Size evolution of early-type galaxies through dry mergers

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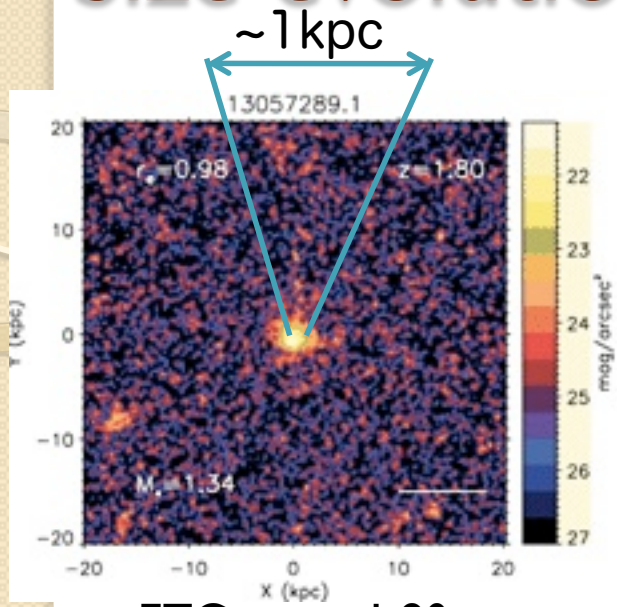
Size evolution of early-type galaxies

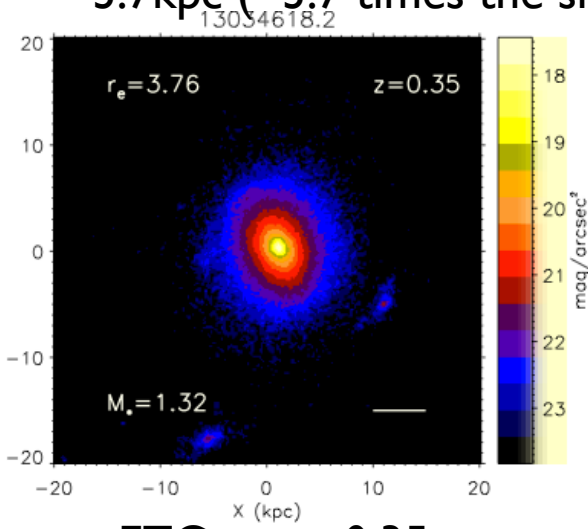


ETGs at z=1.80

Trujillo+ 2007

?

~3.7kpc (~3.7 times the size)



ETGs at z=0.35

HST/ACS
I-band filter

- High-z Early-Type Galaxies (hereafter ETGs)
  - already massive (~10^{11}Msun)
  - old stellar population
  - Quiescent in star formation activity (gas-poor?)
  - Compact
- Compact massive ETGs are very rare in the local Universe (Taylor+ 2010)

Previous studies and Motivation

- Dry minor merger scenario
  - No star formation, keeping the old stellar population
  - High frequency

Observations of the dry merger
van Dokkum 2005

- Previous studies & Issues
  - Naab+ 2009, Oser+ 2012
    - Simple analytical prediction $R_e \propto M_*^{\alpha}, \quad \alpha = \dfrac{d\ln R_e}{d\ln M_*} \cong 2$
    - Consistent with the cosmological simulation
    - Softening length : the order of 100pc
- Motivation
  - N-body simulations of sequential dry minor mergers at higher force resolution (with sufficiently small softening length)

Galaxy models

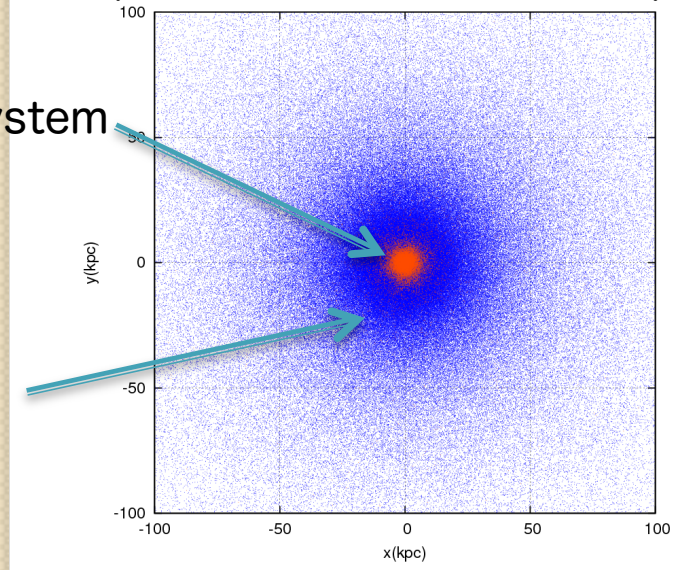
- We reproduce stellar system and dark matter halo with two-component Hernquist profile

