Stability of Disks & the Formation of Massive Clusters

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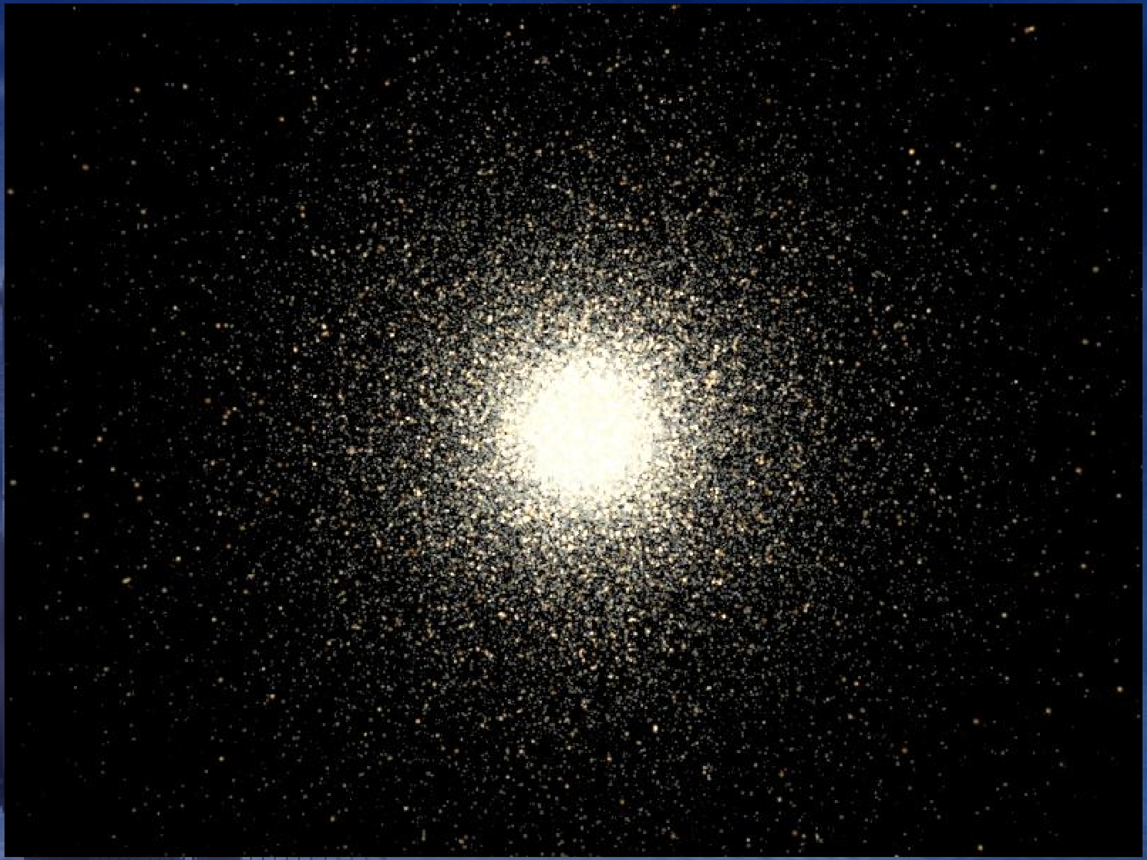
Formation of GCs



Since globular clusters are among the oldest objects in the universe, their formation is related with the physics of the primordial universe.

HST view of the Antennae:

Merging galaxies are forming massive (globular-type) clusters today.

Super-GMC Hypothesis

Giant Molecular Clouds (GMCs) in the galaxy of $\sim 10^6\ M_{\odot}$ form open clusters of $\sim 10^3\ M_{\odot}$ (SF efficiency $\sim 0.1\%$).

Higher SF efficiency cannot solve alone the problem (100% efficiency required).

For GCs of $\sim 10^{5\text{-}6}\ M_{\odot}$ a Super-GMCs with $M > 10^6\ M_{\odot}$ is required (value depend on SF efficency; Harris & Pudritz 94).

Theories for GCs Formation

For the origin of Super-GMCs, most theories assumed changes in the physical conditions of the gas relative to galactic ones:

Hot $T=10^4$ K plasma (due to primordial cooling; Fall & Rees 85).

