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Molecular gas and star formation in bar regions of strongly barred galaxy

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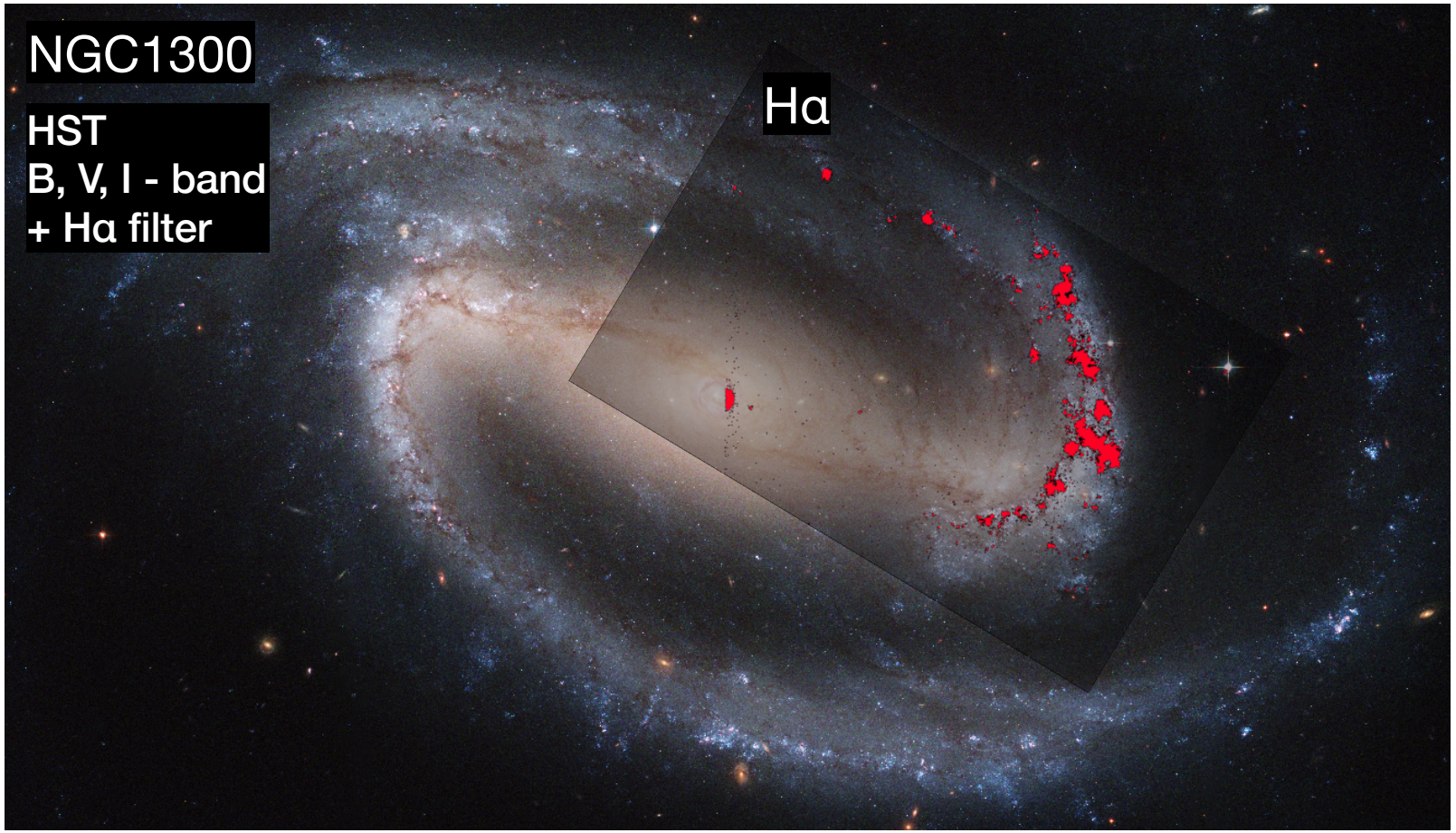
Suppression of SF in bars

- HII regions are seen in spiral arms.
- In the bar regions, although the dark lane implies the presence of dust and molecular clouds, there is no (massive) star formation.



https://www.spacetelescope.org/images/opo0501a/

What prevents star formation in bar regions?

- The molecular clouds may be destroyed by shock due to the high velocity of the gases relative to the bar structure. (e.g., Tubbs 1982)
- Strong shear motion in the bar region may prevent molecular cloud formation (e.g., Athanassoula 1992).
- Combination of these (Reynaud & Downes 1998).

Recent studies

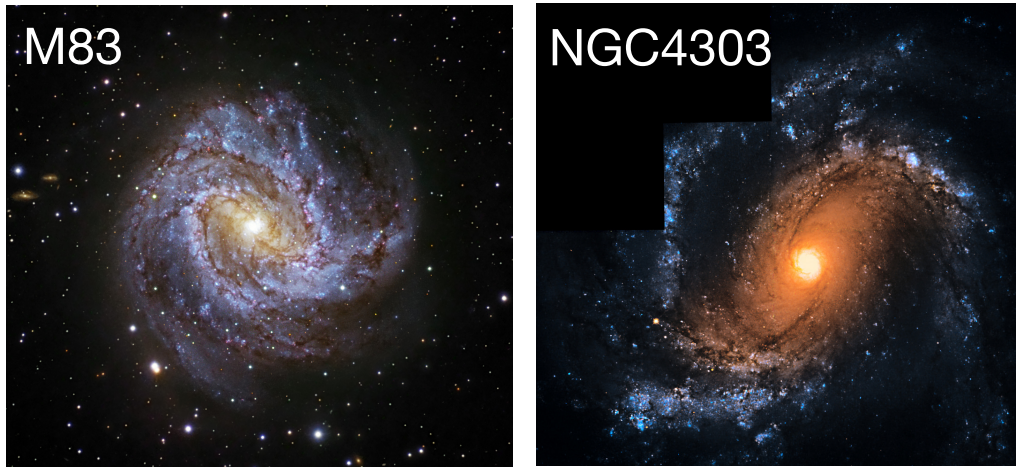
- Molecular clouds in bar regions are gravitationally unbound (e.g., Sorai et al. 2012.)
- The high-speed collision of the clouds in the bar region shortens a gas accretion phase of the cloud cores formed, leading to suppression of core growth and massive star formation (Takahira et al. 2014, 2018)
- Most of the molecular gases may be diffuse in bar region.

