On the size evolution of early type galaxies

Gian Luigi Granato

INAF – Trieste

Cinthia Ragone-Figueroa

Mario Abadi

IATE-Cordoba

Plan:

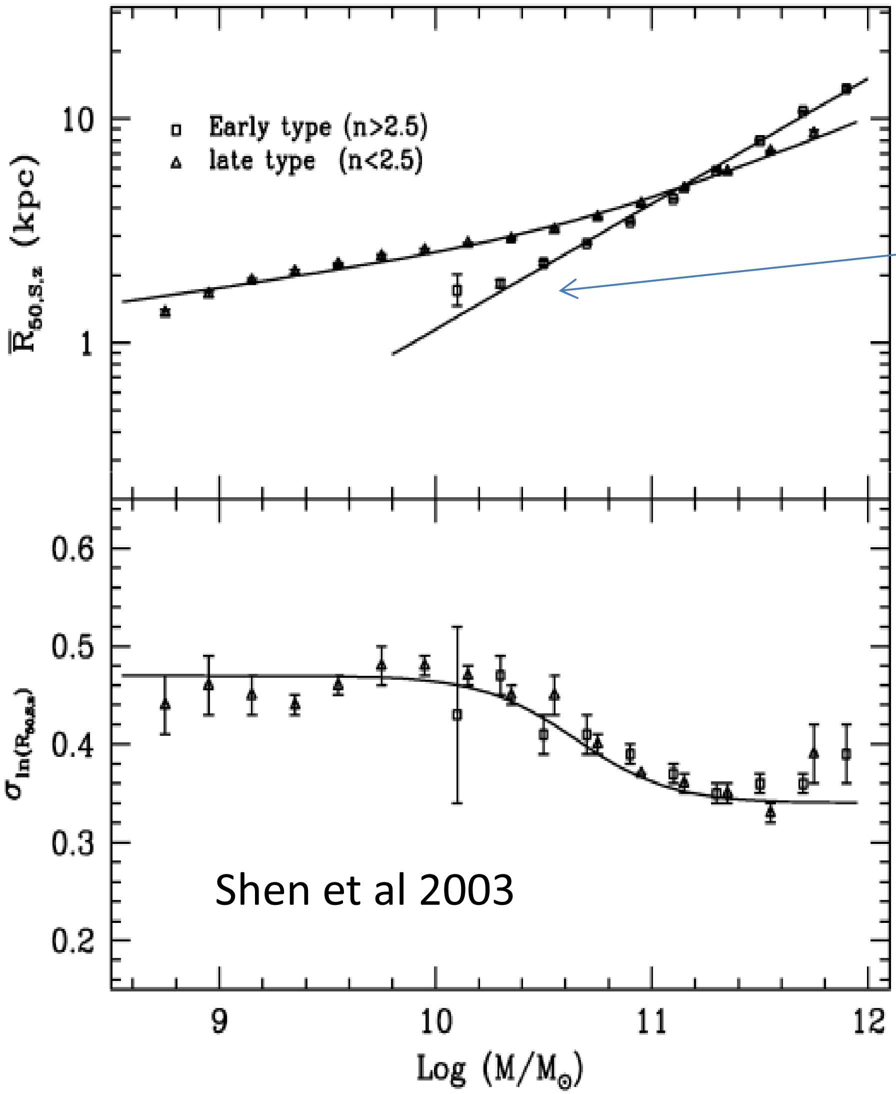
-Generalities on the problem

-Why puffing-up cannot explain what we see so far

--But we could see in the future

--Implications for DMH profiles

Well defined local size-mass relationship

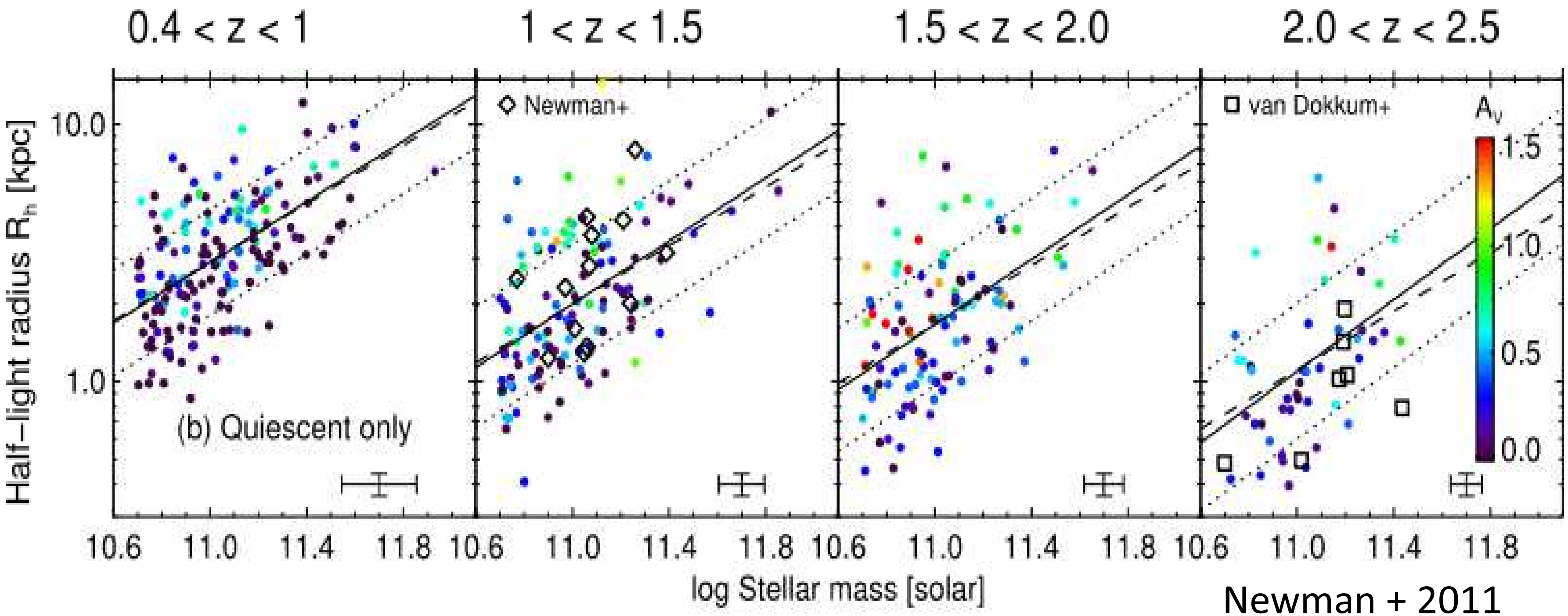


For ETG

$R_e \simeq 2.9\text{e-}6\ (M/M_{\odot})^{0.56}$ Kpc

Observed evolution of the size-mass relationship since z$\sim$2.5

Demonstrated by quite many papers (e.g. Daddi et al. 2005; Trujillo et al. 2006, 2007; Longhetti et al. 2007; Toft et al. 2007; Zirm et al. 2007; van der Wel et al. 2008; van Dokkum et al. 2008; Cimatti et al. 2008; Buitrago et al. 2008; Damjanov et al.2009; Mancini et al. 2010; Ryan et al. 2010; Newman et al 2011)

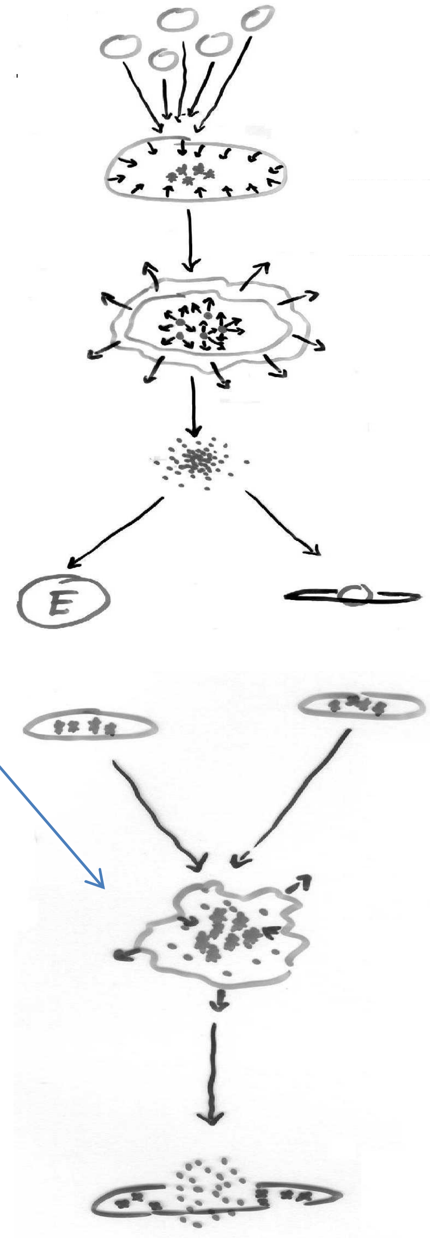


Newman + 2011

- Normalization evolves by a factor a few.
- Supposed to provide clues on mass assembly mechanisms and timing.

