

Filamentary Structures of the Galactic Center 50km/s Molecular Cloud with ALMA

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Outline

1. Introduction

- i. CMZ, ii. Filamentary structure in molecular clouds, iii. the 50MC

2. Observations

3. CS emission line image

- i. a channel map, ii. The filamentary structures

4. SiO, H¹³CO⁺ emission lines images

- i. channel maps, ii. shock region in the 50MC

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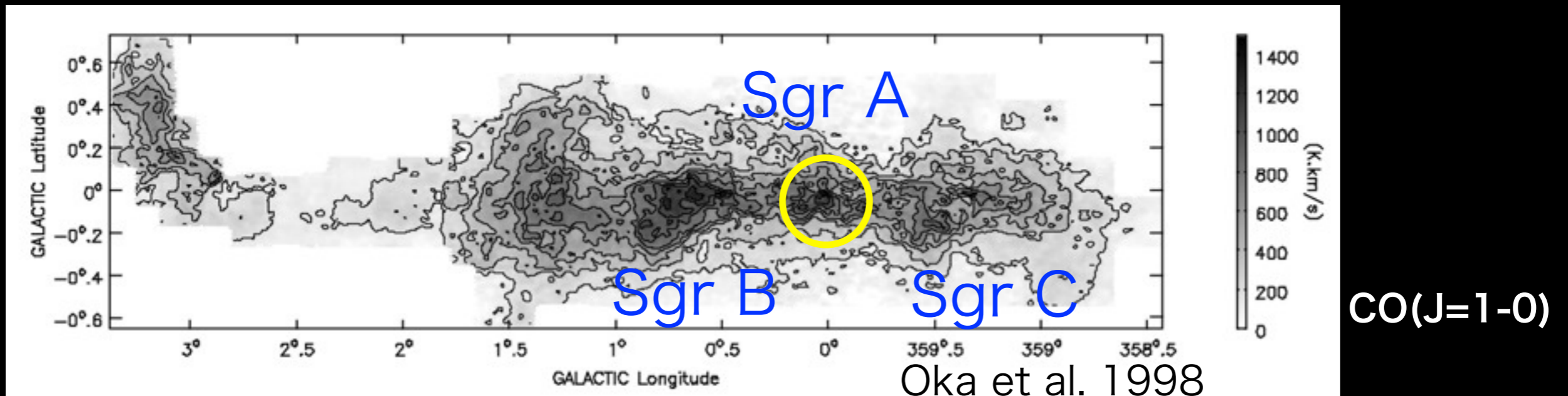
Introduction (CMZ)

CMZ (Central Molecular Zone)

The CMZ is a molecular cloud complex in the Galactic Center region inner ~ 300 pc (Morris&Serabyn 1996). **In the CMZ, the molecular gas is very dense and warm and its velocity dispersion is very large compared to those in the disk region.** However, the star formation is not active in the molecular cloud except for Sgr A, Sgr B2, Sgr C.

The properties of the CMZ and disk region are presented below.

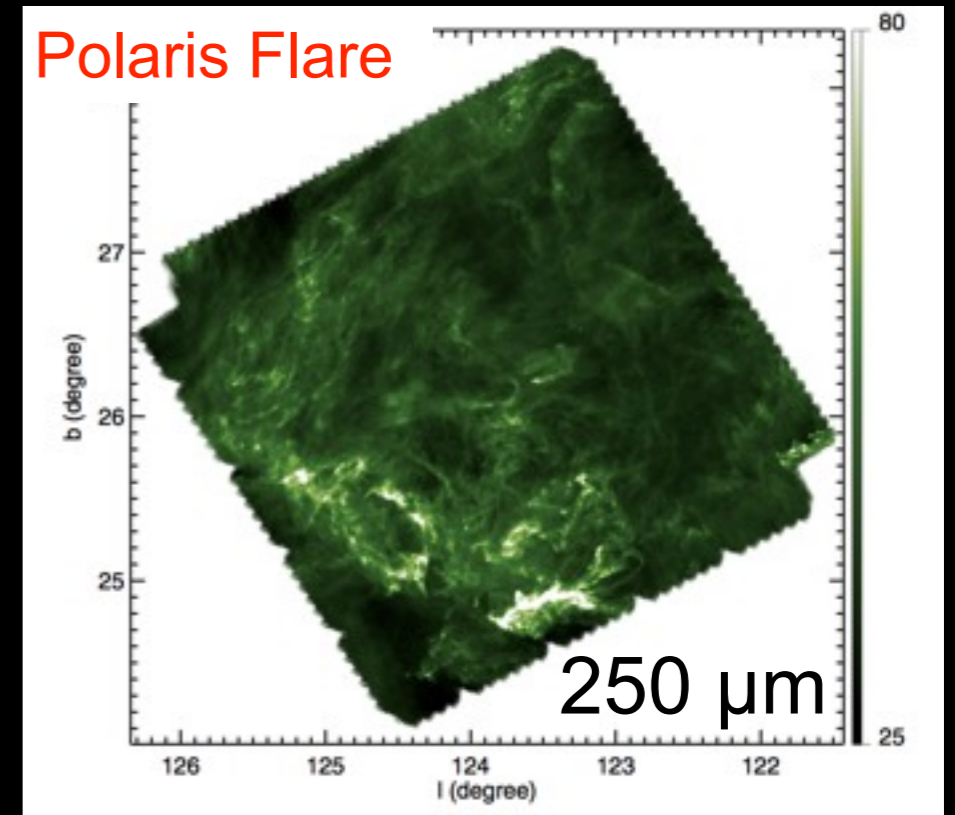
	Density (/cc)	Temp. (K)	ΔV (km/s)	B (mG)
CMZ	$>\sim 1000$	$\sim 10 - \sim 100$	$\sim 15 - \sim 50$	~ 1
Disk	~ 100	~ 15	$\sim 1-5$	$< \sim 0.1$



Filamentary structures in molecular cloud

The Galactic disk region

In molecular clouds, a number of **filamentary structures have been found ubiquitously** by Herschel observation (e.g. Miville-Deschênes et al. 2010, Andre et al. 2010).

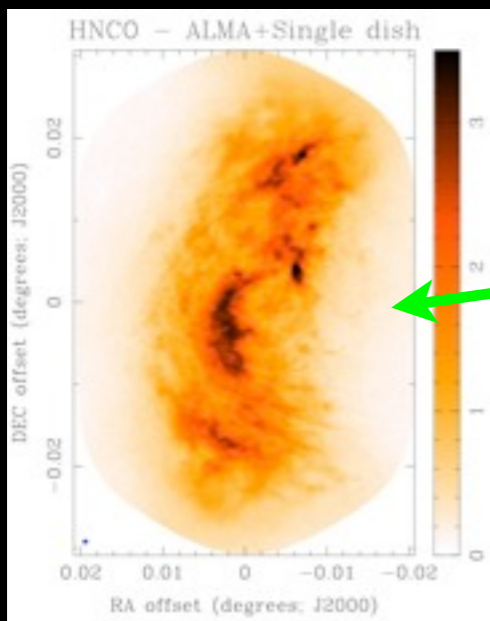


Miville-Deschênes et al. 2010

The Galactic center region

In this region, **Similar filamentary structures** have been also found in G0.253+0.016 with ALMA (Rathborne et al. 2015)

① Do filamentary structures exist in CMZ ubiquitously?

