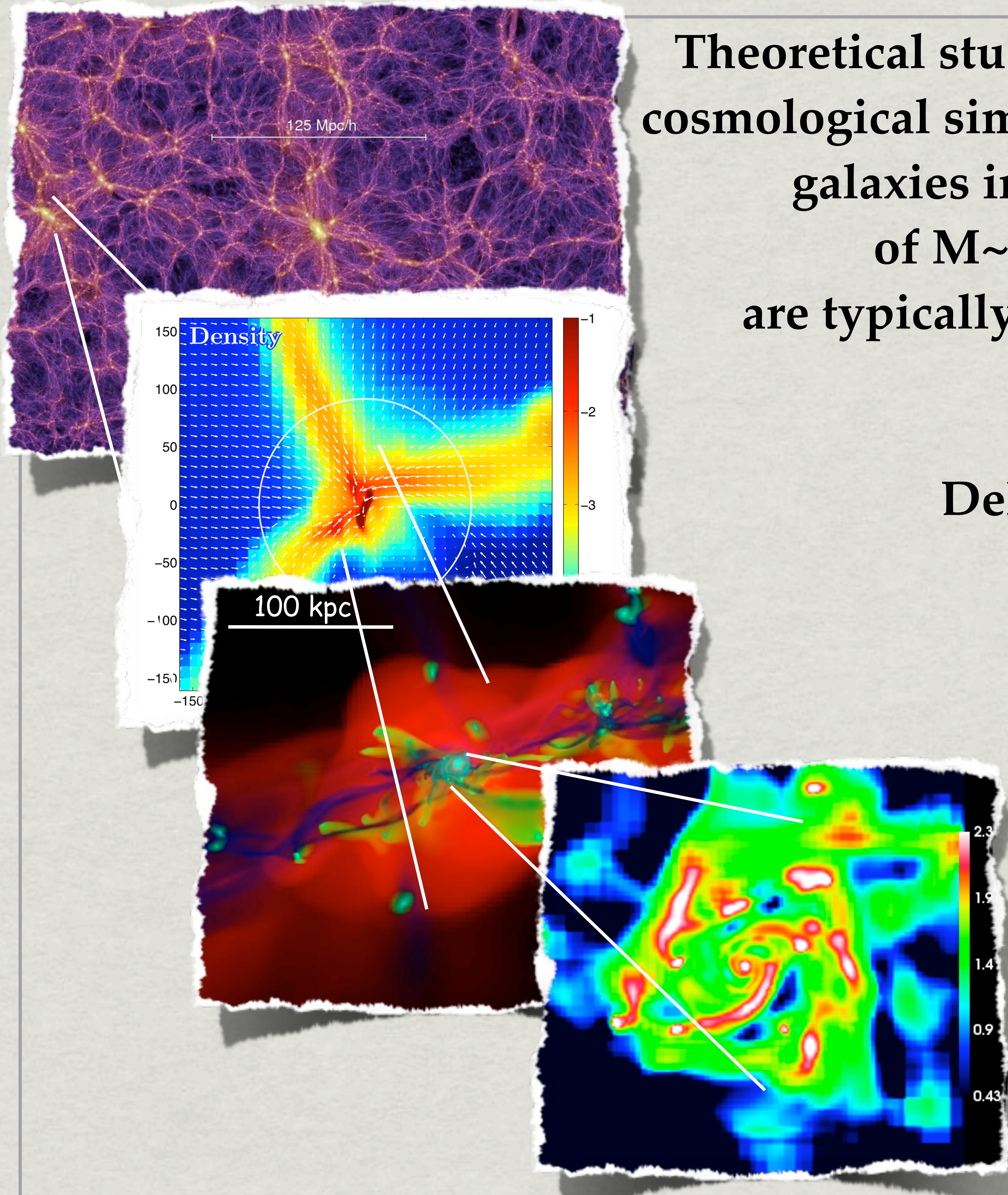
Unstable Disks: Gas and Stars via an analytic model

