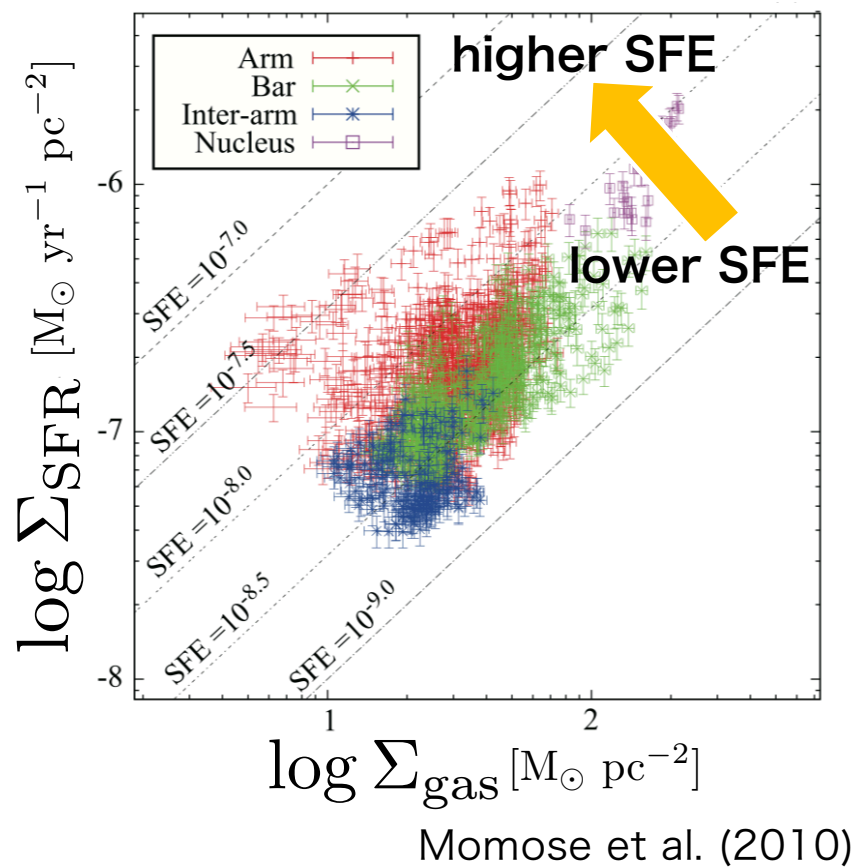# Star Formation in a Barred Spiral Galaxy in Simulations

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1. Introduction

Momose et al. (2010)

$\Sigma_{gas} = $ gas surface density

$\Sigma_{SFR} = $ SFR surface density

- Star formation efficiency

$$\mathrm{SFE} \; [\mathrm{yr}^{-1}] = \frac{\Sigma_{\mathrm{SFR}} \; [\mathrm{M}_\odot \; \mathrm{yr}^{-1} \; \mathrm{pc}^{-2}]}{\Sigma_{\mathrm{gas}} \; [\mathrm{M}_\odot \; \mathrm{pc}^{-2}]}$$

- SFE in bar is lower than in spiral arms.
  - ➤ This mechanism is not well understood yet.

1. Introduction

Perform a simulation of a barred spiral galaxy

the star formation criteria used in cosmological simulations

Estimate SFE in bar and arm region

Investigate whether the star formation criteria used in cosmological simulations can reproduce the observational result of barred spiral galaxies.
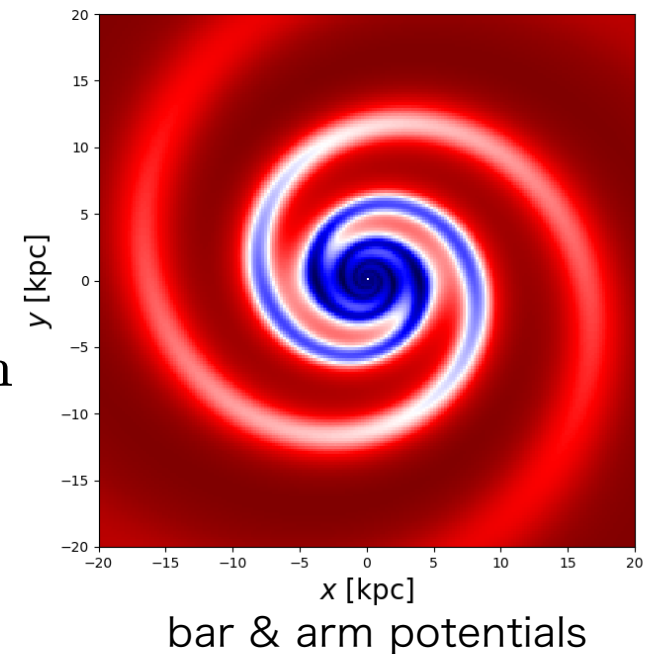
2. Simulation

