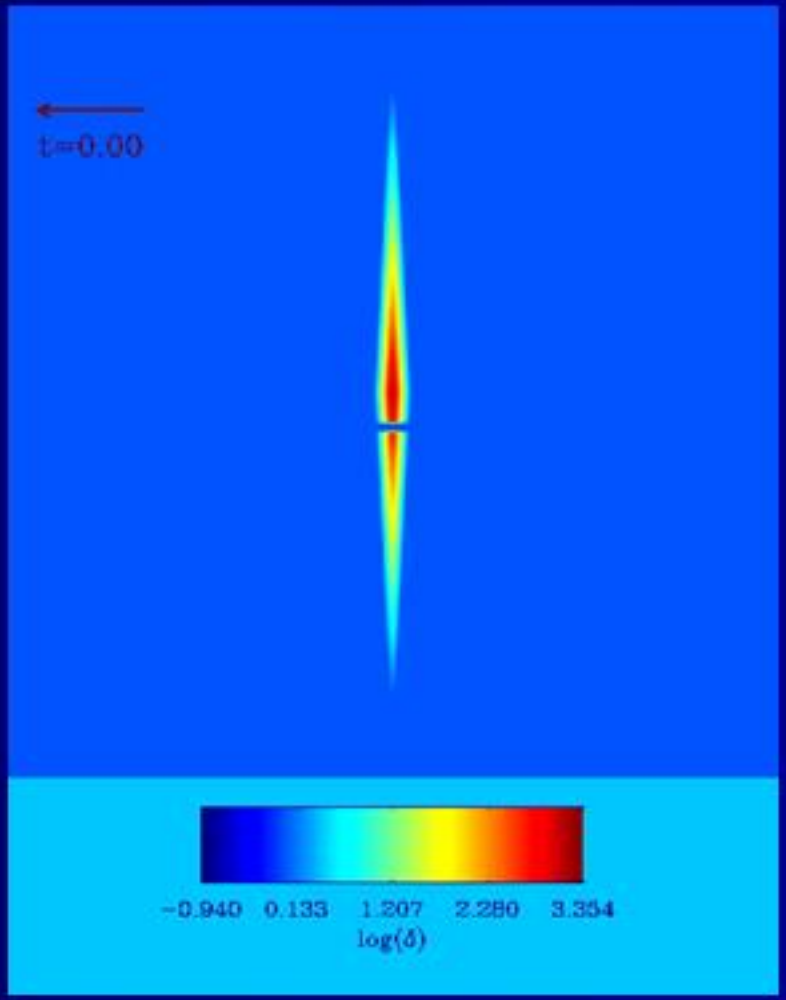
Ram pressure stripping



Content of this talk

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Introduction

- **What is ram pressure stripping?**

- a galaxy moves through a cluster
- hot intercluster medium
- gas removed from galaxy

- **Importance of this process?**

- understanding of morphology-density relation
- evolutionary effects on galaxies and morphological transition
- enrichment of intercluster medium
- star formation history

some general properties

- no direct effects on stellar component
- total breakdown of star formation in stripped parts of the galaxy
- galaxy has a "gas tail" (length ~100kpc)

Phases of stripping

- Instantaneous stripping
- Intermediate phase
- Continuous stripping

Instantaneous stripping

- ram pressure greater than restoring gravitational force
- high mass loss rates
- short: 20-200 megayears
- dependence on inclination

analytical approach

condition for instantaneous stripping $p_{ram} > f_{grav}(r)$

with $p_{ram} = \rho_{ICM} v_{gal}^2$ and $f_{grav}(r) = \Sigma_{ISM}(r) \frac{\partial \Phi}{\partial z}(r)$

→ $\rho_{ICM} v_{gal}^2 > \frac{G}{3} \frac{M \rho_{gas,0}}{r_0}$

stripping time $t_{strip} = \sqrt{\frac{2 s \Sigma_{ISM}}{p_{ram}}}$

- **consequences**

- all gas outside a certain stripping radius is removed from the disk
- most gas is still bound to the galaxy
- bow shocks on upstream side
- ~10% gas fall back on the galaxy (depending on homogeneity of gas-disk)
- at lower ram pressures: gas can settle in a potential minimum on the downstream side -> star formation (new dwarf galaxy?)

Intermediate phase

- transition between other two phases
- previously stripped gas gets unbound or falls back (small percentage)
- highly dynamical
- about 10 times longer than first phase

Continuous stripping

- ongoing small mass losses
  with mass loss rates of about 1 $M_\odot$/year
- can last for gigayears
- does not depend on inclination
- remaining gas in disc will be compressed
  a little enhanced star formation in centre

