EFFECT OF MERGERS ON THE SIZE EVOLUTION OF EARLY-TYPE GALAXIES

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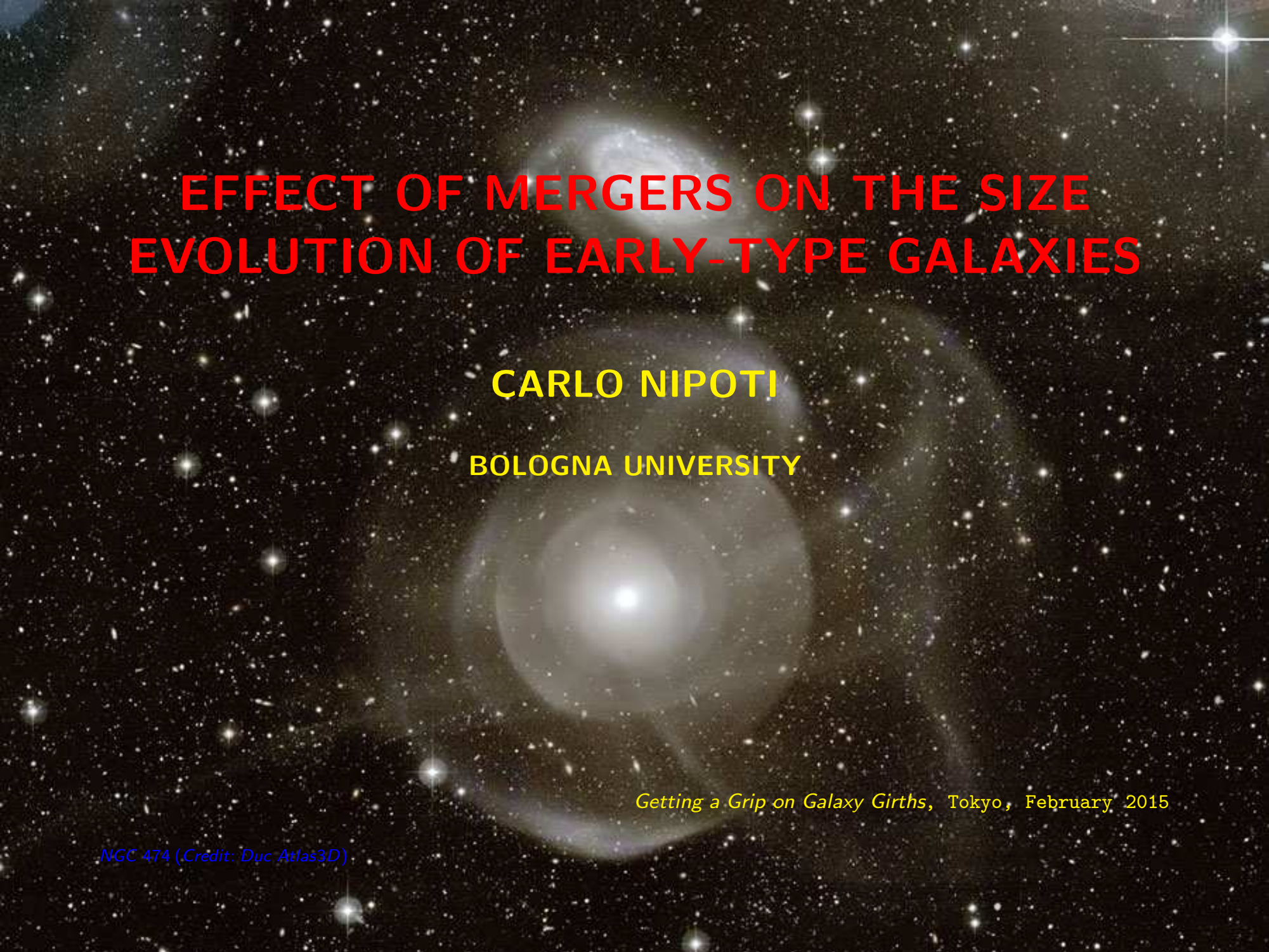
Getting a Grip on Galaxy Girths, Tokyo, February 2015



NGC 474 (*Credit: Duc Atlas3D*)

Dry and wet galaxy mergers

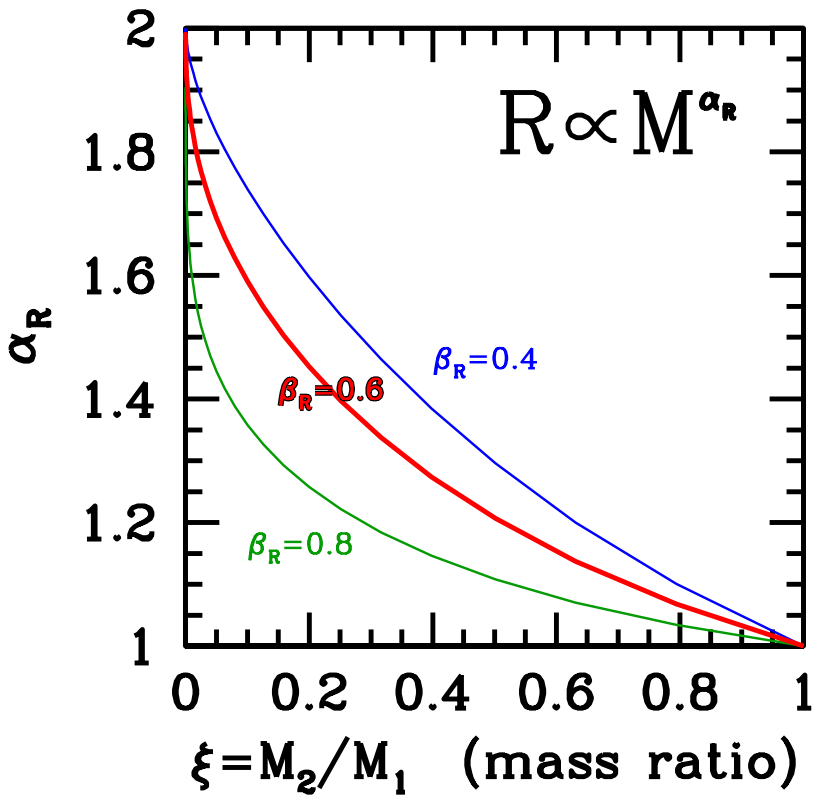
- → Dry = dissipationless, gas-poor, no star formation
- → Wet = dissipative, gas-rich, star formation
- → Mainly dry mergers for early-type galaxies (ETGs)

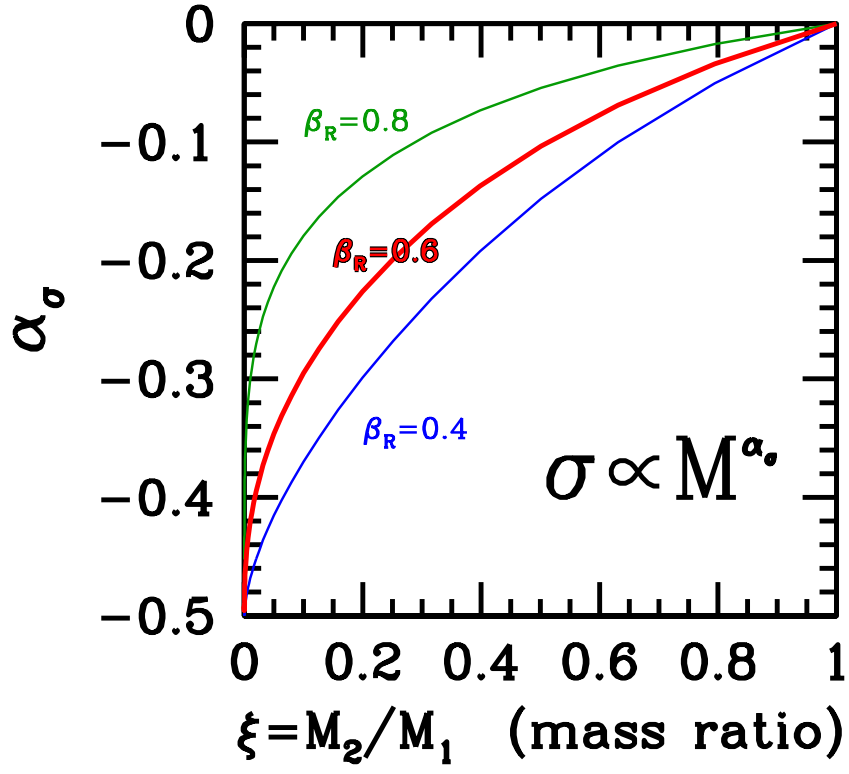
Dry mergers, size (R) and vel. disp. (σ): analytic

- $\rightarrow$ Virial theorem + energy conservation + parabolic
- $\rightarrow$ Galaxy masses: $M_2 \leq M_1$
- $\rightarrow$ $M_2 = M_1 \implies R \propto M,\ \sigma \propto const$
- $\rightarrow$ $M_2 \ll M_1 \implies R \propto M^2,\ \sigma \propto M^{-1/2}$
- $\rightarrow$ Effect is stronger for minor mergers

(Hausman & Ostriker 1978; Ciotti & van Albada 2001; Bezanson et al. 2009; Naab et al. 2009)

Dry mergers: role of mass ratio (analytic)





(Nipoti et al. 2012)

→ For mass ratio $\xi = M_2/M_1$: $R \propto M^{\alpha_R(\xi,\beta_R)}$, $\sigma \propto M^{\alpha_\sigma(\xi,\beta_R)}$

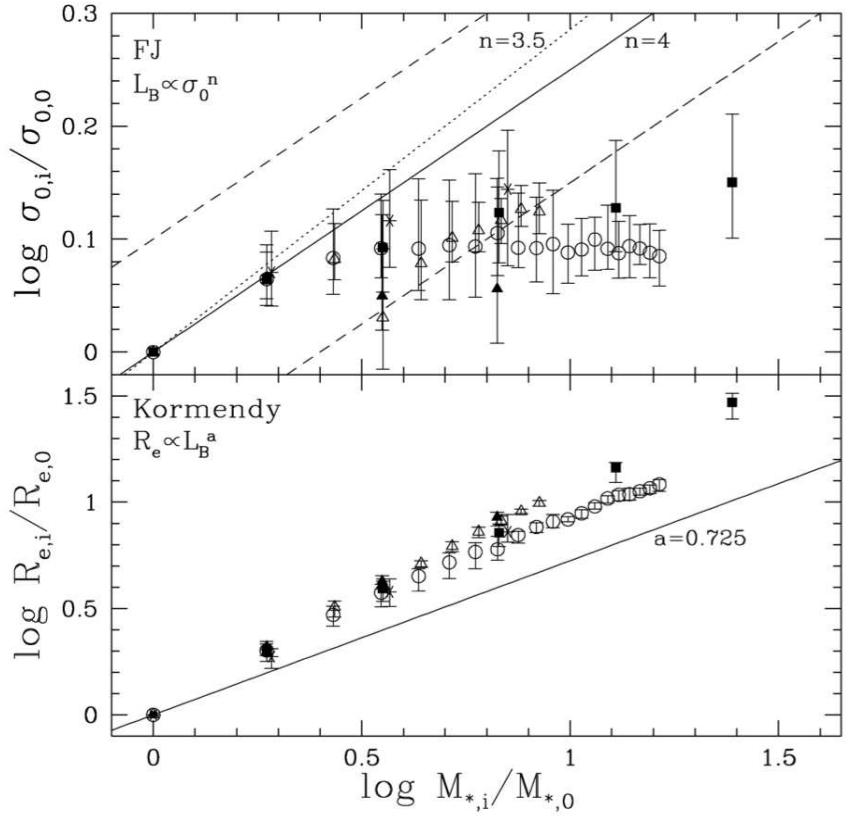
→ $\beta_R \approx 0.6$: slope of observed M_*-R_e relation ($R_e \propto M_*^{\beta_R}$)