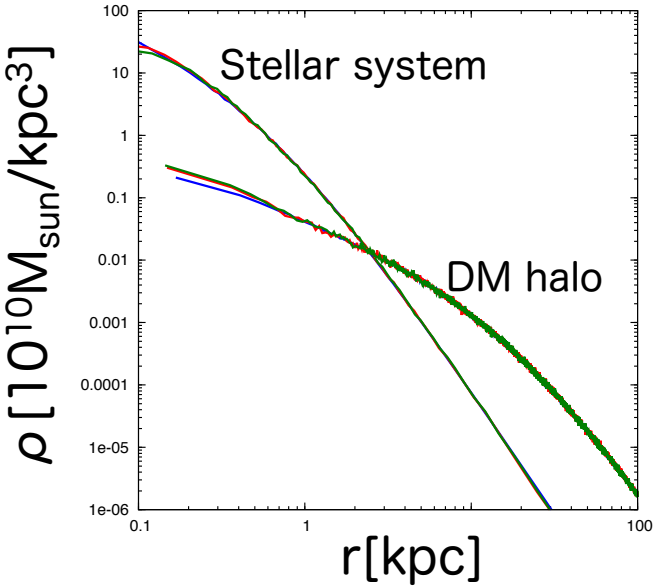
$$\text{Hernquist profile}: \rho_{dm}(r) = \frac{M_{dm}}{2\pi}\frac{a_{dm}}{r\left(r+a_{dm}\right)^3}, \quad \rho_*(r) = \frac{M_*}{2\pi}\frac{a_*}{r\left(r+a_*\right)^3}$$

- The particle velocity is given from distribution function to keep the dynamical equilibrium of the two-component Hernquist profile

Stellar system

DM halo

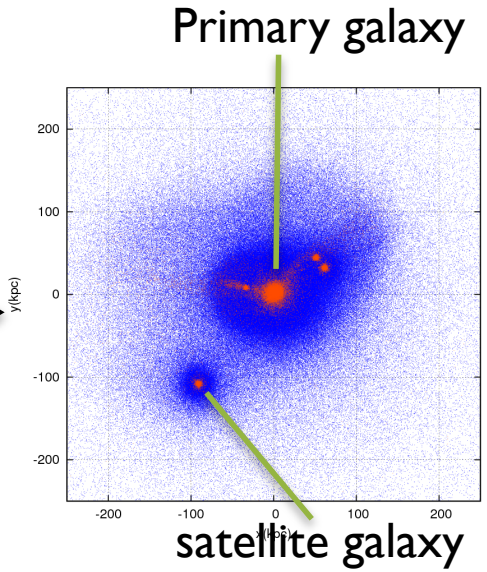


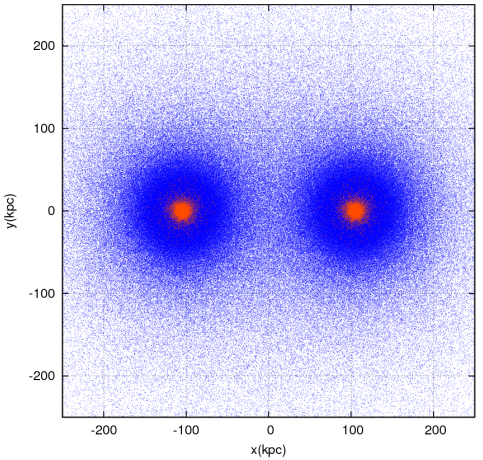


name	M_{dm} [M_{sun}]	M_* [M_{sun}]	r_{vir} [kpc]	R_e [kpc]	a_* [kpc]
primary	10^{12}	10^{11}	105	1.0	0.55
Compact (high density) satellite	10^{11}	10^{10}	48.8	0.464	0.26
Diffuse (low density) satellite	10^{11}	10^{10}	120	1.15	0.63

