ともにbridgeで上昇

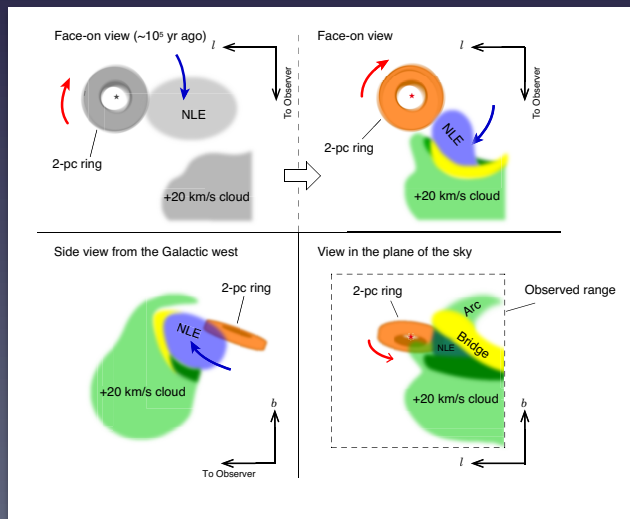
(preliminary)

# Summary



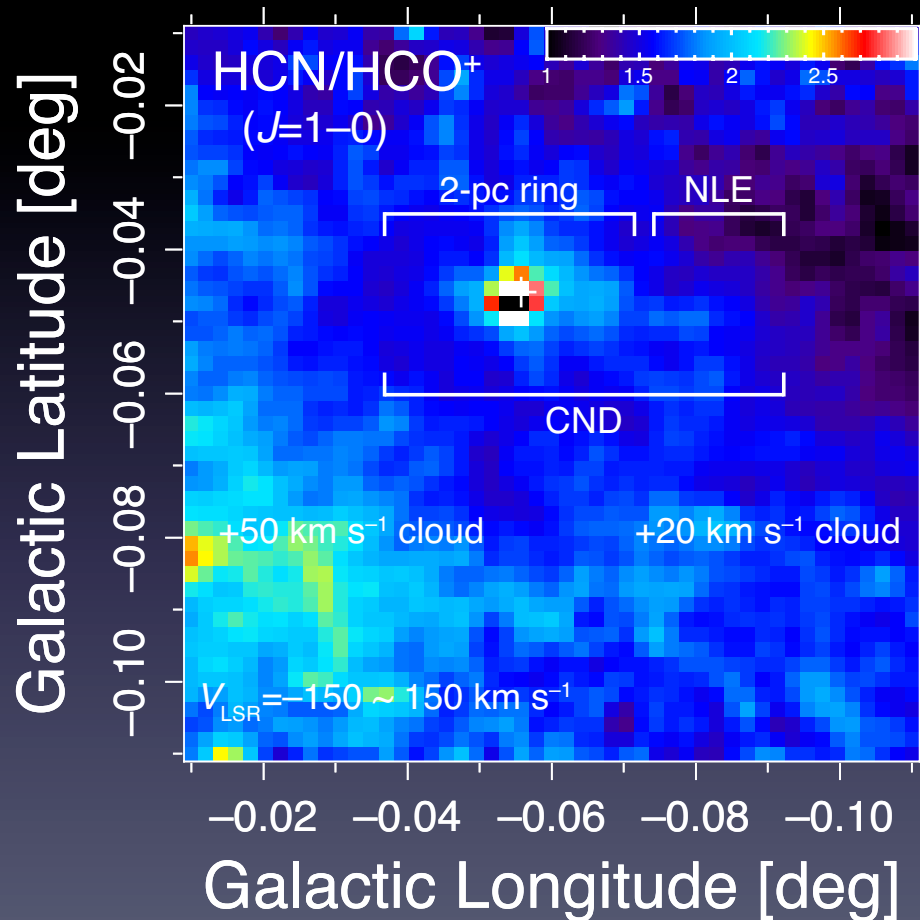
- CND方向のline survey  
→ 大きい分子はCNDで少ない

- OTF mapping of the CND  
→ 20k cloudとCNDを繋ぐ構造を発見  
→ NLEとの衝突(?)