Dry-merger simulations: R and σ

→ Parabolic orbits

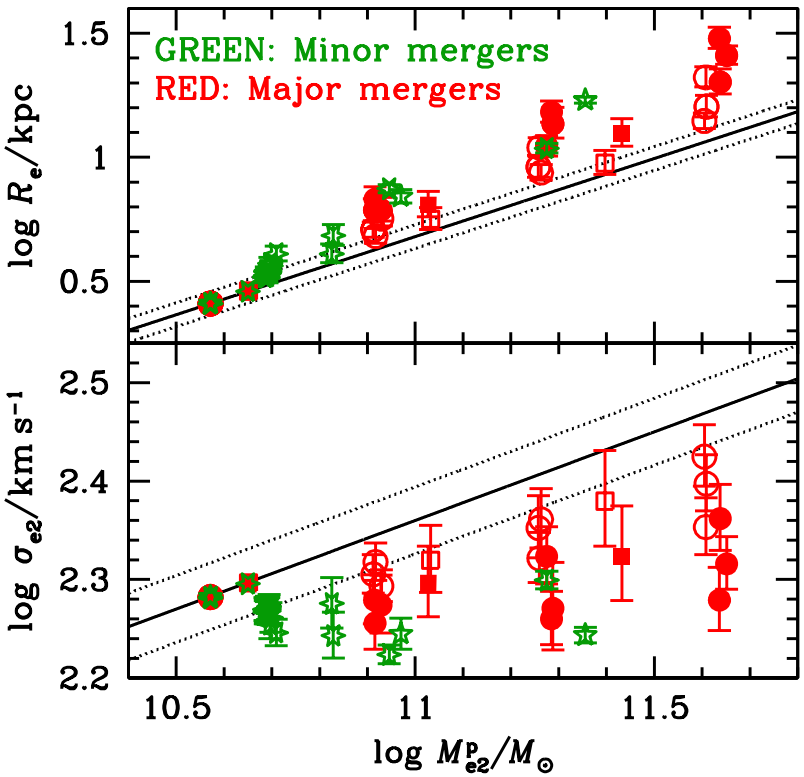
→ Mainly major mergers

→ Deviate from scaling laws



(Nipoti et al. 2003)

Dry-merger simulations: R and σ



(Nipoti et al. 2009, 2012)

→ Realistic galaxies (stars+halos)

→ Realistic orbits

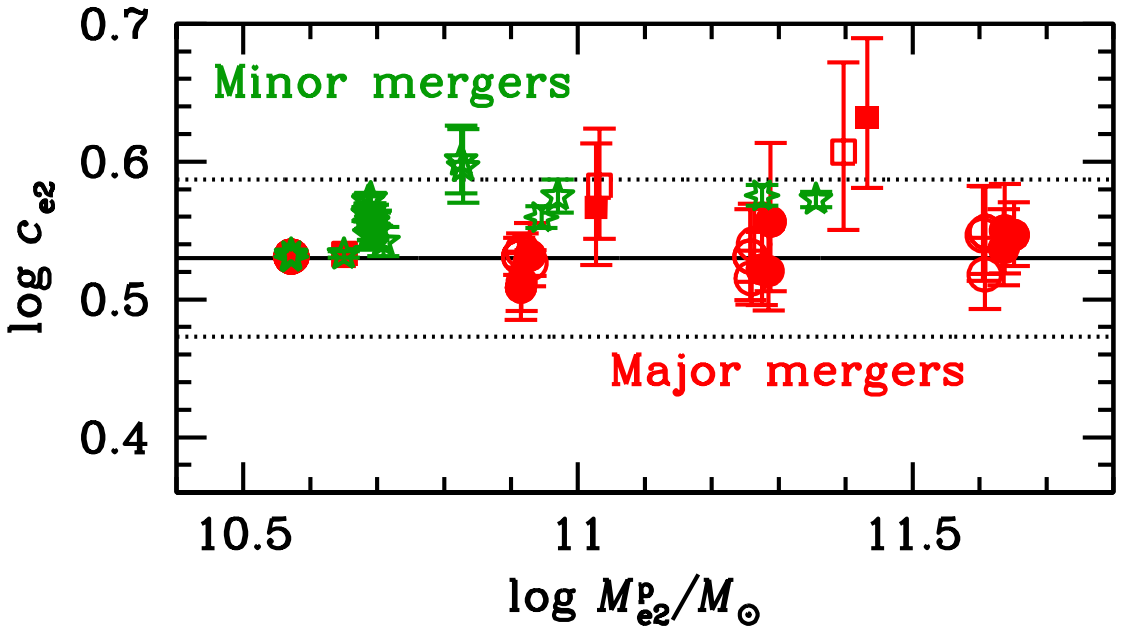
→ Minor and major

→ Deviate from scaling laws

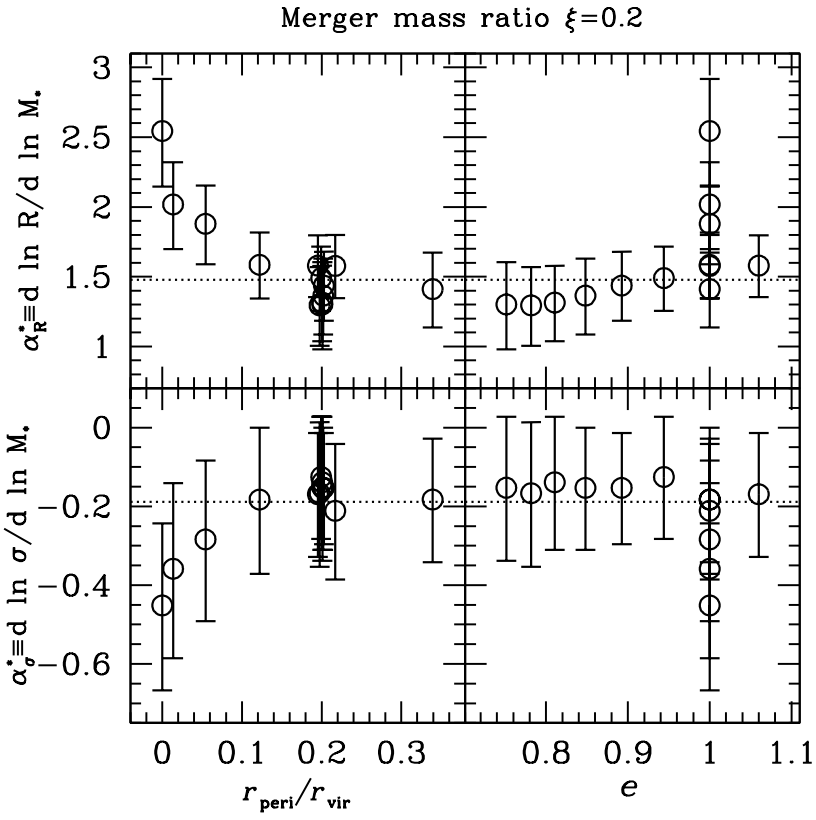
Dry-merging & fundamental plane: $c_{e2} = 2GM^p_{e2}/R_e\sigma^2_{e2}$

$\rightarrow$ FP more robust against dry merging

(Nipoti et al. 2009, 2012)



Effect of merger orbital parameters



(Nipoti et al. 2012)

