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Proceedings of Japan-France Seminar on Chemical Evolution of Galaxies

Formation and Evolution of Dwarf Elliptical Galaxy

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Evolution of the dwarf elliptical galaxy is considered with special attention to gas loss from the galaxy by supernova explosion. The dwarf elliptical galaxy is modeled as a spherical ensemble of gas clouds undergoing mass loss and its structural evolution is followed by N-body simulation. A significant fraction of the initial mass should have been lost from dEs. The characteristic structure of observed dEs is naturally explained if the gas is mainly ejected from the central region of the galaxy.

Keywords: dwarf elliptical galaxy, formation, evolution, dynamics.

§1. Introduction

Recently deep observations revealed the various nature of dwarf elliptical galaxies(dEs). In particular observations of dEs in Virgo cluster by Binggeli et al.1) and Ichikawa et al.2) provide a large number of samples of dEs. Their mean density are plotted against their mass in Figure 1 together with dEs in the local group, normal ellipticals and compact globular clusters (Saito3)). dEs form a characteristic sequence in this figure different from normal ellipticals; the mean density of dEs increases as the mass increases, contrary to the normal ellipticals.

The distinct properties of dEs to normal ellipticals are their low surface brightness, low central concentration and low metallicity.

In the present paper we examine the mass loss from galaxies as a possible mechanism to explain these observed characteristic properties of dEs. If a galaxy loses significant fraction of its mass, the decrease of the selfgravity due to mass loss causes expansion of the system to form an extended low density galaxy. If the gas is lost before enriched by heavy elements, only metal poor stars are left. In this way observed characteristic properties of dEs could be naturally understood as a result of mass loss from galaxies.