- **caused by Kelvin-Helmholtz Instability**

perturbation theory of hydrodynamics

turbulences on the barrier between 2 fluids

$$\rho_{ICM} v_{gal}^2 > \frac{G}{2\pi} \frac{M_0 \rho_{gas,avg}}{r_0}$$

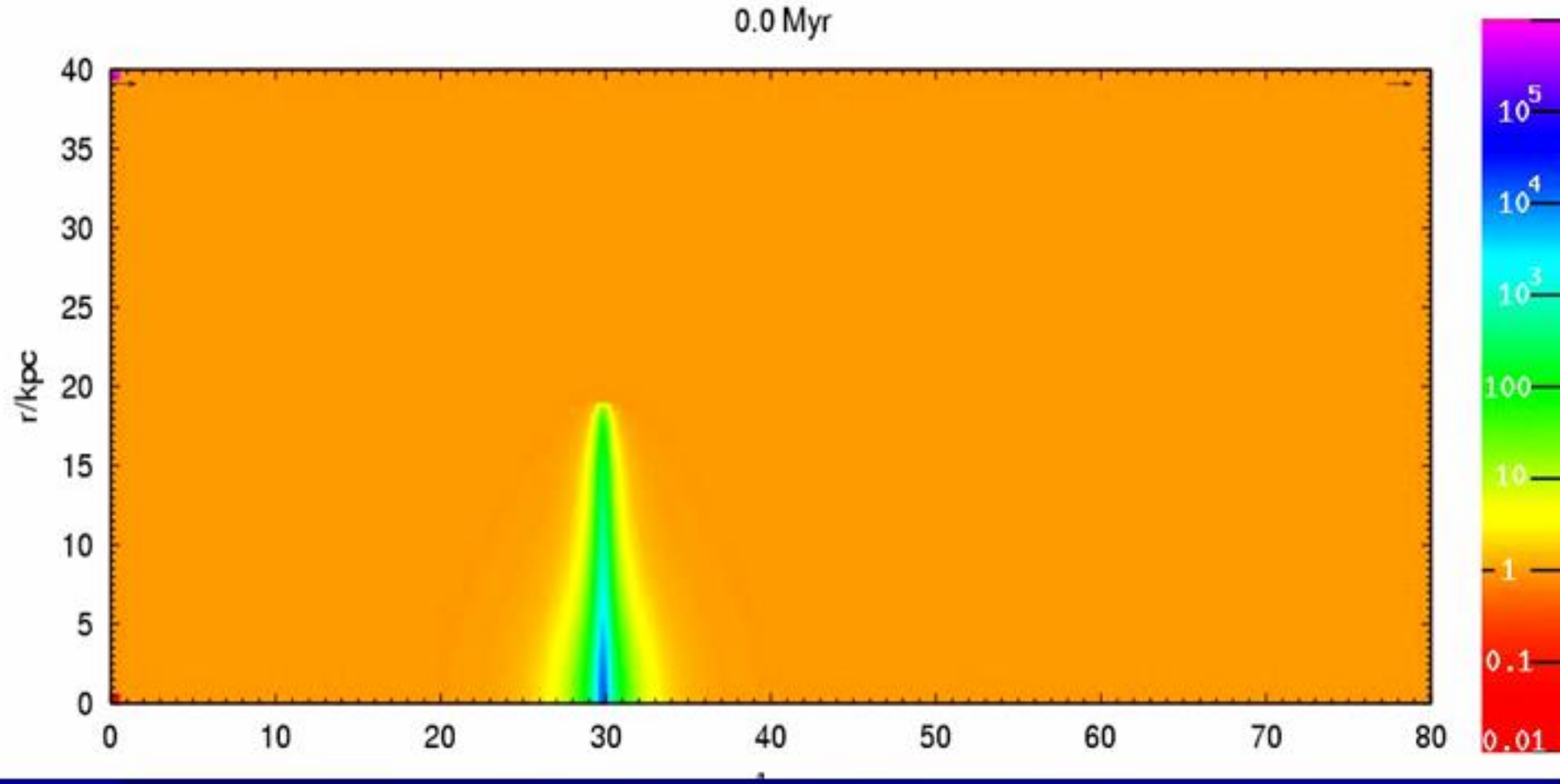
mass loss rate:

$$\dot{M}_{KH} = 0.5\pi R^2 \rho_{ICM} v_{gal}$$

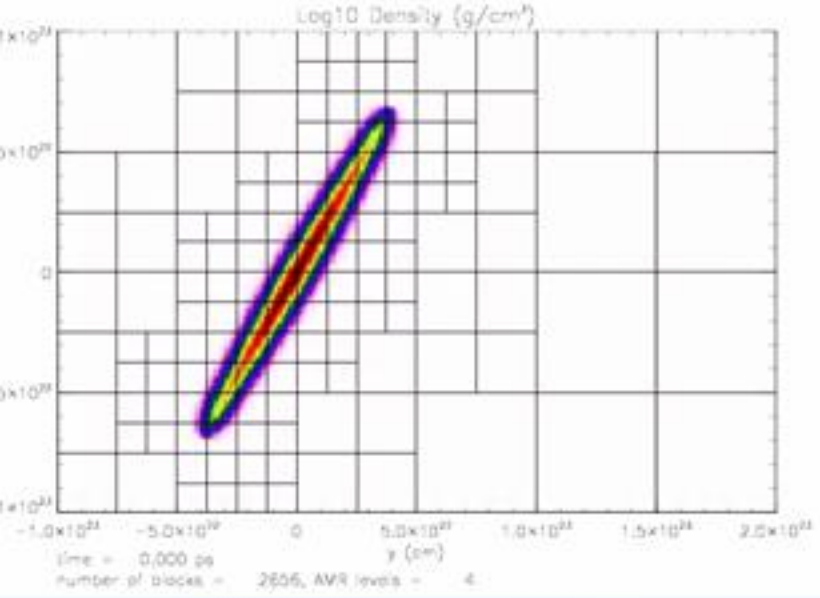
Simulations

- hydrodynamical codes: ZEUS(2D), RIEMANN(2D), BOH(3D), FLASH(3D), Hydra(3D),...
- influence of resolution
- rotation (only in 3D codes possible) and loss of angular momentum
- homogeneity of ISM, star formation, cooling, variations of ram pressure, ...

