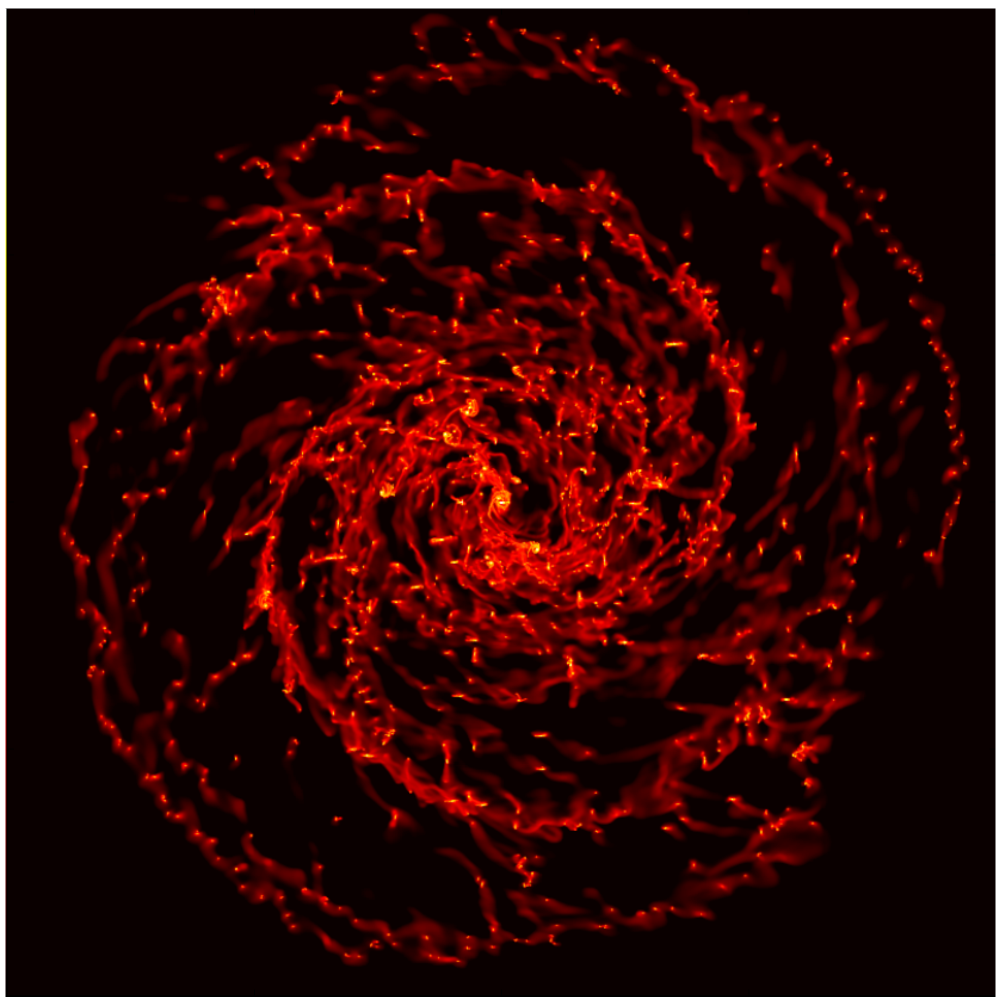
Birthing star forming clouds in the grand design



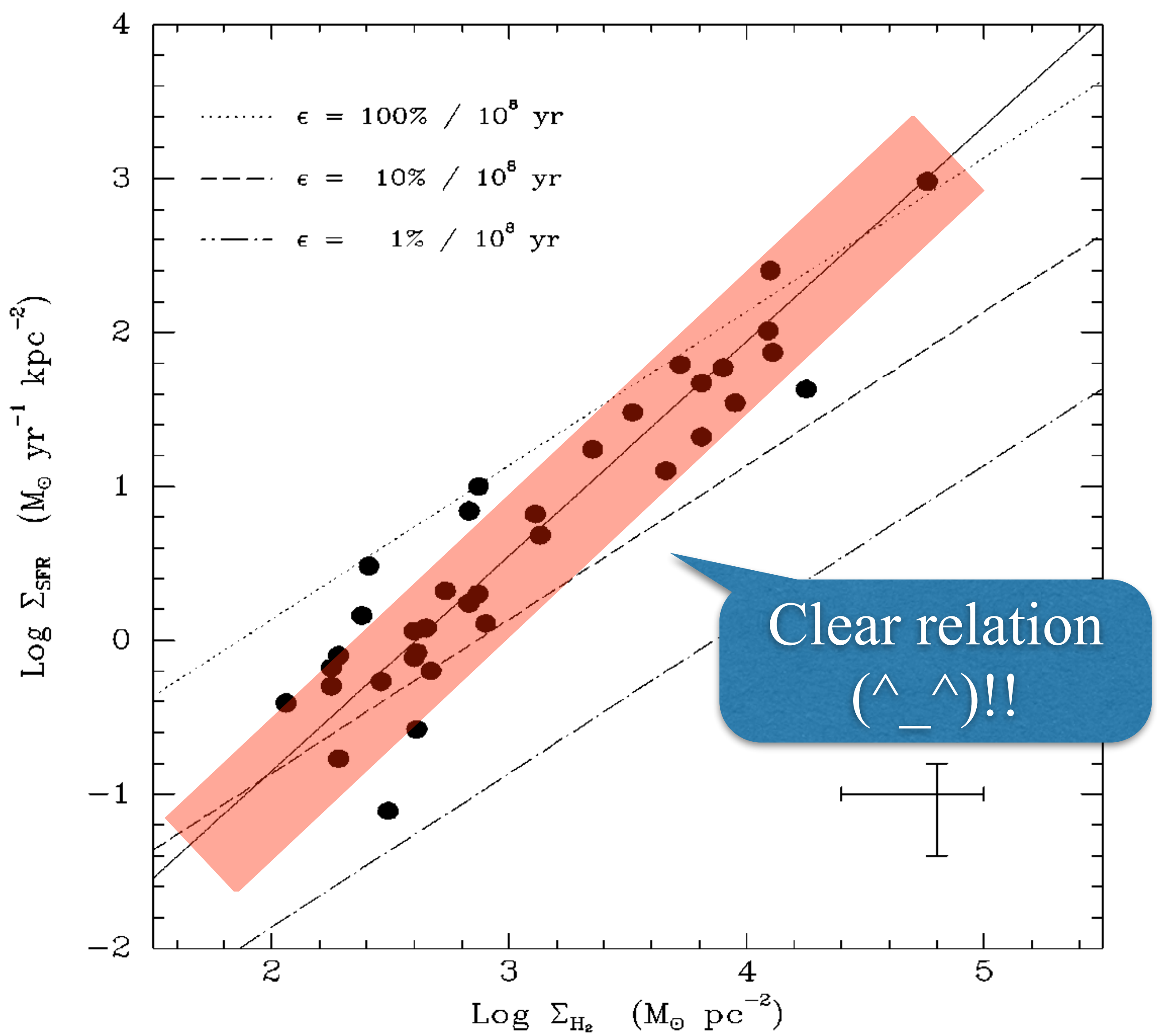
Yusuke Fujimoto (Hokkaido University)

Elizabeth J. Tasker, Asao Habe (Hokkaido University)

Greg L. Bryan (Columbia University)