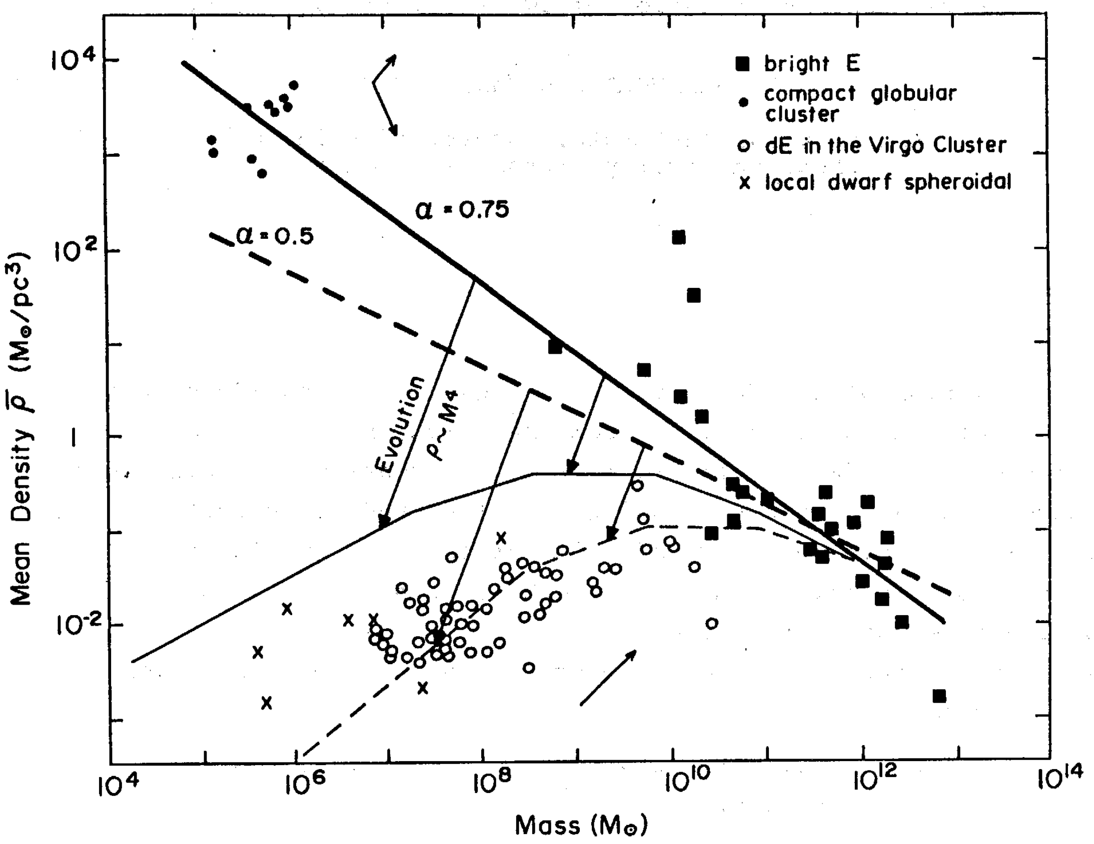

Fig. 1. Mean density($\bar{\rho}$) versus mass diagram originated by Saito[3] for bright ellipticals(■), compact globular clusters(●) and local dwarf spheroidals(×) added the data of dEs in the Virgo cluster(o) from Binggeli et al.[1].

§2. Gas Ejection by Supernova Explosions and Adiabatic Evolution of the Galaxy

The heating of the interstellar gas by supernova explosions has been investigated as a possible mechanism of mass loss from galaxies (e.g. Larson[4]). When the thermal energy of the gas exceeds the escape energy in the galaxy, the gas will be lost from the galaxy. Therefore the total amount of gas ejected from a galaxy can be calculated by equating the total thermal energy of the gas injected by supernovae with the total escape energy of the gas. Since the total thermal energy of the gas is proportional to the total mass of stars so far formed and the escape energy is proportional to $M_g \cdot M/R$, we can obtain a relation between the total ejected gas mass and the initial mass. The fraction F of the mass remained as stars to the initial total mass calculated using the parameters of the supernova heating given by Larson[4] is shown against the initial mass in Figure 2.

The ejected mass found to be quite large for galaxies with small mass; more than half of the initial mass is lost for galaxies of mass smaller than

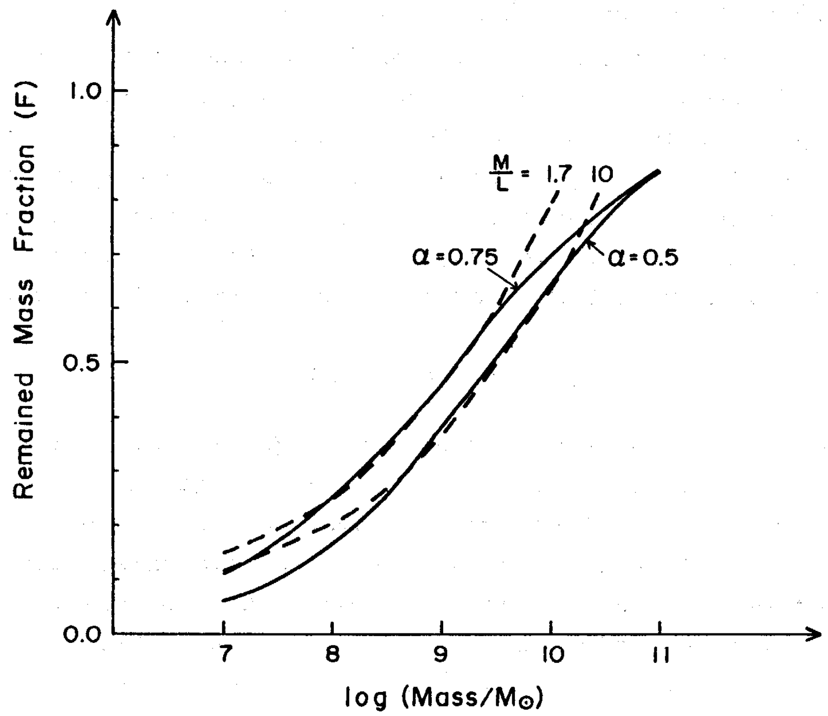

Fig. 2. Remained mass fraction (F) versus initial mass of the galaxy. The solid curves are derived by supernova heating and the dashed curves are derived by equations (1) and (2) for indicated M/L ratio.

about 10^9 $M_\odot$. If such a large amount of gas is lost from a galaxy, the gas loss is taken place adiabatically with time scale longer than the dynamical time maintaining the virial equilibrium, otherwise the system likely to be destroyed.