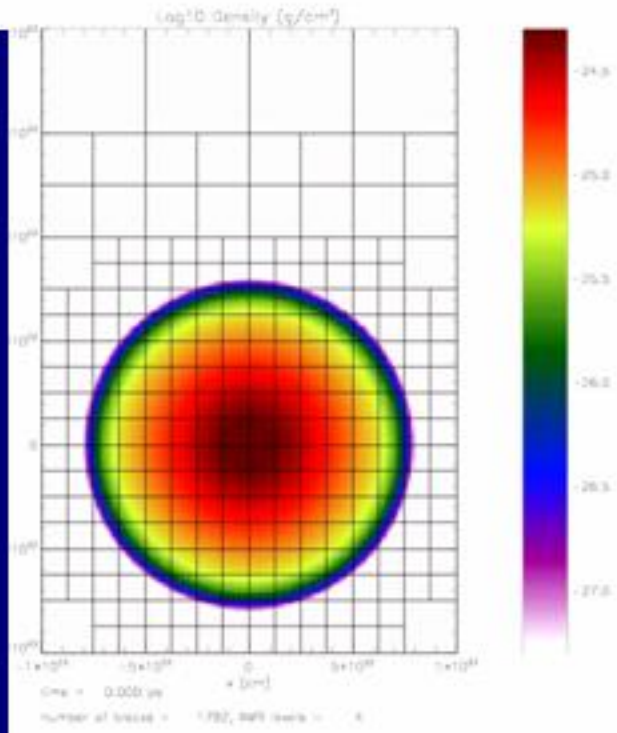
2D ram pressure simulation of a disc galaxy

