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The Age and Number of Galaxies in Clusters: Are Galaxy Groups Unvirialized Galaxy Clusters?

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Abstract

The population and population composition of galaxies in galaxy clusters at present reflect the mass of the clusters and the mass growth of the galaxies in the past. We investigate them for six clusters. We show that galaxies in massive clusters stopped growing at redshifts of ~ 4. Moreover, we find that some small galaxy clusters (groups) have too many massive galaxies for their apparent masses. One possibility is that these groups are much more massive and in a phase just before virialization. If this is the case, they should be called 'infant galaxy clusters' that will be matured clusters in the dynamical time-scale ($\sim 10^9$ yrs).

1.1 Introduction

The mass distribution function (MDF) of galaxies absorbed into but not disrupted in a cluster tells us the *average* time when the galaxies stopped growing as follows. The mass of galaxies increases with time as matter accretes to them through gravity. As a result, the number of massive galaxies increases and the MDF evolves. However, as the potential well of the host cluster (or its progenitors) deepens as the cluster grows up, the released gravitational energy of the cluster allows the galaxies to move fast in the cluster. The large velocity of the galaxies prevents them from gathering more matter and the galaxies cannot grow anymore. Thus, the MDF freezes after that. The MDFs observed at present should depend on the time of the freeze. On the other hand, the integrated MDF or the galaxy population in a cluster depends on the host cluster mass; the more massive a host cluster is, the more massive galaxies are contained in it.

1.2 Models

Our model (SPS) is a further extension of the extended Press-Schechter model (EPS: Bower 1991; Bond et al. 1991) by taking account of the spatial correlation of initial density fluctuations (Fujita et al. 2002). The free parameters of the model are the mass of the host cluster and the average redshift when the galaxies stopped growing (z_f). In the following, we represent the mass of an object by its rotation velocity. Thus, we discuss the velocity distribution function (VDF) instead of the MDF.

1.3 Results

We calculate the VDF of galaxies in a cluster and compare them with the observations (Giovanelli et al. 1997a,b; Scodeggio et al. 1998). The details of the results are

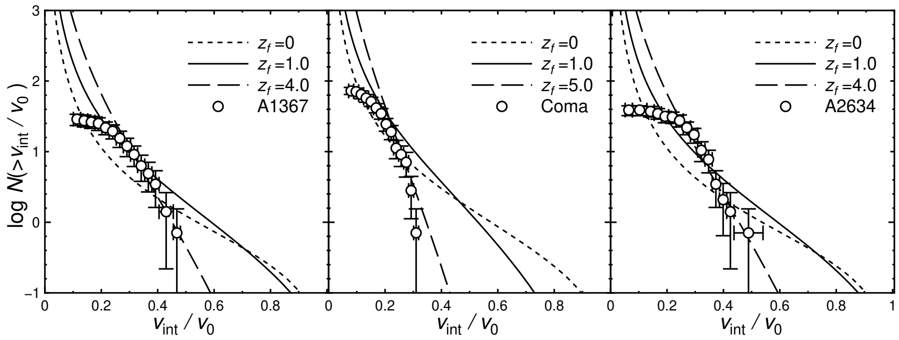

Fig. 1.1. The lines are the predicted VDFs of galaxies in massive clusters. The VDFs obtained by observations are shown by circles.

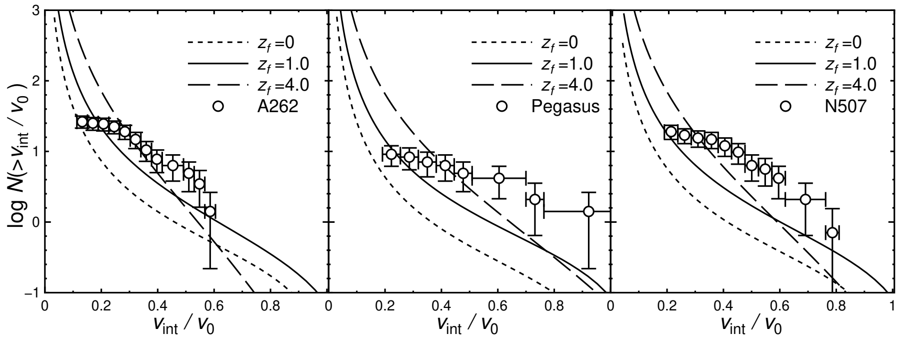

Fig. 1.2. The lines are the predicted VDFs of galaxies in massive clusters. The VDFs obtained by observations are shown by circles.

shown in Fujita (2003). We fix cluster masses at observed values and take z_f as a free parameter. Figure 1.1 shows that galaxies in massive clusters stopped growing at $z_f \sim 4$. The derived formation redshift of the cluster galaxies is comparable to the redshift of major star formation of early type galaxies in massive clusters (Kodama et al. 1998). Since most of the galaxies in our samples are early type galaxies, this explicitly shows that early type galaxies in massive clusters are very old and have not grown for a long time in terms of their masses as well as the stars in them.

