Simulations of Giant Molecular Cloud Formation in the Barred Galaxy, M83, using Enzo

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  Different star formation activity in each region of a barred galaxy

- Simulation

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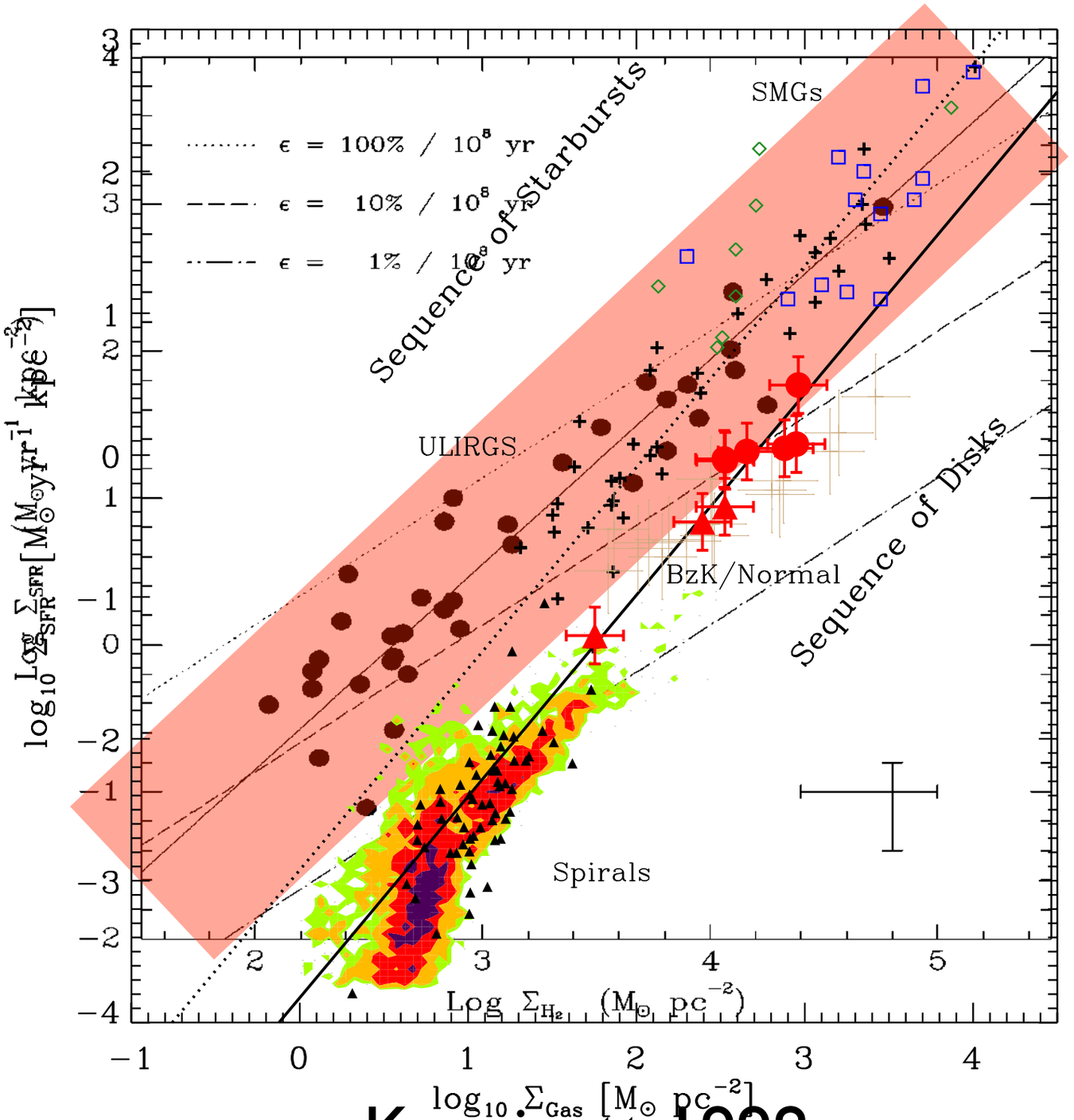
- Results

- Conclusions

Introduction

Correlation between gas and star formation

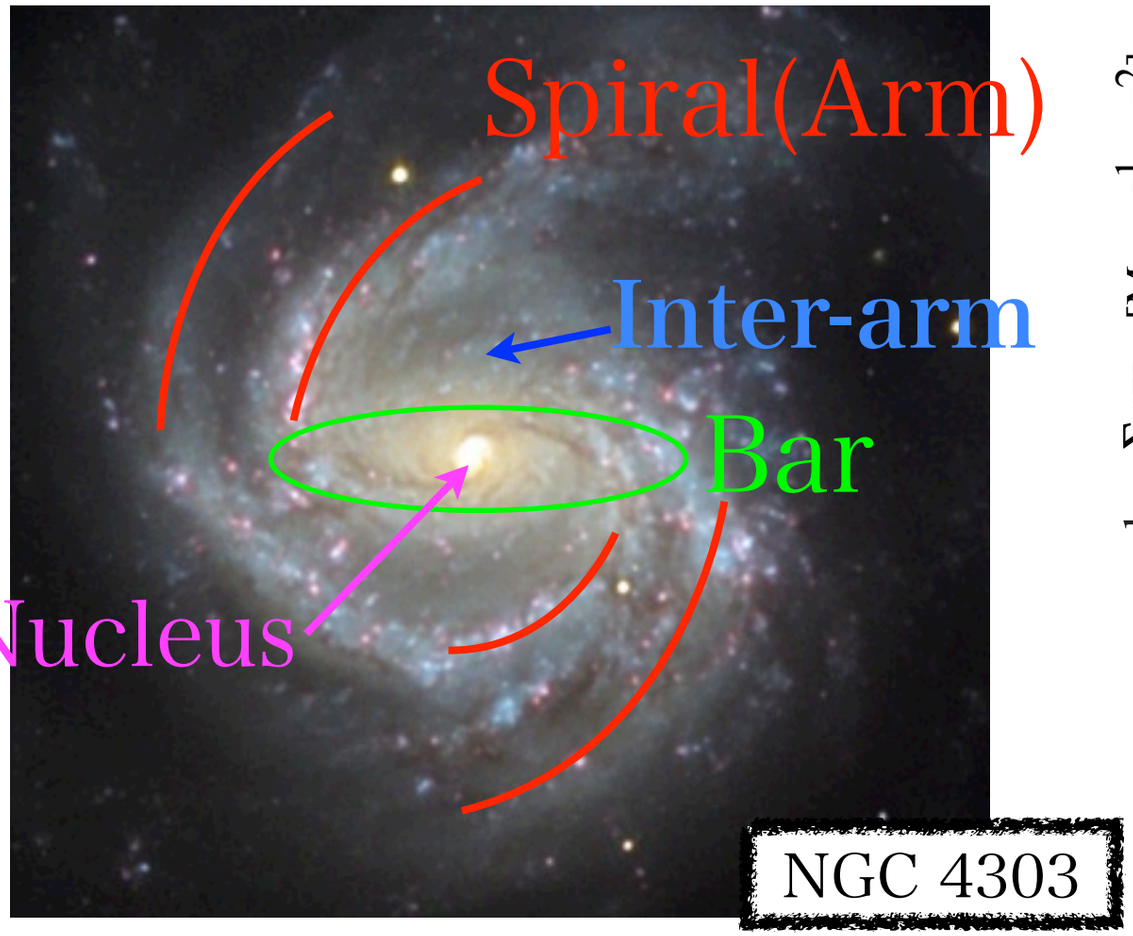
- Star formation is one of the key processes governing the evolution of galaxies.
- Many observations of nearby disc galaxies indicate an empirical relation between the gas surface density and the star formation rate surface density.

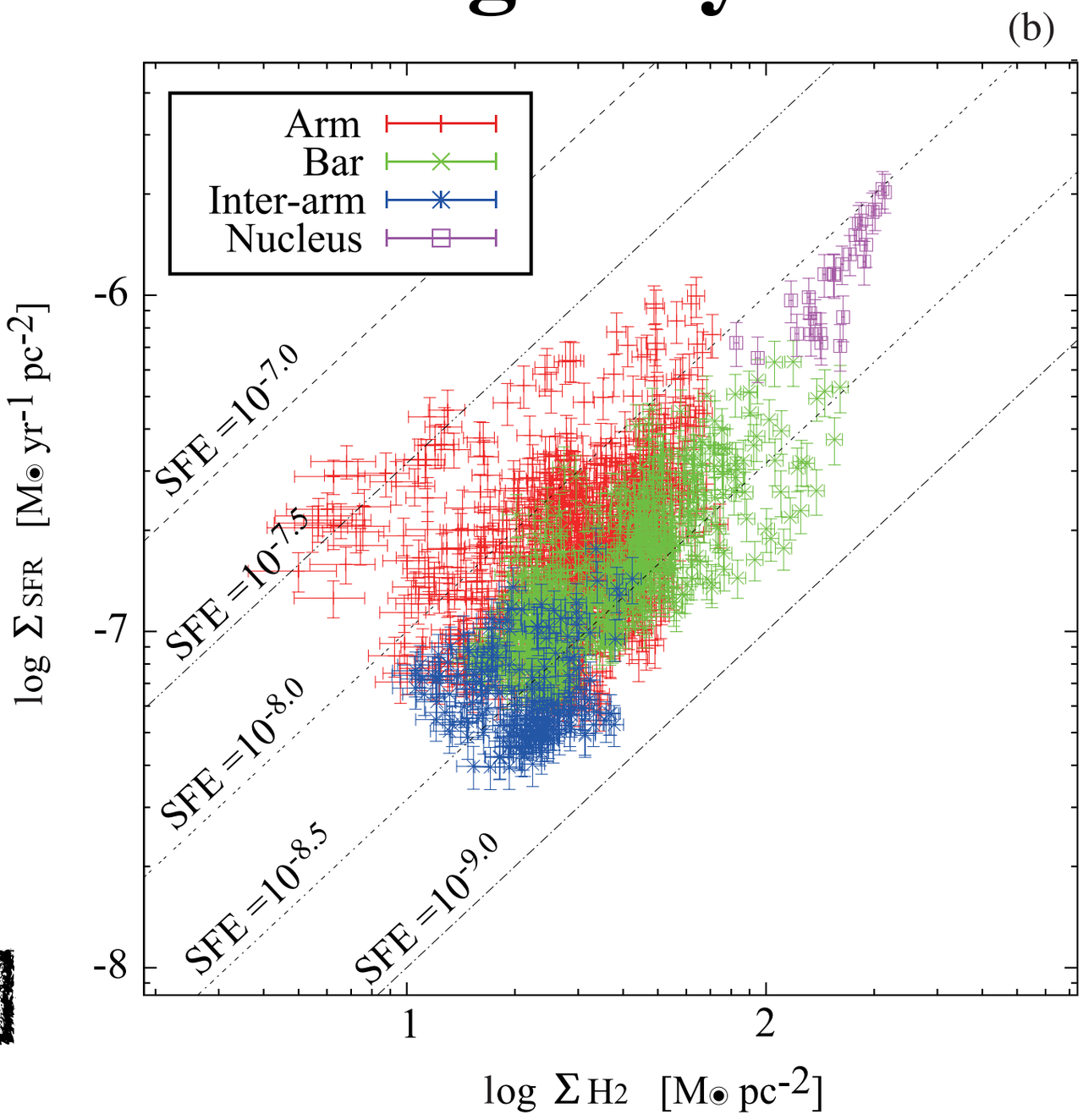


Kennicutt 1998
Daddi et al. 2010

Different star formation activity in each region of a barred galaxy

Momose et al. 2010





- Star formation rate (SFR) and efficiency are twice as high in the spiral arms as in the bar.