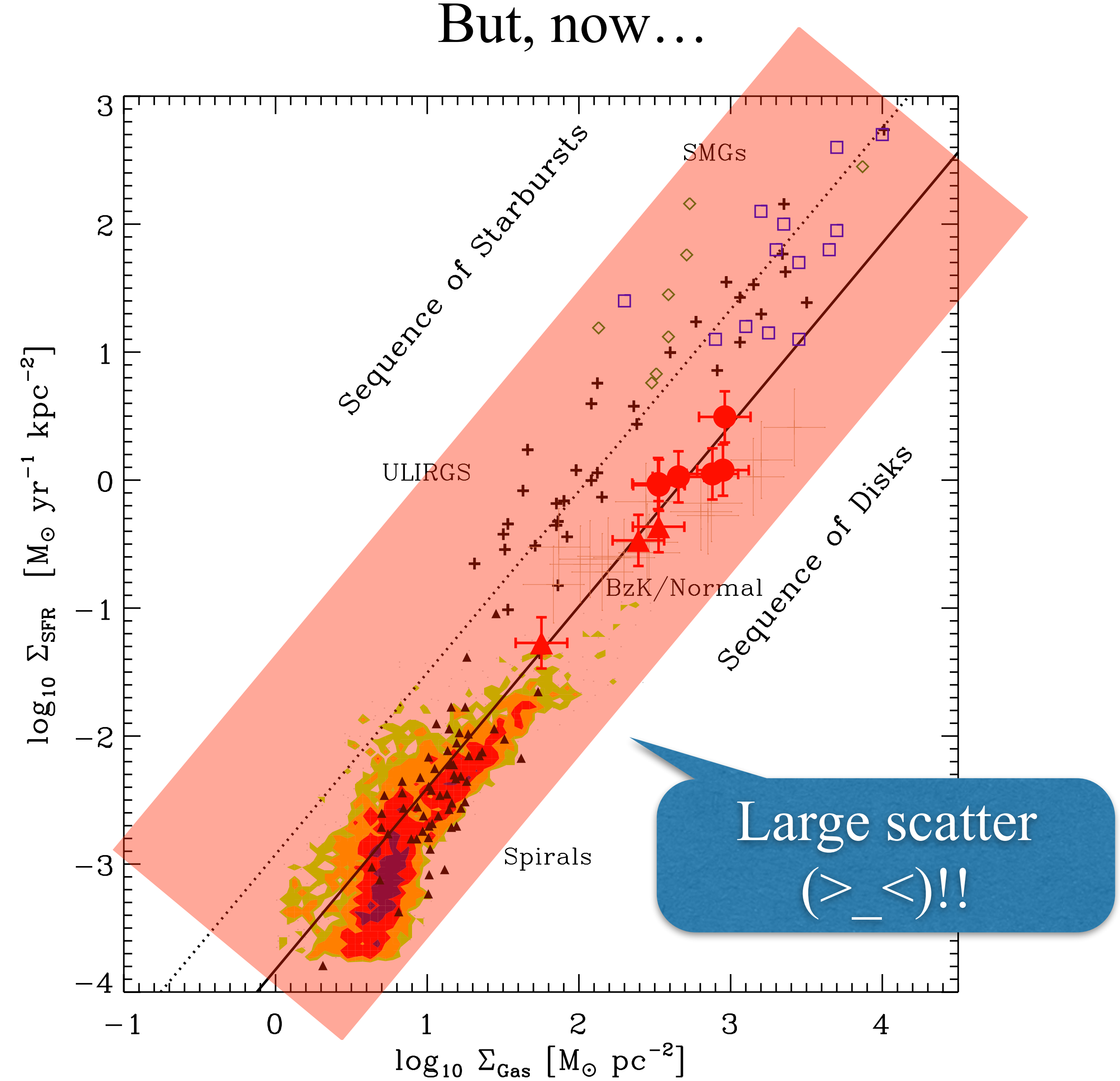
Star formation in galaxies

30 years ago…



Kennicutt 1989

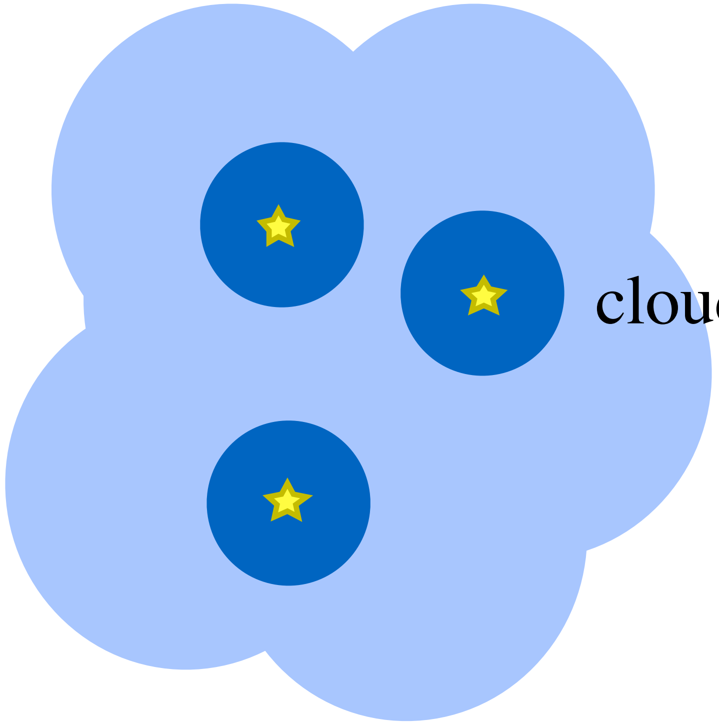
But, now…



Daddi et al. 2010

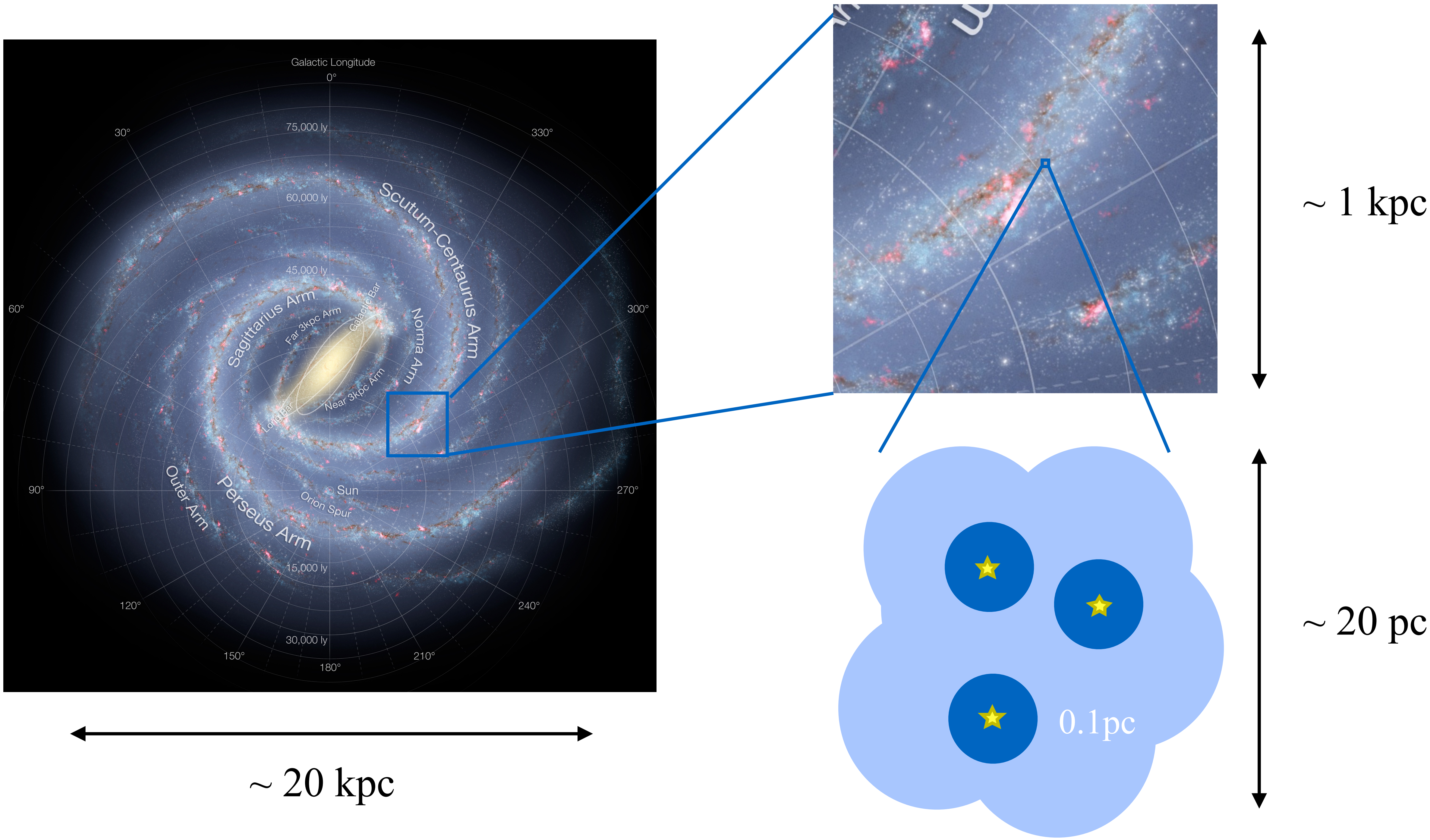
Gas density is not the only factor for star formation.
We have to consider the local process.

Giant molecular clouds = stellar nurseries



Their properties and evolution are the controlling factor
that determines the production of the cloud core and galaxies' star formation.

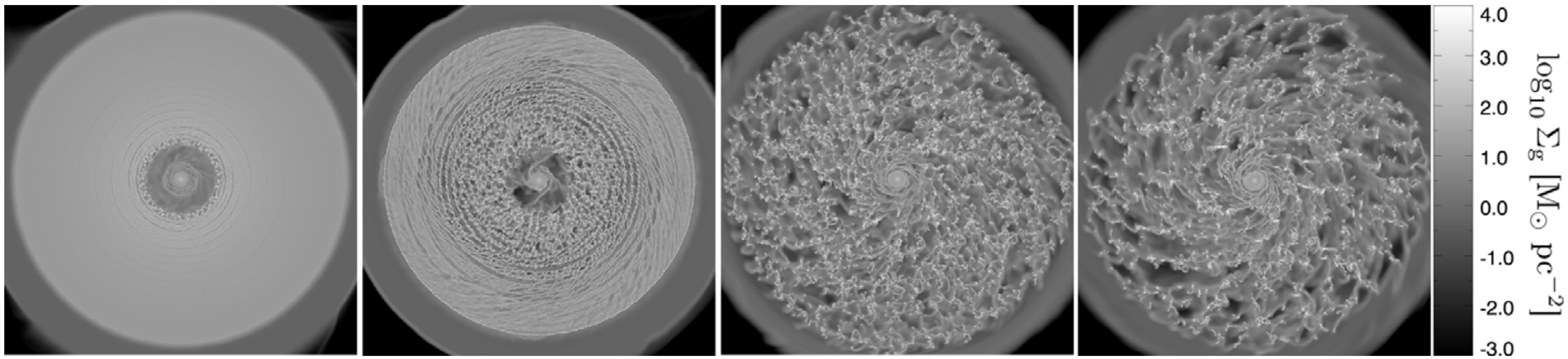
Scale difference makes things difficult.



It has been hard to investigate the GMC formation and evolution taking the global gas dynamics into account.