Marcello Cacciato

in collaboration with Avishai Dekel

Minerva Fellow @ HUJI

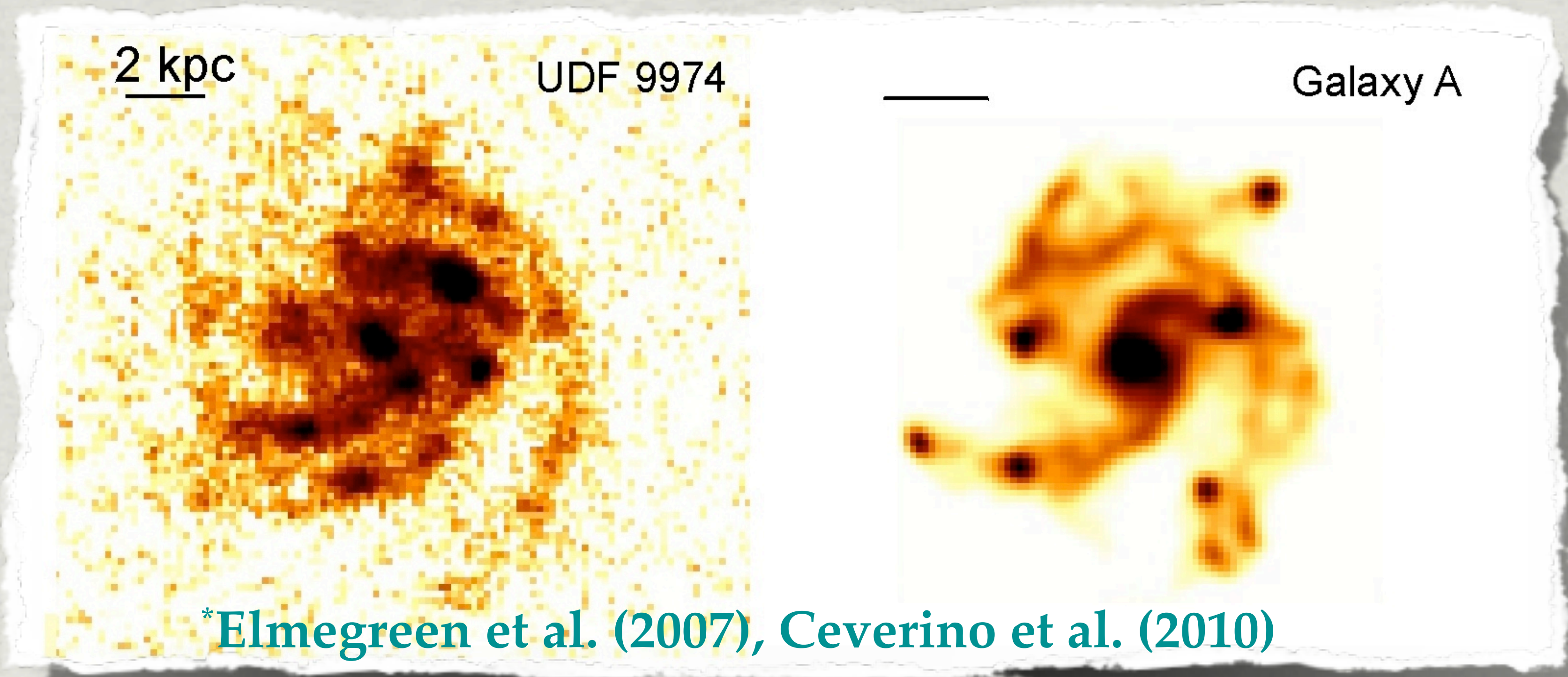
Theoretical studies and hydrodynamical cosmological simulations* have shown that galaxies in dark matter haloes of M~ $10^{12} M_{\odot}$ at z~2 are typically **Stream-Fed-Galaxies**.



Dekel, Sari & Ceverino (2009) propose a scenario where the formation of Stream-Fed-Galaxies is driven by **cold streams**, **disk instability** and the growth of a **central spheroid**.

*Dekel & Birnboim (2006), Keres et al. (2005)

High-z Clumpy Disks



*Elmegreen et al. (2007), Ceverino et al. (2010)

Kinematics consistent with rotating disk with V~200 km/s and σ~50 km/s *

Star formation rates ~$100 M_\odot/yr$ mainly occurring in the clumps*

Several giant clumps of ~1kpc size and M~$10^9 M_\odot$ *

*Genzel et al. (2006), Forster-Schreiber et al. (2006), Elmegreen & Elmegreen (2005)

GAS-RICH GALAXIES
(i.e. Dekel, Sari & Ceverino 2009)

$$\dot{M}_{\rm disk} \sim (1-\gamma)\dot{M}_{\rm acc} - \dot{M}_{\rm evac}$$

γ = clumpiness parameter of the incoming baryons

$\dot{M}_{\rm acc}$ = baryon accretion rate (fixed by cosmology*)

$\dot{M}_{\rm evac}$ = disk mass evacuation rate by clump migration

N.B. the evacuation timescale depends on the clumpiness of the disk

$$\alpha M_{\rm disk} = M_{\rm clumpy-disk}$$

*Neistein et al. (2006), Fakhouri et al. (2010)

DISK INSTABILITY

A rotating gaseous disk becomes unstable to axisymmetric modes once the local gravity, Σ, overcomes both differential rotation, Ω , and pressure, σ.