If mass is lost adiabatically maintaining the virial equilibrium, the product of virial velocity and the radius of the system is kept constant and hence the mean density and the remaining mass satisfy a relation as $\rho \sim m^4$ during the evolution. Thus the final mean density and mass of the system can be calculated for a given initial state.

As the initial state we adopt a dynamically equilibrium state whose mean density $\bar{\rho}$ and the mass m satisfy the relation $\bar{\rho} \sim m^{-\alpha}$, where α is a parameter. Saito$^{3)}$ obtained $\alpha = 0.75$ from mean density and mass of normal ellipticals and compact globular clusters (see Figure 1). In the present paper, however, α is treated as a parameter to be determined.

The final mean density and mass are shown in Figure 1 by solid curve for $\alpha = 0.75$ and dashed curve for $\alpha = 0.5$; initial states are indicated by the thick solid line for $\alpha = 0.75$ and by thick dashed line for $\alpha = 0.5$. The evolutionary path is indicated by arrows. The observed mean density of dEs is well reproduced for $\alpha = 0.5 \sim 0.75$.

§3. Structural Evolution due to the Gas Ejection

After such a significant mass loss considered above the structure could be largely changed, even though the system remains gravitationally bound. Next we investigate the structural evolution caused by the gas ejection, in particular how the central concentration changes as a result of mass loss.

The overall luminosity distribution of dE is best characterized by the central concentration index C. Ichikawa et al.[2)] found a correlation between C and absolute total magnitude M_{BT} for dwarf and normal elliptical galaxies as

$$M_{BT} = -5.18C - 9.24 \ . \qquad (1)$$

If the M/L ratio is constant throughout galaxies, this correlation can be transformed into a relation between C and mass of galaxy.

The protogalaxy is very likely to be clumpy gaseous system, so the galaxy can be modeled as a selfgravitating ensemble of collisionless gas clouds. With this assumption we examined the evolution of the luminosity profile and the central concentration index of dEs with mass loss by N-body simulation. For simplicity we consider a spherically symmetric system, so the model system is composed of gravitationally interacting spherical shells.

As the initial condition we adopt a dynamically steady state in virial equilibrium which is provided by a dynamically relaxed system after a collapse of uniform sphere with virial ratio of $|2T/W| = 0.08$. The surface density profile of this initial steady state is shown in Figure 3(a) and (b).

The ejection of the gas is realized numerically by reducing the mass of each shell with specified manner. Two cases of reducing the mass are considered:

Case I. $d\rho/dt \propto \rho$ (reducing the same fraction from each shell)
Case II. $d\rho/dt \propto \rho^2$ (reducing the mass mainly from the central region)

We did 8 simulations for Case I and 13 for Case II for various fraction of mass reduced and the final structure is analyzed when the system realized a steady state.

The typical final surface density profiles are shown in Figure 3(c) ∿ (f) and the concentration index C against F is shown in Figure 4. As seen in Figure 3(c) and (d), in Case I the surface density profile have hardly changed from the initial profile. On the other hand in Case II the surface density profile becomes exponential structure with low central concentration after the mass loss as is seen in Figure 3(e) and (f). In accordance with the change of the surface density profiles, C decreases as F decreases, while in Case I C does hardly change as F changes.

These result show that the low central concentration of luminosity observed in dEs can be explained by ejection of gas from the central region of the galaxy and the central concentration is correlated with the fraction of the ejected mass.