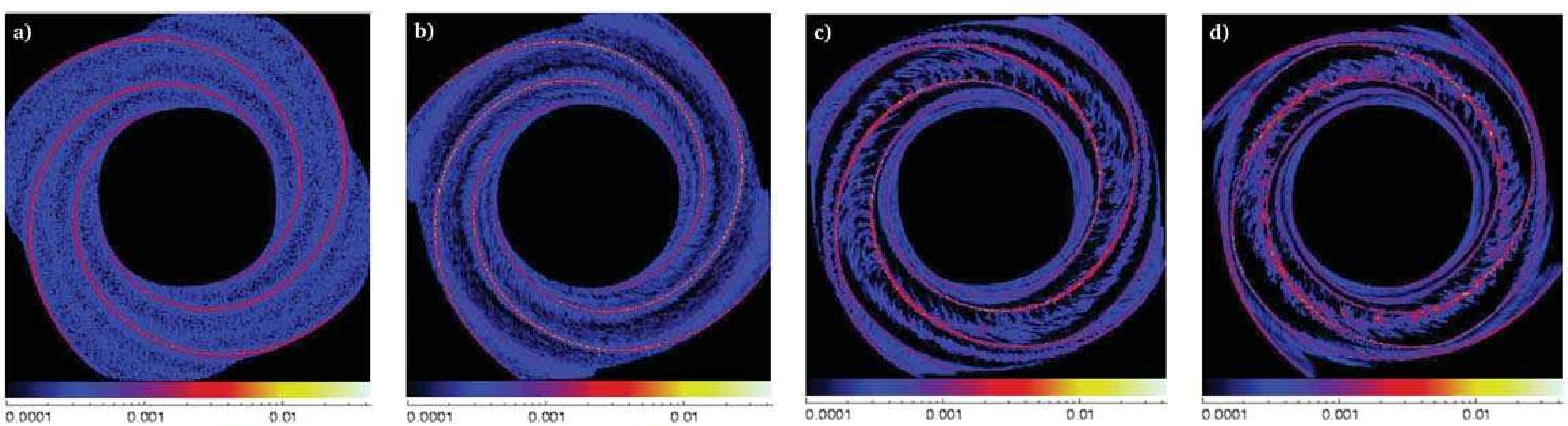
High resolution simulations

Milky-Way type disk galaxy simulation



Tasker & Tan 2009, Tasker 2011, Tasker et al. 2015

Spiral galaxy simulation

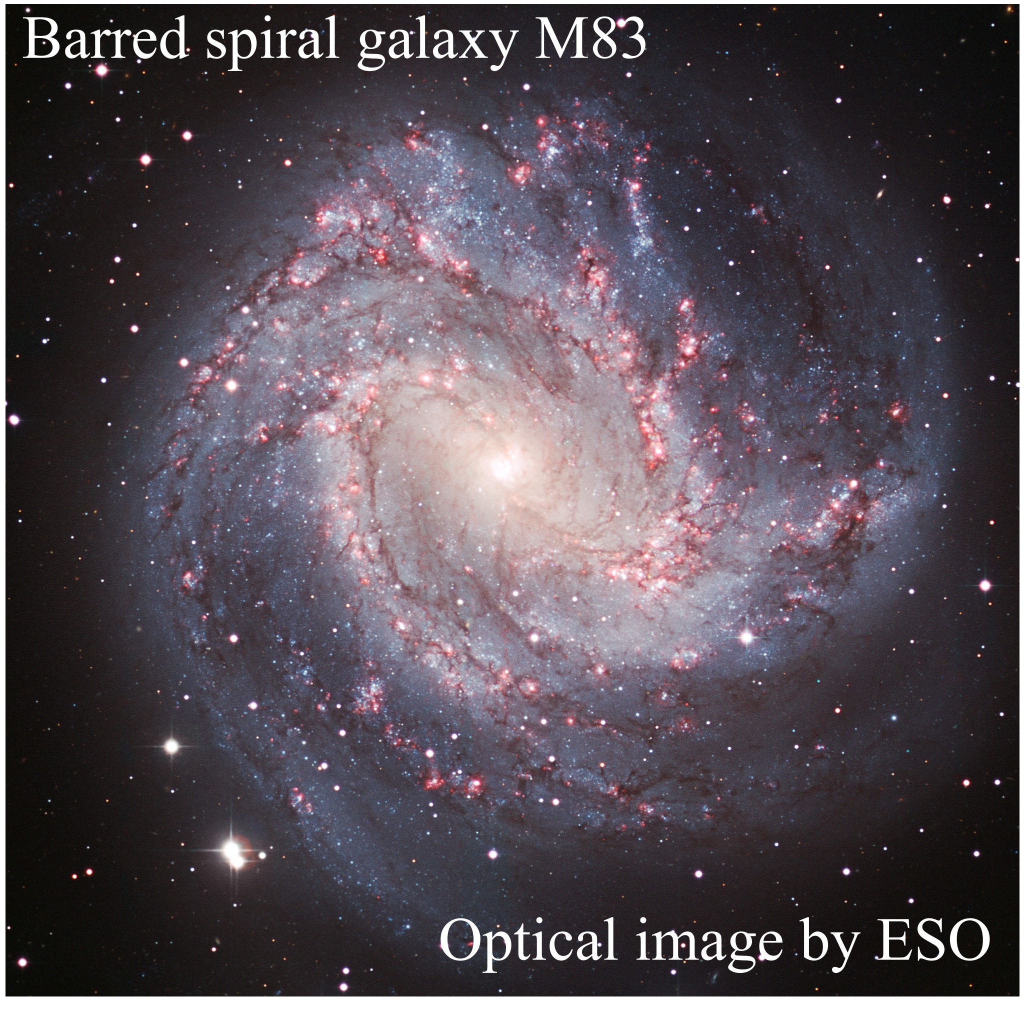


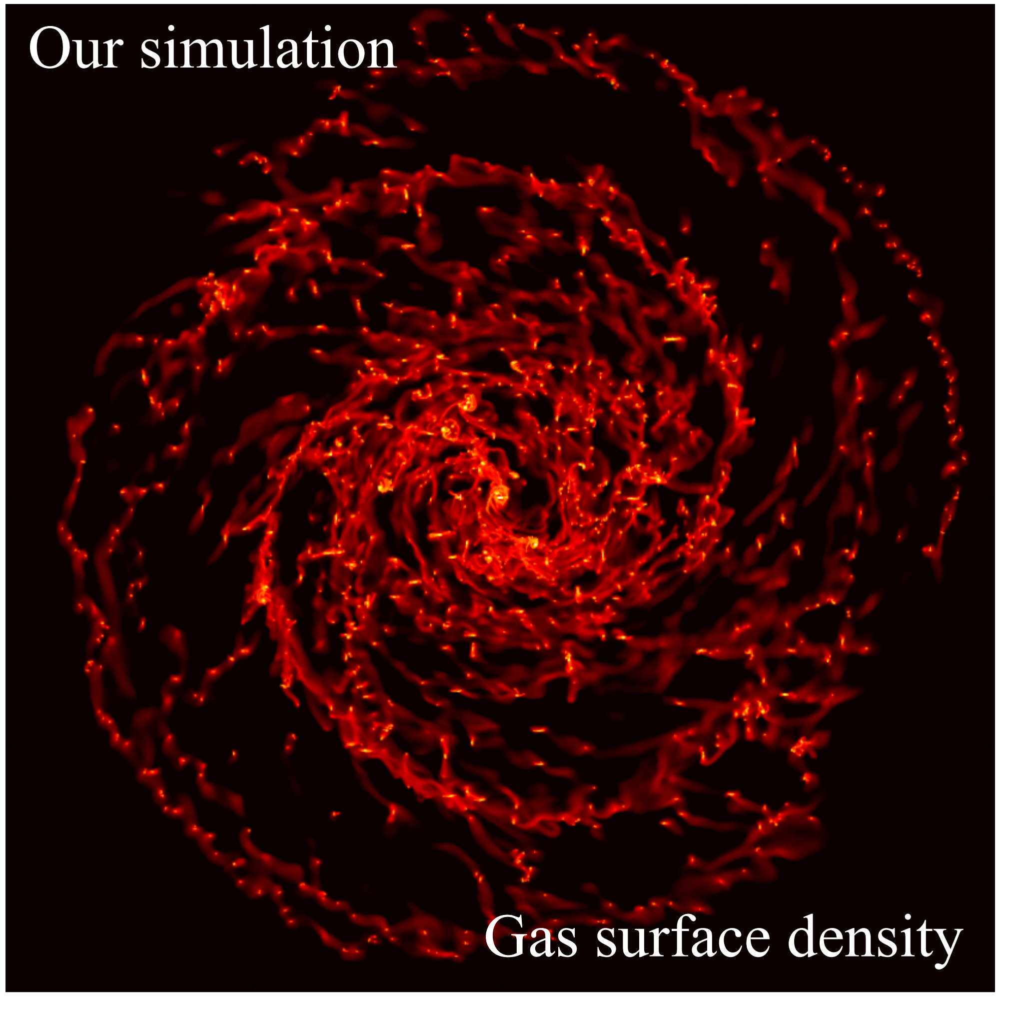
Dobbs & Bonnell 2006, Dobbs et al. 2014

These works indicate impacts of global gas dynamics on the GMCs formation and evolution.

GMCs in a barred spiral galaxy

We performed M83 type barred galaxy simulation (Fujimoto et al. 2014a).



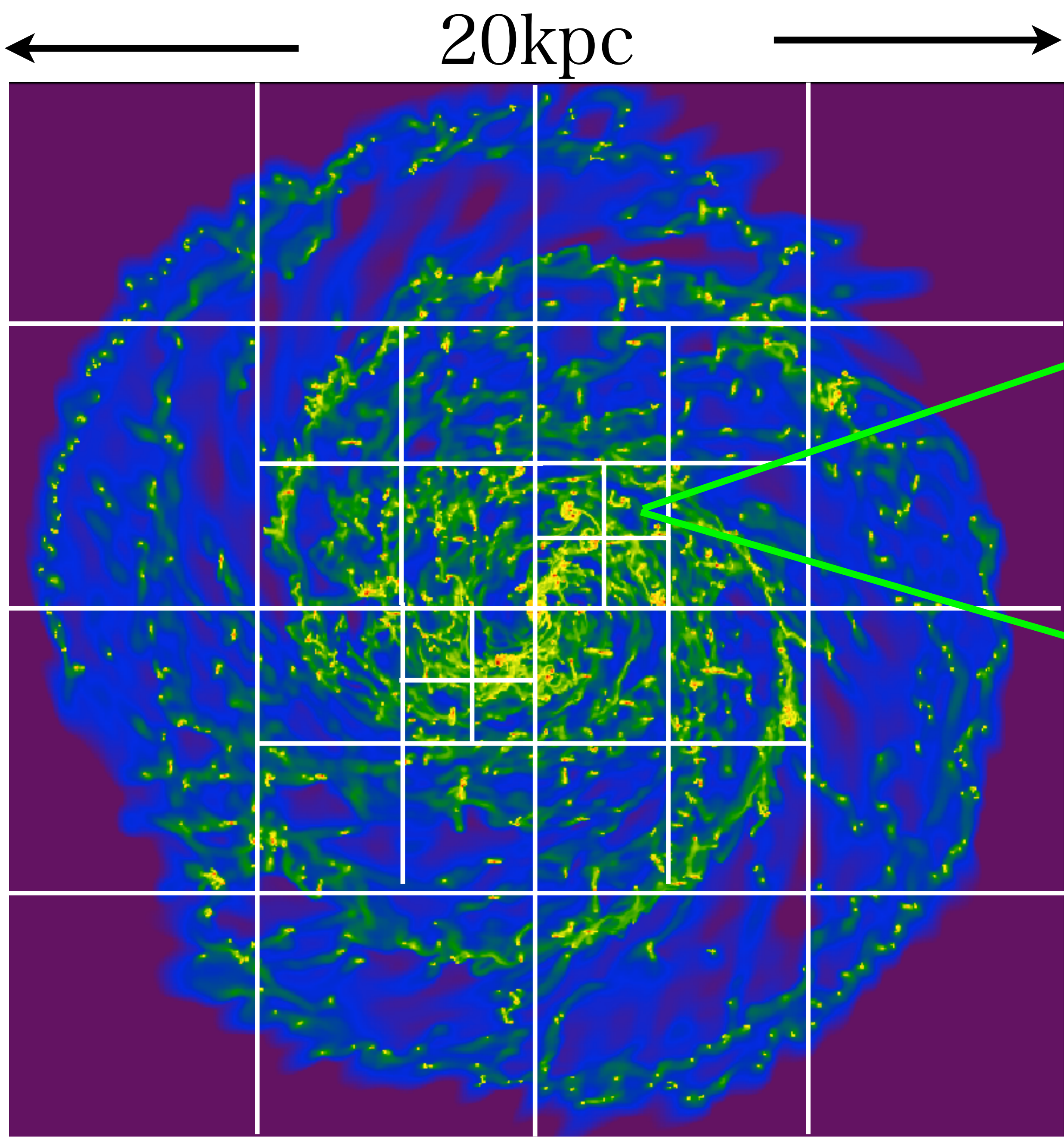


We investigated the impact of the galactic structures (bar and spiral arms) on GMC formation and evolution.

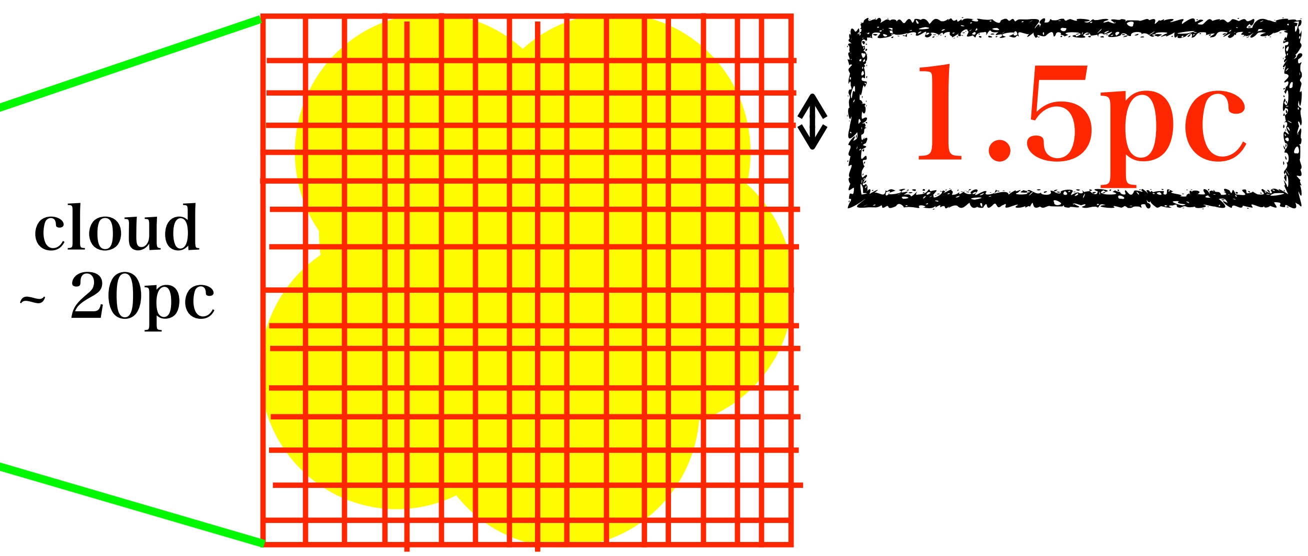
Code

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

(e.g. Bryan et al. 2014, ApJS)



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



refinement level : n=8

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

Radiative cooling

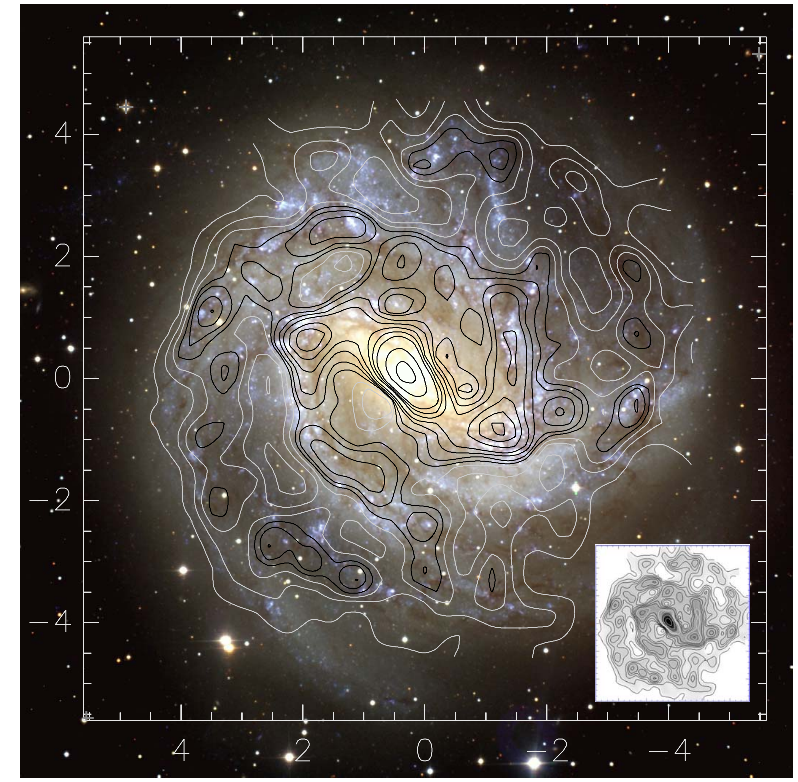
Self-gravity of the gas

(No star formation or feedback)