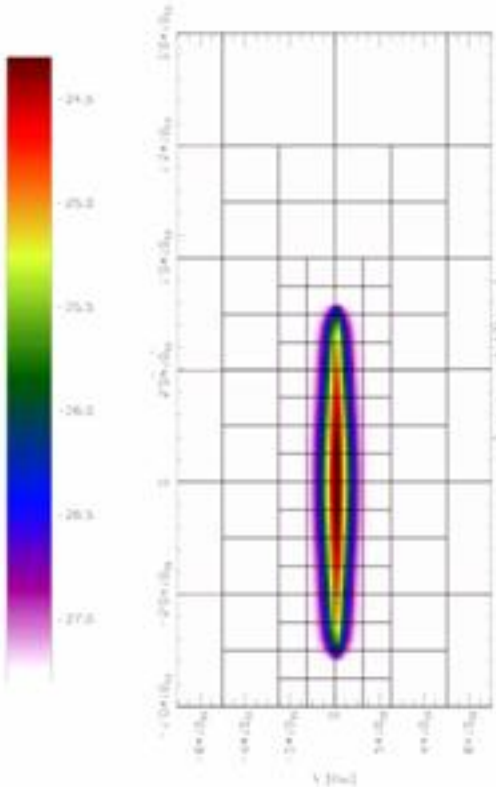


influence of inclination



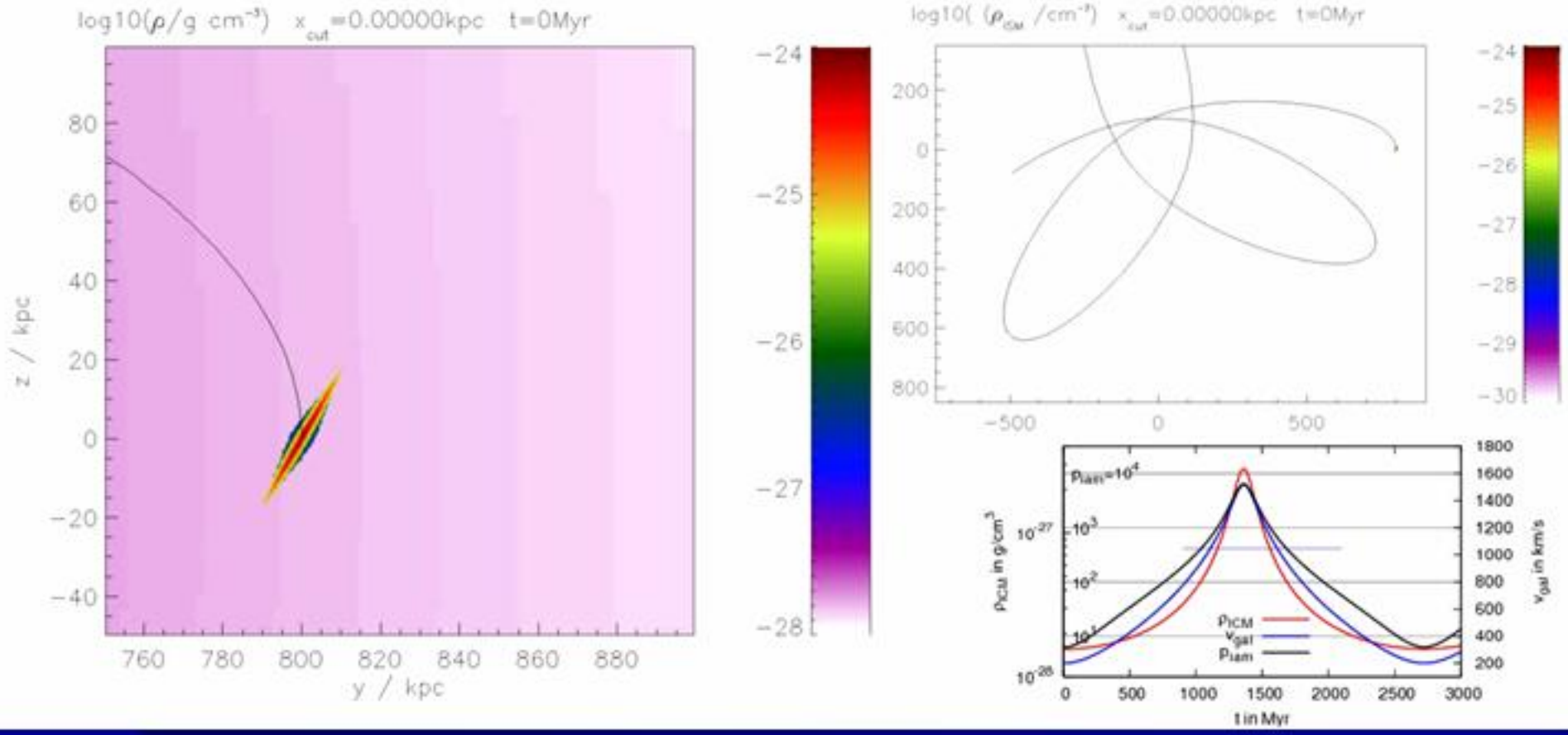
inclination of 30°



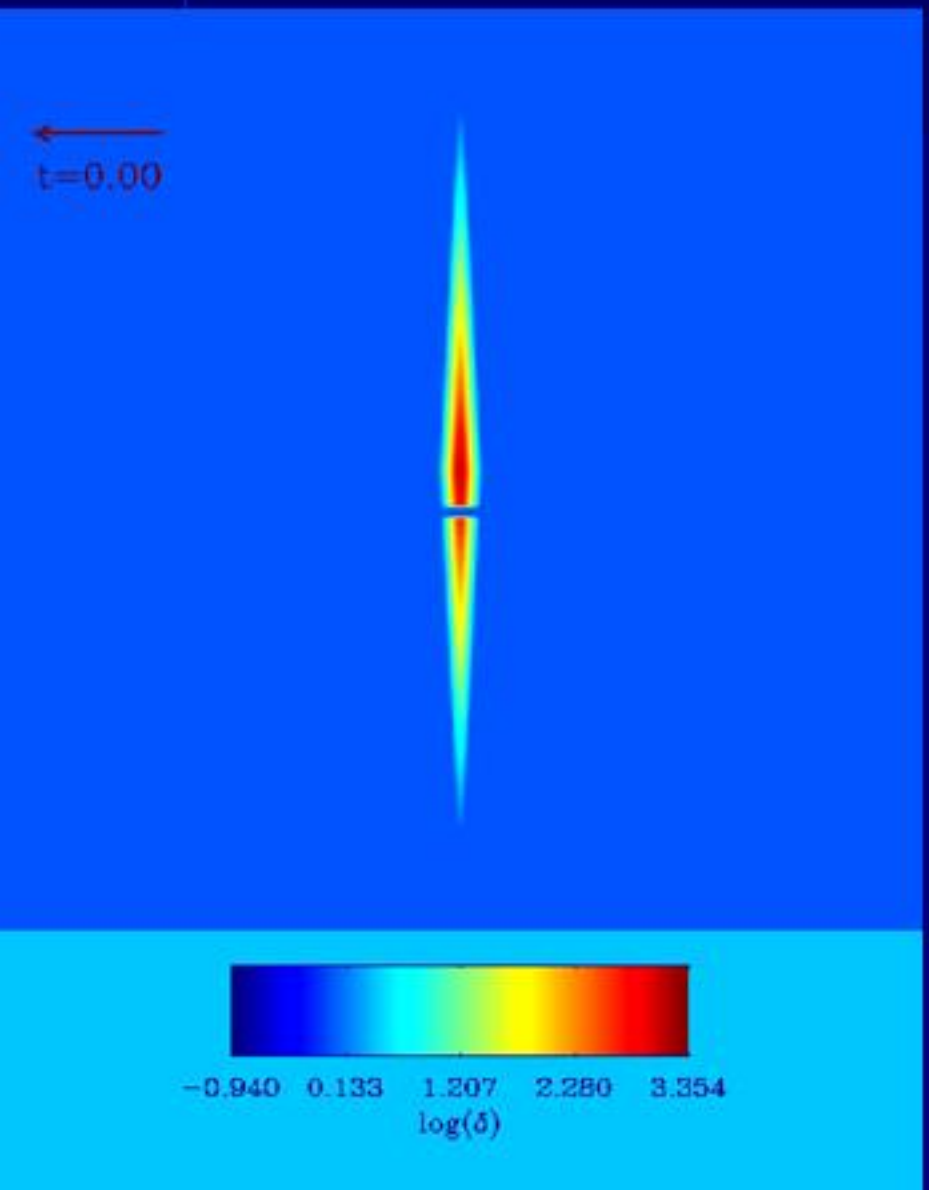