Dry merger models

- Sequential dry minor mergers
  - minor mergers with mass ratio of 10:1 every 0.2 Gyr successively
  - Two sequences with the compact satellites and the diffuse satellites
  - runs are finished at ~3.6Gyr (corresponding to the time interval 0.7<z<2)
- Comparison : dry major mergers
  - mass ratio of 1:1





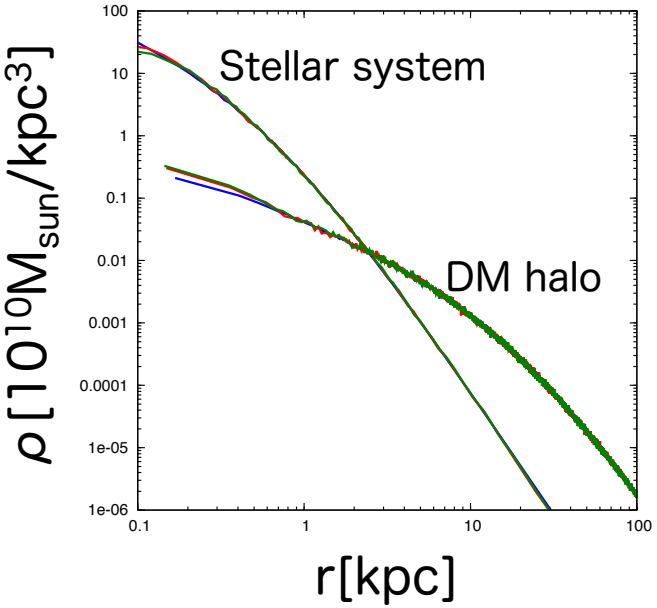
Effective radius: projected radius enclosing half of the stellar mass

Simulation code, resolution, and the test run

- N-body simulation
  - Code: GADGET-2 (Springel 2005)
- Resolution

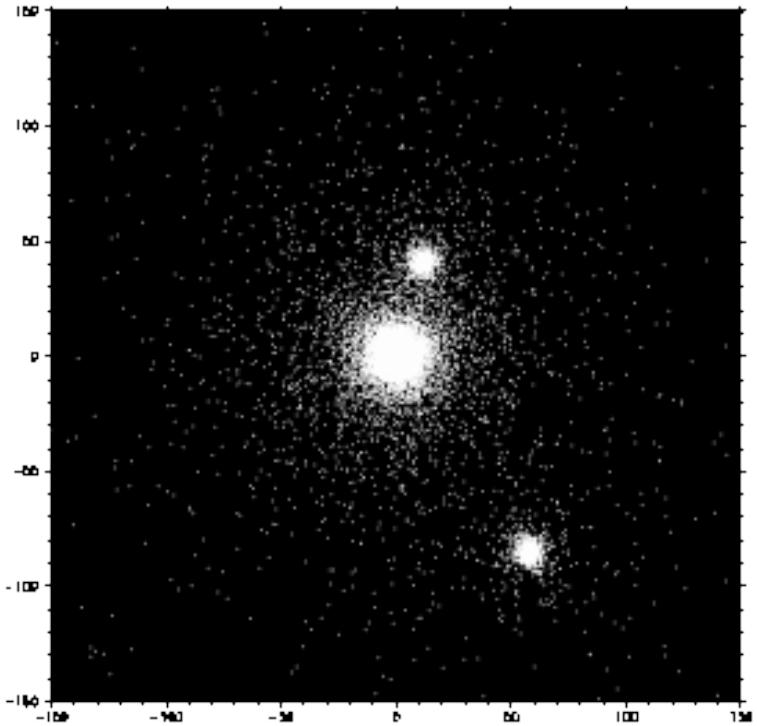
name	N_{dm}	N_*	softening
primary	6.0×10^5	6.0×10^4	30pc
compact satellite	6.0×10^4	6.0×10^3	30pc
diffuse satellite	6.0×10^4	6.0×10^3	30pc

