The Origin of Elliptical Glaxies inferred from their Metallicity Gradients

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1. Abstract

We simulate the formation and evolution of 124 elliptical galaxies (Es) from the CDM initial fluctuation using our GRAPE-SPH code. To make comparison with the observation, we introduce detailed models of the physical processes; radiative cooling, star formation, feedback of Type II and Ia supernovae (SNe II and SNe Ia), and stellar winds (SWs), and chemical enrichment. We then reproduce the tight relations such as Faber-Jackson relation and the mass-metallicity relation, and also reproduce a variety of the internal structures (no relation between metallicity gradients and masses). This is because the metallicity gradients are destroyed by the merging of galaxies. Therefore, the metallicity gradient infers the merging history of the galaxy, from which we discuss the origin of Es.

2. N-body+SPH

We solve the hydrodynamics with Smoothed Particle Hydrodynamical (SPH) method and compute the gravity by the special purpose computer GRAPE (GRAPE5 MUV system of NAOJ and GRAPE6 of Univ. of Tokyo). Our GRAPE-SPH code (N. Nakasato 2000) is highly adaptive in space and time by means of individual smoothing length and individual timestep.

$$\frac{D\rho}{Dt} + \rho\nabla\cdot\mathbf{v} = 0$$

$$\frac{D\mathbf{v}}{Dt} = -\frac{1}{\rho}\nabla P - \nabla\Phi$$

$$\frac{Du}{Dt} = \frac{P}{\rho^2}\frac{D\rho}{Dt} + \frac{\nabla\cdot(\kappa\nabla T)}{\rho} + \frac{\Gamma-\Lambda}{\rho}$$