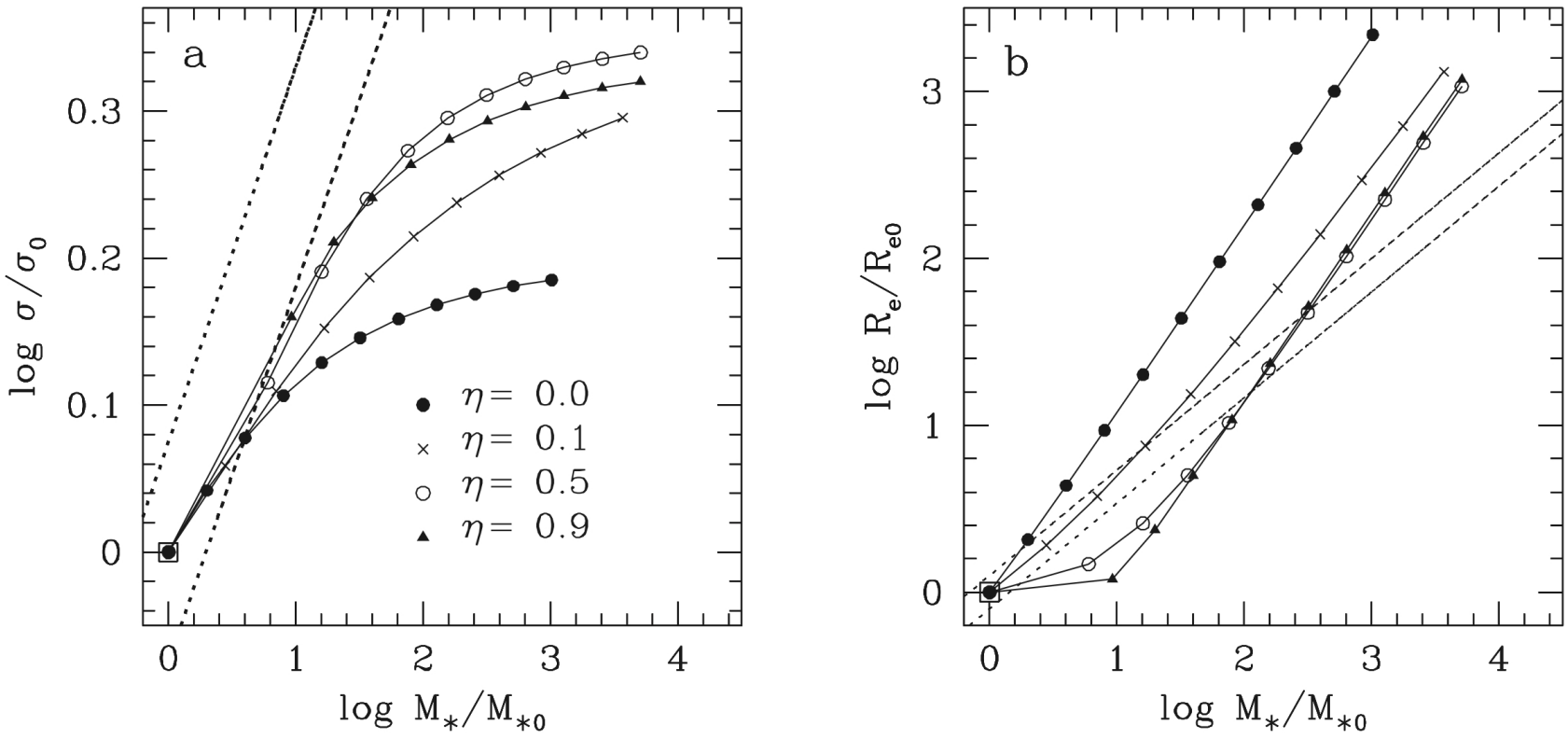
→ e: eccentricity

→ $r_{\rm peri}$: pericentric radius

→ Typically small effect

→ Larger R for head-on

Effect of dissipation (wet mergers): analytic



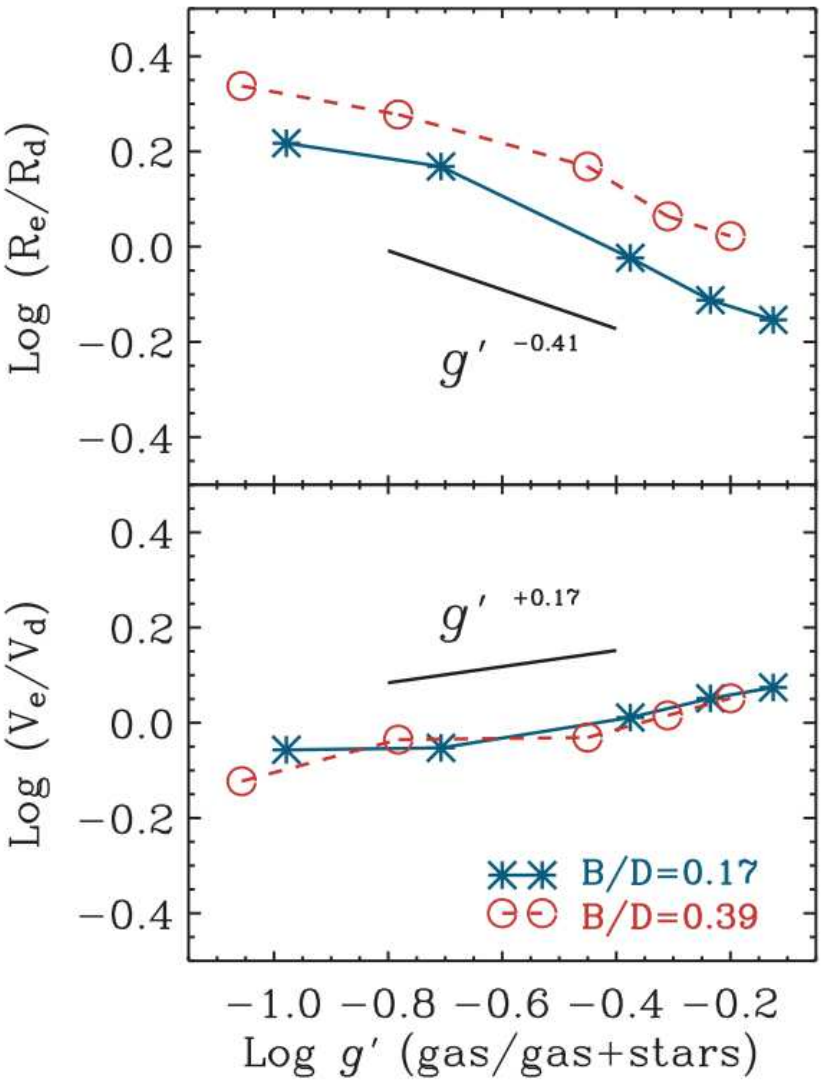
(Ciotti et al. 2007)

→ η: fraction of gas converted into stars

→ Size smaller for wet mergers

→ Velocity dispersion higher for wet mergers

Effect of dissipation (wet mergers simulations)



(Dekel & Cox 2006)

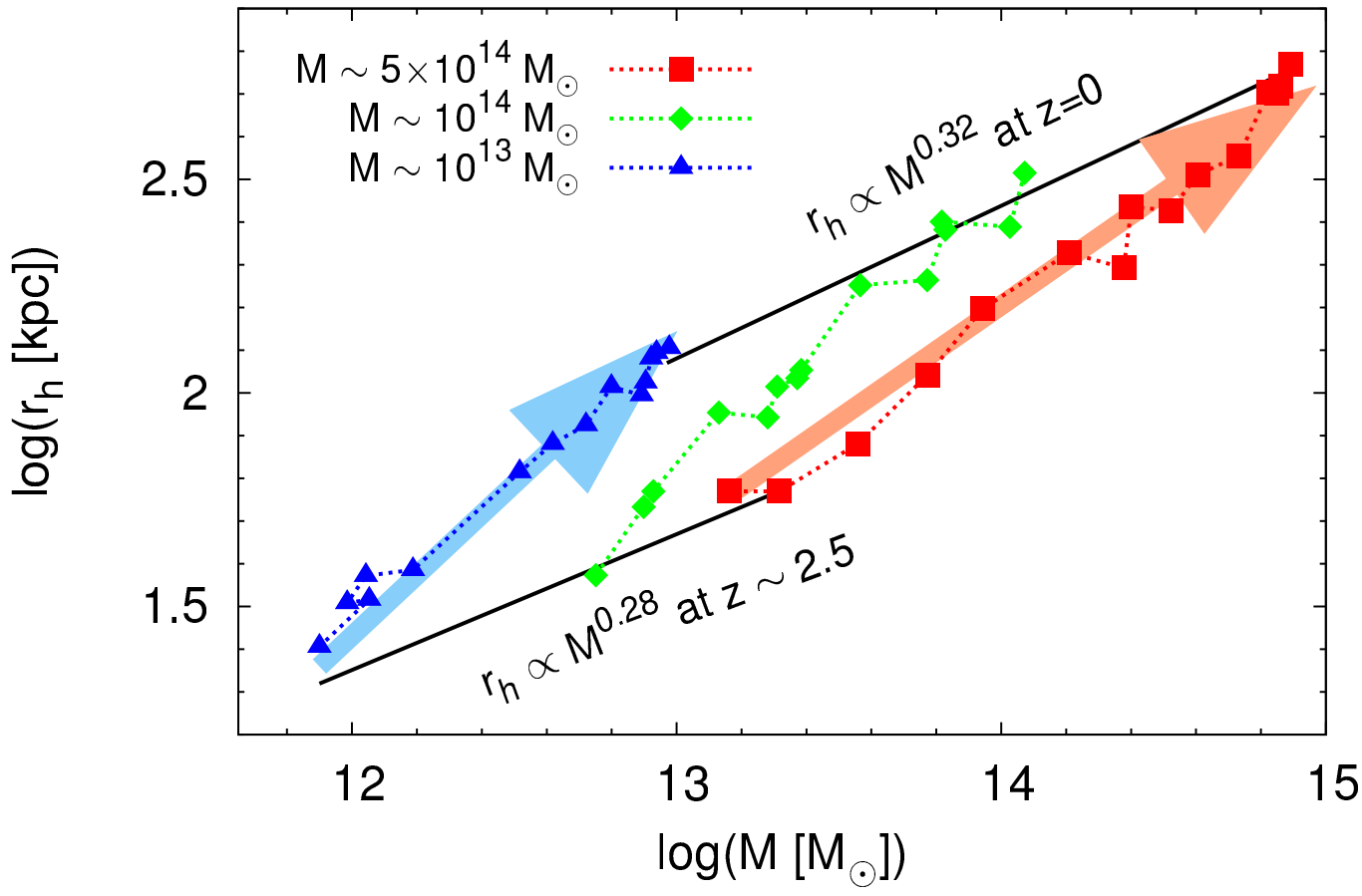
→ Hydro + N-body

→ Size smaller for wet mergers

→ Velocity dispersion higher for wet mergers

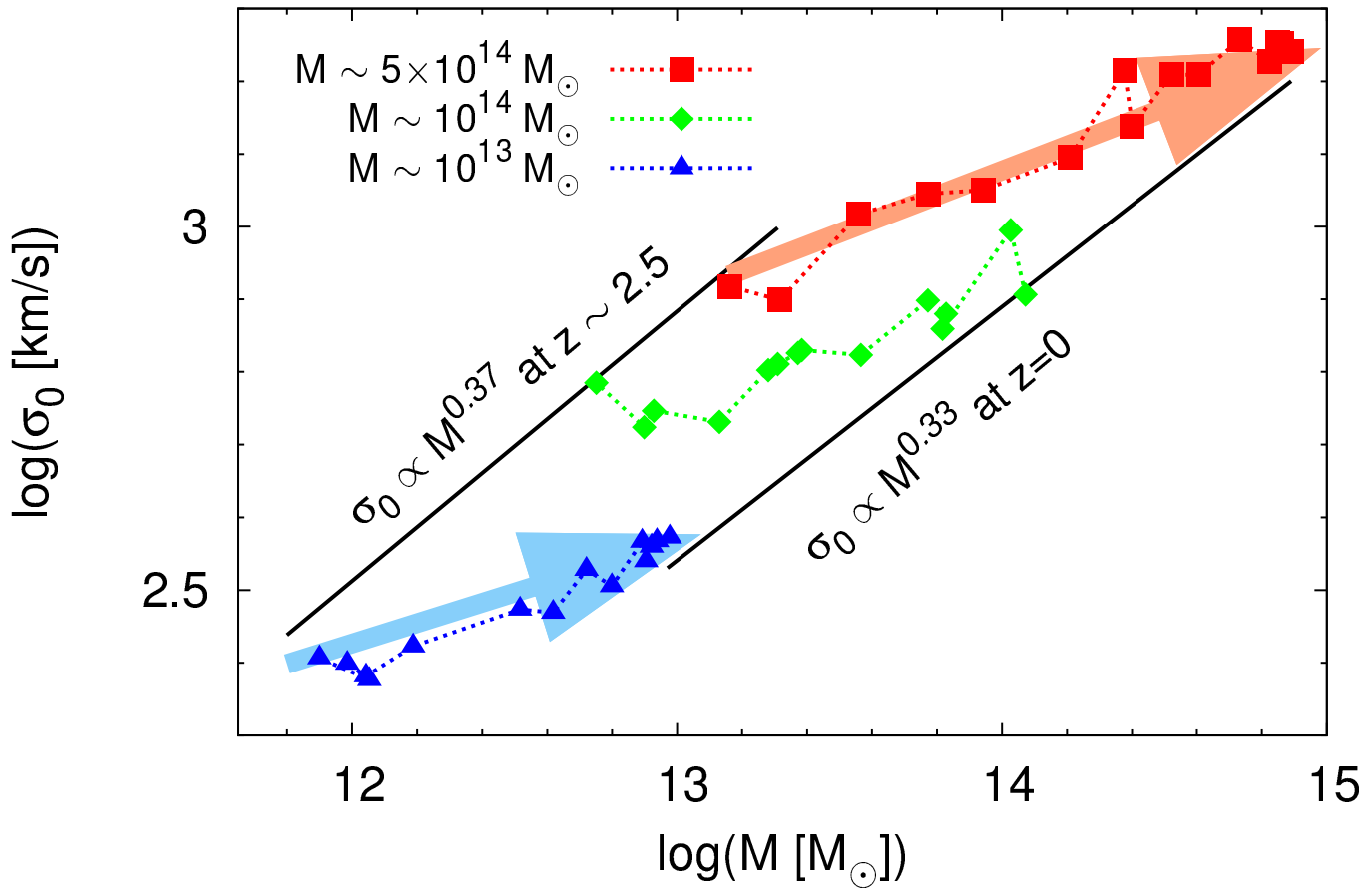
Cosmological evolution: halo size

LCDM DM-only simulation (Posti, Nipoti, Stiavelli & Ciotti 2014)



