Galaxy formation with AMR

Thanks to

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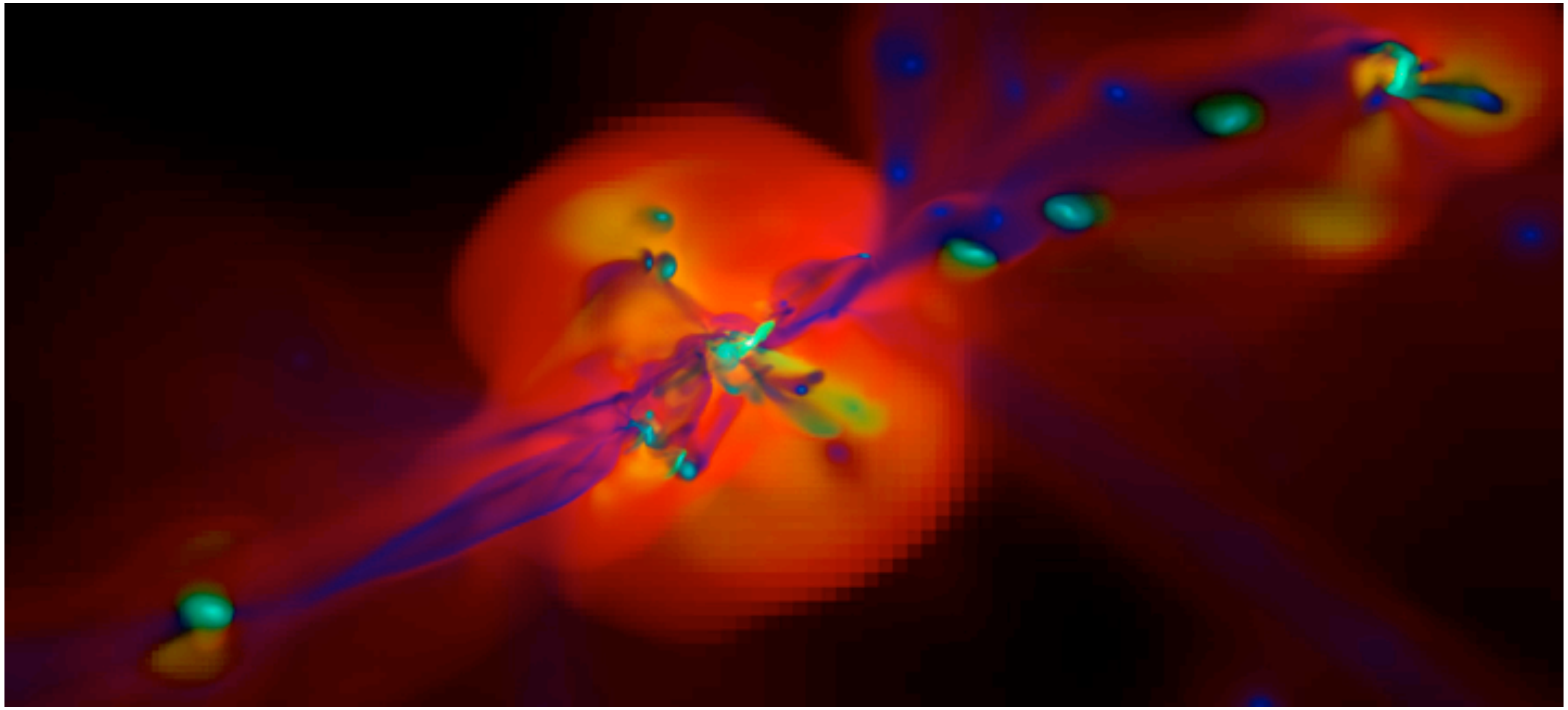
irfu

cea

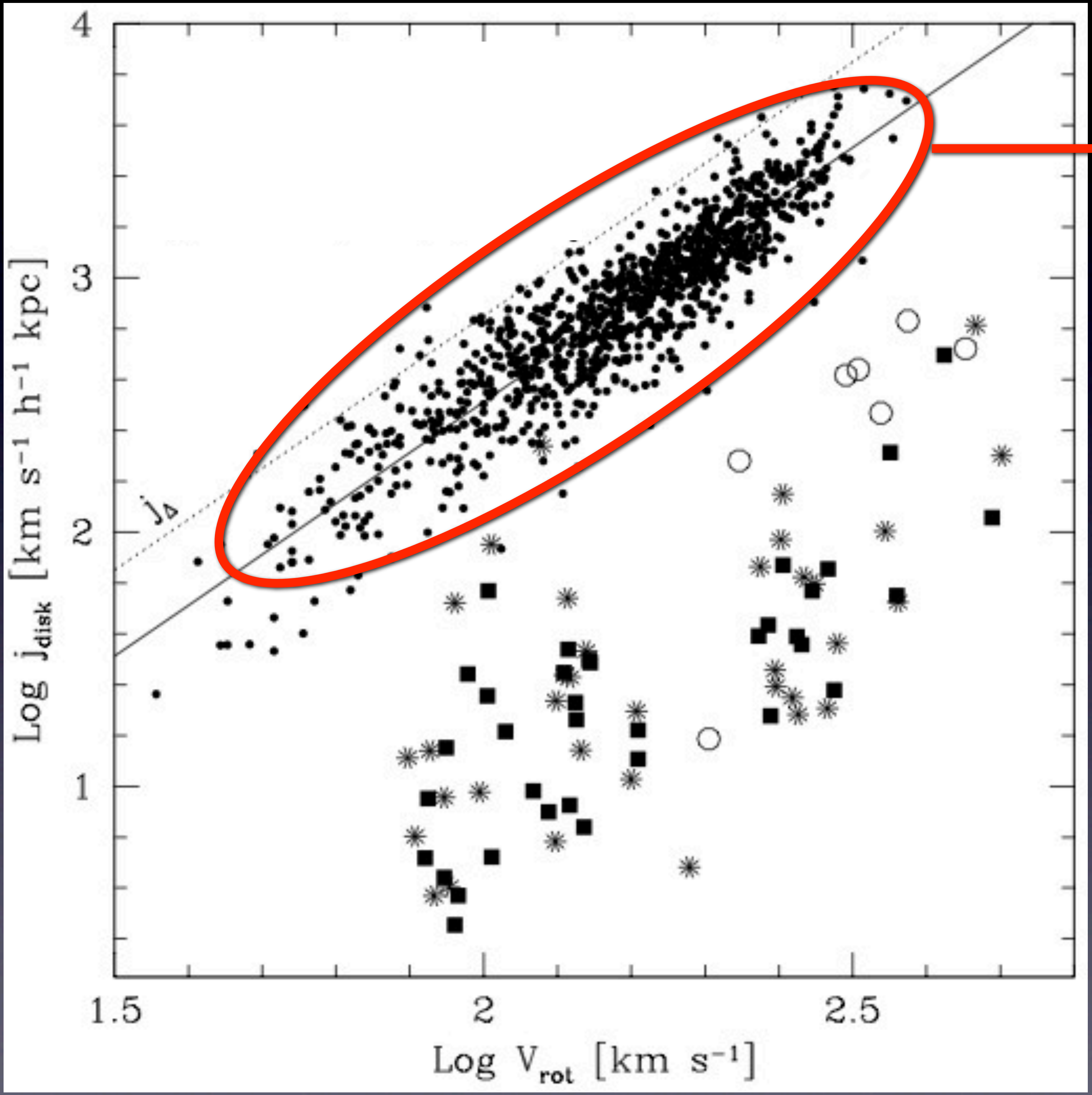
saclay

Outline

- Disc formation in LCDM
- Star formation efficiency and morphology connection
- Baryon fraction and AGN feedback in large galaxies
- Star formation in merging system: resolving the clumpy ISM



A few issues in simulations of galaxy formation

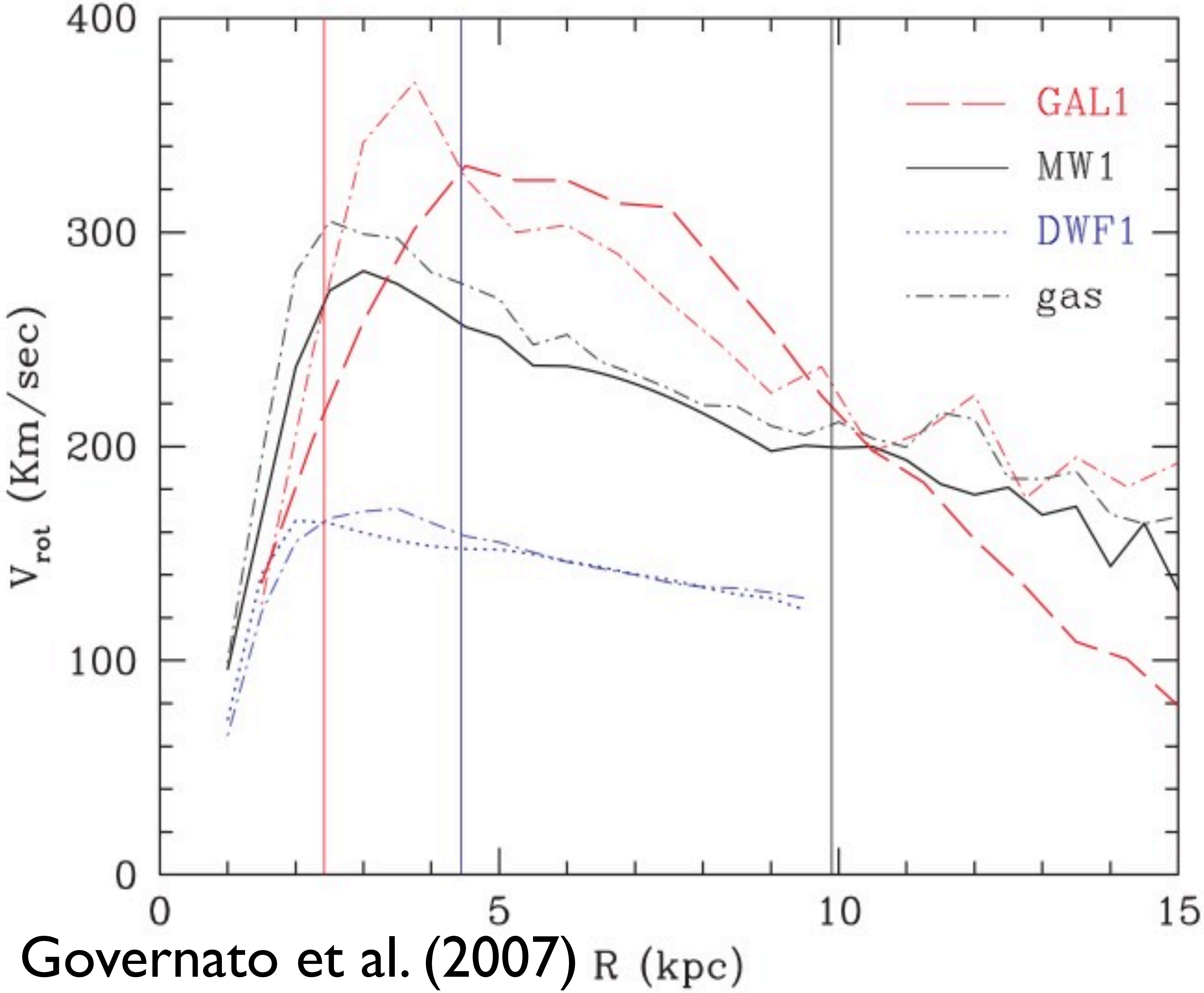


Courteau (1997)
Sb-Sc galaxies

The angular momentum problem

Navarro & Steinmetz (2000)

A few issues in simulations of galaxy formation



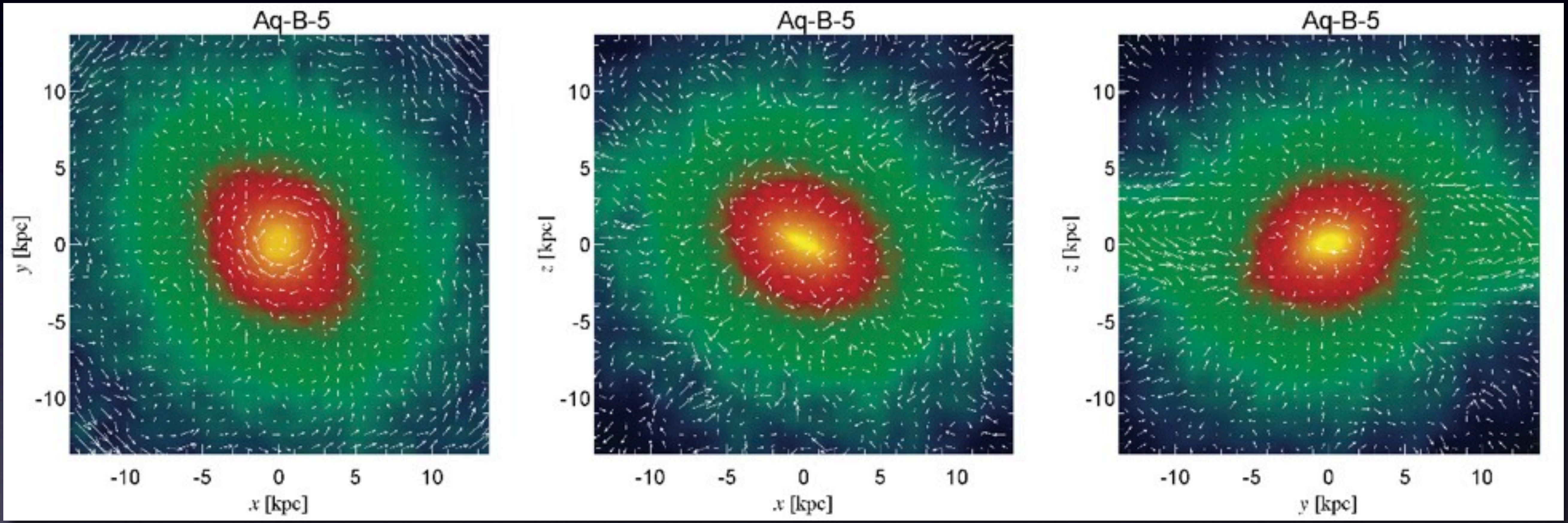
Governato et al. (2007)

Rotation curves are strongly peaked!

A few issues in simulations of galaxy formation

Disks are too small!

Galaxy formation in 8 Milky Way haloes (Scannapieco et al. 2009)
(Hydro + N-body simulations of the Aquarius halos)



Sophisticated models of SNe feedback, winds, star formation etc.
Largest D/T ~ 0.2!!!