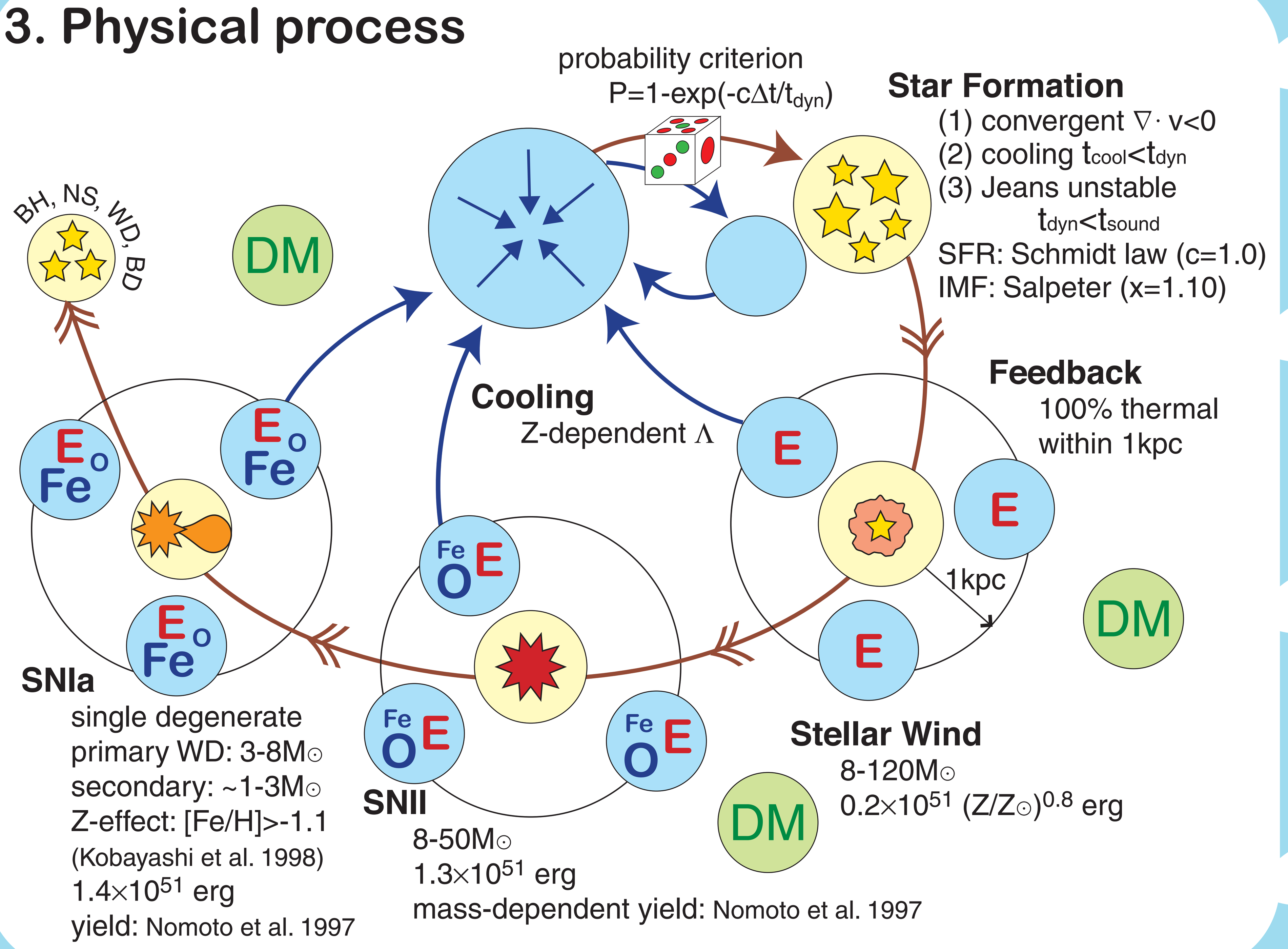
$$\nabla^2\Phi = 4\pi G\rho$$

$$\rho_i = \sum m_j W(\mathbf{r}_i - \mathbf{r}_j; h)$$

$$\frac{D\mathbf{v}_i}{Dt} = -\sum m_j\left(\frac{P_i}{\rho_i^2} + \frac{P_j}{\rho_j^2} + \Pi_{ij}\right)\nabla_i W(\mathbf{r}_i - \mathbf{r}_j; h) - (\nabla\Phi)_i$$

$$\frac{Du_i}{Dt} = -\sum m_j\left(\frac{P_i}{\rho_i^2} + \frac{1}{2}\Pi_{ij}\right)(\mathbf{v}_i - \mathbf{v}_j)\nabla_i W(\mathbf{r}_i - \mathbf{r}_j; h) + \frac{\Gamma-\Lambda}{\rho}$$