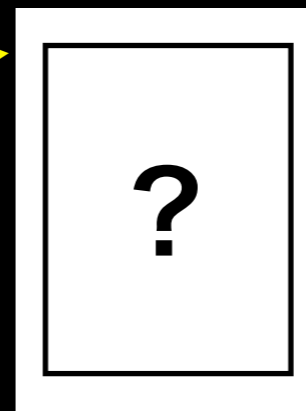


Rathborne et al. 2015

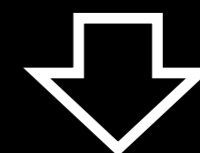


Kruijssen et al. 2014

The region in the vicinity of GC



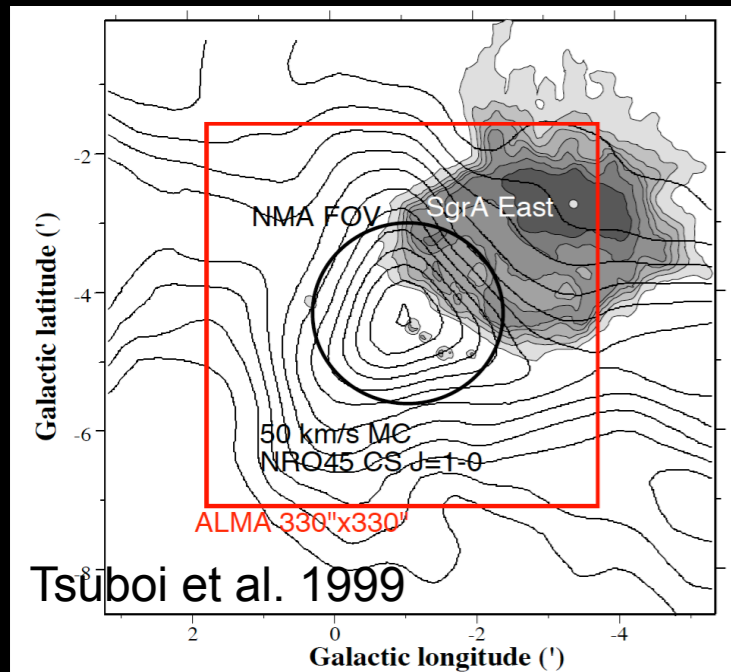
② Do these structures exist in the region closer to the GC?



We observed the 50MC.

The 50km/s Molecular Cloud (50MC)

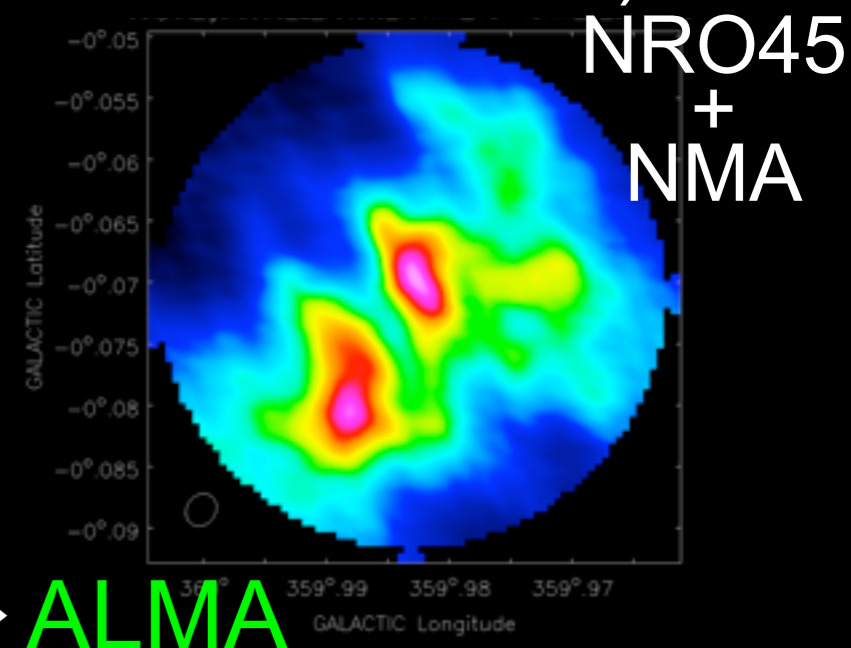
Previous work



- 👁 The 50MC is located to $\sim 3'$ southeast from Sagittarius A* and is the most prominent molecular cloud in the Sgr A region (Fukui et al 1977)
- 👁 This cloud appears to include several compact HII regions. (Ekers et al. 1983, Goss et al. 1985)
- 👁 The triangle structure was discovered from the observations with CS(J=1-0) line using the Nobeyama Radio Observatory 45m Telescope (NRO45) ($\Delta\theta \sim 60'' \sim 2.5\text{pc}$). (Tsuboi et al. 1999)

👁 From CS(J=1-0) imaging using Nobeyama Millimeter Array (NMA), **37 cores** were identified ($\Delta\theta \sim 10'' \sim 0.4\text{pc}$) (Tsuboi et al. 2012). But, **this observation didn't resolve into filamentary structures.**

These observations are not enough to detect filamentary structures in the 50MC.



