楕円銀河の Scaling Relations と Fundamental Plane

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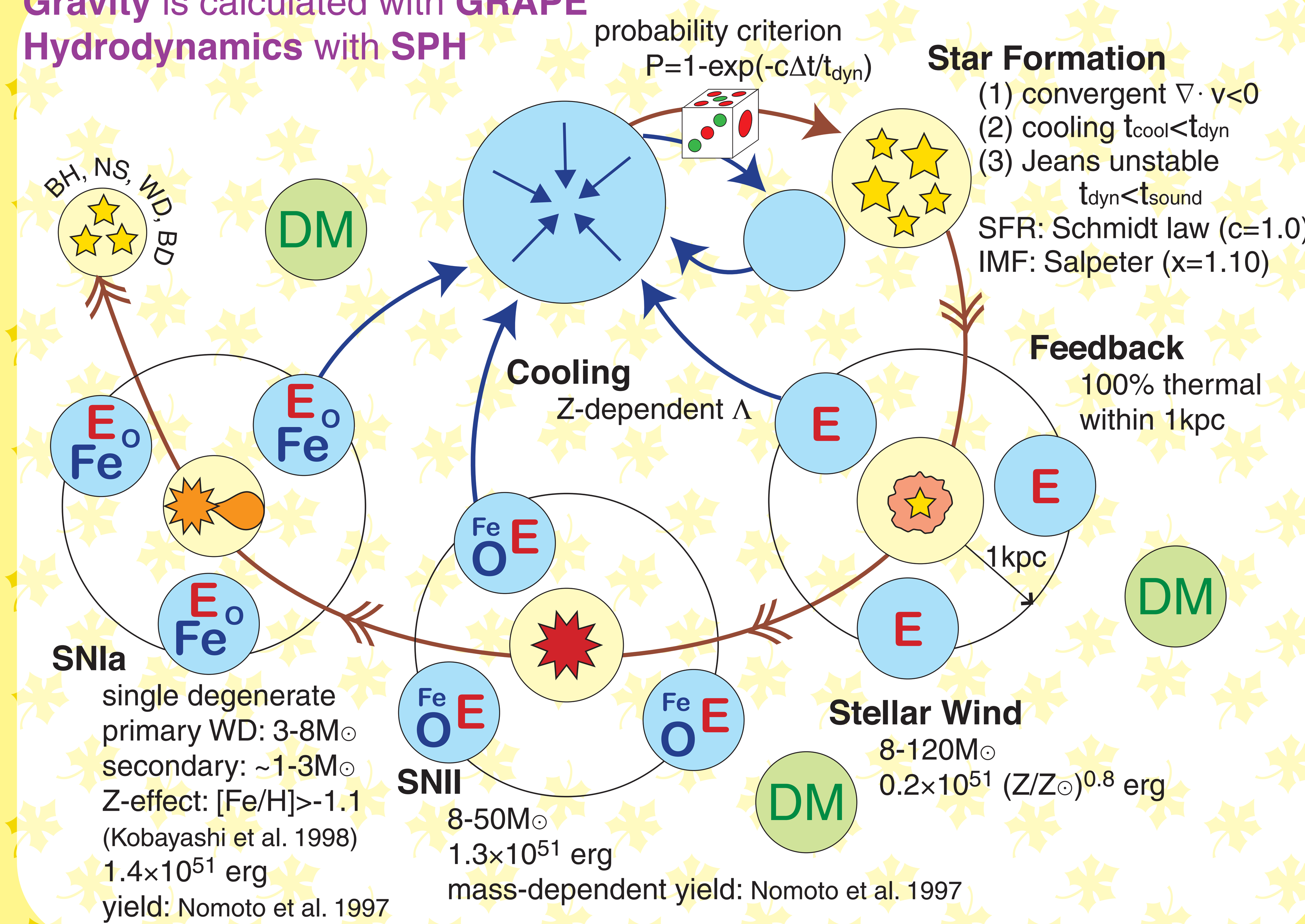
1. Abstract