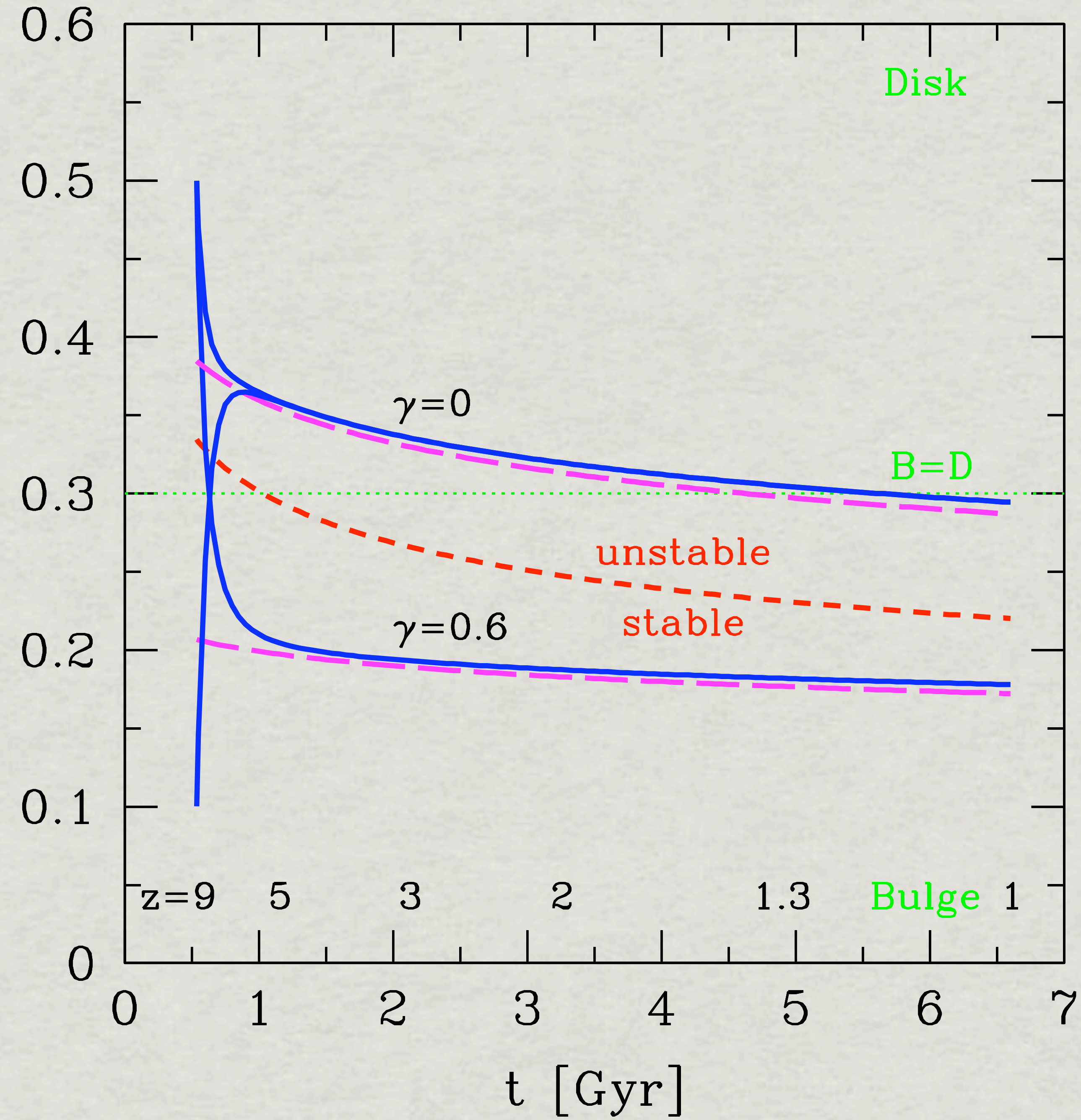
TOOMRE'S CRITERION*: $$Q \propto \frac{\Omega\ \ \sigma}{\Sigma} < Q_{\rm crit} \sim 1$$

Gas-rich disks fragment into big clumps due to gravitational instability.**

The encounters between these clumps is one of the mechanisms through which the disk maintains itself in the marginally unstable state, $Q \sim Q_{\rm crit}$:
disk instability is a self-regulating process.

*Toomre (1964), **Elmegreen & Elmegreen (2005), Bournaud et al. (2008)

$$\delta = \frac{M_{\rm disk}}{M_{\rm tot}(R_{\rm disk})}$$



Bimodality in stability

Gas-only analysis

How does the disk evolve towards z~0?