Romain Teyssier

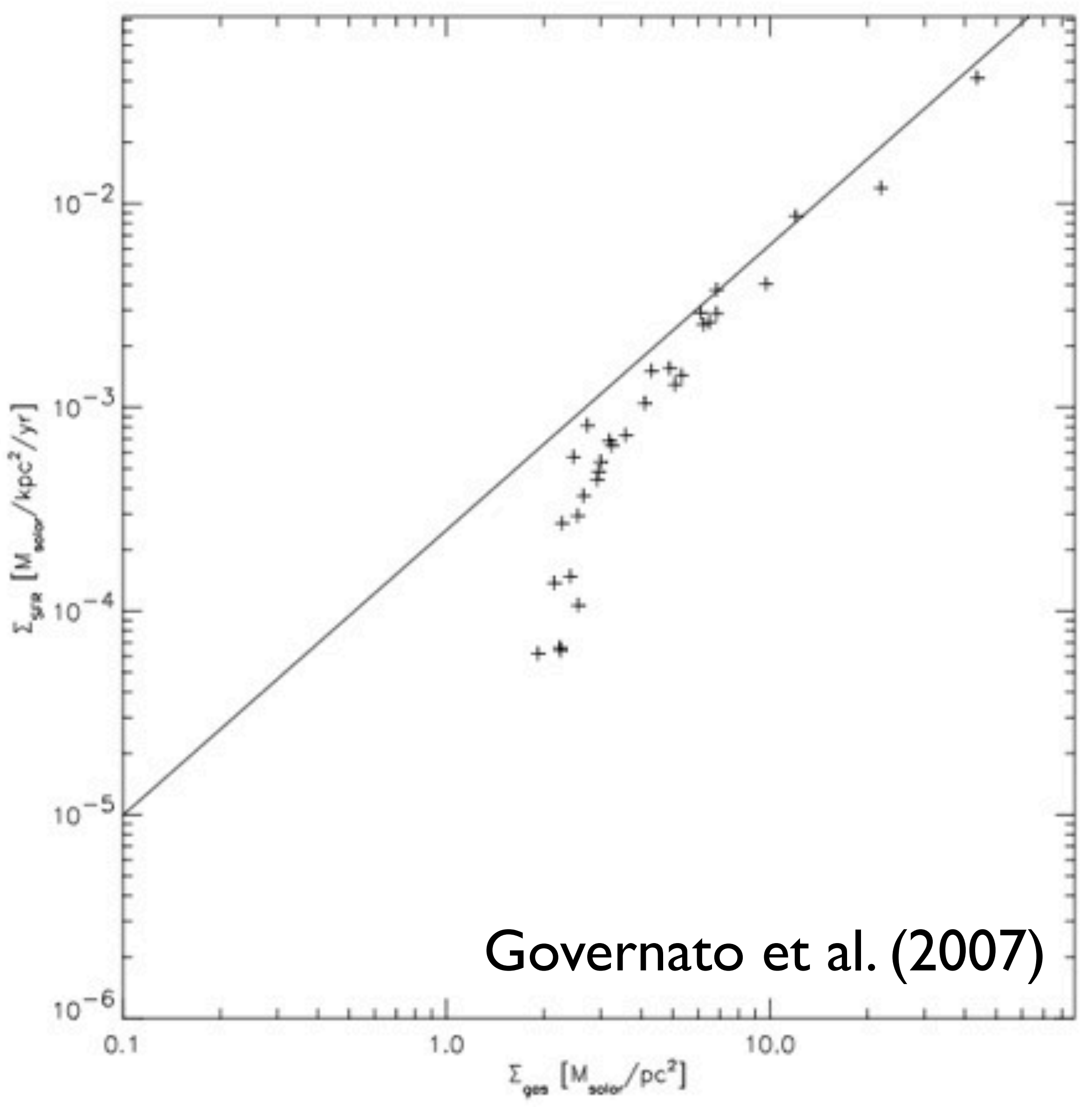
Standard practice of star formation and feedback in simulations of galaxy formation...

1. Tune the star formation efficiency and supernovae feedback to a Kennicutt-Schmidt relation (e.g. Kennicutt 1998), using an isolated disk.

$$\dot{\rho}_* = \epsilon_{\rm ff} \frac{\rho_{\rm g}}{t_{\rm ff}} \text{ for } \rho > \rho_0$$

$$\downarrow$$

$$\Sigma_{\rm SFR} = (2.5 \pm 0.7) \times 10^{-4} \left(\frac{\Sigma_{\rm gas}}{\rm M_\odot pc^{-2}} \right)^N$$

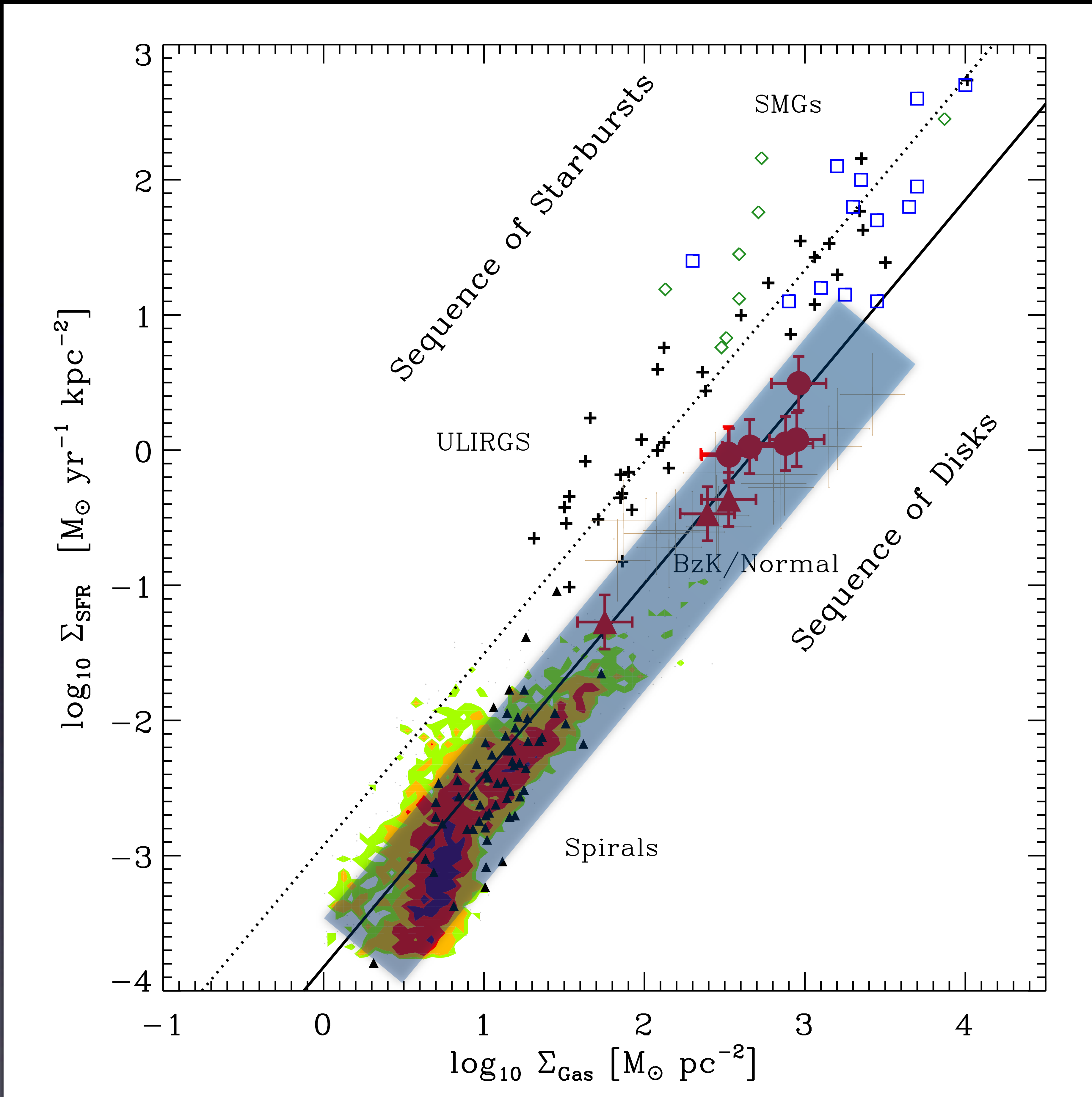


Governato et al. (2007)

2. Assume star formation is regulated by supernovae explosions at high-z. Dump E_{SNII} into the ISM (kinetic, thermal, cooling shutoff etc).

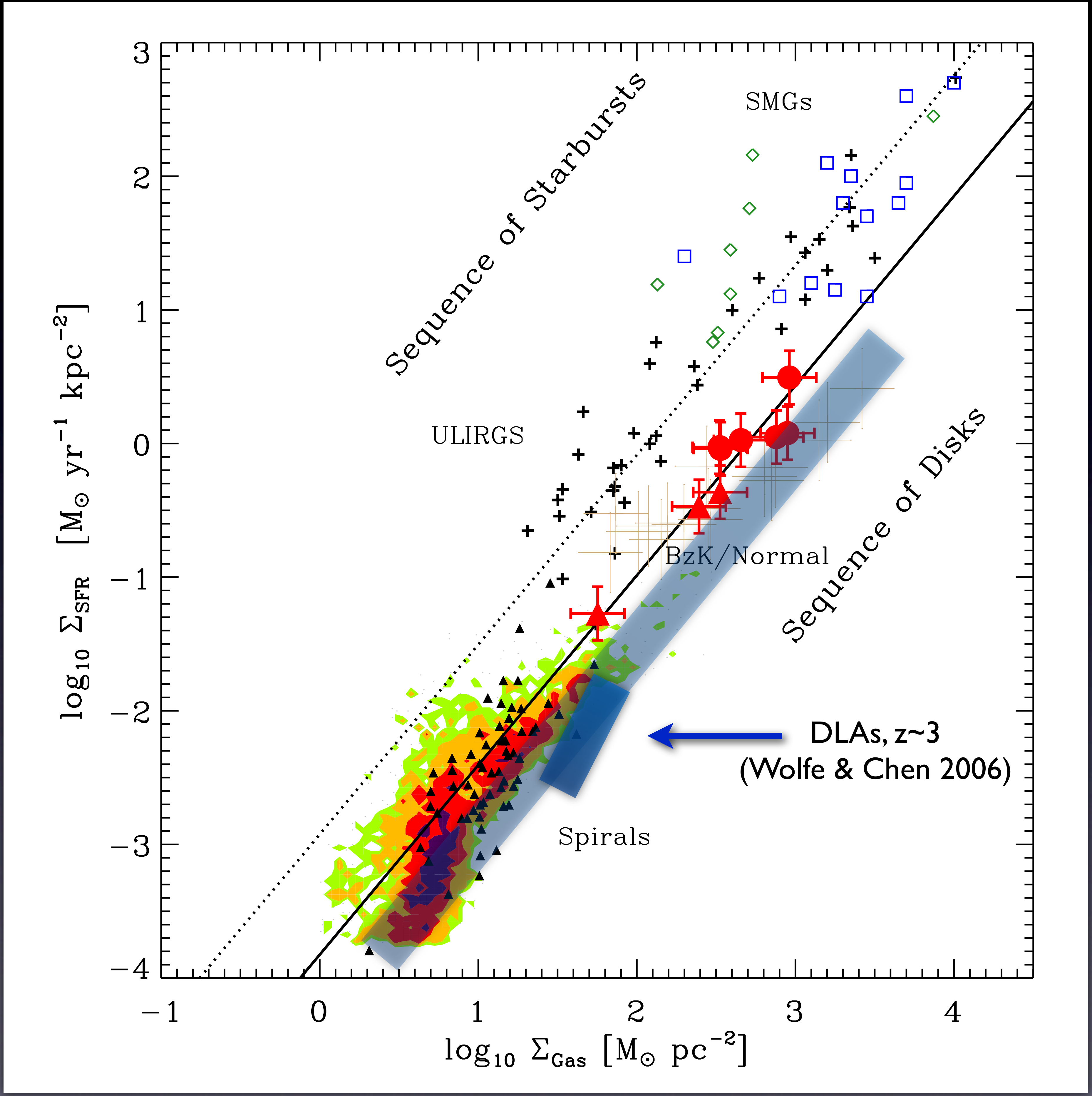
Abadi et al. (2003), Okamoto et al. (2009), Governato et al. (2004, 2007, 2009, 2010), Piontek & Steinmetz (2009), Scannapieco et al. (2008, 2009)

Daddi et al. (2010)
Genzel et al. (2010)



To form late type spirals, star formation must be inefficient at high redshift!

The way gas is converted into stars is observed to vary *among* different galaxies, *within* galaxies and at different cosmic epochs!



Daddi et al. (2010)
Genzel et al. (2010)

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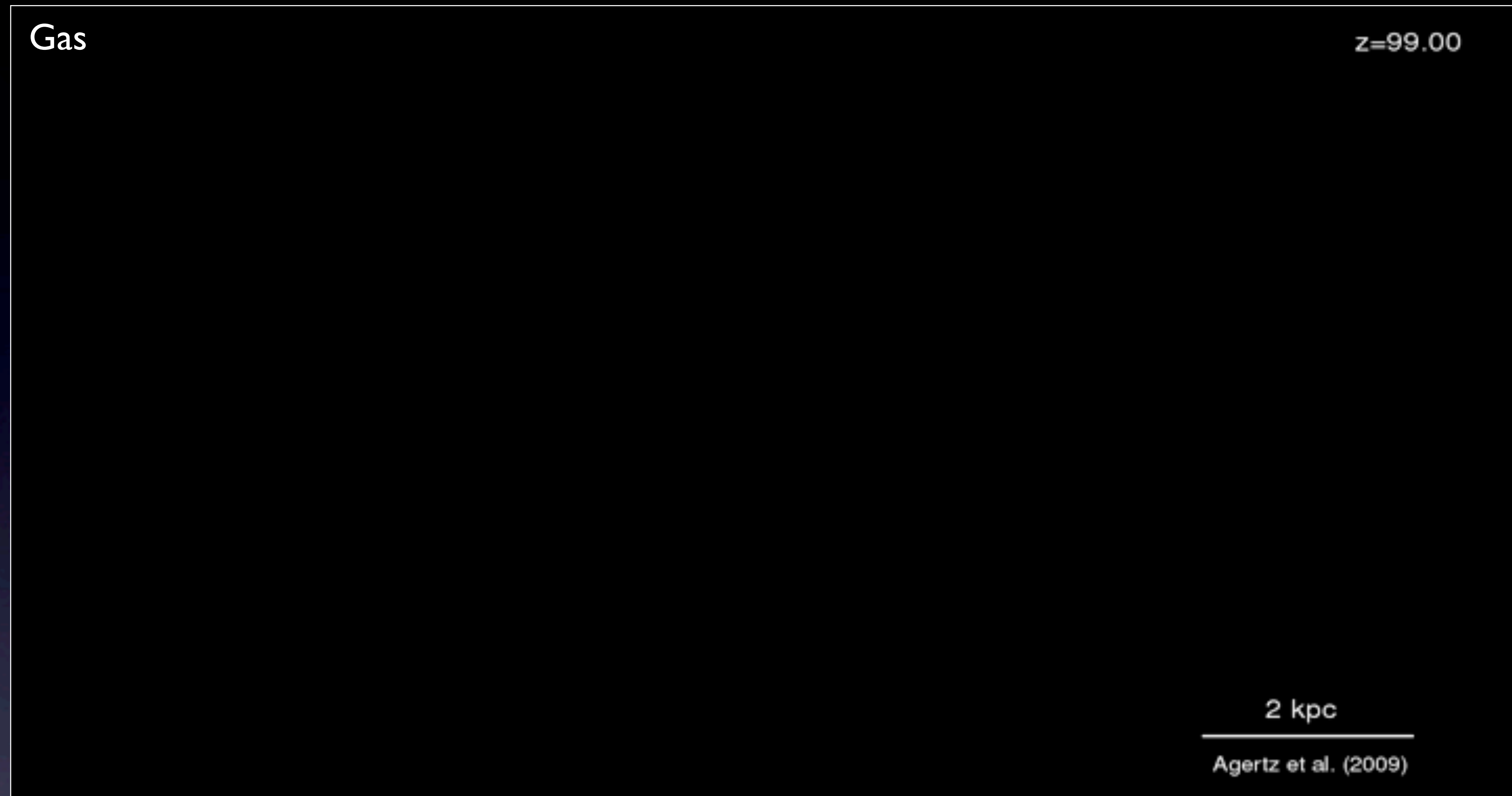
What kind of star formation regulation leads to a realistic spiral galaxy?

We perform a large suite of fully cosmological simulations of galaxy formation, using the AMR code RAMSES targeting a 10^{12} M_{sun} dark matter halo.

$$\Delta x = 150 - 300\,\mathrm{pc}$$



Gas removal via supernova driven winds (Type II SN)

$$E_{\mathrm{SNII}}$$

$$0, 1, 2 \text{ and } 5 \times 10^{51} \text{ ergs}$$

vs.