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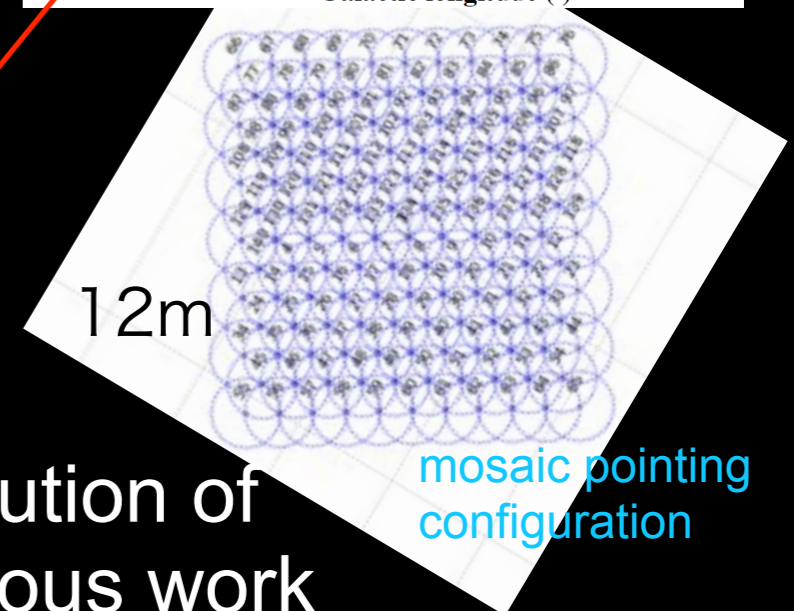
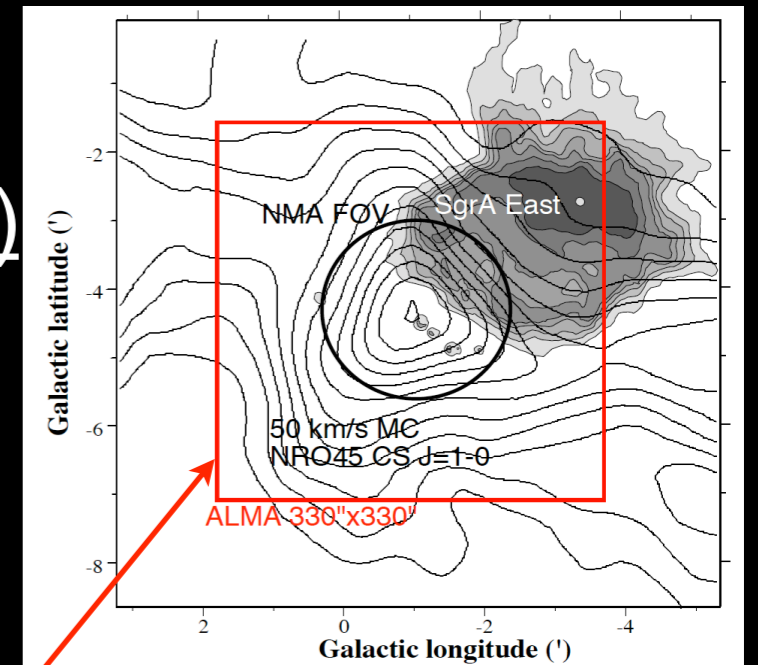
Observations

ALMA cycle 1 data (2012.1.00080.S, PI M.Tsuboi)

The whole of the 50MC was observed using 12m + ACA + TP with mosaic observation. The data of 12m + ACA were just delivered. We have reduced these data with CASA.

Many emission lines are included.

The angular resolution is improved by ~ 10 times compared to those of the previous works.



Source	The 50MC (@~8.5kpc)
Obs. Region	330"x330" (whole of the 50MC)
Angular Resolution	~1.5"x1.5" (~0.06pcx0.06pc)
mosaic pointing	138pointing (12m) 52pointing (7m)
Frequency	Four IFs of Band 3(~85 - 100GHz) <u>CS (J=2-1), SiO(J=2-1), H¹³CO⁺ (J=1-0), C³⁴S(J=2-1), CH₃OH, SO, H42α, etc...</u>

resolution of previous work
 SiO, H¹³CO⁺(NRO45)
 $\Delta\theta \sim 26'' \sim 1.1\text{pc}$
 CS(NMA)
 $\Delta\theta \sim 10'' \sim 0.4\text{pc}$

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The map of the 50MC in CS

velocity range = $-150\text{km/s} \sim 150\text{km/s}$ in $V_{\text{LSR}} (\Delta V = 5\text{km/s})$

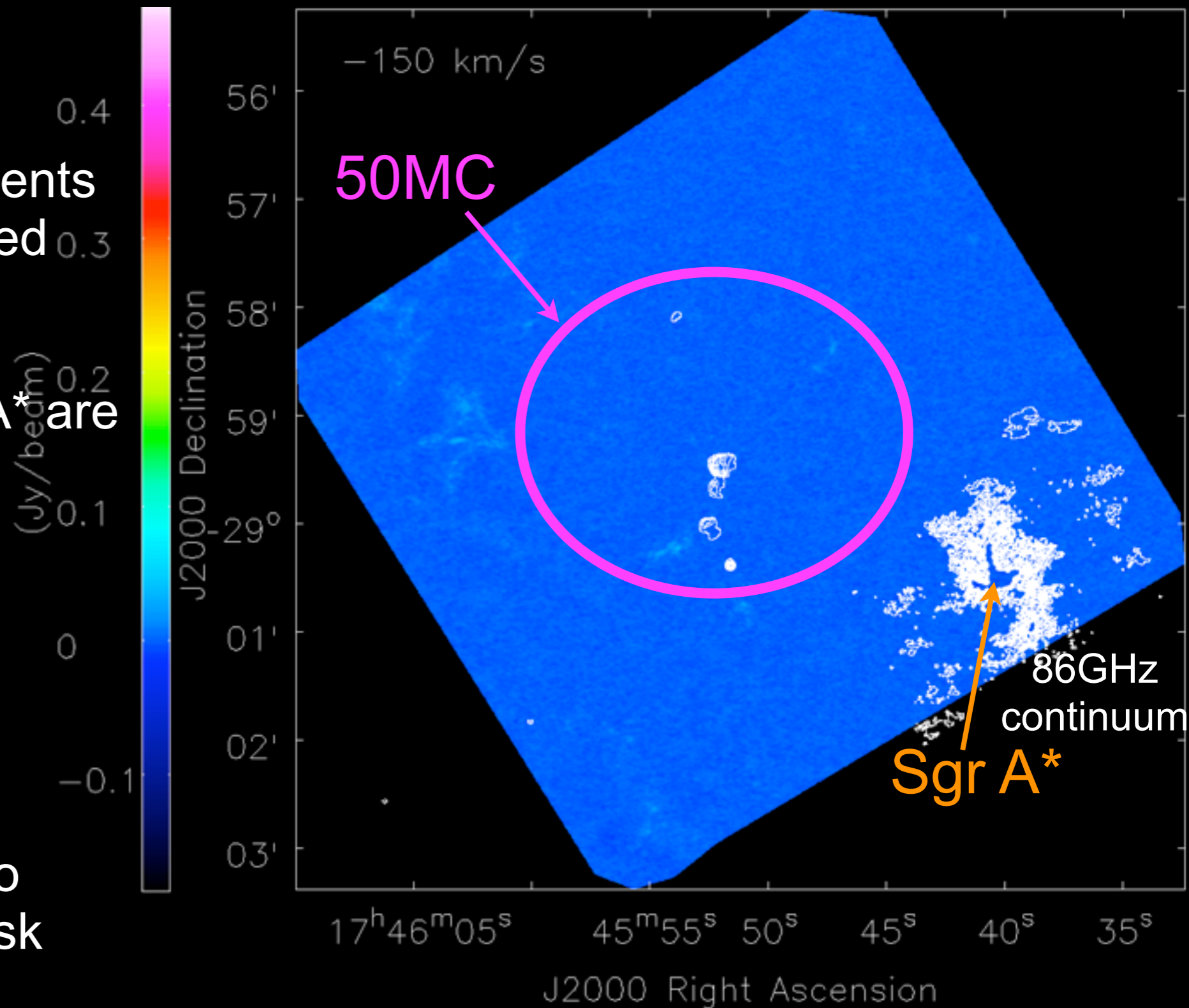
line = CS ($J=2-1$)

The prominent components of the 50MC are resolved into fine structures. In addition, some new structures around Sgr A* are found.