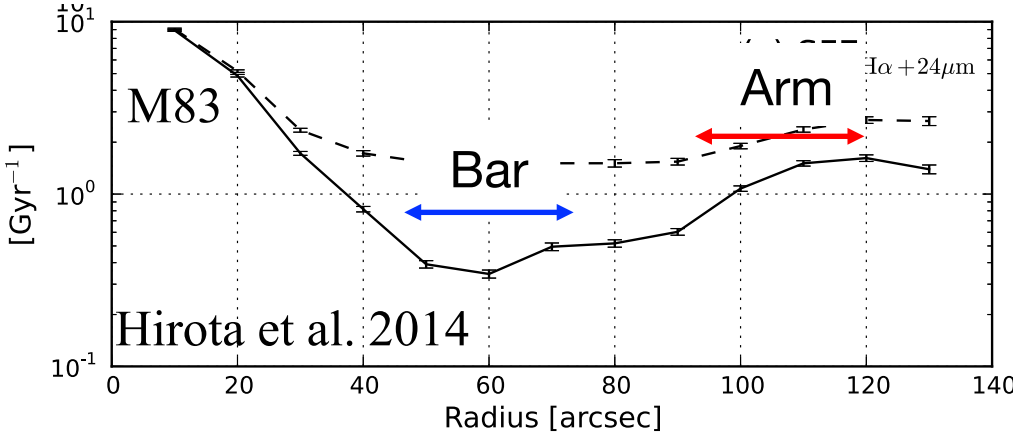
→ **We must resolve molecular gas into clouds.**

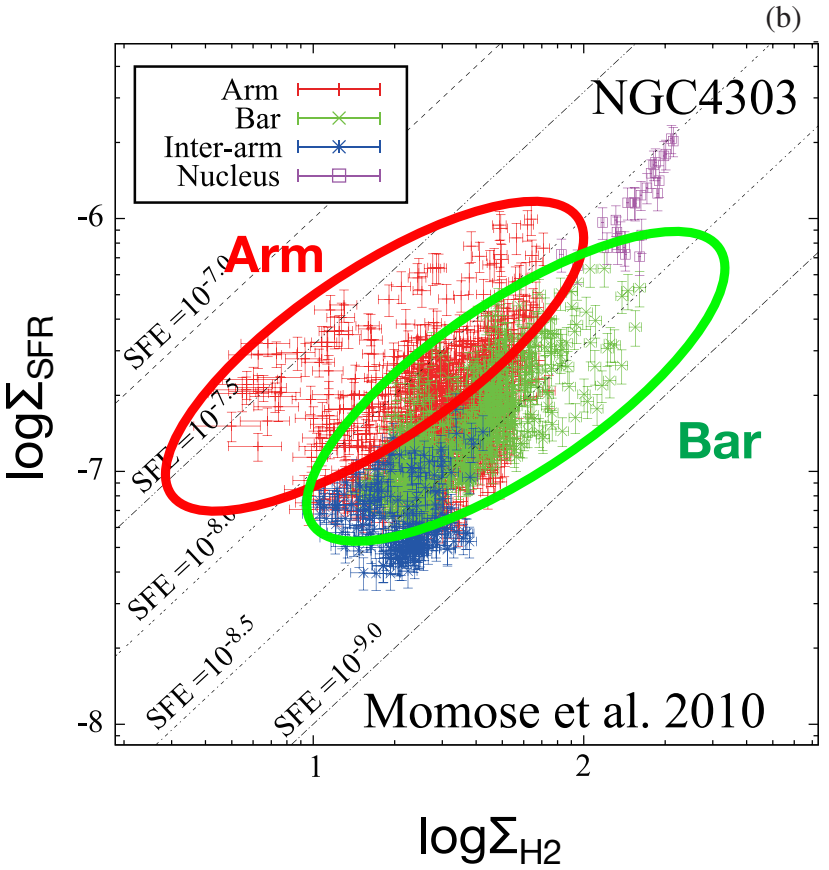
= High resolution CO imaging of barred galaxies is required.

Previous works : intermediate-type bar with SF

- SFE in bar regions is **2~3 times** lower than that in arm region.
  - Too large angular resolution to detect clumps.
  - Many of targets have an intermediate-type bar and do have star-forming regions associated with the bar or bar-like region.







Strongly barred galaxies : ideal lab

CO observations of strongly barred galaxies are important, because the mechanism of the suppression is expected to be clearly seen in such bars.

NGC1300 is the nearest strongly barred galaxy which has remarkable dark lanes in the bar region without HII regions.

- GMCs (~ 50pc) are detectable with ALMA.

NGC1300 (d = 20 Mpc)

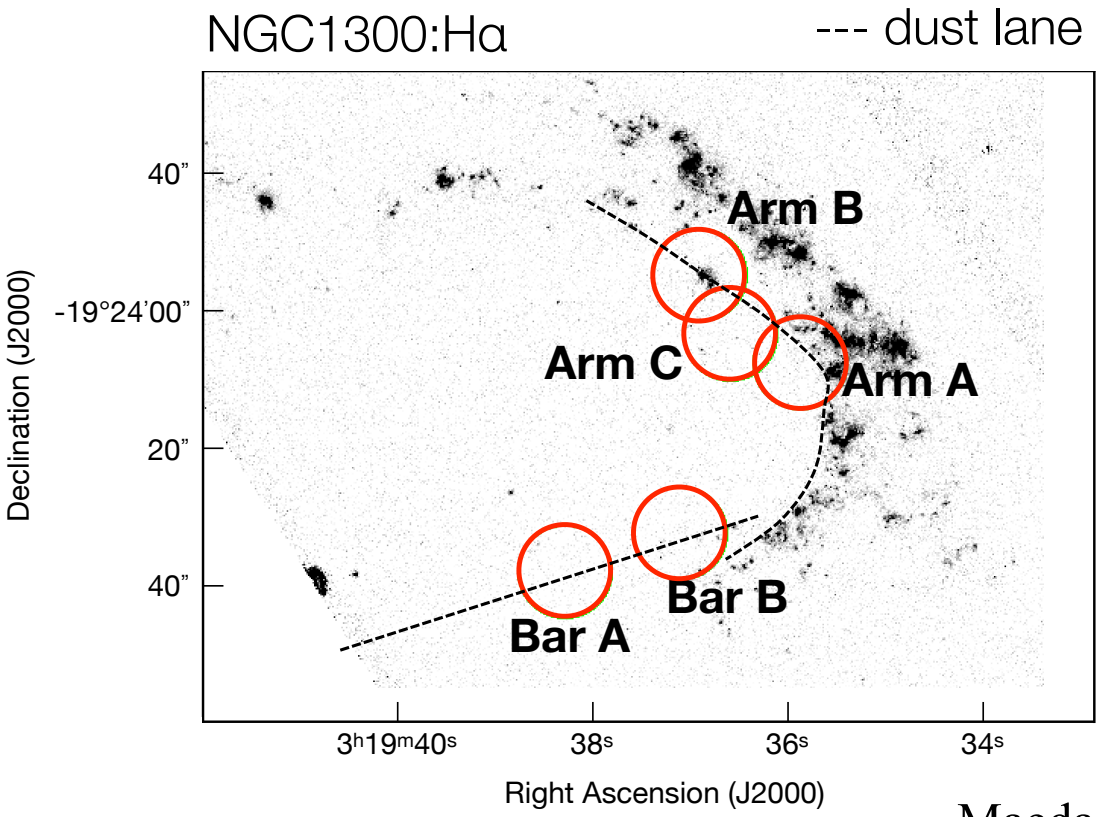
However...