Agertz et al. 2010, in press, arxiv1004.0005

Local, small scale star formation physics

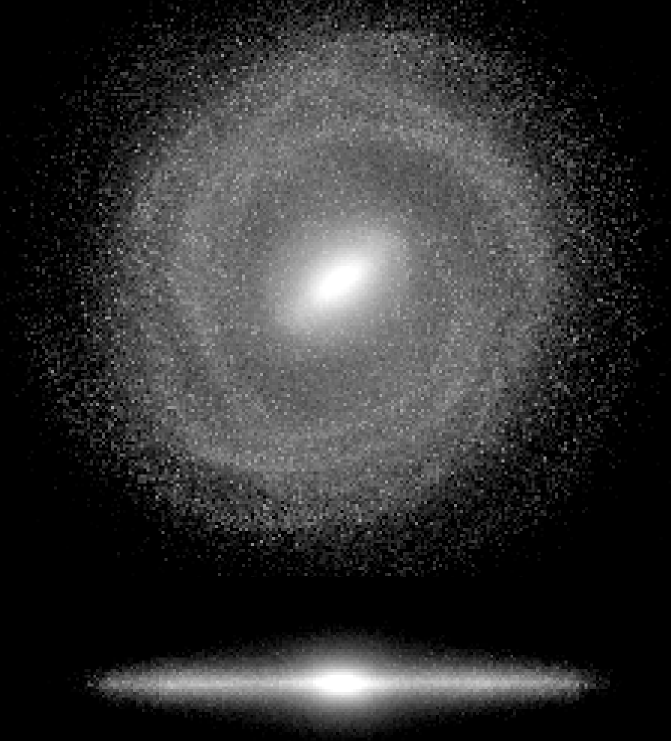
(unresolved physics e.g stellar feedback, H_2 fraction, turbulence, UV field)

$$\epsilon_{\mathrm{ff}}$$

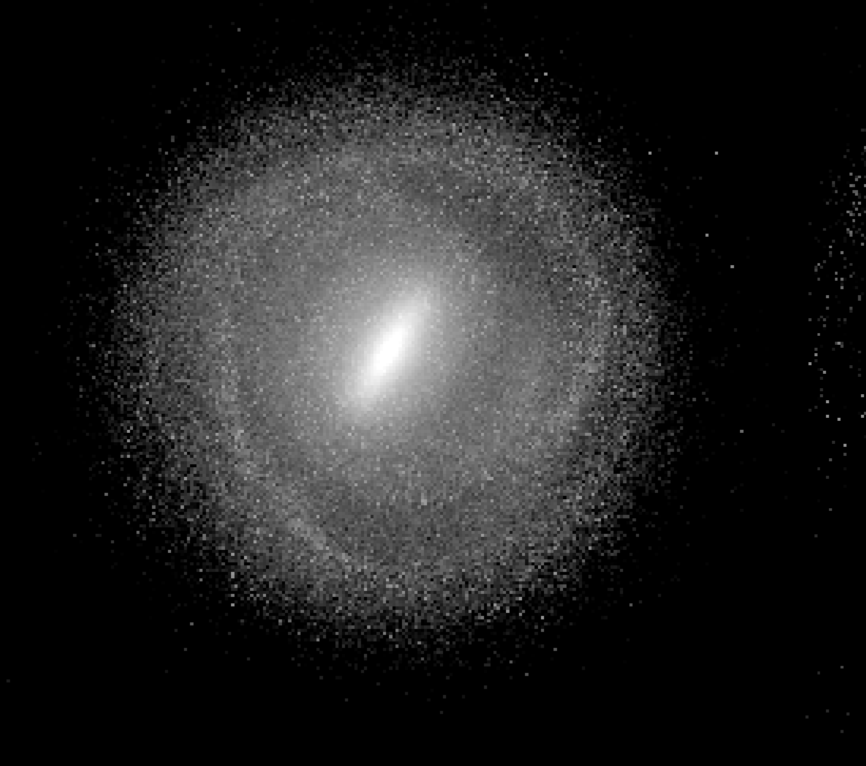
$$1, 2, \text{ and } 5\,\%$$

Stellar disks at z=0

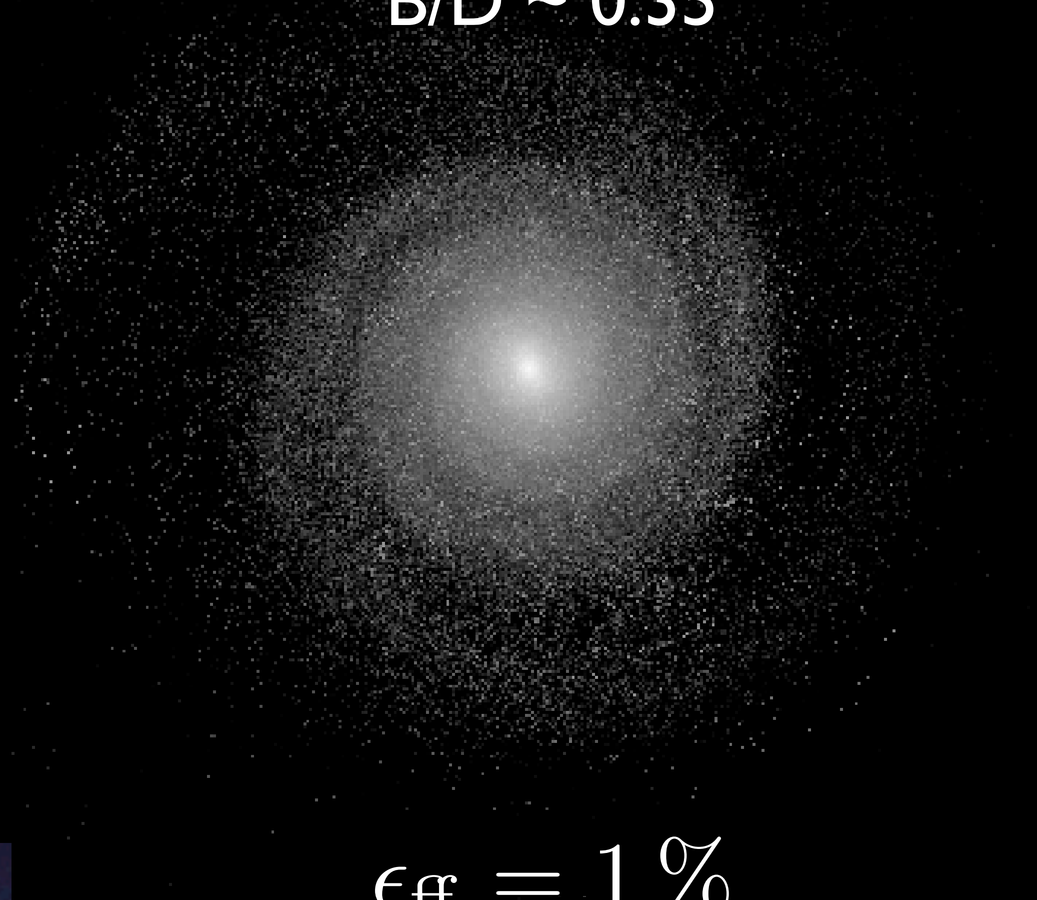
$E_{\rm SNII} = 10^{51}$ ergs
$\epsilon_{\rm ff} = 5\,\%$
B/D ~ 1.25



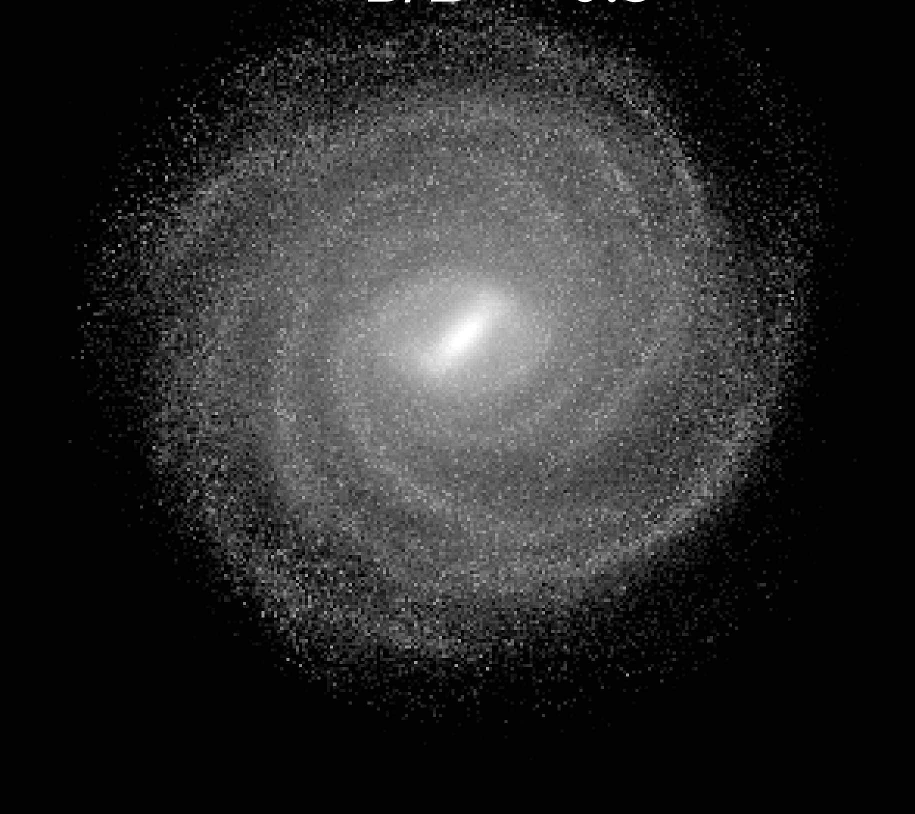
$E_{\rm SNII} = 2 \times 10^{51}$ ergs
B/D ~ 1.16



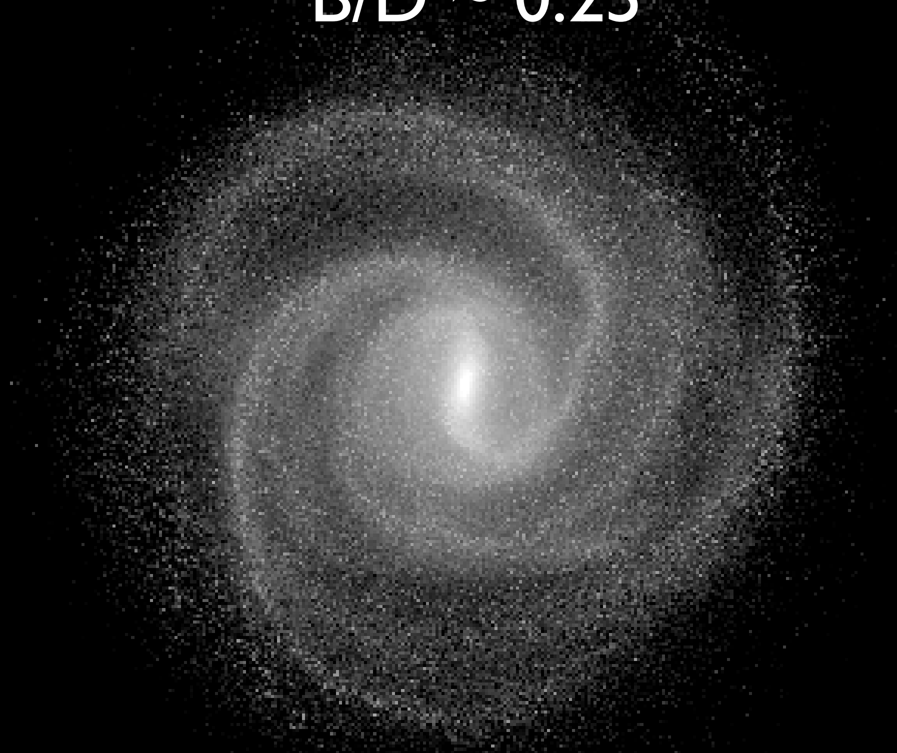
$E_{\rm SNII} = 5 \times 10^{51}$ ergs
B/D ~ 0.35



$\epsilon_{\rm ff} = 2\,\%$
B/D ~ 0.5



$\epsilon_{\rm ff} = 1\,\%$
B/D ~ 0.25

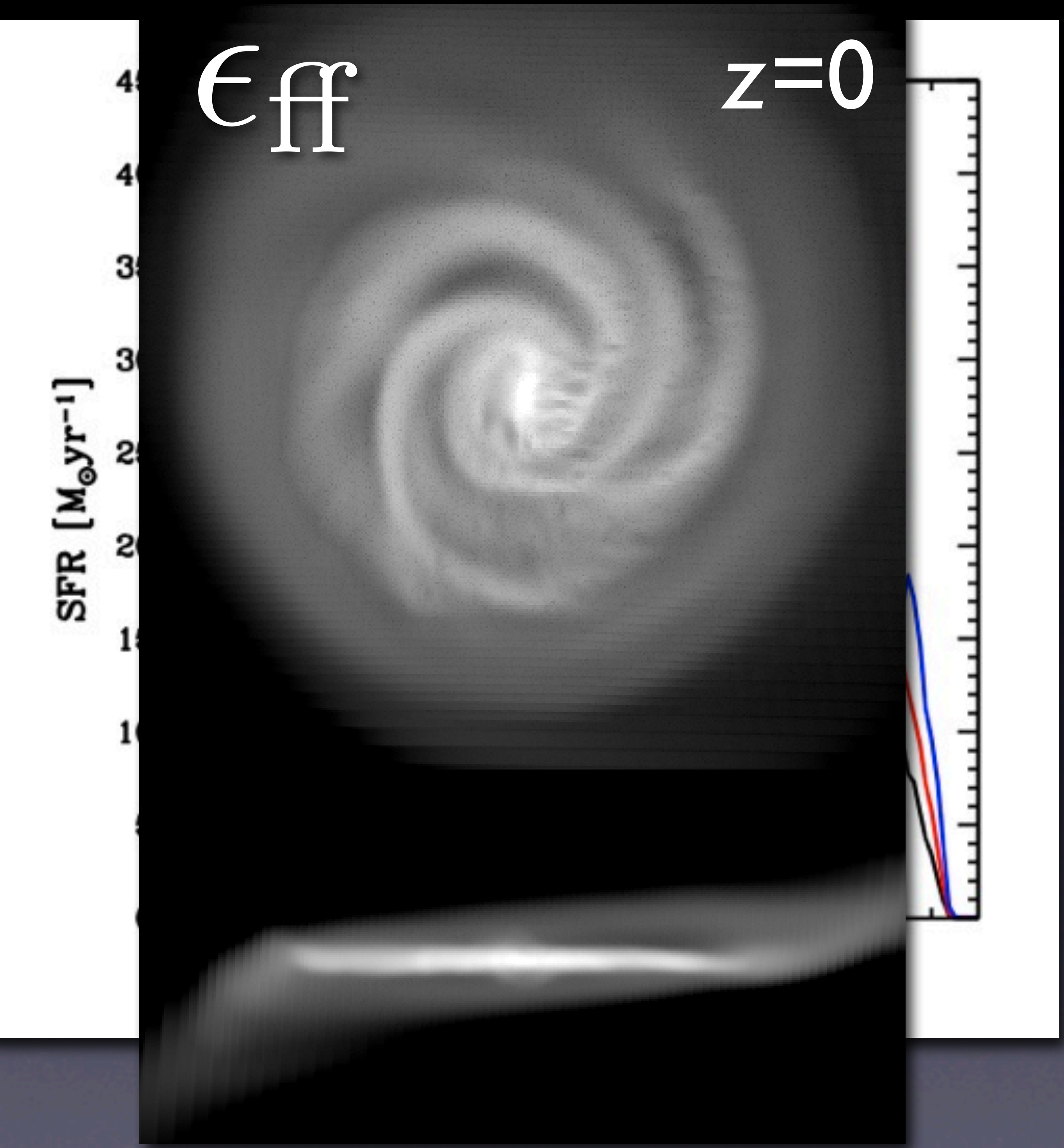


Pseudo bulge!!