Many filamentary structures can be discerned in the 50MC.



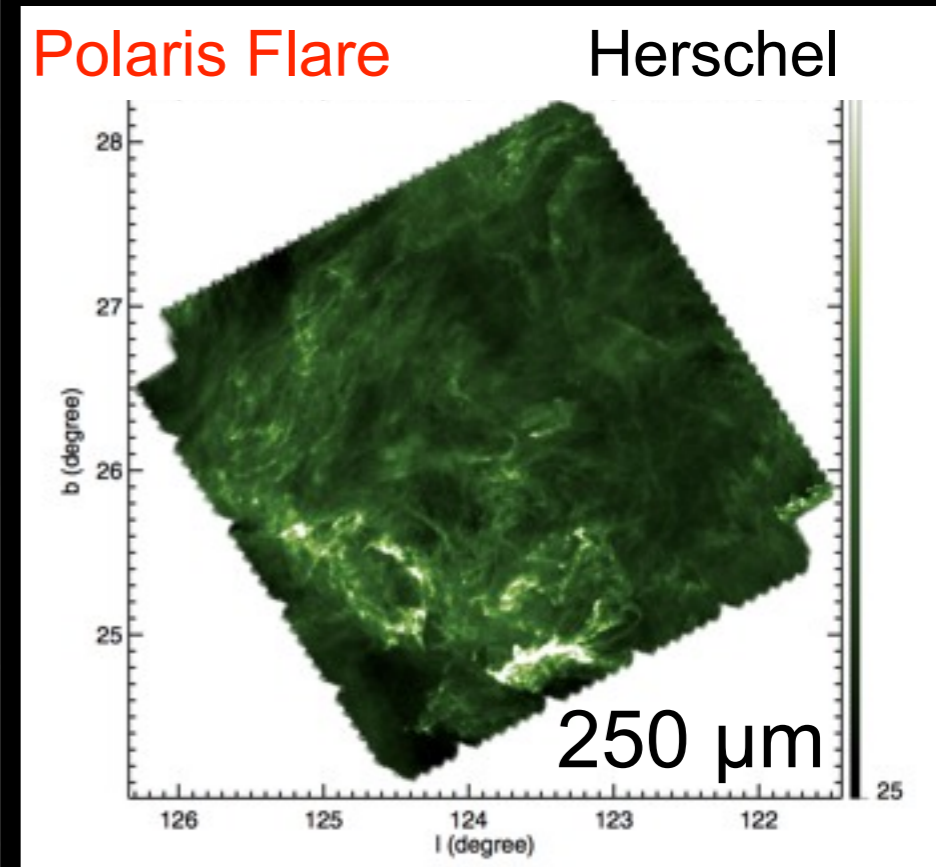
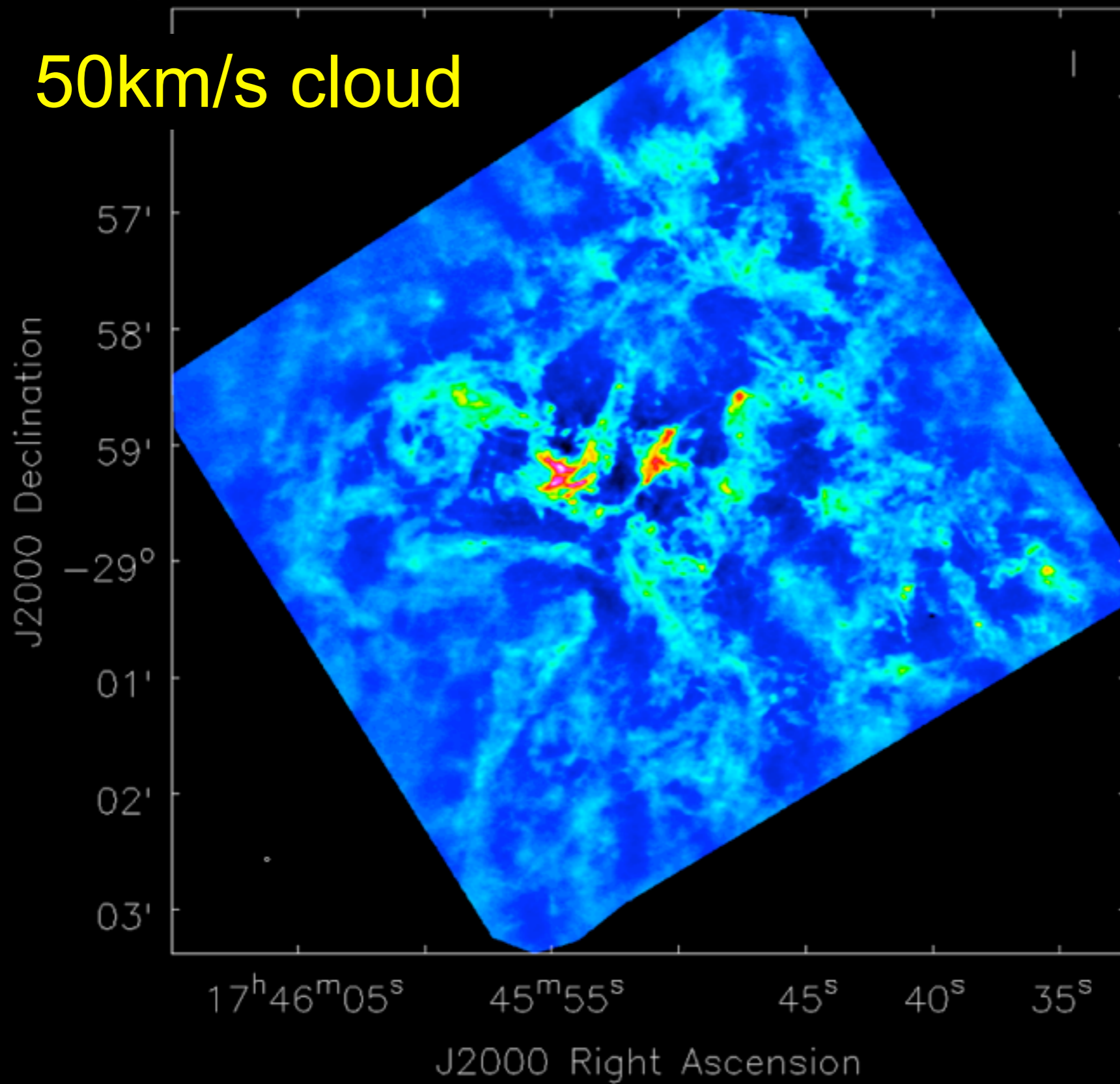
We compare these filamentary structures to those in the Galactic disk region.