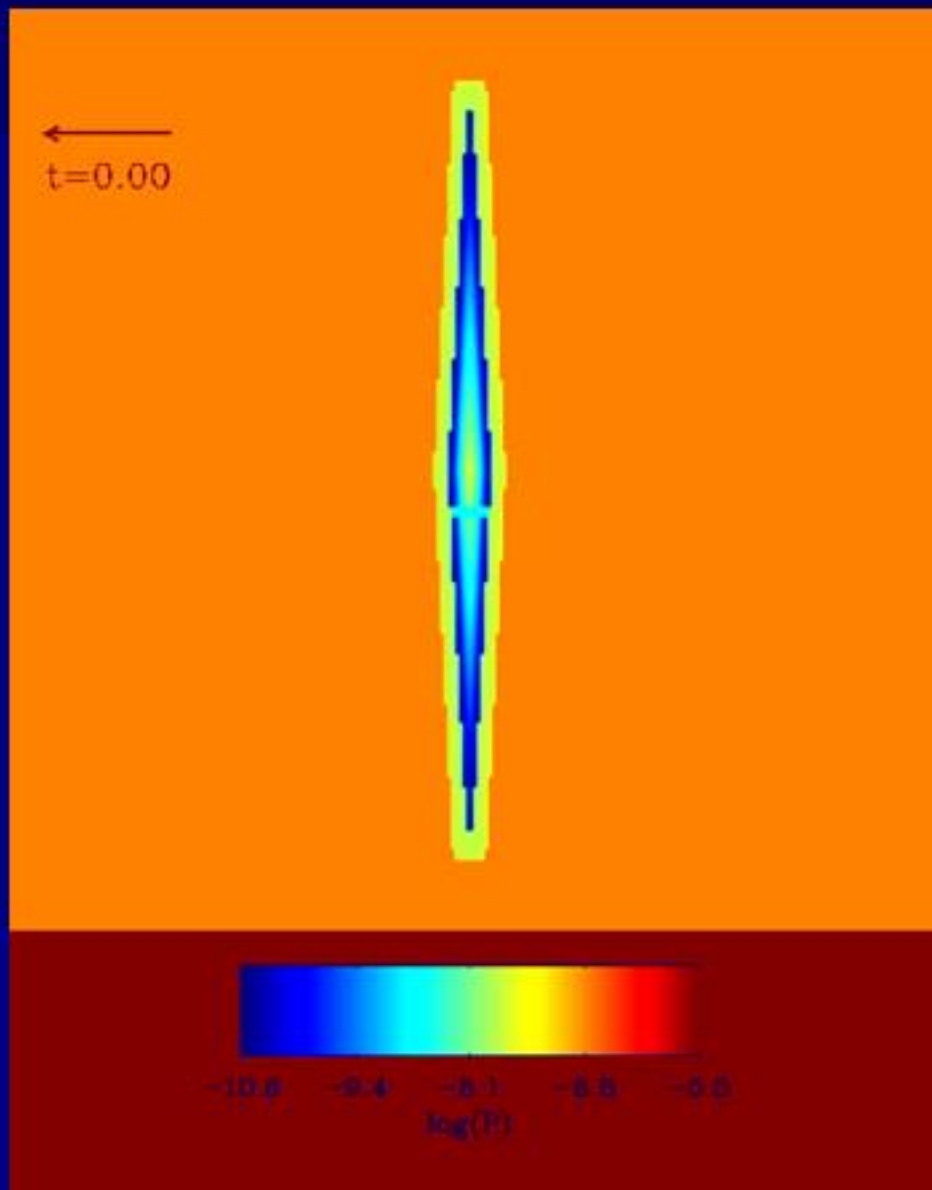
inclination of 90° (edge on)

a galaxy moves through a cluster (3D-calculation)



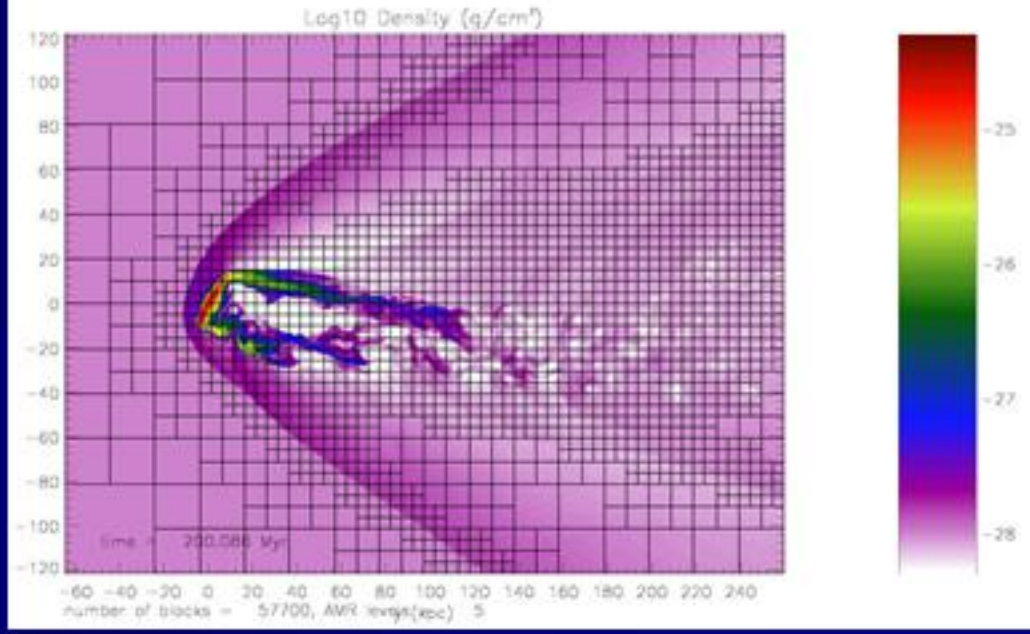
inhomogeneous disc suffering ram pressure



