Galactic satellite systems: radial distribution and environment dependence of galaxy morphology

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ABSTRACT

We have studied the radial distribution of the early (E/S0) and late (S/Irr) types of satellites around bright host galaxies. We made a volume-limited sample of 4986 satellites brighter than $M_r = -18.0$ associated with 2254 hosts brighter than $M_r = -19.0$ from the Sloan Digital Sky Survey Data Release 5 sample. The morphology of satellites is determined by an automated morphology classifier, but the host galaxies are visually classified. We found segregation of satellite morphology as a function of the projected distance from the host galaxy. The amplitude and shape of the early-type satellite fraction profile are found to depend on the host luminosity. This is the morphology–radius/density relation at the galactic scale. There is a strong tendency for morphology conformity between the host galaxy and its satellites. The early-type fraction of satellites hosted by early-type galaxies is systematically larger than that of late-type hosts, and is a strong function of the distance from the host galaxies. Fainter satellites are more vulnerable to the morphology transformation effects of hosts. Dependence of satellite morphology on the large-scale background density was detected. The fraction of early-type satellites increases in high-density regions for both early- and late-type hosts. It is argued that the conformity in morphology of galactic satellite system is mainly originated by the hydrodynamical and radiative effects of hosts on satellites.

Key words: methods: observational – galaxies: formation – galaxies: general – galaxies: interactions.

1 INTRODUCTION

Morphology reflects the integral property of a galaxy, such as stellar populations, gas content and dynamical structures. Its origin is one of the central problems in the study of galaxy formation and evolution. If a galaxy remains isolated after its formation, all of its physical properties would be entirely determined by the initial conditions of the protogalactic cloud and by the subsequent internal evolution. But, it seems unlikely because galaxies are believed to form through a series of minor/major mergers. In fact, the isolated bright galaxies in high-density regions are more likely to be recently merged ones and the morphology of galaxies contains imprints of interaction with environment in addition to the formation process (Park, Gott & Choi 2008).

There is observational evidence that shows an intimate correlation between the morphology of the central galaxy and its neighbours (Wirth 1983; Hickson et al. 1984; Ramella et al. 1987; Osmond & Ponman 2004; Weinmann et al. 2006; Park et al. 2008). Recent analysis of the morphology of Sloan Digital Sky Survey (SDSS; York et al. 2000) galaxies by Park et al. (2007, 2008) showed that galaxy morphology does depend on the large-scale background density but the role of the nearest neighbour is more decisive. The critical roles of the closest neighbour in determining galaxy morphology appear as the galactic conformity (Weinmann et al. 2006) between a galaxy and its neighbours. Galaxy morphology also depends on luminosity in that galaxy morphology is more likely to be early type for brighter galaxies. Since bright galaxies mainly live in high-density regions through the luminosity–density relation, it appears that early types are more prevalent at high densities.

Satellite systems are good places to inspect the environmental dependence of galaxy morphology and to study the galaxy formation process since they are abundant and very localized systems with a size of less than 1 Mpc. Most of the previous studies of satellite galaxies were focused on the radial distribution of satellite galaxies (Sales & Lambas 2005; van den Bosch et al. 2005; Chen et al. 2006, dark matter halo (McKay et al. 2002; Prada et al. 2003; van den Bosch et al. 2004)) and angular distributions (Zaritsky et al. 1997; Sales & Lambas 2004; Zentner et al. 2005; Yang et al. 2006; Bailin et al. 2007; Kang et al. 2007; Libeskind et al. 2007; Sales et al. 2007). The morphology of satellite galaxies is also an observable
The purpose of this paper is to study the relation between the morphology of satellite galaxies and the local environment such as the host morphology and background density. We use large and homogeneous morphology samples made by both visual and automated classifications. We see a tight correlation between the host and satellites morphologies. The satellite systems in our study are hosted by the typical bright galaxies, and are not, in general, large groups or clusters of galaxies. Our host sample is dominated by the $L_*$ galaxies, and their satellites are fainter by about two magnitudes.