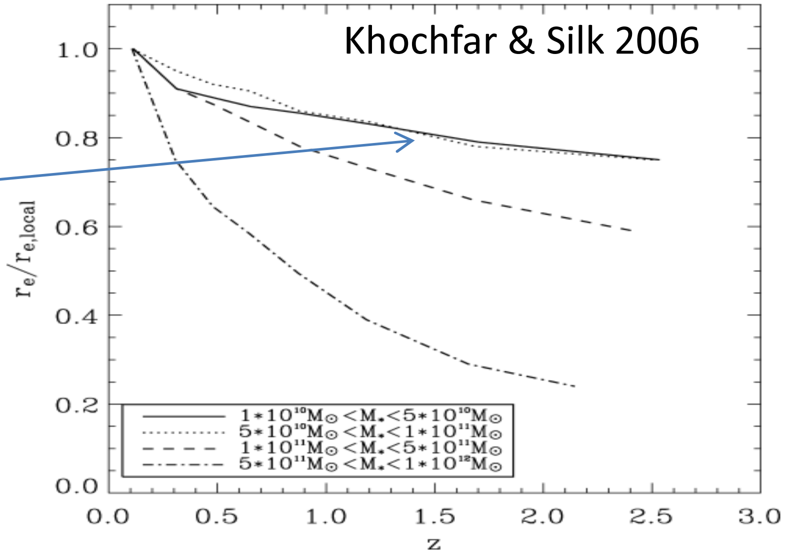
ETGs assembly mechanisms

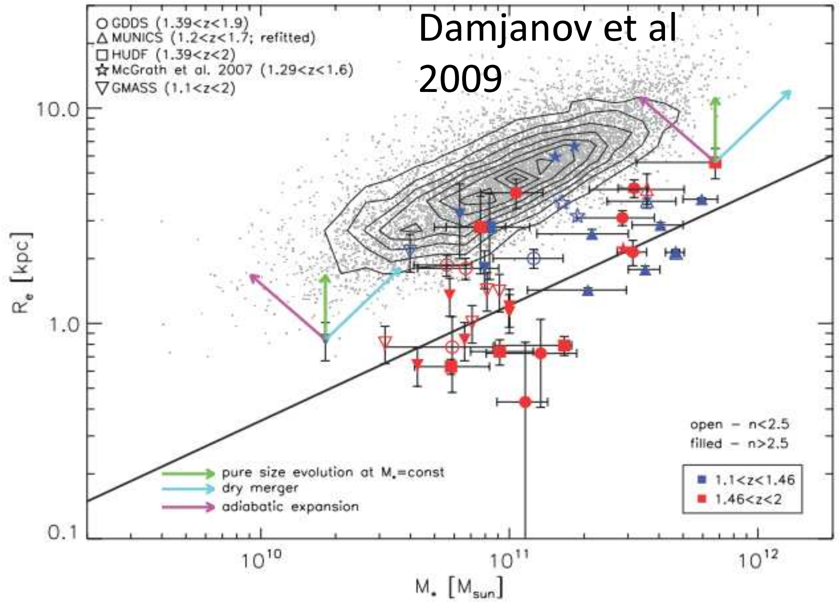
- Since decades, two competing scenarios for the formation of ETGs have been hotly debated:
  - (Quasi-)monolithic collapse at high-z
  - Disk mergers over most of the Hubble time
- The latter has been ruled out by observations: stars in Es are old and already mostly assembled in single units at z>1-2
- Theory and observations are converging to a picture somewhere in between: a fast (say 1 Gyr) phase of mergers of star forming blobs at high-z, possibly followed by some degree of DRY mergers.
- But details (e.g. nature of blobs at high-z, importance and nature of dry mergers) are still uncertain.
- Size evolution could provide clues



Proposed explanations for size evolution

- Newly formed objects at lower z have larger sizes, due e.g. lower gas richness and less dissipation. Insufficient to explain all (Khochfar & Silk 2006 (SAM); Hopkins + 2009 (phenom.); Newman + 2011), particularly at $M_* < 10^{11}$;
- A sequence of major dry mergers. Too many required since $R \propto M$;
- Many minor dry mergers, wherein $R \propto M^2$ (optimistic). Promising, but likely cannot account for all (Hopkins et al 2010), particularly at z>1 (Newman et al 2011);
- “Gravity loss” due to expulsion of baryonic mass by galactic winds or/and stellar evolution (Fan et al 2008,2010; Damjanov et al 2009);





Expulsion of baryonic mass

- Suggestion made originally by Fan et al (2008) in the context of a specific SAM for SMBH-spheroid co-evolution (Granato et al 2004)
- But more general: independently of still unclear “details” of formation mechanism of ETGs, very likely they underwent, at some point over their history, important ($\sim$ 50%) ejection of baryonic matter.
- Actually, virtually all realistic galaxy formation models include
  - Prompt early galactic winds driven by AGN and/or SNae
  - Later mass loss due to stellar evolution

What happens to the leftover stars? The star cluster approximation

- Many works on star cluster dynamics. Similar problem.
- When a cloud of gas collapse to form stars, only a fraction ε (efficiency) of its mass has time to be converted into stars before being dispersed by SNae and stellar winds
- Major difference: absence of embedding DM Halo

What happens to the leftover stars?
The star cluster approximation

- Two extreme regimes allow approximated analytical treatment, (almost) confirmed by simulations

$$\text{slow ejection} \quad t_{ejection} \qquad t_{dyn} \Rightarrow \frac{R_{fin}}{R_{ini}} = \frac{1}{\varepsilon} = \frac{M_{ini}}{M_{fin}}$$

$$\text{fast ejection} \quad t_{ejection} \qquad t_{dyn} \Rightarrow \frac{R_{fin}}{R_{ini}} = \frac{\varepsilon}{2\varepsilon - 1} = \frac{M_{fin}}{2M_{fin} - M_{ini}}$$

- In the latter case the expansion is greater, and the system is dispersed if $M_{fin} < M_{ini}/2$

Why we run simulations?

Puffing up early-type galaxies by baryonic mass loss: numerical experiments

Paper I: MNRAS July 2011

Cinthia Ragone-Figueroa[1*], Gian Luigi Granato[2†]

[1] *Instituto de Astronomía Teórica y Experimental, IATE, CONICET-Observatorio Astronómico, Universidad Nacional de Córdoba, Laprida 854, X5000BGR, Córdoba, Argentina*
[2] *Istituto Nazionale di Astrofisica INAF, Osservatorio Astronomico di Trieste, Via Tiepolo 11, I-34131 Trieste, Italy*

- In ETGs the DM halo expected to affect efficiency and timescale of size evo;
- Also intermediate regimes (as for expulsion timescale) are relevant;

MOREOVER

Effects of baryon mass loss on profiles of large galactic dark matter haloes

Paper II: MNRAS submitted yesterday

Cinthia Ragone-Figueroa[1*], Gian Luigi Granato[2†] & Mario G. Abadi[1‡]

- It is also interesting to investigate the effect of baryon ejection on haloes

How we run simulations?