Cosmological evolution: halo velocity dispersion

LCDM DM-only simulation (Posti, Nipoti, Stiavelli & Ciotti 2014)



Cosmological evolution: galaxy R and σ

Two simple (complementary) models:

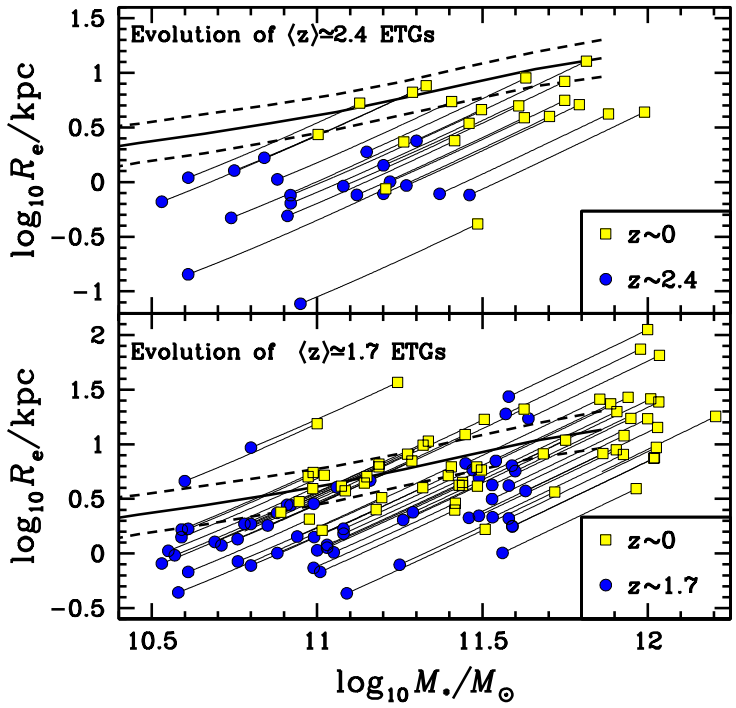
- Nipoti et al. (2012):
  - → Merger rate from Millenium
  - → R_{e} and σ from dry merger model

- Posti et al. (2014):
  - → Cosmological simulation
  - → $R_{\mathrm{e}} \propto r_{\mathrm{halo}}$
  - → $M_* = f(M_{\mathrm{halo}}, z)$ from abundance matching

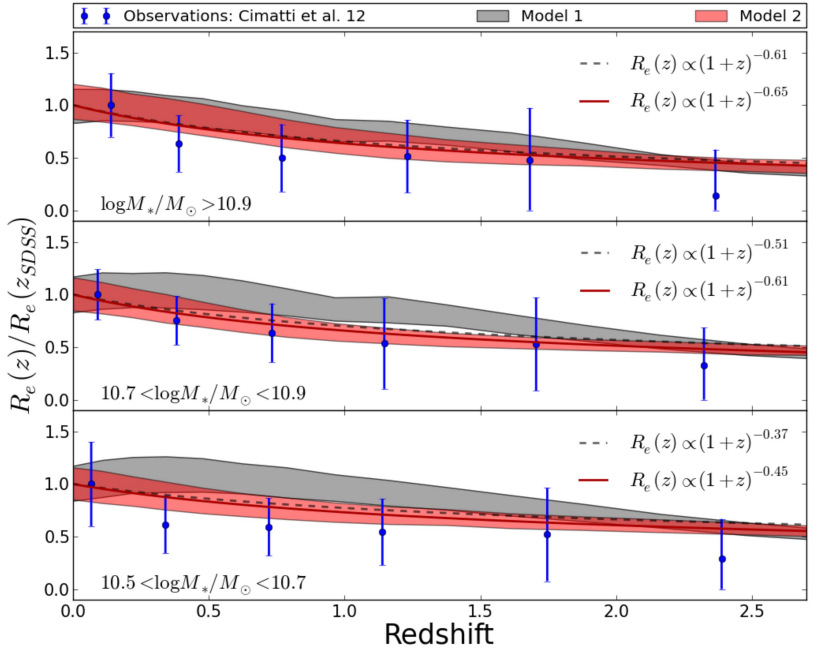
Size evolution of ETGs: LCDM vs. observations

Nipoti et al (2012)

Cimatti, Nipoti & Cassata (2012)



Posti et al. (2014)

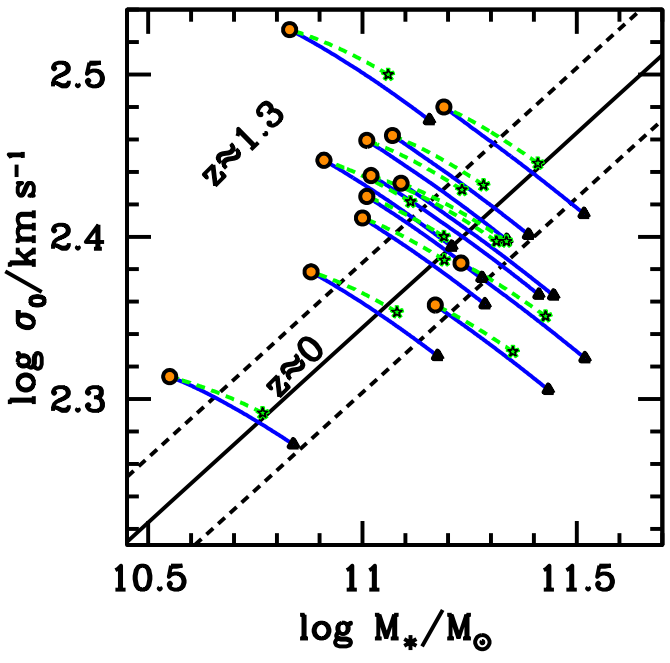


→ Observed $\approx$ predicted at $z \lesssim 2$

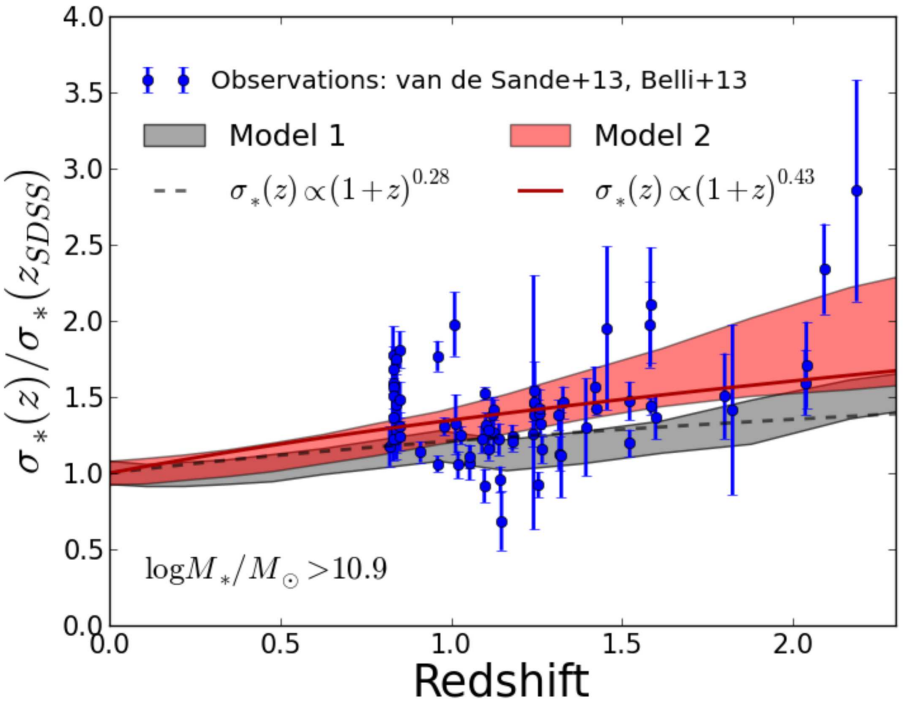
→ Observed evolution stronger than predicted by LCDM at $z \gtrsim 2$

σ evolution of ETGs: LCDM vs. observations

Nipoti et al. (2012)



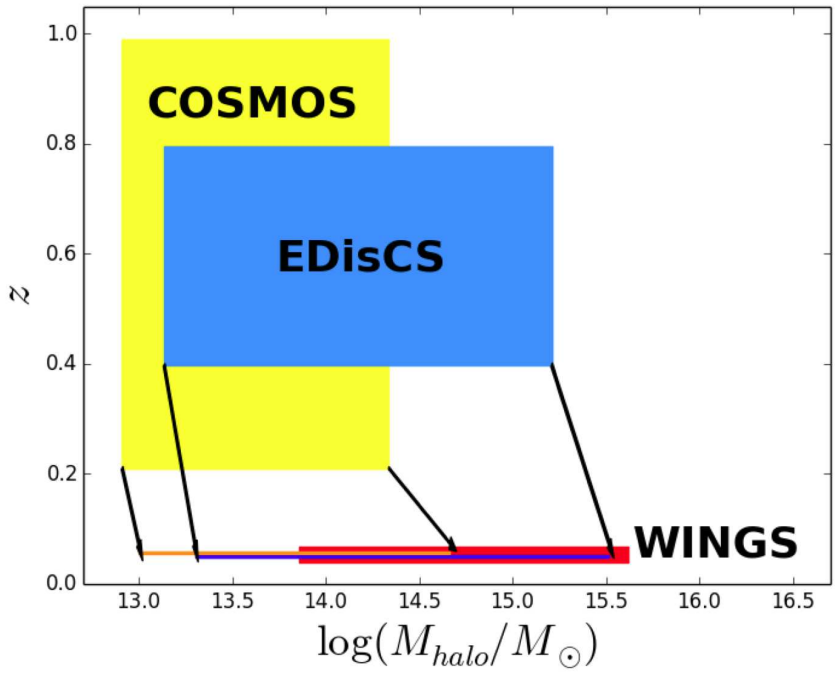
Posti et al. (2014)