2 DATA

2.1 Isolated satellite systems

The basic source of data is the large-scale structure sample (LSS), DR4plus, from the New York University Value-Added Galaxy Catalogue (NYU-VAGC; Blanton et al. 2005) which is a subset of the SDSS Data Release 5 (DR5; Adelman-McCarthy et al. 2007). The primary sample of galaxies used here is a subset of the LSS–DR4plus, which includes main galaxies (Strauss et al. 2002) with extinction corrected apparent Petrosian $m$ magnitudes in the range $14.5 < r_p < 17.77$ and redshifts in the range $0.001 < z < 0.5$. Our survey region covers 4464 deg$^2$, which is shown in fig. 1 of Park et al. (2007). To this primary sample, we added the galaxies brighter than the bright limit ($r_p = 14.5$) of the sample. Various existing redshift catalogues are searched for the redshifts of the bright galaxies with no spectrum. The catalogues include RC3 (de Vaucouleurs et al. 1991), Catalogue of nearby Galaxies (Tully & Fisher 1988) and updated Zwicky catalog$^1$ (ZCAT 2000 Version). In case of no measured redshift even in these catalogues, we used the redshift taken from NASA/IPAC Extragalactic Data base$^2$ (NED) when available. We added 5503 bright galaxies to the primary sample. The final data set consists of 370789 galaxies with known redshift and photometry. Throughout this paper, we use a flat $\Lambda$CDM cosmology with density parameters $\Omega_m = 0.27$ and $\Omega_\Lambda = 0.73$.

To search for isolated satellite systems, we take two steps. We first look for isolated galaxies in a volume-limited sample of galaxies brighter than the $r$ band absolute magnitude $M_r = -19.0 + 5\log h$ (hereafter we are going to drop the term $5\log h$) and with redshifts between 0.02 and 0.047. The lower redshift limit is chosen to make our sample as complete as possible since galaxies with $z < 0.02$ in the SDSS seem to be incomplete even though we supplemented bright galaxies (Park et al. 2007). The comoving space number density of galaxies is approximately constant in the radial direction at $z > 0.02$, but drops significantly at $z < 0.02$. The upper limit of $z = 0.04724$ corresponds to the survey limits of $r = 17.77$ for a galaxy with $M_r = -18.0$.

A target galaxy is isolated if the projected separation to its nearest neighbour galaxy is larger than the virial radii of both galaxies. The neighbours of a target galaxy with $M_r$ are those with absolute magnitude brighter than $M_r + 1.0$, and velocity difference less than 1000 km $s^{-1}$. We have also used the most influential neighbour instead of the nearest one for a comparison in the measurement of the projected separation $r_p$. Our results are basically the same for these two choices. The most influential neighbour is the neighbour which induces the highest local density at the location of the target galaxy. Given $r_p$ between them, we calculate the local mass density due to the neighbour with luminosity $L_n$ by

$$\rho_n = 3\gamma_n L_n / 4\pi r_p^3,$$

where we adopt the mass-to-light ratios $\gamma_n = 2$ for early types and 1 for late types. This choice is based on the morphology-specific central stellar velocity dispersion and on the pairwise peculiar velocity difference of early- and late-type galaxies with their neighbours (see Park et al. 2008, for more details). We define the virial radius of each galaxy as the radius where the mean density within the sphere centred at the galaxy given by equation (1) becomes the virialized density, which is set to 766 $h^{-1}$ kpc (see section 3.1 of Park et al. 2008). The mean mass density is obtained from $\bar{\rho} = \sum_n \gamma_n L_n / V$ where the summation is over all galaxies in our full volume-limited sample of volume $V$ with the absolute magnitude constraint $M_r < -18.0$. An early- or late-type galaxy with $M_r = -20$ has virial radius of 300 or 240 $h^{-1}$ kpc, respectively. For those with $M_r = -20.5$, the virial radii are 350 and 280 $h^{-1}$ kpc, respectively.

