Formation and Chemodynamical Evolution of Elliptical Galaxies

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1 Introduction

Two competing scenarios of the formation of elliptical galaxies have so far been proposed: [A] Elliptical galaxies should form monolithically by gravitational collapse of gas cloud with considerable energy dissipation (e.g., Larson 1974; Arimoto & Yoshii 1987), or [B] alternatively ellipticals should form via mergers of relatively small galaxies (e.g., Kauffmann & White 1993; Cole et al. 1994).

I construct the GRAPE-SPH chemodynamical model that includes various physical processes associated with the formation of stellar systems; radiative cooling, star formation, feedback of Type II and Ia supernovae, and of stellar winds, chemical enrichment, and UV background radiation (see Kobayashi 2002, PhD thesis, for the detail). By comparing the theoretical predictions with the detailed observations, I discuss the formation and evolution of elliptical galaxies.

2 Results

I simulate 72 slow-rotating spherical fields (spin parameter $\lambda \sim 0.02$), and obtain 124 galaxies (82 ellipticals and 42 dwarf galaxies) from the CDM initial fluctuation. Most stars of ellipticals form with the initial star burst at $z \gtrsim 2$, while dwarfs undergo relatively continuous star formation. All simulated galaxies have the de Vaucouleurs' surface brightness profiles. In my scenario, galaxies form through the successive merging of sub-galaxies. The merging history is various and the difference lies in the seed in the initial conditions. According to the merging histories, I classify ellipticals into 2 classes; [A] *Monolithic-like* (i.e., non-major merger): Galaxies form at $z \sim 3$ through the assembly of many subgalaxies with the stellar masses of $M \sim 10^{8-9}$. [B] *Major merger*: Galaxies undergo the major merger at $z \lesssim 3$ with the mass ratios of merging galaxies being $f \gtrsim 0.2$.

I reproduce the slopes of the relations among global properties, although the luminosities and surface brightnesses of the simulated galaxies are 10 times smaller than the observation: i) the Faber-Jackson relation, ii) the effective radius-surface brightness relation, iii) the fundamental plane, and iv) the mass/luminosity-metallicity relations.

I success in reproducing the observations of the radial metallicity gradients: i) The average of the oxygen gradients is ~ -0.3 and the dispersion is ~ 0.2, which are both consistent with the observations with the Mg_2 index (Kobayashi & Arimoto 1999). ii) For iron, the dispersion is ~ 0.2, and the average is ~ -0.4, which is steeper than oxygen. This is because the late star formation increases the iron abundance at the center. iii) No correlation between gradients and masses is produced. The metallicity gradients do not depend on the galaxy mass, and the variety of the gradients stems from the difference of the merging histories. At $M > 5 \times 10^9 M_\odot$, the galaxies that form monolithically have steeper gradients, and the galaxies that undergo major mergers have shallower gradients. The distributions for [A] non-major merger and [B] major merger galaxies are quite different.

3 Conclusions and Discussion

I simulate the chemodynamical evolution of a hundred elliptical galaxies using the GRAPE-SPH code. I reproduce the slopes of the correlations among global properties such as the fundamental plane and the mass-metallicity relation. Simultaneously, I reproduce the variety of the internal structures, i.e., no correlation between metallicity gradients and galaxy masses.

The global properties of elliptical galaxies are mainly determined from the galaxy masses, while the metallicity gradients are much affected by the merging events. Therefore, the merging histories can in principle be inferred from the observed metallicity gradients of the present-day galaxies. The observed variation in the metallicity gradients cannot be explained by either the *monolithic collapse* only or the *major merger* only. It is well reproduced in the present model where both formation processes arise based on the CDM scenario.