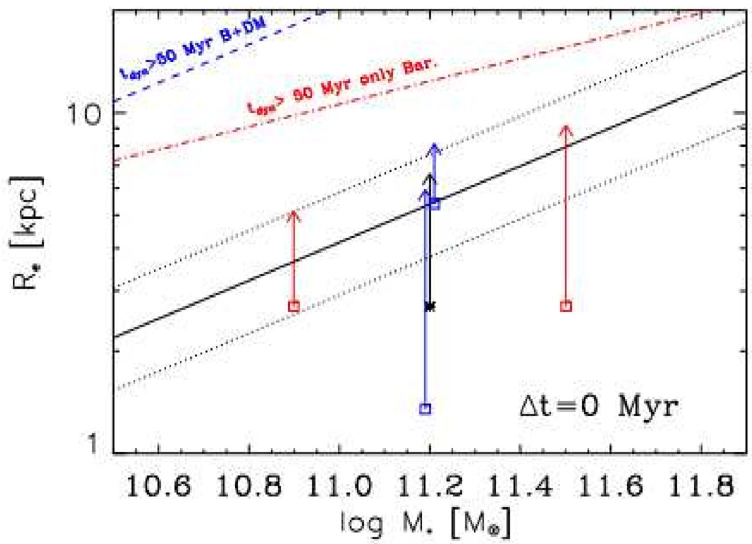
- We investigate the evolution of spheroidal distributions of collision-less particles, comprising two components (stars and DM), under a change of potential due to a loss of baryonic mass, either residual gas or the mass lost from stars.
- MassLoss(t) is given, due to “external” causes (feedbacks, or stellar evo).
- We don’t have to treat gas dynamics: simple N-body simulations.

Numerical technique and setup

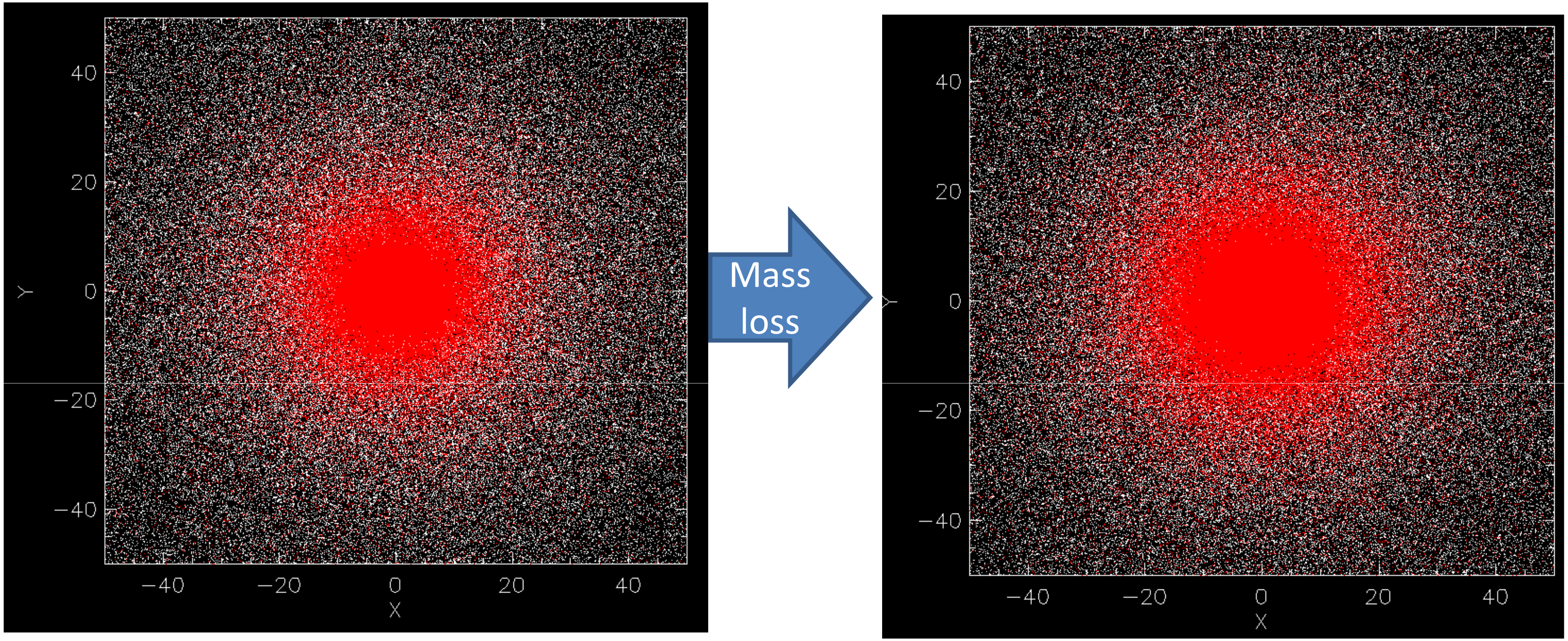
- Gadget II, typically 1E6, half DM half "baryons", softening 0.35 Kpc and 0.02 respectively. Results VERY stable wrt large variations of all these things.
- Initial conditions thought to get a configuration, after the loss of 20-80% of baryons, consistent with our basic knowledge of the properties of local large ETGs (baryon to DM mass ratio, scale-lengths, size as a function of stellar mass):
- NFW profile for DM (R_{vir}=170 Kpc, c=4, but also runs with adiabatic contraction), Hernquist profile for baryons (R_e=2.7 Kpc). Equilibrium σ^2 solving Jeans equation. M_{vir}=1e13; $M_{vir}/M_B(t=0)$=25.
- Computed evolution under exponential loss of a fraction 1-ε of baryonic mass, over a time scale Δt:

$$M_B(t) = M_B(0)\exp\left(\frac{\ln\varepsilon}{\Delta t}t\right)$$

- Δt=0, 2, 5, 20, 80 Myr   ($t_{dyn} \simeq$ 5 Myr)
- ε=0.2,0.4,0.6,0.8



A horrible rendition

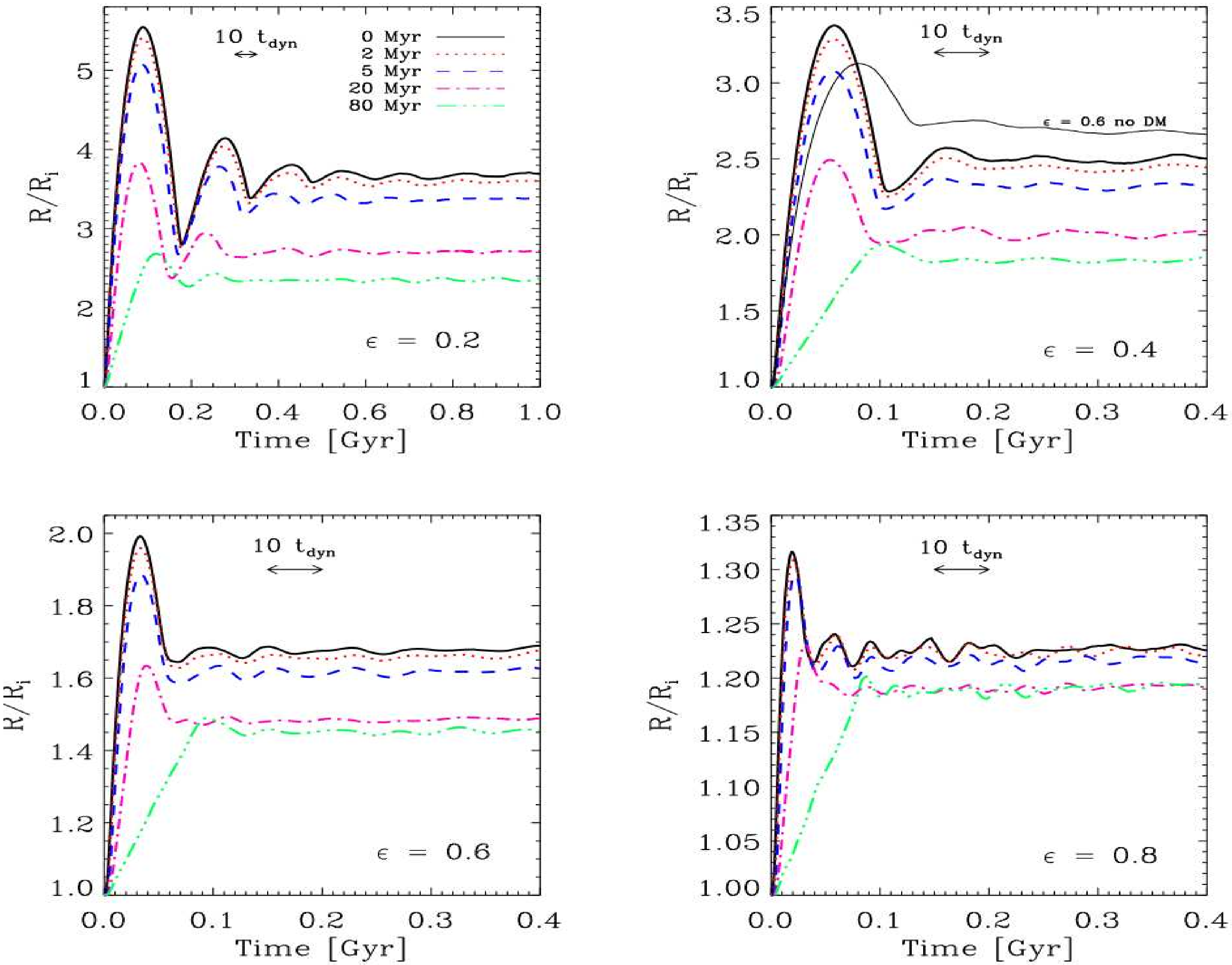


Equilibrium before mass loss…

… and after mass loss

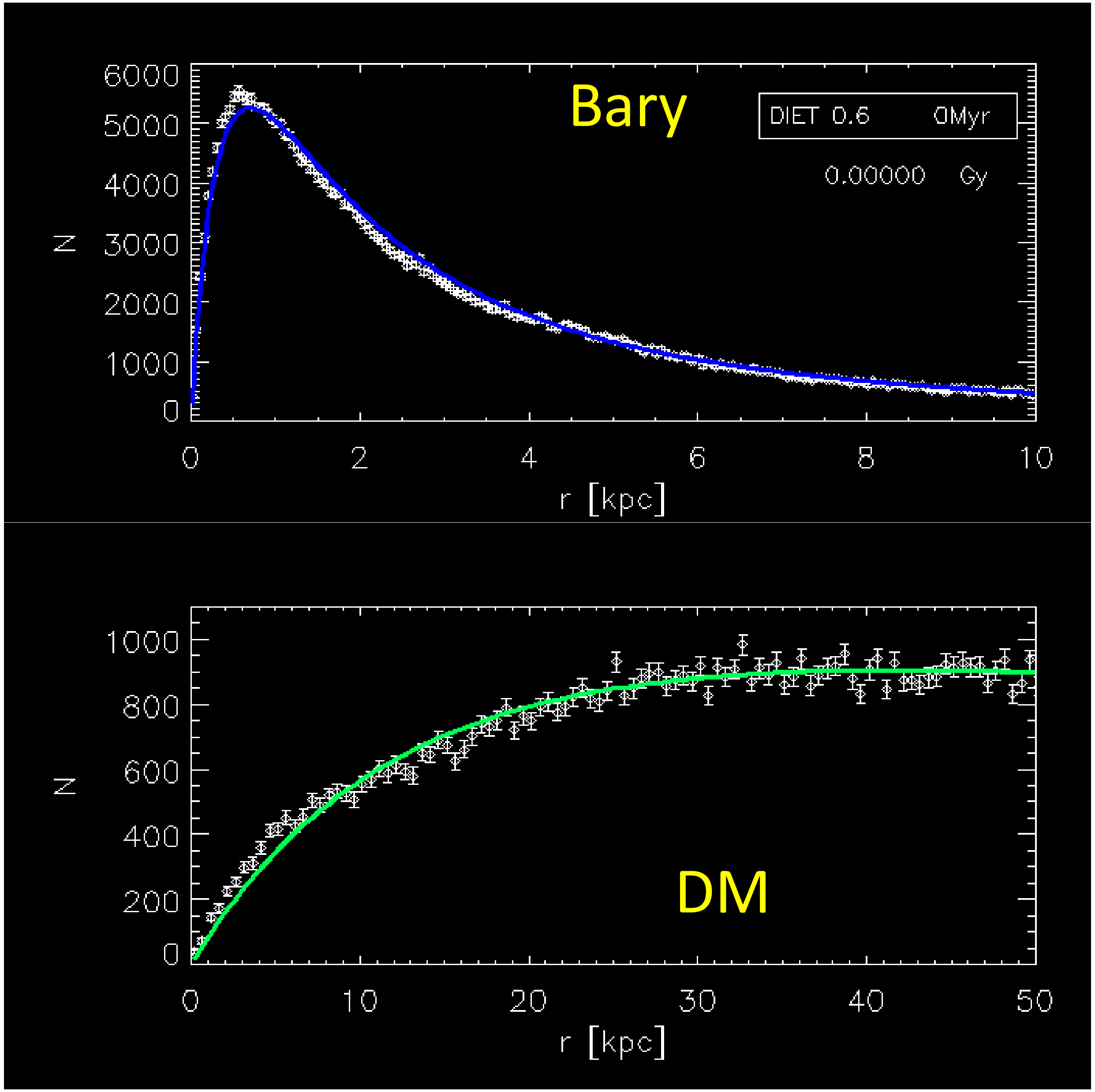
Red dots: baryons
White dots: DM

Size evolution



Effects on density profiles - (ε > 0.5)

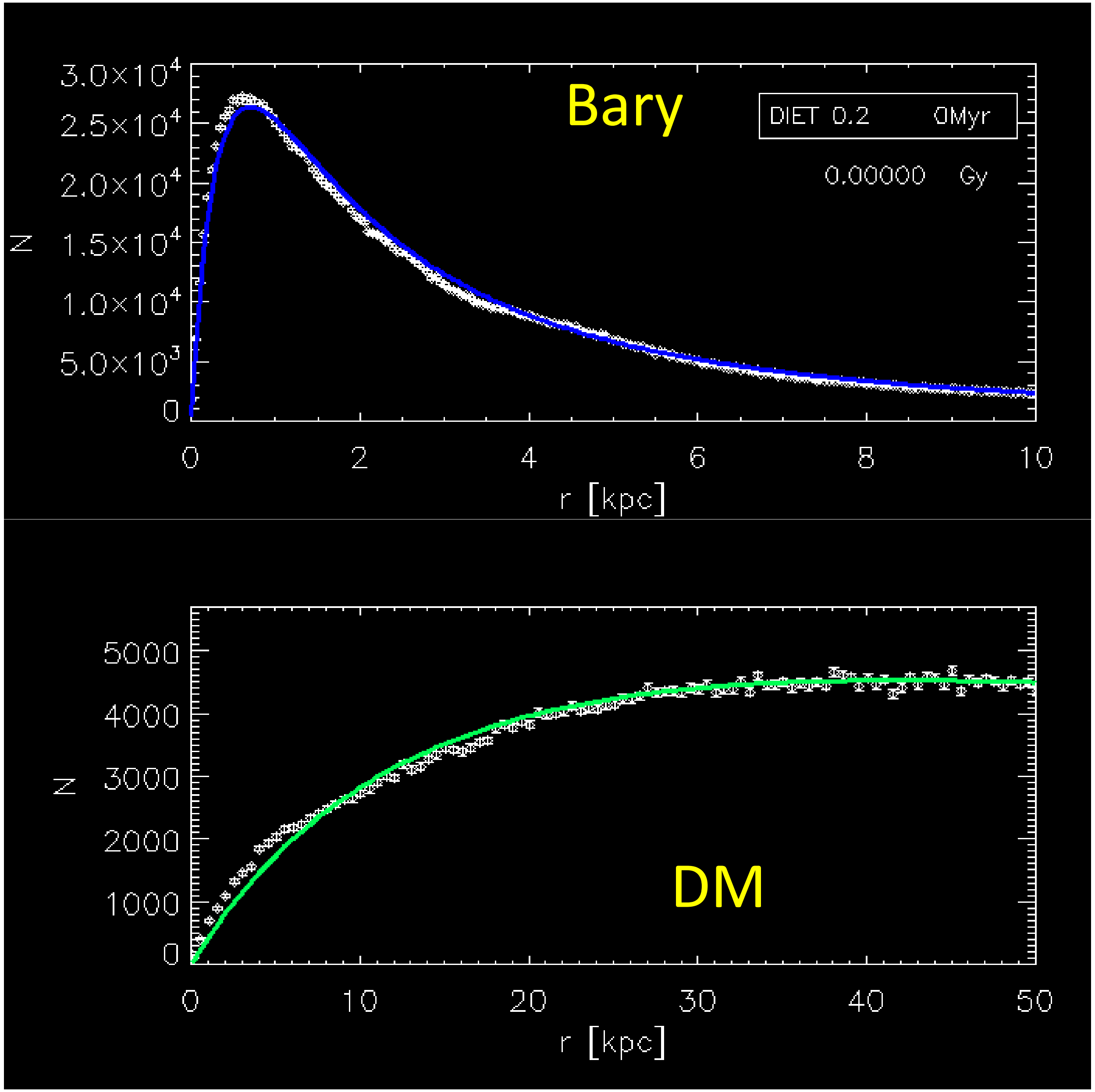
- In the fast regime, if (and only if) expulsion is "moderate" (ε > 0.5), after a transient very disturbed phase, baryons recover original functional form (Hernquist) , with larger scale –length: expansion;
- As for DM, baryon expansion drags to some level DM particles, thus the final profile is always flattened in the very inner region wrt NFW