Galaxy model

Initial gas distribution

gas distribution of the barred galaxy M83
(Lundgren et al. 2004)



Stellar potential

potential model based on 2Mass K-band image
of the barred galaxy M83 (Hirota et al. 2009)

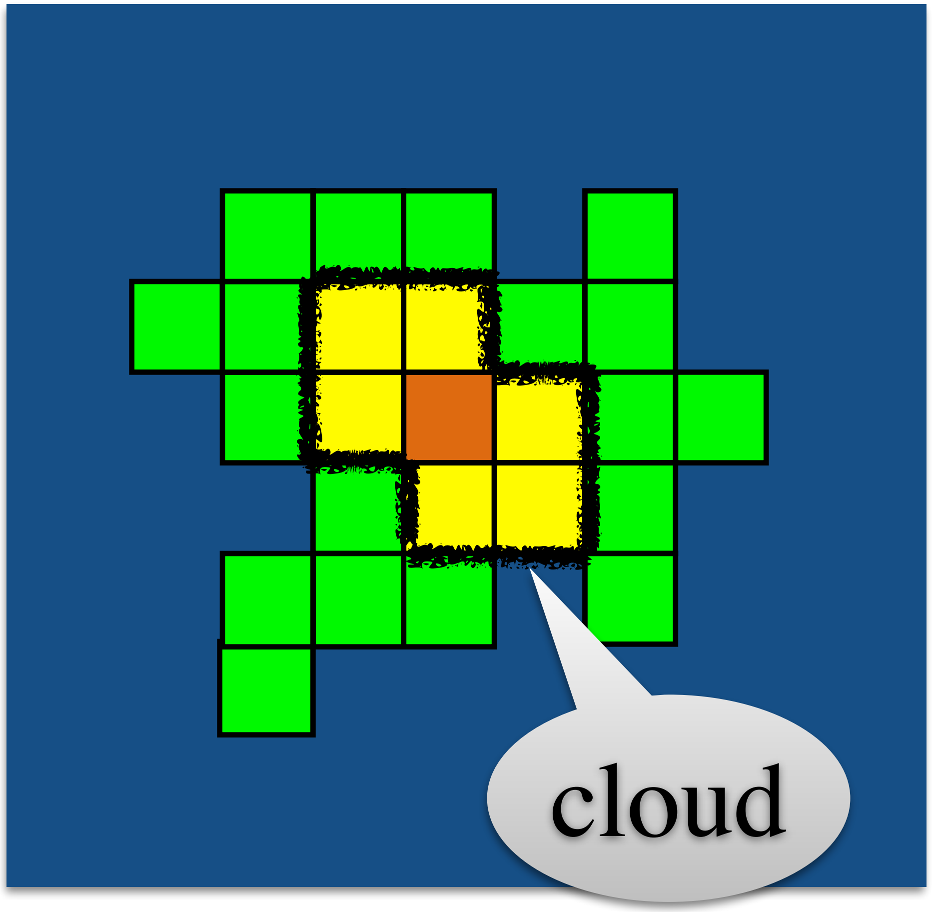
Static dark matter potential

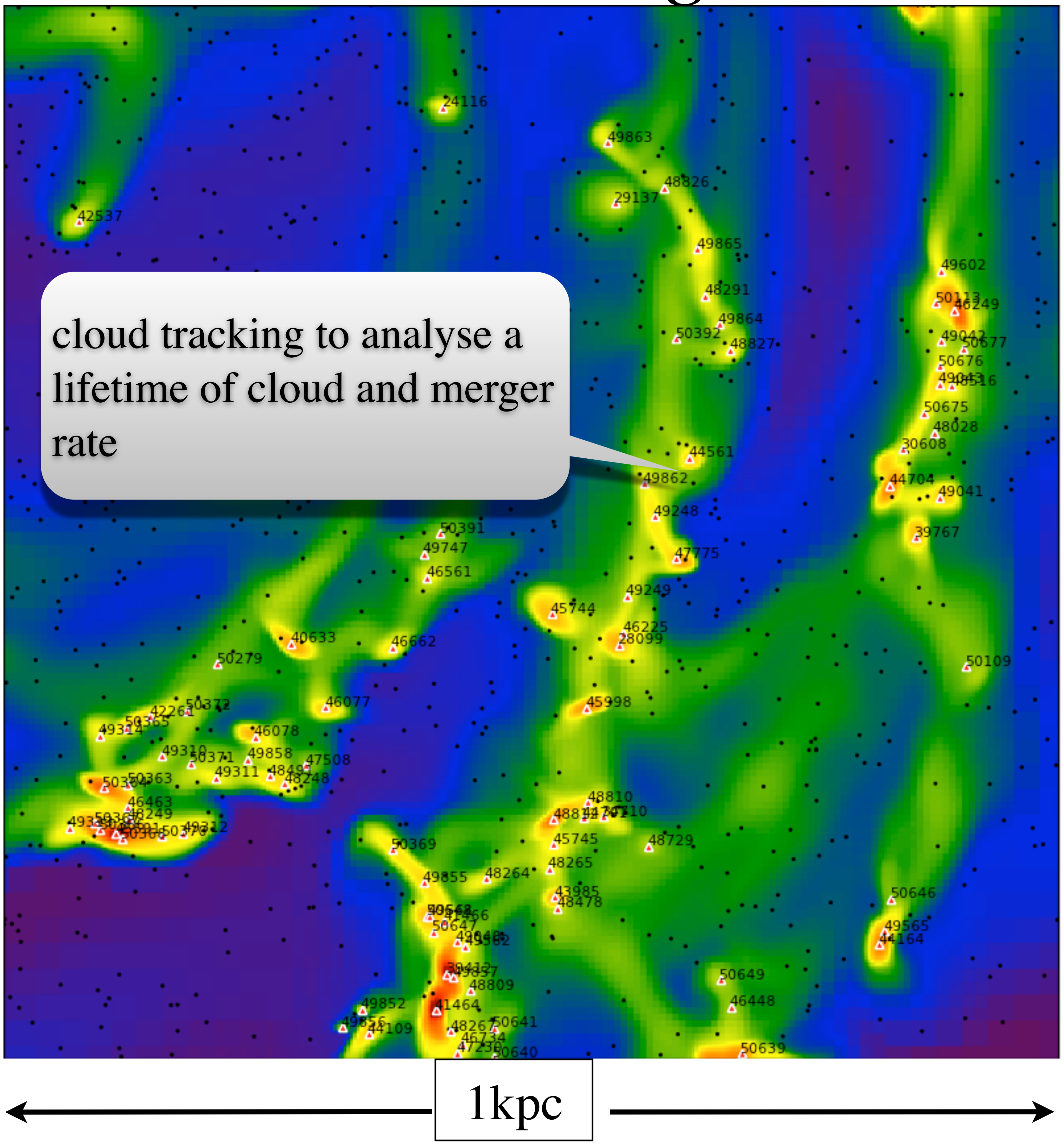
NFW profile (Navarro, Frenk & White 1997)