Our study

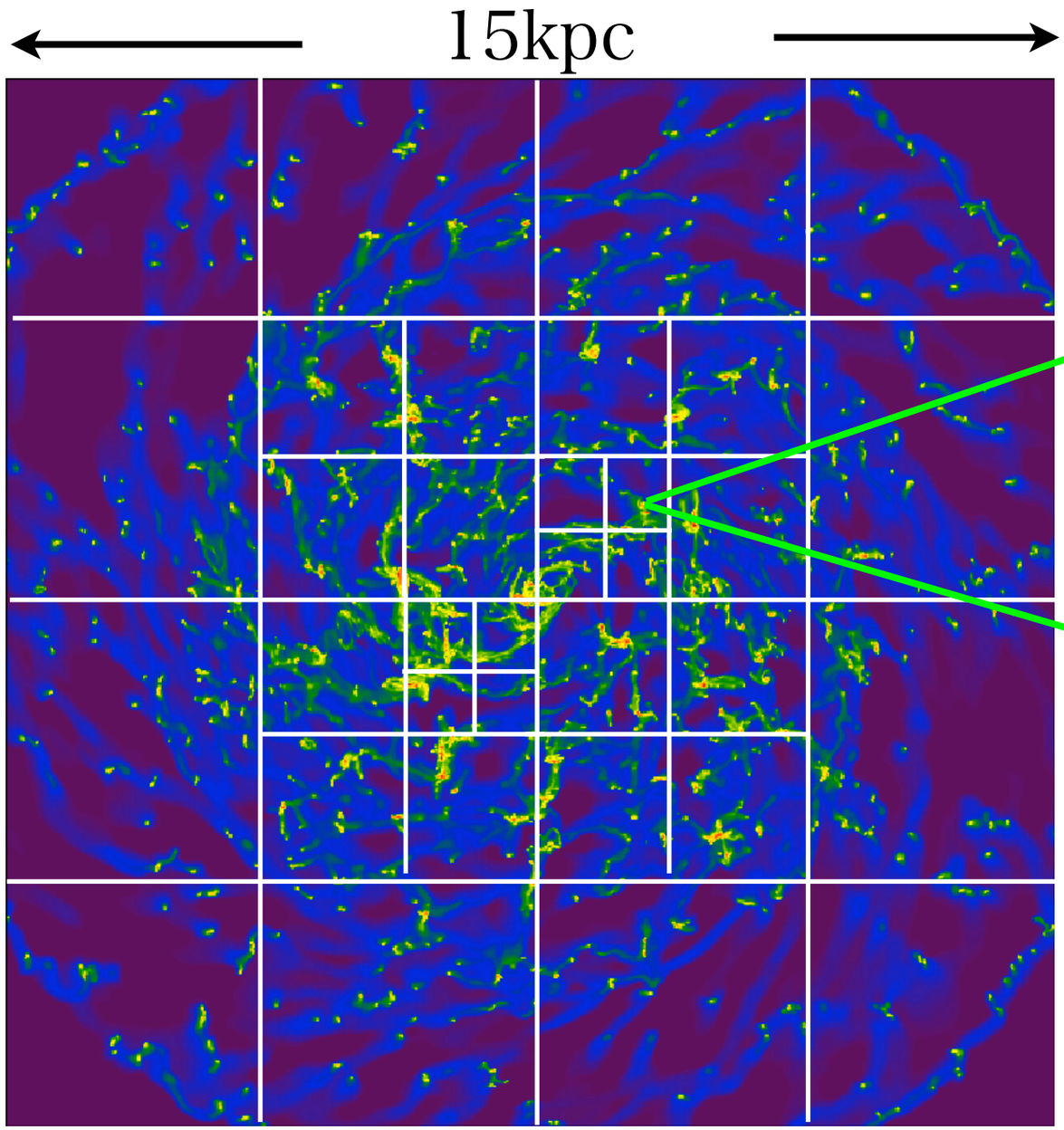
- What is the physical process that creates this difference?
- Stars are formed in giant molecular clouds (GMCs).
- Could there be a difference in the properties of the GMCs in each region?

We performed 3D hydrodynamical simulations of the barred galaxy M83 at high resolution and investigated the properties of the GMCs.

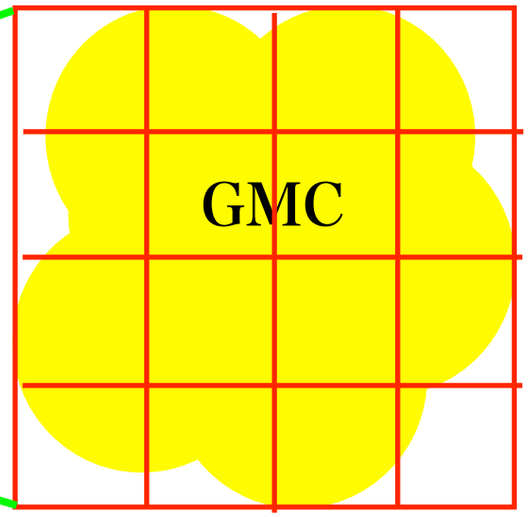
Simulation

The code

- Enzo : a 3D adaptive mesh refinement (AMR) hydrodynamics code



Box size : $(50\,\mathrm{kpc})^3$ Root grid : 128^3



3pc !!

refinement level : n=7

$$\Delta x_n = \Delta x_0 \times 2^{-n}$$

Radiative cooling : T > 300K

Self-gravity of gas

No star formation or feedback

We used Cray XT4 @ CfCA

CPU : 256 Time : ~ 2 weeks

The Initial Structure of the Galactic Disc

Observational gas distribution

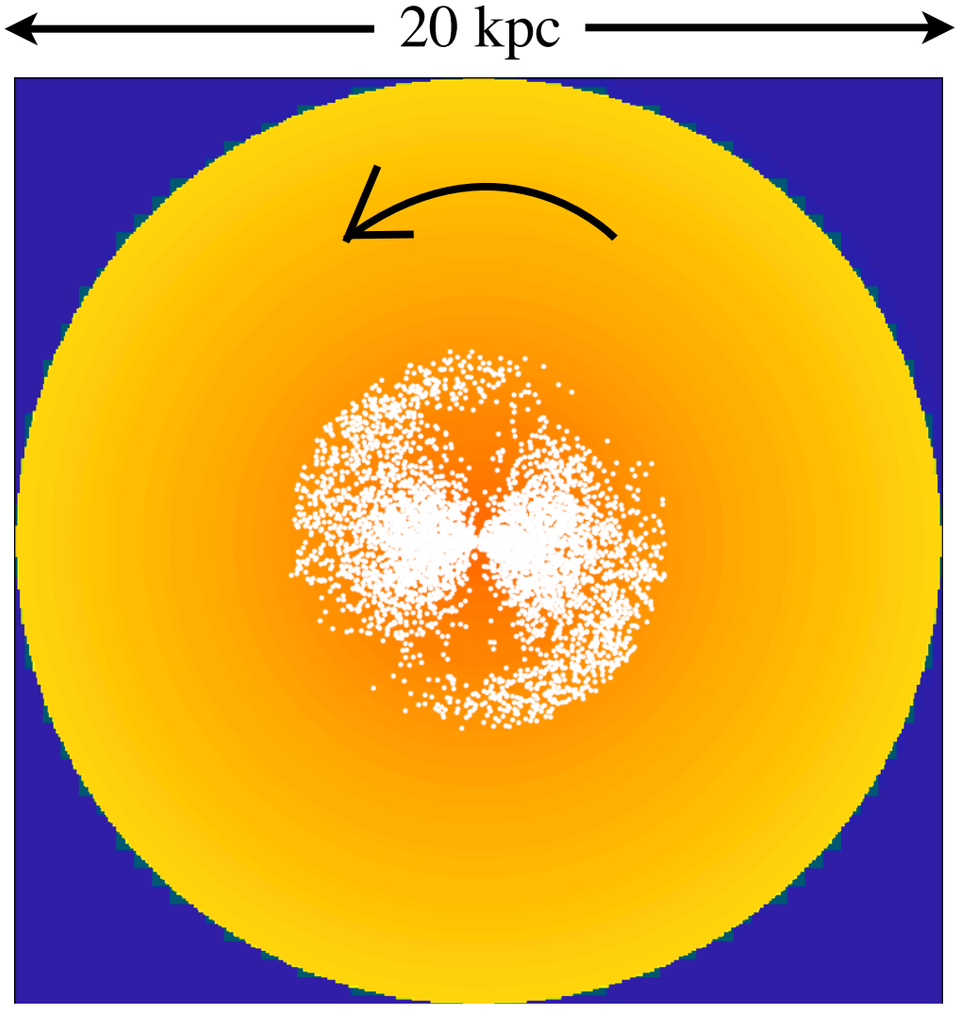
$$\rho(\mathrm{r},\mathrm{z}) = \rho_0 \exp\left(-\frac{\mathrm{r}}{2265\mathrm{pc}}\right) \mathrm{sech}^2\left(\frac{\mathrm{z}}{100\mathrm{pc}}\right) \mathrm{M}_\odot/\mathrm{pc}^3$$

H_2 gas distribution from
Lundgren et al. (2004)

Stellar potential

(Hirata 2009 Private communication)

- disc + bar + spiral
- 10^5 fixed motion star particles
- The pattern speed of the bar and spiral is 54 km/s/kpc.