Effects on density profiles - (ε < 0.5)

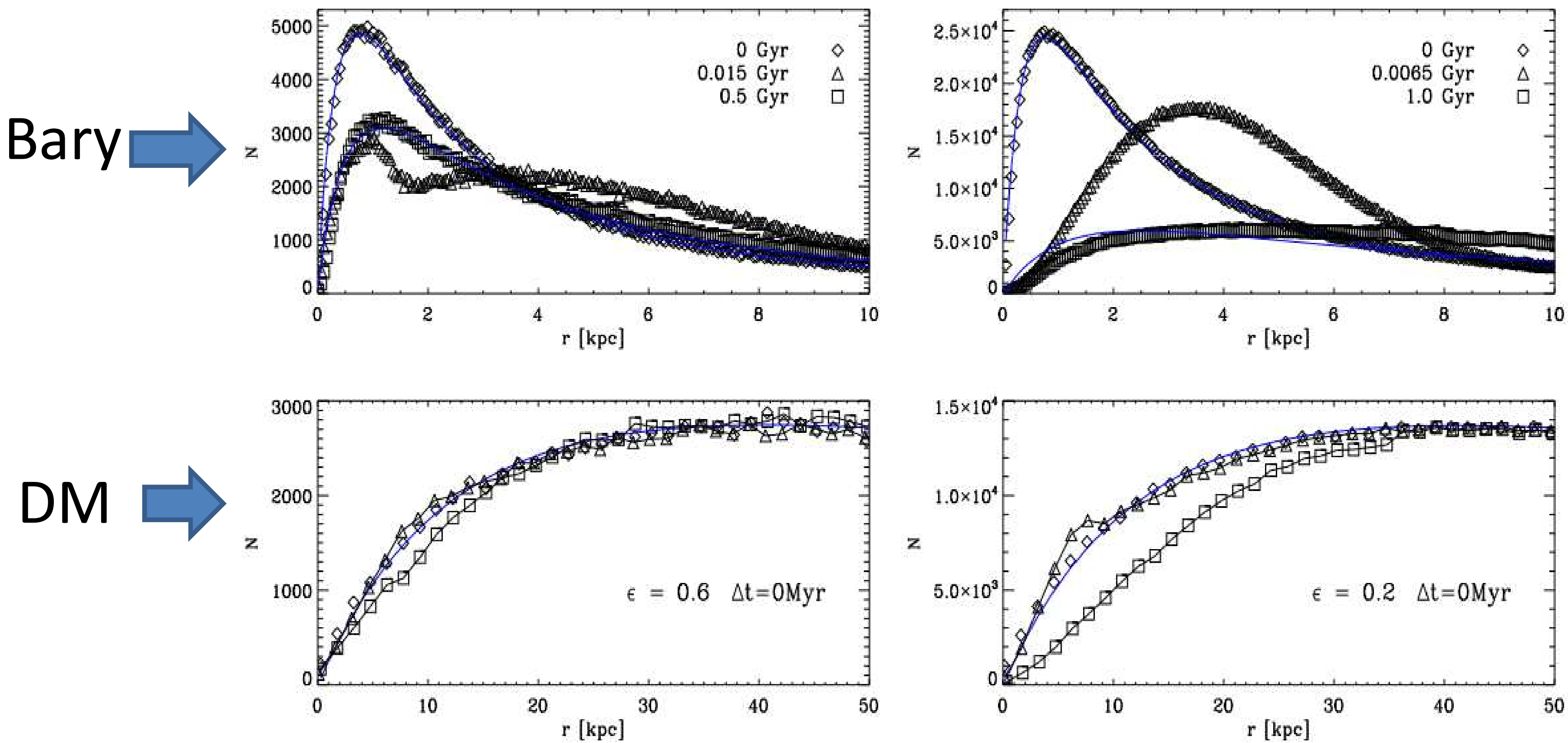
- if expelled fraction is dominating (ε < 0.5) baryons never recover original functional form (Hernquist)

- Dark Matter



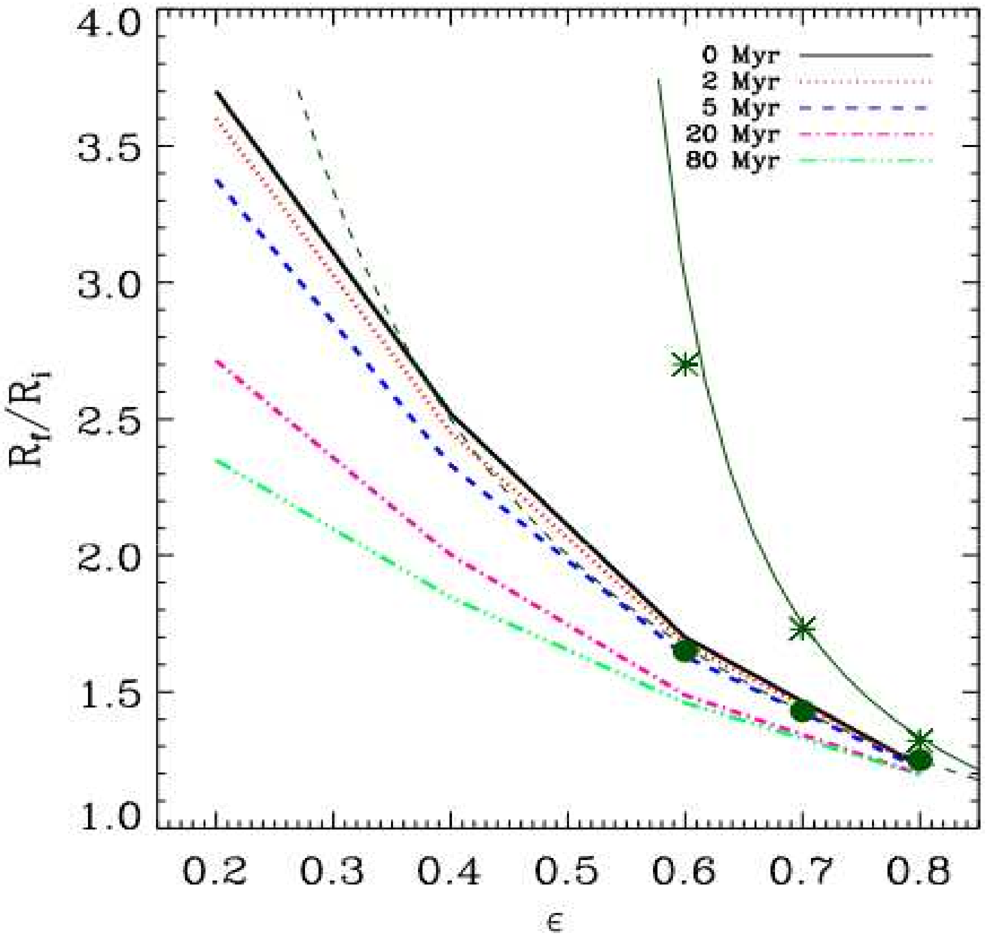
Effects on density profiles

- In the fast regime, if (and only if) expulsion is “moderate” ($\varepsilon > 0.5$), after a transient very disturbed phase, baryons recover original functional form (Hernquist) , albeit with larger scale –length;
- As for DM, baryon expansion drags to some level DM particles, thus the final profile is always flattened in the very inner region wrt NFW



