HIERARCHICAL EVOLUTION IN POOR GROUPS OF GALAXIES

Ann I. Zabludoff1,2 and John S. Mulchaey3

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ABSTRACT

To examine the evidence for hierarchical evolution on mass scales of $\sim 10^{13} - 10^{14} M_\odot$, we apply a statistic that measures correlations between galaxy velocity and projected position (Dressler & Shectman) to data for six poor groups of galaxies, HCG 42, HCG 62, NGC 533, NGC 2563, NGC 5129, and NGC 741. Each group has more than 30 identified members (Zabludoff & Mulchaey). The statistic is sensitive to clumps of galaxies on the sky whose mean velocity and velocity dispersion deviate from the kinematics of the group as a whole. The kinematics of galaxies within $\sim 0.1 h^{-1} Mpc$ of the group center do not deviate from the global values, supporting our earlier claim that the group cores are close to virialization or virialized. We detect significant substructure (at $\geq 299.9\%$ confidence) in two of the groups with the most confirmed members, HCG 62 and NGC 741, that is attributable mostly to a subgroup lying $\sim 0.3 - 0.4 h^{-1} Mpc$ outside of the core. We conclude that at least some poor groups, like rich clusters, are evolving via the accretion of smaller structures from the field. With larger poor group surveys, the incidence of such accretion and the distribution of subgroup masses are potential constraints of cosmological models on mass scales of $\sim 10^{13} - 10^{14} M_\odot$ and on physical scales of $\sim 0.5 h^{-1} Mpc$.

Subject headings: galaxies: clusters: general — large-scale structure of universe

1. INTRODUCTION

The evolution of structure on different mass scales is one of the outstanding issues in cosmology. For example, although galaxy clusters of $\sim 10^{15} M_\odot$ (including Virgo [Binggeli 1993; Böhringer et al. 1994], Coma [Mellier et al. 1988; Briel, Henry, & Böhringer 1992; White, Briel, & Henry 1993], and Abell 754 [Zabludoff & Zaritsky 1995]) are clearly evolving from the accretion of smaller groups, it is uncertain whether poor groups of $\sim 10^{13} - 10^{14} M_\odot$ also evolve hierarchically. There is some indirect evidence that the evolution of poor groups is similar to that of rich clusters; the galaxies and hot gas in poor groups follow the same relationships found among the X-ray temperature, X-ray luminosity, and galaxy velocity dispersion for rich clusters (Mulchaey & Zabludoff 1998, hereafter MZ98). Historically, however, the number of known poor group members has been too small to examine individual groups for direct evidence of hierarchical evolution.

Multiobject spectroscopy now makes it possible to obtain “cluster-size” samples of galaxies in poor groups and to identify substructure, if it exists, in the same manner as for rich clusters. Substructure in clusters was not detected until the number of spectroscopically confirmed cluster members exceeded $\sim 30 - 50$ galaxies. Recent poor group surveys have reached this membership level (Zabludoff & Mulchaey 1998a and 1998b, hereafter ZM98a and ZM98b, respectively). The discovery of substructure in poor groups would provide new cosmological constraints by establishing that hierarchical evolution is occurring on mass scales of $\sim 10^{13} - 10^{14} M_\odot$ and on physical scales of $\sim 0.5 h^{-1} Mpc$. The detection of substructure would also support the picture in which at least some poor groups evolve as low-mass analogs to rich clusters.

In this Letter, we describe the results of applying a substructure statistic (Dressler & Shectman 1988, hereafter DS88) to the six best-sampled poor groups in ZM98a and ZM98b, the most detailed spectroscopic surveys of poor groups to date.