3. Physical process



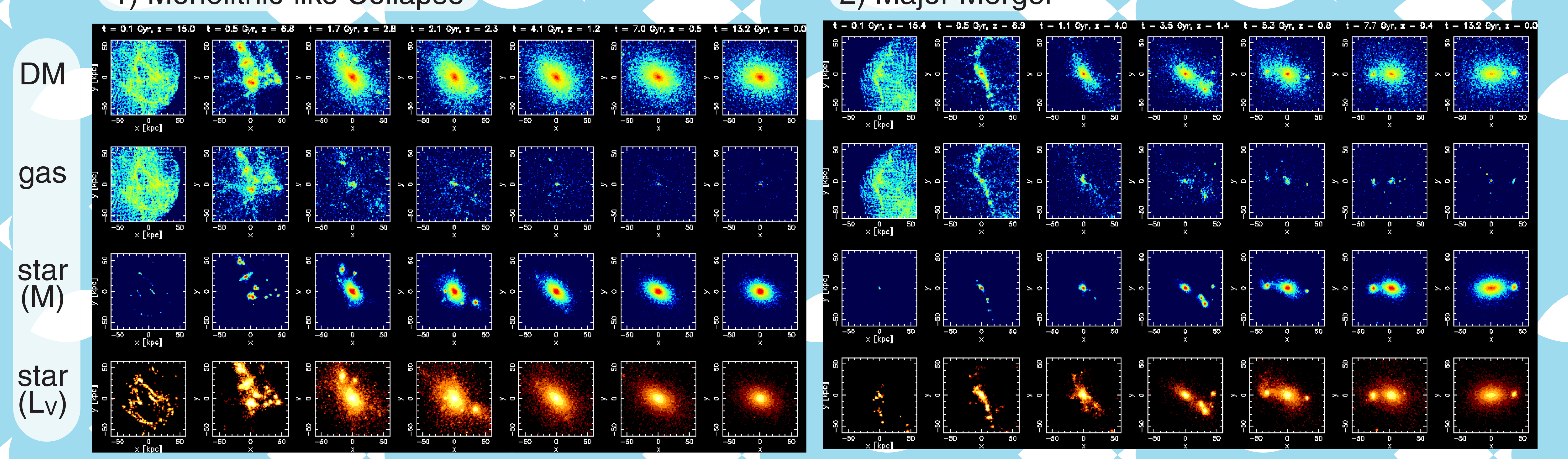
4. Initial Condition

- cosmological initial condition GRAFIC (Bertschinger 1995)
- H_0=50, Ω_0=1.0, λ_0=0.0, σ_8=1, z_c~23
- 1-3σ over-dense region: a sphere with 1.5 Mpc radius
- N_{tot}~10000,60000 (the half for gas, the rest for DM)
- M_{tot}~10^{12} M⊙, baryon fraction=0.1
- M_{gas}~10^{6-7} M⊙, M_{DM}~10^{7-8} M⊙
- small rotation: spin parameter λ~0.02

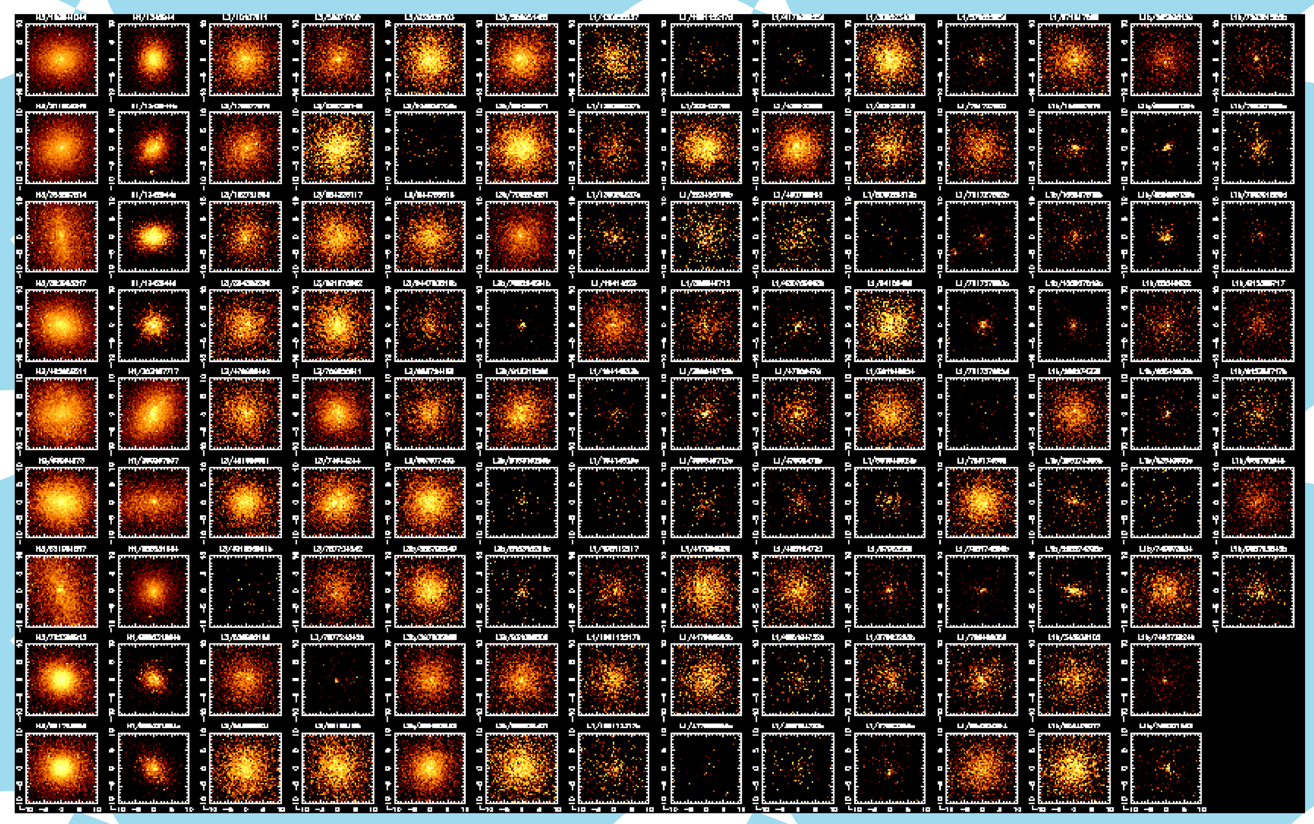
We calculate 70 fields and obtain 124 Es, all of which formed by the star burst and have de Vaucouleurs SB profiles.