GMC collisions (due to magnetic fields; Harris & Pudritz 94).

Higher pressure confinement (higher turbulence environment; Ashman & Zepf 01).

Super-GMCs Formation Via Gravitational Instability

- Linear stability analysis of a uniformly rotating disk, simplest illustrative case (Toomre 1964).

- Dispersion Relation:
  $w^2 = 4\Omega^2 - 2\pi G|k|\Sigma_{gas} + k^2 C_S^2 < 0$

- Limiting Cases:

$\Omega = 0$: $\lambda > \lambda_{JEANS} = C_S^2/G\Sigma_{gas}$ are unstable.

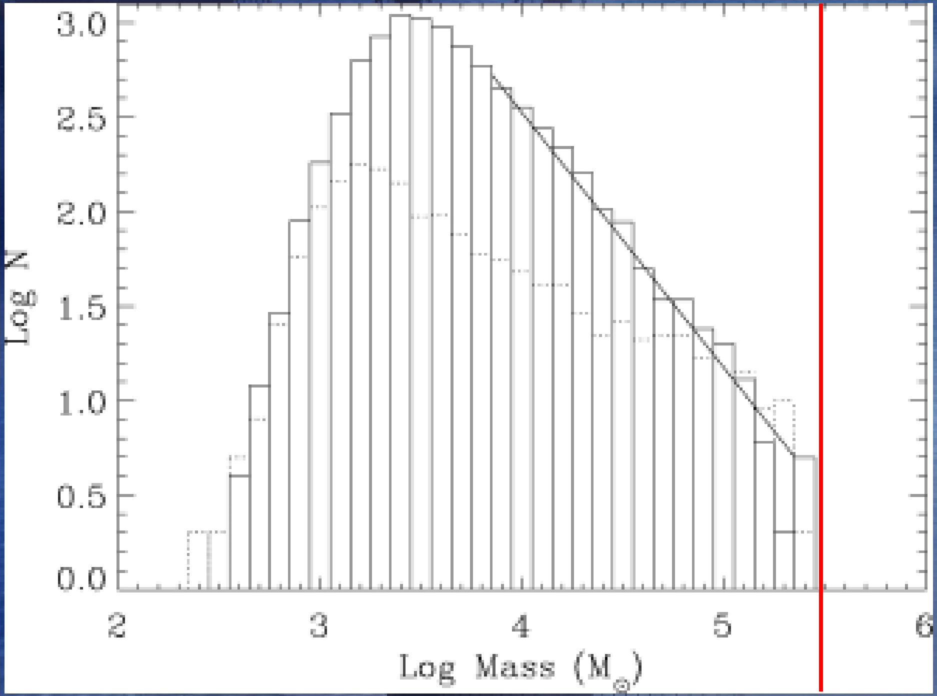
$C_S^2 = 0$: $\lambda < \lambda_c = \pi^2 G\Sigma_{gas}/\Omega^2$ are unstable.