- CO emission line has not been detected towards the bar regions.

Before going to ALMA: 45-m observations

NRO 45-m (2016/17)

- beam size = 13.”5ϕ = **1.3 kpc**
- on source time = 0.5 ~ 2.7hrs / point
- rms = 8 ~ 16 mK at 10 km/s bin

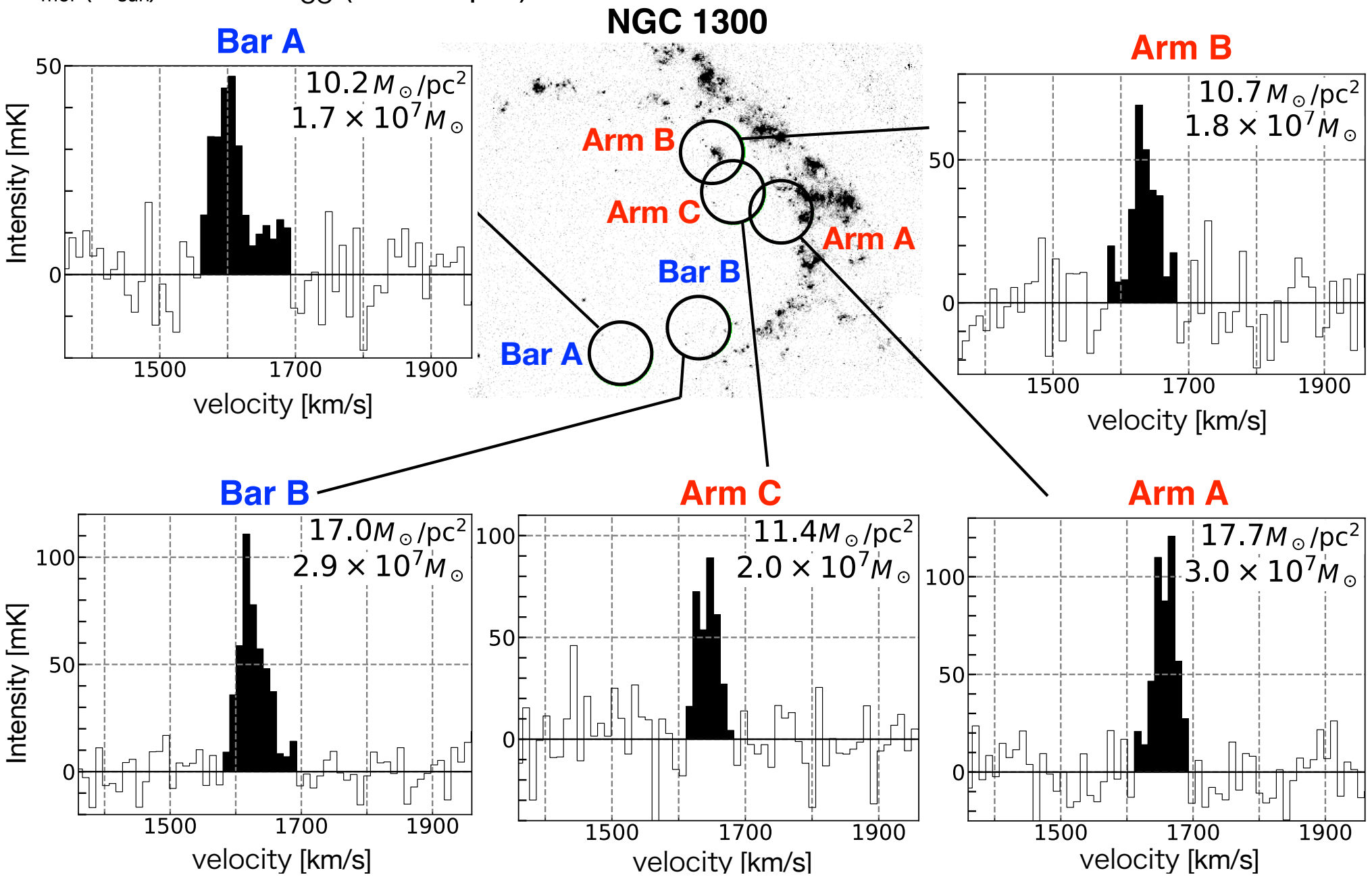


Maeda et al. 2018

Molecular gases exist in bar regions

M_{mol} (M_{sun}) = 4.36 L'_{CO} (K km/s pc^2)