- GMCがCNDの進化には重要
- GMCは確かに中心核近傍にある

# HCN/HCO<sup>+</sup> intensity ratio



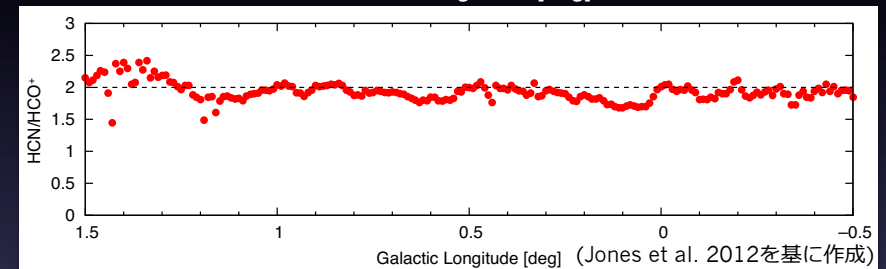
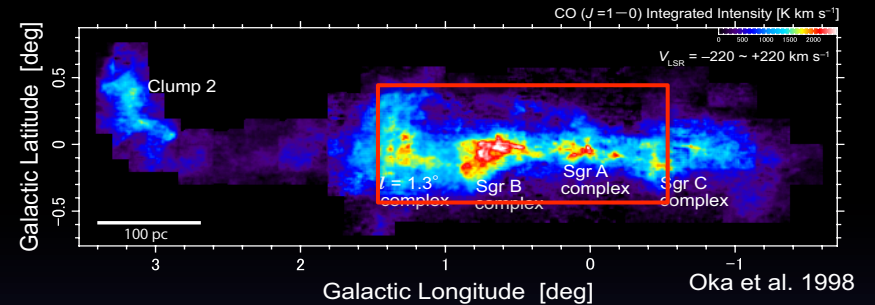
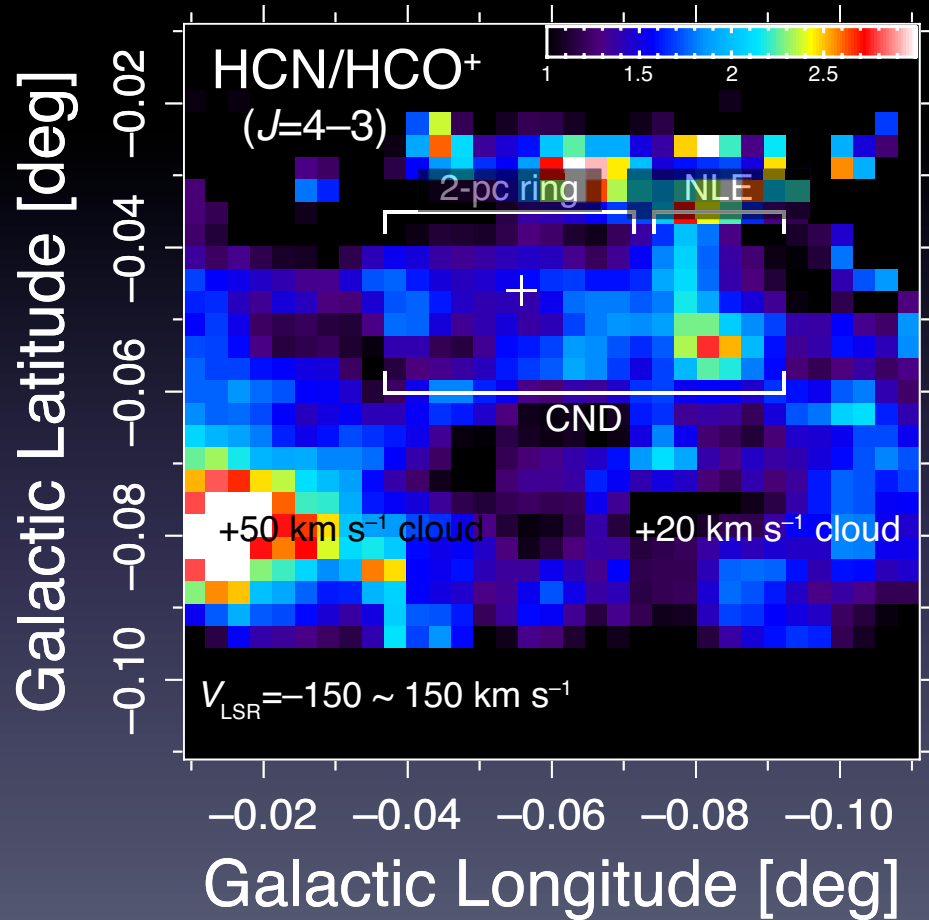
HCN 1–0/HCO<sup>+</sup> 1–0  
> 1 in AGNs  
< 1 in starburst