We found 8883 isolated galaxies in our volume-limited sample. They are physically isolated ones in the sense that they are not hydrodynamically interacting with neighbours. In all previous studies, isolation is determined by using a pre-selected fixed radius ignoring the physical size of individual galaxies involved. A blindly large radius of the isolation boundary results in too small sample size, while any fixed value in the right range results in contamination in the sample with interacting galaxies added.

Once the bright isolated galaxies are found, we search for satellites associated with them. We limit the satellite candidates only to galaxies with $M_r$ brighter than $-18.0$, a limit one magnitude fainter than that of the host candidates. This choice gives us a uniform and complete selection of satellites for host galaxies also uniformly and completely selected across our sample volume (see fig. 1 below). At each location of the isolated galaxies, we search for galaxies

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1 [http://www.cfa.harvard.edu/~huchra/~zc]
2 [http://nedwww.ipac.caltech.edu/]

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Figure 1. Our volume-limited sample of the host galaxies (red points) and satellites (blue). Upper and right panels show their number density distributions as a function of redshift and luminosity ($M_r$), respectively. The host distribution shows our sample boundaries in redshift. Some of the satellites lie beyond the redshift boundaries of the volume-limited sample because we allowed 500 km $s^{-1}$ difference in radial velocity between a host and its satellites.
with velocity difference less than 500 km s\(^{-1}\), absolute magnitude more than one magnitude fainter (but brighter than \(-18.0\)) and the projected separation less than the smaller of \(1\ h^{-1}\) Mpc and \(r_p\) (neighbour) \(- r_{\text{vir}}\) (neighbour), where the latter is the difference between the host neighbour separation and the neighbour’s virial radius. We used the Petrosian \textit{g} band absolute magnitude for satellite identification because \textit{g} magnitude is most similar to the \textit{B} magnitude that is used for some bright galaxies whose SDSS photometry is too poor to be used without correction.

Among the 8883 isolated galaxies, 2254 have satellites and the total number of satellites belonging to these systems is 4986. Fig. 1 shows the distributions of the host galaxies (red points) and satellites (blue points) in luminosity and redshift space. Upper and right panels show their number density distributions as a function of redshift and luminosity (\(M_L\)), respectively. The host distribution shows our sample boundaries in redshift. Some of the satellites lie beyond the redshift boundaries because we allowed 500 km s\(^{-1}\) difference in radial velocity in the search for satellites. The median absolute magnitude of the hosts is \(M_L = -20.47\), which is very close to that of the \(L_\text{r}\) SDSS galaxies (Choi, Park & Vogelez 2007). Therefore, the host galaxies of our satellite systems are dominated by normal bright galaxies, and are not in general the central \(cD\) galaxies holding the bright galaxies as satellites. The median absolute magnitude of our satellites is \(-18.67\). So they are not dwarf galaxies, but subluminous bright galaxies typically 1.8 mag fainter than their hosts. Since both our hosts and satellites are selected uniformly in the absolute magnitude space, our study of satellite morphology is unbiased against host and satellite luminosity.

### 3 PROPERTIES OF SATELLITE SYSTEMS

#### 3.1 Morphology and radial distribution of satellites

We measured the early-type fraction \(f(E_s | L_h)\) and surface number density \(\Sigma(E_s)\) of satellite galaxies as a function of projected distance \(r_p\) from the host galaxies. The top panel of Fig. 2 shows the early-type fraction of satellites associated with our isolated early-type hosts \(f(E_s | L_h)\) (filled circles) and isolated late-type hosts \(f(E_s | L_h)\) (open circles). The innermost bin is \(r_p < 37.8\ h^{-1}\) kpc, which corresponds to the fiber collision radius of 55 arcsec at the outer boundary \((z = 0.04724)\) of our volume-limited sample.