The final expansion factor

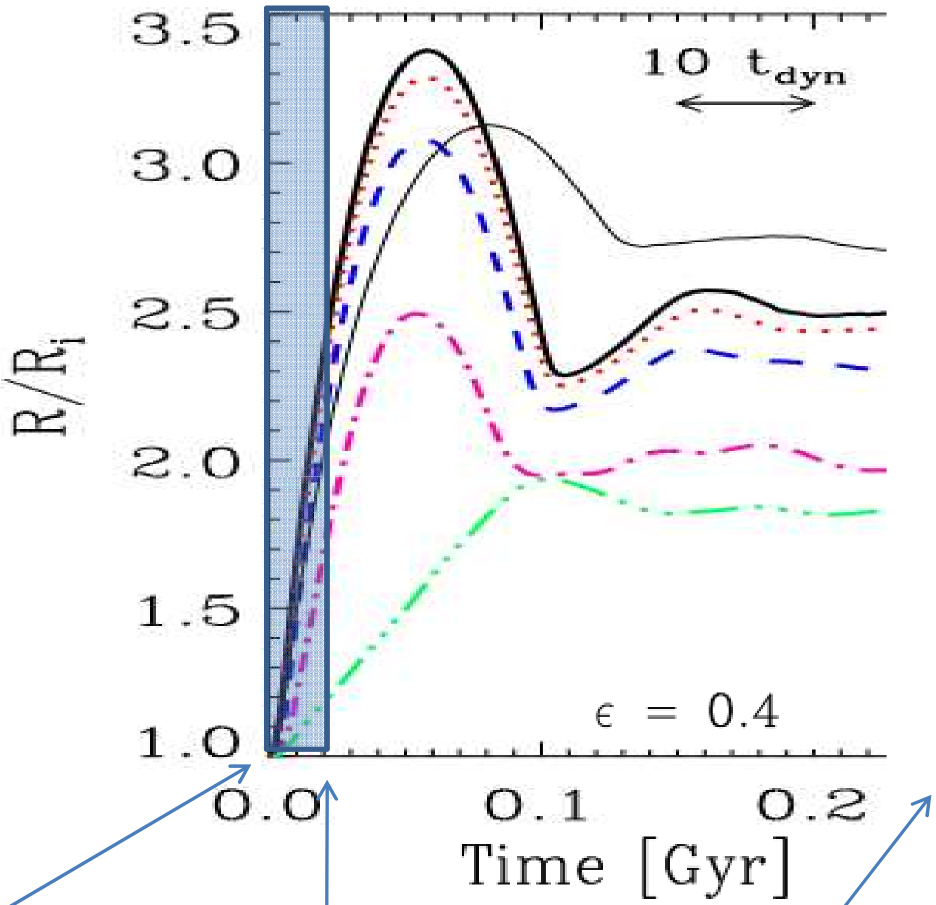
- Test runs without DM confirm previous findings
- DMH limits expansion and keeps bound the galaxy even if >80% of baryons are ejected
- slower expulsion $\Rightarrow$ less expansion
- Even with DMH included, conceivable to get "interesting" expansion factors $\sim$ 2-3
- Apparently ok to explain observed size evo, but….



M_{fin}/M_{ini}

Puffing up by galactic winds cannot explain the observed size evolution

- Expansion occurs during ~ 20 Myr after the end of star formation (a few t_{dyn})
- But high-z ETGs are observed still compact >0.5-1 Gyr after the end of star formation.
- If any, signatures of this process should be searched for in much younger systems



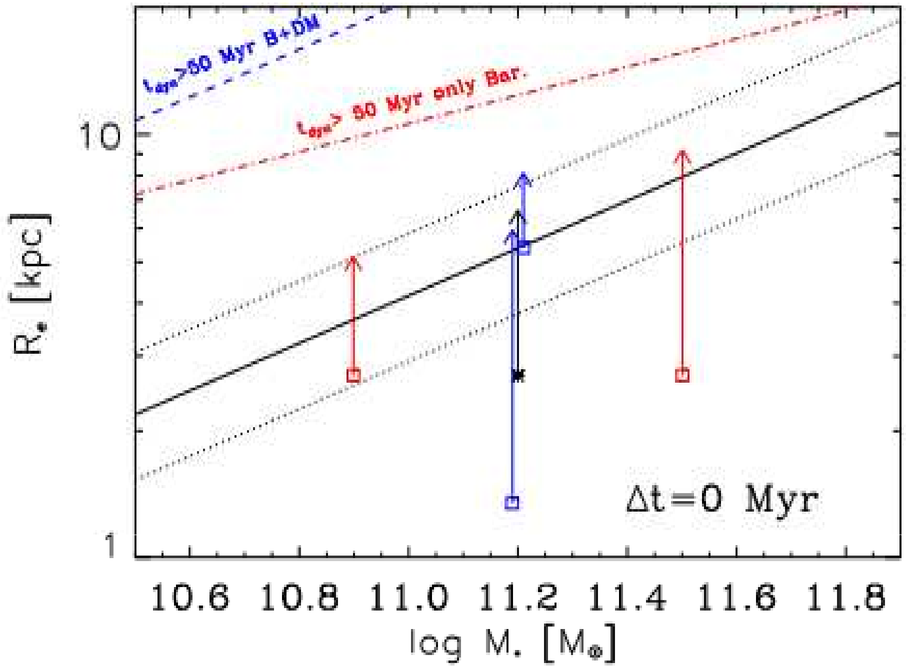
Residual gas expelled, Star formation stops

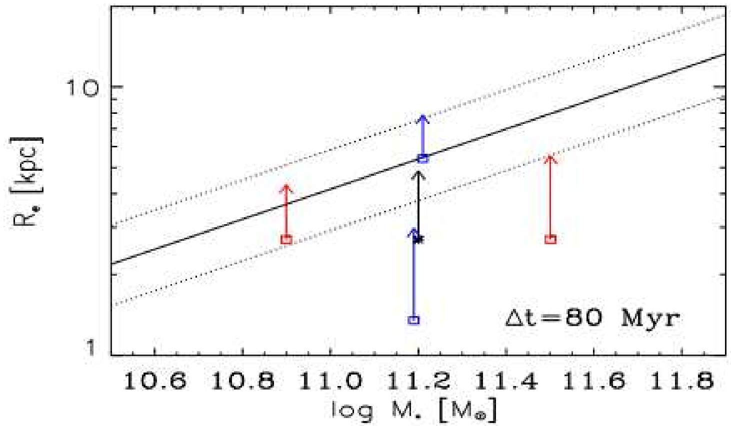
Final size reached (and transiently surpassed)