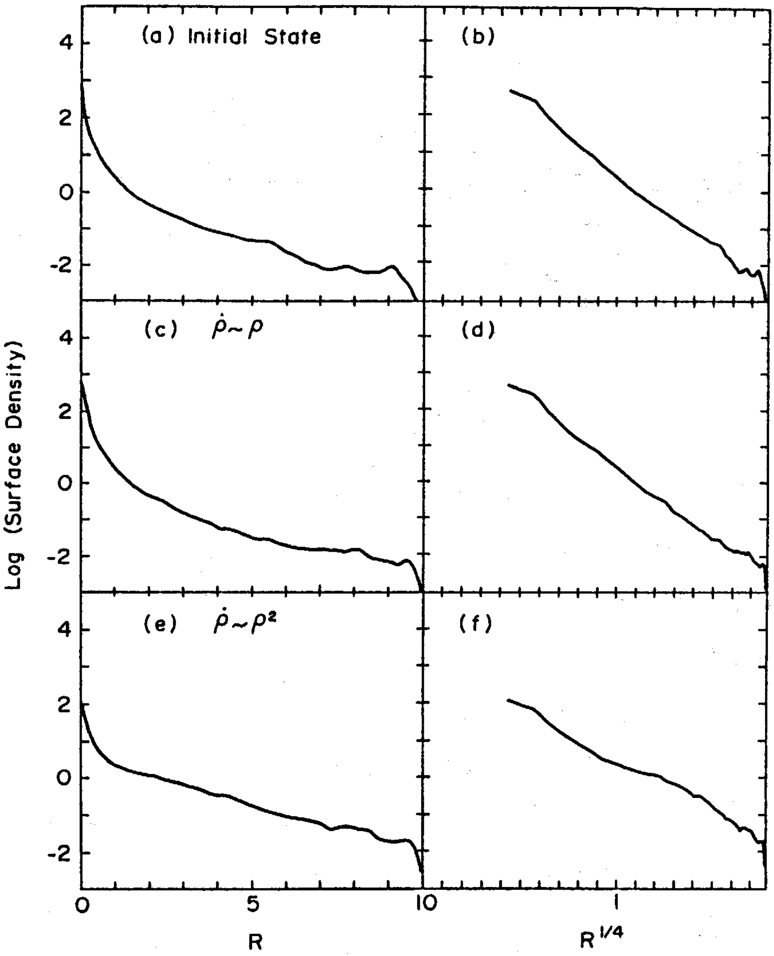

Fig. 3. The surface density profiles for the initial steady state (a) (b) and the typical examples of Case I (c)(d) and Case II (e)(f) in the linear scale R (left hand panel) and $R^{1/4}$ (right hand panel). The unit of the ordinate is arbitrary.

The least square fit to the concentration index C in Figure 4 for Case II is obtained for $F < 0.4$ as

$$C = 2.0 \,\mathrm{Log}\, F + 2.0 \ . \qquad (2)$$

If we eliminate C in equations (1) and (2), we can get a relation between F and M for a given M/L ratio. The relations between F and M for $M/L = 1.7$ and 10 are shown Figure 2 by dashed curves. The dashed curves thus obtained agree well with solid curves derived on the basis of gas loss by supernova explosion.

These results show that, if the mean density and mass of dEs satisfy $\rho \sim m^{-\alpha}$ with $\alpha = 0.5 \sim 0.75$ when they are formed, the mass ejection caused by supernova explosion from the central region of the galaxy and the resulting dynamical relaxation naturally explain the observed structural properties of dEs summarized in section 1.