We simulate the formation and chemodynamical evolution of 128 elliptical galaxies (Es) using a GRAPE-SPH code that includes various physical processes that are associated with the formation of stellar systems: radiative cooling, star formation, feedback from Type II and Ia supernovae and stellar winds, and chemical enrichment. We succeed in reproducing the observed global scaling relations under our CDM-based scenario, e.g., the Faber-Jackson relation, the Kormendy relation, and the fundamental plane. An intrinsic scatter exists along the fundamental plane, and the origin of this scatter lies in differences in merging history. Galaxies that undergo major merger events tend to have larger effective radii and fainter surface brightnesses, which result in larger masses, smaller surface brightnesses, and larger mass-to-light ratios. We can also reproduce the observed color-magnitude and mass-metallicity relations, although the scatter is larger than observed.

2. Model

Gravity is calculated with **GRAPE**
Hydrodynamics with **SPH**



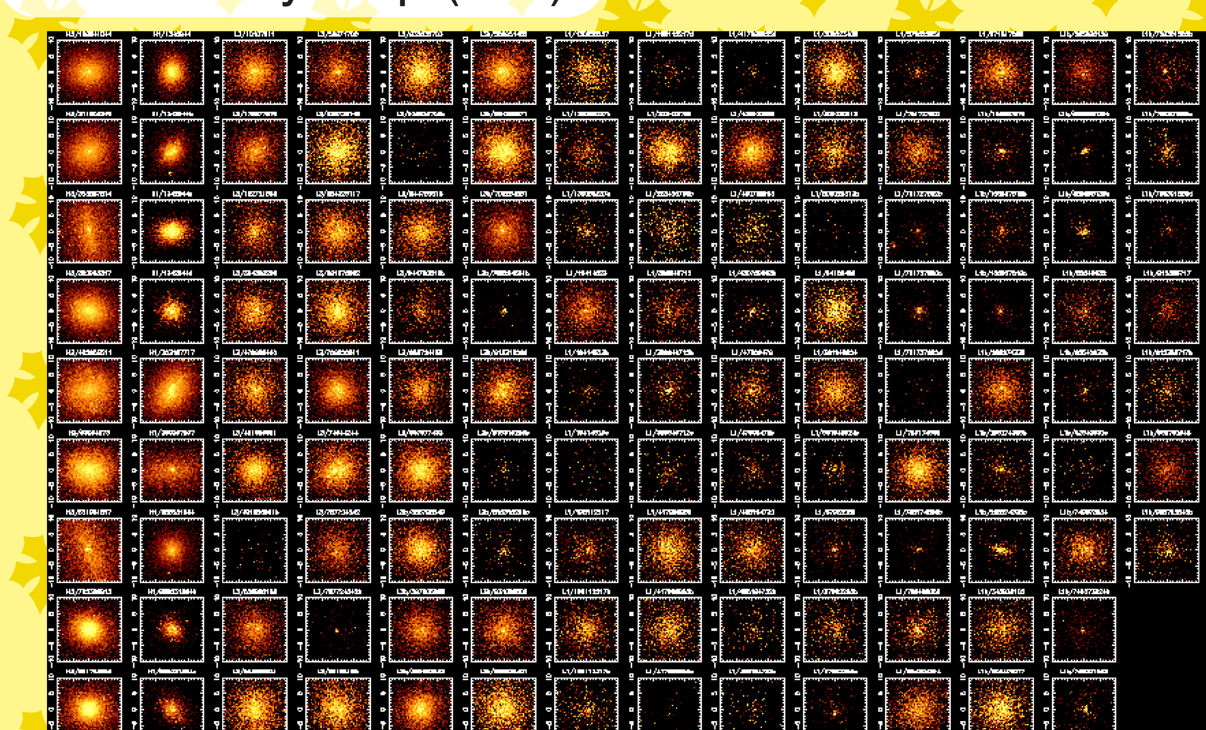
3. Initial Condition

- cosmological initial condition with GRAFIC (Bertschinger 1995)
- $H_0=50$, $\Omega_0=1.0$, $\lambda_0=0.0$, $\sigma_8=1$, $z_c\sim25$, 1-3σ
- a sphere with r, M_{tot} (baryon fraction=0.1) and N_{tot} (the half for gas)
- $m_{gas}\sim10^{6\text{-}7}\ M_\odot$, $m_{DM}\sim10^{7\text{-}8}\ M_\odot$
- small rotation: spin parameter $\lambda\sim0.02$