Maeda et al. 2018



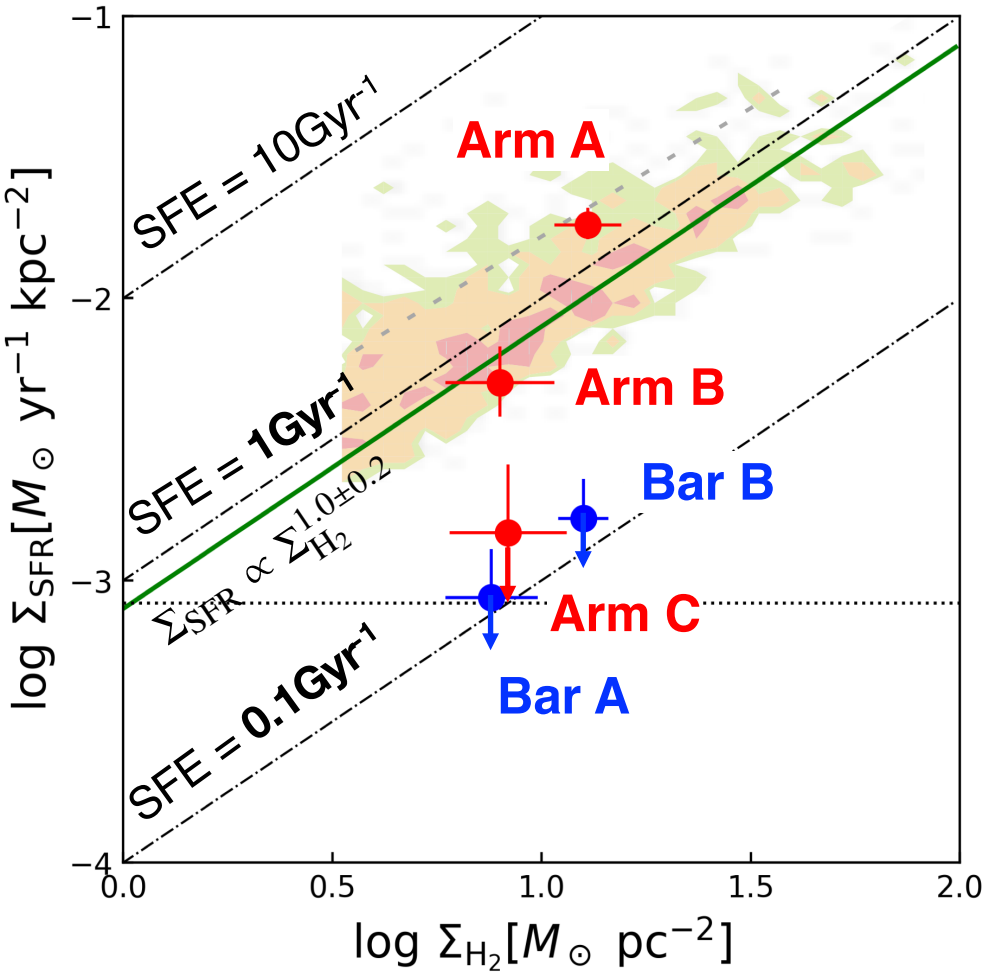
very low SFEs in strongly bar region

Using continuum subtracted Hα image from HST, we derived SFEs on 1.3 kpc scale:

$$\mathrm{SFE} = \frac{\Sigma_{\mathrm{SFR}}}{\Sigma_{\mathrm{H_2}}}\ (\mathrm{yr}^{-1})$$

- SFEs in Arm A & B are comparable to previous observations of spirals.
- **SFEs in bar of NGC1300 are ~10 times smaller than that in arm.**

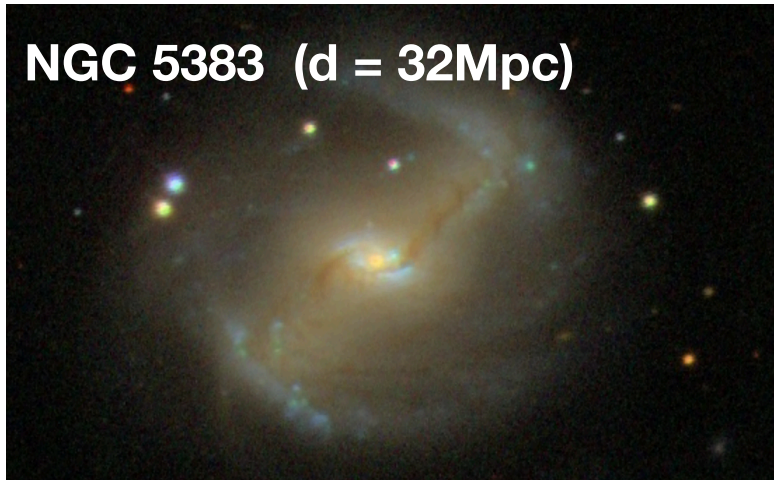
  → SF is remarkably suppressed in strongly bar regions.
- The low SFE in Arm C is consistent with the absent of HII regions there.

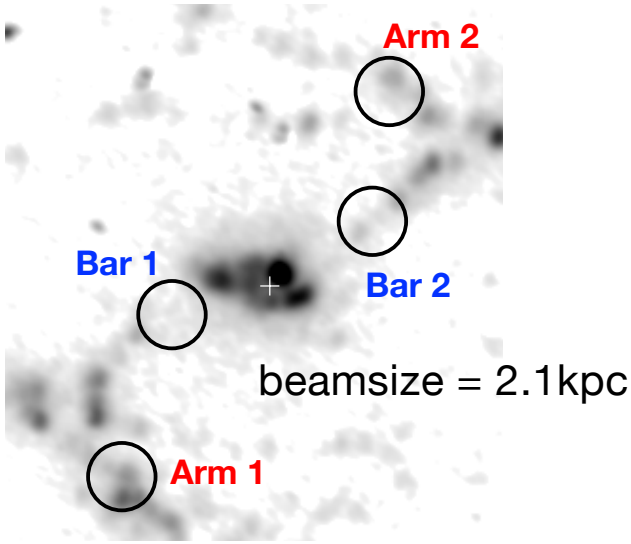


Red : Arm , Blue : Bar
Color regions by Bigiel et al. (2008) show SFEs in 18 nearby spiral galaxies on 0.75 kpc scale.

NGC5383

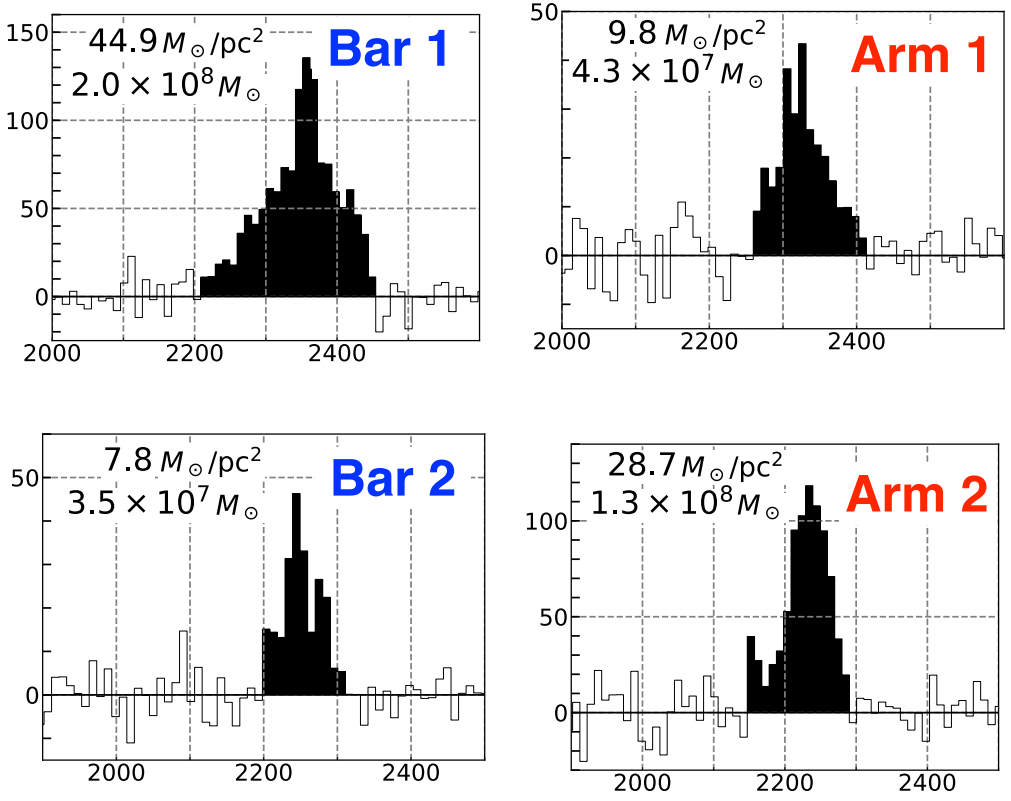
The very low SFEs are also seen in bar regions of strongly barred galaxy NGC5383.