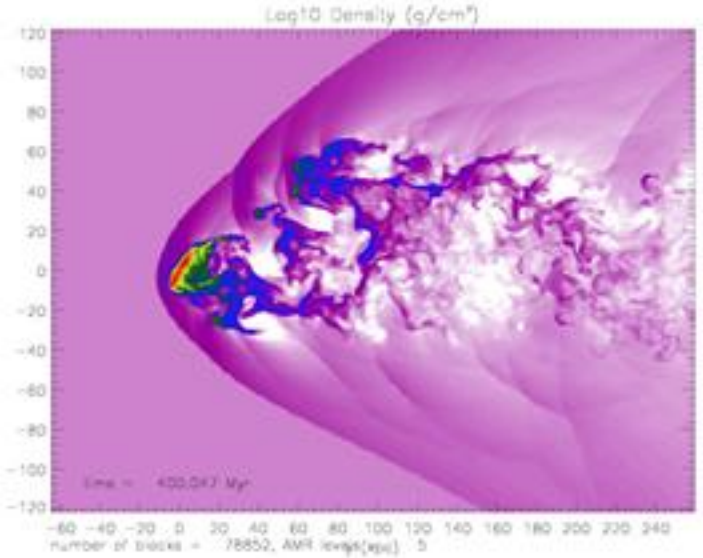


3 phases of stripping

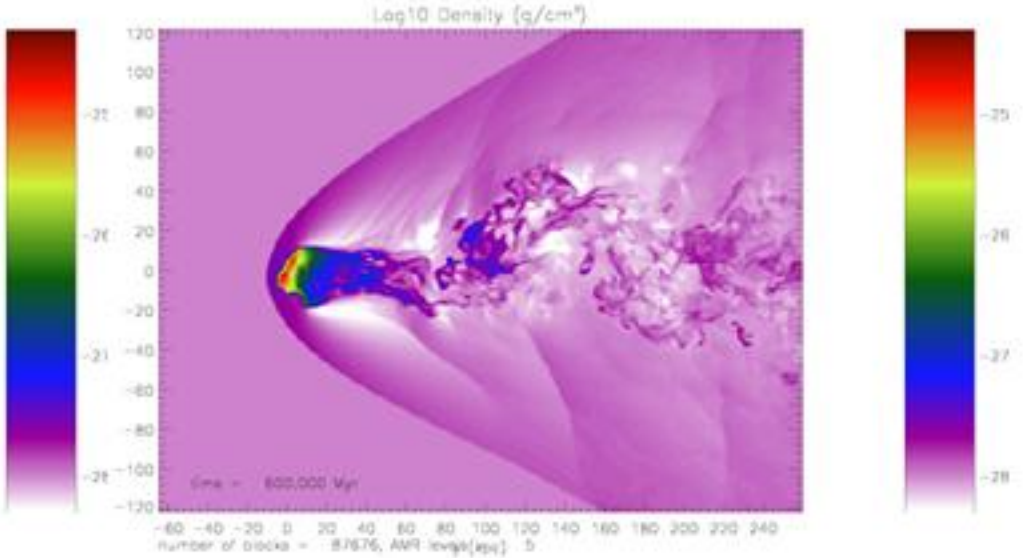
instantaneous stripping



intermediate phase



continuous phase



Dependence on type of galaxy

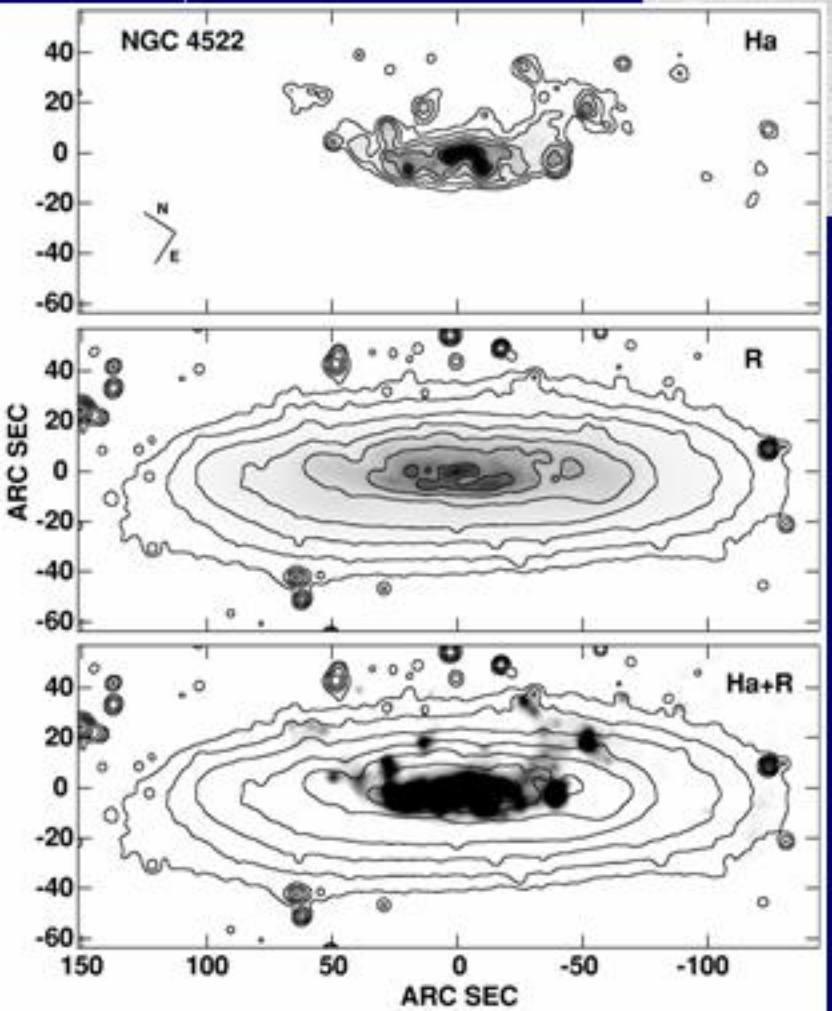
- Spiral galaxies
- Elliptical galaxies
- Dwarf galaxies