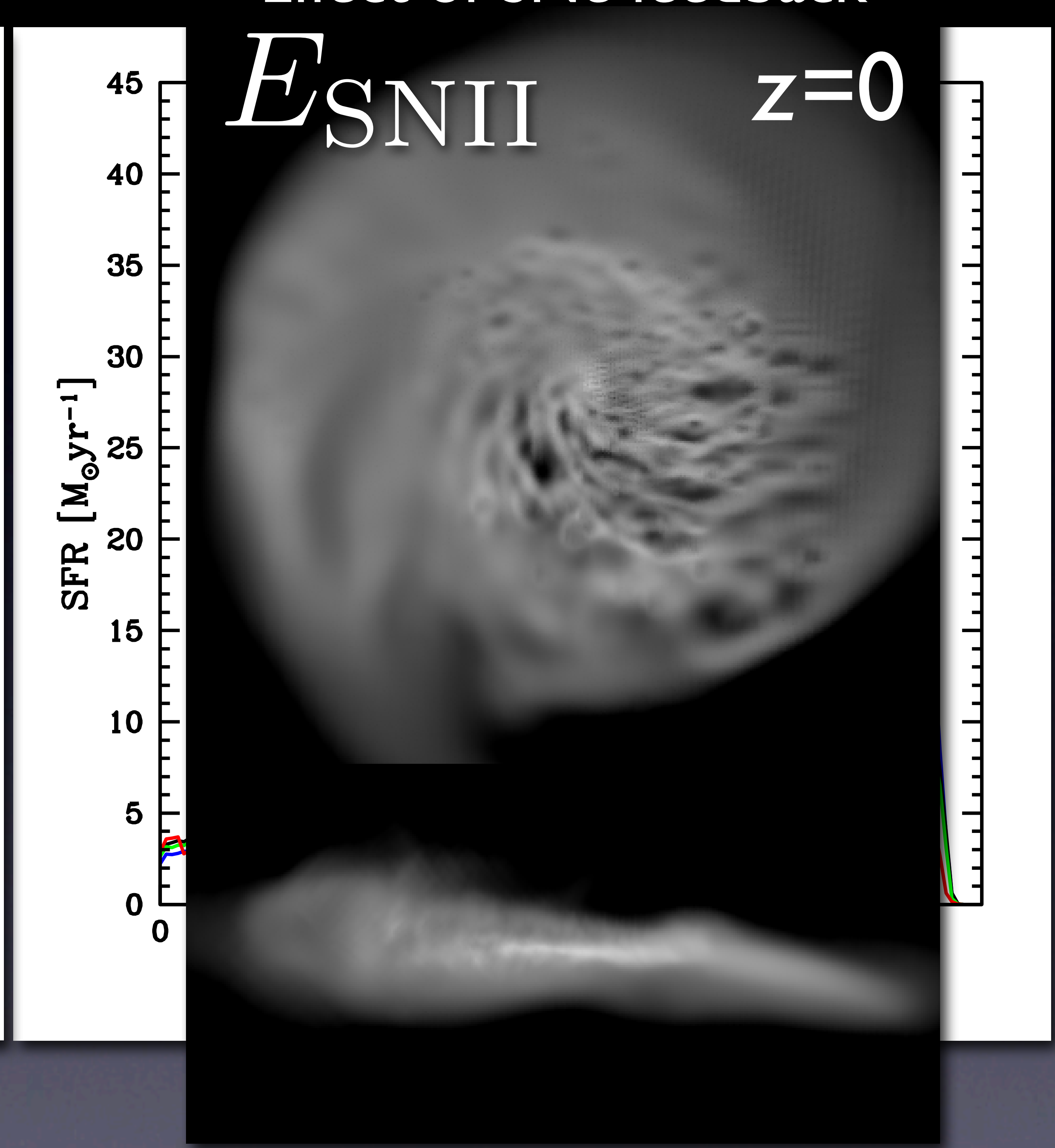
er

Star formation histories

Effect of SFE

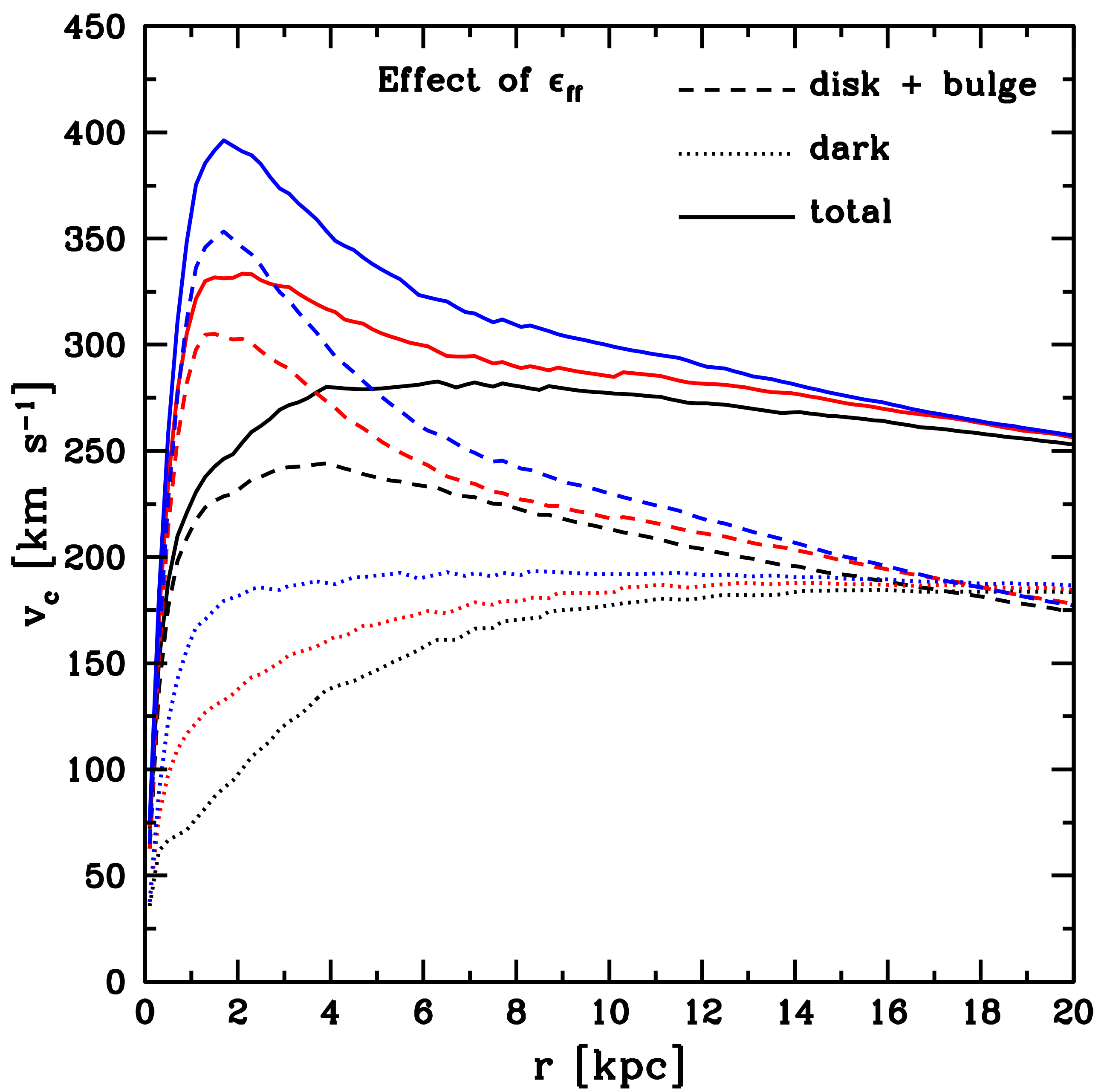


Effect of SNe feedback

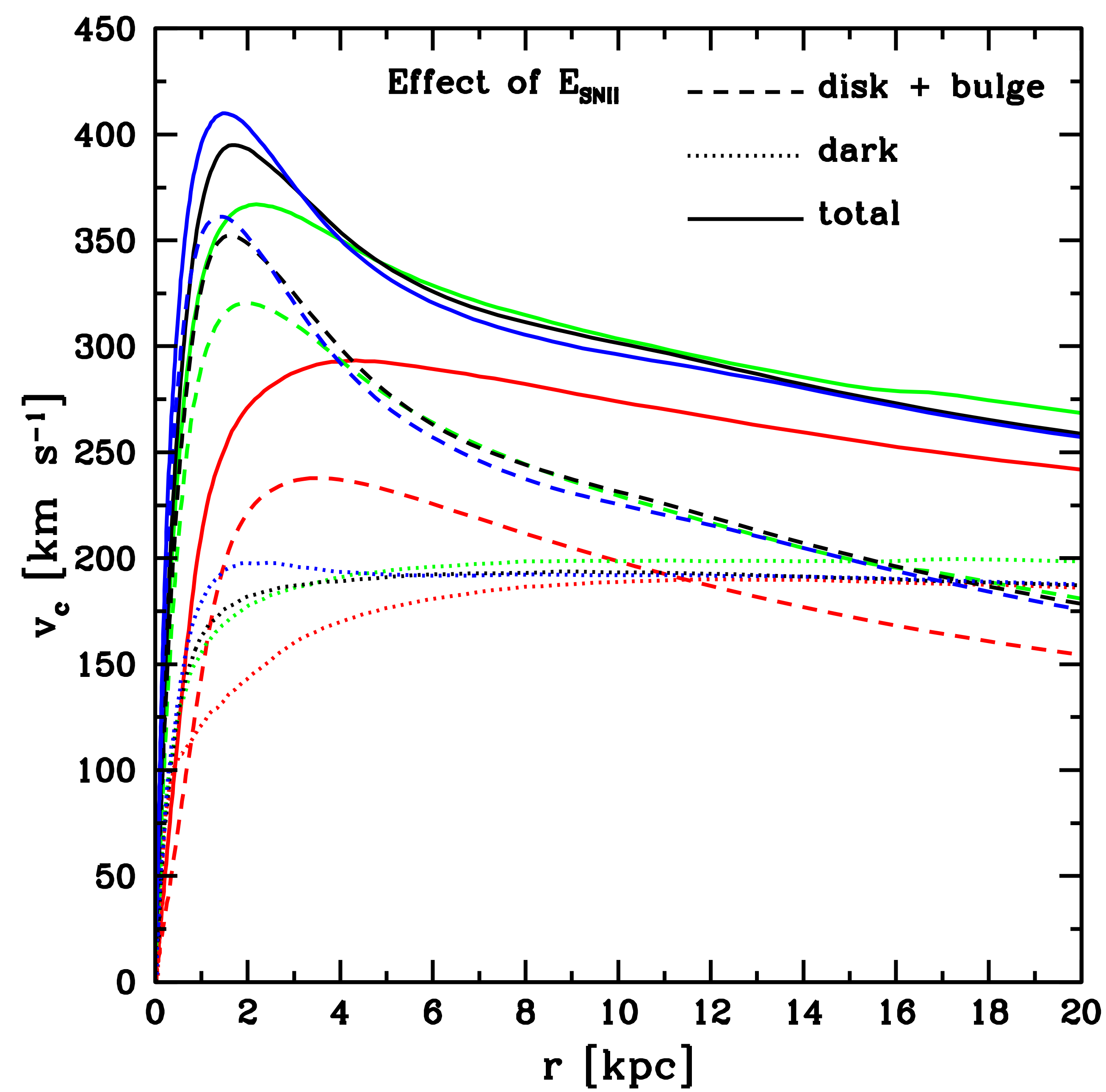


Circular velocities

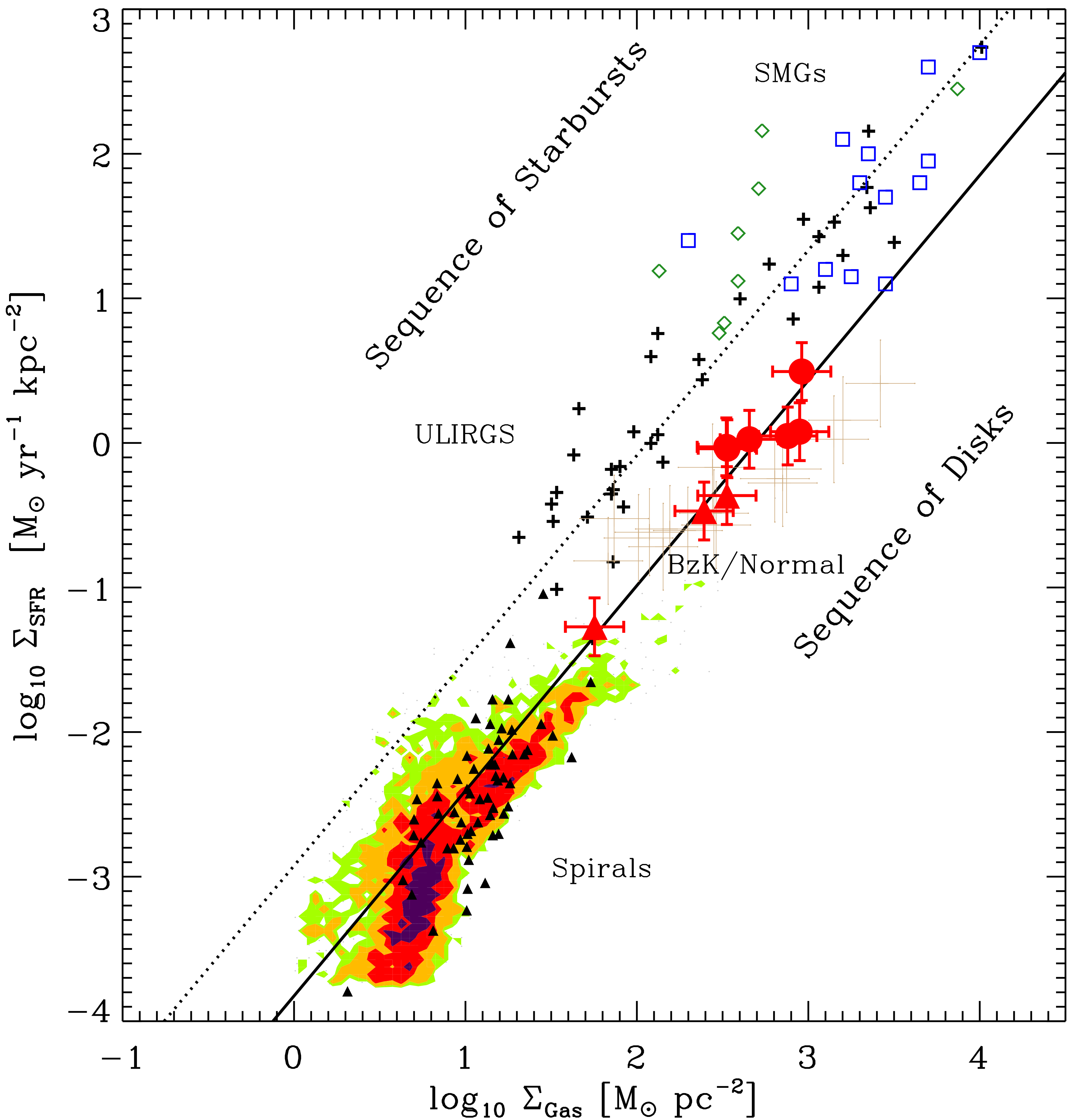
Effect of SFE



Effect of SNe feedback



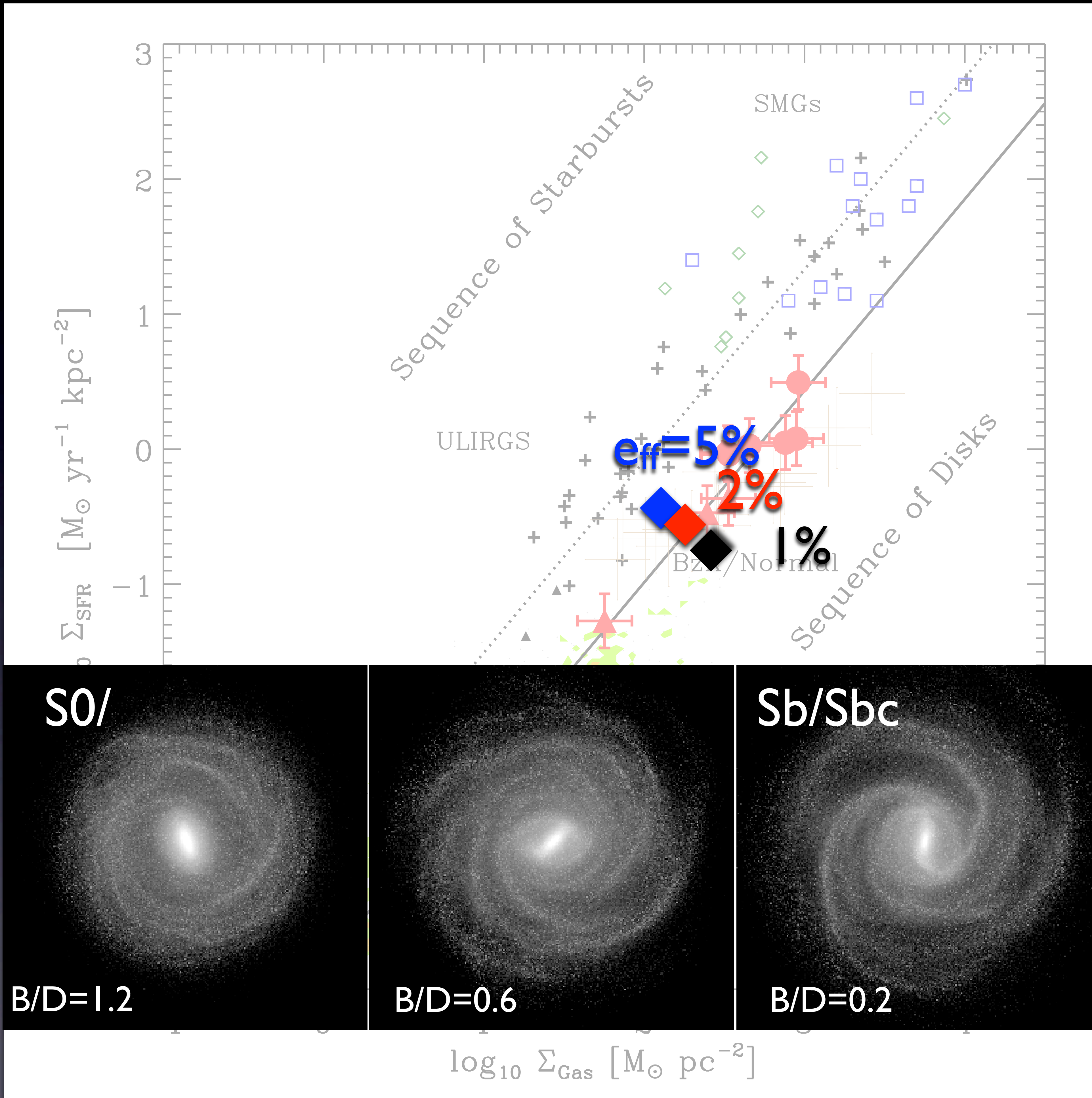
10-20% scaling recovers the Milky Way



Daddi et al. 2010; Genzel et al 2010

z=3

The simulated disks with a low B/D correspond to lower Σ_{SFR} in the spiral sequence.



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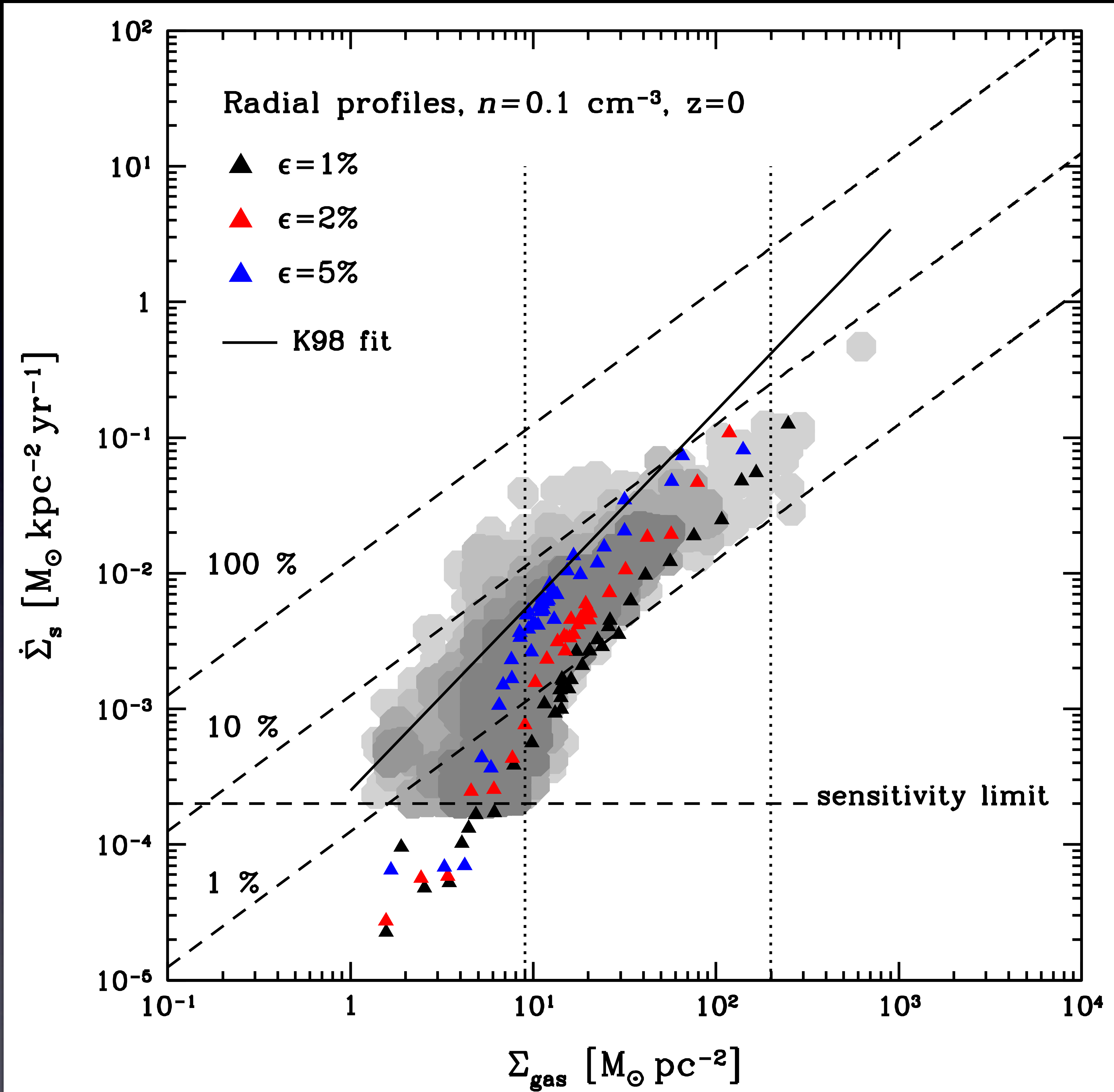