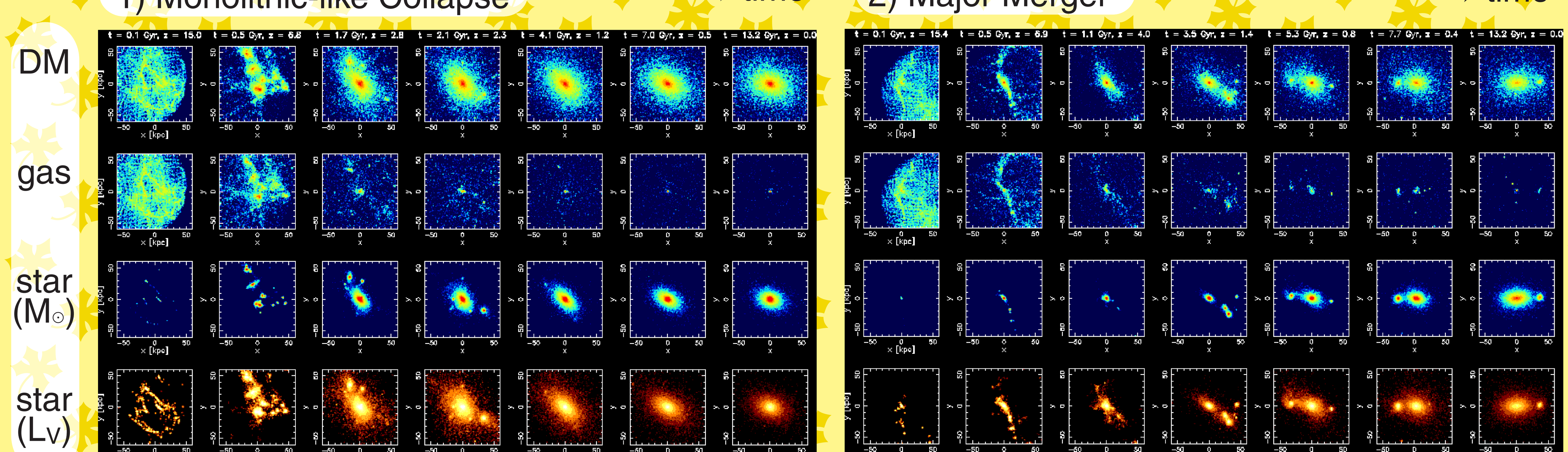
	r [Mpc]	M [M⊙]	N_{tot}
H	1.5	1×10^{12}	60000
L	1.5	1×10^{12}	10000
cD	3	6×10^{12}	60000

We calculate 74 fields and obtain 128 Es (74 giants, 45dwarfs, 9 cDs).
All Es formed by the star burst at z>2, and have de Vaucouleurs SB profiles.

V-luminosity Map (z=0)



1) Monolithic-like Collapse → time　　2) Major Merger → time



4. Elliptical galaxies

- How elliptical galaxies form and evolve? monolithic collapse vs. disk-disk merger.
- We adopt a CDM fluctuation as the initial condition.
  → successive merging of subgalaxies with ~$10^{9\text{-}10}\ M_\odot$,
  → some ellipticals: no merger, some: major merger

