GRAPE-SPH Chemodynamical Simulation of Elliptical Galaxies II: The Origin of the Scatter of the Fundamental Plane

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1. Model

We simulate the formation and chemodynamical evolution of galaxies with 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, and chemical enrichment (Kobayashi 2004, hereafter K04). As discussed in K04, the galaxies of the K04 simulation are more extended, and the star formation parameter c should be reduced to make the star formation timescale longer. Here we show the results with $c = 0.1$, instead of 1.0 in K04. Initial conditions are the same in K04, where we adopt 1σ or 3σ over dense region of the CDM initial fluctuation with the comoving radius $r \sim 1.5$ Mpc, $M \sim 10^{12} M_\odot$ (baryon fraction of 0.1), $N \sim 10000$ and 60000, and the spin parameter $\lambda \sim 0.02$. In addition, we add a new sample of cD galaxies using a wider field with $r \sim 3$ Mpc and $N \sim 60000$.

From 79 fields with different cosmological initial conditions, we obtain 135 galaxies (9 cDs, 79 ellipticals, and 47 dwarfs). Different galaxies undergo different evolution histories. The difference is seeded in the initial condition. Galaxies form through the successive merging of subgalaxies with various masses, which varies between a major merger at one extreme and a monolithic collapse of a slowly rotating gas cloud at the other. We classify galaxies the simulated galaxies from the merging histories, where we define the major merger from the stellar mass ratio $f \equiv M_2/M_1 \gtrsim 0.2$.

2. Results

The variety of the merging histories in the CDM picture produces the observed variety of the metallicity gradients (K04). On the other hand, the observed elliptical galaxies follow the tight correlations among global properties. Here we succeed in reproducing the global scaling relations such as the Faber-Jackson relation, the luminosity-effective radius relation, and the surface brightness-effective radius relation from cD galaxies to dwarf ellipticals. The dispersion is also comparable to the observed one.

Figure 1 shows the fundamental plane shown in the κ-space (Bender et al. 1992), where the parameters κ_1, κ_2, and κ_3 express masses, surface brightnesses, and mass-to-light ratios, respectively. The κ_1-κ_2 diagram (lower panel) is the face-on view of the fundamental plane. There is no correlation between masses and surface brightnesses. The κ_1-κ_3 diagram (upper panel) is the edge-on view. There is a relation with a shallow slope; more massive ellipticals have large "mass-to-light ratios". This "mass-to-light ratio" is a value defined with σ_0, and is similar not to the total mass-to-light ratio but to the stellar mass-to-light ratio. The origins of the slope are high metallicity, old age, and large baryon fraction for massive ellipticals.

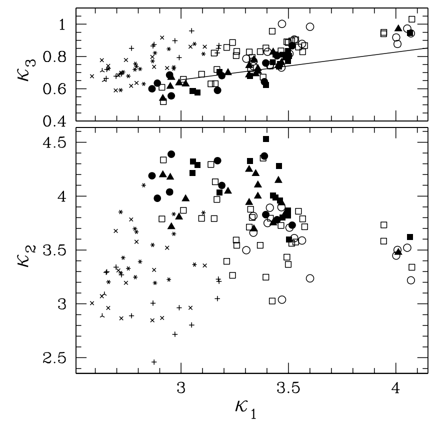

Figure 1: The fundamental plane shown in the κ-space; the edge-on view (upper panel) and the face-on view (lower panel). The symbols that show the merging histories for elliptical galaxies and star formation histories for dwarf galaxies are: [1] monolithic (filled circles), [2] assembly (filled squares), [3] minor merger (filled triangles), [4] major merger (open squares), and [5] multiple major merger (open circles); [D1] initial starburst (asterisks), [D2] continuous star formation (crosses), [D3] continuous star formation with recent star burst (plus), and [D4] recent starburst (three-pointed stars). The solid line shows the observed relation (Pahre 1999).

The intrinsic scatter exists along the fundamental plane. The origin of scatter is clearly shown with the symbols; merger galaxies (open symbols) have smaller κ_2 and larger κ_3 than non-merger ellipticals (filled symbols). In our simulation, the galaxies that undergo the major merger tend to have larger r_e and fainter I_e. There is no significant change in σ_0 and total luminosity L. From the definition, these result in smaller κ_2 ($\propto L\sigma_0^2 r_\mathrm{e}^{-5}$) and larger κ_3 ($\propto L^{-1}\sigma_0^2 r_\mathrm{e}$). Therefore, we conclude that the origin of the scatter along the fundamental plane is the difference in the merging history.

Kobayashi, C. 2004, MNRAS, 347, 740 (K04)
Pahre, M. A. 1999, ApJS, 124, 127