Continuum-subtracted Hα image (Sheth et al. 2000)

CO(1-0) observations with 45-m



Maeda et al. 2018

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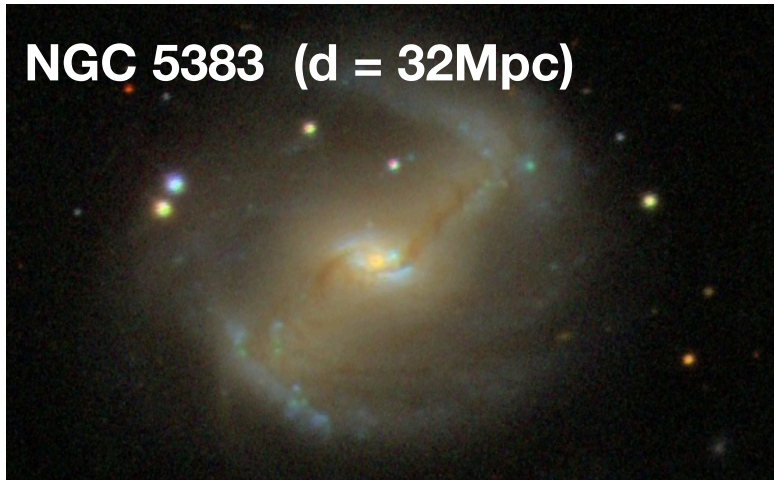
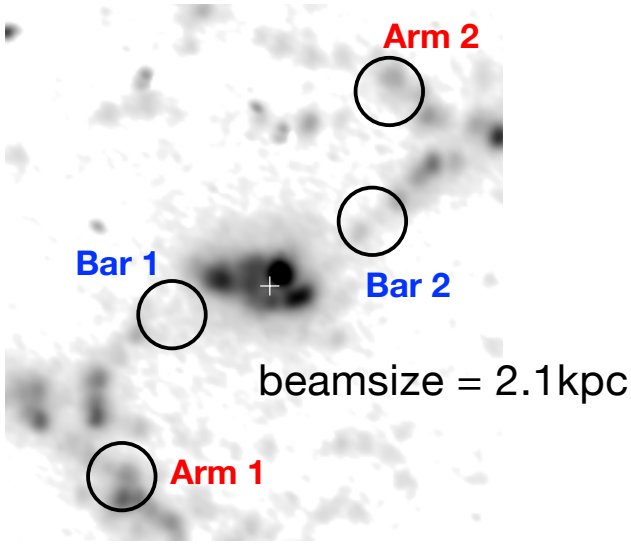
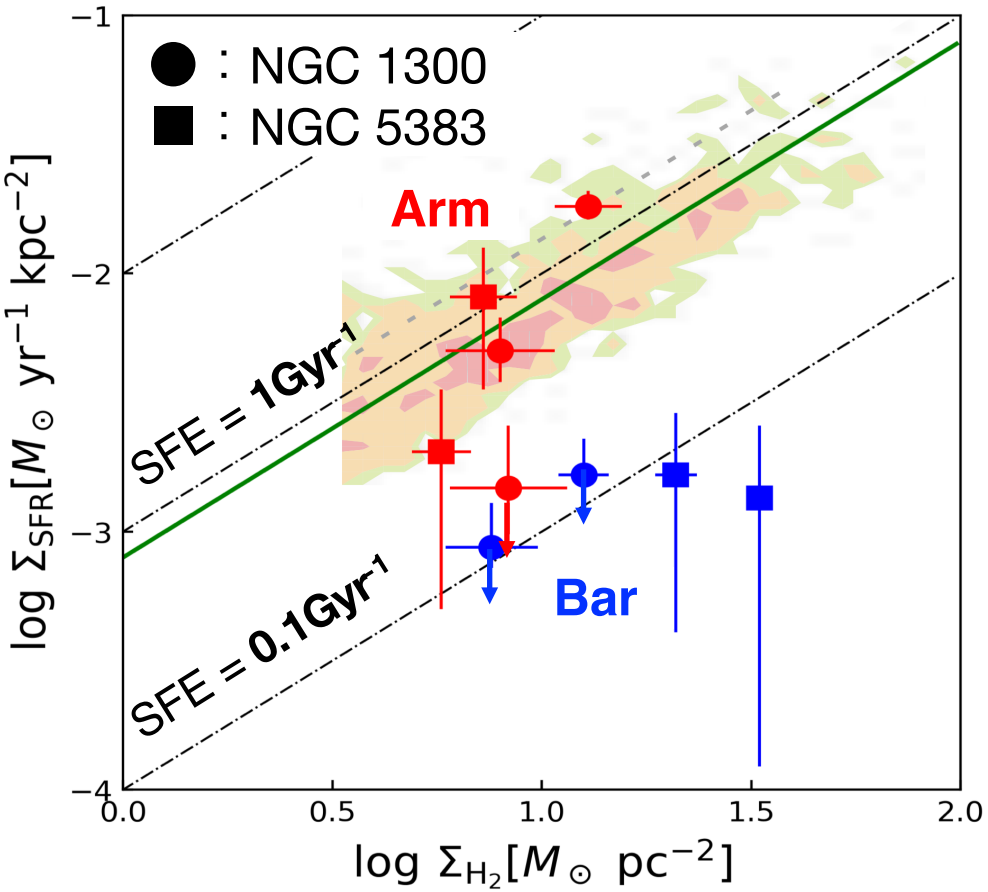