→ LCDM predictions consistent with current observations

ETG size evolution & environment

Vulcani et al. (2014)



→ COSMOS groups at $z \approx 0.6$
(George+11)

→ EDisCS clusters at $z \approx 0.6$
(White+05)

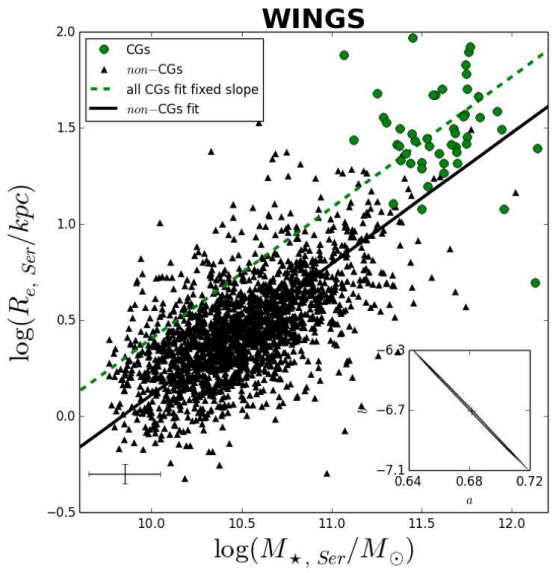
→ WINGS clusters at $z \approx 0$
(Fasano+06)

→ Galaxies evolve: $M_*(z)$, $R_e(z)$, $\sigma(z)$

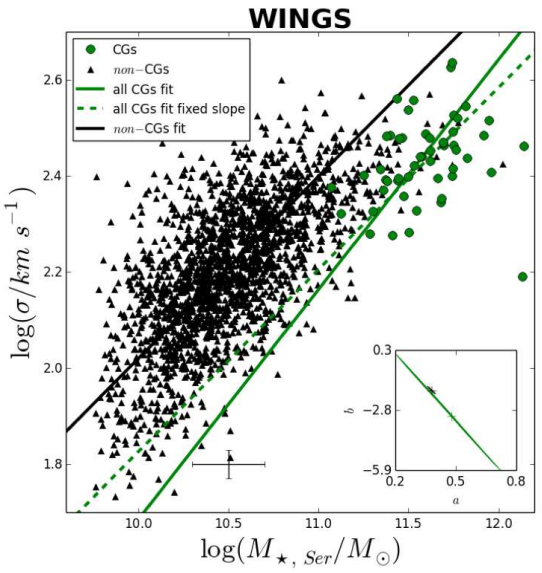
→ Environment evolves: $M_{\rm halo}(z)$ (group → cluster)

R_e-σ-M_*: centrals vs. satellites at $z \approx 0$

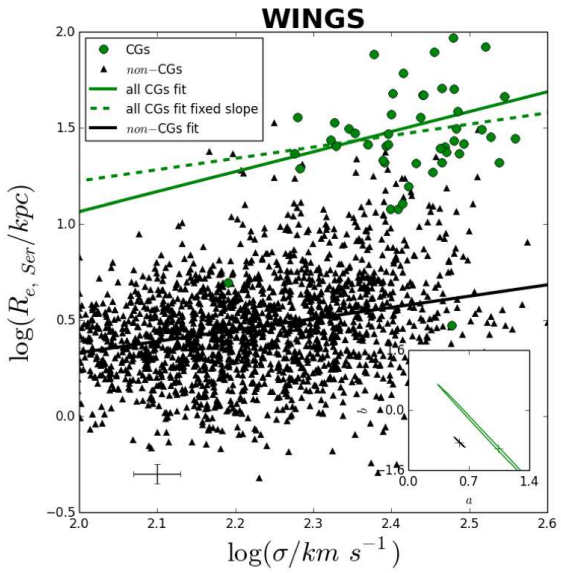
Vulcani et al. (2014)



R_e vs. M_*



σ vs. M_*



R_e vs. σ

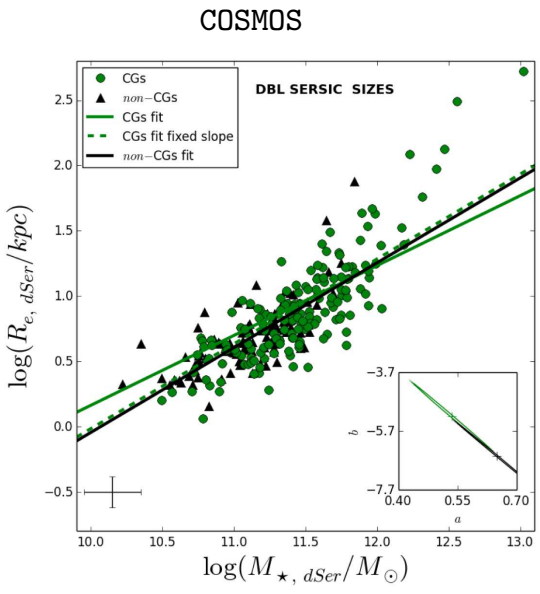
→ Observed clusters at $z \approx 0$ (WINGS)

→ Large offset between centrals and satellites

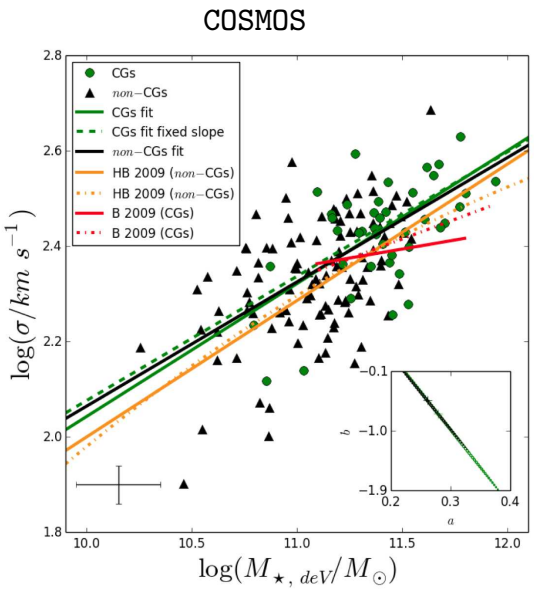
see also Lauer+07, Bernardi 09, Hyde & Bernardi 09, Valentinuzzi+10

R_e-σ-M_*: centrals vs. satellites at $z \approx 0.6$

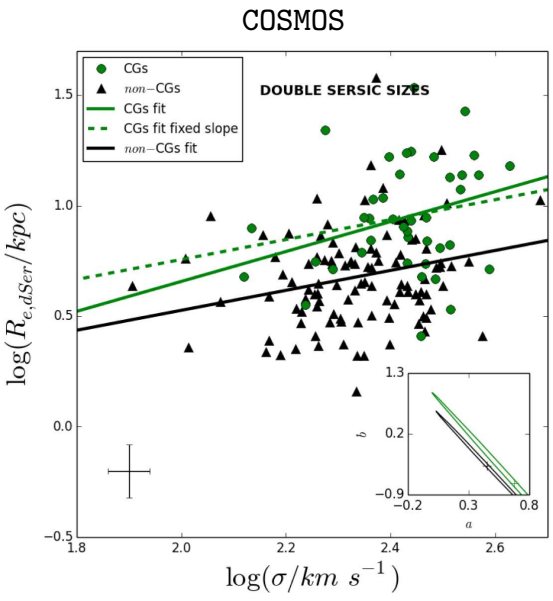
Vulcani et al. (2014)



R_e vs. M_*



σ vs. M_*

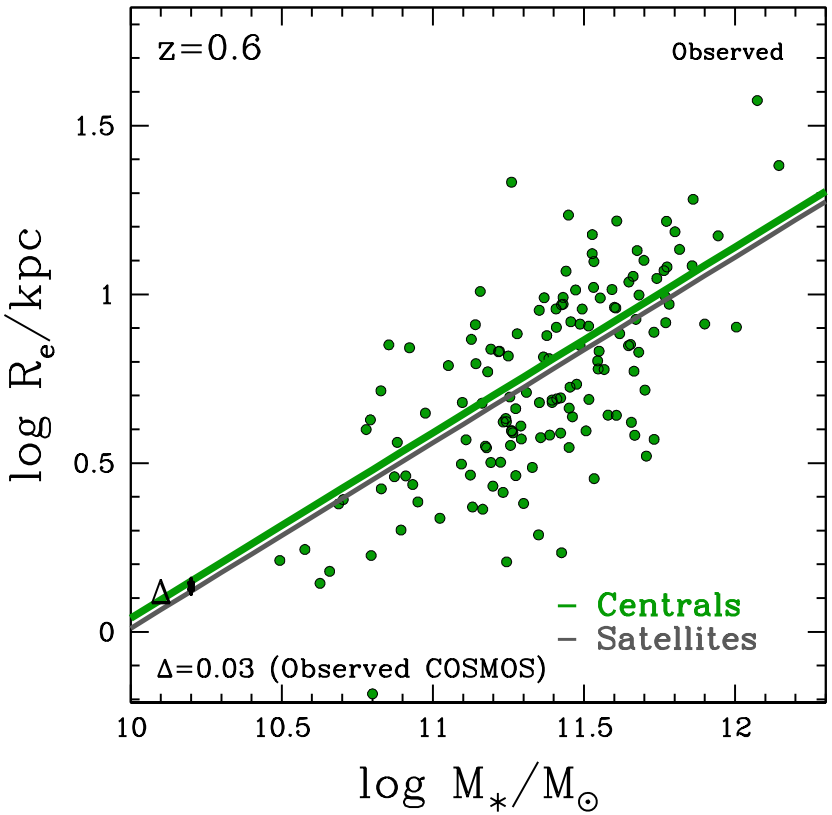


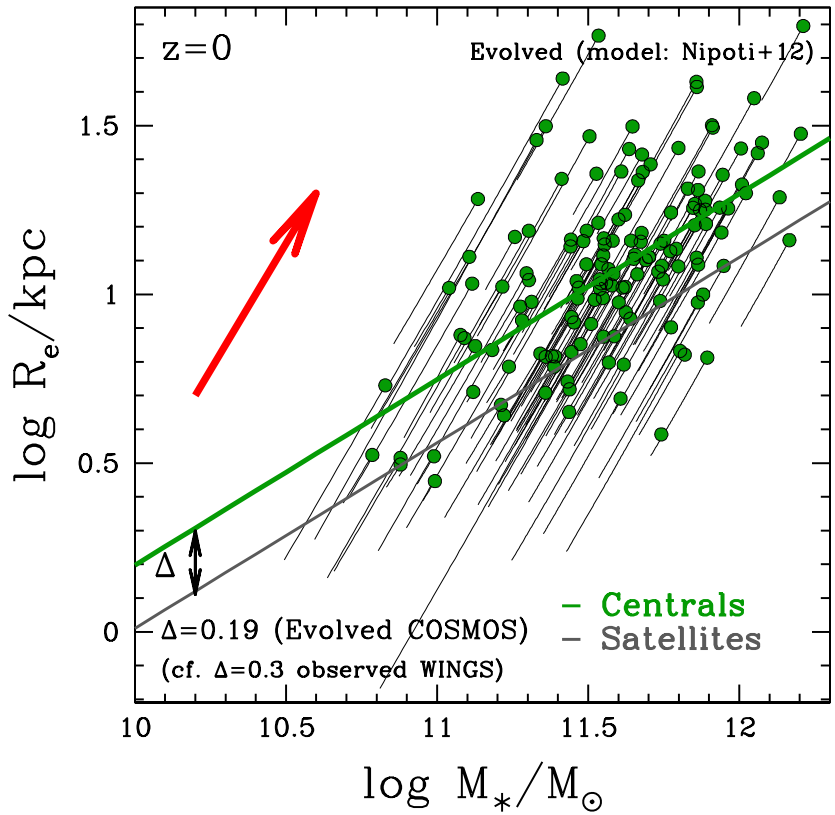
R_e vs. σ

→ Observed groups at $z \approx 0.6$ (COSMOS)