Filamentary structures

SgrA_CS21_concat.image.subimage_15~45km_p_s-raster

50km/s cloud



Miville-Deschênes et al. 2010

These filamentary structures seem to be similar.

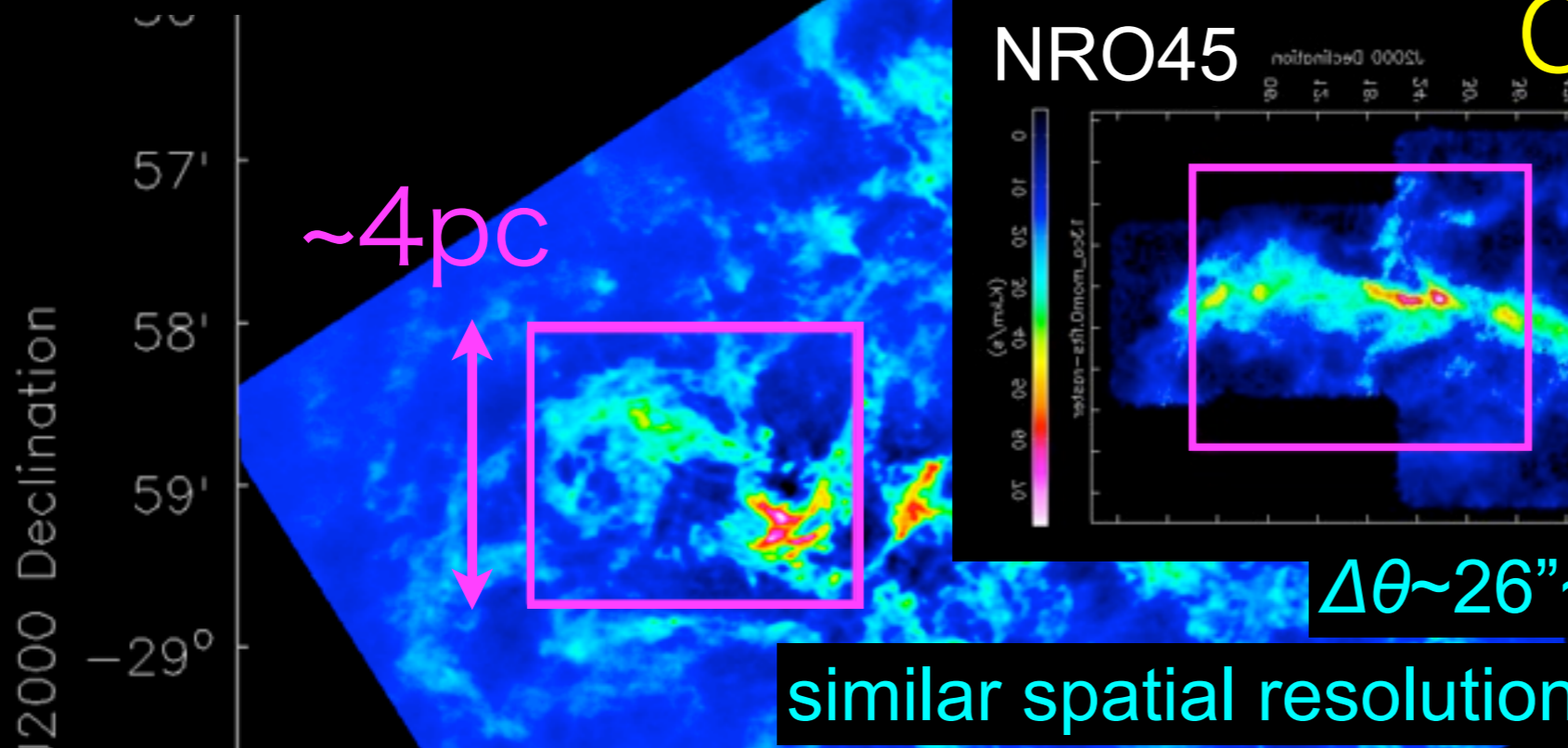
In order to compare these structures with same spatial resolutions, we use Orion A.

Filamentary structures

SgrA_CS21_concat.image.subimage_15~45km_p_s-raster

50km/s cloud

Orion A



Similar filamentary structures are unveiled.

$\Delta\theta \sim 26'' \sim 0.05\text{pc}$ (@~450pc)

similar spatial resolution

$\Delta\theta \sim 1.5'' \sim 0.06\text{pc}$ (@~8.5kpc)