2. GROUP SAMPLE

In this analysis of substructure in poor groups, we consider six nearby systems ($3800 < cz < 7000$ km s$^{-1}$) drawn from our spectroscopic survey of 12 optically identified groups (ZM98a). We choose the six groups, HCG 42, HCG 62, NGC 533, NGC 741, NGC 2563, and NGC 5129, because each has more than 30 spectroscopically confirmed members (see ZM98a for the details of the membership algorithm). The group members range in absolute magnitude from the three or four brightest ($M \leq M^* + 4$) galaxies identified in past surveys to the large population of dwarfs ($M \leq M^*$) discovered in ZM98a. All six groups have X-ray halos extending out to radii of $\sim 200 - 300$ $h^{-1}$ kpc and X-ray temperatures of $\sim 1$ keV (MZ98). In this Letter, we use the galaxy velocity data from ZM98a combined with new velocities for 51 additional group members (ZM98b). The number of known members within $\sim 0.5 h^{-1}$ Mpc (approximately the virial radius) of each group center ranges from 35 to 63 galaxies.

3. RESULTS AND DISCUSSION

To search for substructure in the six poor groups, we use the method applied by DS88 to rich clusters. This test identifies a fixed number of nearest neighbors on the sky around each galaxy, calculates the local mean velocity and velocity dispersion of the subsample, and compares these values with the mean velocity and velocity dispersion of the entire group. The kinematic deviations of the subsamples from the global values are summed. This sum is larger for a group with a kinematically distinct subgroup than for a similar group without substructure.

For each galaxy $i$, the deviation of its nearest projected neighbors from the kinematics of the group as a whole is defined as $\delta_i \equiv (n^{1/2} \sigma_{i}) [(\bar{v}_{loc} - \bar{v})^2 + (\sigma_{loc} - \sigma)^2]^{1/2}$, where $\bar{v}$ is the mean velocity for the group, $\sigma_i$ is the group line-of-sight velocity dispersion, and $n$ is the number of nearest neighbors (including the galaxy) used to determine the local mean velocity $\bar{v}_{loc}$ and local velocity dispersion $\sigma_{loc}$. The total deviation for
Fig. 1.—For each group, the top panel shows the distribution of group members on the sky. There are 35 galaxies in HCG 42, 63 in HCG 62, 36 in NGC 533, 41 in NGC 741, 44 in NGC 2563, and 38 in NGC 5129. The dashed line in the NGC 741 and NGC 5129 fields is the survey boundary (see ZM98a). The second panel is the same as the top panel, except that the radii of the circles are scaled by $\delta$, where $\delta$ is the deviation of the nearest neighbors from the kinematics of the group as a whole. The third panel shows the results of the Monte Carlo trial (out of 1000) with the largest value of the Dressler-Shectman (D888) statistic $\Delta$. The bottom panel is the trial with the median value of $\Delta$. The scale bar below the bottom panel is $0.5\,h^{-1}\text{Mpc}$. 
the group is defined as the sum of the local deviations, \( \Delta \equiv \sum |\delta_i| \) for all \( i \leq N_{grp} \), the number of group members. As pointed out in DS88, the \( \Delta \)-statistic is similar to the \( \chi^2 \) statistic, except that the \( \delta_i \)'s are not squared before summation in order to reduce the contributions of the largest, rarest deviations. If the galaxy velocity distribution of the group is close to Gaussian, and the local variations are only random fluctuations, \( \Delta \approx N_{grp} \).

To calculate \( \delta \), we choose \( n = 11 \) (as in DS88). This choice allows robust determinations of \( \bar{v}_{loc} \) and \( \sigma_{loc} \). Silverman (1986) argues that using \( n \sim N_{grp}^{1/2} \) nearest neighbors (=6–8 for these groups) maximizes the sensitivity of such a test to small-scale structures while reducing its sensitivity to fluctuations within the Poisson noise (also see Bird 1994b). To check the robustness of the \( n = 11 \) assumption,
we compare the results below with those for \( n = 6 \). The conclusions drawn from the \( n = 6 \) and \( n = 11 \) cases are the same.

Calibration of the \( \Delta \)-statistic for each group is required because (1) the \( \delta \)'s are not statistically independent and (2) the velocity distribution may not be intrinsically Gaussian even if there are no subgroups (e.g., the group members may follow predominantly circular or radial orbits). We determine the significance of the observed \( \Delta \) by comparing it with the results of 1000 Monte Carlo trials in which galaxy velocities are drawn randomly from the observed distribution and assigned to galaxy positions. This scrambling technique effectively destroys any substructure (DS88). If the probability is low that a group without substructure has a \( \Delta \)-value at least as large as that observed, then we consider the substructure detection significant.