→ No (or small) offset between centrals and satellites

Modeling evolution of group ETGs: R_e-M_*

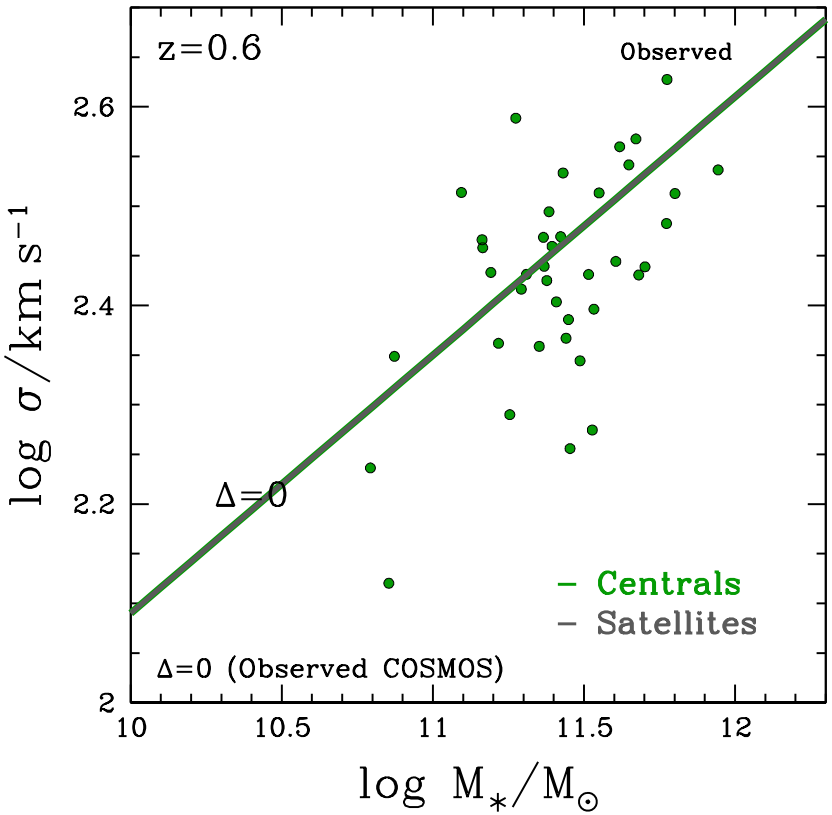


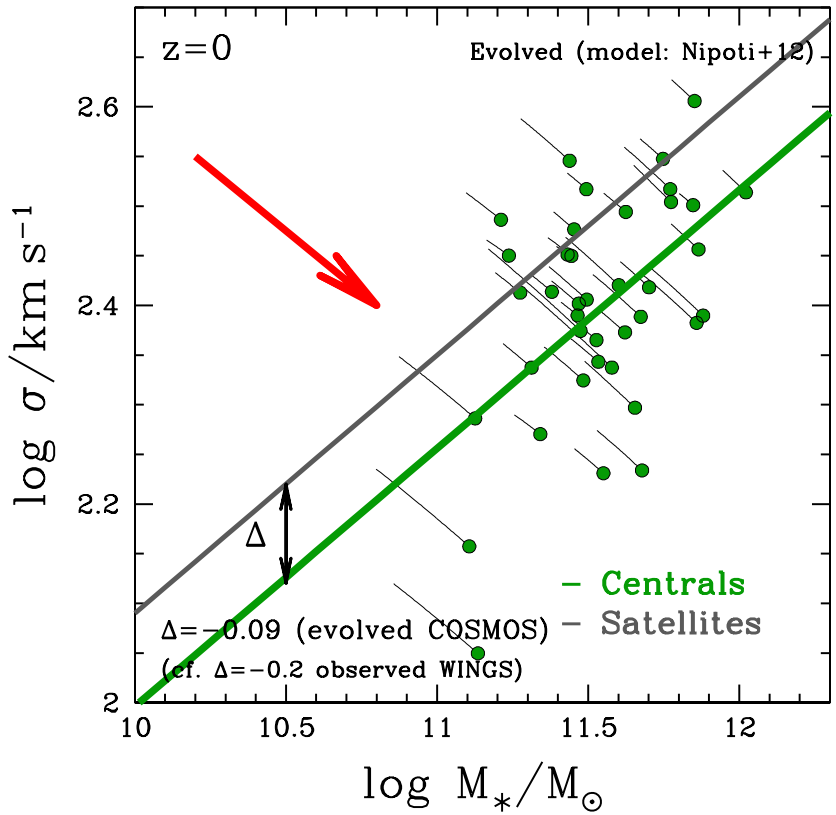


→ Predicted $z \approx 0$ offset smaller than observed in WINGS

→ Initial conditions: COSMOS data (Vulcani+14)
→ Evolution of centrals: LCDM+dry mergers (Nipoti+12)
→ No evolution of satellites

Modeling evolution of group ETGs: σ-M_*





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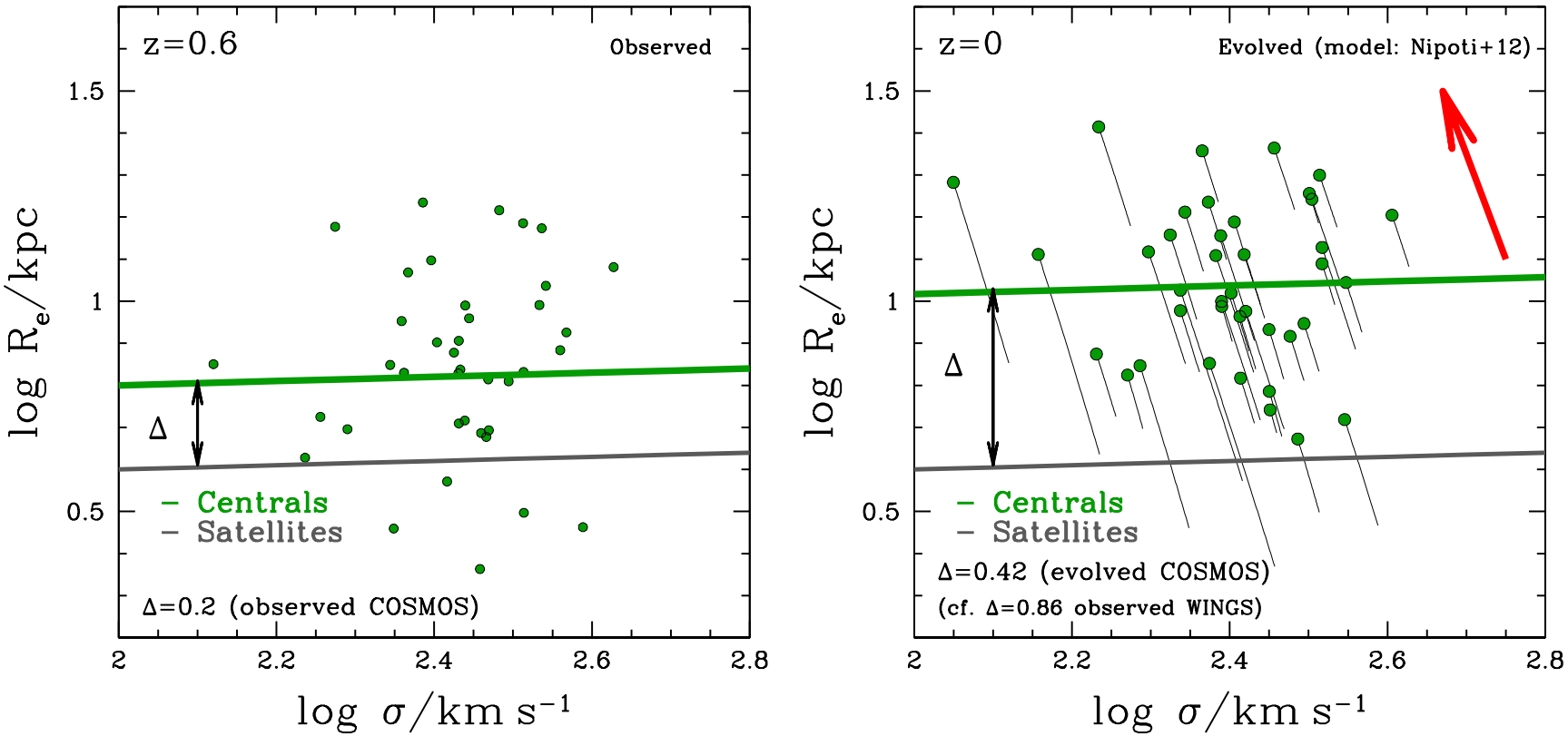
Modeling evolution of group ETGs: R_e-σ