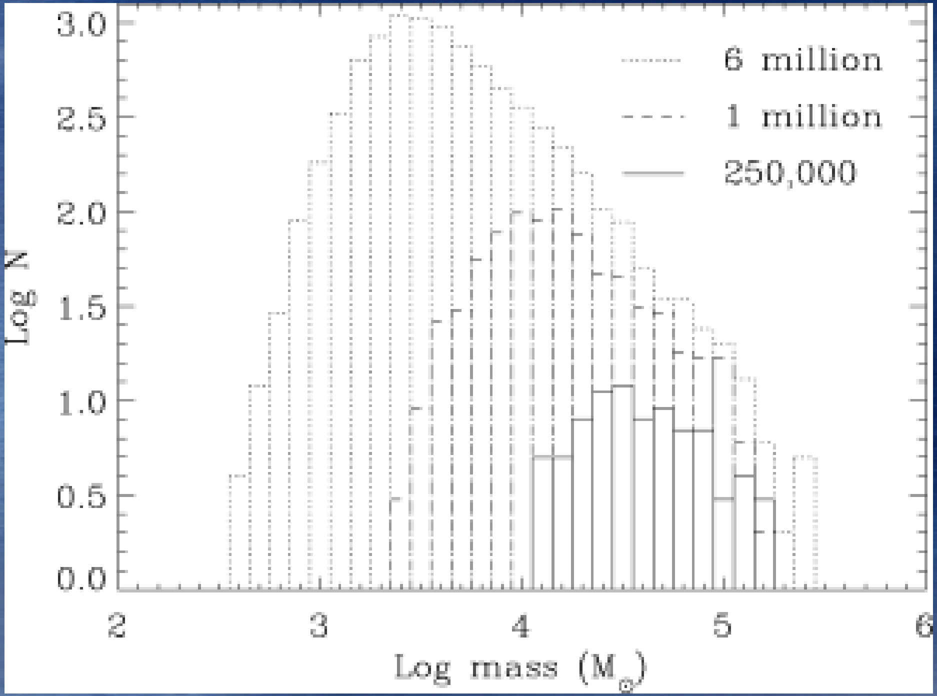
Largest Unstable Wavelength

- General result of linear stability analysis :
- All wavelength between λ_{Jeans} and λ_c are unstable. When $\lambda_{JEANS} \approx \lambda_c$, Q (Toomre Par.) is ≈ 1.
- Clouds of masses up to $M_{max} = \sum_{gas}(\lambda_c /2)^2$ could form (in the absence of other processes) and fragment down to M_{jeans} (molec gas).
- We propose that the formation of Super-GMCs is associated with variations of this largest unstable scale and thus with the current formation of massive stellar clusters on a galaxy.

Dobbs & Bonnell (2007)

SPH run of GMC formation in a 'Milky Way' galaxy:





$$M_{max} = \pi \Sigma_{gas} (\lambda_c /2)^2 = \frac{\pi^5 G^2 \Sigma_{gas}{}^3}{4\,\Omega^4} \approx 6\ 10^5\ M_\odot$$

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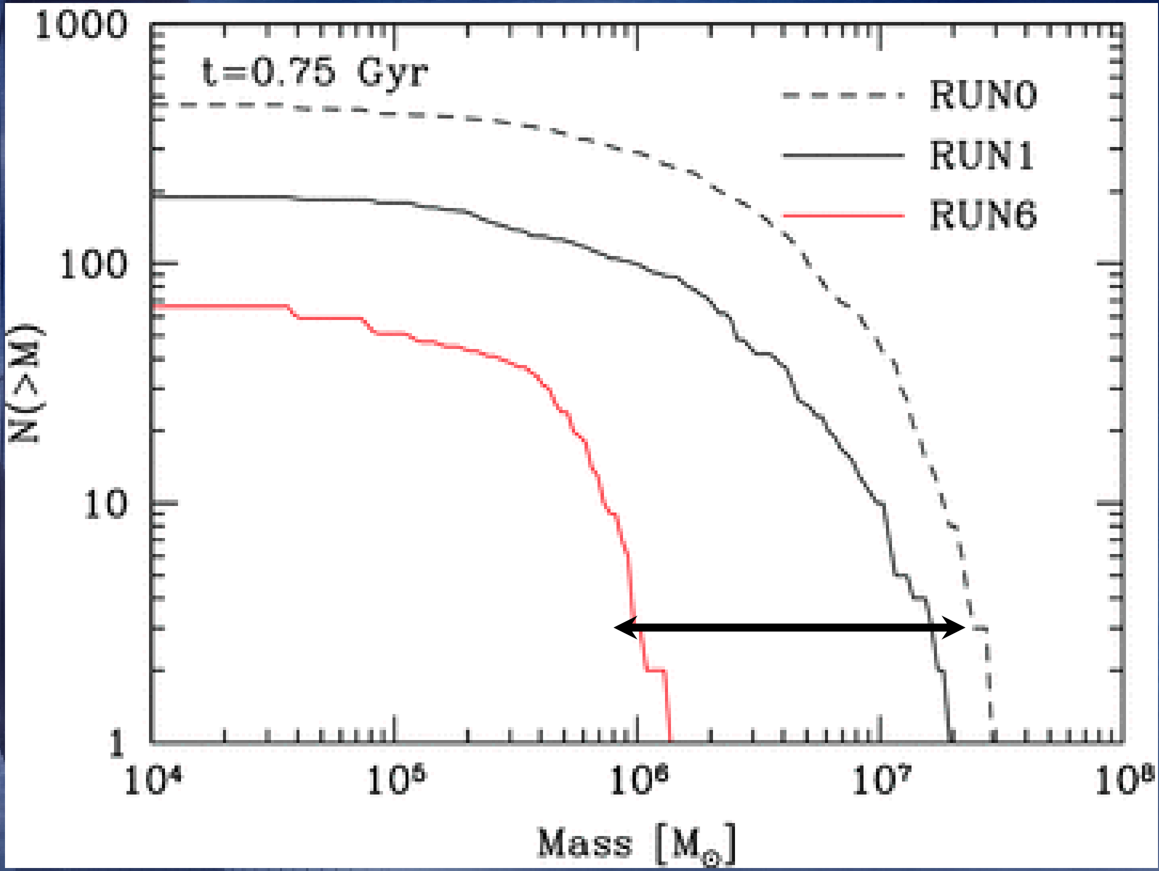
Agertz et al. (2009)