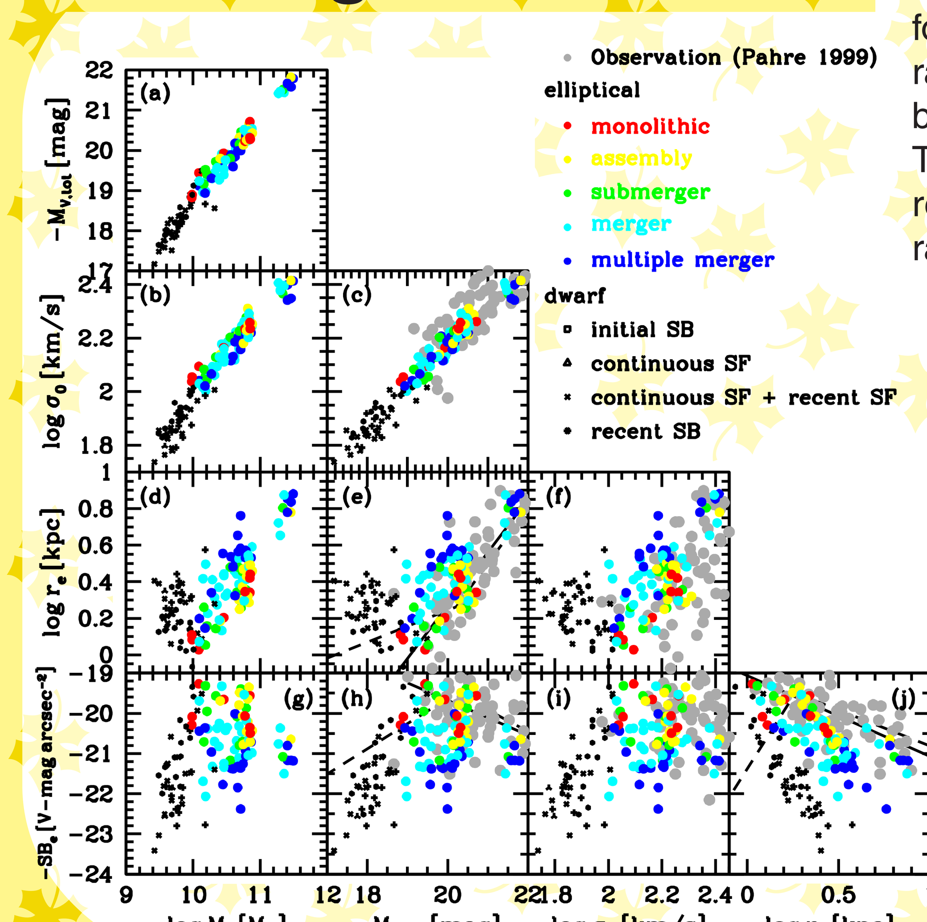
The merging history depends on the initial fluctuation.

5. Metallicity Gradients

Kobayashi (2004) MNRAS, 347, 740

- Merger destroys the radial metallicity gradients
  → monolithic-like Es have steeper gradients merger Es have flatter gradients
- No relation between the gradients and the mass, which is consitent with the observation (Kobayashi & Arimoto 1999)
- Merging histories can, in principle, be inferred from the observed metallicity gradients of present-day galaxies.

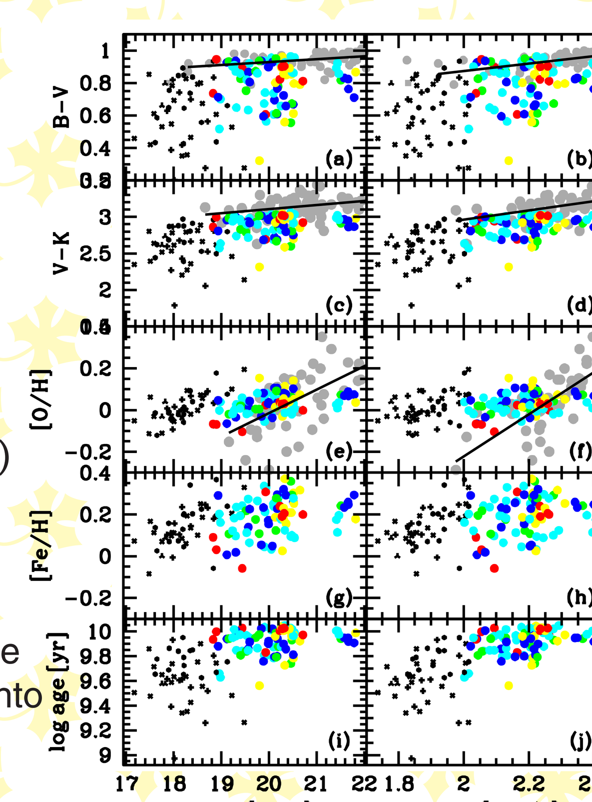
6. Scaling Relations



The star formation timescale controls when and where stars form in the contracting gas cloud, determines the effective radius at given mass, and is constrained by observation to be ten times longer than the local dynamical timescale.
The different relations for ellipticals and dwarfs could be reproduced, although simulated dwarfs have larger effective radii than observed because of the lack of resolution.