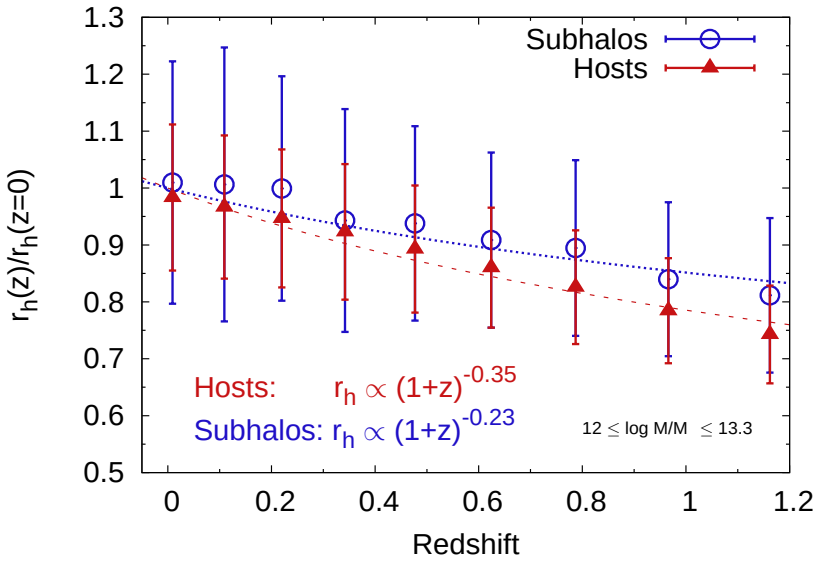


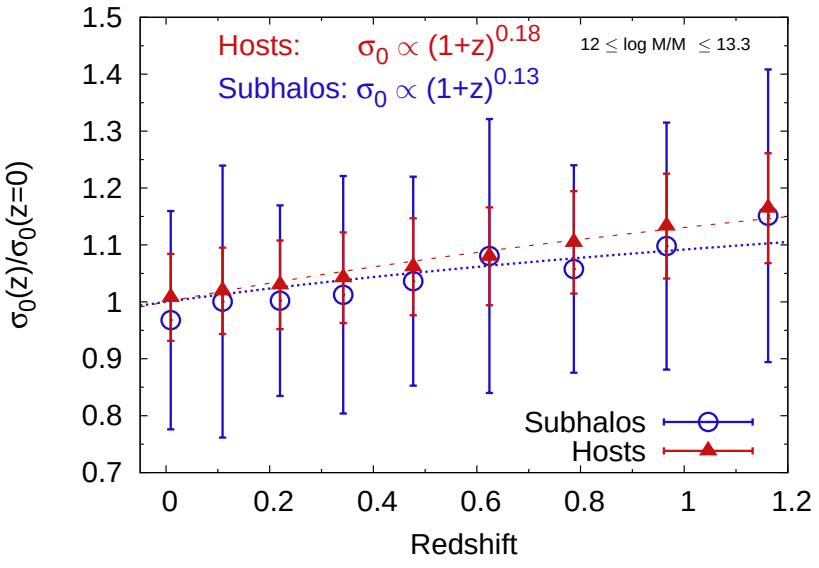
→ Predicted $z \approx 0$ offset smaller than observed in WINGS

→ Initial conditions: COSMOS data (Vulcani+14)
→ Evolution of centrals: LCDM+dry mergers (Nipoti+12)
→ No evolution of satellites

Evolution of halos: hosts vs. subhalos

Cosmological simulation of Posti et al. (2014)



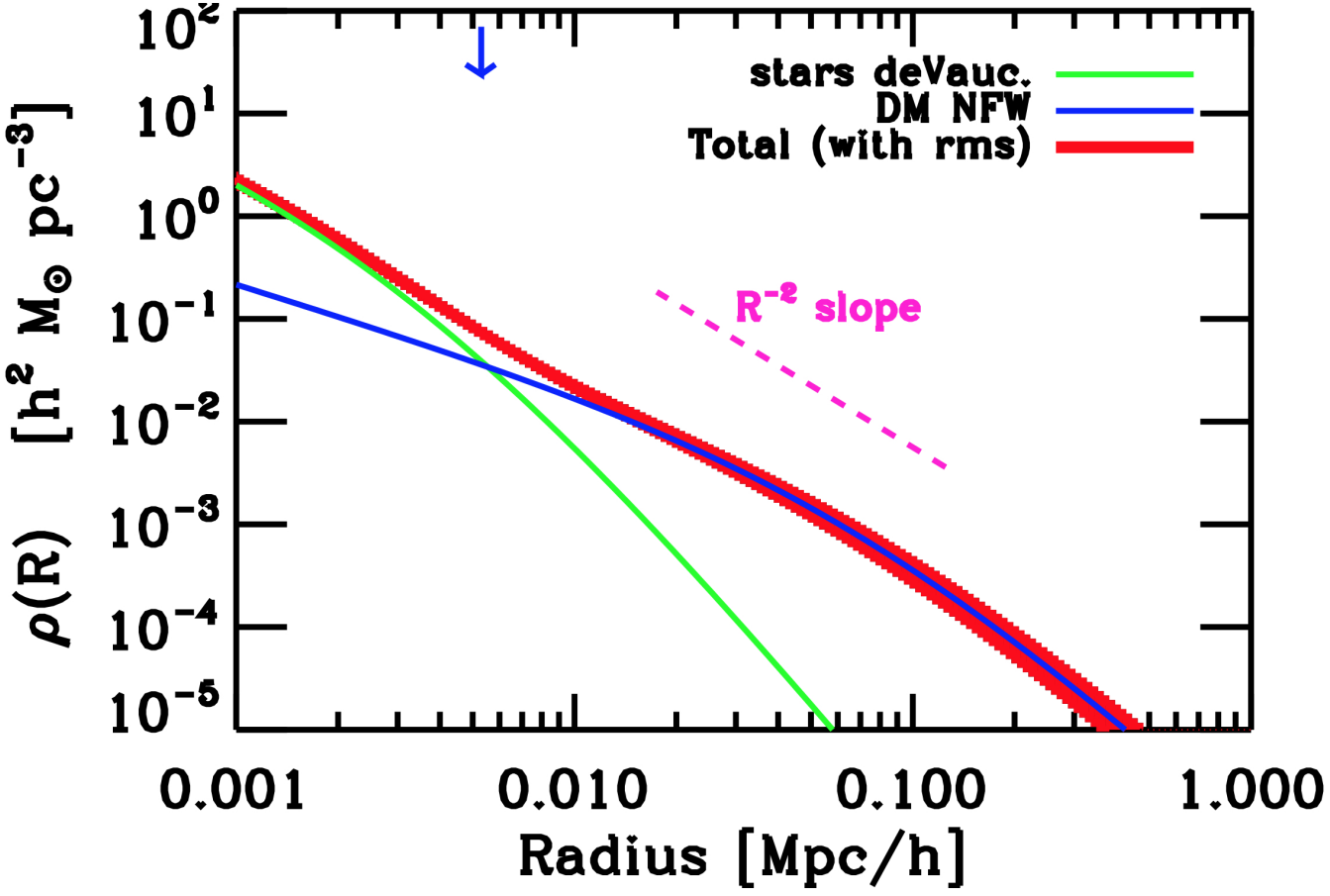


→ No big difference between hosts and subhalos

→ Trend: hosts evolve more than subhalos

→ Dependence on halo mass?

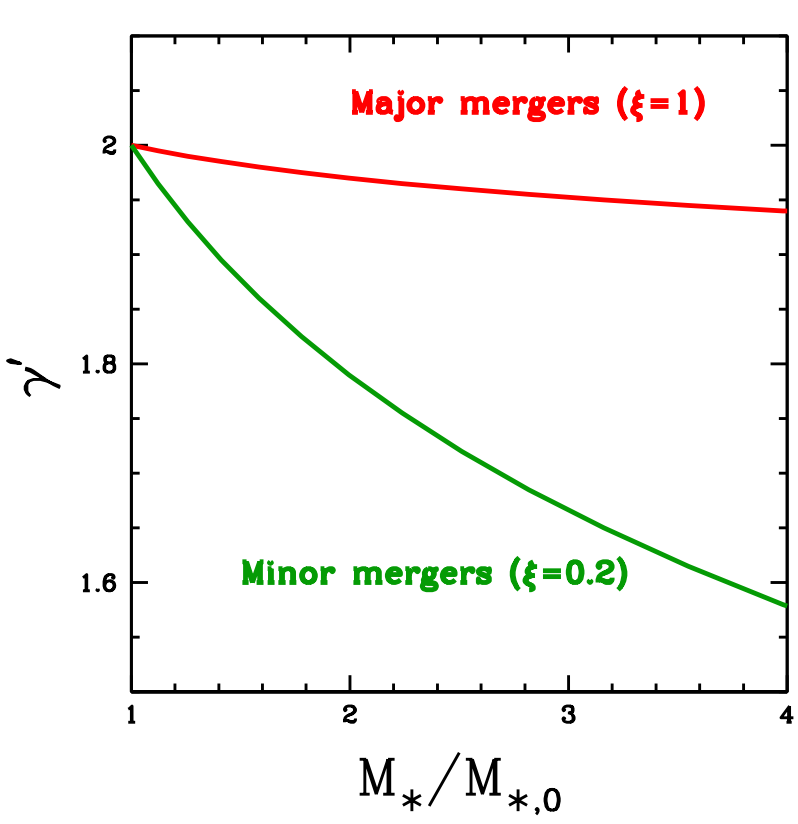
Total density slope γ' ($\rho_{\rm tot} \propto r^{-\gamma'}$)

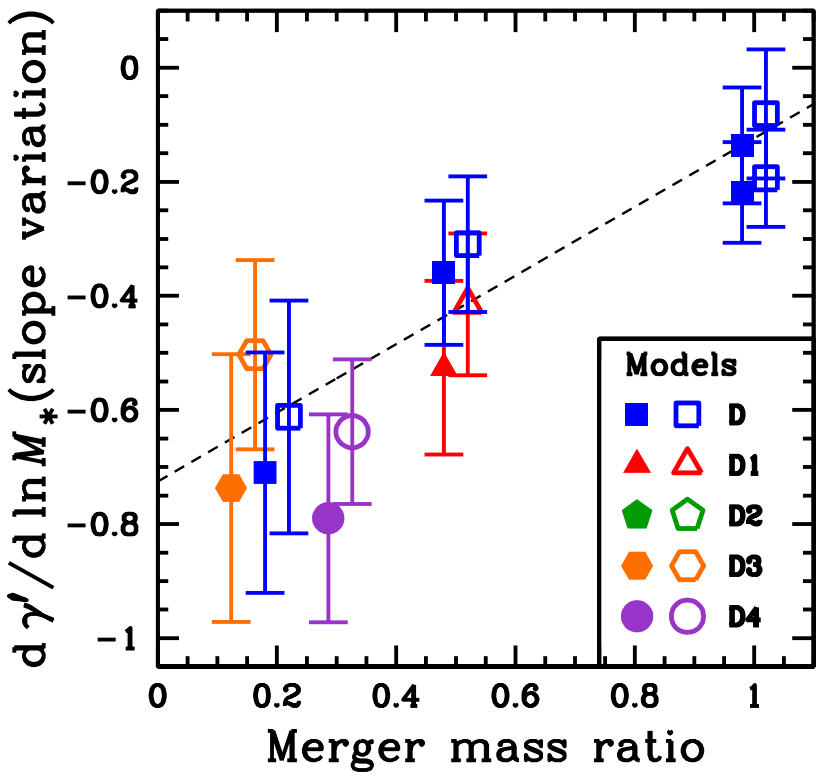


SLACS ETGs - weak lensing (Gavazzi et al. 2007)