z=0 Efficiency suite

Kennicutt-Schmidt relation
+
THINGS data
(Bigiel et al. 2008)

Romain Teyssier

The baryon fraction problem

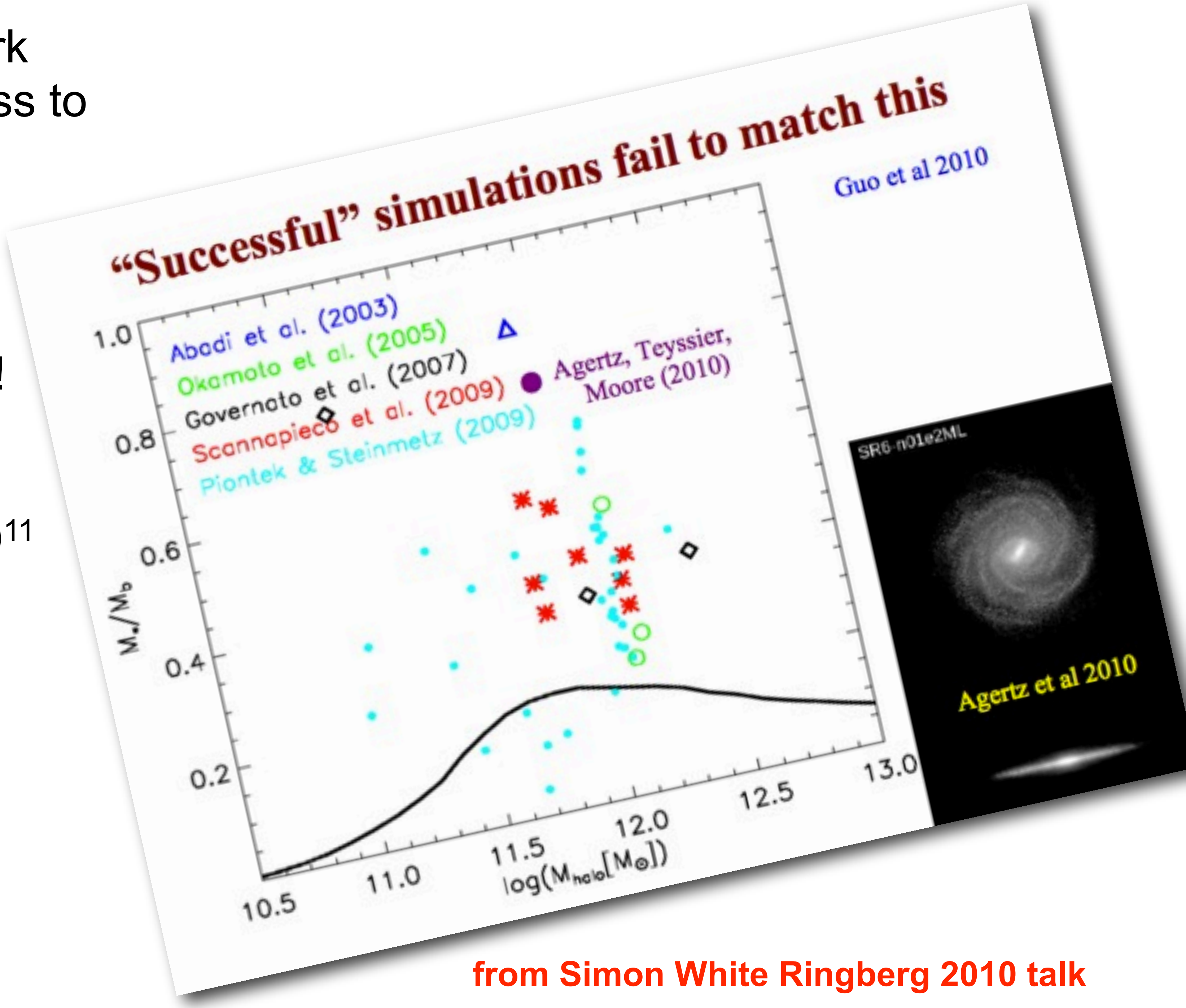
Using abundance matching with dark halos, one can relate the stellar mass to the halo mass.

This gives $M_{halo}=2\times10^{12}$ M_{sol} for the Milky Way and 25% baryon fraction!

Our simulation suggests $M_{halo}=7\times10^{11}$ M_{sol} with 80% baryon fraction.

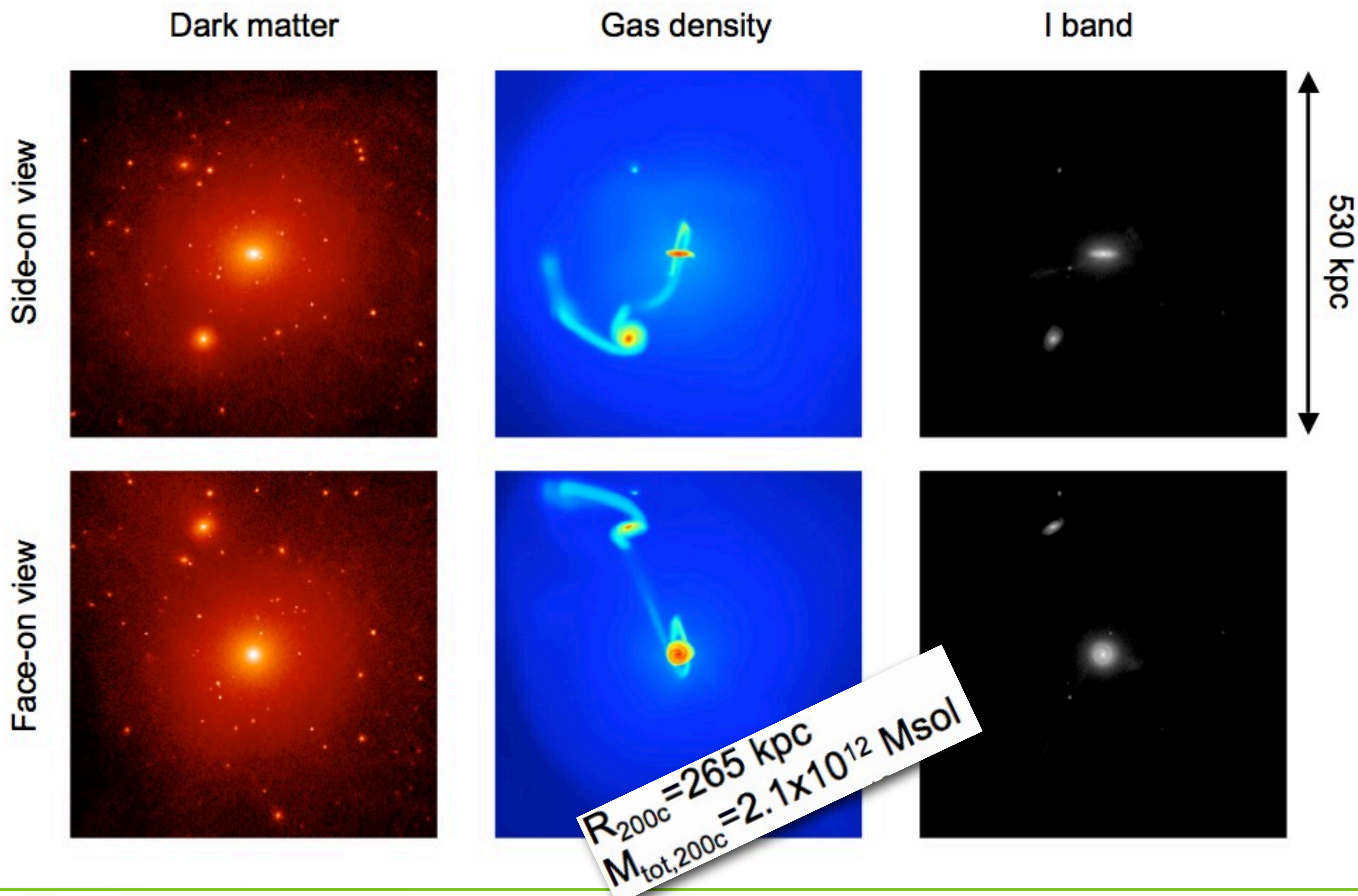
Low baryon fraction in MW models requires very efficient feedback.

Transition from late to early type galaxies around the Milky Way halo mass.