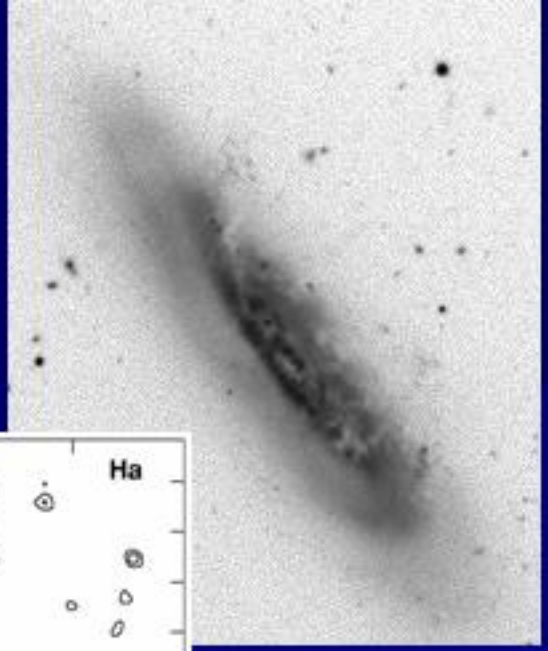
Spiral galaxies

- no star formation in outer disk
- enhanced star formation in centre
- anaemic galaxies
- transformation into S0-galaxies

Observations

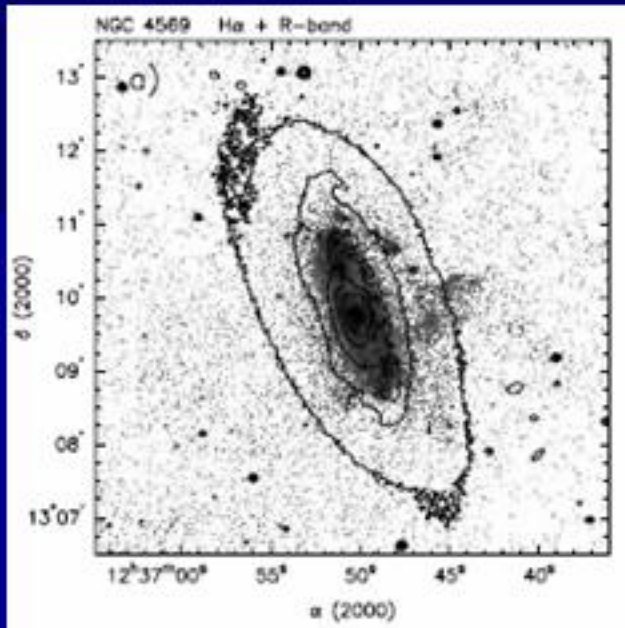
NGC 4522

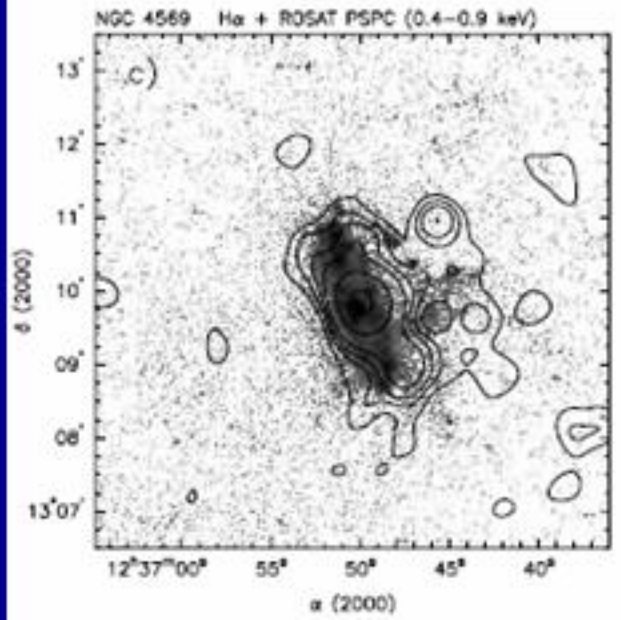




other examples:
NGC 4388,
NGC 4548,
NGC 4848, ...