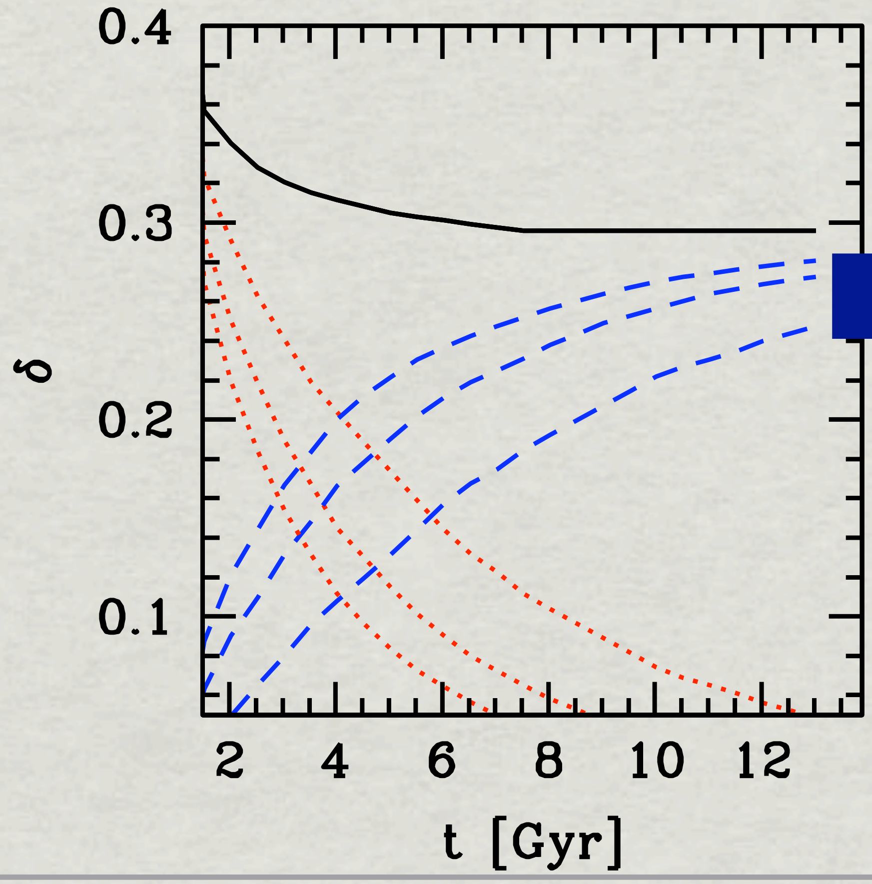
What is the impact of the developing (hotter) stellar component?

Towards Stellar Dominated Galaxies (an analytical model)

$$\dot{M}_{\rm gas,disk} \sim (1-\gamma)\dot{M}_{\rm acc} - \dot{M}_{\rm gas,evac} \quad -\dot{M}_{\rm SFR}$$

$$\dot{M}_{\rm star,disk} \sim (1-\gamma)\dot{M}_{\rm acc} - \dot{M}_{\rm star,evac} \quad +\dot{M}_{\rm SFR}$$

where $\dot{M}_{\rm SFR} = \epsilon_{\rm SFR}\frac{\eta_{\rm gas} M_{\rm gas}}{t_{\rm ff}}$ **with** $\epsilon_{\rm SFR} \sim 0.01, \eta_{\rm gas} \sim 1$ *