- Code : GIZMO (Hopkins 2015)

- Barred spiral galaxy
  ➢galactic potentials
  $$\Phi_{\mathrm{bulge}} + \Phi_{\mathrm{disk}} + \Phi_{\mathrm{halo}} + \Phi_{\mathrm{bar}} + \Phi_{\mathrm{arm}}$$

- N_{gas} : $\sim 1.5 \times 10^{7}$

- Mass per a gas particle : $\sim 800\ \mathrm{M}_{\odot}$

bar & arm potentials

2. Simulation

- Star formation criteria (Hopkins+ 2013, 2018)
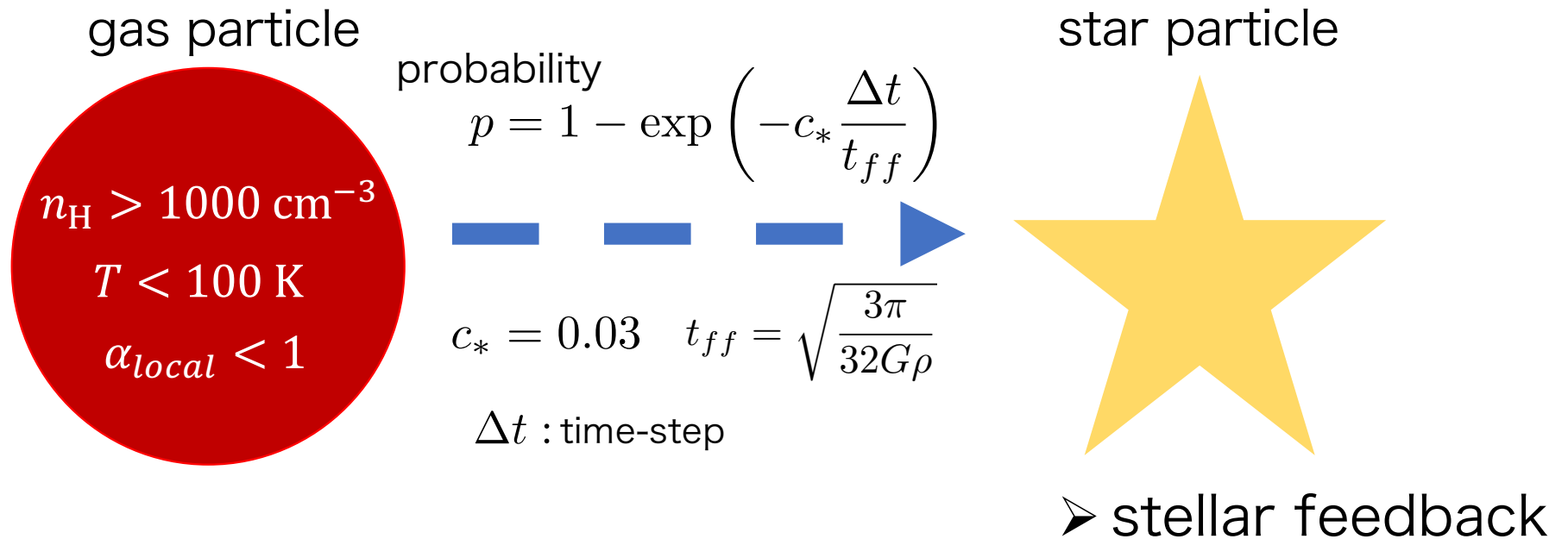 - virial parameter $\alpha_{local} \rightarrow$ locally gravitationally bound or not