It can be noted that \(f(E_s | L_h)\) is significantly higher than \(f(E_s | L_h)\) at least out to about 350 \(h^{-1}\) kpc, which is roughly the virial radius of the typical early-type host galaxies analysed in this study. This result means that the morphology of satellites tends to be similar to that of hosts. It demonstrates the morphology–radius relation at the galactic scales. A similar finding was reported by Weinmann et al. (2006) for galaxies in groups and clusters, and by Park et al. (2007, 2008) for galaxy pairs. For late-type hosts, the early-type satellite fraction increases very slowly as satellites approach their hosts. Some of this effect must be due to the morphology–luminosity relation. The early-type hosts are in general brighter than the late-type hosts, and correspondingly the satellites of our early-type hosts are also on average brighter than those of late-type hosts due to our satellite finding process, i.e. more than one magnitude fainter relative to the host. Because of the morphology–luminosity relation, the morphology of early-type hosts’ satellites is, in general, earlier than that of late-type hosts’ satellites even if there is no direct physical influence of the host on satellites. We do not think this is the main reason for the host–satellite morphology correlation we found because the satellite morphology is a very strong function of host–satellite separation in early-type host systems and the early-type satellite fractions for early- and late-type hosts remain constant at \(r_p \sim 1\ h^{-1}\) Mpc.

Irrelevance of the morphology–luminosity relation to our findings can also be demonstrated by the early-type satellite fraction plot drawn for hosts with fixed luminosity. The middle and bottom panels of Fig. 2 show the early-type satellite fractions for host galaxies

\[ f(E_s | L_h) \]

Figure 2. Early-type fraction of satellite galaxies as a function of projected distance from host galaxies. In the top panel, satellites are divided into those associated with early- (filled circles) and late-type (stars) hosts. In the middle and bottom panels, satellites are further divided into those having magnitude difference with hosts greater than \(1.9\) (solid lines) and less than \(1.9\) but more than \(1.0\) (dashed lines).
brighter than $M_r = -20.5$ and fainter than $-21.0$, respectively. We allowed an overlap in $M_r$ to decrease the statistical fluctuations. We also divided satellites into a subset more than $\Delta M_g = 1.9$ mag fainter than the host and a subset more than 1.0 but less than 1.9 mag fainter. Drawn are the four cases of early-type hosts ($E_h$) and satellites with $\Delta M_g > 1.9$ (filled circles, solid line), $E_h$ and satellites with $1.0 < \Delta M_g < 1.9$ (open circles, dashed line), $L_g$ and satellites with $\Delta M_g > 1.9$ (stars, solid line) and $L_g$ and satellites with $1.0 < \Delta M_g < 1.9$ (crosses, dashed line).

The satellites with smaller $\Delta M_g$ are on average brighter than those with larger $\Delta M_g$, and are more likely to be early types in accordance with the morphology–luminosity relation. The mean level of $f(E_s)$ at very large $r_p$ is indeed higher for smaller $\Delta M_g$ satellites in both middle and bottom panels of Fig. 2. Once we subtract the dependence of this asymptotic value on host and satellite luminosity from these figures, interesting dependence of $f(E_s)$ on $r_p$ and host morphology becomes evident. The fraction of early-type satellites associated with early-type hosts, $f(E_s|E_h)$, depends on $r_p$ more sensitively for fainter satellites (compare the open and filled circles). This is true for both relatively bright (middle panel) and faint (bottom panel) hosts. It can also be noted from the middle and bottom panels that the outer boundary of the region of early-type host influence is farther for brighter hosts. The net effects of the late-type hosts on satellite morphology seem insignificant.

The satellites of early-type hosts are likely to be deprived of their cold gas through the hydrodynamic and radiative interactions with the X-ray emitting hot gas of their host. The satellites of late-type hosts are, in principle, able to get cold gas from their hosts although the hot gas in the halo of late-type hosts can also remove the cold gas in their satellites. Based on a detailed study of morphology–environment relation of galaxy pairs, Park et al. (2008) concluded that the galaxy morphology–local density relation is mainly due to the interaction between nearest neighbour galaxies. When galaxies are closer than their virial radii, they start to interact hydrodynamically and this causes the conformity in morphology of close galaxy pairs. The present results support their scenario, and this seems to be the origin of the morphology conformity in galactic satellite systems.