- Test run



blue: 0Gyr
red: 1.8Gyr
green: 3.6Gyr

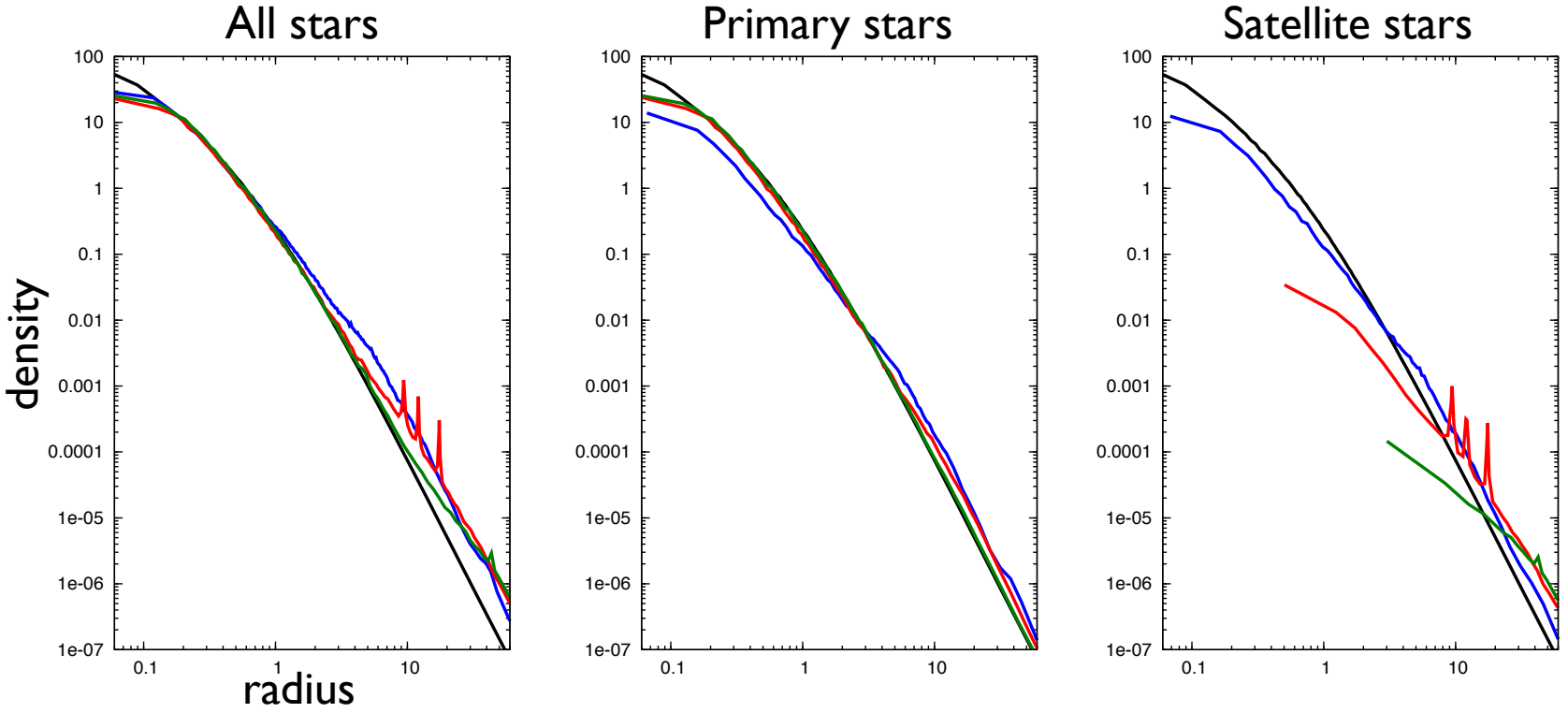
Animation : sequential dry minor mergers



- Only stellar particles are plotted
- The falling satellites are disrupted ← tidal stripping and shocking
- The surviving cores are merged with the primary galaxy after the several encounters ← dynamical friction

Density profiles

Black : initial
Red : 10 minor mergers, compact
Green : 10 minor mergers, diffuse
Blue : 1 major merger



- difference between the three runs is in the density profile of the satellite stars
- in the case of the minor mergers of the compact satellites the size growth is the most effective.