Cloud definition and tracking

cloud :
coherent structure contained within contours at the threshold density of

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



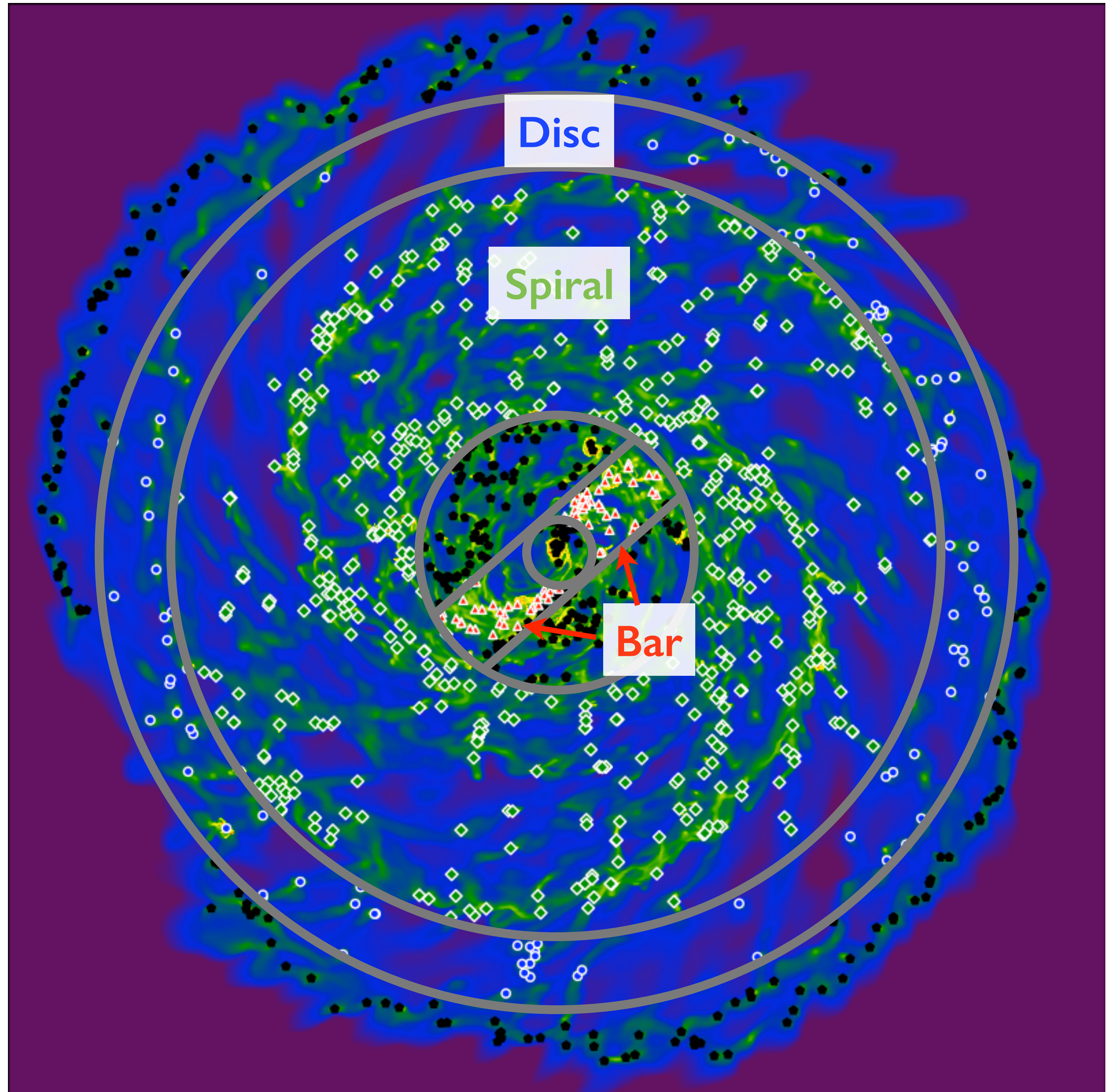


Three galactic regions

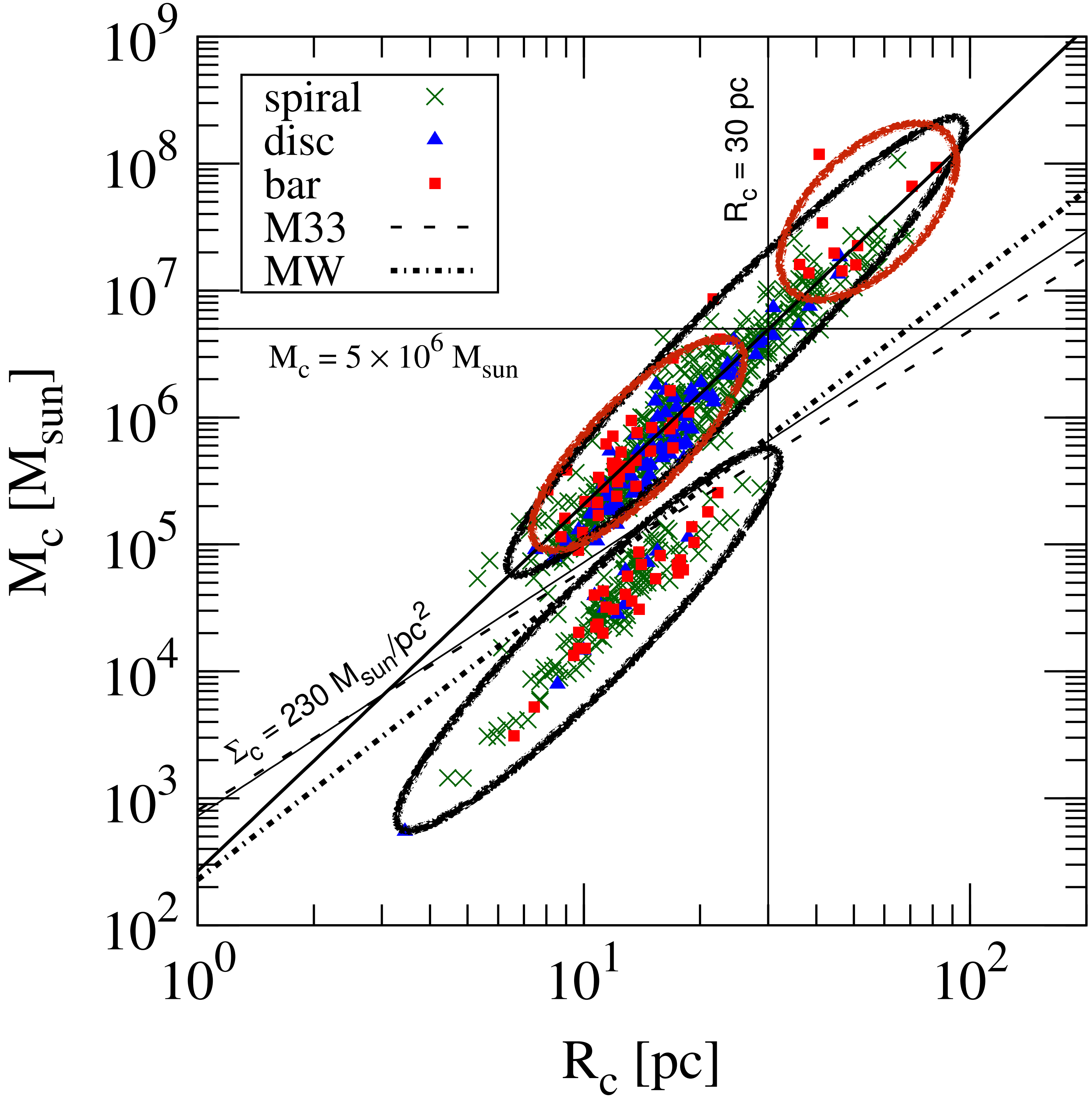
- Bar region : box-like region at the galactic centre

- Spiral region : ring region within the radii 2.5 < r < 7.0 kpc.

- Disc region : ring region outside the spiral region

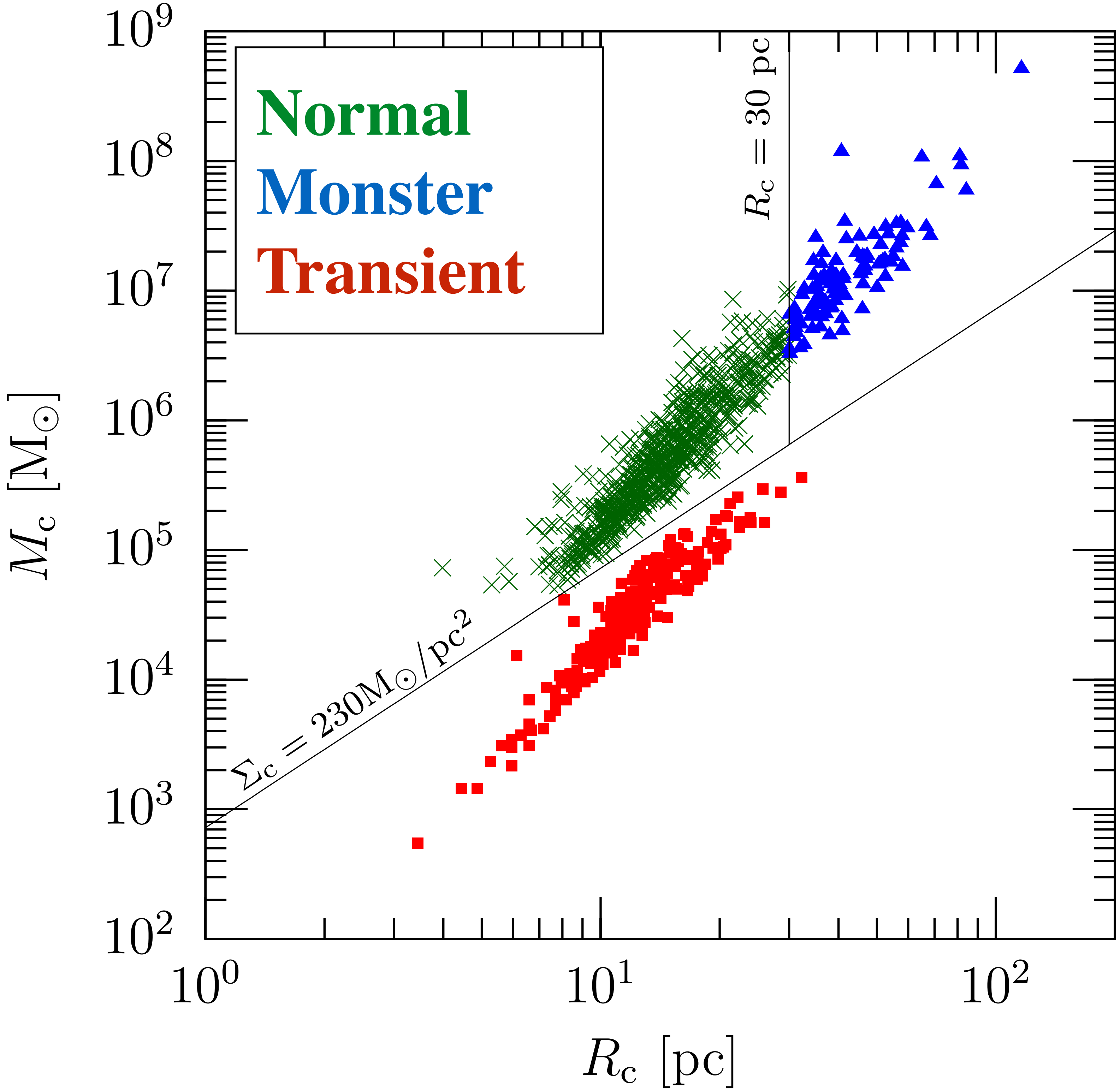


Cloud radius-mass scaling relation



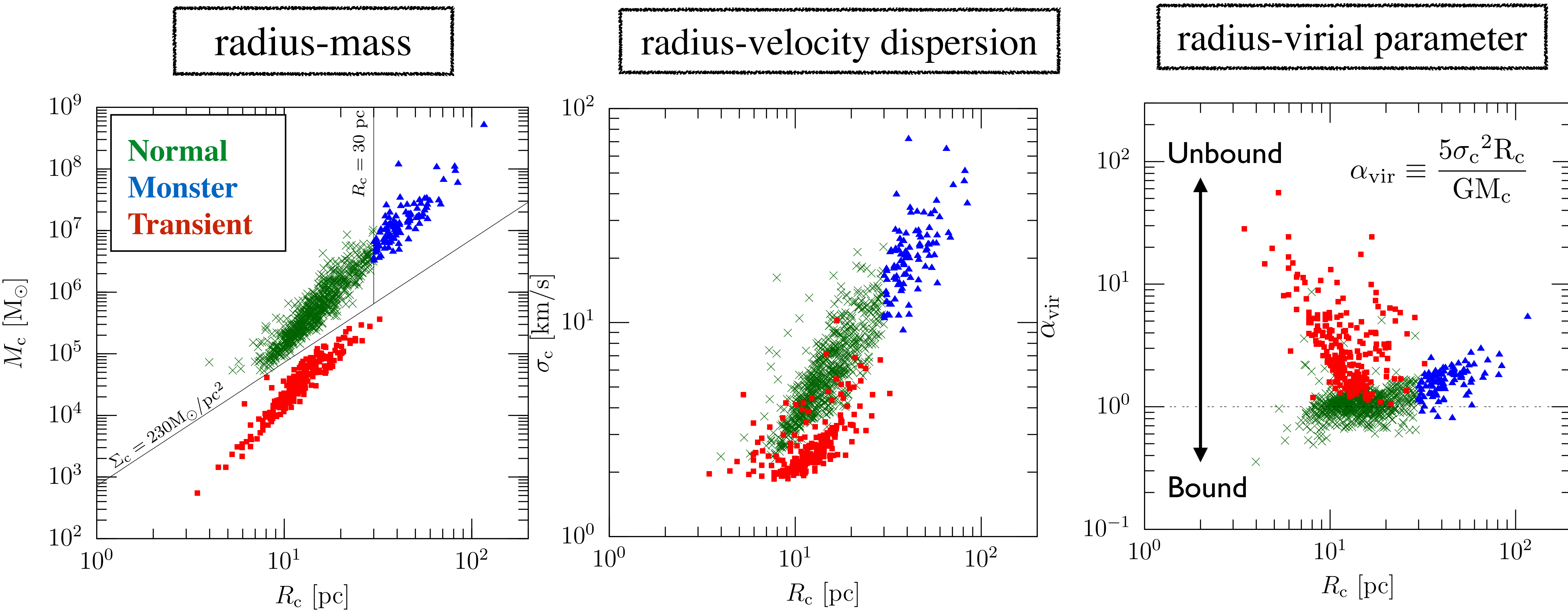
- Hard to see the difference between the three galactic regions.