One major difference between our result and that of Park et al. is that the satellite morphology does not tend to be of late type as satellites approach a late-type host. The galaxy pairs in Park et al.’s sample are dominated by those with similar luminosity and therefore their interaction can affect physical properties of both galaxies significantly. On the other hand, in the current analysis satellites are typically 1.8 mag fainter than hosts, and the influence is largely lopsided from hosts to satellites. The slight rising tendency of $f(E_s)$ very close to late-type hosts can be because satellites are suffering from cold gas stripping and ionization by the host halo gas, but cannot actively catch the cold gas from their hosts as efficiently as companion galaxies having luminosity similar to the hosts.

The slopes of the surface density profiles also reflect the physical effects of their host galaxies on satellites. Fig. 3 presents the satellite surface number density profiles for early- (top panel) and late-type hosts. The ratio of two profiles in each panel gives the morphology fraction in the top panel of Fig. 2.

It demonstrates the number density profile of satellites critically depends on both host and satellite morphology. The surface density profiles show why $f(E_s|E_h)$ decreases more rapidly than $f(E_s|L_h)$. It is due to the dramatic drop in the surface density of early-type satellites hosted by early-type hosts $\Sigma(E_s|E_h)$, and to the slower drop of that of late-type satellites hosted by early-type hosts $\Sigma(L_g|E_h)$. This makes late-type satellites dominant in the satellite systems of early-type hosts at $r_p > 100 \sim 200 \ h^{-1} \ kpc$, where the exact location depending on the host luminosity and the host–satellite magnitude difference (see Fig. 2). In the systems hosted by late-type galaxies, late-type satellites are dominant at all $r_p$. The shapes of the surface density profiles of both early- and late-type satellites, $\Sigma(E_s|L_h)$ and $\Sigma(L_g|L_h)$, are similar to each other, making their ratio roughly constant of $r_p$. At large separations, $r_p > 600 \ h^{-1} \ kpc$, the surface densities of satellites belonging to early- (upper panel) and late-type (lower panel) hosts approach roughly the same ratio, resulting in $f(E_s) \approx 0.2$. This seems the field value of galaxy morphology for galaxies having absolute magnitudes similar to those of the satellites in our sample.

The morphology fraction shown in Fig. 2 is the result of projection of the three-dimensional distribution on the sky. In order to get a rough idea on the central morphology fraction, we try to deproject the profile as follows. We assume the radial number density of each of early- and late-type satellites follows a power law $\rho(r) = \rho_0 r^{-\gamma}$. Then, the projected density follows the form (Binney & Tremaine 1987).

$$\Sigma(r_p) = \rho_0 r_p^{-\gamma} \frac{1}{\gamma - 3} \int r_p^{-3} \left( \frac{\gamma - 3}{2} \right)^{\gamma - 2}.$$  (2)

The parameters in the fraction are obtained from a least-square fit to the innermost three points shown in Fig. 3 for each case of host and satellite morphology. Only two parameters are free. We found the slope of the three-dimensional profile is $-1.8 \sim -1.9$ at $< 200 \ h^{-1} \ kpc$ except for the late-type satellite associated with early-type host case, which has about $-1.5$. The true fraction of early-type satellites very close to early-type hosts is found to reach about 0.71 and 0.78 at $r = 30$ and $10 \ h^{-1} \ kpc$, respectively. On the other hand, the fraction for late-type hosts in three-dimensional is nearly the same as that shown in Fig. 2 because the slope of radial density profile is almost independent of satellite morphology in this case.
3.2 Background density dependence

As argued in the previous sections, the morphology conformity in galactic satellite systems seems to be due to the local effects of hosts on their satellites. However, the galactic conformity can be affected by the global environment as well as local one. Park et al. (2008) showed that, even though the morphology of galaxies depends mainly on luminosity and the small-scale environment due to the nearest neighbor, it also depends on the large-scale background density. The dependence of galaxy morphology on the large-scale density was found even when both the luminosity of the target galaxy and the environment due to the nearest neighbor were fixed. This was explained by the dependence of the hot halo gas of galaxies on the large-scale density. In this section, we look for a similar effect on galactic satellites.