Density profiles

Black : initial
Red : 10 minor mergers, compact
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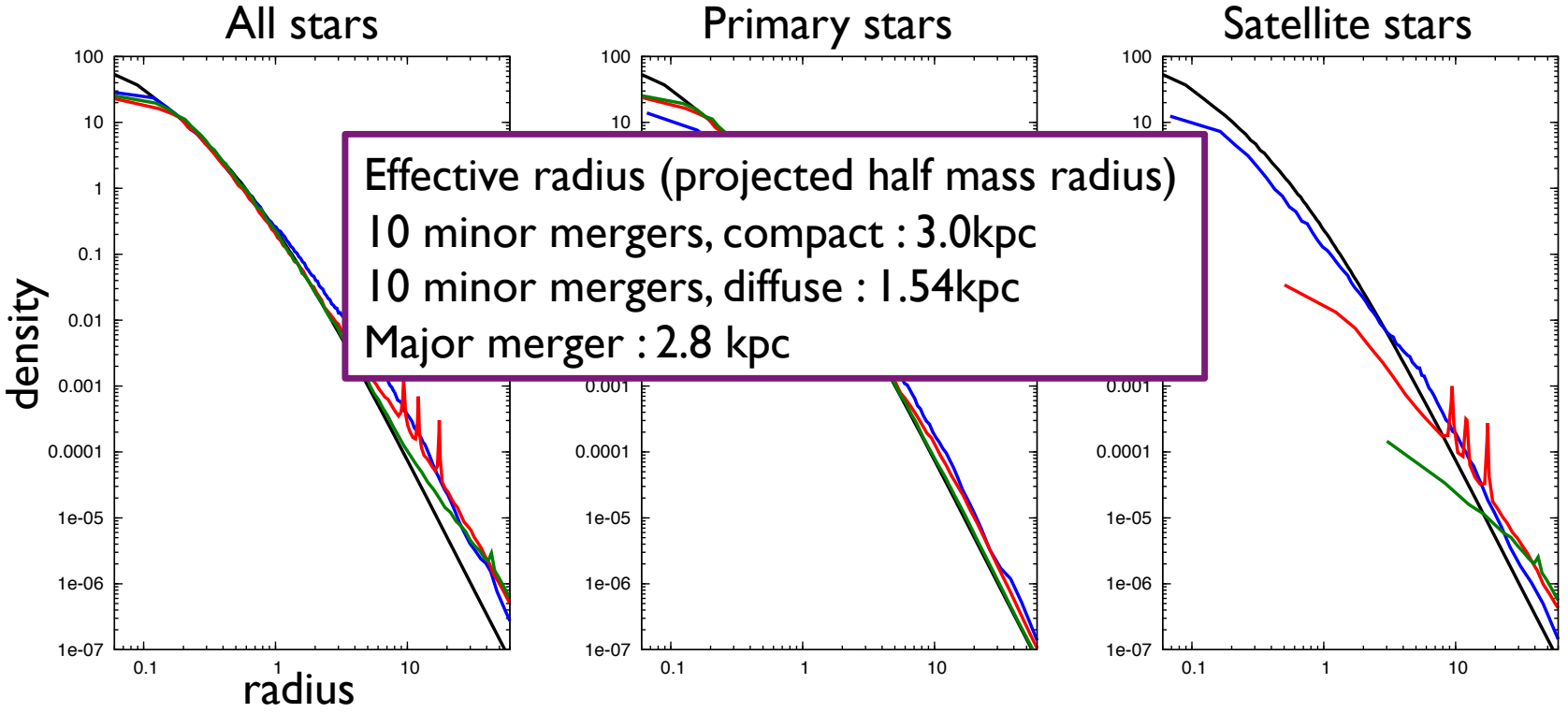


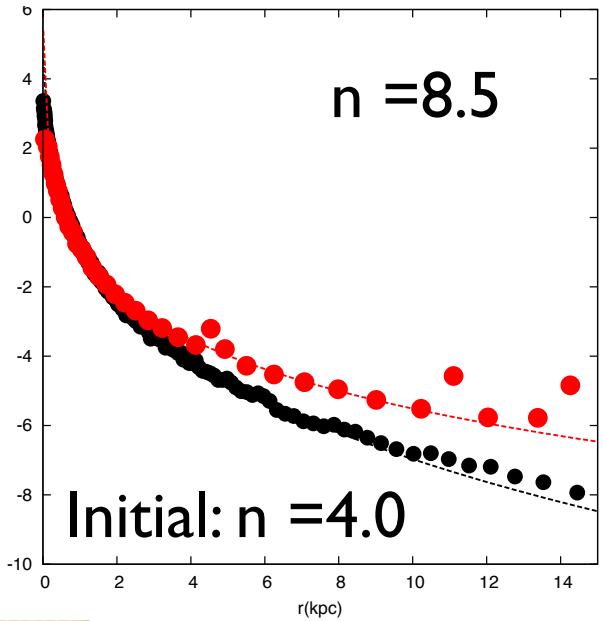
Effective radius (projected half mass radius)
10 minor mergers, compact : 3.0kpc
10 minor mergers, diffuse : 1.54kpc
Major merger : 2.8 kpc

- difference between the three runs is in the density profile of the satellite stars
- in the case of the minor mergers of the compact satellites the size growth is the most effective.