Continuum-subtracted Hα image



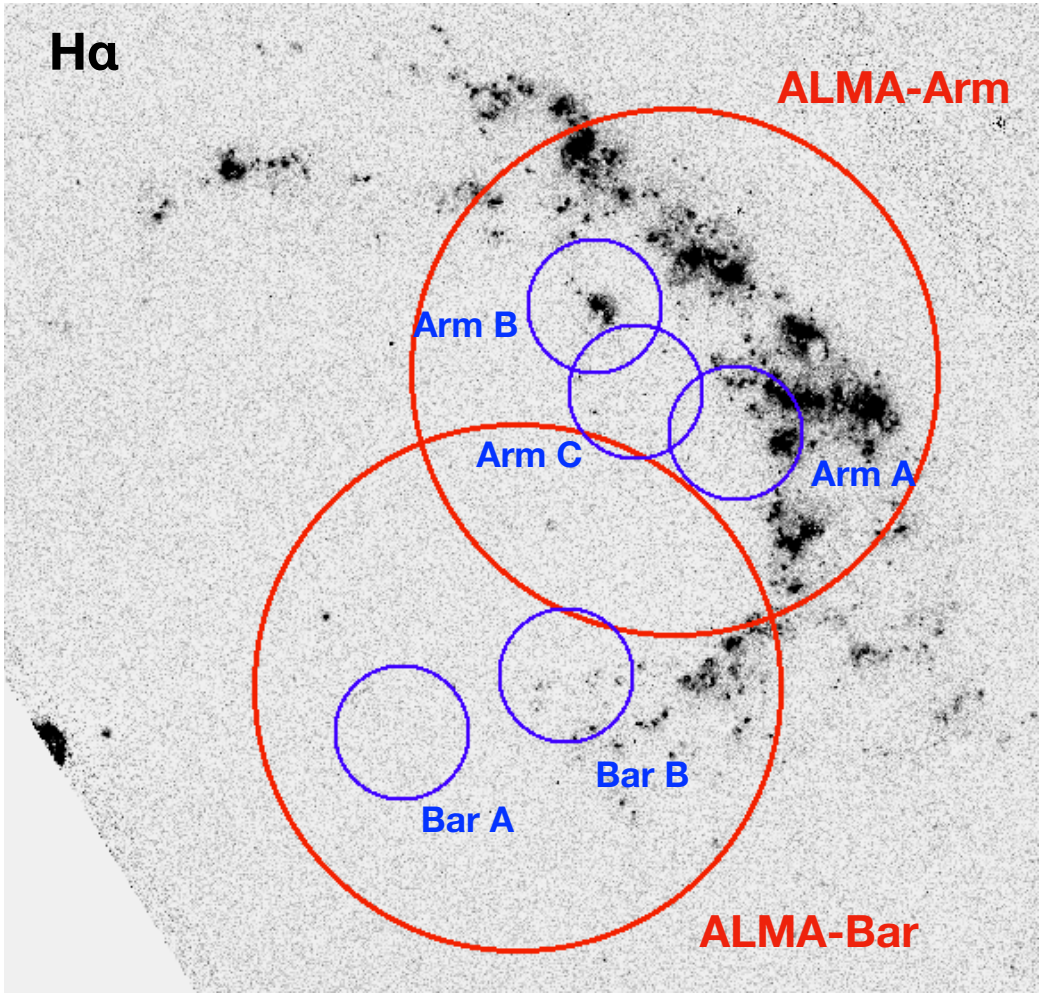
Red : Arm , Blue : Bar
Color regions by Bigiel et al. (2008) show SFEs in 18 nearby spiral galaxies on 0.75 kpc scale.

CO(1-0) observations with ALMA

ALMA Cycle 5 (2017.0.00248.S)

FoV ~ 54”ϕ = 3.2 kpc × 2 points (Arm & Bar)

- beam size ~ 0.”42 × 0.”30 = 42pc × 30pc
- on source time ~ 2.7hrs / point
- rms = 0.7 mJy/beam at 2.0 km/s bin