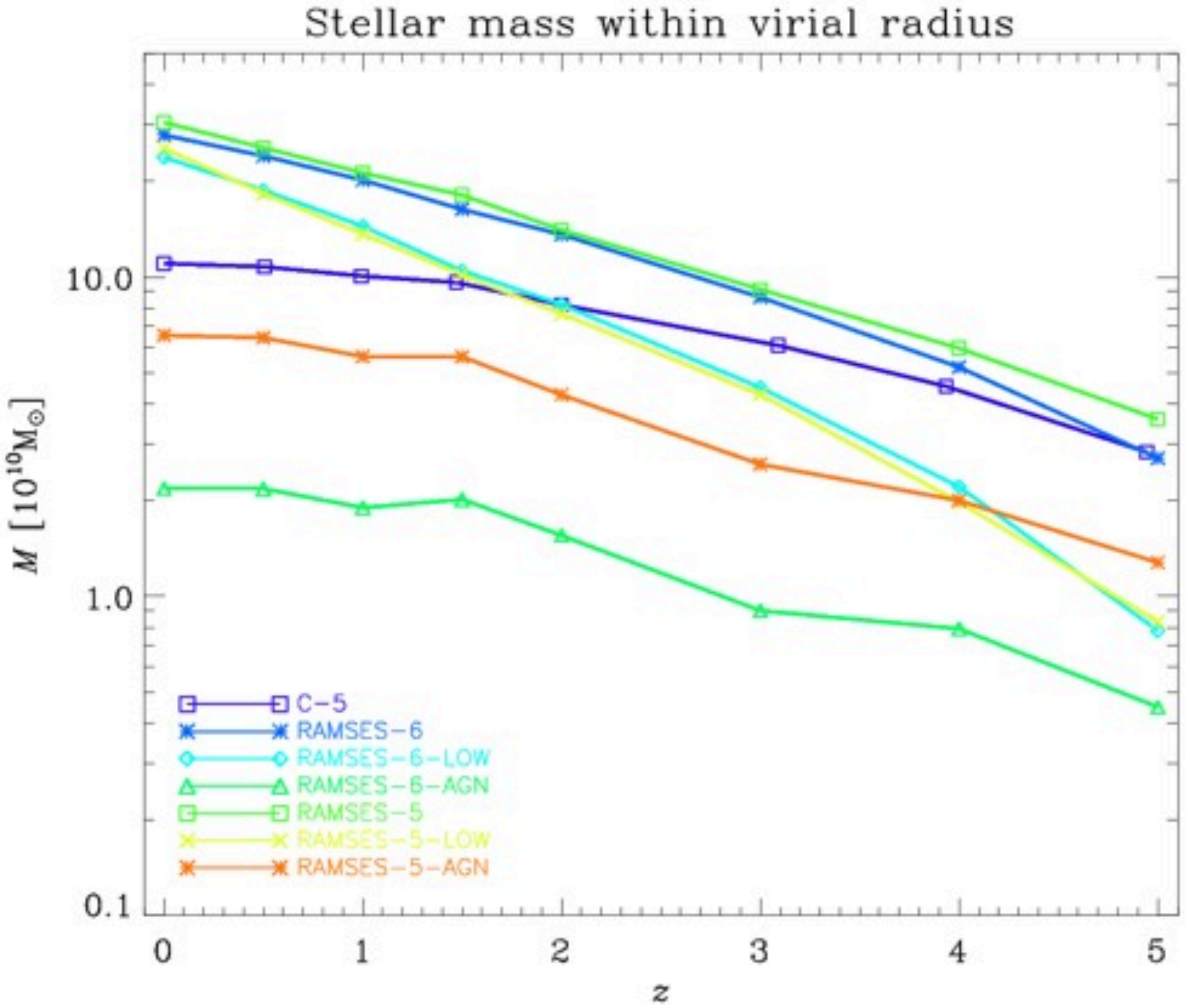


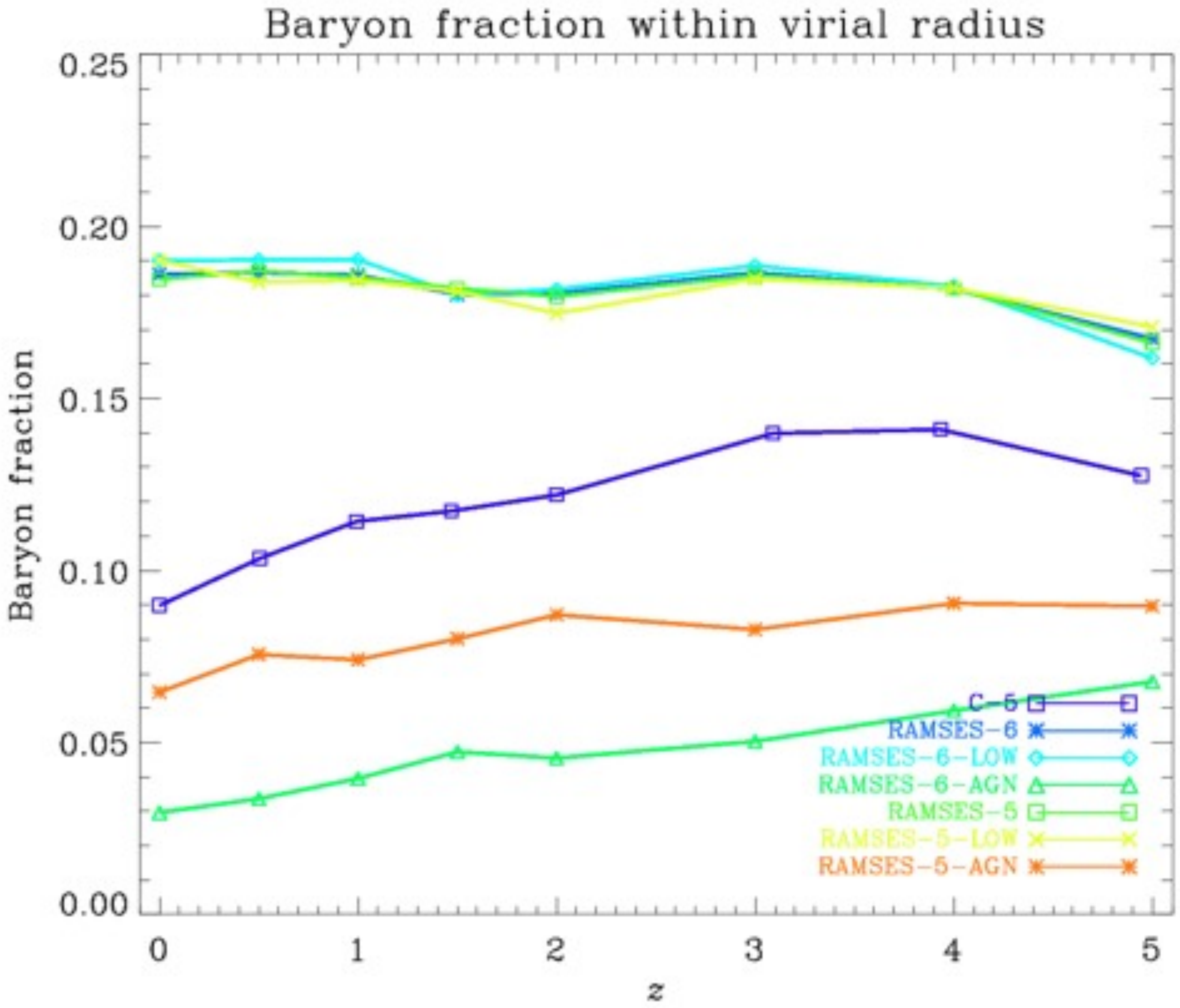
from Simon White Ringberg 2010 talk

The Aquila project (Navarro et al. in prep)



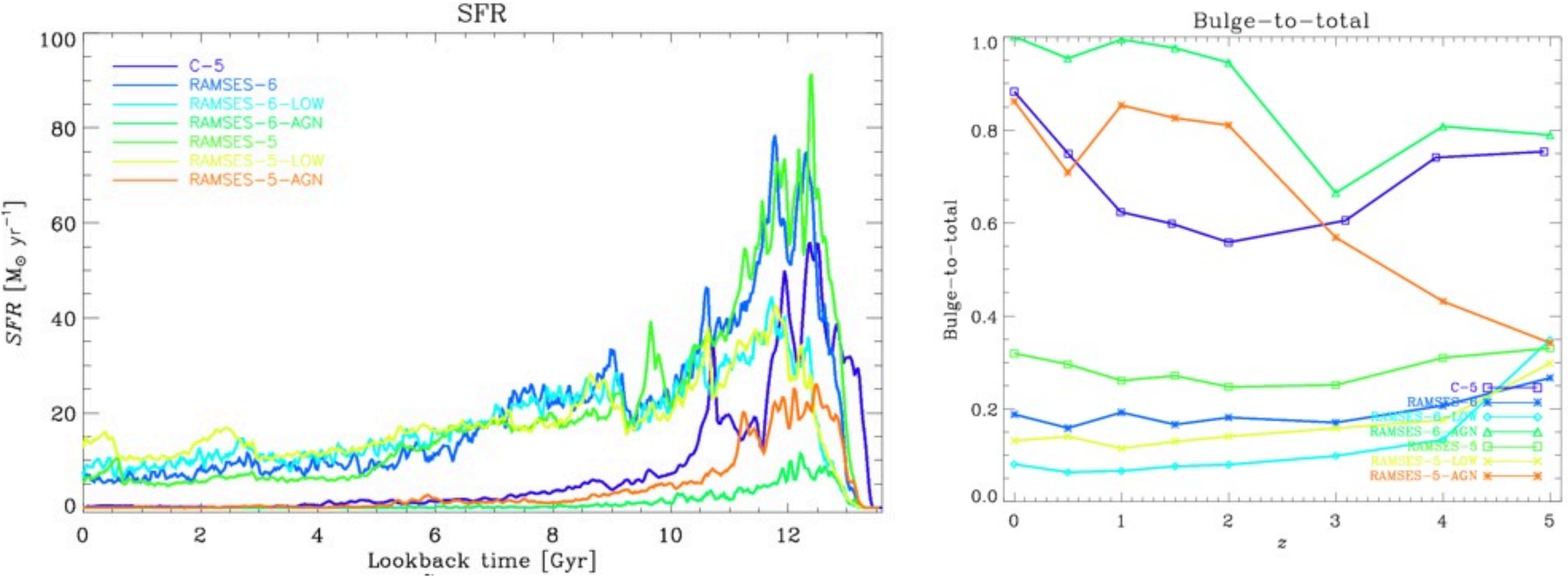
Strong feedback remove baryons from the halo...



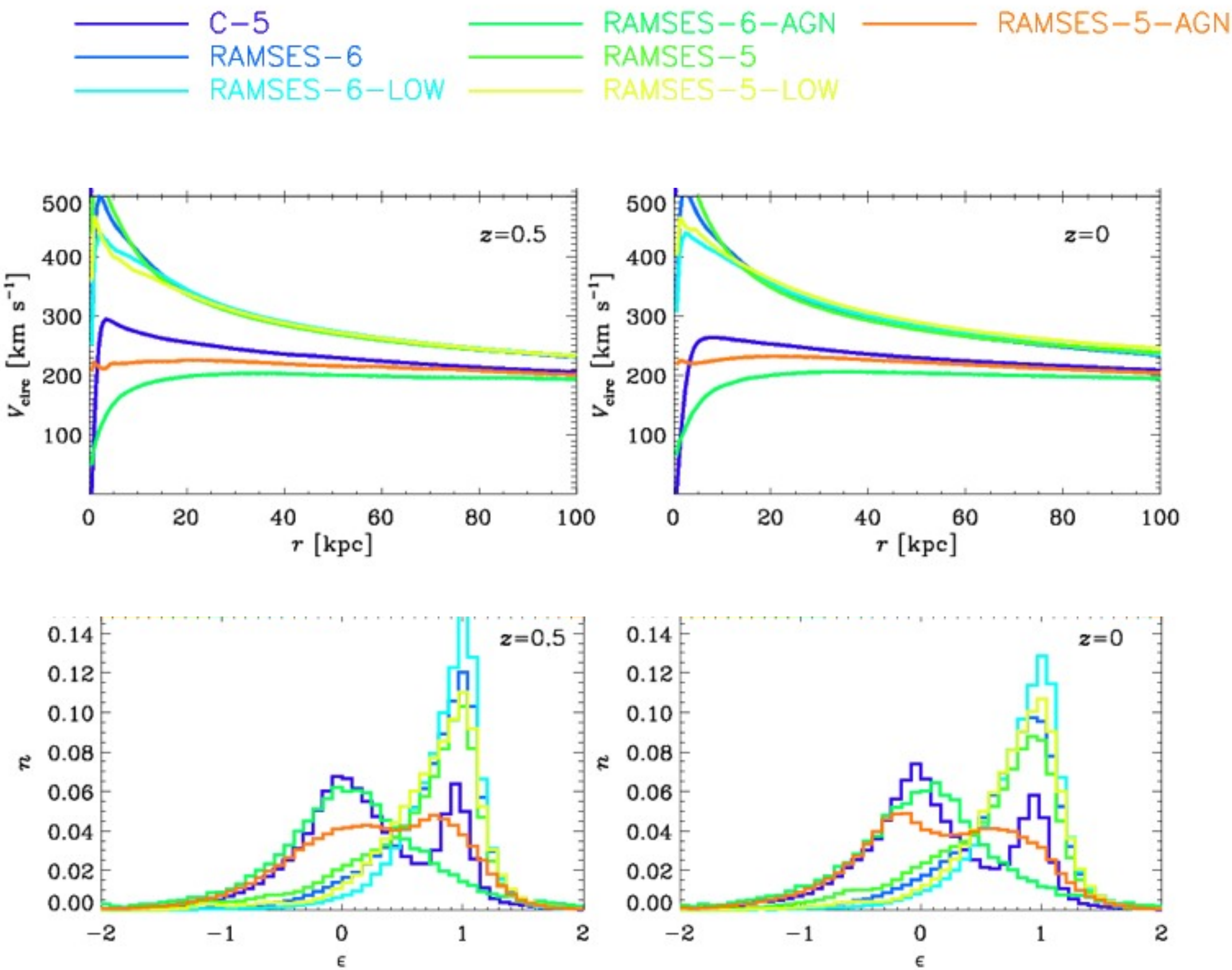


We adapted to AMR the AGN feedback model of Booth & Schaye (2010).

...but lead to the formation of dead spheroids.