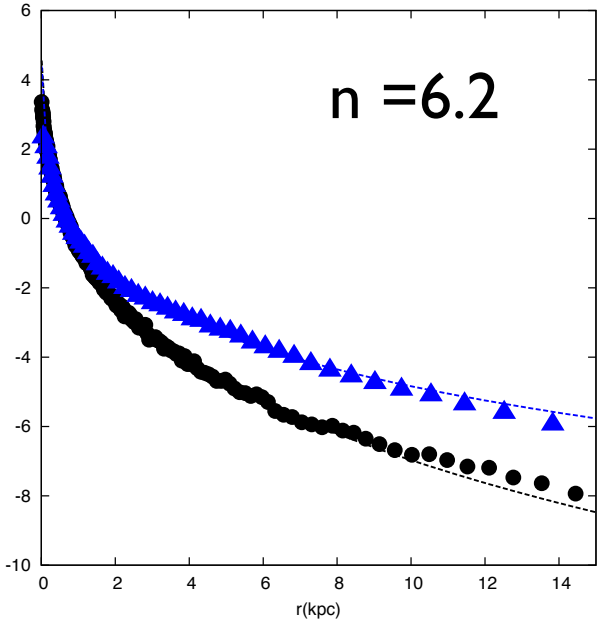
Surface density profiles and Sersic indices