But high-z ETGs observed still compact

Variation of initial conditions

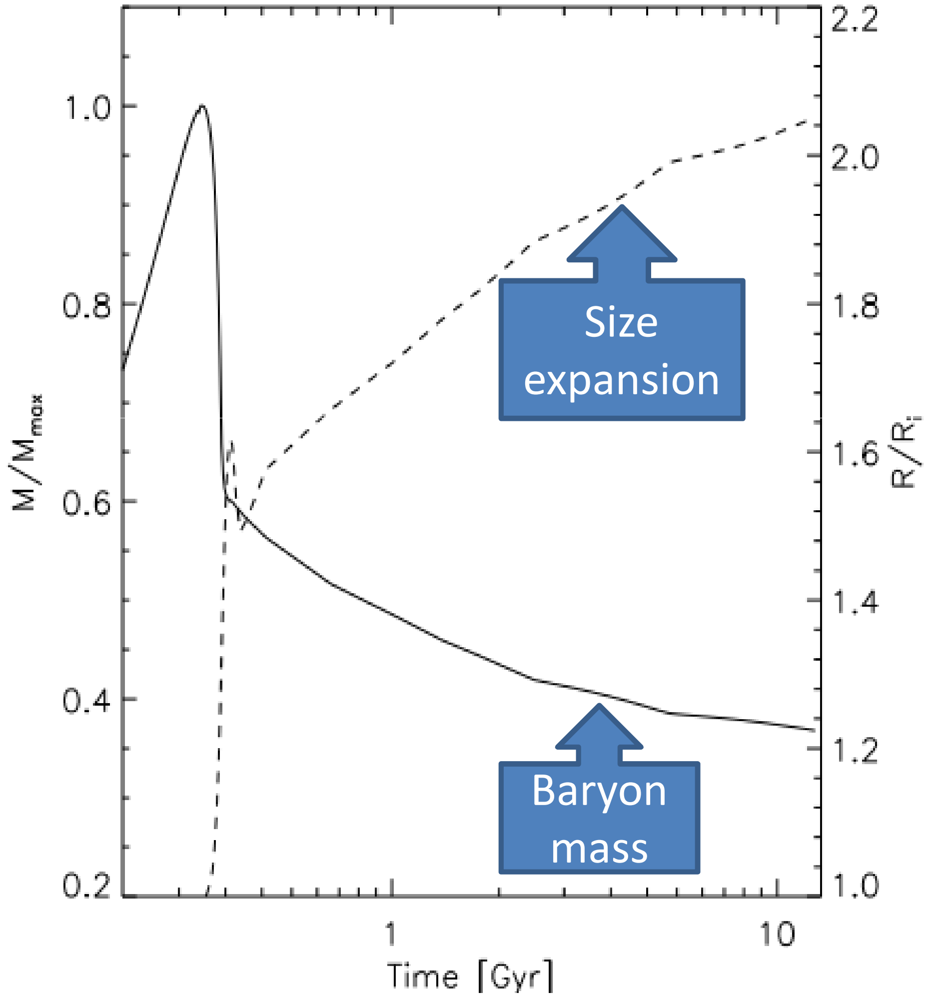
- •Suggestive trade-off between initial size and expansion factor ⇒ final state always quite close to local size-mass relationship
- •If we are to increase initial $t_{dyn} \propto R^{1.5} M^{-0.5}$ by a factor >10 (minimal requirement to match old stellar ages of compact high-z ETGs) initial state would already lie well above local relationship.





Size expansion for a specific SAM for SMBH-spheroid co-evolution, including AGN driven galactic wind and stellar evolution mass loss (Granato et al 2004)

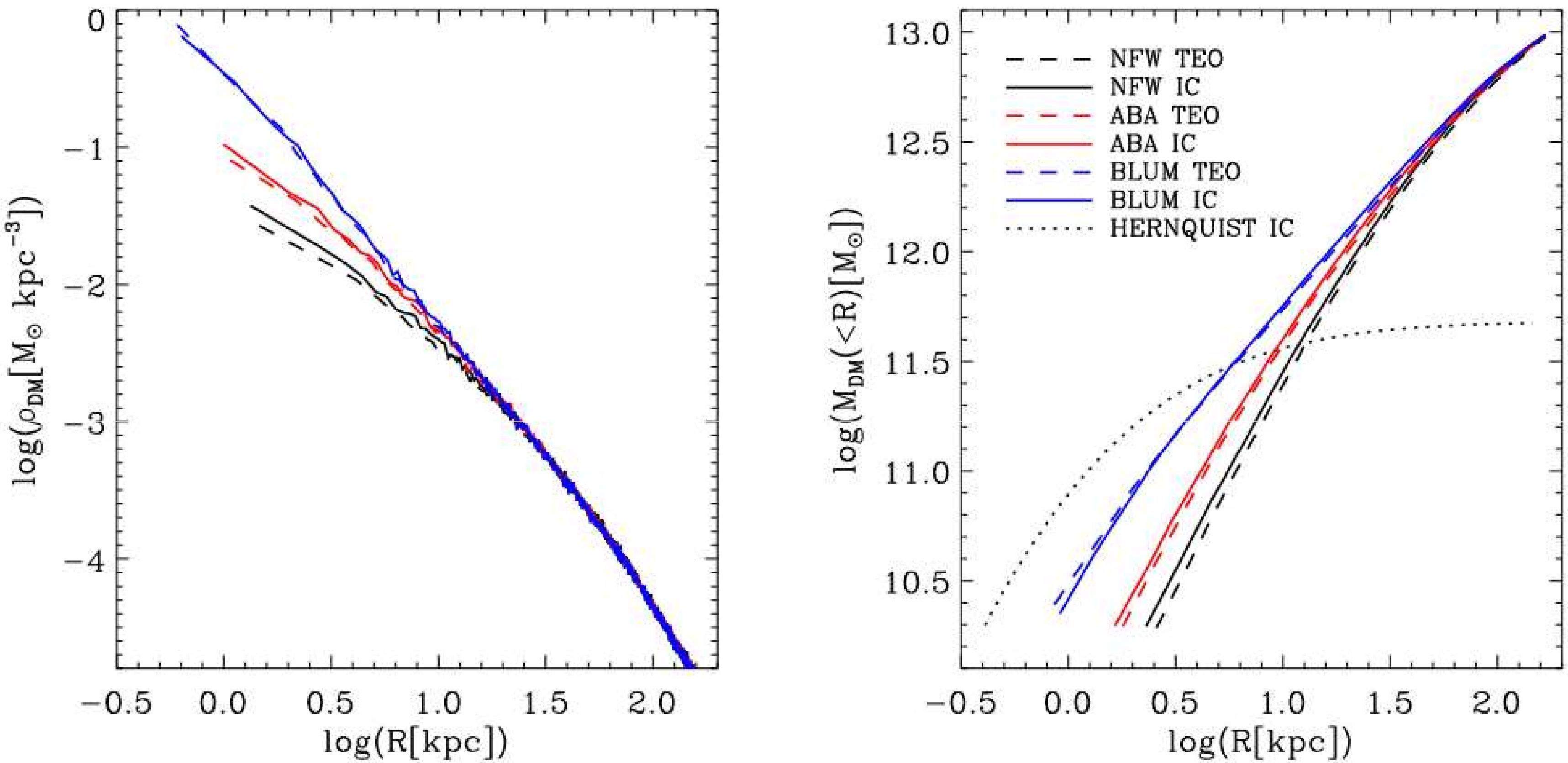
- Fast (30 Myr) expansion by a factor 1.6 just after SF termination due to galactic winds
- Further secular expansion by another 20-30%, due to gas given back to gas phase by stellar evo, assuming not retained. Here details depends on IMF, stellar lifetimes and yields.



DMHs in ellipticals: cuspy or cored?