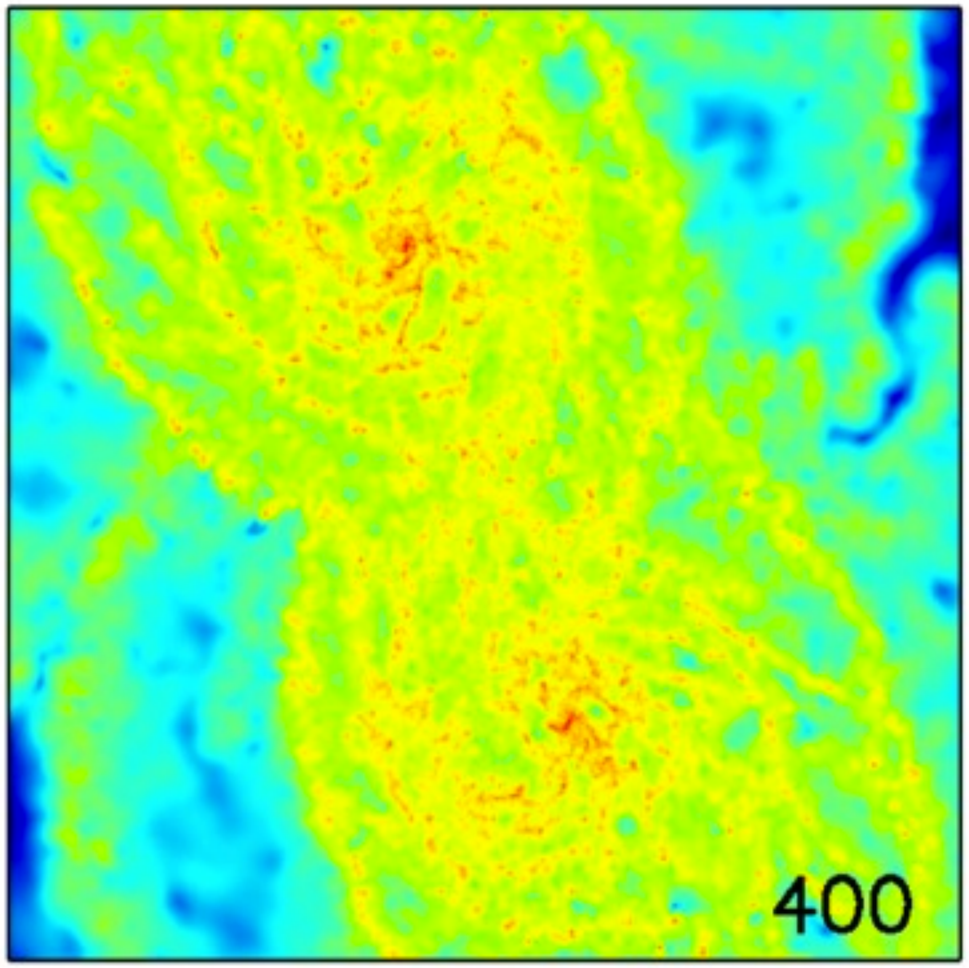
At 2x10[12] Msol, we got flat V_{circ} OR disks !

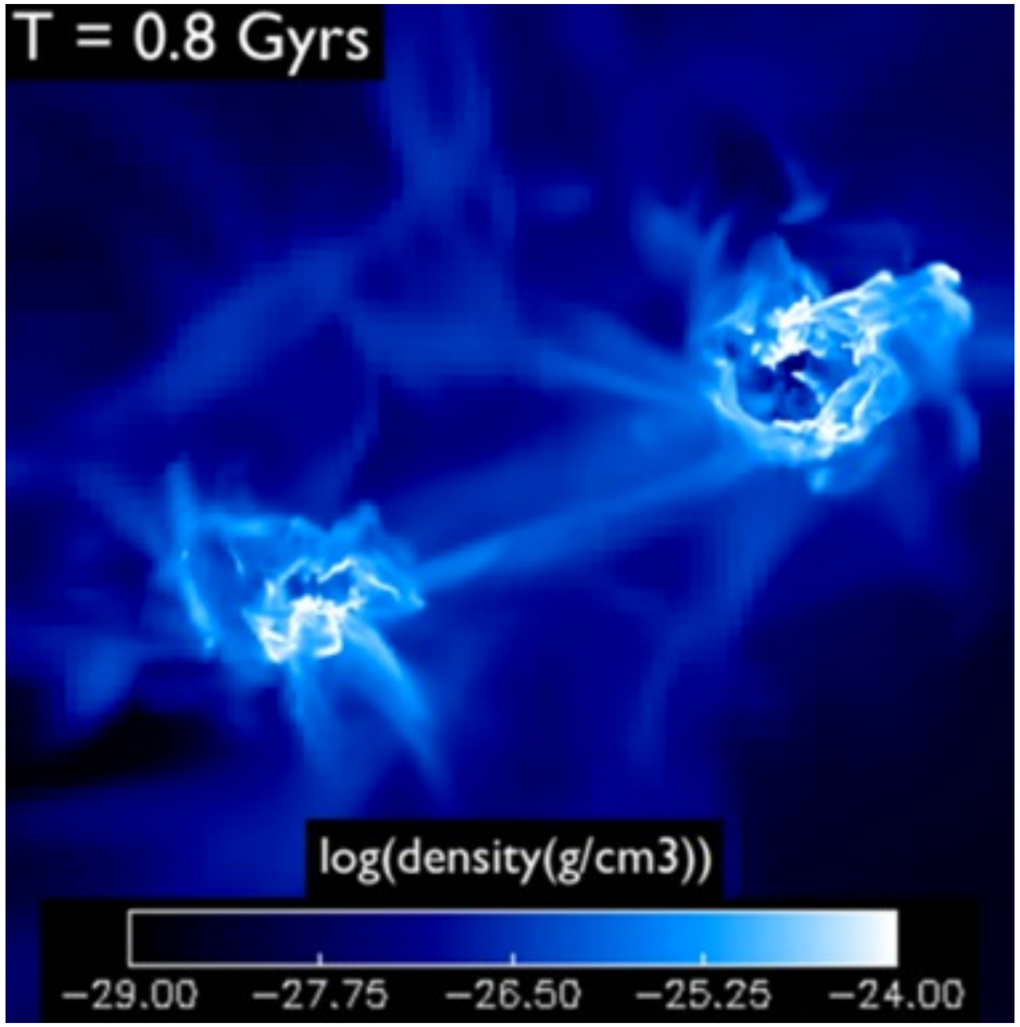


Circularity PDF

High-resolution simulations of mergers

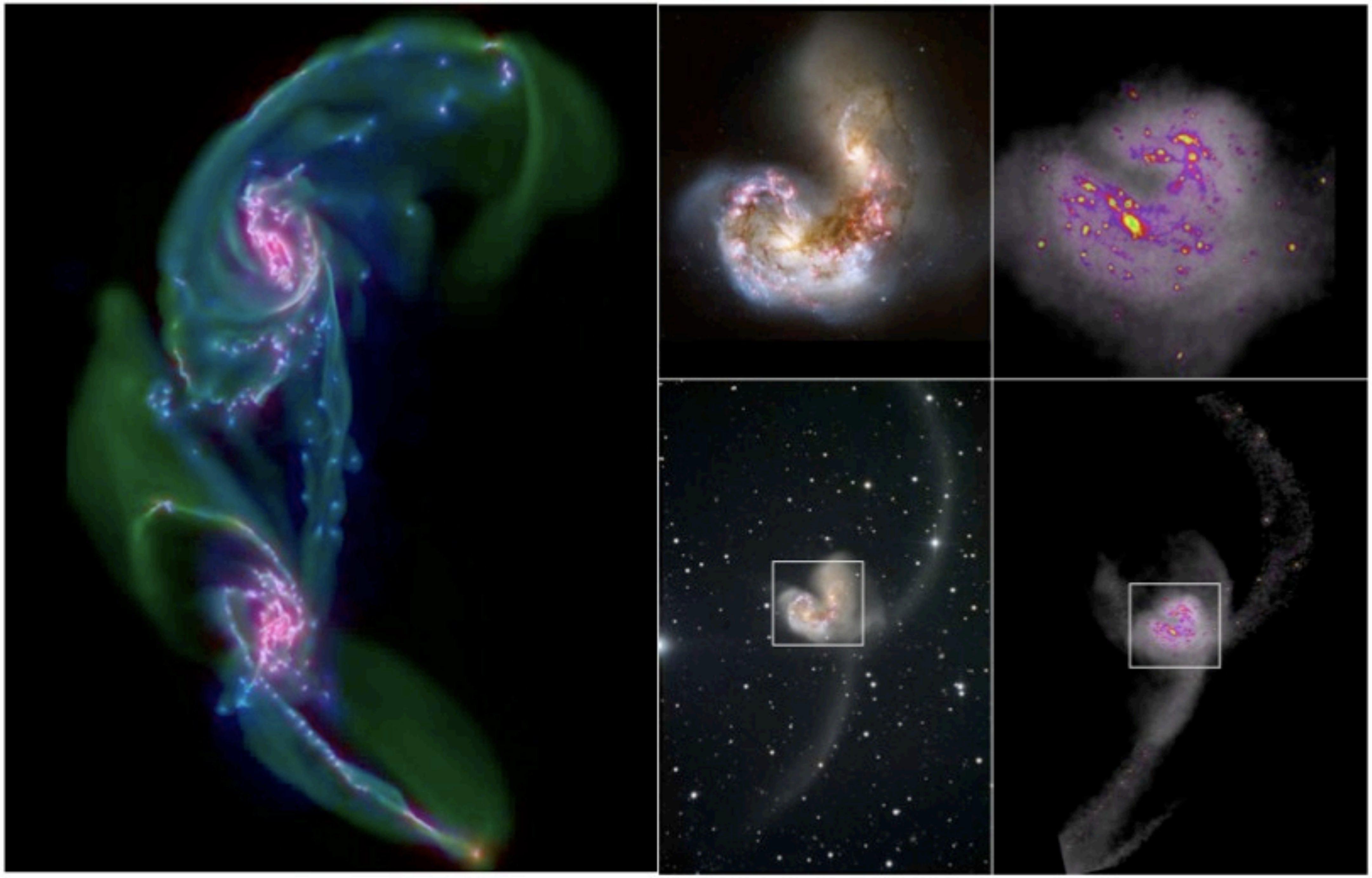
Saitoh et al. (2009)
Shock-induced star formation





Kim, Wise and Abel (2009)
Hot gas outflows

Clump formation in the Antennae galaxy

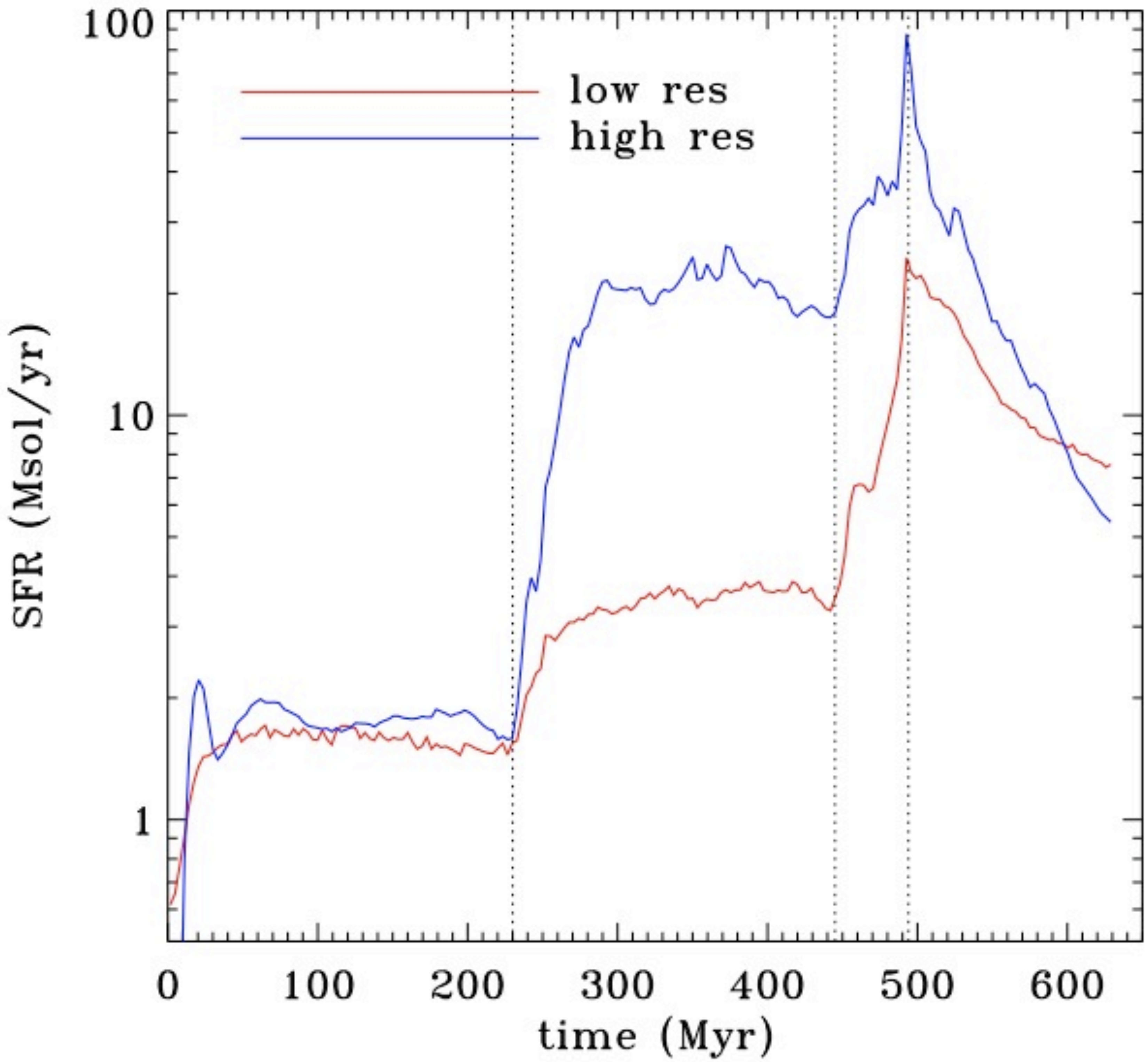


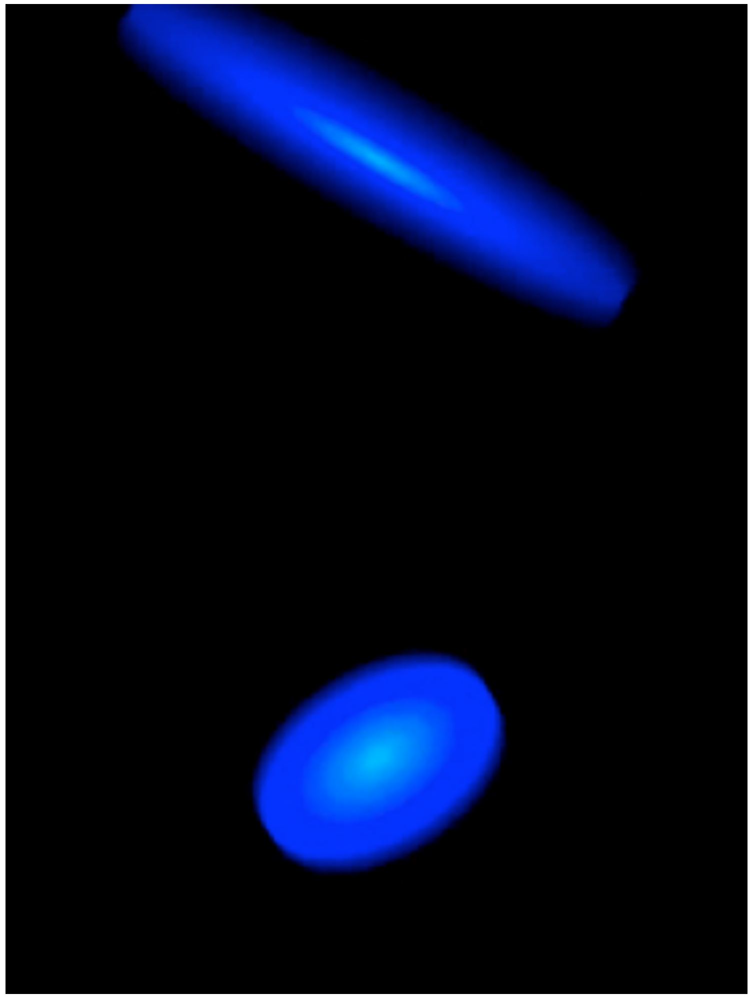
No feedback. Star formation with 1% efficiency for gas density above 10 H/cc.

12 pc resolution, 40×10^6 gas cells 20×10^6 particles

Teyssier, Chapon & Bournaud, ApJL, in press, arxiv1006.4757.