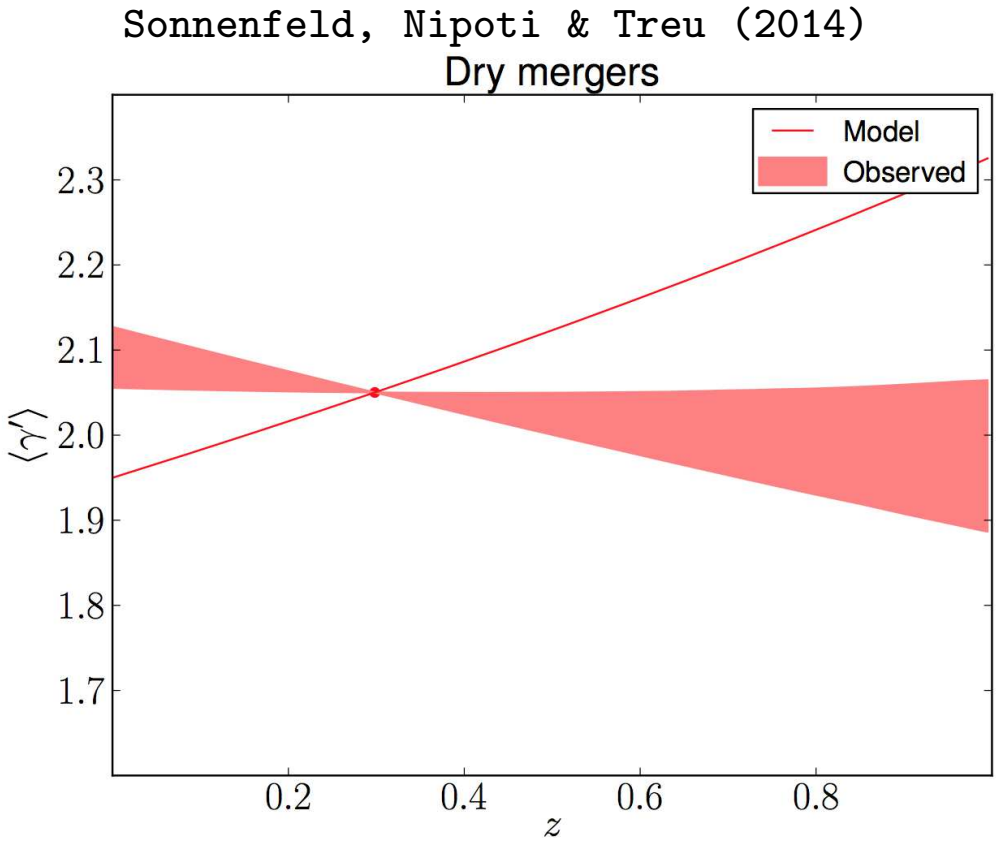
Dry mergers make γ' decrease

Nipoti at al. (2009), Sonnenfeld, Nipoti & Treu (2014)





Evolution of γ': dry mergers vs. observations



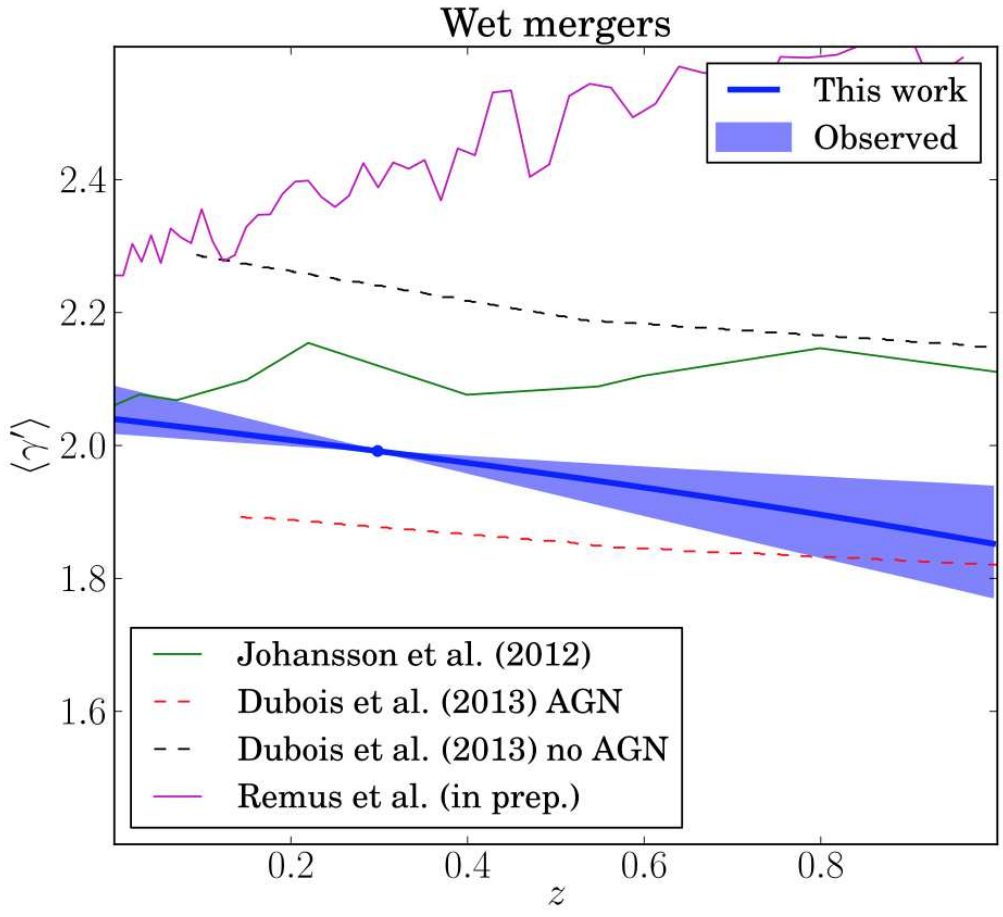
→ Model: Nipoti et al. (2012) + γ' (N-body)

→ Observations: SLACS+SL2S lenses (Sonnenfeld et al. 2013)

→ Evolution of γ' not explained by purely dry mergers

Evolution of γ': wet (damp) mergers vs. observations

Sonnenfeld, Nipoti & Treu (2014)

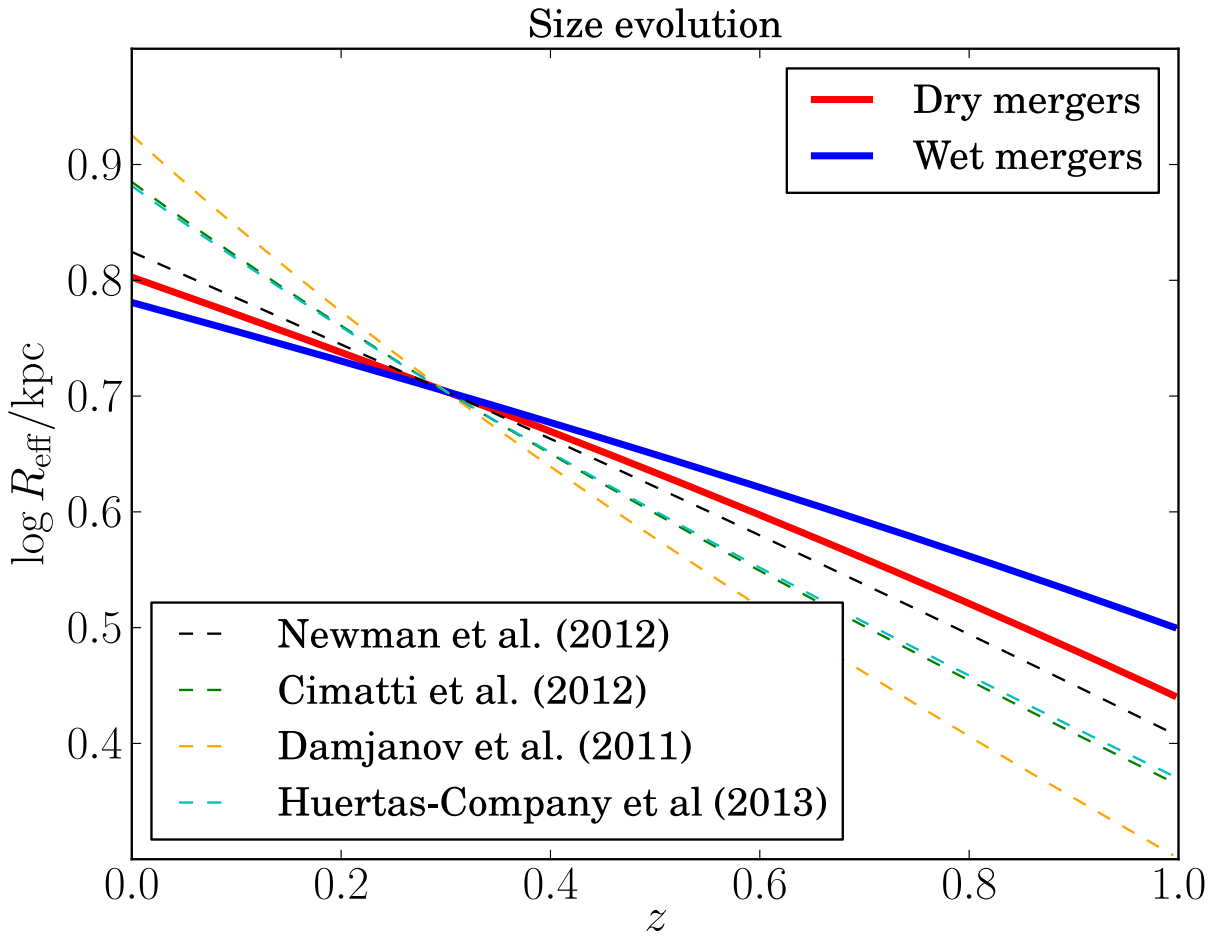


→ Toy-model dissipation

→ Small amount of dissipation helps reproduce $\gamma'(z)$

Dry and wet mergers vs. observations: $R_e(z)$

Sonnenfeld, Nipoti & Treu (2014)



Conclusions

- $\rightarrow$ LCDM consistent with $R_{\rm e}(z)$ and $\sigma(z)$ of ETGs at $z \lesssim 2$
- $\rightarrow$ Observed $R_{\rm e}(z)$ stronger than predicted at $z \gtrsim 2$
- $\rightarrow$ Group centrals evolve much faster than satellites
- $\rightarrow$ Evolution of γ' not explained by purely dry mergers
- $\rightarrow$ "Damp" mergers: promising at $z \lesssim 1$

Questions

- → How do we explain the very strong evolution of central galaxies in groups and clusters?
- → Is redshift evolution of Sersic index observed/observable?
- → Size evolution of ETGs: how much individual evolution, how much progenitor bias?