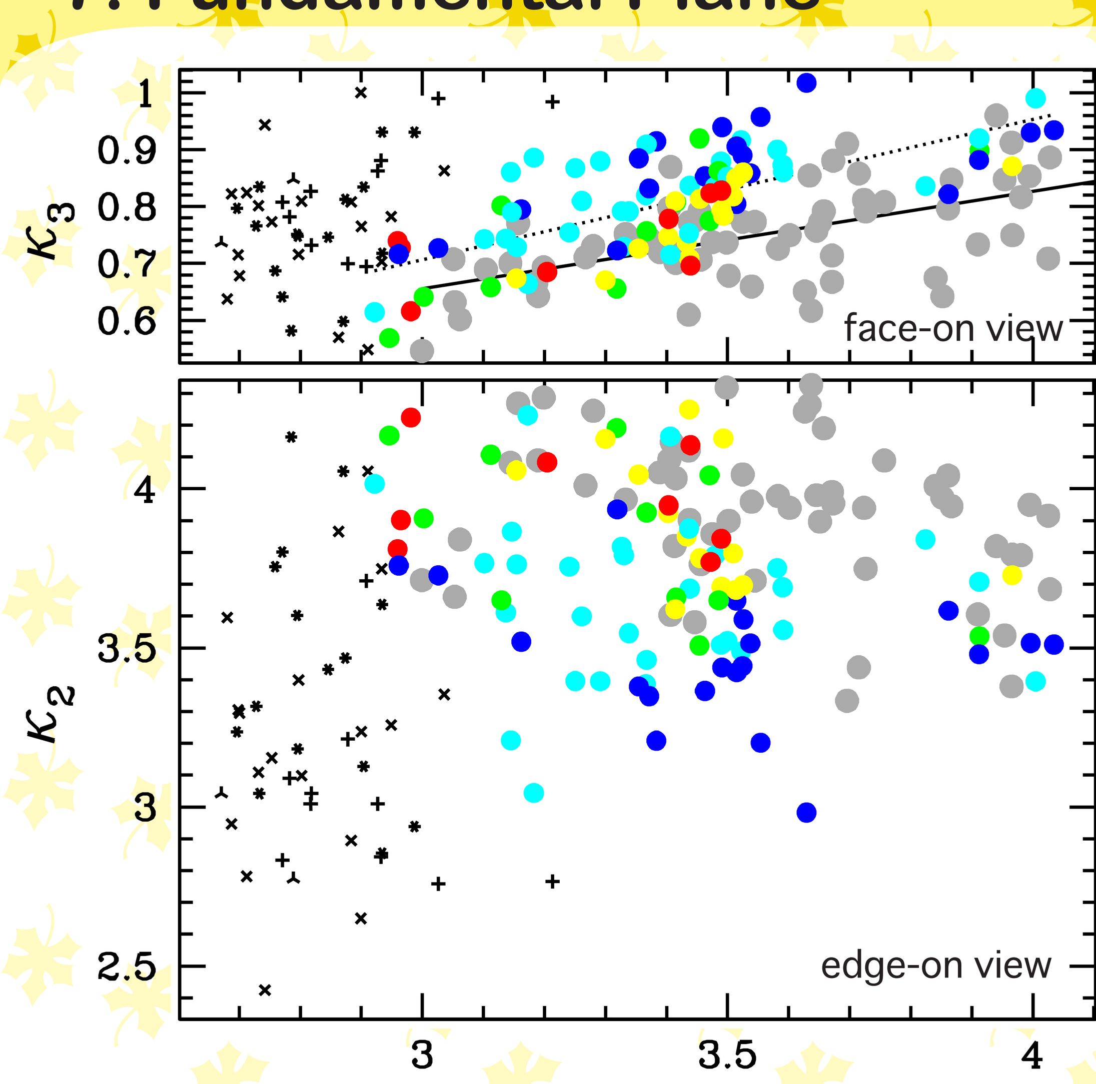
○Faber-Jackson関係(c)
○光度-半径 関係(e)
○半径-面輝度 関係(j)
△dwarfの違う関係