1) Monolithic-like Collapse → time

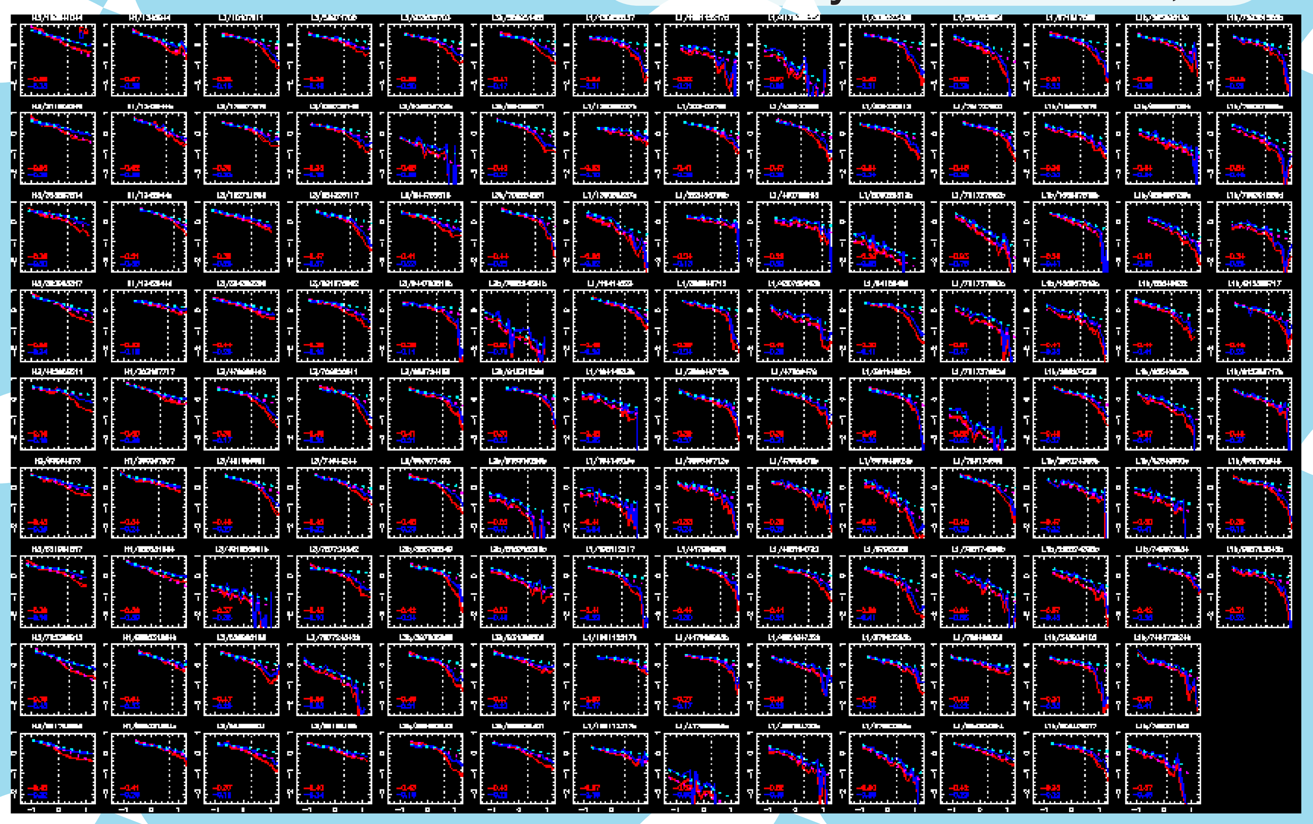
2) Major Merger → time



V-luminosity Map (z=0)