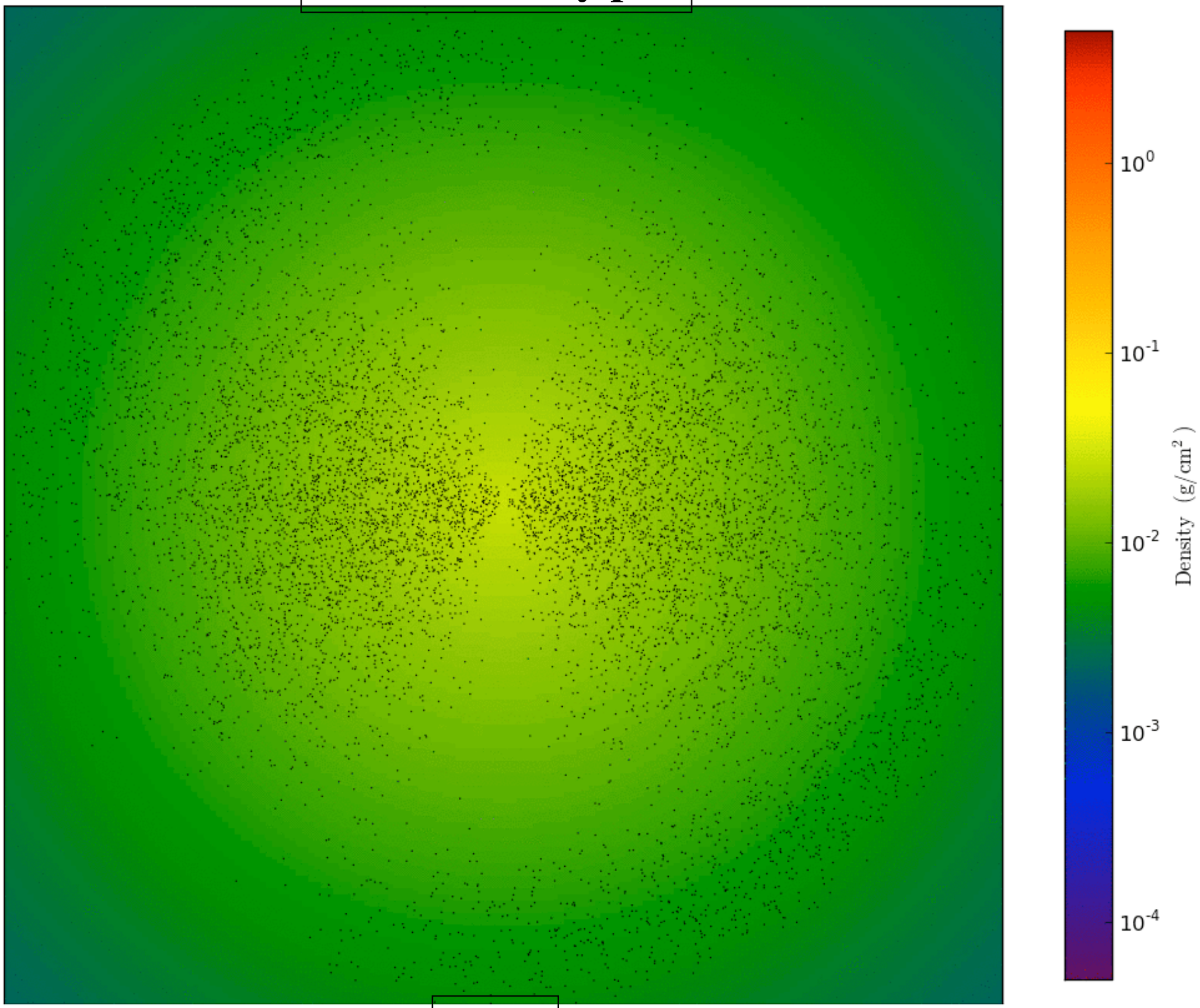
bar + arm star particles are shown

Static dark matter potential

NFW profile $\rho(\mathrm{r}) = \dfrac{\rho_0}{(\mathrm{r}/\mathrm{r_s})(1+\mathrm{r}/\mathrm{r_s})^2}$

Results

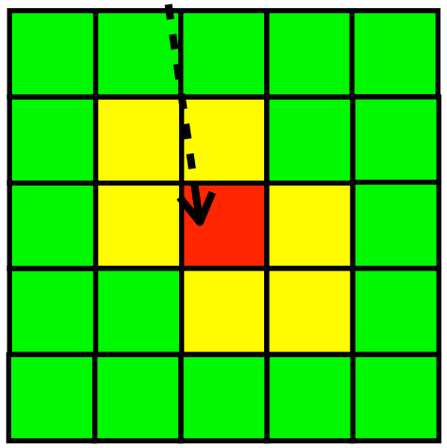
Surface density plot



Cloud identification

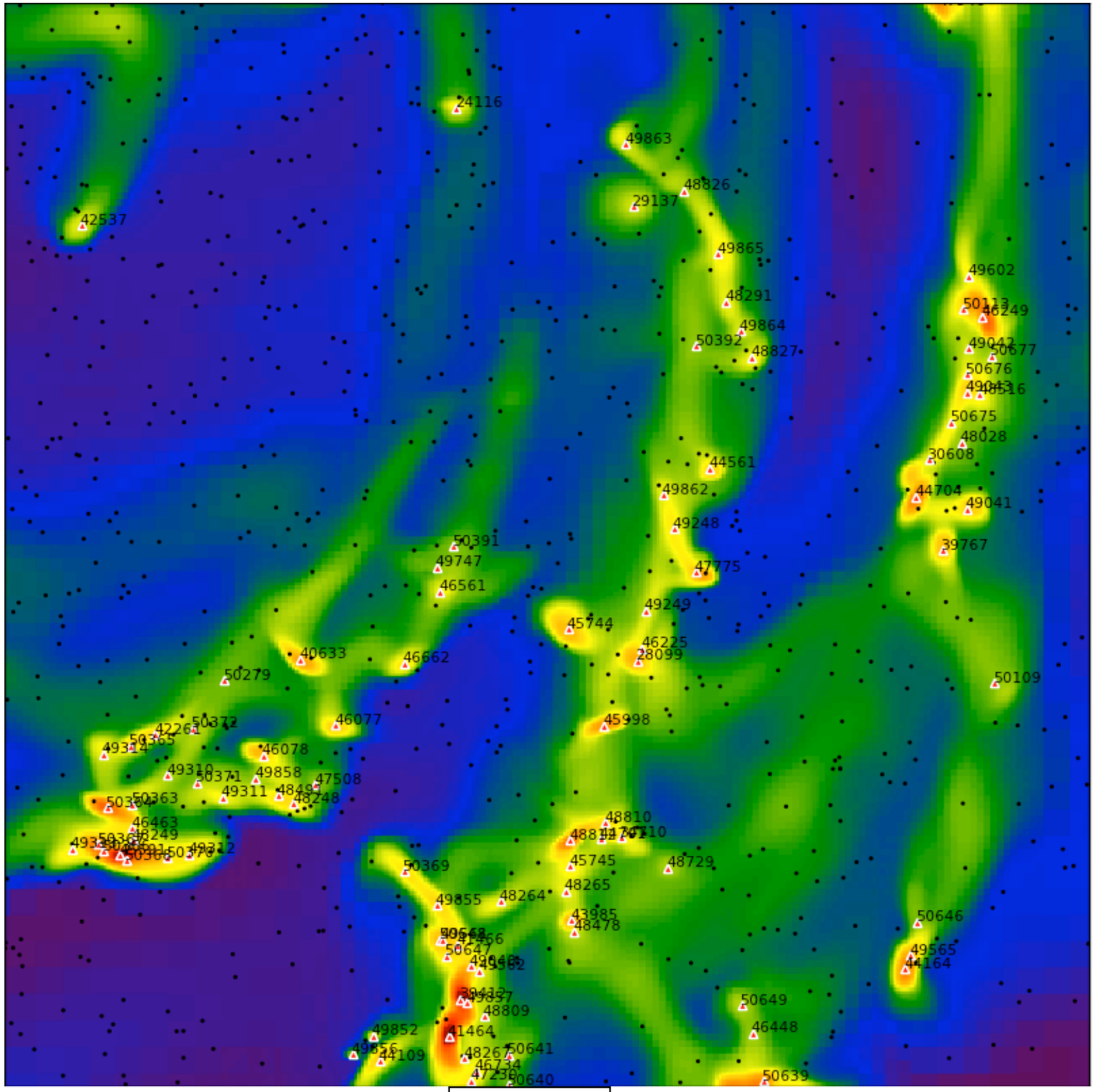
Find peaks in the gas density field with