Three cloud types



RESULTS

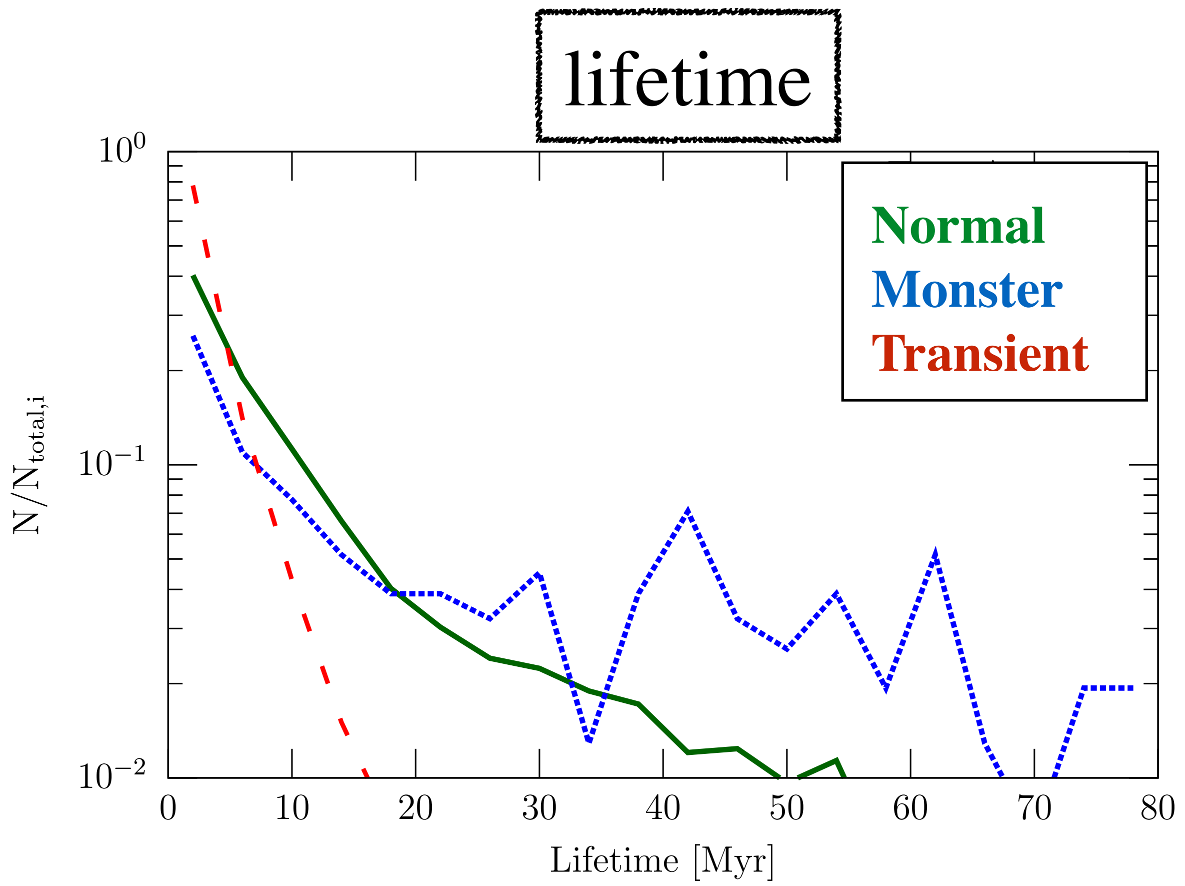
Three cloud types

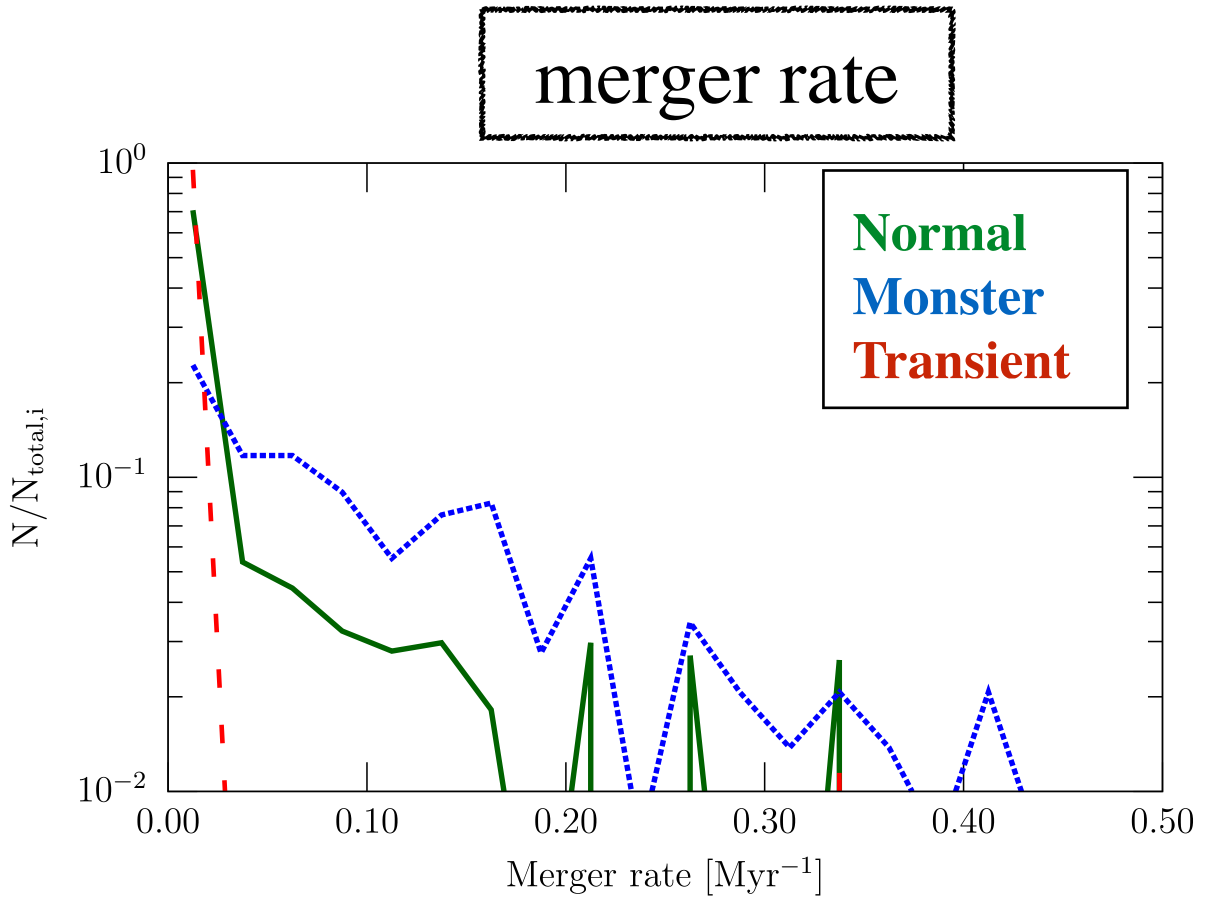


❖ Cloud classification based on radius-mass relation

- **Normal** : the most **common** clouds. $M_c \sim 5 \times 10^5 M_\odot$ $R_c \sim 15$pc $\sigma_c \sim 6$km/s $\alpha_c \sim 1$
- **Monster** : **massive GMAs** which have larger radius than 30 pc.
- **Transient** : **unbound** clouds which have lower density than 230 $M_\odot/pc^2$

Cloud lifetime and merger rate





- **Monster** :
  long lifetime (> 40 Myr)
  high merger rate (t_merger < 10 Myr)

- **Transient** :
  short lifetime (< 10 Myr)
  low merger rate (t_merger > 100 Myr)

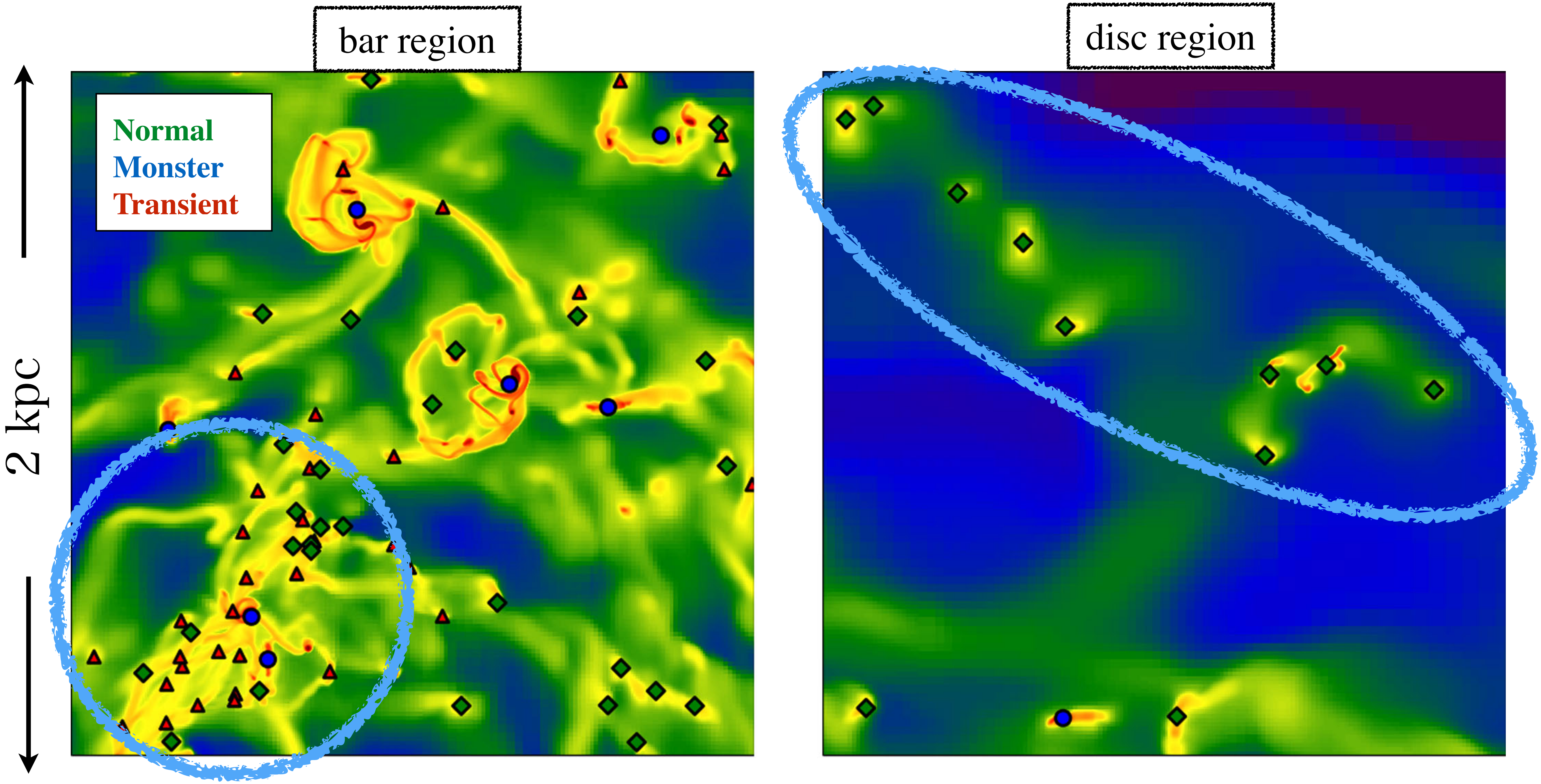
- **Normal** : middle properties between Monster and Transient.

Percentage of each cloud type in each galactic region

	Bar	Spiral	Disc
Normal	50%	64%	83%
Monster	13%	13%	6%
Transient	38%	23%	11%

- In all regions, the most numerous cloud type is normal.
- In the bar region, percentages of monster and transient are highest.
- In contrast, in the disc region, these percentages are lowest.