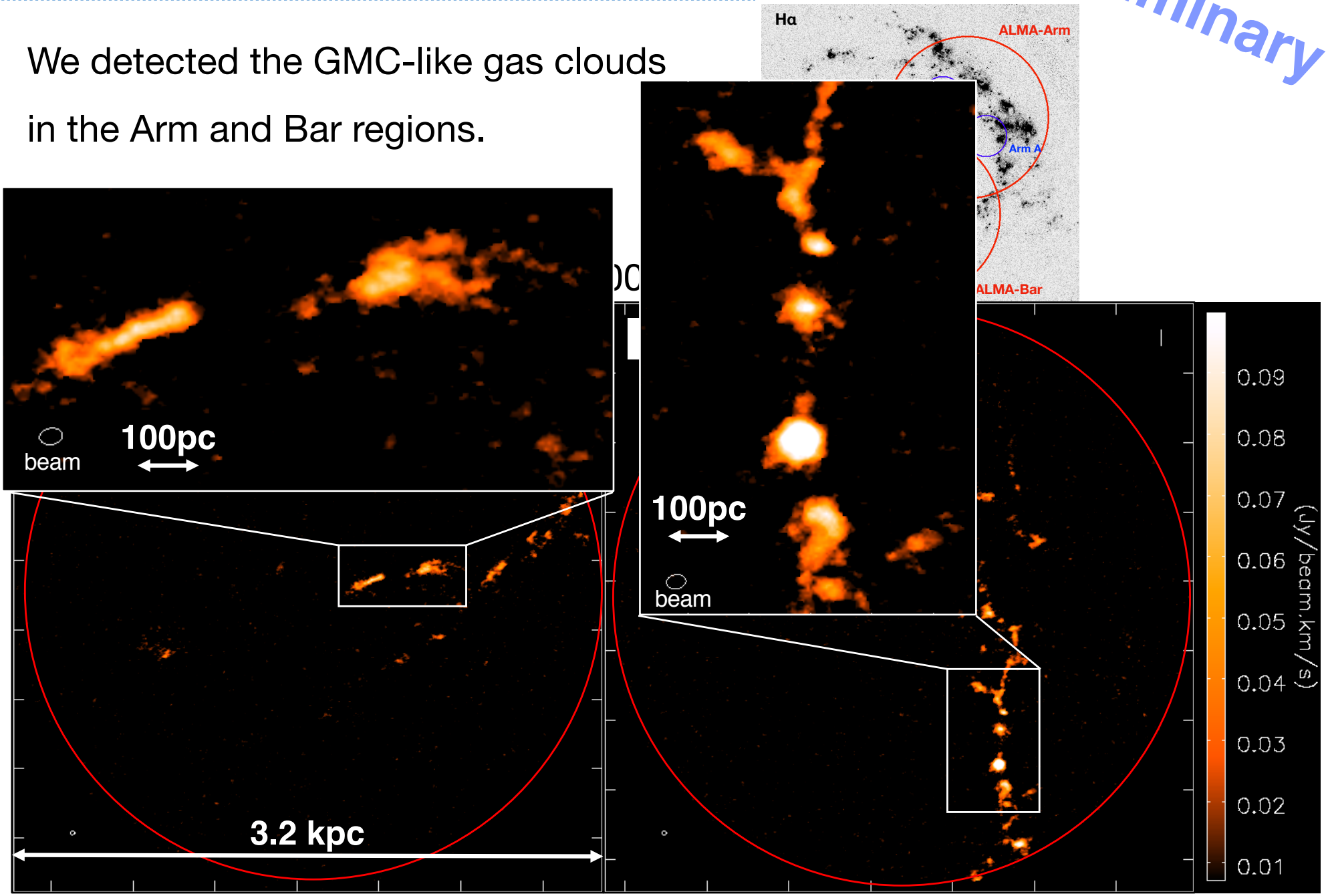


CO imaging with ALMA

Preliminary

We detected the GMC-like gas clouds

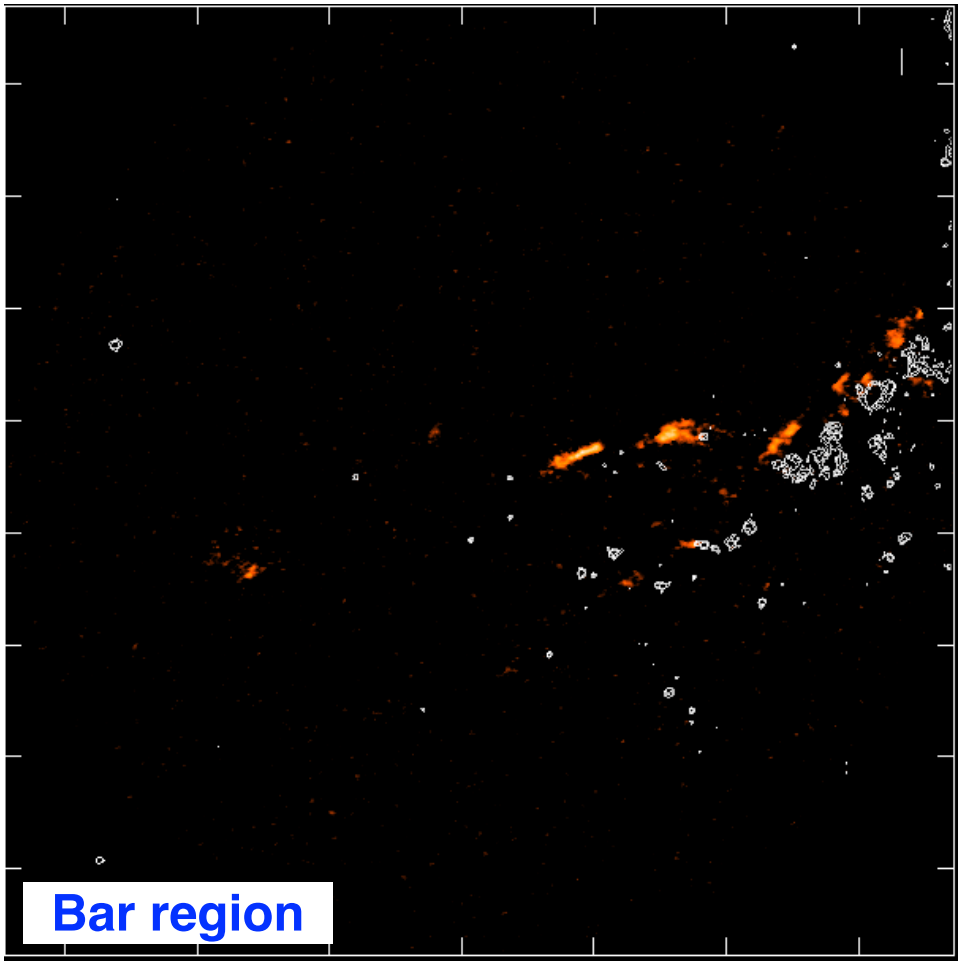
in the Arm and Bar regions.