$$\rho \geqq 100\mathrm{cm}^{-3}$$

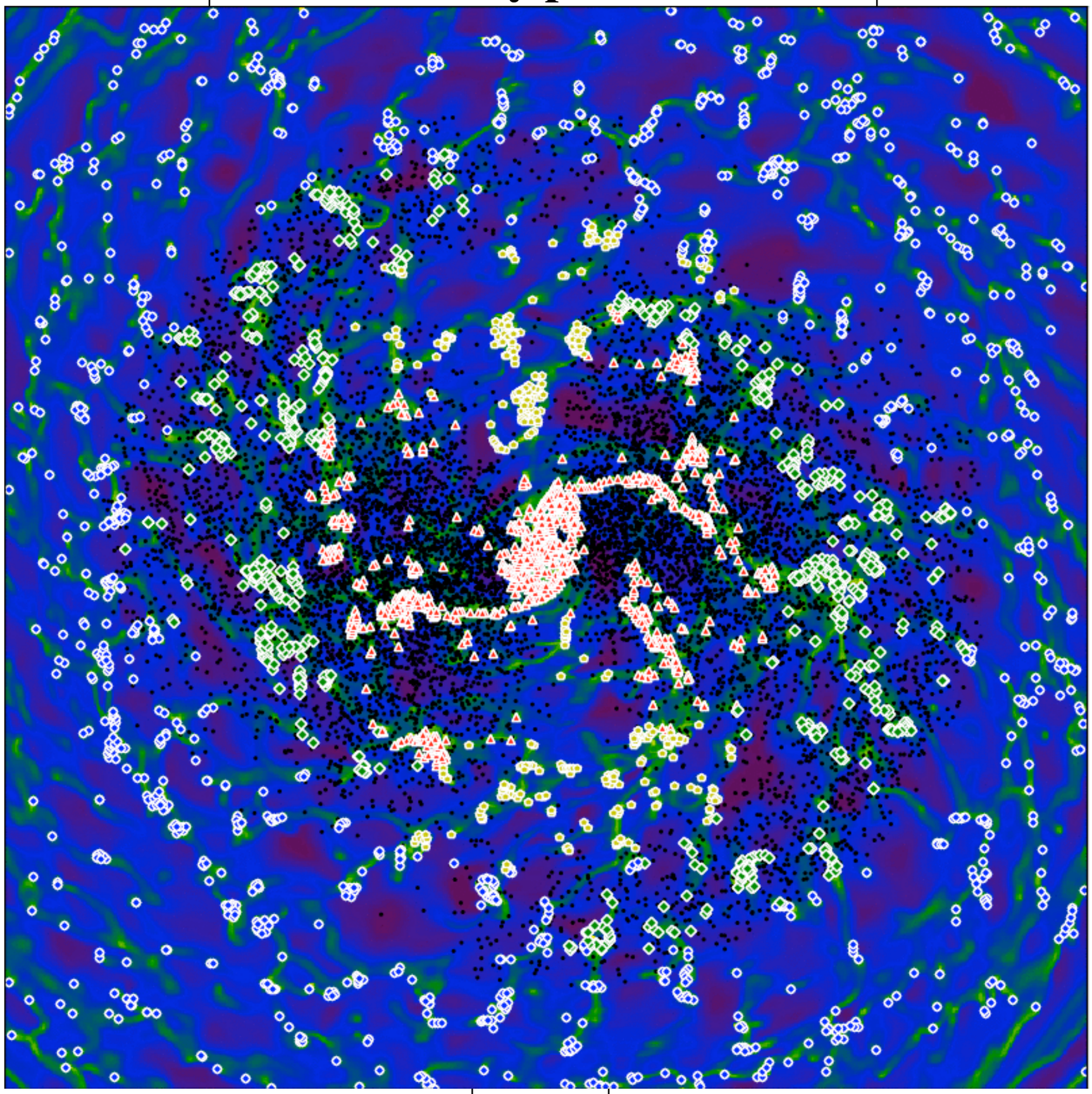


Search peak neighbours for cells also with

$$\rho \geqq 100\mathrm{cm}^{-3}$$



Surface density plot with clouds



10kpc

disc clouds

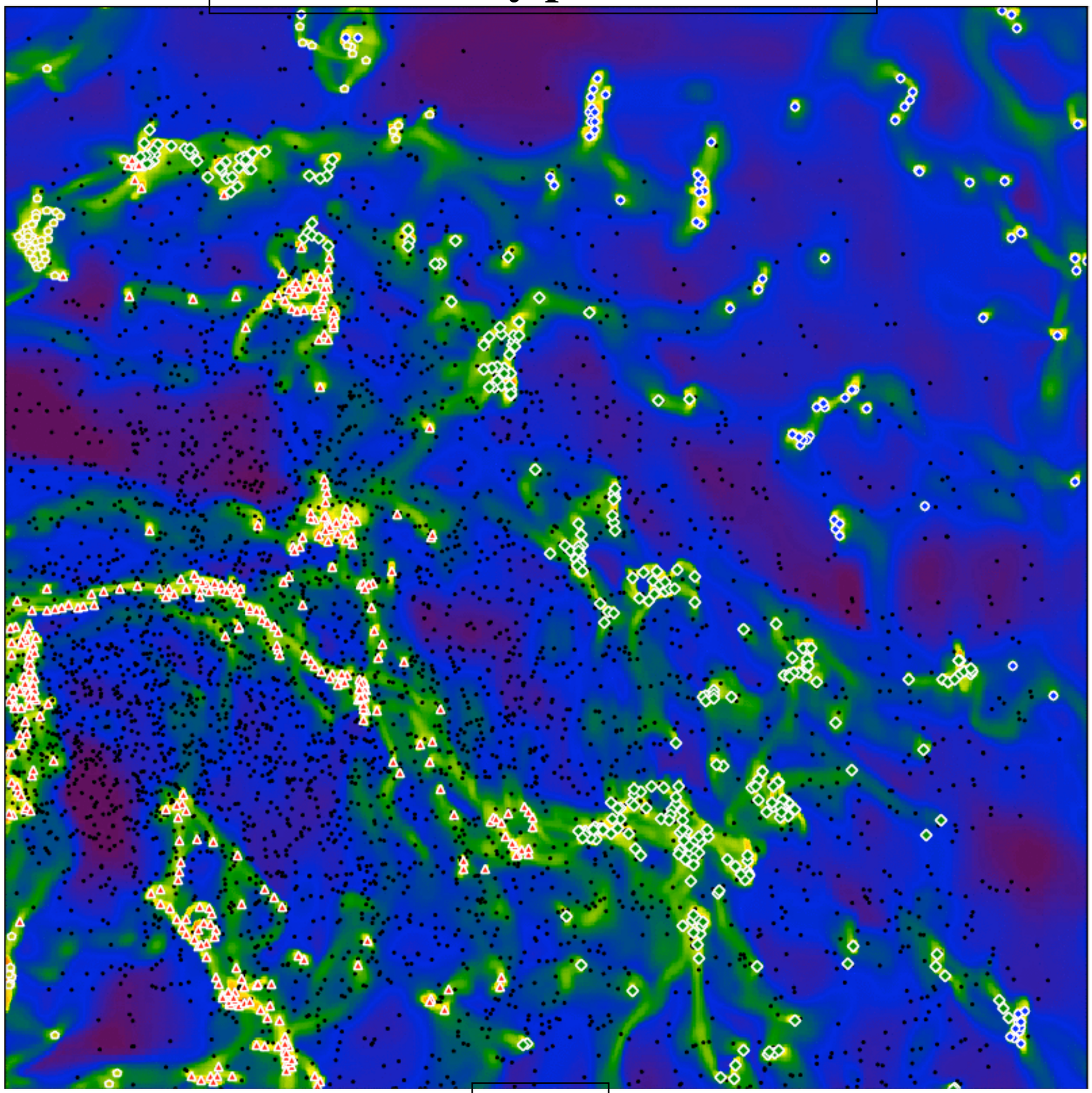
spiral clouds

bar clouds

inter-arm clouds

star particles

Surface density plot with clouds



4kpc

disc clouds

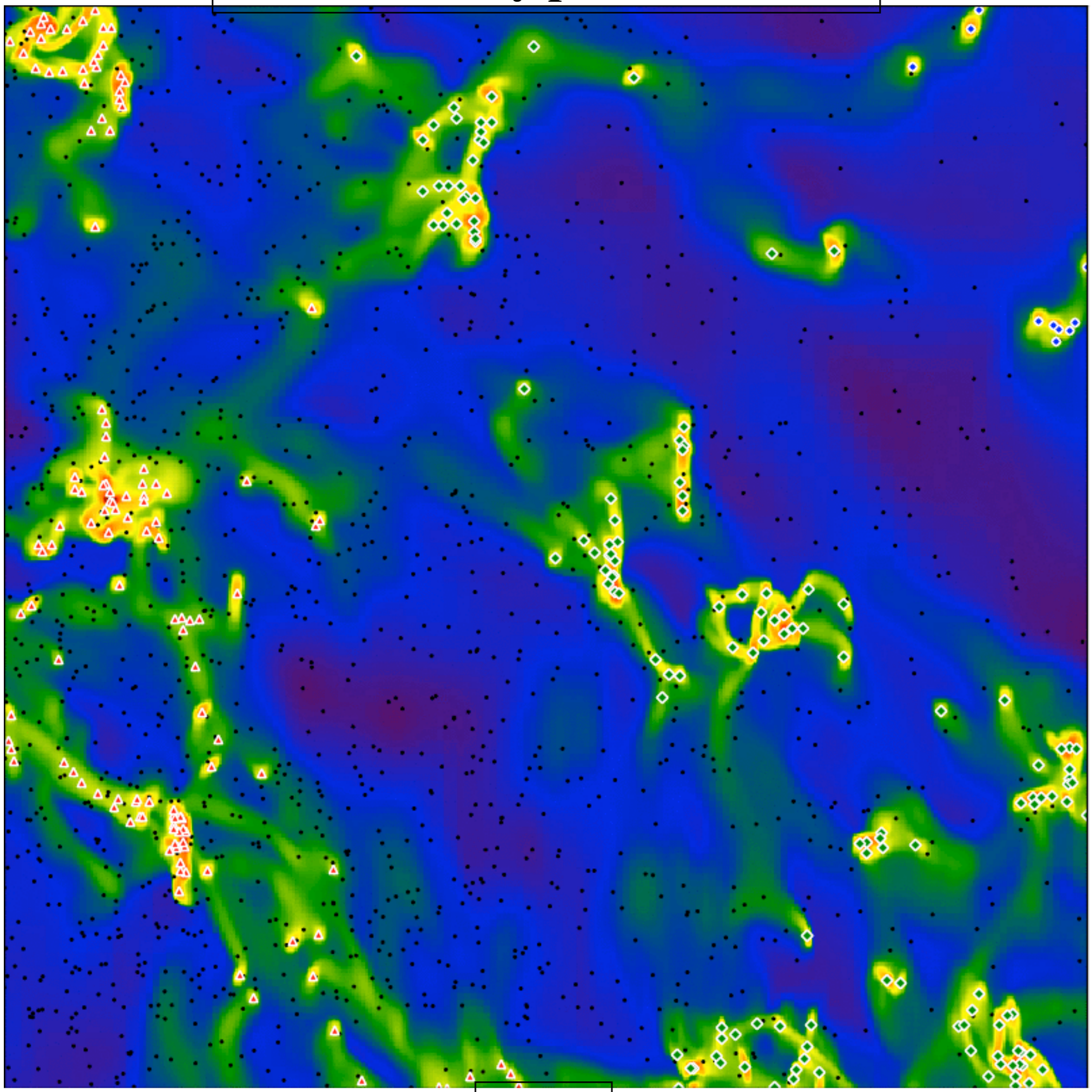