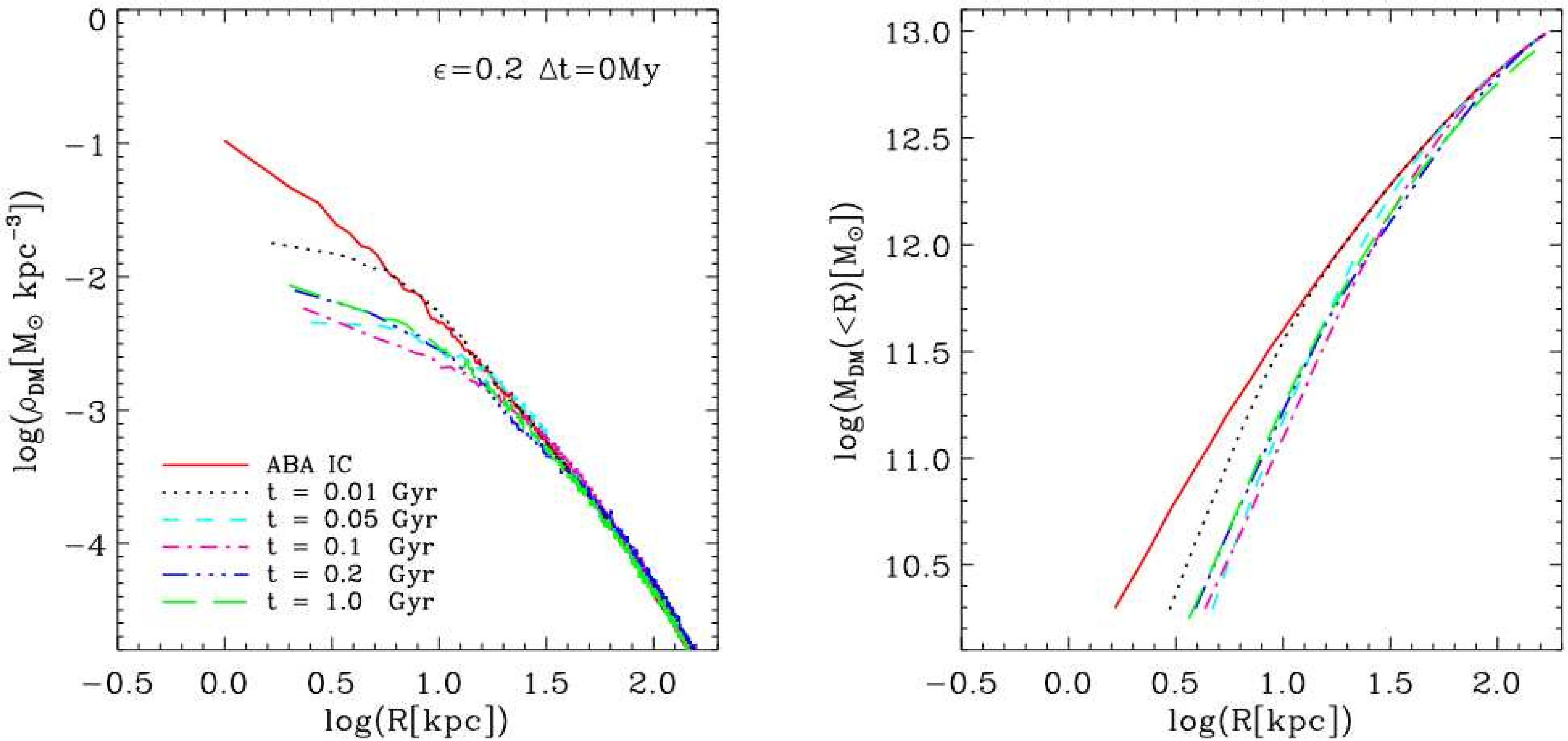
- A general prediction of cosmological, gravity only, simulations is that DM haloes should have cuspy density profiles, independently of the mass scale.
- At low to intermediate galactic scales (dwarfs, LSB, spirals) observations clearly tell us that the halos are instead cored.
- Mismatch attributed to backreaction of galaxy formation on DM, more than counteracting initial adiabatic contraction.
- At cluster scales it's unclear: since years, several claims for cores (e.g. Ricthler+ 2011) as well as for cusps (Zitrin+ 2011).
- In between, ie. at the largest galactic scales (ETGs), studies are in infancy. A few very recent claims for cusps (e.g. Tortora+ 2010, Sonnenfeld+ 2011) as well as for cores (e.g. Memola+ 2011)

What happens to DM profiles: IC



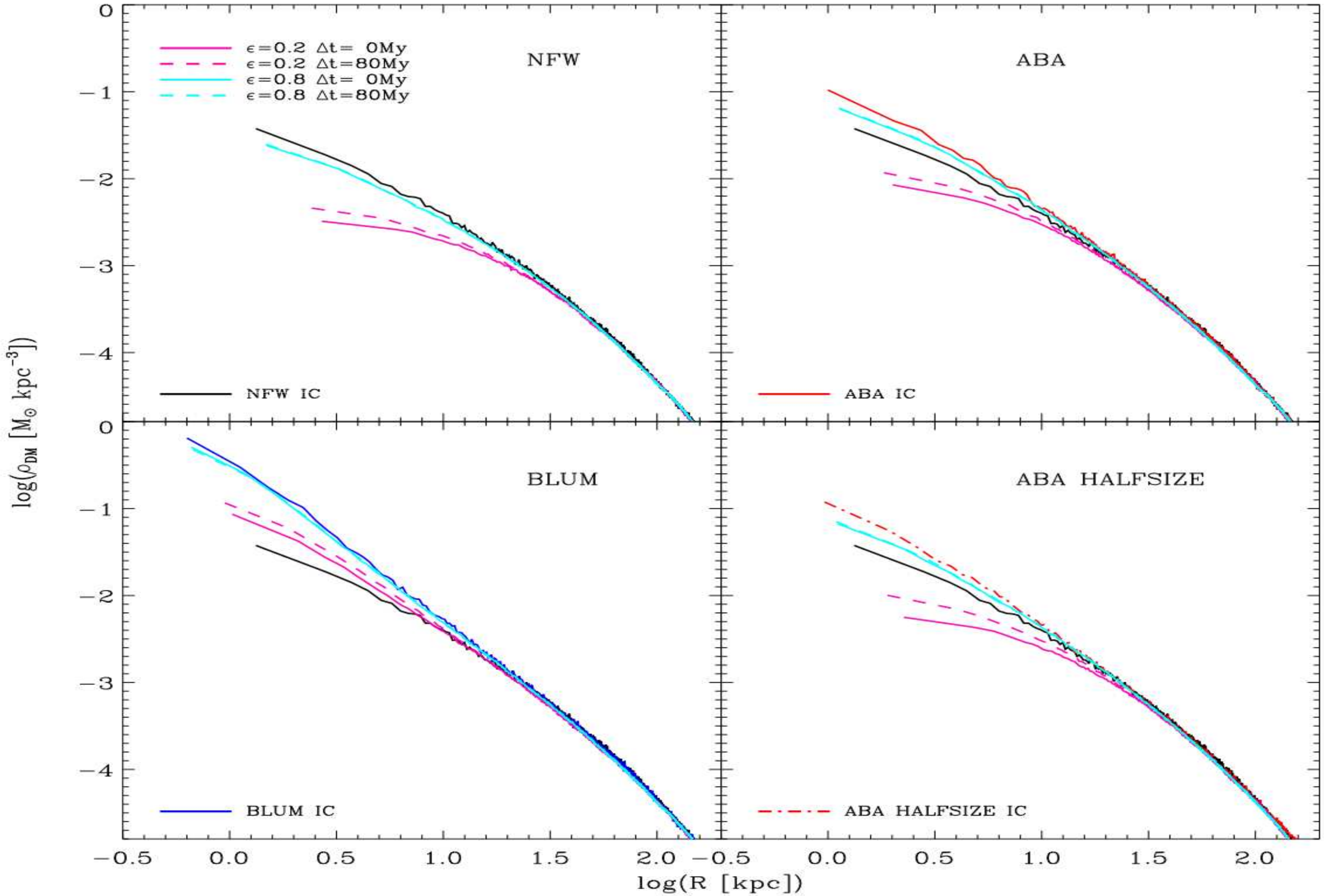
We run also from Initial Conditions (IC) including adiabatic contraction according to various prescriptions

Sample time evolution



A few tens of dynamical times after baryon mass loss, a new equilibrium is reached, characterized by sizeable flattening within the effective radius if expelled fraction is important

Dependence of final equilibrium on efficiency, timescale, and initial profile



- For realistic adiabatic contraction, the final DMH profile is predicted to be substantially flatter than NFW
- Claims for cuspy density profiles of DMH in ETGs could be difficult to reconcile with an effective AGN (or stellar) feedback during the evolution of these systems.

Summary

- Observed size evolution still unclear. Minor dry mergers could do part, but likely not all, of the job, particularly at z>1 (Newman et al 2011).
- But even puffing up due to galactic wind cannot explain size evolution of ETGs observed so far.
- Nevertheless, the process is likely to occur and have a role in deciding final morphology of ETGs. But signatures should be searched for in much younger systems.
- Puffing up due to stellar evolution mass loss may contribute, but not dominate, observed size evolution.
- Possible tension between the idea of important AGN feedback and claims of cuspy DMH density profiles in elliptical galaxies.
- In the future it could be of some interest:
  - to investigate in detail the moderate expansion due to passive evolution of stellar populations (e.g. dependence on IMF etc);
  - to evaluate how to catch in observations expansion due to galactic winds