gas velocity　　sound speed　　gas particle size

$$\alpha_{local} = \frac{\|\boldsymbol{\nabla} \otimes \boldsymbol{v}\|^2 + (c_s/h)^2}{8\pi G \rho}, \quad \|\nabla \otimes \boldsymbol{v}\|^2 = \sum_{i,j} \left(\frac{\partial v_i}{\partial x^j}\right)^2$$

gas density
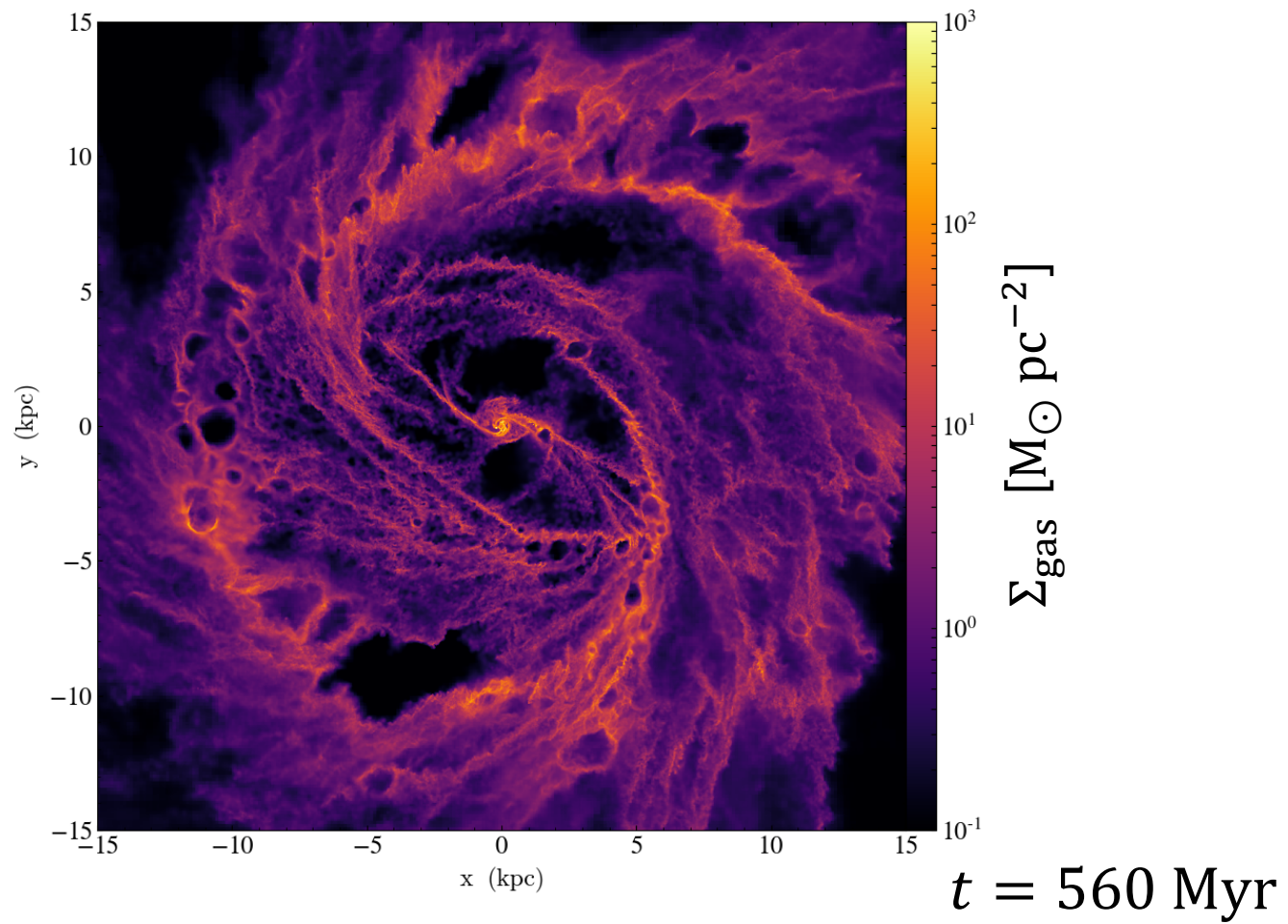
- $\alpha_{local} < 1 \Rightarrow$ gas is locally gravitationally bound.
- $\alpha_{local} > 1 \Rightarrow$ gas is locally gravitationally unbound.