$$I(R) = I_0 \exp\left[-b(n)\left(\frac{R}{R_e}\right)^{1/n}\right]$$

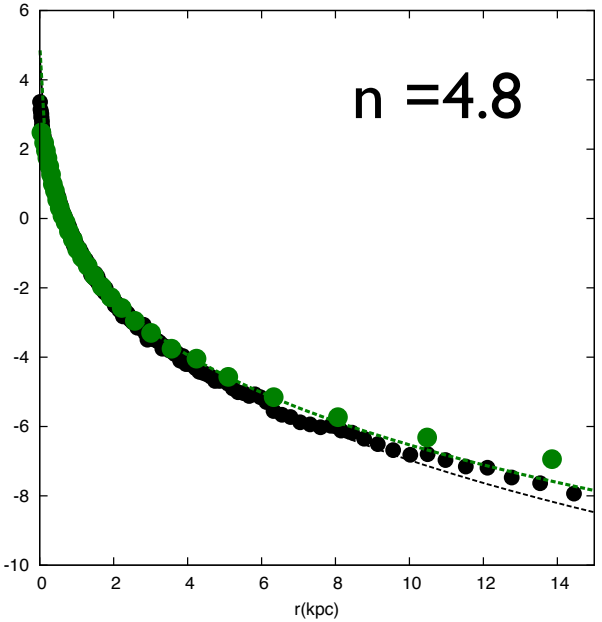
10 minor merger, compact



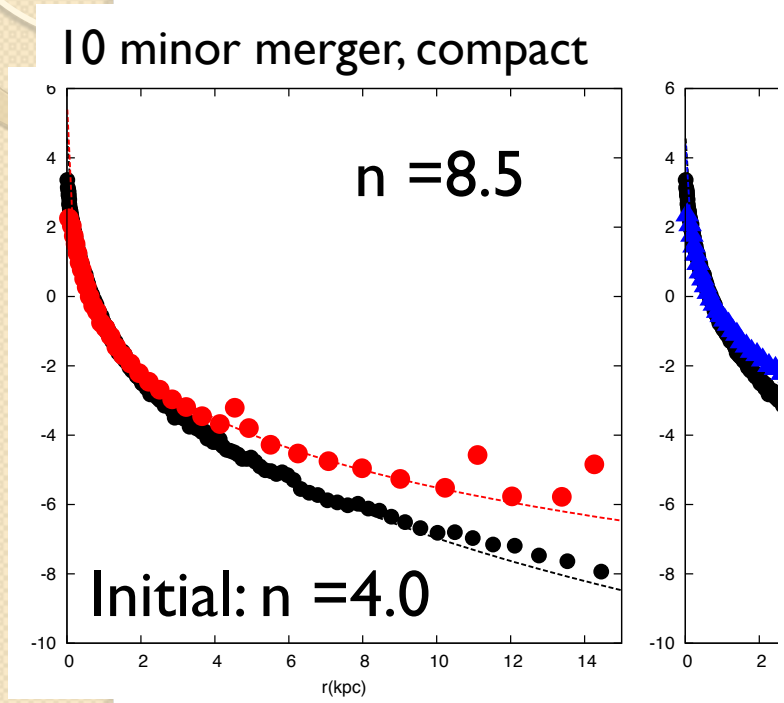
1 major merger

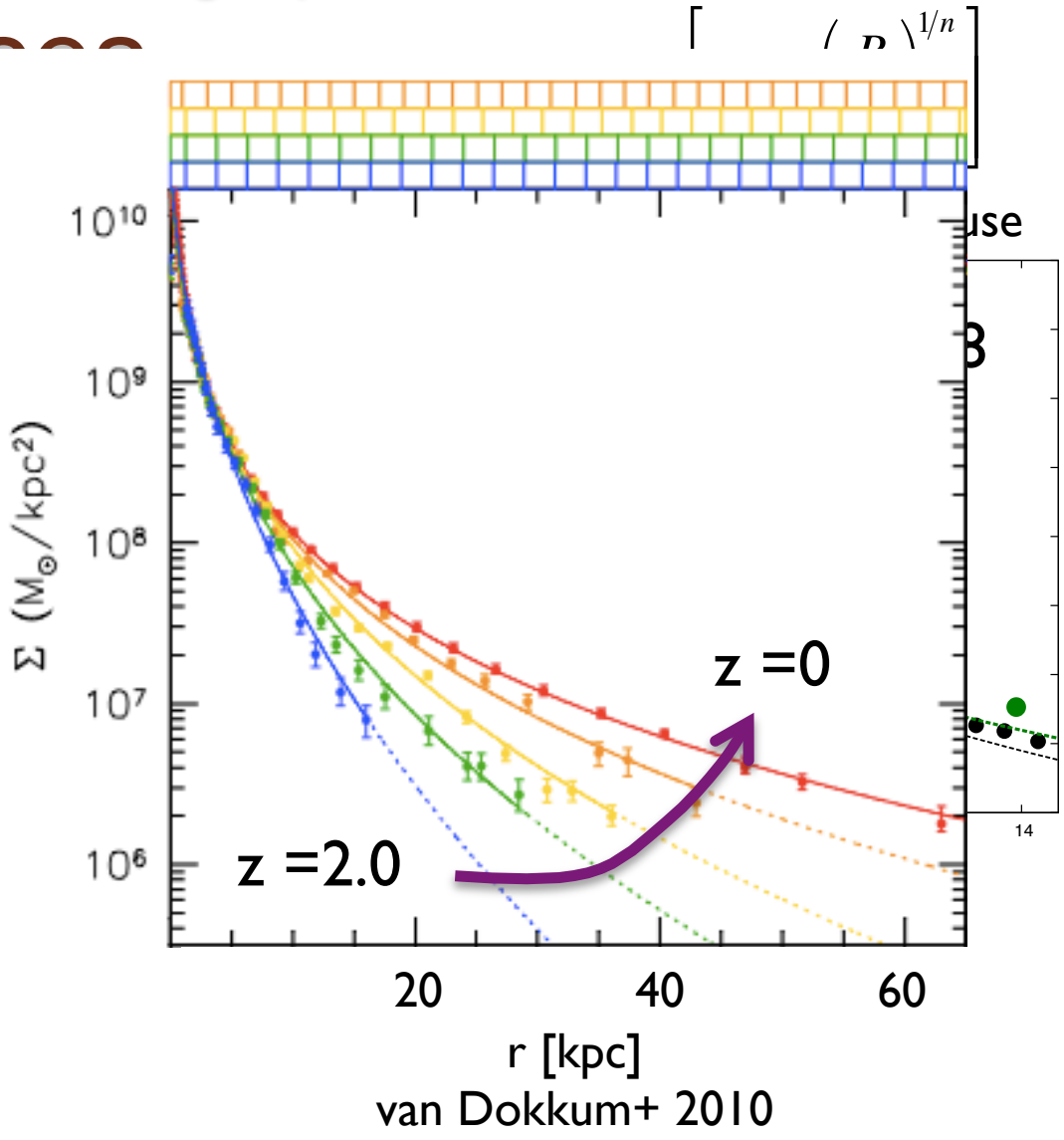


10 minor merger, diffuse



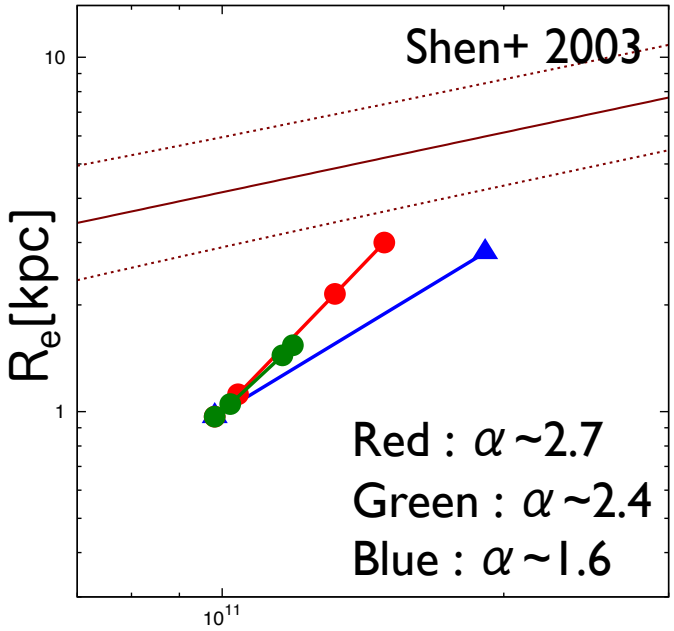
Surface density profiles and Sersic indices



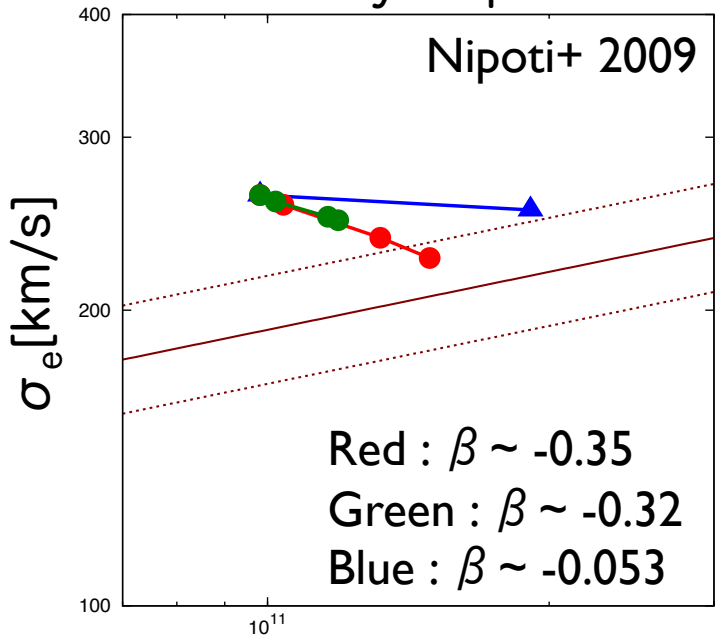


Changes of size and velocity dispersion

Stellar mass-size relation



Stellar mass-velocity dispersion relation



Efficiency

$$\frac{r_f}{r_i} = \left(\frac{M_f}{M_i}\right)^{\alpha}, \quad \frac{\sigma_f}{\sigma_i} = \left(\frac{M_f}{M_i}\right)^{\beta}$$

- In the case of the sequential minor mergers of compact satellites,
  - the size growth efficiency α reaches ~2.7 (Naab+ 2009: α ~2)
  - decrease of the velocity dispersion is the most efficient ← heating and expansion by dynamical friction

Summary

- We perform high-resolution N-body simulation to investigate changes of sizes and velocity dispersions of early-type galaxies by dry minor mergers of two-component galaxies
- Efficient size growth occurs by sequential dry minor mergers of the compact satellites
  - mass deposit of satellite stars in the envelope of the primary galaxy
- Efficient decrease of velocity dispersion occurs by minor mergers of compact satellites
  - expansion of the primary stars by dynamical friction heating
- In future works, we will incorporate the compact stellar system in dark matter haloes obtained from cosmological simulations and perform cosmological dry merger simulations.