spiral clouds

bar clouds

inter-arm clouds

star particles

Surface density plot with clouds



2kpc

disc clouds

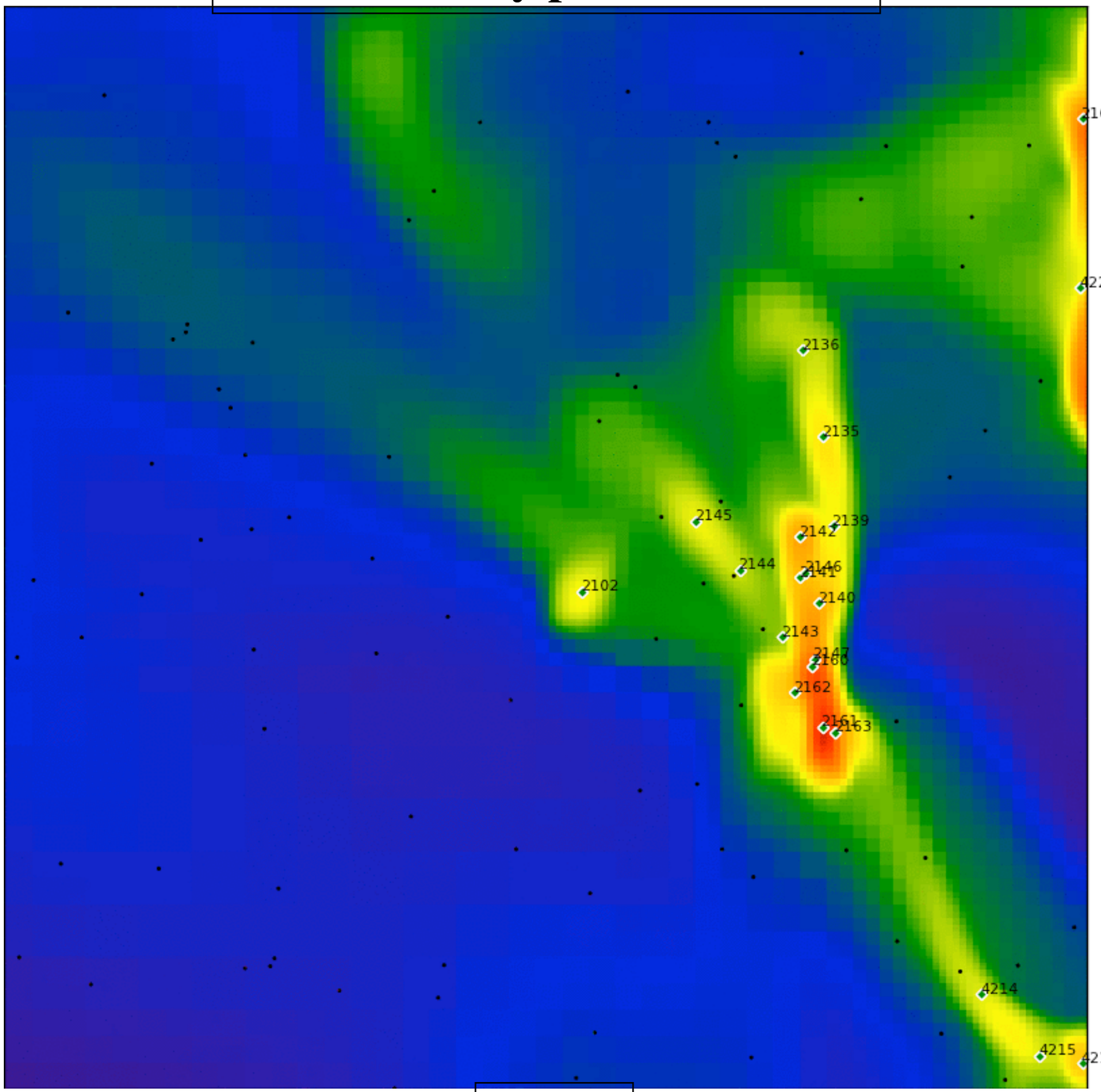
spiral clouds

bar clouds

inter-arm clouds

star particles

Surface density plot with clouds



disc clouds

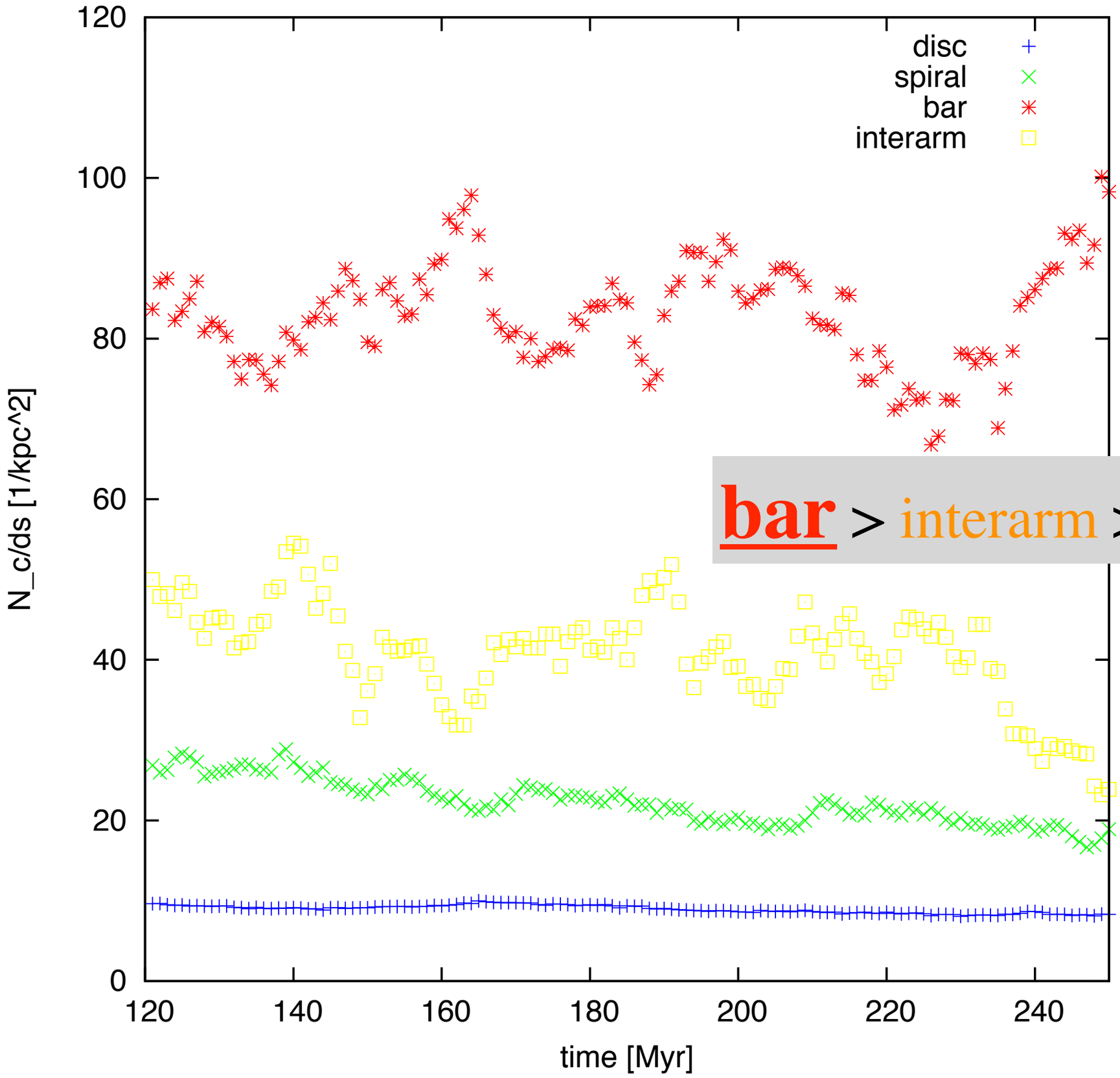
spiral clouds

bar clouds

inter-arm clouds

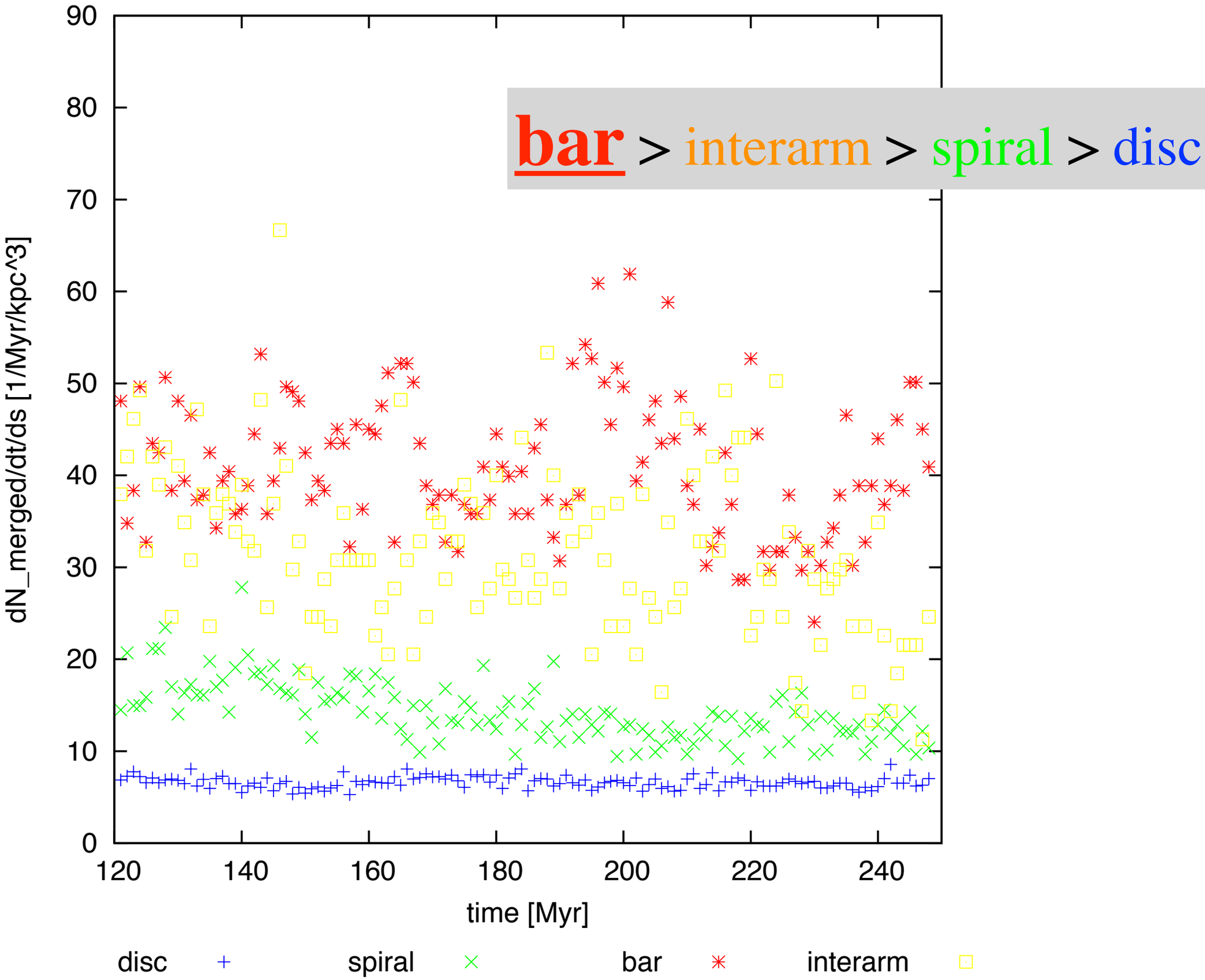
star particles