2. Simulation

- Star formation criteria

gas particle

$n_{\mathrm{H}} > 1000\ \mathrm{cm}^{-3}$

$T < 100\ \mathrm{K}$

$\alpha_{local} < 1$

probability

$$p = 1 - \exp\left(-c_* \frac{\Delta t}{t_{ff}}\right)$$

$c_* = 0.03$ $t_{ff} = \sqrt{\dfrac{3\pi}{32G\rho}}$

Δt : time-step
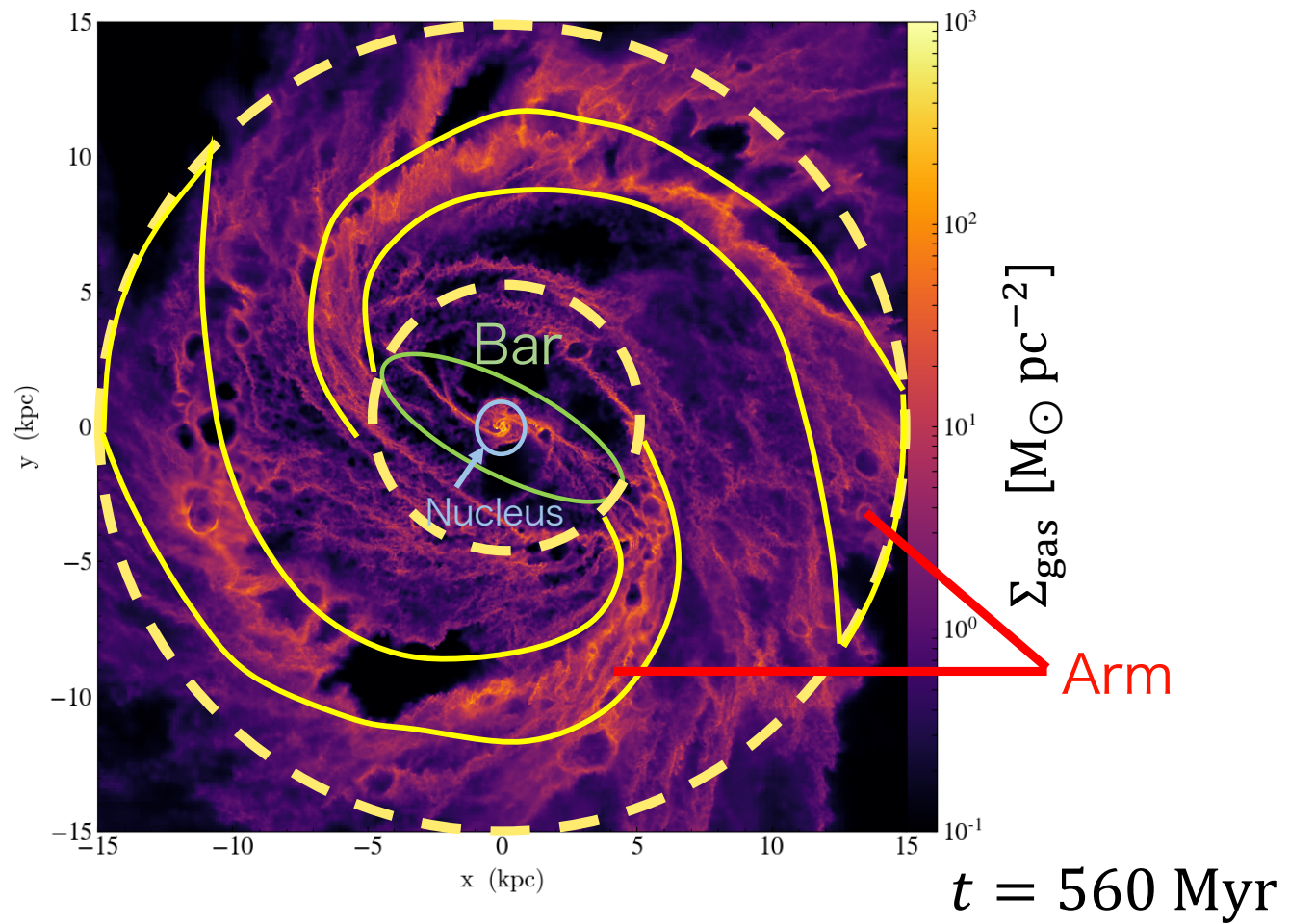
star particle

➢ stellar feedback

3. Result

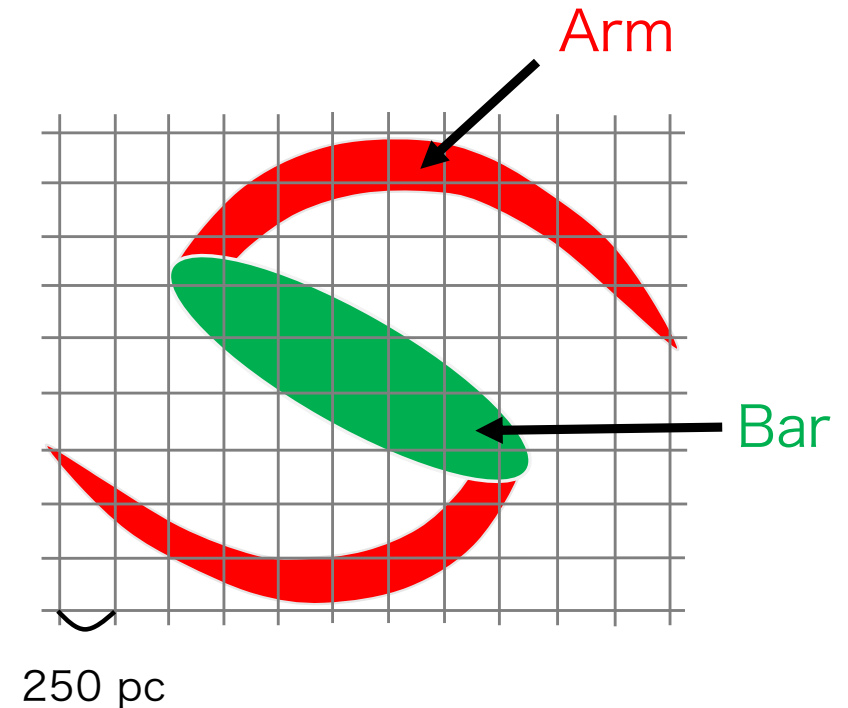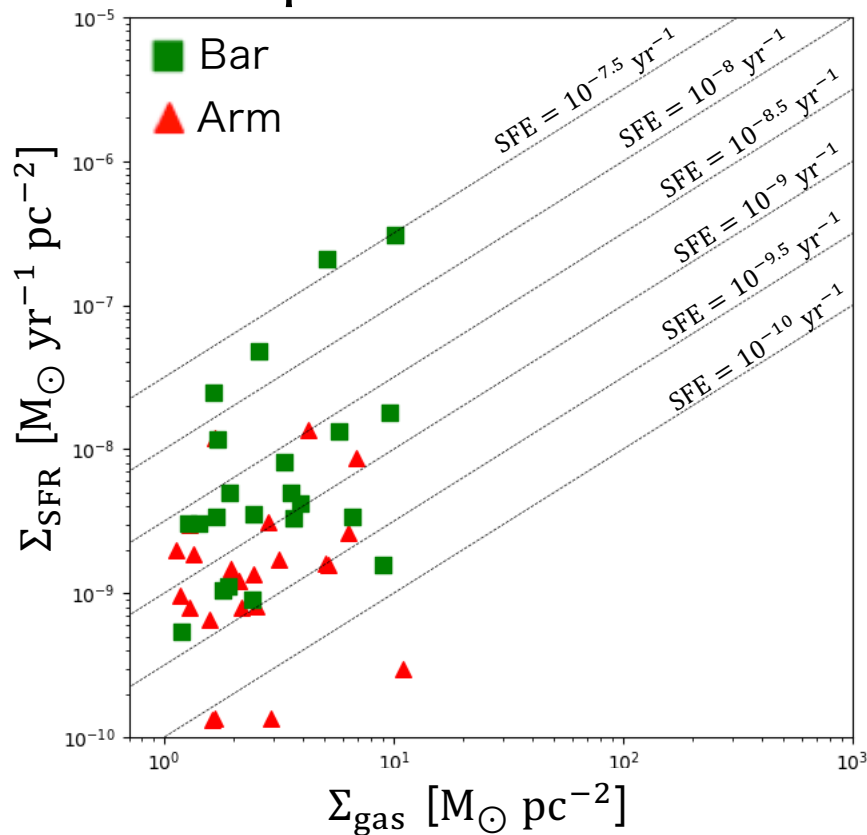$t = 560$ Myr