AMR runs of disk galaxies with different gas fractions:



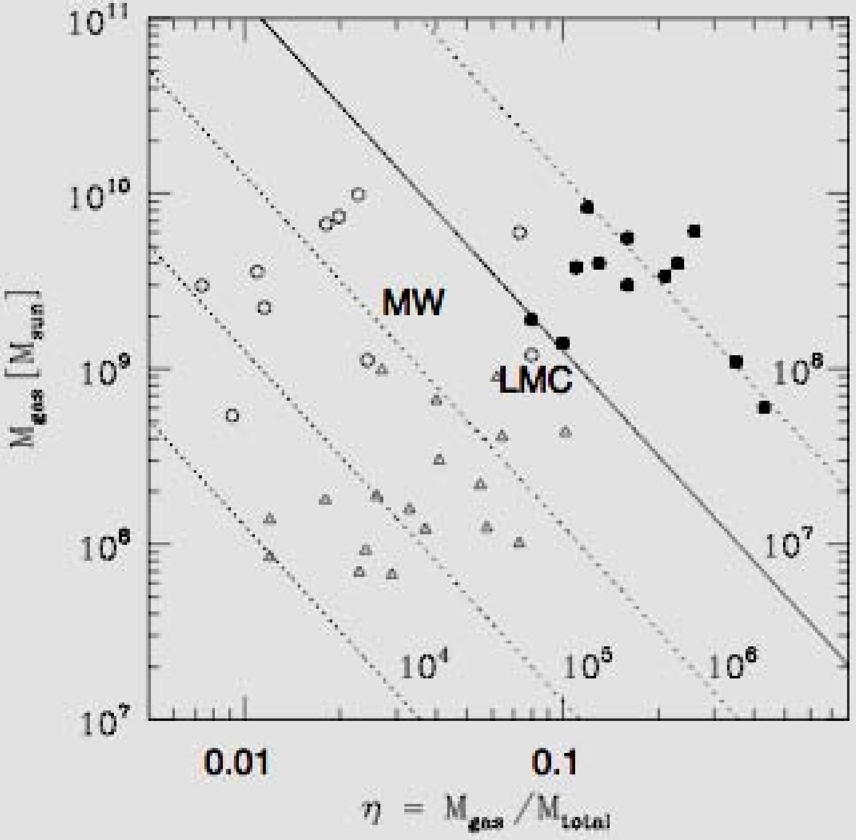
$\Sigma_{Run1} = 3\ \Sigma_{Run6}$ ⇨ $M_1^{max} - M_6^{max} \approx \times 3^3 = 27$

Escala & Larson (2008)