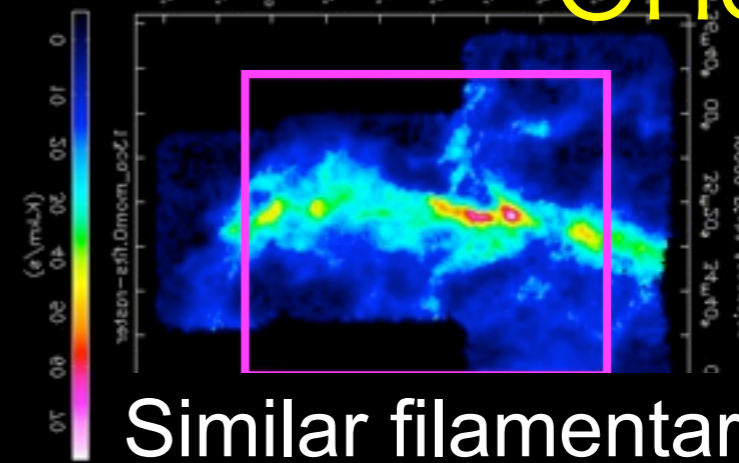
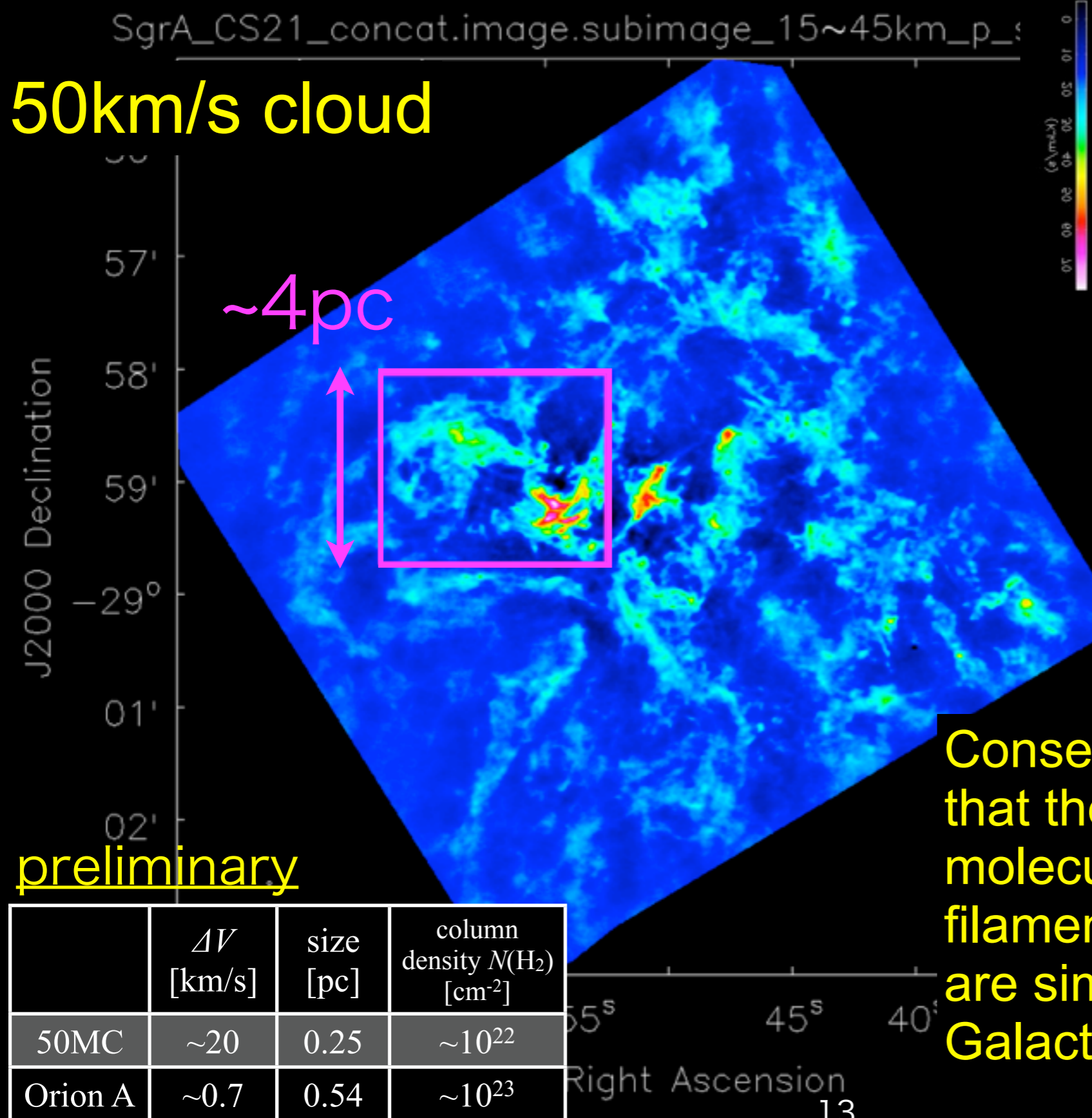
<u>preliminary</u>	ΔV [km/s]	width [pc]	column density $N(\text{H}_2)$ [cm ⁻²]
50MC	~20	0.25	~10 ²²
Orion A	~0.7	0.54	~10 ²³

35^s

Filamentary structures

Orion A

50km/s cloud



Similar filamentary structures are unveiled.

Additionally, many filamentary structure and clumpy structure are existing.

Consequently, we have found that the galactic center molecular clouds include many filamentary structures which are similar to those in the Galactic disk region.

preliminary

	ΔV [km/s]	size [pc]	column density $N(\text{H}_2)$ [cm^{-2}]
50MC	~20	0.25	~ 10^{22}
Orion A	~0.7	0.54	~ 10^{23}

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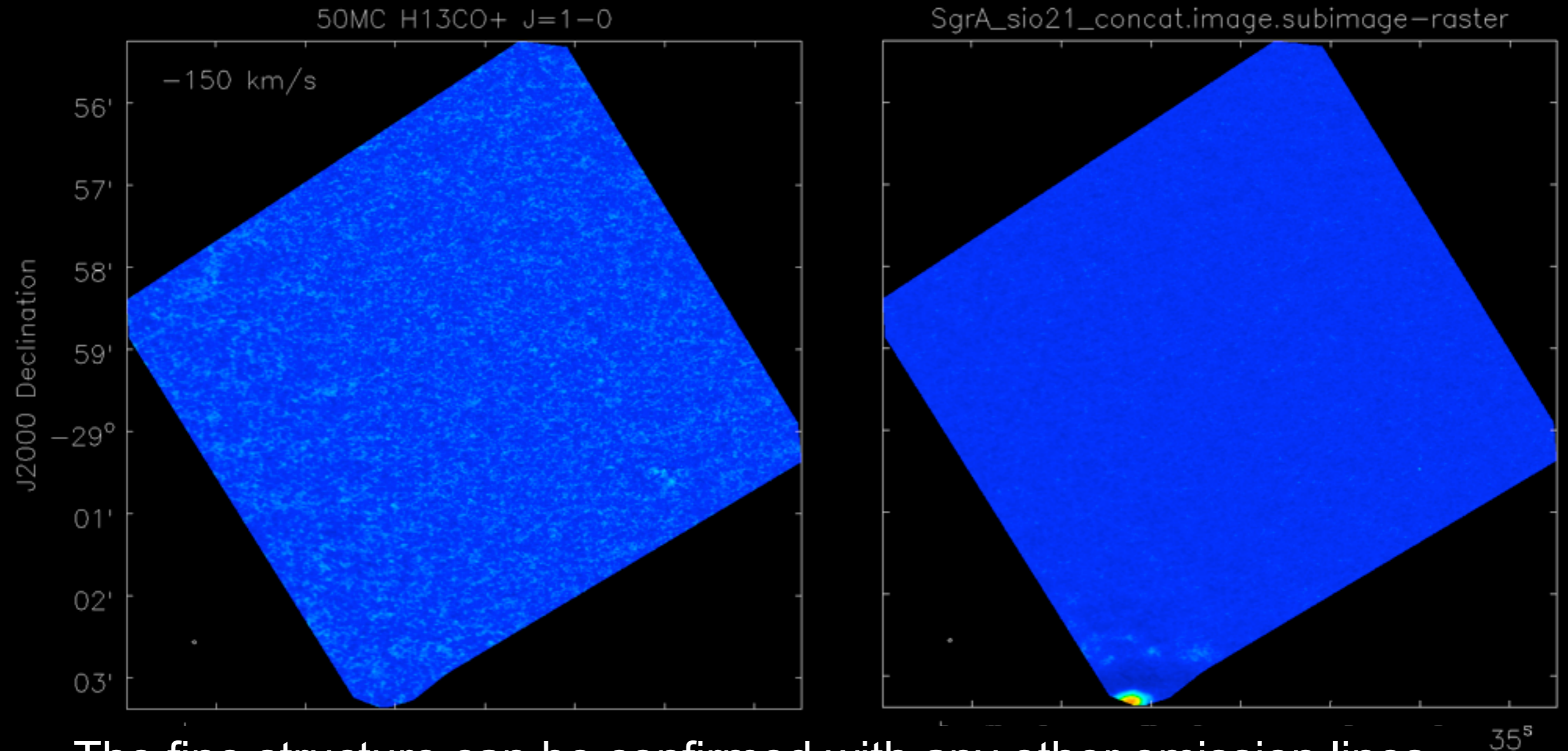
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The map of the 50MC with SiO, H¹³CO⁺

velocity range = -150km/s~150km/s ($\Delta V=5$ km/s)