3. Result

$t = 560$ Myr

3. Result

- analysis (KS plot)
  1. divide whole region into cells whose size is comparable to observational resolution (250 pc)
  2. estimate Σ_{gas} and Σ_{SFR} in each cell

- 100 Myr constant SFR (Calzetti+ 2007)

$$\mathrm{SFR} = \frac{\mathrm{M}_{\mathrm{star}}(< 100\ \mathrm{Myr})}{100\ \mathrm{Myr}}$$

Arm

Bar

250 pc

3. Result

KS plot

median SFE (Bar) $\sim 2 \times 10^{-9}$ yr^{-1}

median SFE (Arm) $\sim 6 \times 10^{-10}$ yr^{-1}
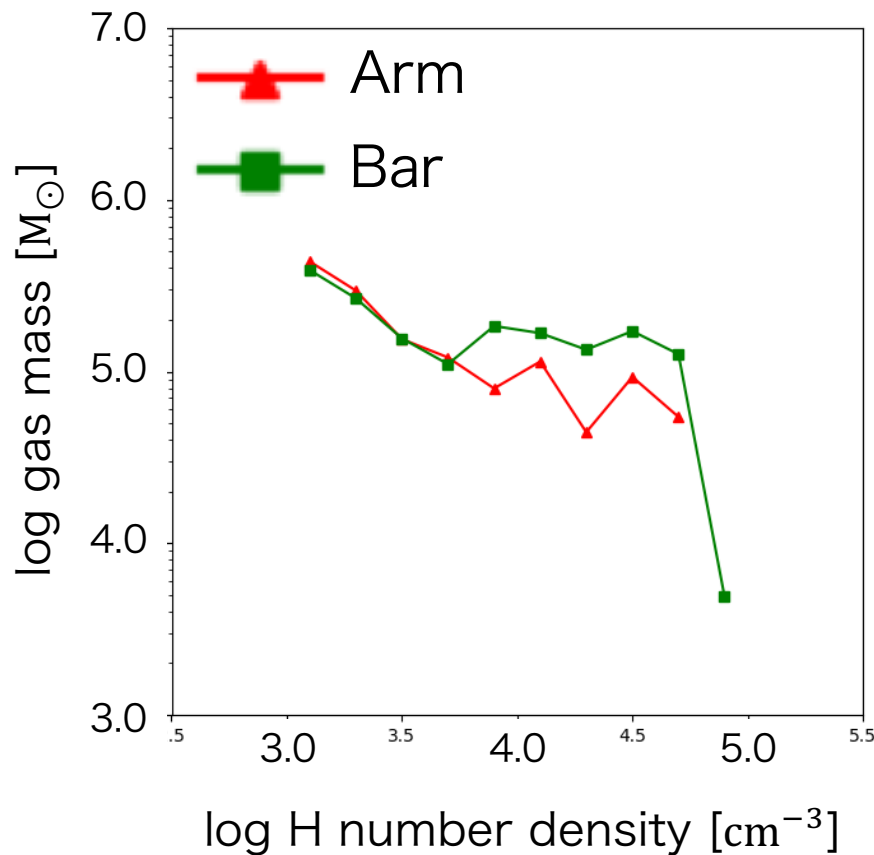
SFE in bar is higher than in arm.