the number density of clouds

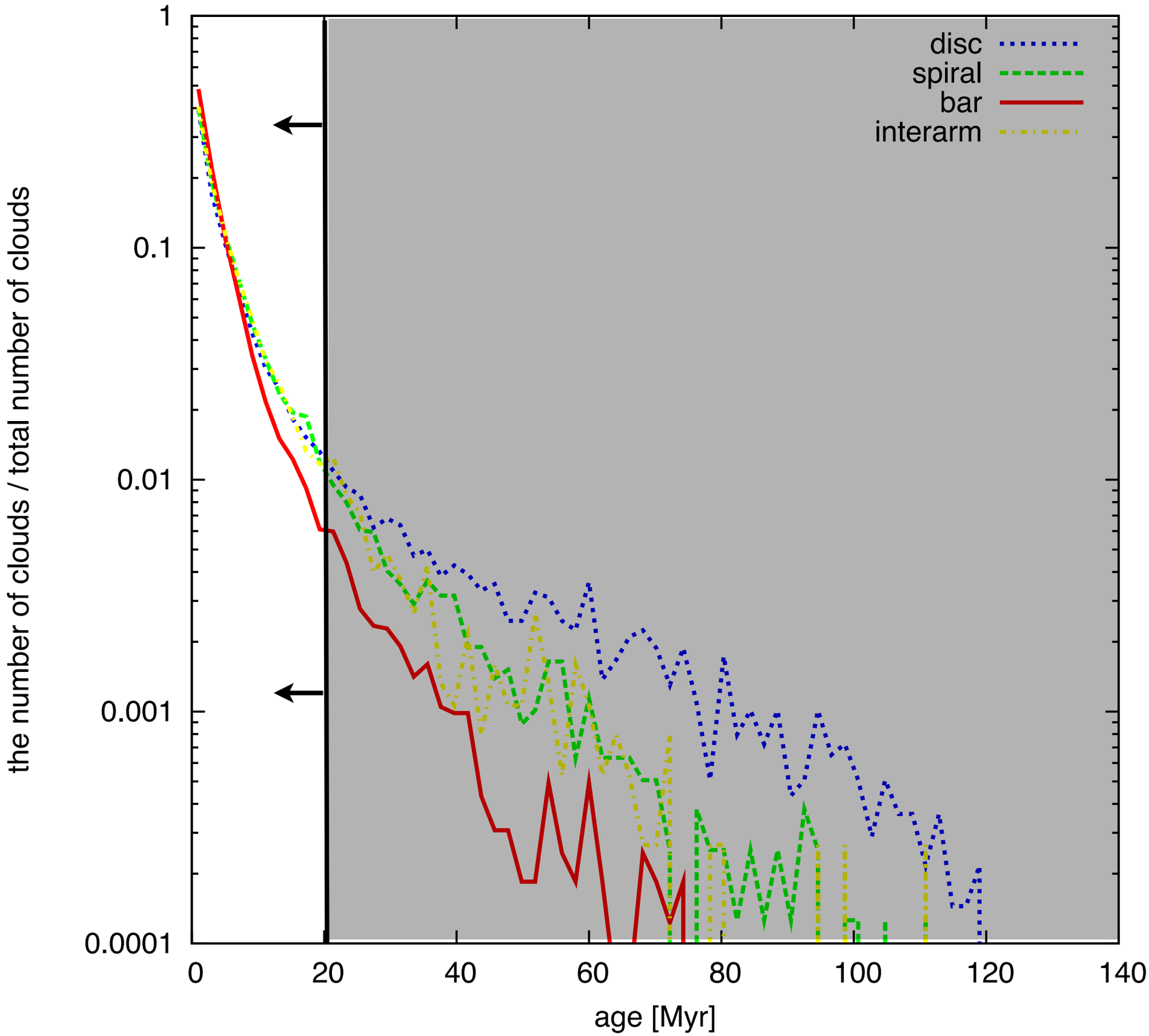


bar > interarm > spiral > disc

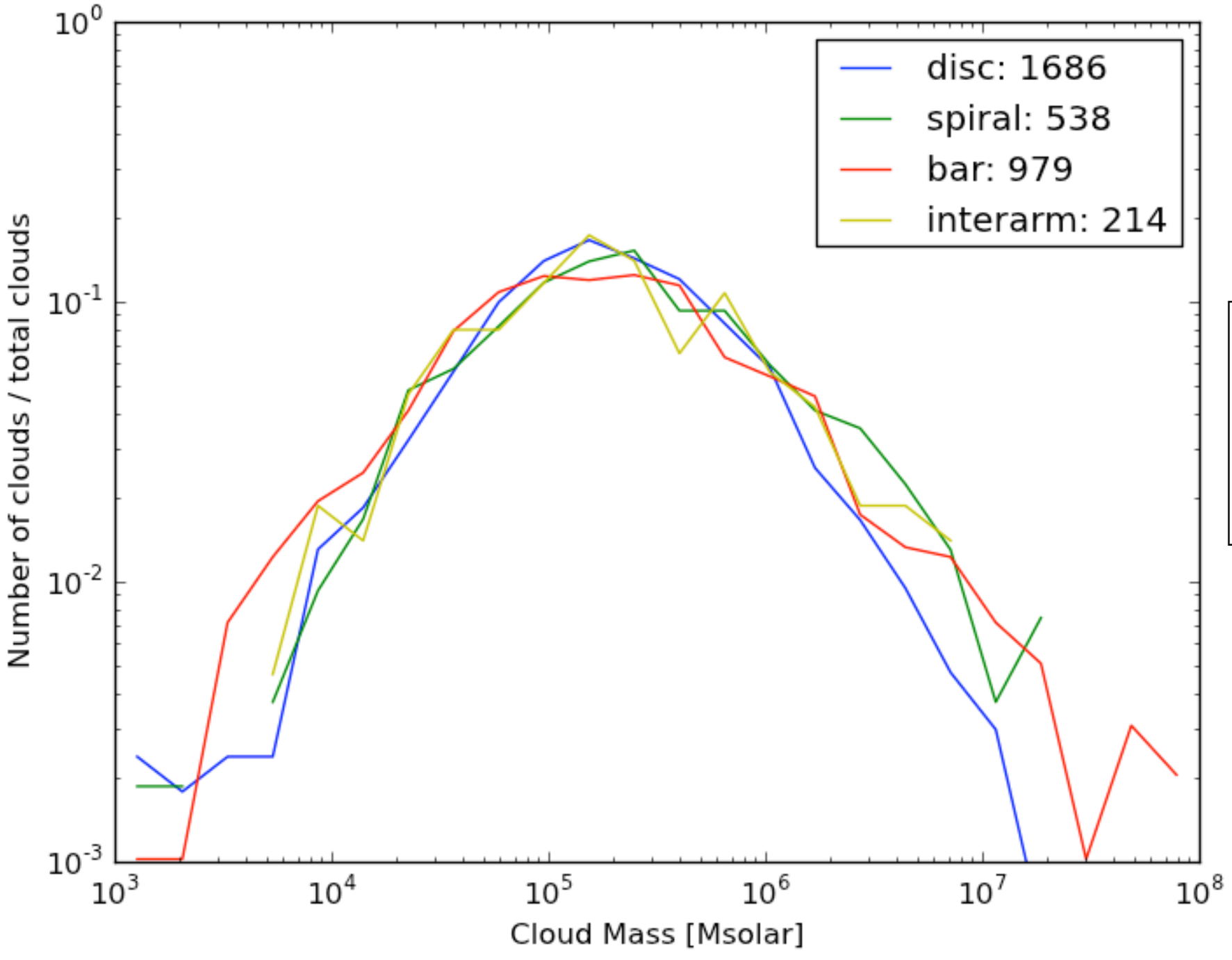
evolution of merger rate per volume



Cloud lifetime

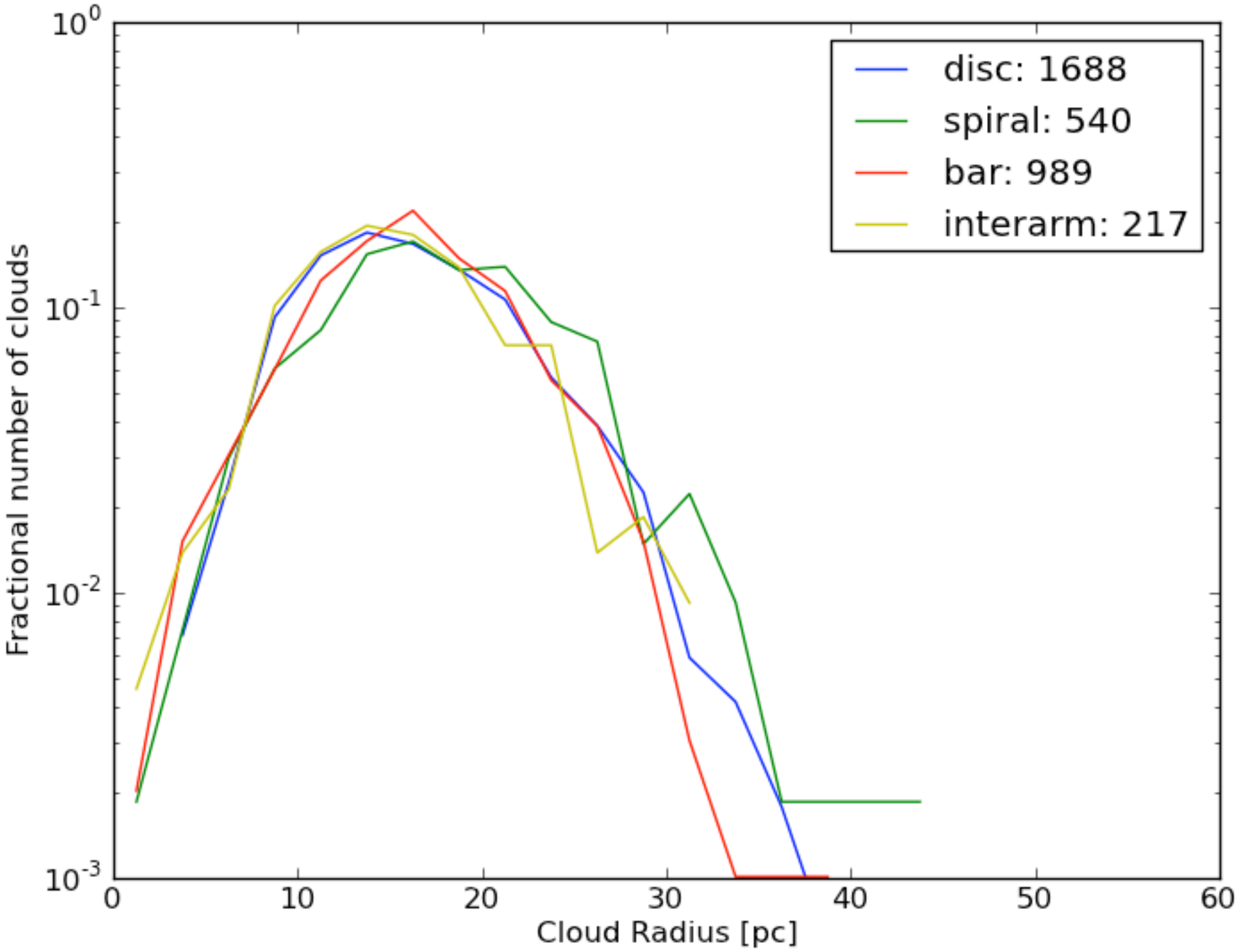


Cloud Properties - mass -



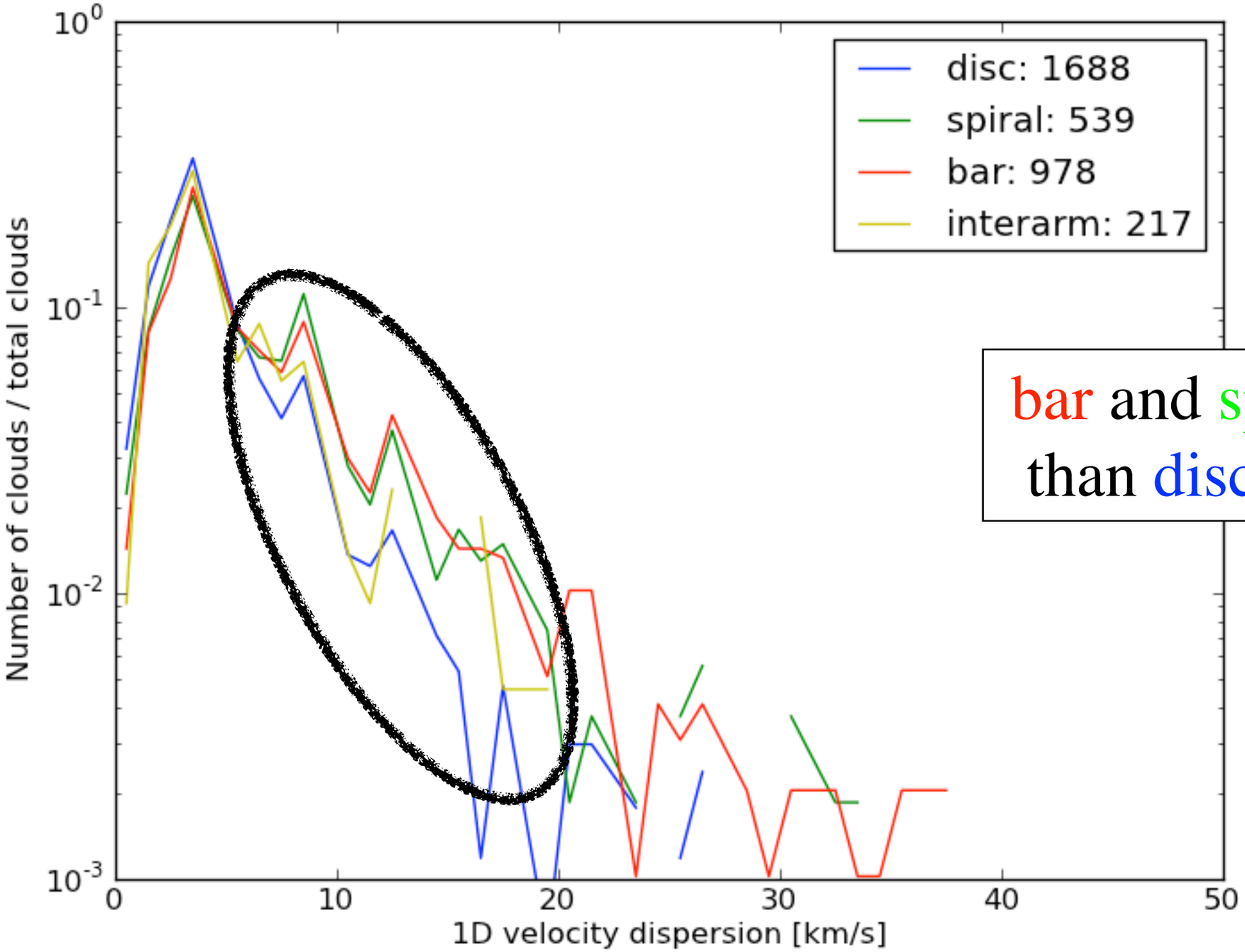
No significant difference between regions

Cloud Properties - radius -



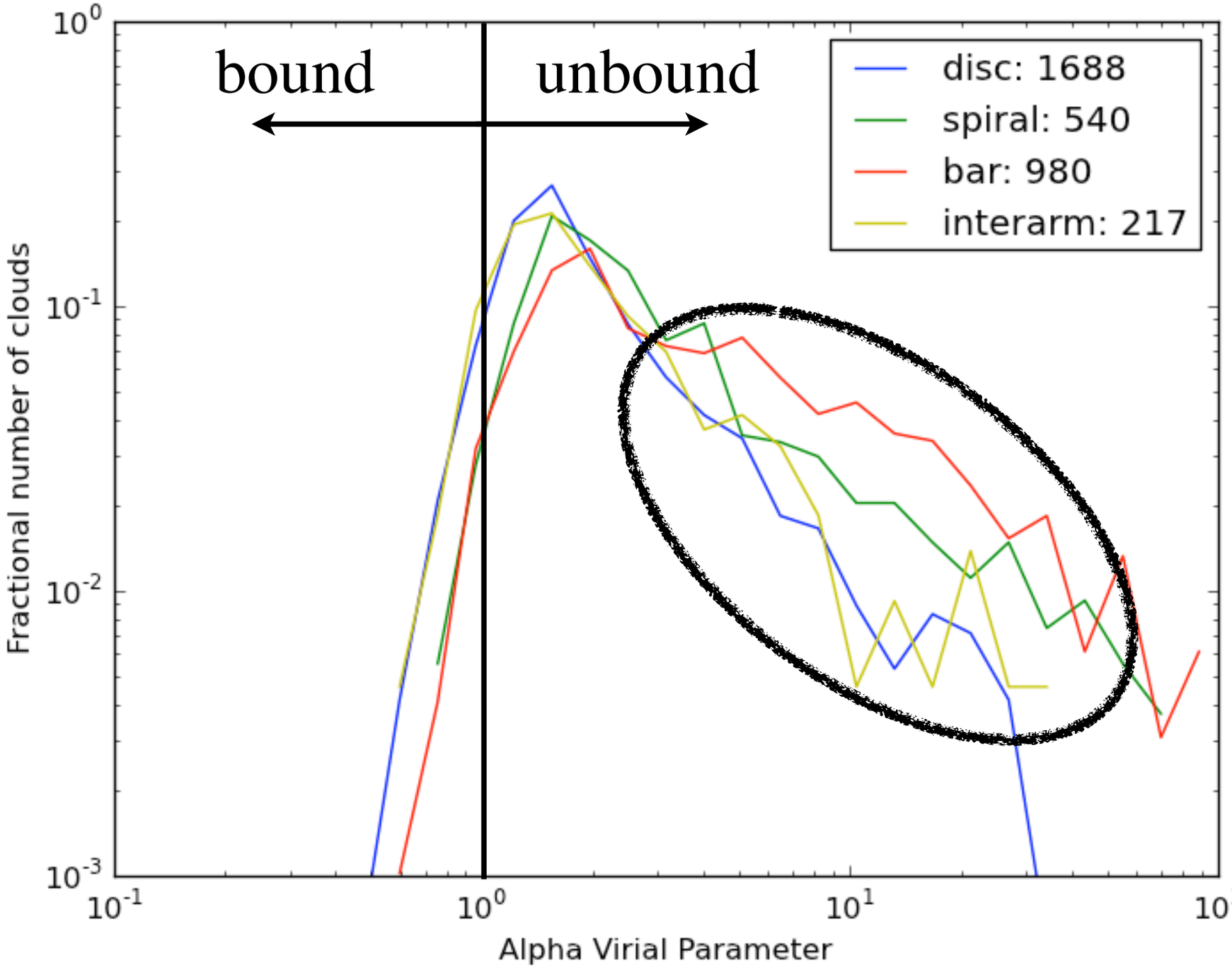