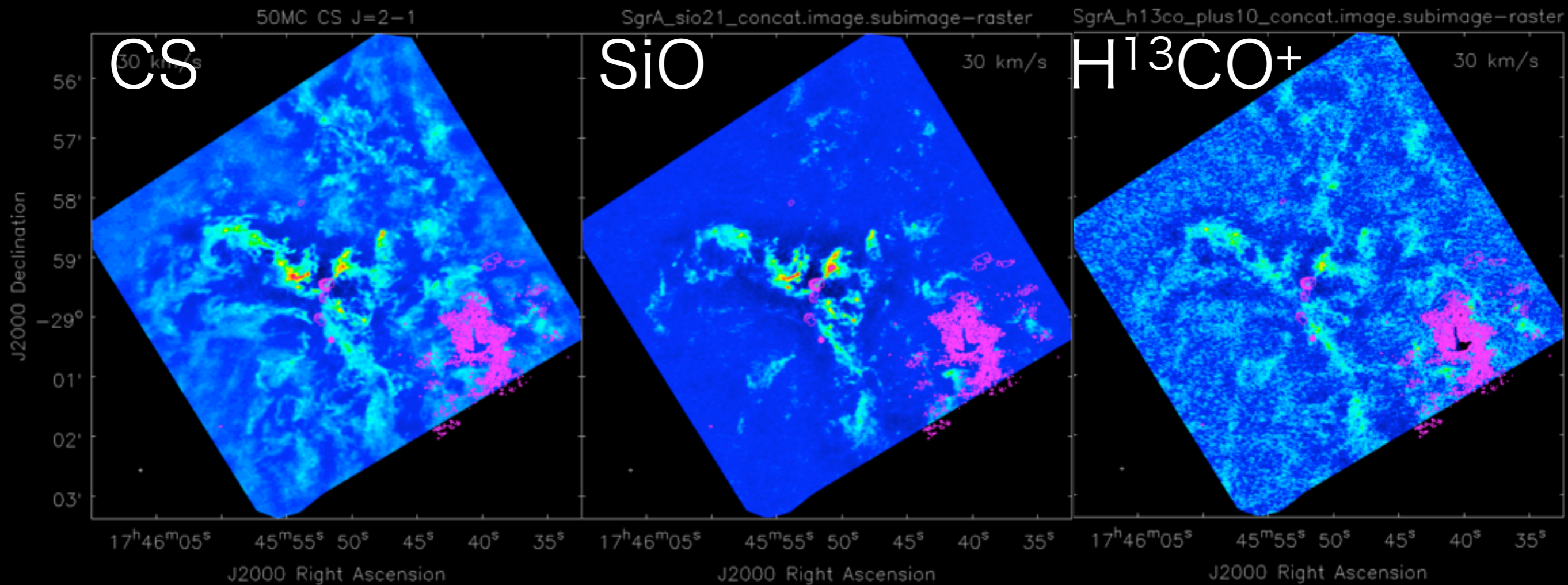
line = H¹³CO⁺ ($J=1-0$)

line = SiO ($J=2-1$)



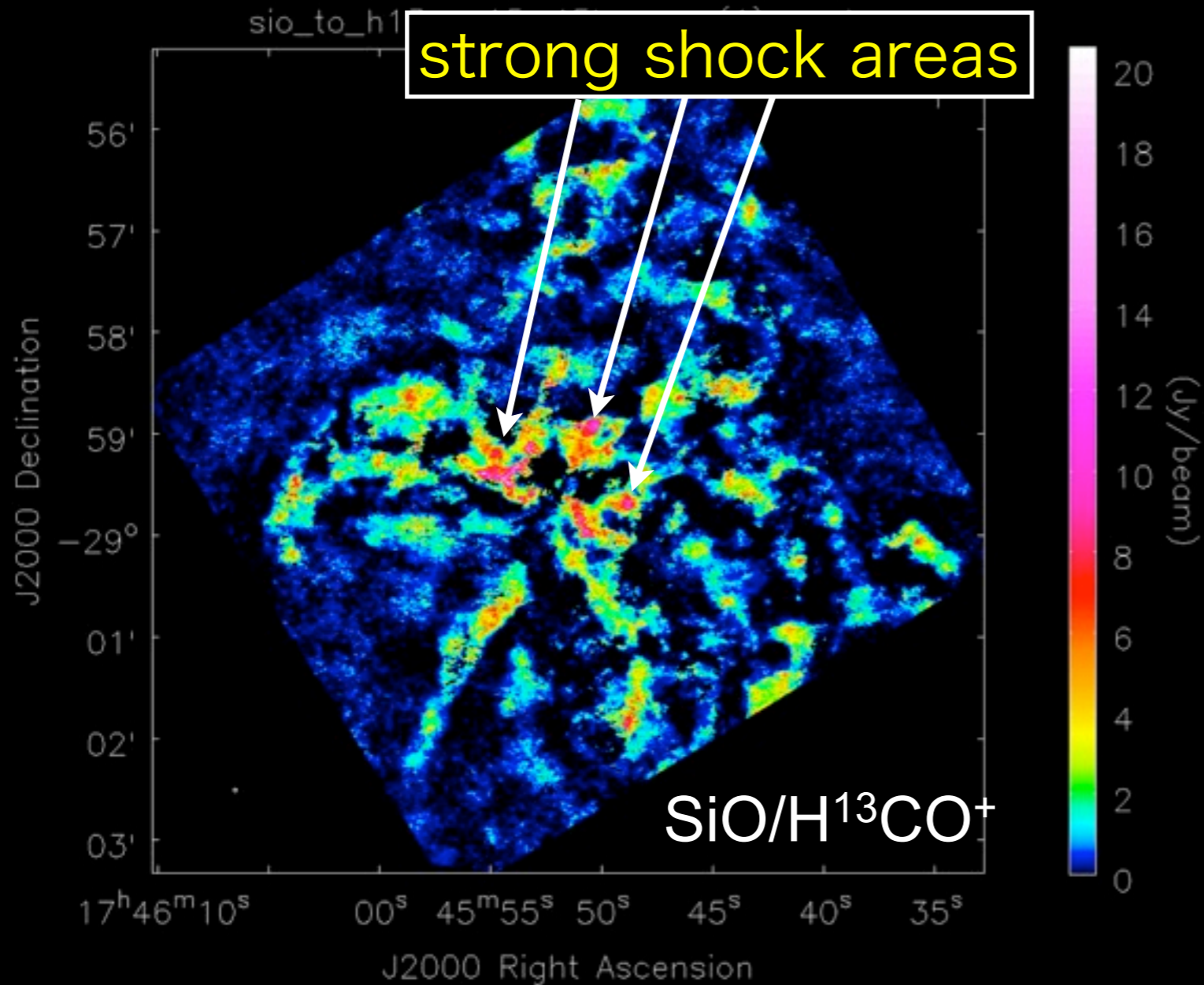
The fine structure can be confirmed with any other emission lines. We can study dense parts of the clumps in H¹³CO⁺ and the details of the shocked region in SiO.