Visual inspection



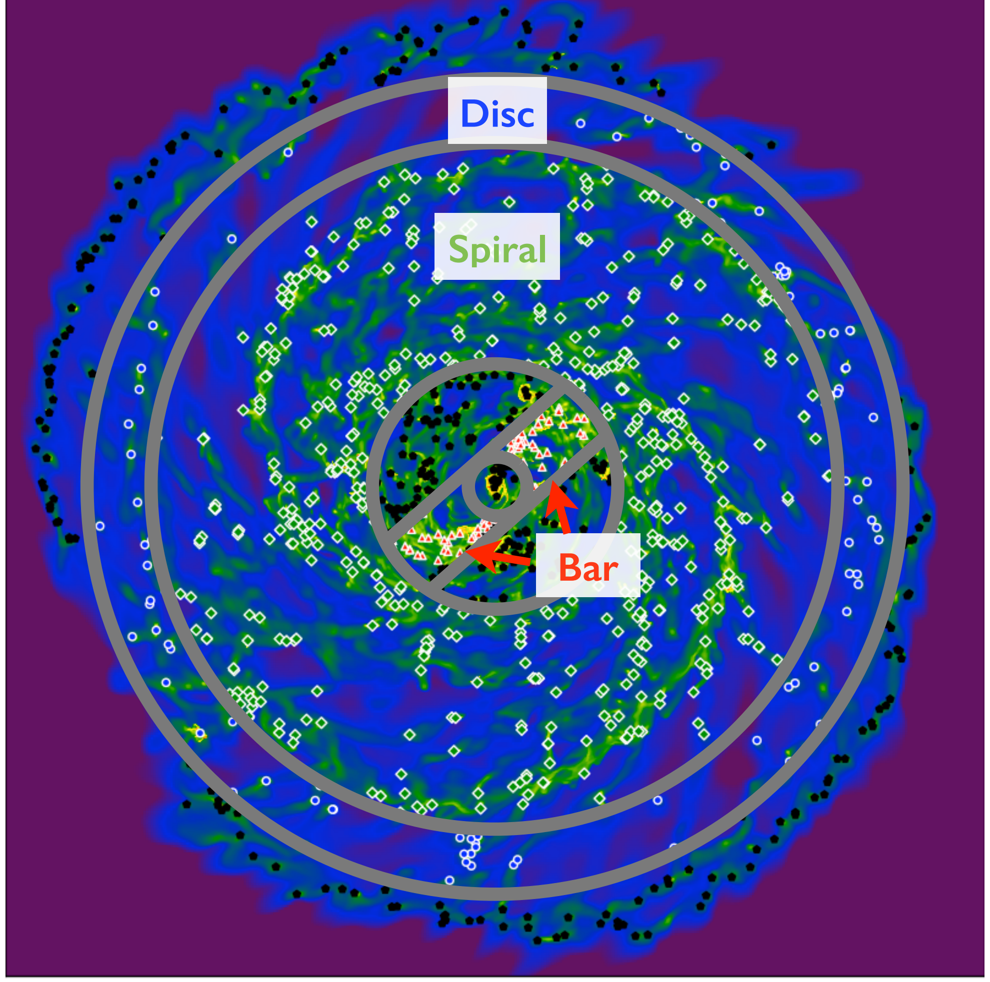
- In the bar region, massive monster clouds are the most obvious, forming GMAs that drag in surrounding gas.
  In the dense tidal filamentary structures, transient clouds are formed.
- In the disc region, the clouds are more widely spaced and lack filament structures around them. The vast majority of the clouds are normal clouds.

Summary

- The typical value of the cloud properties is **independent** of galactic environment.

$$M_c \sim 5 \times 10^5 M_\odot \quad R_c \sim 15\text{pc}$$

- The percentages of the three cloud types are different between the three regions.
  - Bar region
    - **Highest fraction of monster and transient clouds** due to the high cloud density from the elliptical motion boosting the interaction rate between clouds.
  - Spiral region
    - **The next high fraction of monster and transient clouds** due to the spiral potential encouraging interactions.
  - Disc region
    - **A large population of normal clouds** due to the lack of the grand design potential to gather gas.



	Bar	Spiral	Disc
Normal	50%	64%	83%
Monster	13%	13%	6%
Transient	38%	23%	11%

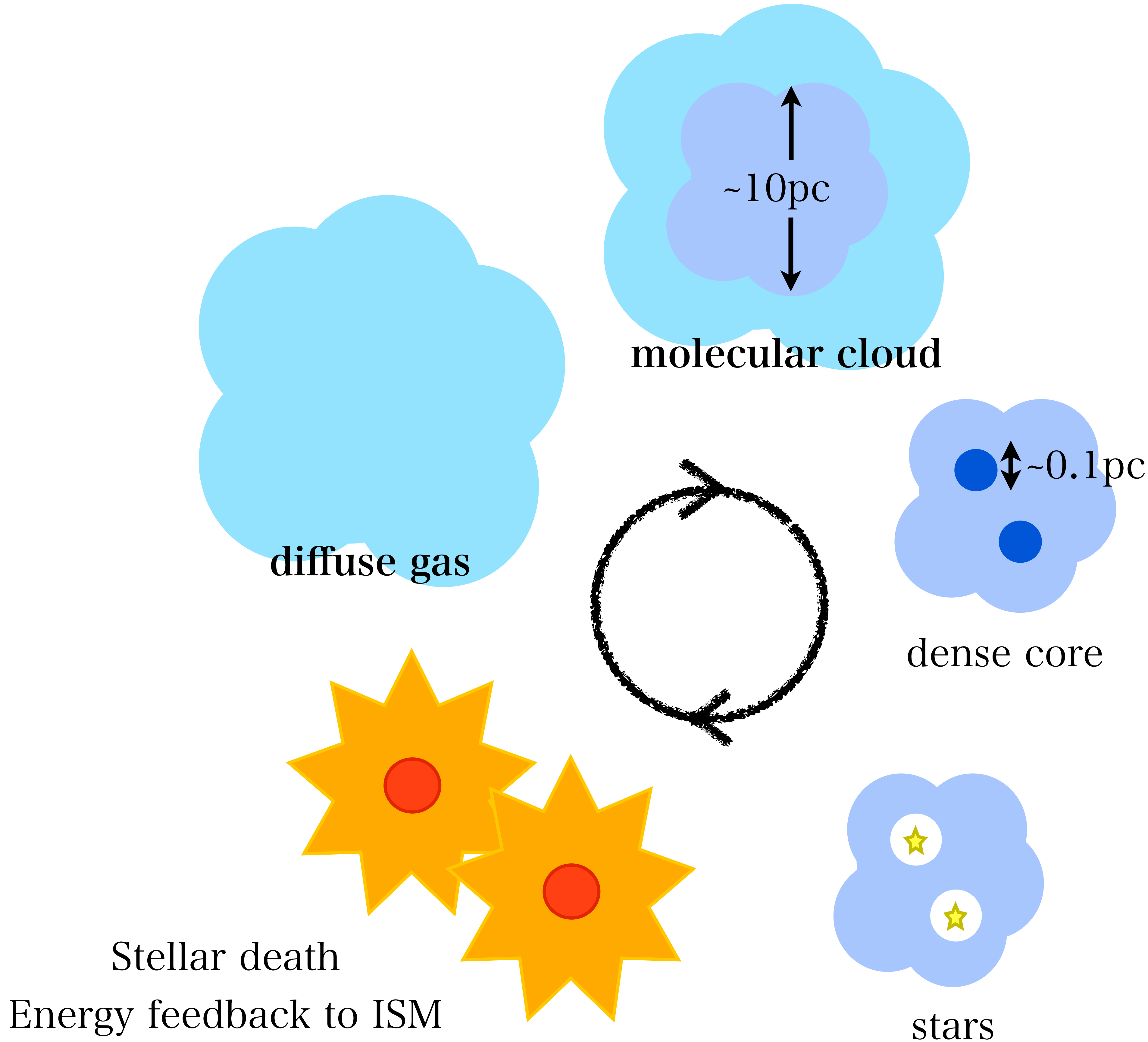
see also Fujimoto et al. (2014a)

Important message

Cloud-cloud interactions is quite different between galactic environment.

That gives different cloud populations in each galactic regions.

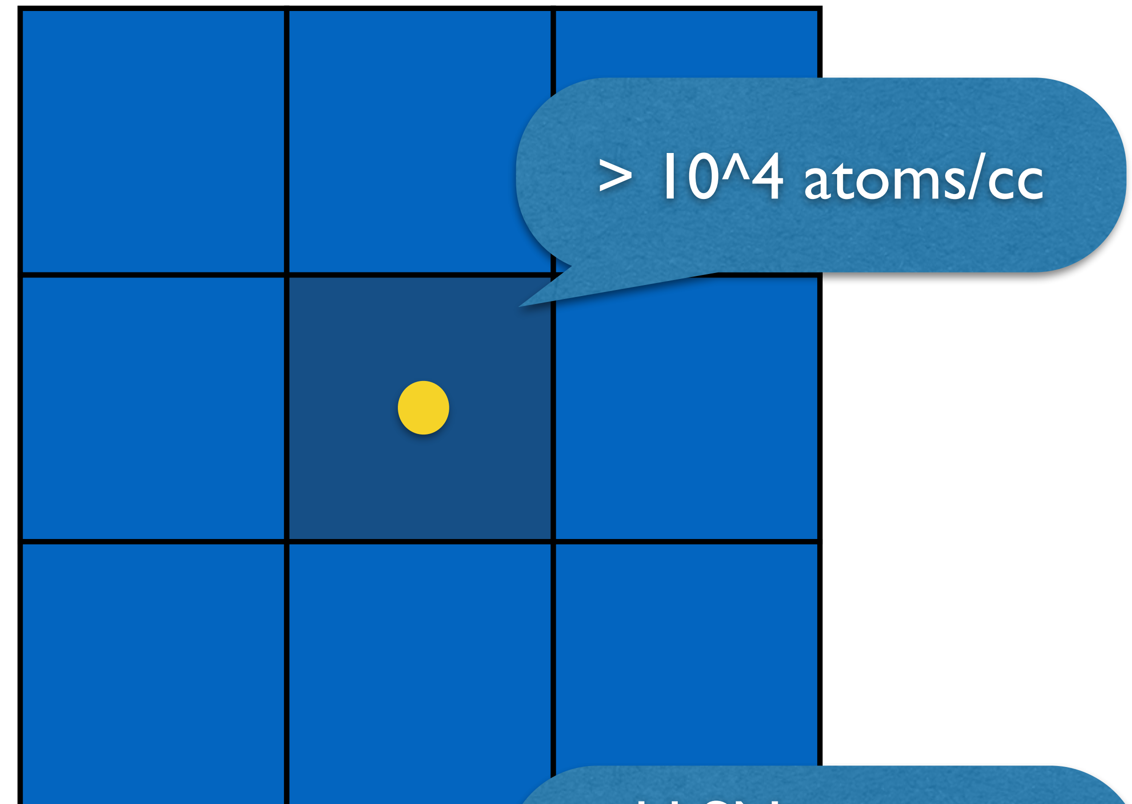
Stellar feedback to the ISM



Method of SF and FB

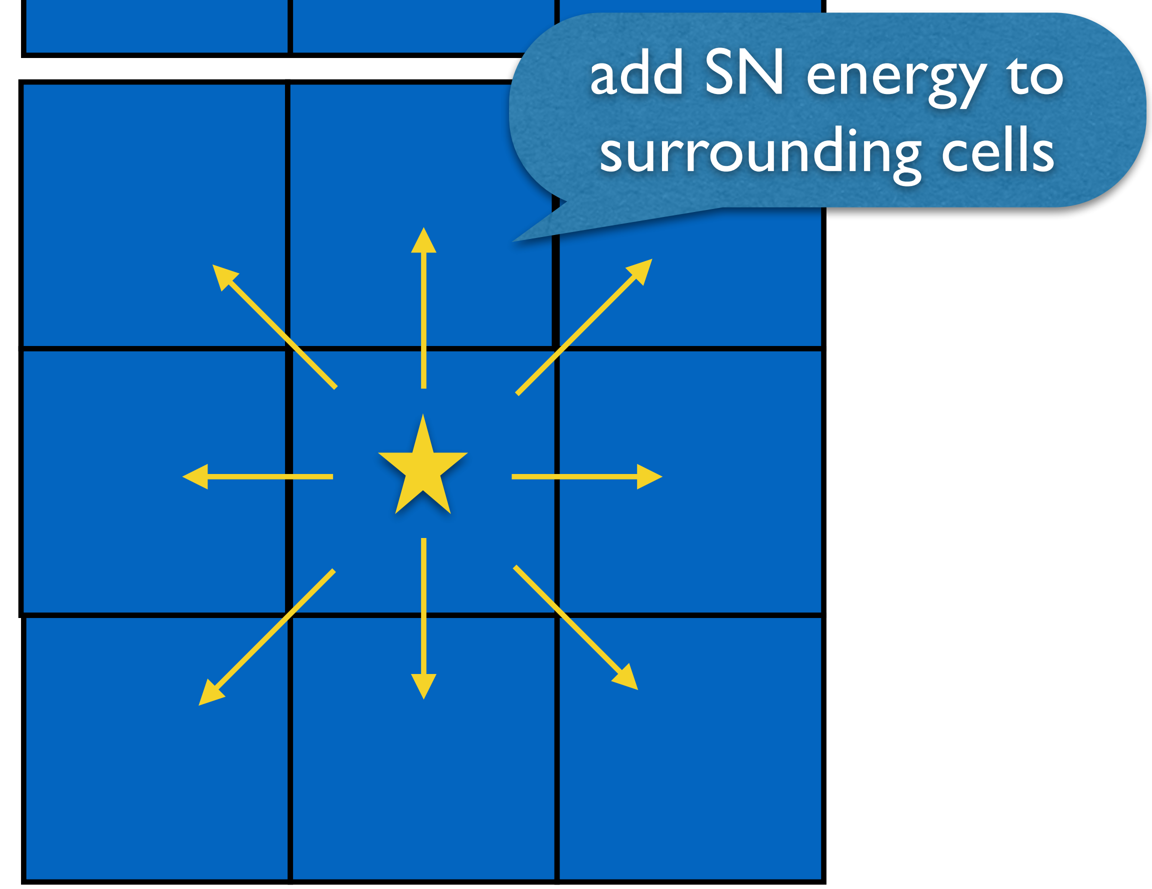
Star formation

Star particle is formed
in the denser cell than 10^4 atoms/cc.