△色-等級 関係(a-d)
△質量-金属量 関係(e-h)
　質量-年齢 関係なし(i-j)
○younger dwarfs



Adopting the Salpeter IMF, the mass-metallicity relations can be reproduced, although the slope is shallower and the scatter is larger than observed, which are because the feedback is not so effective that most metals are locked into stars in the simulation. The color-magnitude relation also shows a larger scatter because the star formation does not terminated completely in the simulations.
The luminosity-weighted ages of dwarfs span in wide range, 3-8 Gyr, depending on their star formation histories, while ellipticals are as old as 7-10 Gyr independent of their mass.

7. Fundamental Plane



An intrinsic scatter exists along the fundamental plane, and the origin of the scatter in the simulation lies in differences in merging history. Galaxies that undergo major mergers tend to have larger effective radii and fainter surface brightnesses, which result in larger κ_1 (mass), smaller κ_2 (surface brightness), and larger κ_3 (mass-to-light ratio).

- monolithic
- assembly
- semi-merger
- merger
- double merger
- dwarfs

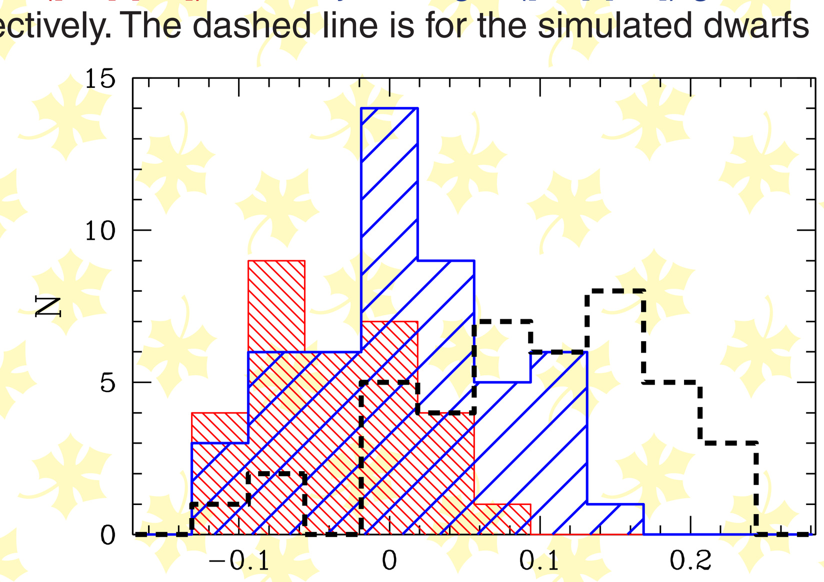
gray points & solid line: observation (Pahre 1999)

$\kappa_1 \equiv (\log\sigma_0^2 r_e)/\sqrt{2}$

$\kappa_2 \equiv (\log\sigma_0^2 I_e^2 r_e^{-1})/\sqrt{6}$

$\kappa_3 \equiv (\log\sigma_0^2 I_e^{-1} r_e^{-1})/\sqrt{3}$

Histograms of deviations from the fundamental plane. The red and blue areas are for the simulated non-major merger ([E1]-[E3]) and major merger ([E4]-[E5]) galaxies, respectively. The dashed line is for the simulated dwarfs



8. Discussion: Origin of Ellipticals

The origin of elliptical galaxies can be understood under the CDM picture. Galaxies form through the successive merging of subgalaxies with various masses. Their merging histories vary between a major merger at one extreme, and a monolithic collapse of a slow-rotating gas cloud at the other extreme. The majority of stars formed in a initial star burst at z>2, and the star formation during merging events is small. Internal structure such as metallicity gradients is greatly affected by merging histories, while the global properties are determined from overall masses according to the scaling relations.