The map of the 50MC with SiO, H¹³CO⁺

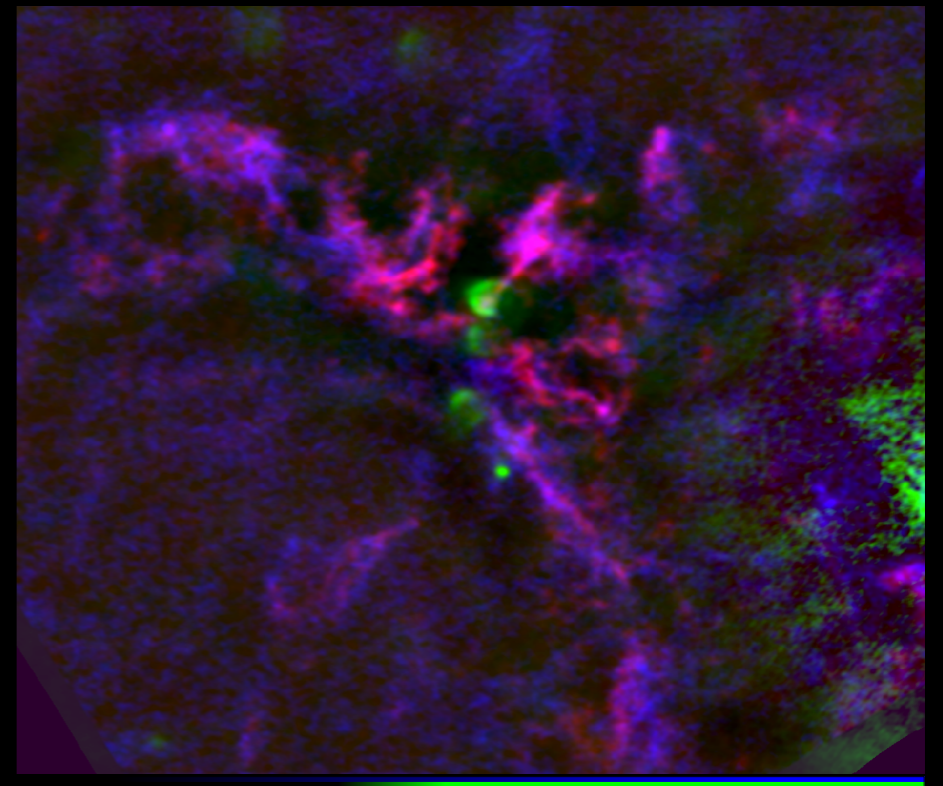


For these emission lines, these structures are similar.
From SiO and H¹³CO⁺, we found that **shock regions and denser regions also extend filamentary.**

Shock region the 50MC



SiO ($J=2-1$) [shock]
H¹³CO⁺ ($J=1-0$) [denser]
86GHz continuum



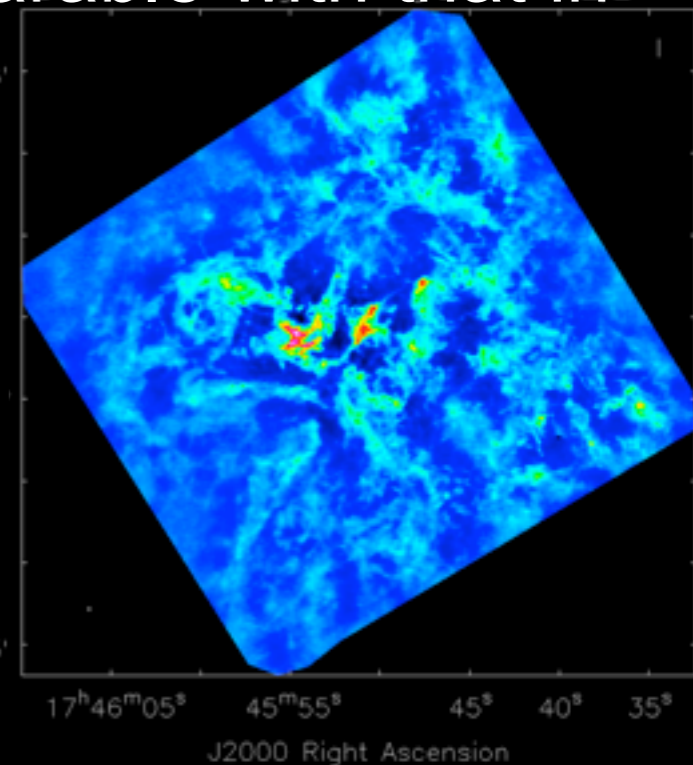
We can use a intensity ratio of SiO/H¹³CO⁺ as shock tracer.
In filamentary structures, this intensity ratio is more than 5.
The filamentary structures seem to be along HII regions.
These particularly strong shock areas are clumpy rather than filamentary.

Summary

We observed the whole of 50km/s molecular cloud in the Galactic center Sgr A region using many emission lines (CS (J=2-1), SiO(J=2-1), H¹³CO⁺ (J=1-0), C³⁴S(J=2-1), CH₃OH, SO, H42 α , etc...).

The angular resolution is $\sim 1.5''$ (~ 0.06 pc).

1. We found that the prominent components of the 50MC are **resolved into many filamentary structures in CS image**, so we think that **molecular clouds may have filamentary structures in GC, ubiquitously**. The widths of these filamentary structures are comparable with that in the disk region.
2. Fine structures are confirmed in SiO and H¹³CO⁺ image. Using these maps, we found that **shock regions and denser regions also extend filamentary**. **Particularly strong shock areas are clumpy rather than filamentary**.



Future works

We will estimate column densities and mass of these filaments and explore the relation of these structures and shock regions. And, we will estimate core mass function of the 50MC because it can be expected that more molecular cores will be identified.

END

Thank you.