We used the galaxy number density estimator defined by 20 nearest $L_*$ galaxies with $-20.0 > M_r > -21.0$ drawn from the full volume-limited sample:

$$\rho_{20}/\bar{\rho} = \sum_{i=1}^{20} W_i(|x_i - x|)/\bar{\rho}, \quad (3)$$

where $W(r)$ is a spline-kernel weight and $\bar{\rho}$ is the mean number density of the $L_*$ galaxies in the SDSS. This choice is the same as those used by Park et al. (2007). The median value of the effective Gaussian smoothing scale, corresponding to the adaptive spline smoothing, is $4.7 h^{-1} \text{Mpc}$.

The top panel of Fig. 4 shows the distributions of the large-scale density for early- (solid line) and late-type (dotted line) hosts. It can be seen that their distributions have nearly the same shape when log $\rho_{20}/\bar{\rho} < 0.8$. This is inconsistent with the fact that the early-type fraction is, in general, a monotonically increasing function of the local density (see fig. 5 of Park et al. 2007). A Kolmogorov–Smirnov (KS) test was performed to judge whether or not the distributions are consistent with the hypothesis that they are drawn from the same distribution. The KS test cannot reject the hypothesis at about 95 per cent significance level. This may be because the isolation constraint on hosts excluded more early types than late types in high-density regions. However, as can be seen in the bottom panel of Fig. 4, our isolated host sample still respects the luminosity–density relation.

![Figure 4](https://example.com/figure4.png)

**Figure 4.** Distributions of the large-scale background density at the location of our isolated host galaxies, divided into morphology subsets (upper panel) and luminosity subsets (lower panel).

Fig. 5 shows $f(E_s)$ as a function of the projected separation from host galaxies. We fixed the luminosity of host galaxies to $-20.5 > M_r > -21.5$ to separate the luminosity effects from the background density effects on galaxy morphology. The large-scale environment is divided into high- and low-density regions. The luminosity of hosts is fixed to $-20.5 > M_r > -21.5$.

![Figure 5](https://example.com/figure5.png)

**Figure 5.** Early-type fractions of satellite galaxies as a function of the projected distance from host galaxies. The top panel is for high-density regions and the bottom panel for low-density regions, respectively. The luminosity of hosts is fixed to $-20.5 > M_r > -21.5$.

Fig. 5 shows $f(E_s)$ as a function of the projected separation from the hosts in different large-scale background density regions. We fixed the luminosity of host galaxies to $-20.5 > M_r > -21.5$ to separate the luminosity effects from the background density effects on galaxy morphology. The large-scale environment is divided into high- and low-density regions with $\rho_{20}/\bar{\rho} > 2.2$ and $< 2.2$, respectively, where $\rho_{20}/\bar{\rho} = 2.2$ is the median density for our isolated hosts.

It can be seen in Fig. 5 that $f(E_s)$ is higher in high-density regions for both early- and late-type hosts with fixed luminosity. The background density seems to play a definite role in determining the morphology of galactic satellites. The background density can directly affect the satellites, or affect them indirectly through the host whose properties depend statistically on the background density. Park et al. (2008) found that the early-type galaxies in high-density regions have higher X-ray luminosity than those in low-density regions even when their optical luminosity is the same. This means that the hot halo gas of early-type galaxies is hotter and denser at high densities. Taking into account this finding, we interpret the background density dependence of the satellite morphology as due to the hydrodynamic and radiative effects of the hot gas of host galaxies on satellites. This is supported by the fact that even though $f(E_s)$ is generally higher in high-density regions in Fig. 5, it is so only when satellites are close to their hosts and $f(E_s)$ at $r_p$ much larger than the host’s virial radius is rather independent of the background density. If the background density directly affects the morphology of satellites, the satellite morphology should depend on the background density at all host-satellite separations. It can be also noted that $f(E_s)$ is higher for early-type hosts than for late-type hosts both in high- and low-density regions. Therefore, the conformity in morphology at galactic scales prevails in both high- and low-density environments.
The $f(E_s)$ in high-density environment decreases almost linearly with $r_p$ while $f(E_s)$ in low-density environment decreases nearly exponentially. It is surprising to see this background density dependence even if we fixed host morphology and luminosity. All $f(E_s)$ seems to converge at $r_p > 600$ $h^{-1}$ kpc. This is a scale a little larger than the virial radius of the host galaxies under consideration. The virial radii are about 280 and $350$ $h^{-1}$ kpc for late- and early-type galaxies with $M_1 = -20.5$. In the analysis of luminous galaxy pairs, the dependence of galaxy morphology on the neighbour’s morphology appears at separations of $r_p \lesssim r_{200}$ (Park et al. 2008). This was explained by the hydrodynamic interactions between the pairs within the virialized region.