No significant difference between regions

Cloud Properties - 1D velocity dispersion -



bar and spiral are higher than disc and inter-arm

Cloud Properties - virial parameter -

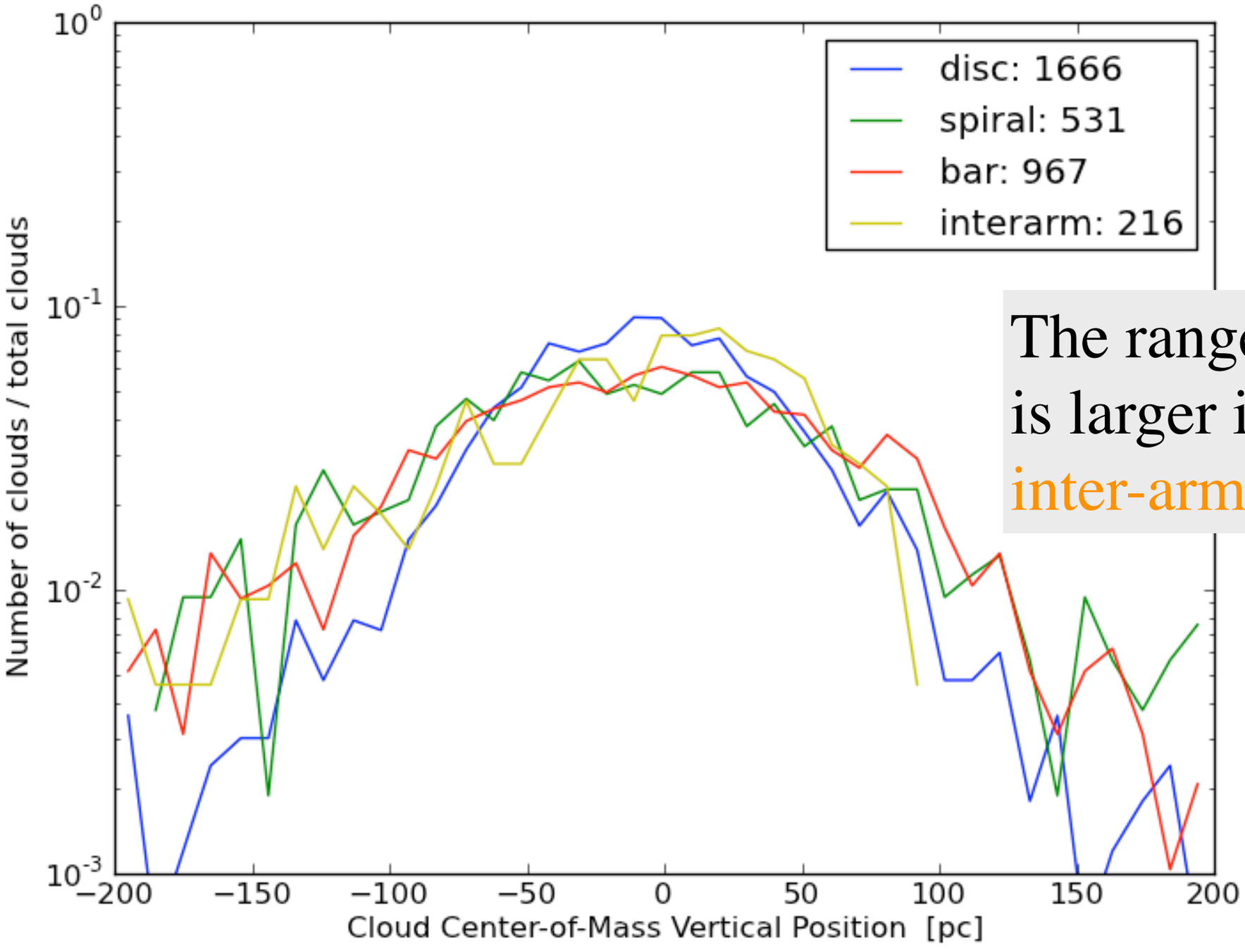


Measure of gravitational binding:

$$\alpha_{\mathrm{vir}} \equiv \frac{5{\sigma_{\mathrm{c}}}^2 \mathrm{R_c}}{\mathrm{G M_c}}$$

bar clouds are less bound than others.