NGC 4569



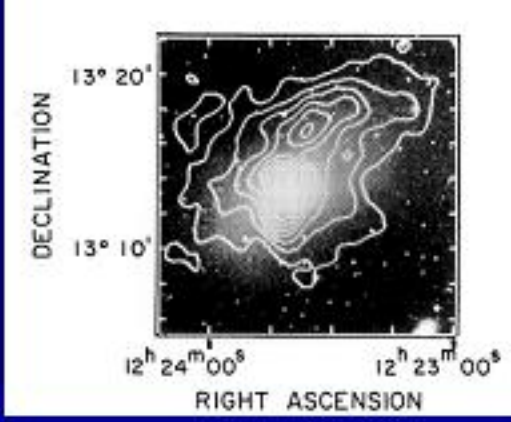


Elliptical galaxies

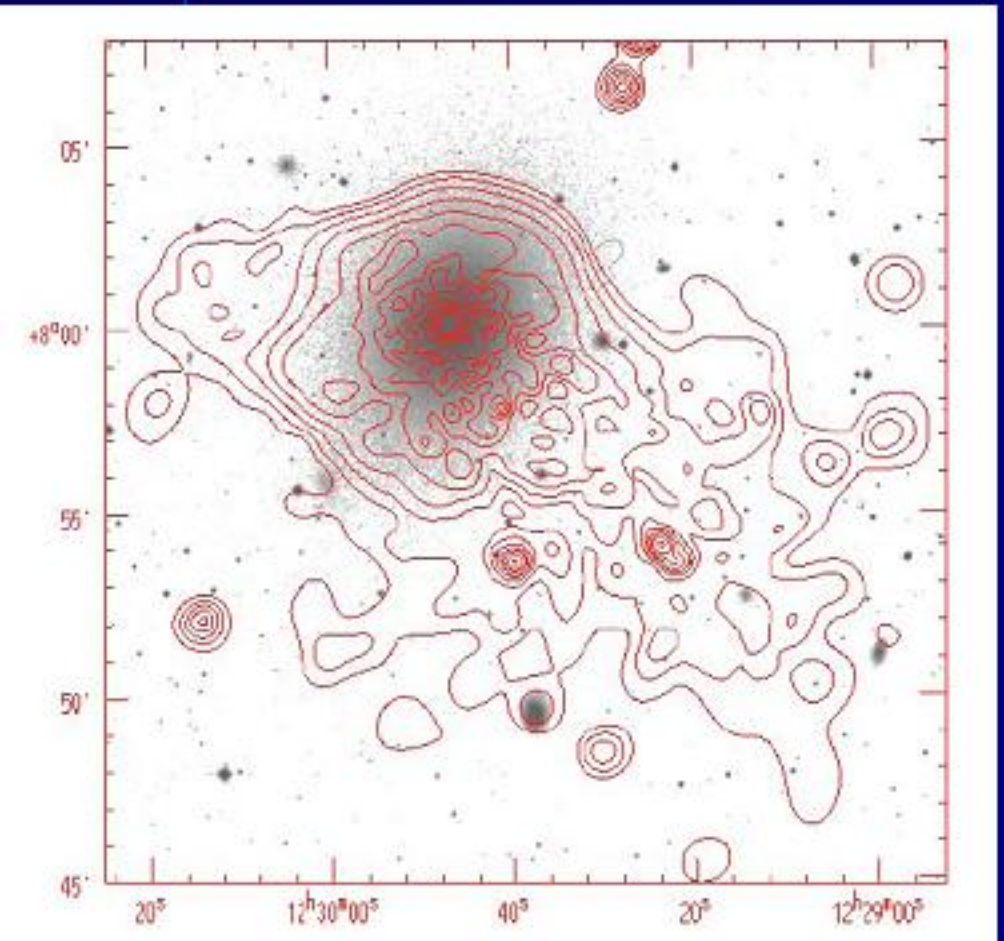
- hot dust and gas are stripped
- stripped material was part of halo
- deformed gas halo visible in X-ray
- no effects on galactic evolution, but on the chemical composition (metallicity)

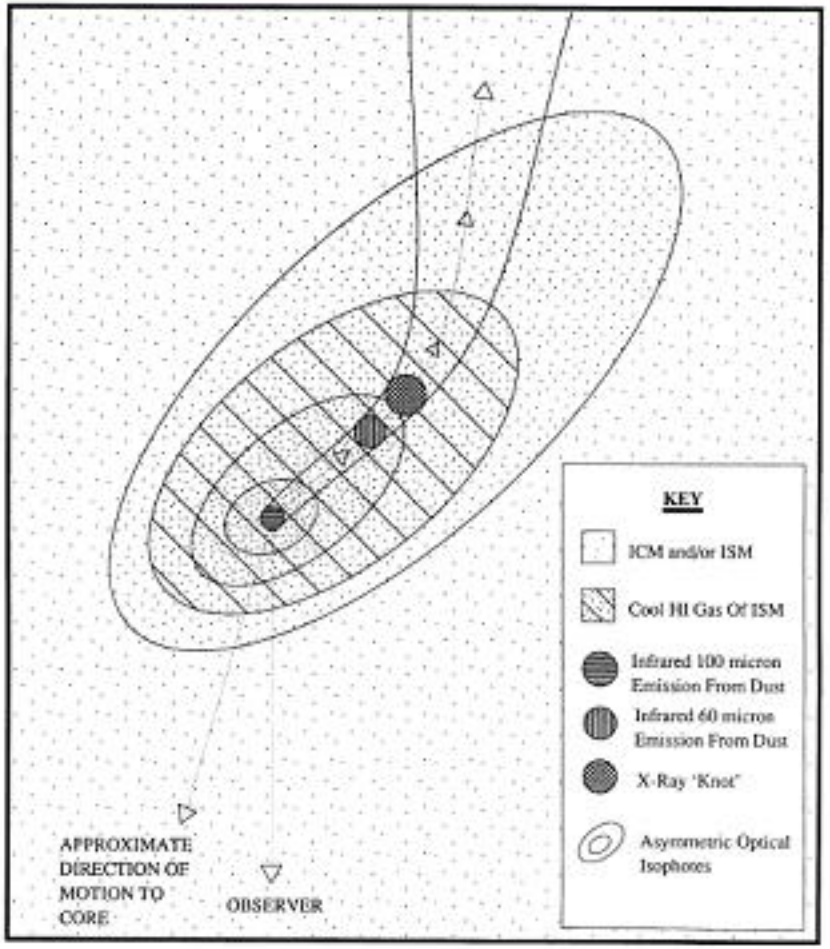
Observed objects

M 86



NGC 4472





Dwarf galaxies

- easier stripped ($M<10^9 M_\odot$ instantaneous)
- also stripping in galaxy groups
  (but less efficient (only 10-25% of ISM))
  (create conditions for moderate ST)
- observed objects: Holmberg II (in M81 group), several dwarfs in Virgo-cluster

Conclusion

- effective enrichment of ICM
- can transform spiral galaxies into S0
- indirect effects on stellar component due to displaced star formation
- some details are still a object of discussion

References

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