(e.g. Kohno et al. 2004)

## Our Galaxy

~2 in CMZ  
~1.6 in 2-pc ring  
< 1 in disk

# HCN/HCO<sup>+</sup> intensity ratio



Our Galaxy

~2 in CMZ

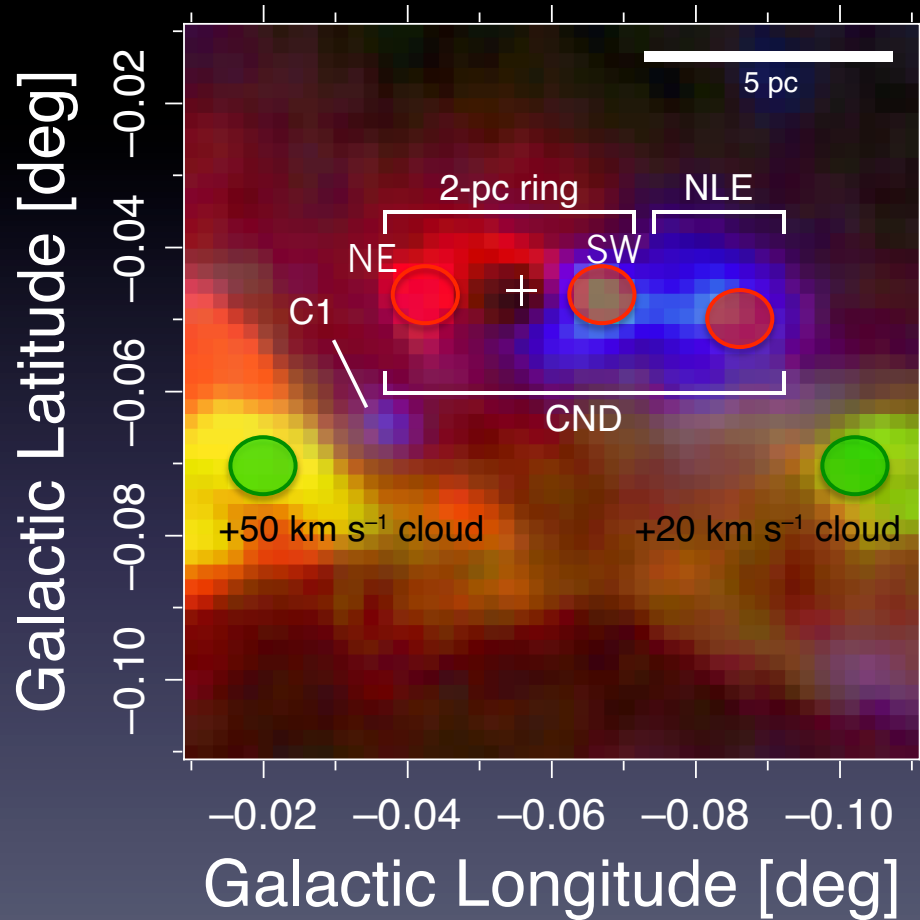
~1.6 in 2-pc ring

< 1 in disk

過去のAGN activityの影響？

# LVG analysis

(preliminary)



(今後 空間分布を出す予定)

	$n(\text{H}_2)$ [ $\text{cm}^{-3}$ ]	$T$ [K]	$[\text{HCN}]/$ $[\text{HCO}^+]$
20k	$10^{4.9-5.3}$	30-50	$10^{1.1-1.3}$
50k	$10^{4.6-5.0}$	50-60	$10^{1.6-1.7}$
bridge	$>10^6$	60-150	$10^{0.7-0.9}$
2-pc NE	$10^{5.0-5.2}$	$>100$	$10^{0.7-0.8}$
2-pc SW	$10^{5.0-5.4}$	$>100$	$10^{0.8-1.0}$
NLE	$10^{4.7-5.0}$	$>100$	$10^{1.0-1.3}$
C1 cloud	$10^{4.1-4.6}$	$>200$	$10^{1.4-1.6}$

※温度は高いとうまく決まらない

Possible XDR probe:  $[\text{HCN}]/[\text{HCO}^+]$   
~1 in the Galactic disk

2-pc ringではGMCに比べ  
微妙に減っている?!