Metallicity Gradient: Fe, O



5. Elliptical galaxies

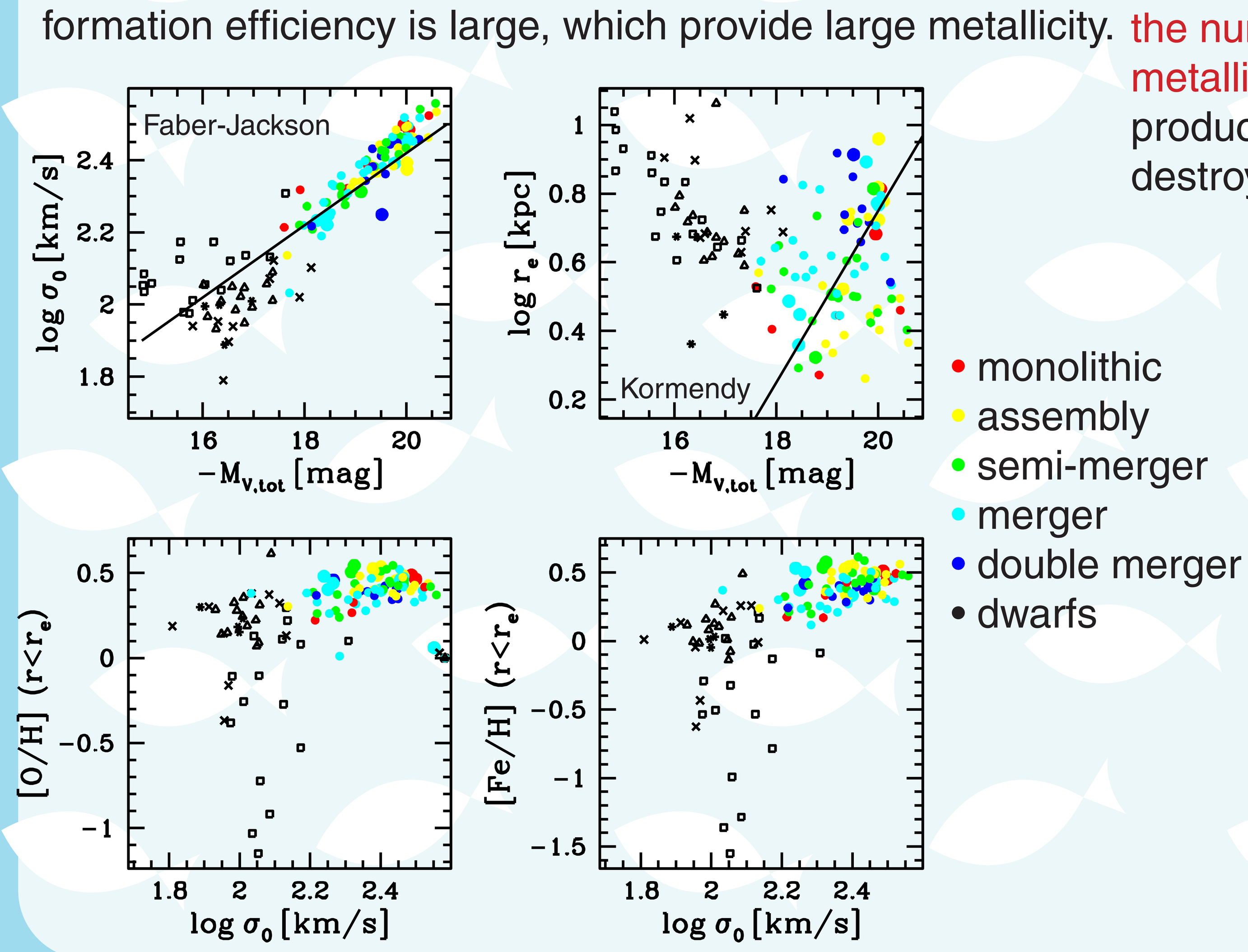
- How elliptical galaxies form and evolve?
  Two distinct scenarios have been debated;
  monolithic collapse vs. disk-disk merger.

We adopt the CDM fluctuation as the initial condition.
→ successive merging of subgalaxies with ~10^{9-10} M⊙,
→ some ellipticals: no merger, some: major merger
The merging history depends on the initial fluctuation.