Previous studies showed that the fraction of interlopers could be large at large $r_p$ (Prada et al. 2003) and that the interloper fraction depends on the colour of the satellites, with interlopers being rare amongst the red satellites, but making up about half of the blue satellites. If our satellite samples were dominated by interlopers at large $r_p$, the difference in $f(E_s)$ in high- and low-density regions could be simply due to the interlopers which respect the morphology–density relation. However, Fig. 5 shows that $f(E)$ converges to about 0.2 both in high- and low-density regions and both for early- and late-type host galaxies. Therefore, the satellites at large separations do not show the trends that are expected for the general background galaxies. This indicates our results are not significantly affected by interlopers.

4 DISCUSSION AND CONCLUSIONS

We have found the morphology–radius relation for galactic satellite systems. Early-type satellites are prevalent in the vicinity of early-type hosts. The origin of the conformity in morphology is thought to be the hydrodynamic and radiative effects of hosts on satellites in addition to the tidal (gravitational) effects.

The satellite morphology is found to depend on the large-scale background density. In high-density regions, the early-type fraction of satellites decreases relatively slowly beyond the virial radius of the host galaxy. However, in low-density regions the fraction of satellites with early morphological type drops sharply at separations of $r_p \sim 50 \sim 200$ $h^{-1}$ kpc for both early- and late-type host systems. As we fixed the mass of host galaxies by fixing luminosity and morphology, this difference must be coming from non-gravitational effects. It is argued that the hot halo gas of the host galaxies is responsible for the prevalence of early-type satellites in the vicinity of hosts, and that in high-density regions the hot halo gas can be more confined by the ambient intergalactic medium and has higher density and temperature, which can better deplete the cold gas in satellites more efficiently.

The galactic conformity found from the present sample of satellite systems is not much affected by the detailed selection criteria of the satellites. The magnitude difference between host and satellites is not critical because we obtained similar results for the satellite systems defined by different magnitude differences. Using the most influential neighbours instead of the nearest neighbours in identification of isolated hosts and satellites also did not make much difference. We also examined whether or not our results are affected by our isolation requirement for host galaxies, and found that all of our results qualitatively remain the same. We made exactly the same analysis for satellites defined for host galaxies which are not constrained to be isolated. In this analysis, a galaxy becomes a satellite if it finds a host galaxy within $r_p = 800$ $h^{-1}$ kpc that is more than 2 mag brighter and has velocity difference less than 500 km s$^{-1}$. If there is more than one such hosts, the closest one is chosen. Hosts are limited to $M_1 < -20.0$, and satellites have $M_1 < -18.0$. We found 8353 satellites in 3472 systems. We obtain basically the same results for these satellite systems as for the isolated ones but with much higher statistical significance. Therefore, our results are robust against various choices of parameters used to identify hosts and satellites.

In a forthcoming paper, we will study the shape and internal properties of satellites. Rather than dividing satellites into early and late types, we will adopt a new classification scheme that is more appropriate for the satellite galaxies. We found this is necessary because our satellite galaxies are fainter and located in the special environment given by the hosts compared to the normal bright galaxies for which the usual morphology classification schemes are developed.

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