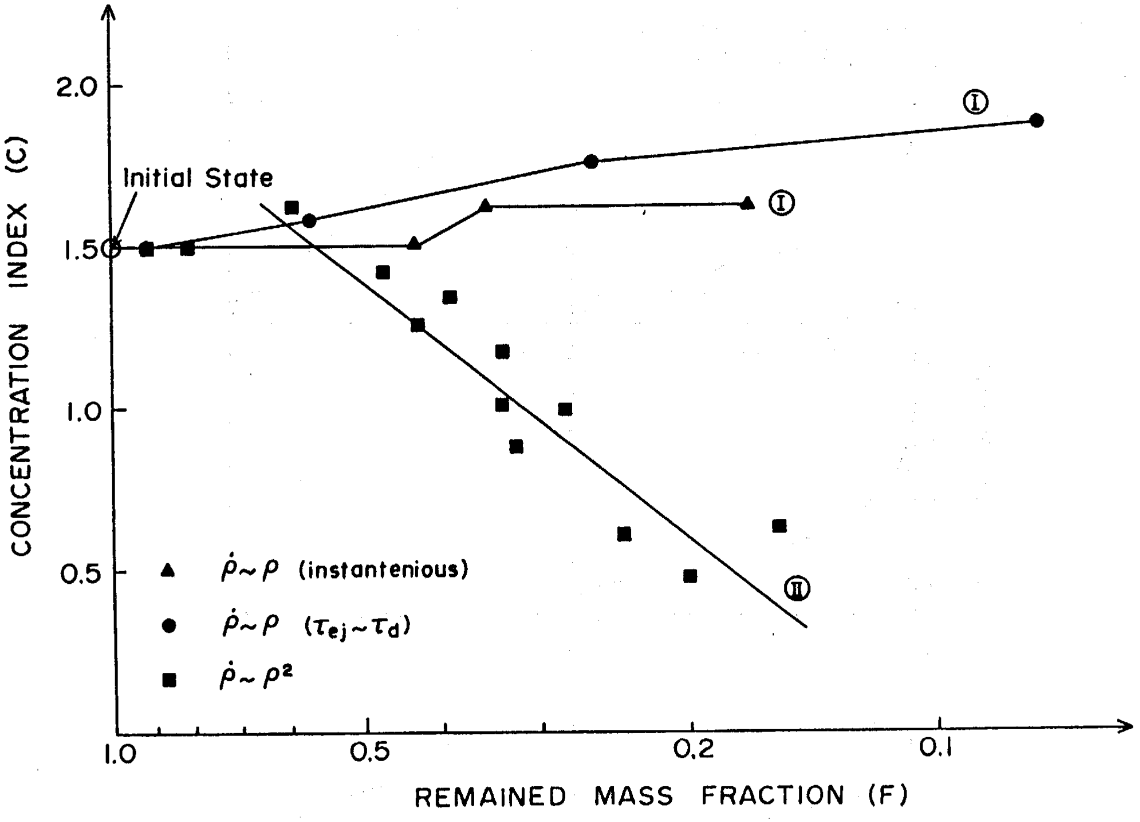

Fig. 4. Concentration index (C) versus remained mass fraction (F) for the two cases given by the figures in the circle. Initial state is given by open circle. For Case I two time scales of mass loss are considered instantaneous (▲) and dynamical time scale (●). The line for Case II is least square fit for F < 0.4.

§4. Chemical Evolution

Observations show the deficiency of metallicity of dEs compared with normal elliptical galaxies. For example [Fe/H] of Draco and Ursa Minor in the Local group is about -2.2. If the chemical evolution is followed by the simple model, such a small metallicity is generated before less than 1% of the gas is transformed into stars. Therefore there must be some mechanism to suppress the increase of metals in dEs. The suppress of metal enrichment may be possible if metal enriched gas ejected from stars directly escape from the galaxy. This is possible if the gas is very clumpy and gas density is low in the inter-clump space, so that the heated gas can flow out through inter-clump space before mixed with clump gas.

Another important point is reported by Yoshii[5)] in this conference that the metallicity of dEs can be higher if evolution of stars and selection effects are taken into account. If this is the case, no mechanics is needed to suppress the increase of metals in dEs in the present model.

§5. Dark Matter

In the above discussion no dark matter is considered. Even in the presence of dark matter, galaxies less than $10^{8.8}$ $M_\odot$ can eject gas more than half of their total mass by supernova explosions. In this case, however, the gaseous matter is likely not to be self-gravitating and the ejection can not change the structure of the galaxy significantly by dynamical relaxation.

If the dynamical relaxation is not effective, ejection of mass from the central region reduces the central concentration effectively. Therefore in order to explain the lower central concentration of matter in dEs, again, the gas should have lost mainly from the central region of the galaxy.

§6. Summary and Conclusions

If the dwarf ellipticals are formed as a clumpy gaseous system whose mean density and the mass satisfy a relation $\rho \sim m^{-\alpha}$ with $\alpha = 0.5 \sim 0.75$, the observed characteristic properties are naturally explained as a result of mass loss by supernova heating of the gas. The mass fraction of the ejected gas to the initial mass is quite large for galaxies of mass less than 10^9 $M_\odot$ and the gas is lost mainly from the central region of the galaxy.

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