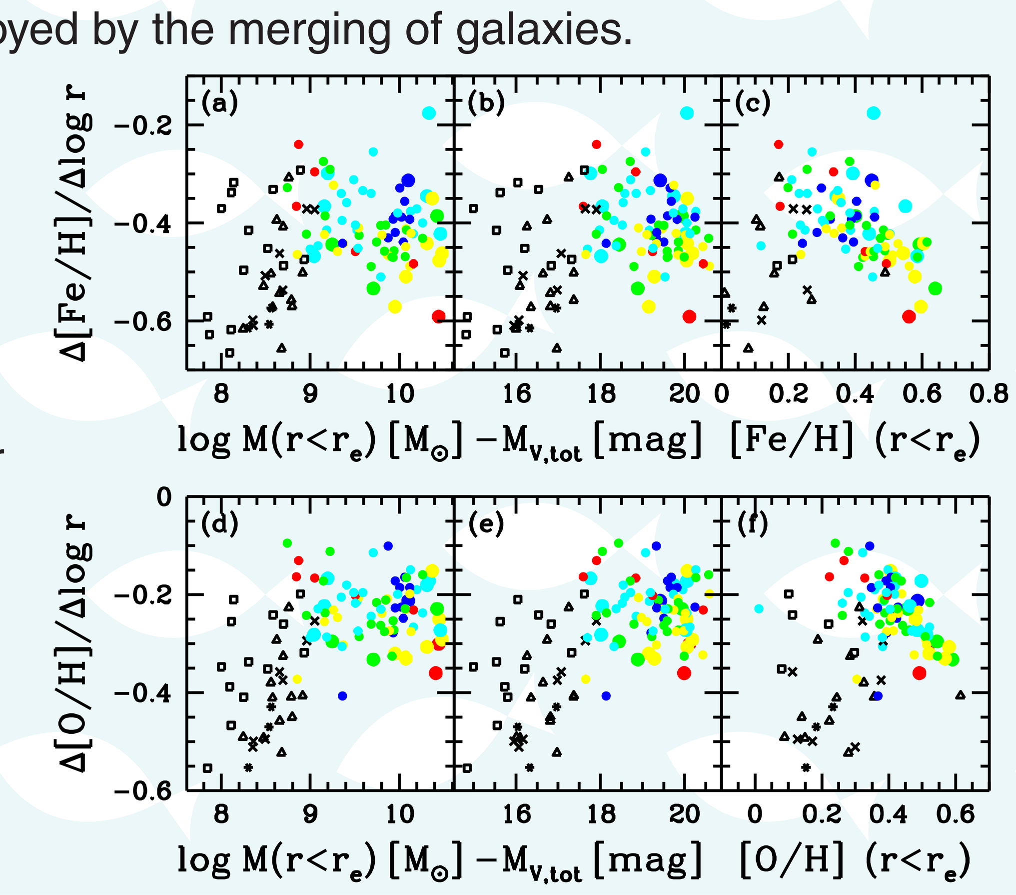
- Observations of elliptical galaxies show
  - Tight relations among global properties, e.g., FJ, CMR, Mg_2-σ, FP....
  - A variety of the internal structures e.g., metallicity gradients do not correlate with mass
- We simulate many ellipticals and do the statistical study.

6. Results

We reproduce the tight relations: Faber-Jackson relation, Kormendy relation, and the mass-metallicity relation.
In a massive elliptical, the density is large, and the star formation efficiency is large, which provide large metallicity.



We reproduce the observed average (-0.3) and dispersion (-0.8 to 0) of the metallicity gradients (Kobayashi & Arimoto 1999); Most Es have the metallicity gradients, and the gradients do not correlate with masses or metallicities. However, we find that the number and scale of the merging events correlate with the metallicity gradients (see color dots). The dissipative collapse produces the steep gradients as -0.1, and such gradients are destroyed by the merging of galaxies.



7. Discussion: Origin of Ellipticals

The global properties of ellipticals are mainly determined from the masses, while the metallicity gradients are much affected by the merging events. Merging histories can be inferred from the observed metallicity gradients of present-day Es. (The Galaxy with steep gradient is non-merger.) Es form through the successive mergings of galaxies with various masses, which looks like a major merger on one extreme end, and a monolithic collapse of slow-rotating gas cloud in the other extreme end. The observed metallicity gradients cannot be explained by either monolithic collapse only or major merger only. Both formation processes are required.

Future Work: If metallicity gradients are observed for field and cluster galaxies, it is possible to discuss the environmental effect on the galaxy formation.