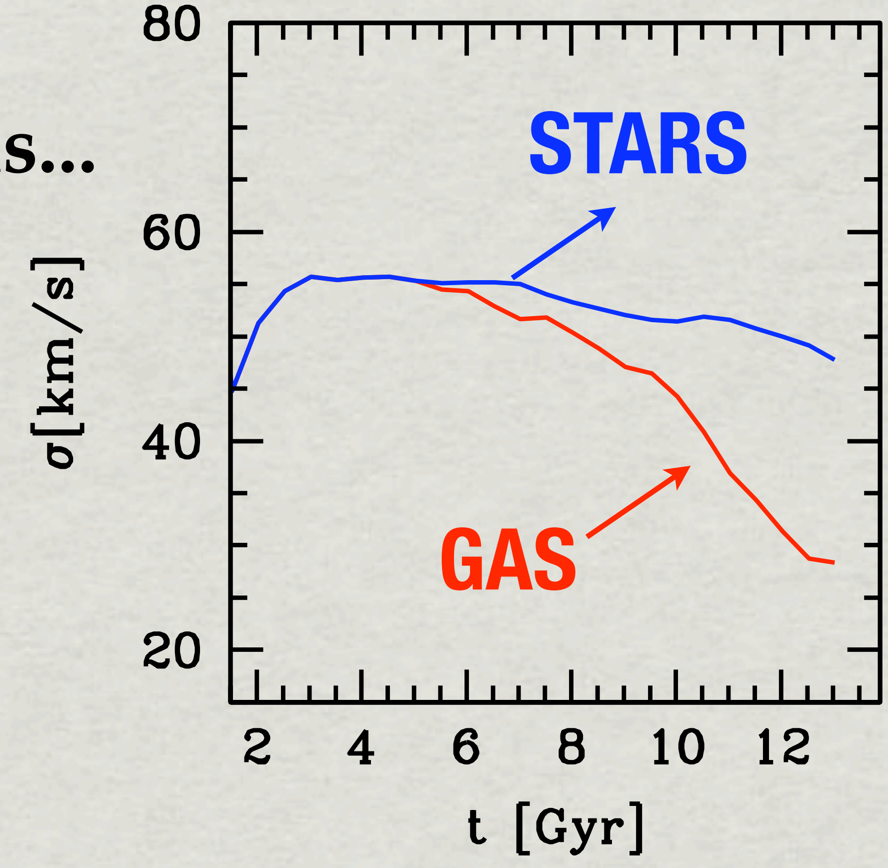
different star formation efficiency

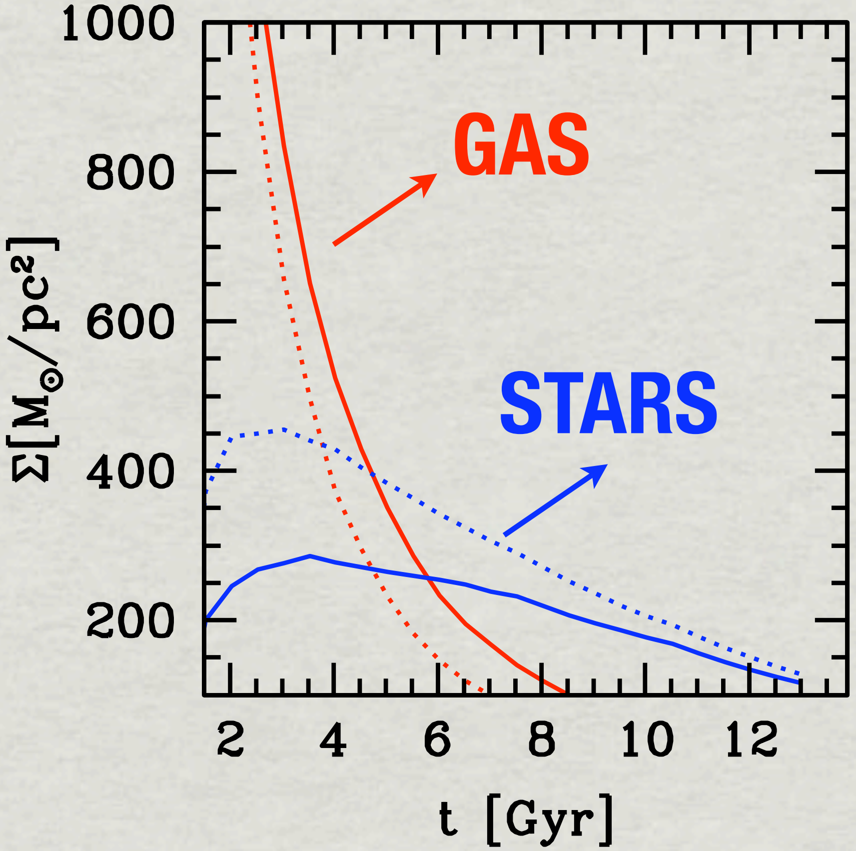
Simply creating stars from gas does NOT affect the results...

*Krumholz et al. (2009)

...unless stars are (much) hotter than gas...

(it requires a model for the evolution of $\sigma_{\rm star}(t)$)





...and stars actively participate in the disk evolution

(it requires different treatment for the migration of stars and gas)

Evolution of a gas+stars disk

Assumptions:

$$Q \to Q_{\rm g+s}(\Sigma_{\rm g}, \Sigma_{\rm s}, \sigma_{\rm g}, \sigma_{\rm s}, \Omega) \neq Q_{\rm g} + Q_{\rm s}\ ^*$$

$$Q_{\rm g+s} = Q_{\rm crit}$$ **(the disk regulates itself to be marginally unstable)**

$$\dot{M}_{\rm gas,evac} = \zeta_{\rm gas,evac}\dot{M}_{\rm evac}$$

$$\dot{M}_{\rm stars,evac} = \zeta_{\rm stars,evac}\dot{M}_{\rm evac}$$

(gas and stars can migrate on different timescales)

$$\sigma_{\rm s}^2 = \sigma_{\rm s,old+young}^2 + \sigma_{\rm s,heat}^2$$

Results:

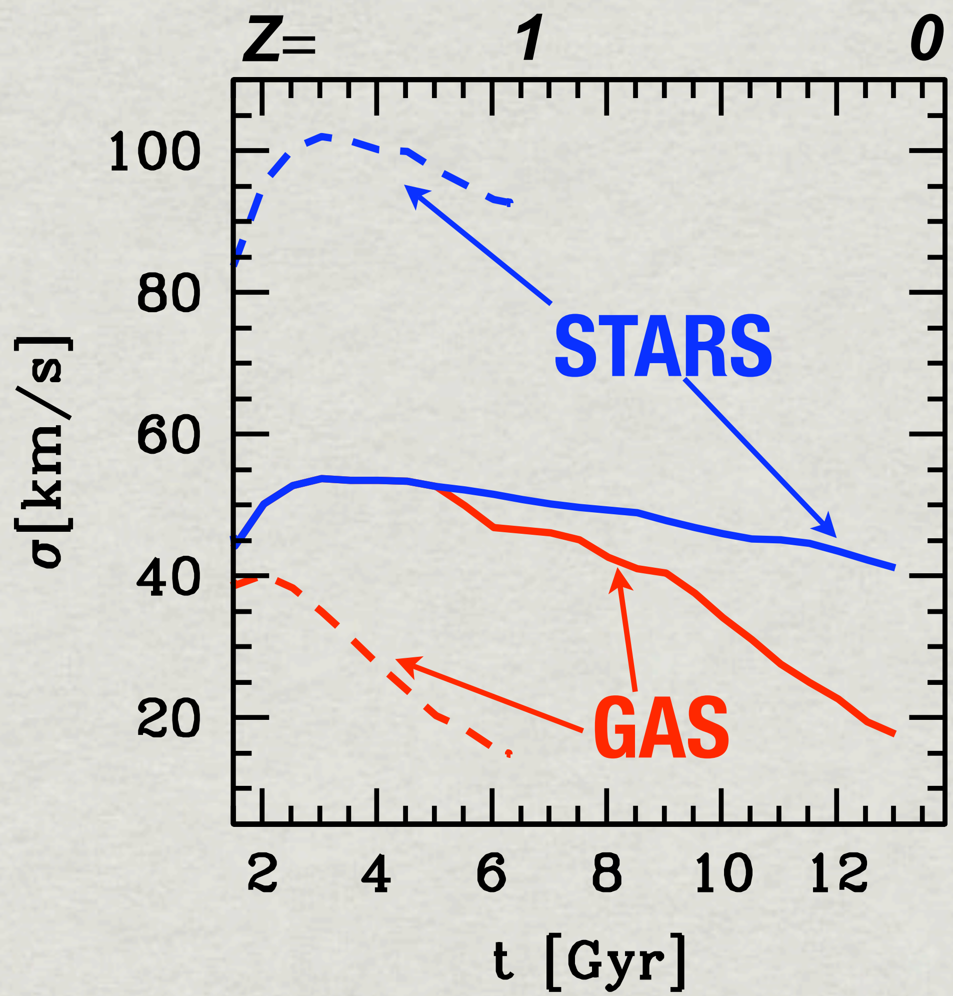
$$\delta = \delta(t)$$ **(the evolution of the disk)**