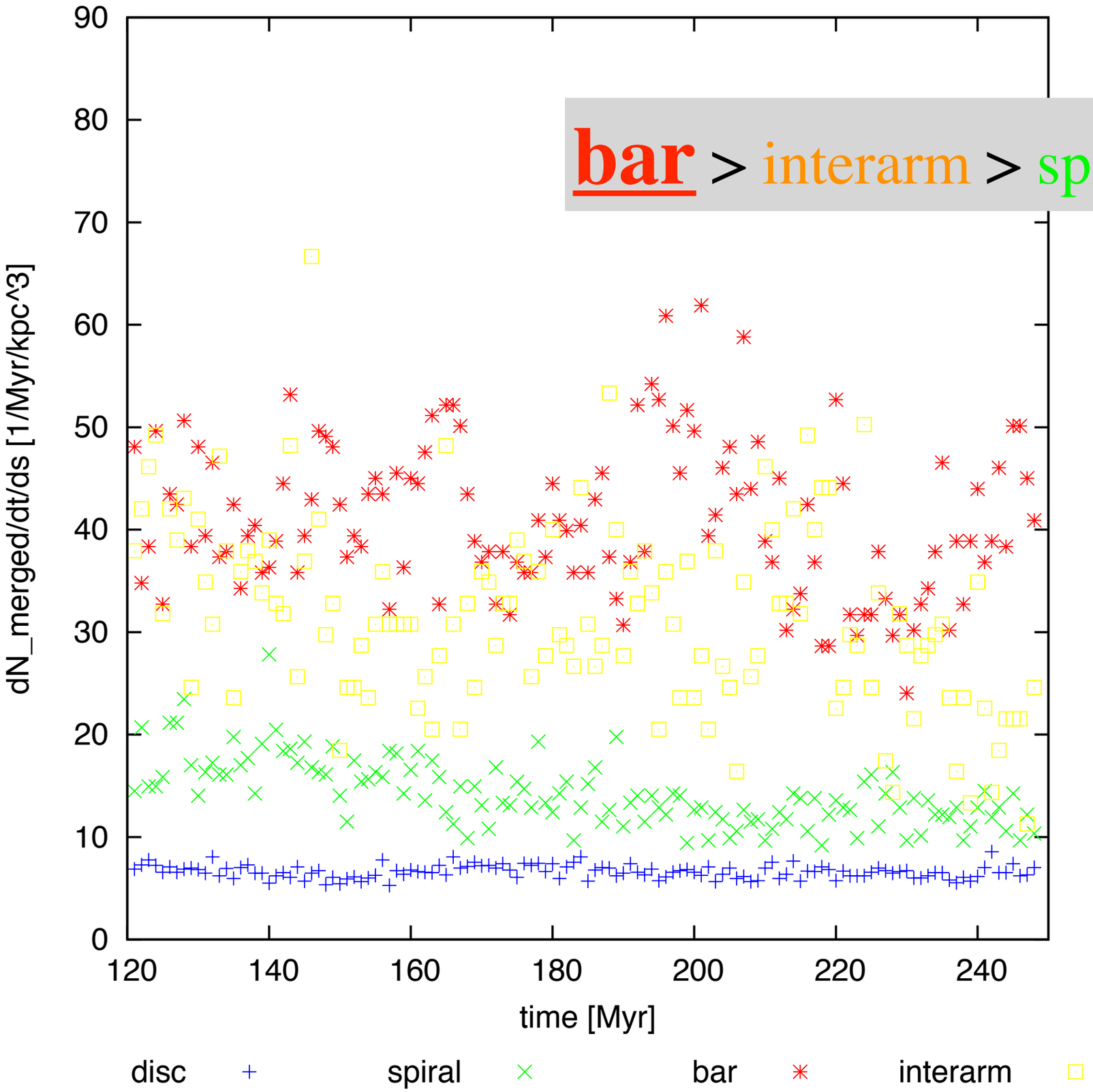
vertical distribution



The range in vertical position is larger in bar, spiral, and inter-arm than in disc

evolution of merger rate per volume

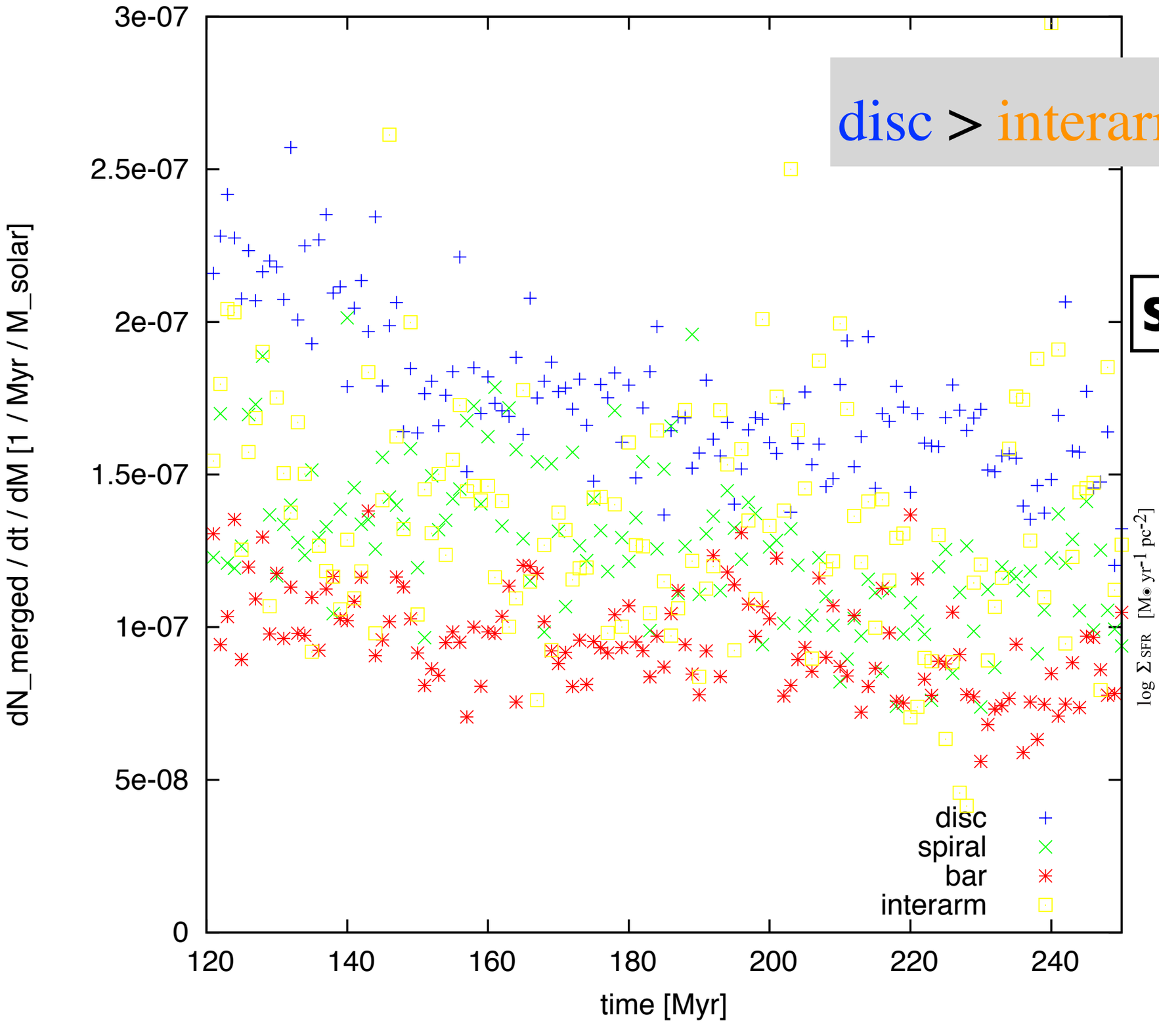
bar > interarm > spiral > disc

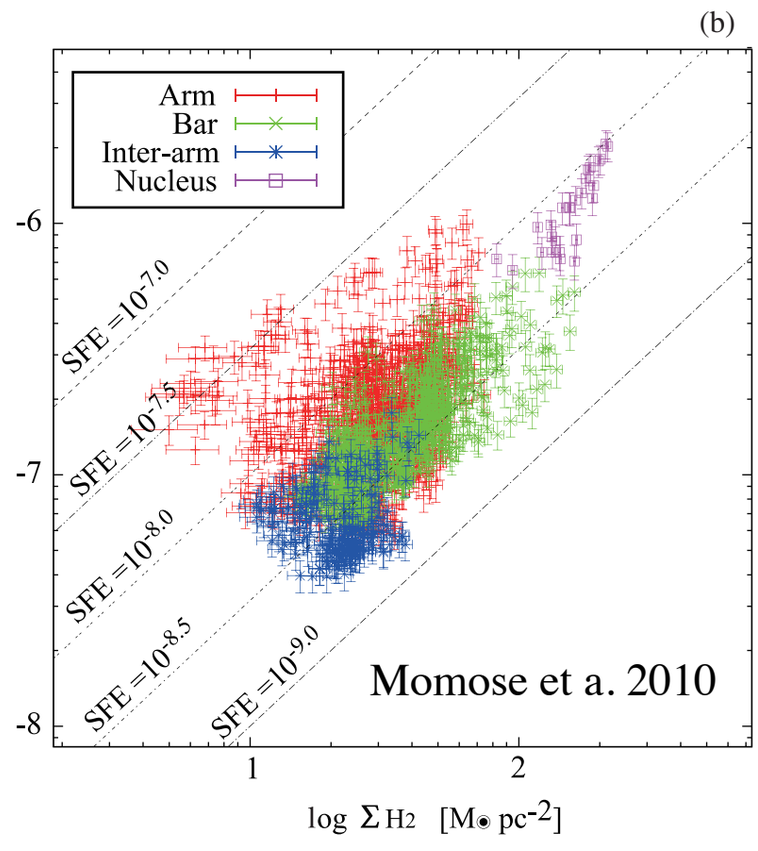


evolution of merger rate per mass

disc > interarm > spiral > **bar**

SFE_spiral > SFE_bar





Conclusions

- The cloud number density is much higher in the bar regions.
- The merger rate per volume is much higher in the bar regions.
- Cloud size and mass are independent of cloud environment.
- Clouds in the spiral arm and bar tend to have high velocity dispersion and be less bound than those in disc.
- The merger rate per mass is much lower in the bar regions.
- If cloud collisions trigger massive star formation, this would explain the star formation activity in the barred galaxy.