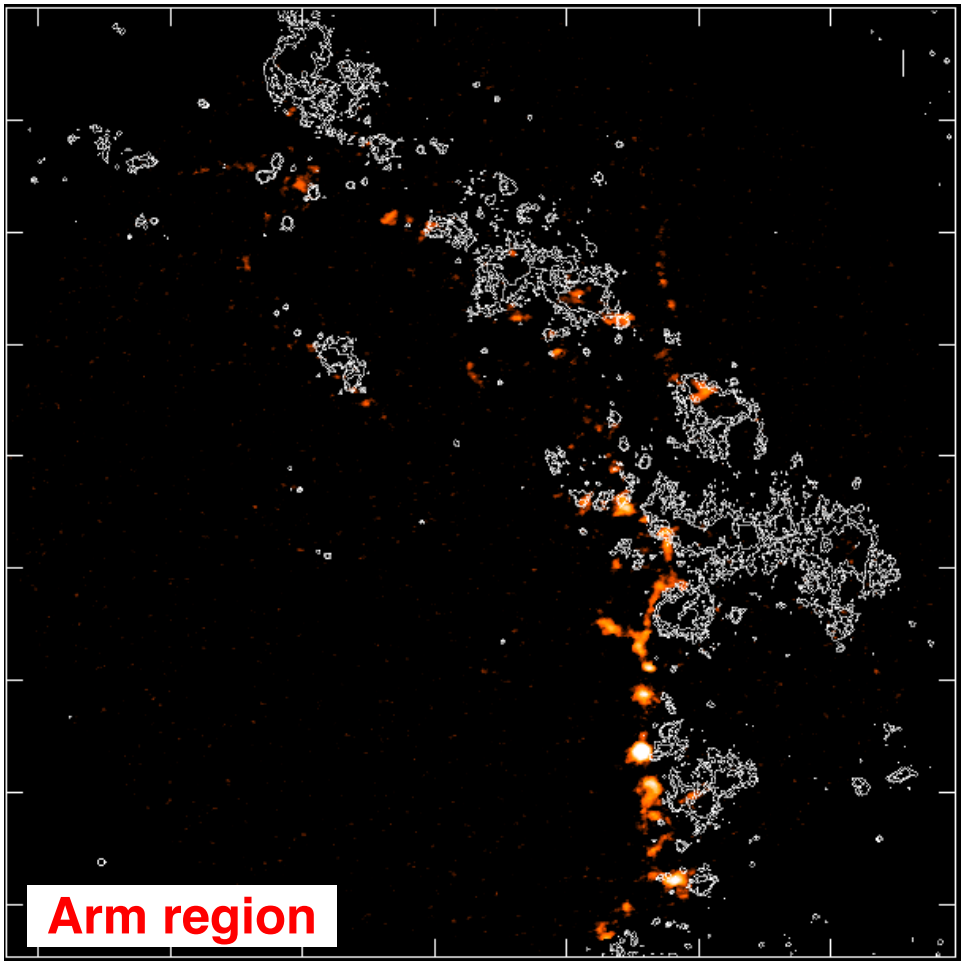


Hα + CO map

Preliminary

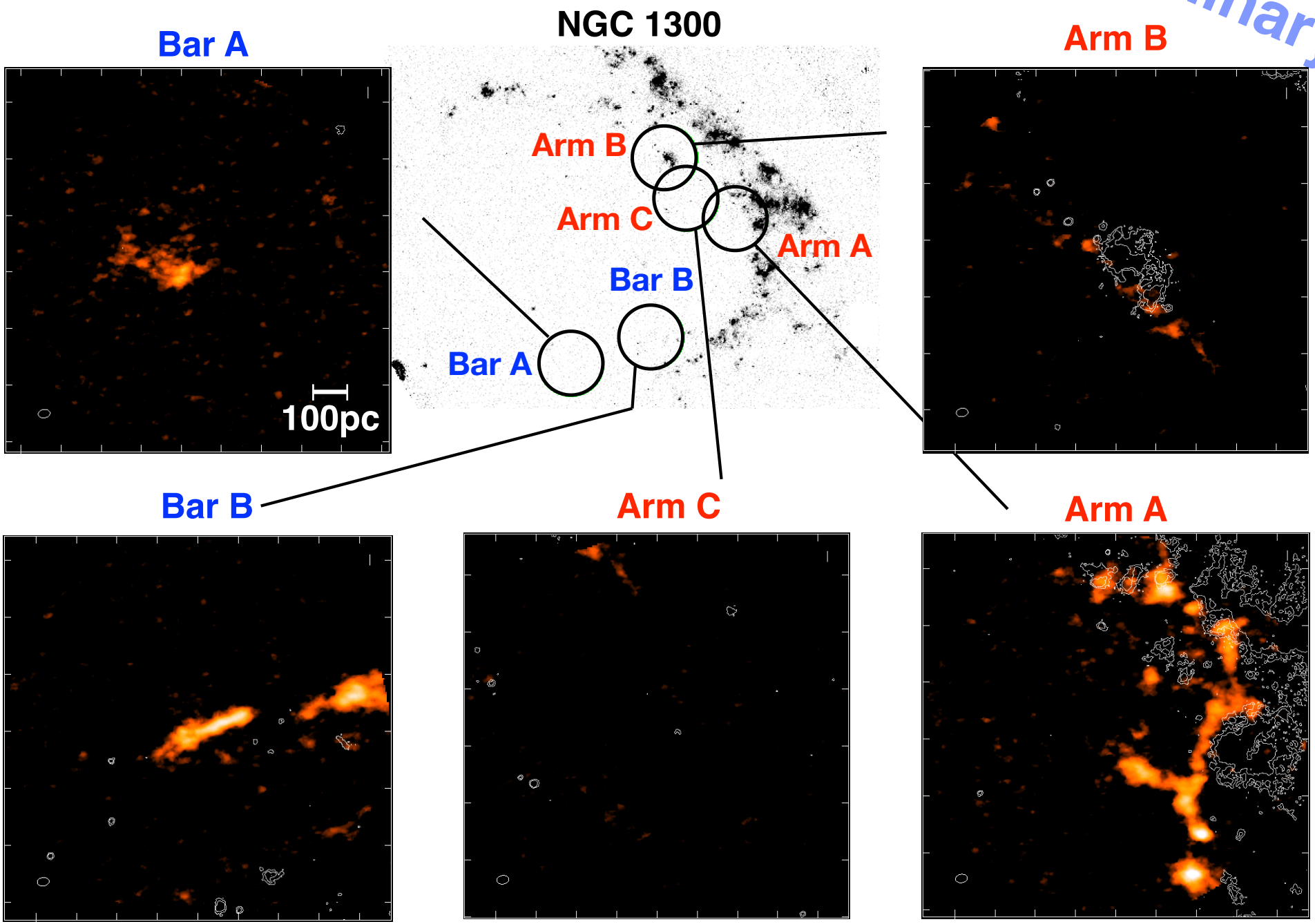
- Arm region : HII regions and GMC-like gas clouds are coexist (e.g., M51).
- Bar region : There are GMC-like gas clouds without HII regions.
  → A possibility that GMCs are formed but massive SFs are not occurred.





Comparison with 45-m observations

Preliminary



Comparison with 45-m observations

Preliminary

We estimate the amount of diffuse emission distributed on the scale larger than 400 pc (= LAS of this ALMA observations).

	L'co(45m) (K km/s pc2)	L'co(ALMA) (K km/s pc2)	fraction (%)
Arm A	6.9×10^6	4.1×10^6	~40
Arm B	4.1×10^6	5.7×10^5	~85
Arm C	4.6×10^6	3.4×10^5	~90
Bar A	3.9×10^6	1.1×10^6	~70
Bar B	6.7×10^6	1.8×10^6	~70

- In Arm A, ALMA has detected 40% of total-flux with NRO 45-m.

  cf. M51: L'_{CO}(PdBI) /L'_{CO}(PdBI+30m) ~ 50 % (Pety et al 2013)

- In Bar, Arm B & C, diffuse gases may be account for the most of total gases.

  →This is the cause of the low SFE in bar regions?

Next Step : identification of GMCs

We are identifying GMCs in NGC1300 by using clumpfind/CPROPS.

Deriving the properties of GMCs

- Radius
- velocity width → M_{vir}
- L_{CO} → M_{mol} → virial parameter
- relative velocity distributions

→ Investigation of the cause of SF suppression.

- Gravitationally unbound cloud in bar regions

  → Large virial parameters of GMCs in bar regions

- The high-speed collision of the clouds

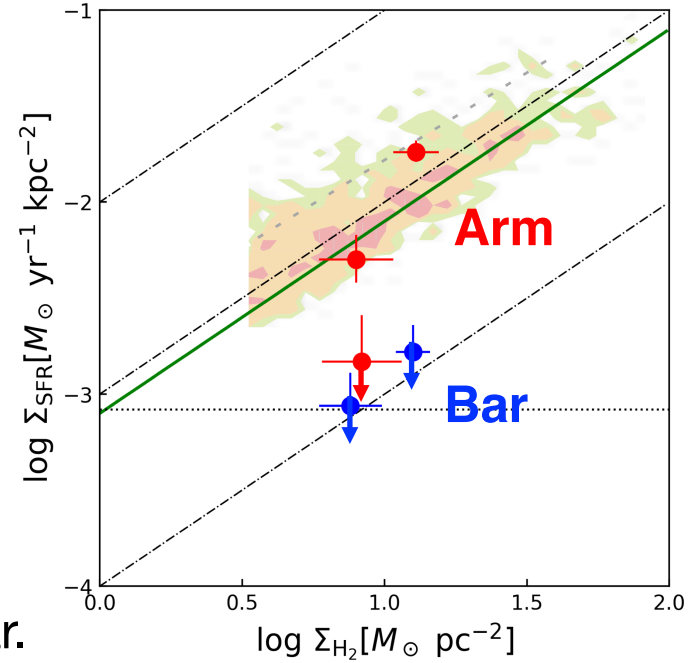
  → High relative velocity of GMCs in bar regions

Summary

- Strongly barred galaxy, NGC1300 is one of the suitable targets to investigate the cause of star formation suppression in bar regions.
- However, CO emission line has not been detected towards the bar regions.

<u>CO observations with the Nobeyama 45-m telescope</u>

- The molecular gases do exist in the bar regions without associating clear HII regions.
- SFEs in bar of NGC1300 are ~10 times smaller than that in arm.



<u>CO observations with the ALMA</u>

- We detected the GMC-like gas clouds in the arm and bar.
- Molecular gas may be mostly distributed on scales larger than 400 pc.
- We will identify GMCs and investigation of the cause of SF suppression.