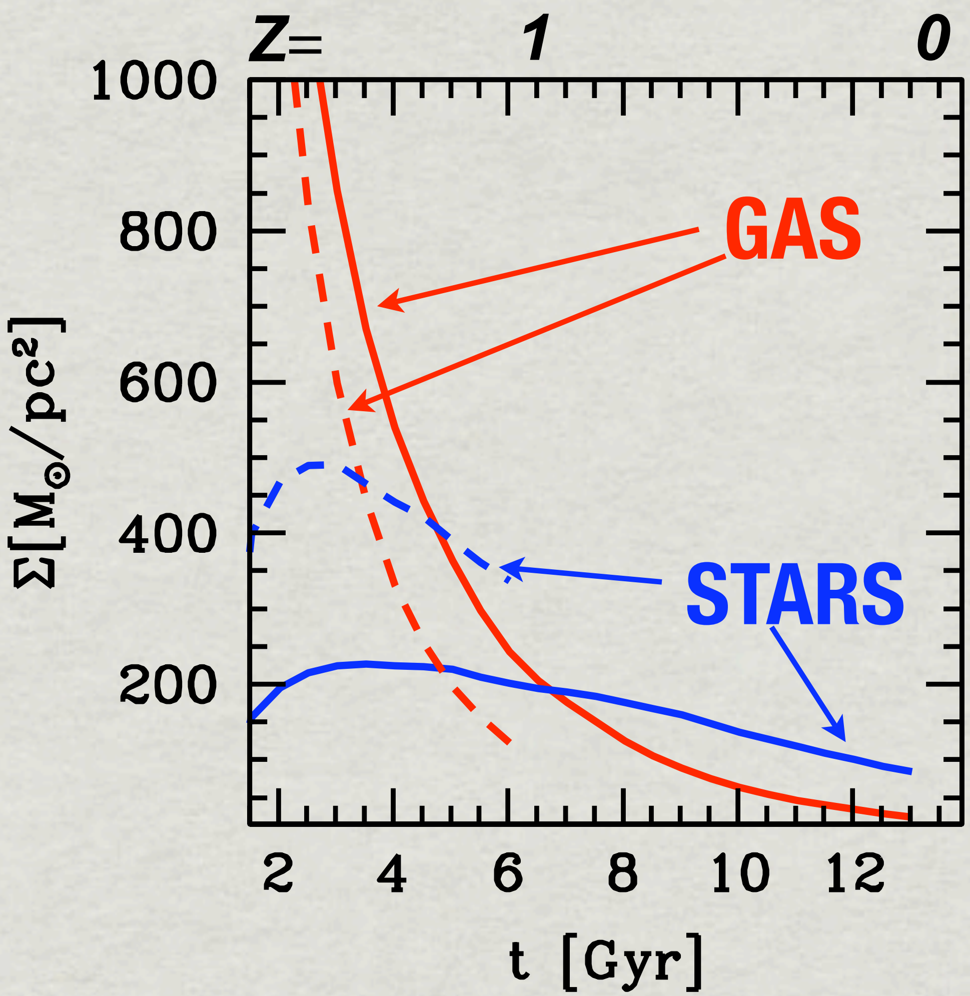
$$\sigma_{\rm g} = \sigma_{\rm g}(\Sigma_{\rm g}, \Sigma_{\rm s}, \sigma_{\rm s}, Q_{\rm crit})$$

(the gas velocity dispersion responds to the evolution of the disk)

*Jog & Solomon (1984), Rafikov (2001)