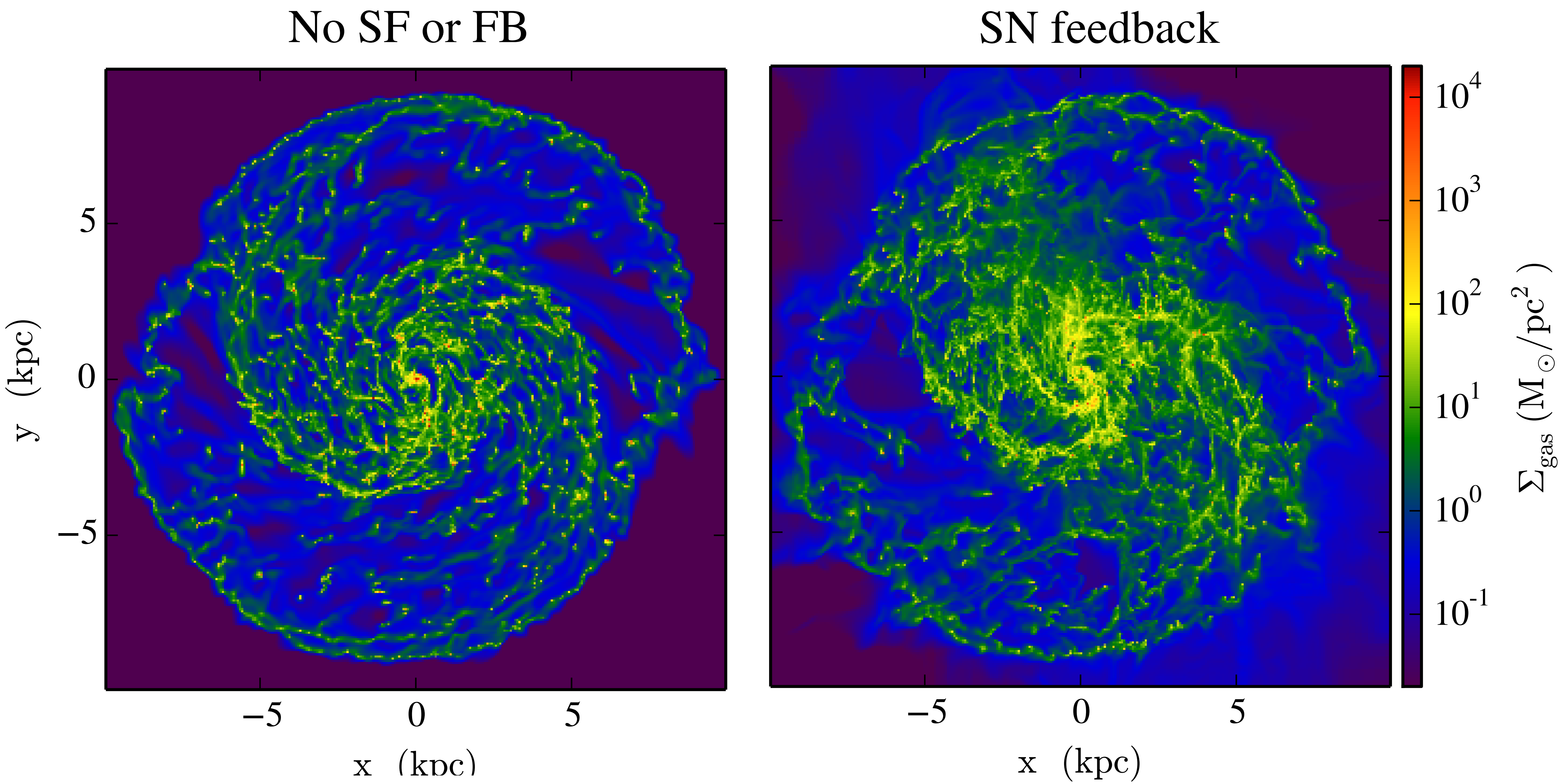


Supernova feedback

10^51 ergs energy input per 1 SN.



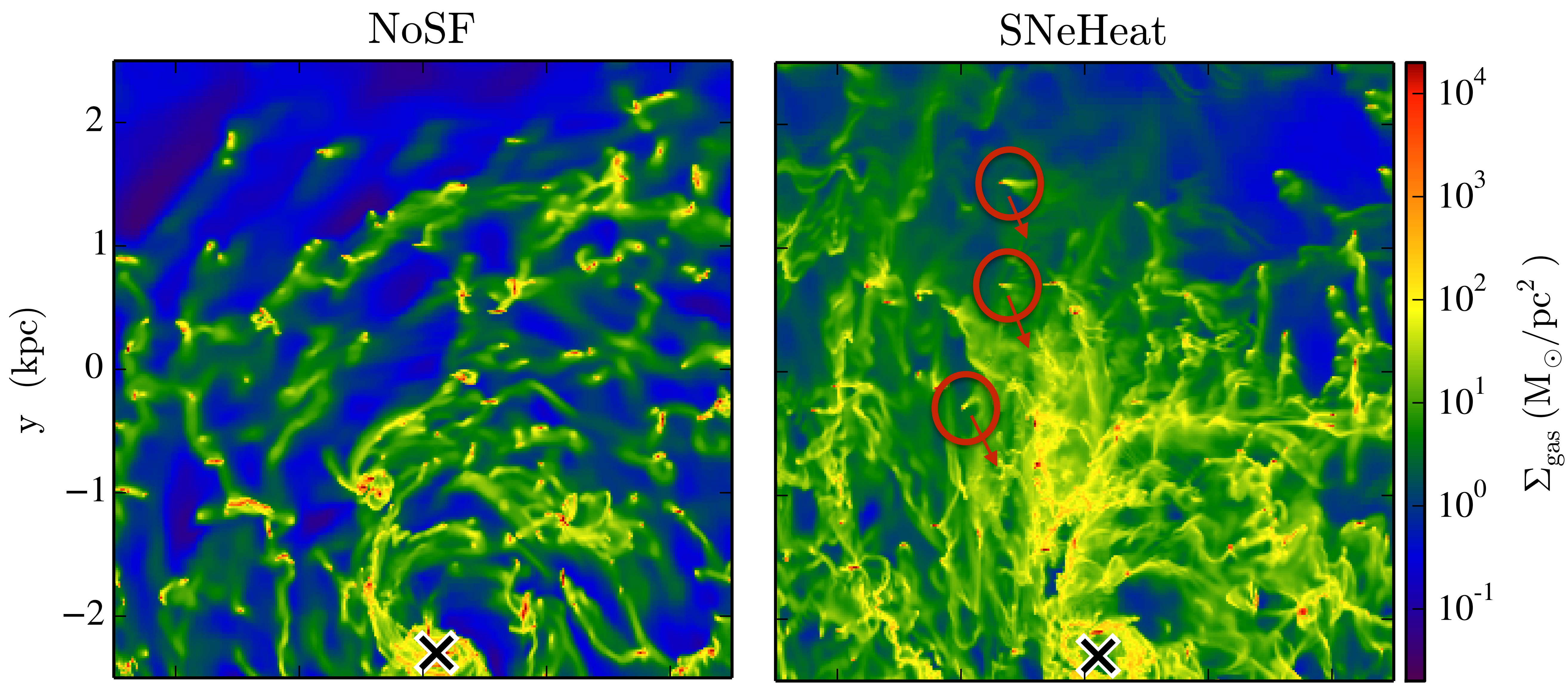
ISM dispersion caused by SN



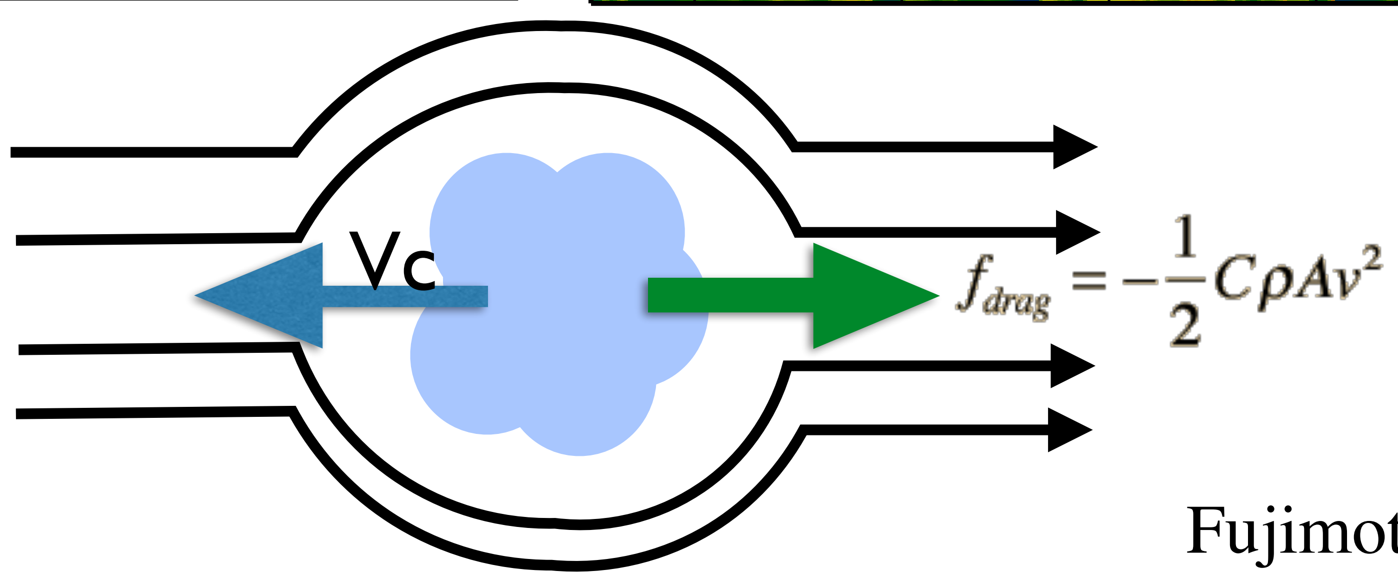
High inter-cloud density due to gas dispersion by SN.

Fujimoto+ 2015 (in prep)

Inflow of clouds by the high density ISM



Angular momentum loss



Fujimoto+ 2015 (in prep)

Thank you!