Associated star formation history

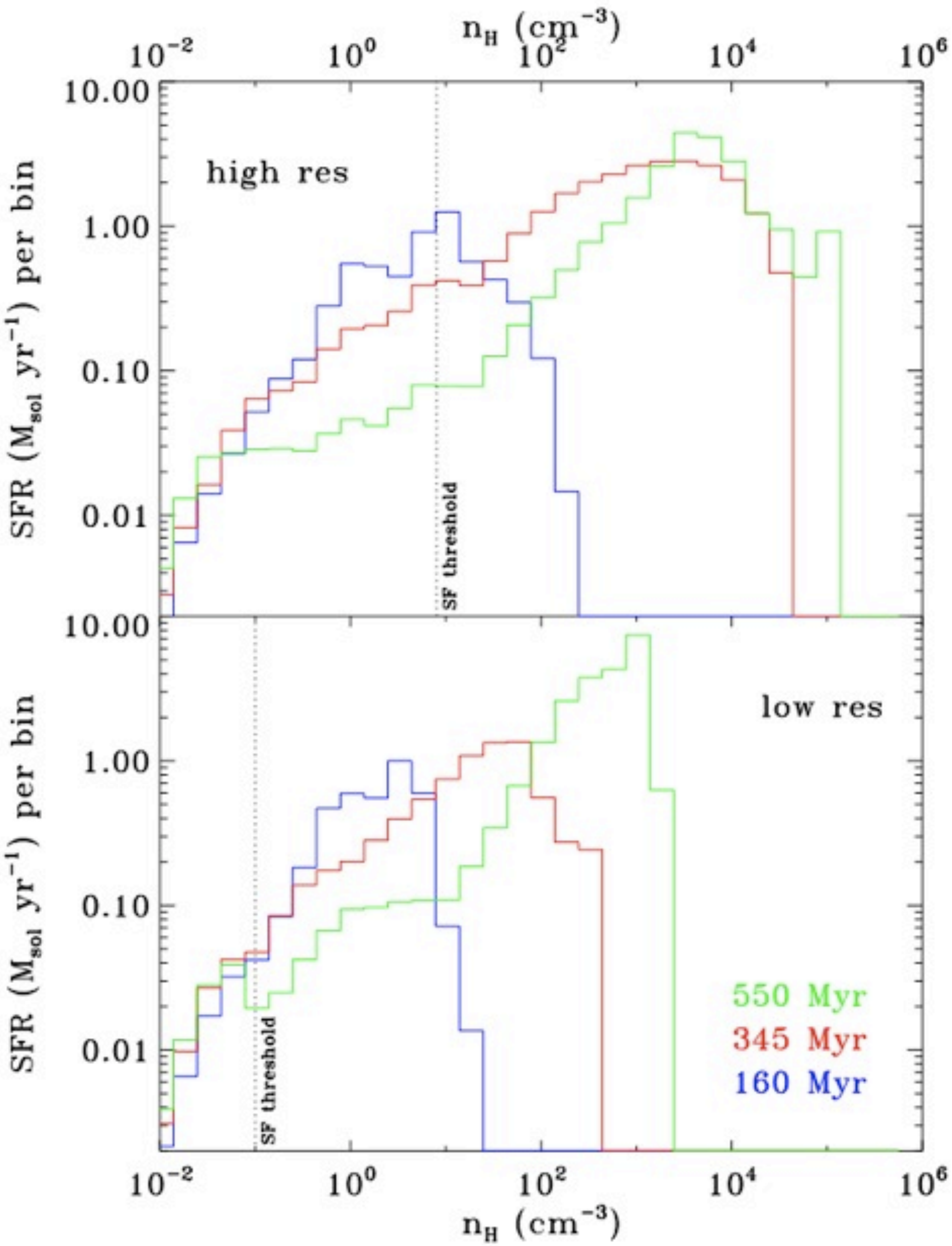




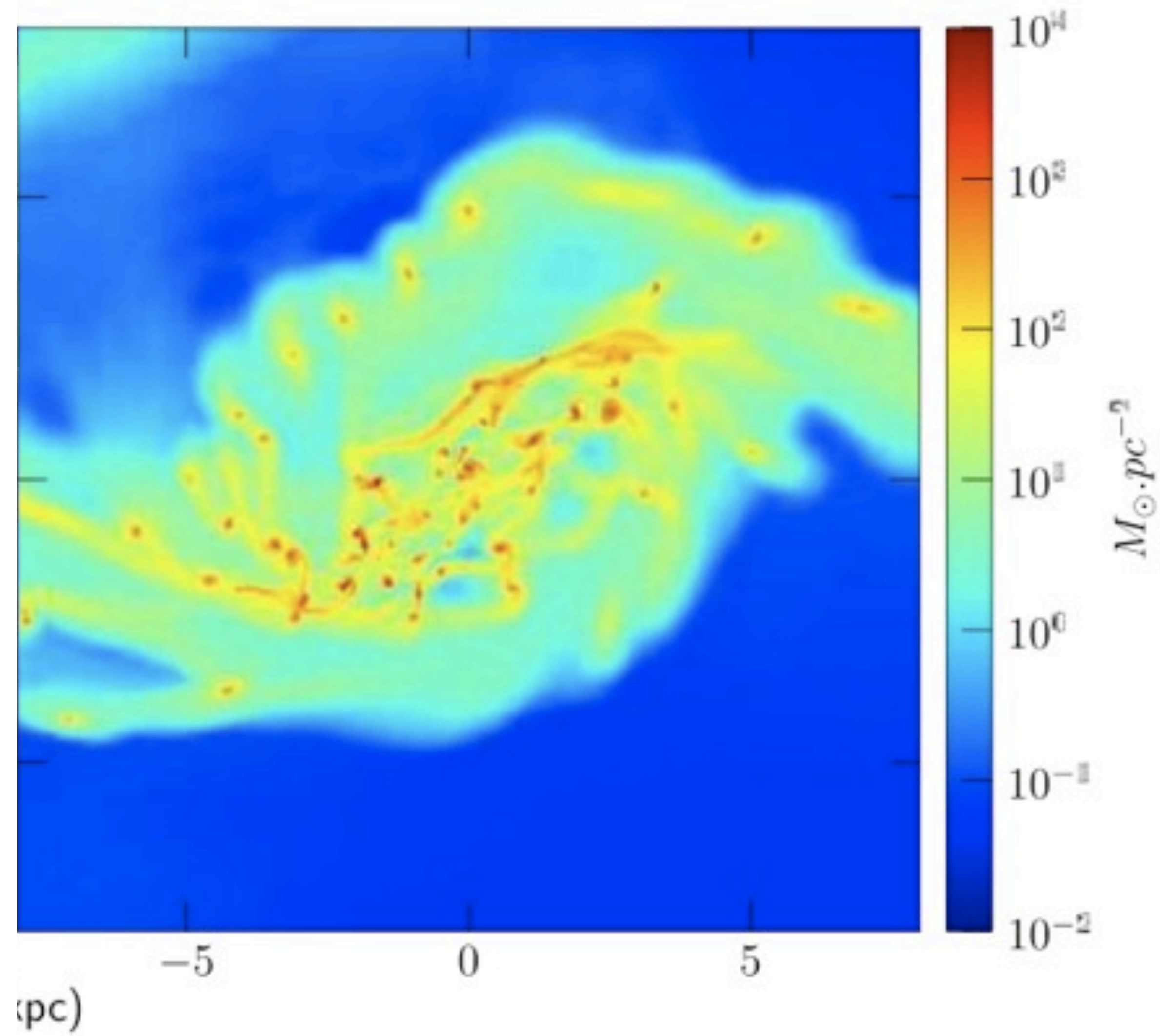
Movie: Daniel Pomarède
with SDvision

Between first and second pericentric passages, smooth disc models (96 pc) find SFR ~ 3-4 Msol/yr, a factor of 5-10 below clumpy disc models (12 pc) !

Fragmentation: the driving mechanism for starbursts ?

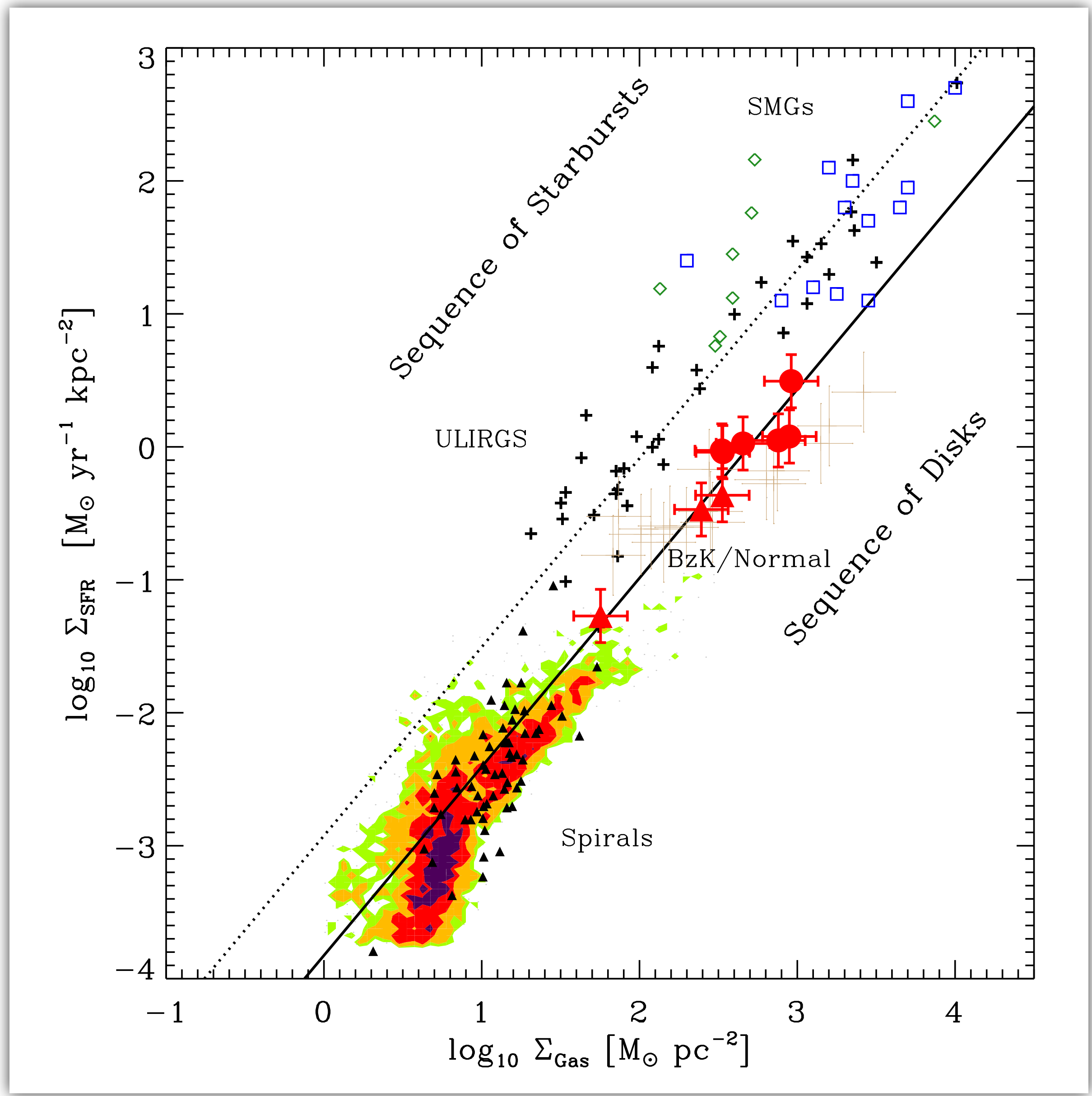


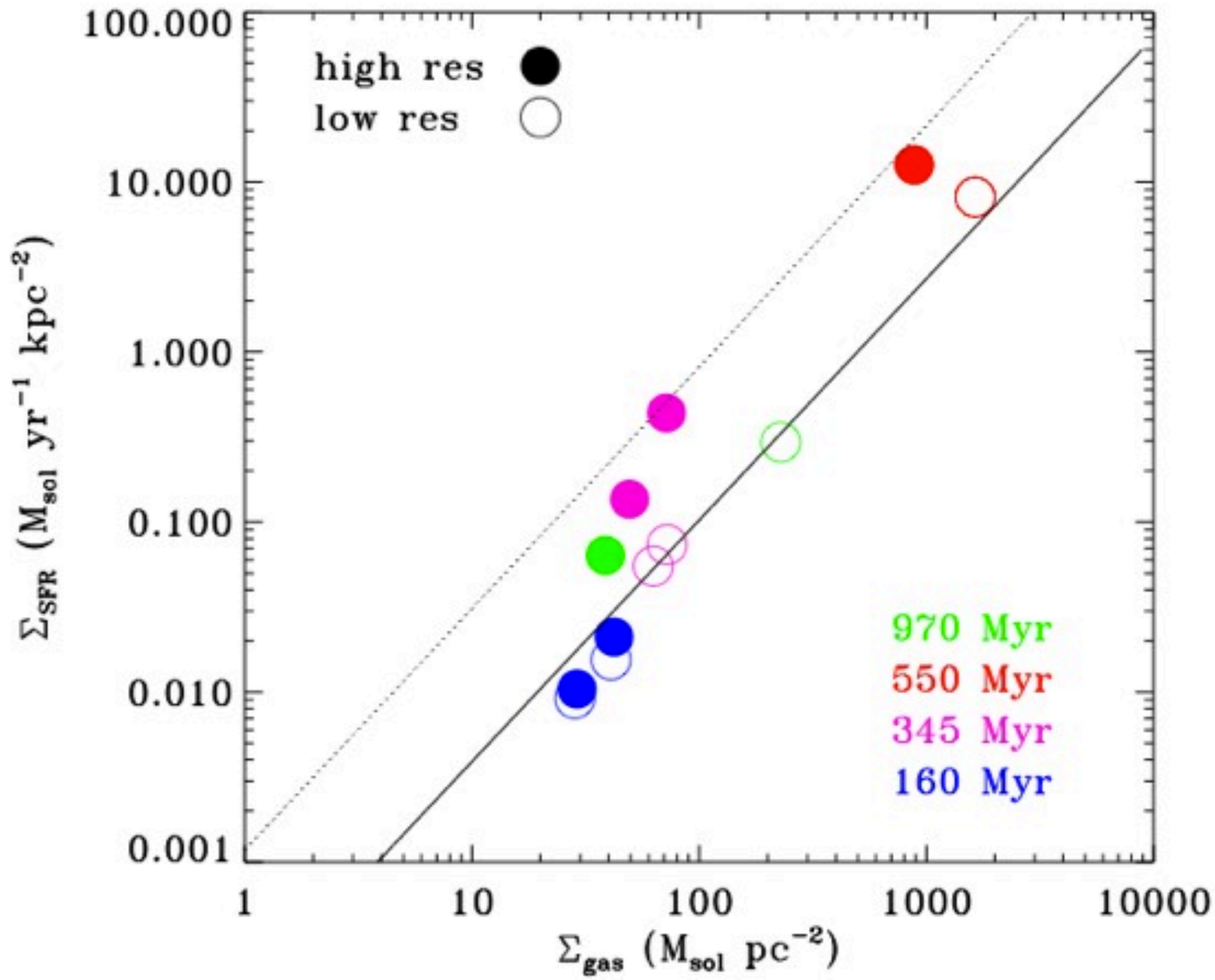
high res



ırbation. With high res and low T
ıally unstable and fragments in

Kennicutt-Schmidt diagram





Daddi et al. 2010
Genzel et al. 2010

α_{CO}=1 ?

Conclusions

- Low star formation efficiency leads to the formation of disc dominated systems.
- Internal processes (SF+FBK) play an important role in shaping galaxies.
- Low baryon fraction can be obtained with strong feedback but at the expense of destroying the disk.
- With smooth discs (low res > 100 pc), the SF efficiency cannot be self-consistently predicted.
- With clumpy discs (high res < 100 pc), we capture a strong, non linear evolution in the global SFE: transition from quiescent to starburst regime ?
- To get a clumpy ISM for quiescent disc galaxies, we need a resolution < 1 pc ! (see Bournaud *et al.* submitted)