SF criteria used in cosmological simulations cannot reproduce the observational results.

Need to introduce better models for star formation in galaxy simulations
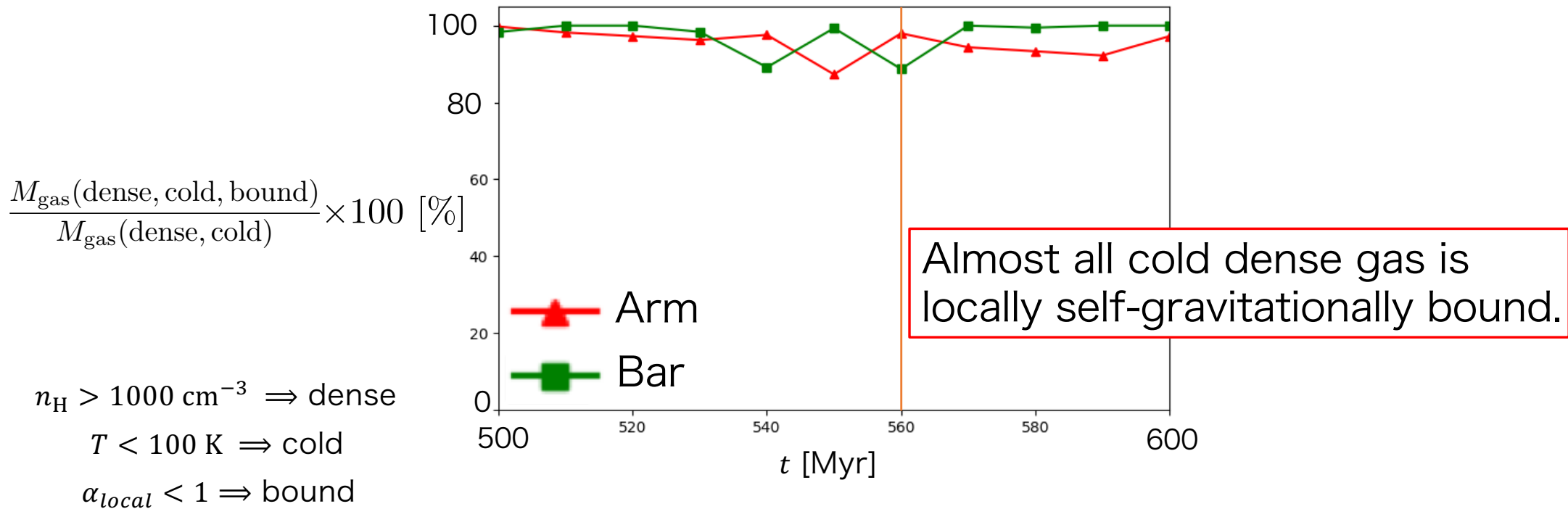
3. Result

total gas mass of each density

- $10^3 < n_H < 10^{3.8}$ [cm^{-3}]
  - ➤Almost the same gas mass in bar and arm.

- $10^{3.8} < n_H$ [cm^{-3}]
  - ➤More gas in bar than in arm.

SFR in bar is higher than in arm.

3. Result

How much cold dense gas is locally self-gravitationally bound

$$\frac{M_{\mathrm{gas}}(\mathrm{dense,\,cold,\,bound})}{M_{\mathrm{gas}}(\mathrm{dense,\,cold})} \times 100 \ [\%]$$

$n_{\mathrm{H}} > 1000 \ \mathrm{cm}^{-3} \Rightarrow$ dense

$T < 100 \ \mathrm{K} \Rightarrow$ cold

$\alpha_{local} < 1 \Rightarrow$ bound

Almost all cold dense gas is locally self-gravitationally bound.

5. Conclusion

- Recent observations of barred spiral galaxies suggest that SFE in bar is lower than in arm.
- We perform the simulation to investigate whether the star formation criteria used in cosmological simulations can reproduce the observational results of barred spiral galaxies.
- The star formation criteria cannot reproduce the observational results.
- Almost all gas which is cold and dense in bar and arm is locally self-gravitationally bound.