In two groups, HCG 62 and NGC 741, the observed value of \( \Delta \) is significant at the \( \geq 99.9\% \) confidence level. Such high \( \Delta \)-values might arise from substructure but could also result from smooth variations in the group’s velocity field (e.g., rotation or velocity shear; Malumuth et al. 1992) and/or from a dependence of \( \sigma \), on radius (Bird 1994b). ZM98a show that \( \sigma \) is constant out to radii of \( \sim 0.5 \, h^{-1} \) Mpc in the combined velocity dispersion profile for the sample groups. To determine whether substructure is in fact responsible for the high \( \Delta \)-values in HCG 62 and NGC 741, we examine the local deviation \( \delta \) for each group member. A concentration of large \( \delta \)-values on the sky indicates a kinematically distinct subgroup.

Figure 1 shows the projected spatial distribution of the group members for each group (top panel). The second panel shows this distribution with the radii of the circles weighted by \( e^d \) (as in DS88). Because each point is not statistically independent, a few very deviant galaxies can boost the \( \delta \)-values for a large number of nearby points. Therefore, a visual comparison with the Monte Carlo simulations is required to assess the significance of any structures. The third panel shows the results of the Monte Carlo trial (out of 1000) with the largest \( \Delta \)-value, or the greatest total deviation. The results of the trial with the median \( \Delta \)-value are shown in the bottom panel.

The significance of the seven large clustered circles to the northeast of HCG 62 and the five large clustered circles to the south of NGC 741 is high. In each case, the large \( \delta \)-values show that a subgroup not in equilibrium with the global group potential is the principal source of the significant \( \Delta \)-value. Each of the two subgroups lies a projected distance of \( \sim 0.3-0.4 \, h^{-1} \) Mpc outside of the group core.

On the other hand, the clustering of small circles within \( \sim 0.1 \, h^{-1} \) Mpc of all of the group centers indicates that the core mean velocity and velocity dispersion are similar to the global values for the group. This result suggests that the group cores are close to virialization or virialized and is consistent with the conclusions from our earlier studies of group dynamics (ZM98a; MZ98).

4. CONCLUSIONS

Of the six best-sampled poor groups of galaxies (each has more than 30 known members), two have significant substructure. In each case, the substructure detection is due mostly to a subgroup lying \( \sim 0.3-0.4 \, h^{-1} \) Mpc outside of the core. It is worth noting that we detect substructure in two of the groups with the most confirmed members (HCG 62 and NGC 741) and also that our substructure statistic (from DS88) is not sensitive to subgroups that are well superposed on the sky (Bird 1993, 1994a). These two points suggest that the fraction of poor groups with substructure is higher than the \( \sim 30\% \) reported here. We conclude that poor groups, like rich clusters, evolve hierarchically and that some poor groups are still accreting smaller structures today. In contrast, the cores of all of the poor groups (within \( \sim 0.1 \, h^{-1} \) Mpc) appear to be relaxed, an observation consistent with our earlier claims that the cores are close to virialization or virialized (ZM98a; MZ98). Deep spectroscopic surveys of groups in a large group sample would place limits on both the incidence of substructure and the distribution of subgroup masses, providing a new test of cosmological models on mass scales of \( \leq 10^{13}-10^{14} \, M_\odot \) and on physical scales of \( \leq 0.5 \, h^{-1} \) Mpc.

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3 Even the Local Group, which is less massive than these groups (\( \sim 4 \times 10^{12} \, M_\odot \) [Zaritsky et al. 1989] vs. \( \sim 10^{13.5}-10^{14} \, M_\odot \) [ZM98a]), is forming from the collapse of the Milky Way and M31 subgroups (Kahn & Woltjer 1959). There is also some evidence that AWM/MKW poor clusters (Albert, White, & Morgan 1978; Morgan, Kayser, & White 1975), which are typically \( \sim 2\times4 \) times more massive than these groups, have bound clumps at much larger radii (\( \geq 1-2 \, h^{-1} \) Mpc; Beers et al. 1995).

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