Result



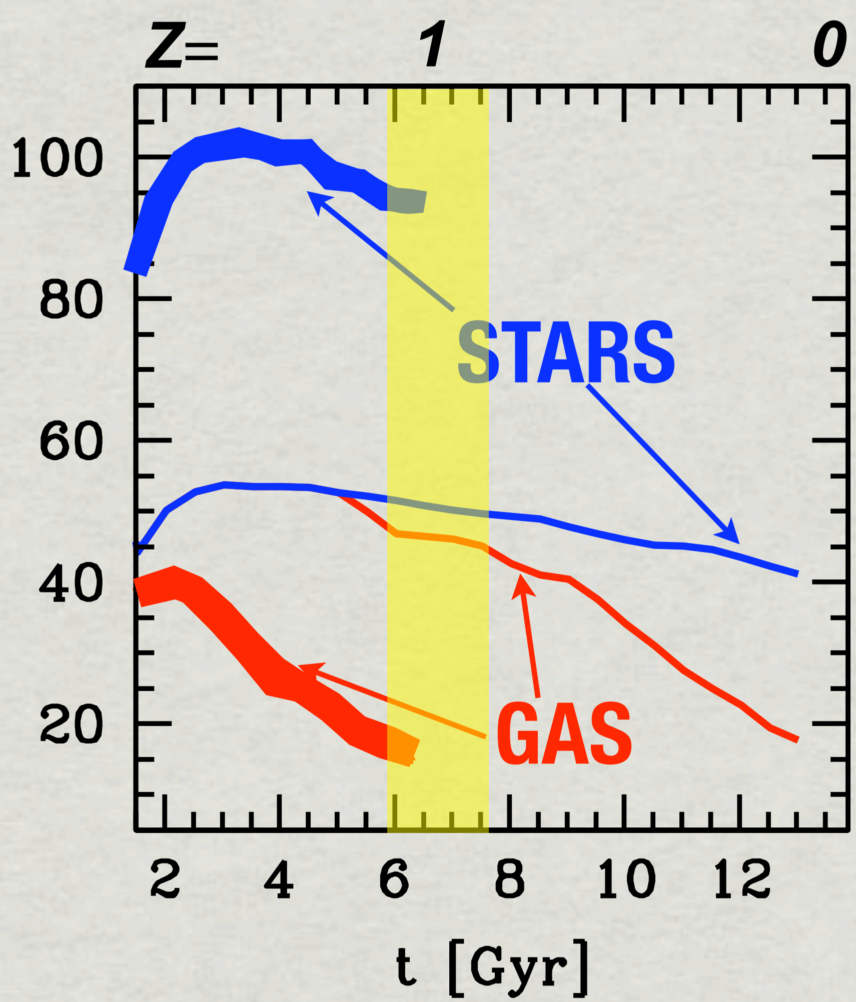


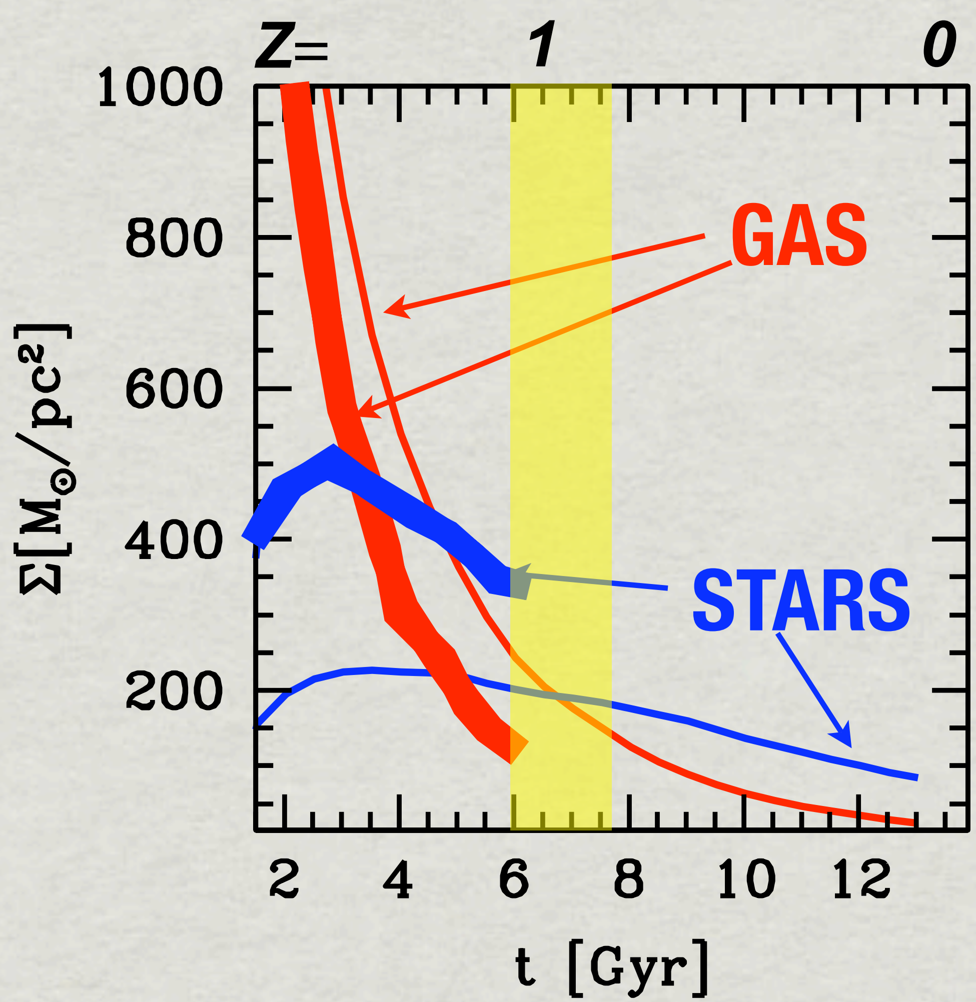
— — model with
slower migration
higher sf efficiency
heating of stars

$\sigma_g \sim 10$--> σ_g **of the order of thermal motions --->**
gas cannot cool further-->instability cannot continue!!!

The gas+stars treatment allows disk stabilization
(already at z~1)

Result





— — model with slower migration higher sf efficiency heating of stars

$\sigma_g \sim 10$--> σ_g **of the order of thermal motions --->**
gas cannot cool further-->instability cannot continue!!!

The gas+stars treatment allows disk stabilization (already at z~1)

Open Questions

What is the real mechanism that drives the turbulence?
Is it only gravity?
Or does feedback play an important role?

To what extent can the disk be assumed
at a marginally unstable state at any time?

Can a disk have alternate phases of stability and instability?

We intend to further develop the analytical model
in synergy with results from hydrodynamical numerical simulations*.

*Ceverino et al. (2010)

Thanks