Figure 3 shows the VDFs of galaxies in small clusters and groups. Our predictions are inconsistent with observations. The reason is that the numbers of galaxies in these clusters and groups are too large. The excess of galaxies suggests that the actual masses of these small clusters or groups are much larger than their apparent masses estimated on the assumption that they are relaxed and virialized. They may be 'infant galaxy clusters' just before virialization. In fact, if we assume that the masses of these clusters or groups are larger than the apparent values, the observations become consistent with the predictions.

1.4 Discussion

If the groups we investigated are infant galaxy clusters, we expect that they will relax and virialize within their dynamical time-scales ($\sim 10^9$ yrs). Considering the selection effect that groups having many galaxies in small regions can easily be observed, many of groups observed so far may be such infant galaxy clusters. In particular, compact galaxy groups such as the Hickson groups (Hickson 1982), which are small galaxy groups that are crowded with galaxies, are good candidates of infant galaxy clusters. Some of these groups may be collapsing and virializing at present. In fact, observations support the idea. First, the properties of compact groups (e.g. the X-ray luminosities or the spatial distribution of the galaxies) vary widely among the groups (Pildis et al. 1995; Ribeiro et al. 1998). This may reflect that we are seeing different dynamical stages of cluster or group evolution. Second, HCG 62, which is one of the Hickson groups, has hard X-ray emission (Fukazawa et al. 2001). This may be the result of gas accretion toward the group and the particle acceleration at the shock waves or in turbulence formed in the rapidly accreting gas; the accelerated particles could produce the nonthermal hard X-ray emission via inverse Compton scattering of photons (Fujita, & Sarazin 2001; Fujita et al. 2003). In the future, direct observations of matter distribution around groups through gravitational lensing will be particularly important to reveal the process of cluster formation. For example, diffuse density enhancement may be observed around some groups. It will also be important to compare the results of the SPS model with those of gravitational lensing, optical, and X-ray observations for many clusters and groups systematically to reveal the whole picture of cluster formation.

Finally, we note that Evrard et al. (1996) used cosmological gasdynamic simulations to investigate the accuracy of cluster mass estimates based on X-ray observations; they found that X-ray mass estimates are very accurate and the errors are 14%-29%. However, recent X-ray observations have shown that the structure of clusters is much more complicated than the results of numerical simulations done by Evrard et al. (1996) and have shown that many clusters have not fully relaxed. Recently, Chandra observatory found that clusters often have substructures with small X-ray temperatures called 'cold fronts' (Markevitch et al. 2000; Vikhlinin et al. 2001). These show that clusters often have dark halos with the scales of galaxy groups, which is also shown by recent ultra-high resolution simulations (Okamoto, & Habe 1999; Ghigna et al. 2000). For the three groups we investigated, the observations of X-ray temperature (or velocity dispersion of galaxies) might have been made only for possible central substructures, because it is often difficult to observe the X-ray temperatures (or the velocity dispersion of galaxies) of the relatively diffuse outer regions of the possible host clusters, especially when the host clusters are small. This could lead to the underestimation of the host cluster masses. The hard X-ray emission from HCG 62 may come from the diffuse hotter gas in the outer region of the cluster. If this kind of emission is observed in groups with an excess of galaxies, it would be an evidence that the groups are infant clusters.

1.5 Conclusions

We study the velocity distribution functions (VDFs) of galaxies in clusters. We show that galaxies in some clusters stopped growing at a very early time of the universe or redshift of ~ 4, which is comparable to the redshift of major star formation in early type galaxies in clusters. Moreover, we find that some galaxy groups have too many massive galaxies for their apparent masses. One possibility is that these groups are in a transient phase and are much more massive than their apparent masses. If this is the case, they should be called 'infant galaxy clusters' that will be matured clusters in the dynamical time-scale ($\sim 10^9$ yrs). Considering the selection effect for observations, many of galaxy groups observed so far may be such infant clusters.

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