Rot support +

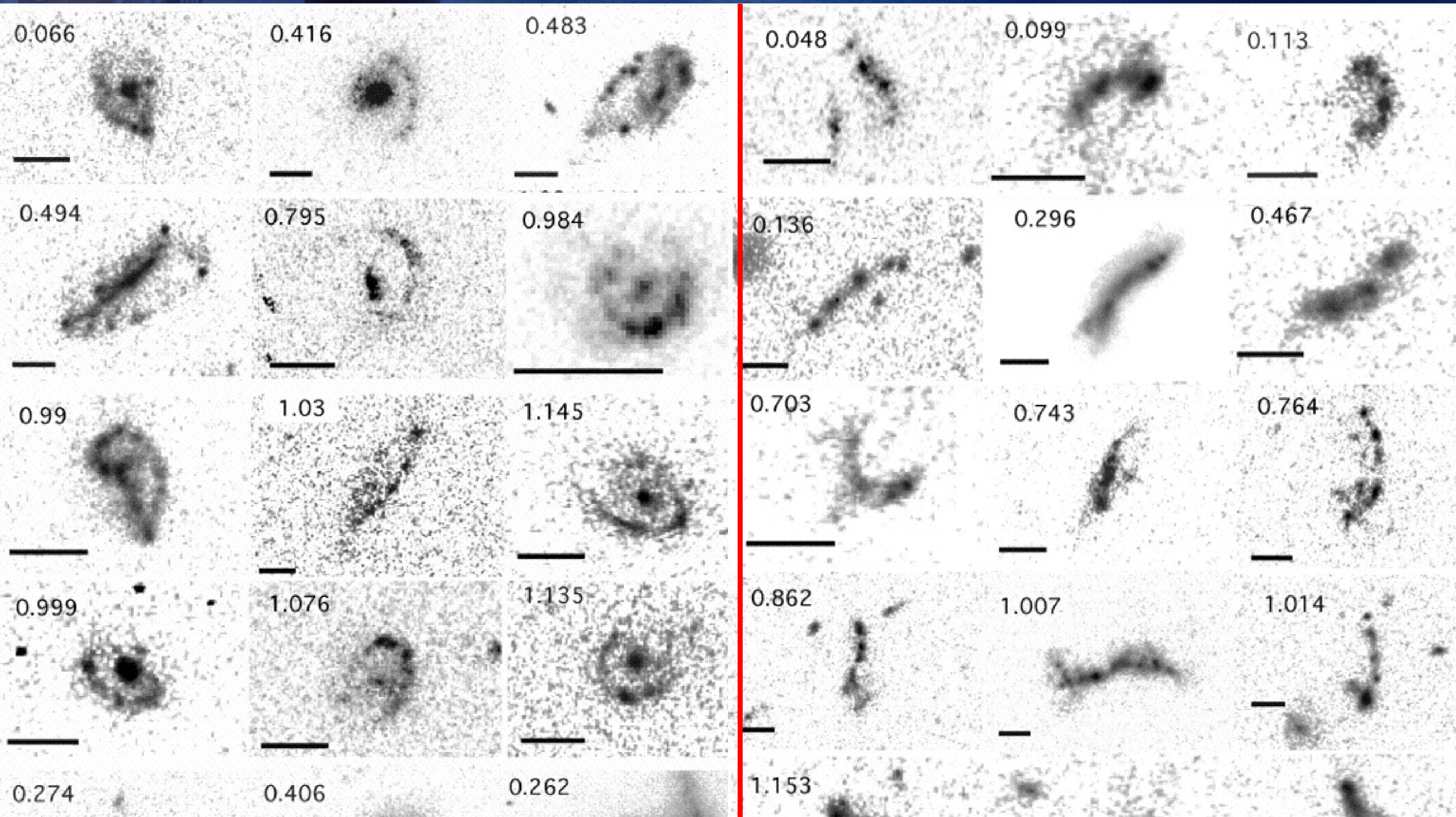
$\eta = M_{gas} / M_{tot}$

$M_{max} = M_{gas}\,\eta^2$

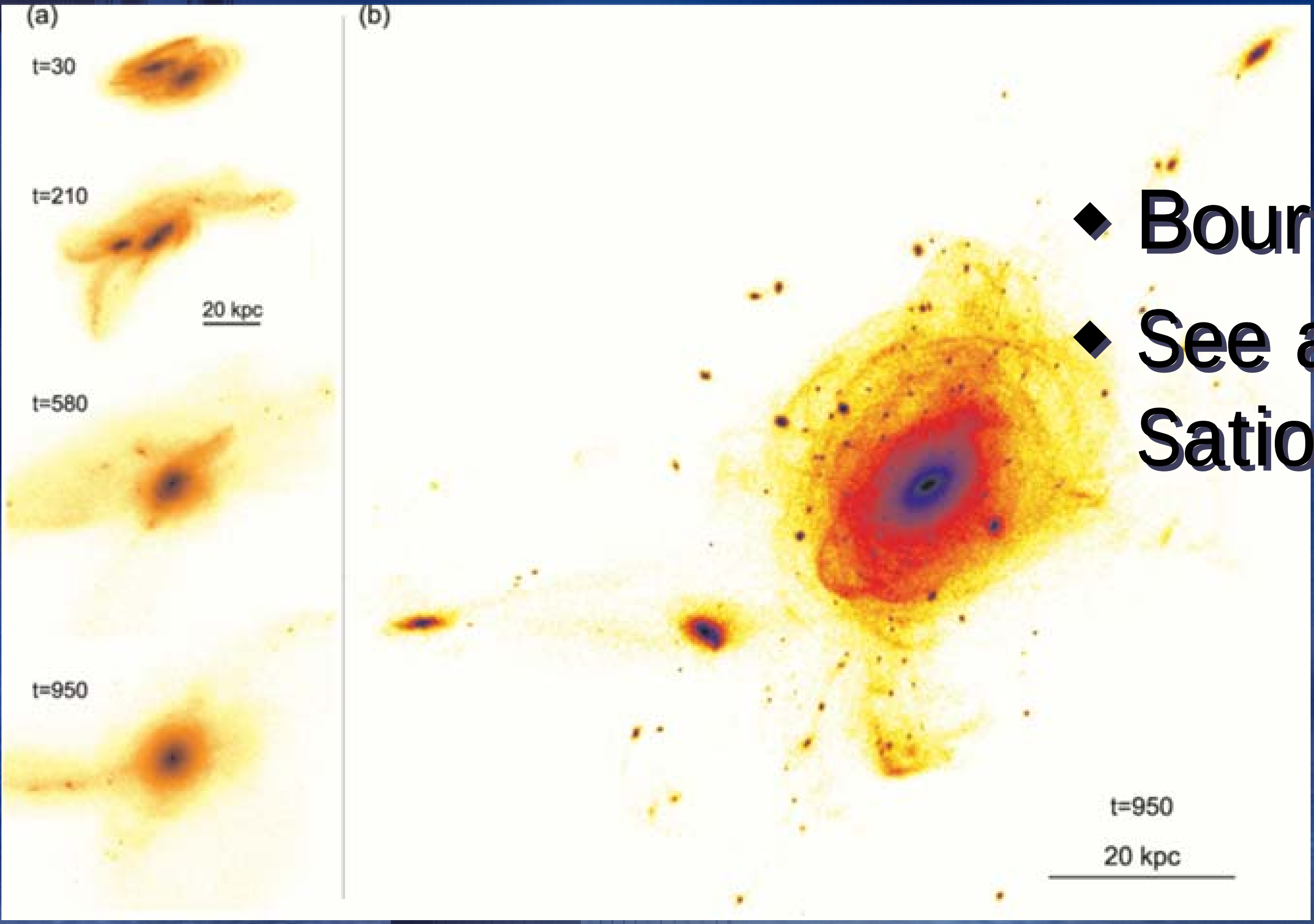


Clumpy Disk / Chain Galaxies

(*Elmegreen² 06*)



Simulations Galaxy Mergers



- Bournaud et al. 08'
- See also posters by Satioh and Renaud.

The max cloud mass is valid besides the disk geometry (early merger) because is set by the local balance between centrifugal and self-grav forces.

Summary

- In a rotating system, there is a well defined maximum unstable scale set by rotation.
- Variations of this maximum mass scale can explain the existence of Super-GMCs in some galaxies, and thus the formation of young massive stellar clusters.
- We found that starbursts and gas-rich proto-galaxies, are galaxies with favorable sites for Super-GMCs formation.

NGC2403 (Drissen et al. 99)