MORE BLUE GALAXIES IN THE COMA CLUSTER

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ABSTRACT

An examination of the spatial distribution of color and concentration-index selected samples of galaxies towards the Coma cluster has revealed the presence of a large population of early/mid-type blue galaxies. This concentration of galaxies is offset from the center of Coma, and displays an elongated distribution oriented perpendicular to the major axis of the Coma cluster. The majority of these galaxies for which published redshifts are available have redshifts consistent with membership in the Coma cluster. Published spectra are available for several of these galaxies; in all such cases, the spectra exhibit starburst or post-starburst (E+A) features. Explanations in terms of galaxy infall or galaxy interactions have difficulty matching the observed properties of this structure and its constituent galaxies.

INTRODUCTION

Blue galaxies have held a special place in efforts to understand the formation and evolution of galaxy clusters ever since Butcher & Oemler (1978) showed that their fraction increases dramatically for clusters of increasing redshift. Although often viewed as competing scenarios, it is likely that both ram pressure stripping by intercluster gas and galaxy interactions contribute to the presence of blue galaxies in clusters. The fraction of blue galaxies is then a measure of a combination of dynamical youth, depth of the cluster potential, hot gas fraction, and available supply of infalling galaxies.

The presence of substructure in clusters is usually taken as a sign of recent cluster-cluster or cluster-group mergers. Structures of blue galaxies in clusters very likely point to such activity as well. Several examples of peculiarities in the (x, y), (x, y, cz), and morphological distribution of Coma cluster galaxies are now known. In addition to the spatial segregation between early- and late-type galaxies (Dressler 1980), Kent & Gunn (1982), and Zabludoff & Franx (1993), have shown that within Coma late-type galaxies have a higher velocity dispersion than those of early-type. Zabludoff & Franx also find an offset in the mean redshift between early and late types. Bernstein *et. al.* (1994) present evidence based on the Tully-Fisher relation that many "Coma spirals" may not be located in Coma at all. In this contribution we discuss evidence for substructure in the form of a spatially coherent population of blue galaxies in Coma.

THE "BLUE BLOB" IN COMA

In Odewahn & Aldering (1995; hereafter OA95) we examined the spatial distribution of galaxies, in a 289 degree^2 region at the north Galactic pole, divided into subsamples based on their photometric properties. These galaxies are themselves a diameter-limited ($12''$) subsample taken from scans of POSS I obtained with the Minnesota Automated Plate Scanner. For each galaxy the O magnitude, O-E color, and image concentration index (CI) was measured after application of a density-to-intensity conversion to the pixel data. We showed in OA95 that the later two quantities are dependent on morphological type for this dataset. Pairs of smoothed surface-density maps respectively showing the upper and lower 40 percentiles of the color and CI data demonstrated that red or high-CI galaxies are significantly more clustered than blue or low-CI galaxies. This difference in clustering is what is expected from the morphology-density relation (Dressler 1980; Postman & Geller 1984) since, statistically, red or high-CI galaxies have early morphological types.

In these maps (cf. figure 17 of OA95), the Coma cluster is dominated by red, high-CI galaxies. The distribution of these galaxies is elliptical, with ellipticity ~ 0.3 and major-axis position angle of $\sim 70°$. Less prominent is an elongated concentration of galaxies in the blue galaxy map offset from the center of the Coma cluster by $17'$ W, $6'$ N and oriented roughly perpendicular to the Coma cluster. No corresponding feature exists in the low-CI map. The offset of this feature from the center of Coma and it's radically different orientation argue against it being the blue tail (either real, or induced by photometric errors) of the distribution of Coma cluster galaxy colors. We take this as evidence for a spatially concentrated population of blue, early/mid-type galaxies located in the direction of the Coma cluster.

We have dubbed this feature the "Blue Blob," or BB for brevity. As defined here, the BB contains 46 galaxies with diameter $\geq 12''$ and O-E ≤ 1.28 mag spread over an elliptical region extending $\sim 90'$ N-S and $\sim 50'$ E-W, centered $17'$ W and $6'$ N of Coma. The same region contains 100 galaxies with $\geq 12''$ and O-E ≥ 1.52 mag. The 6 degree^2 region centered on Coma defined in OA95 contains 461 galaxies, therefore the Blue Blob constitutes 10% of galaxies towards Coma.

REDSHIFTS & SPECTRAL FEATURES

To test whether the Blue Blob is comprised of actual Coma members, as opposed to fore/background galaxies, we searched ZCAT (Huchra *et. al.* 1993) and the recent deep redshift catalog of Biviano *et. al.* (1995). This search yielded 16 redshifts, 14 of which were consistent with Coma cluster membership and 2 of which were well beyond Coma. The magnitude distribution for galaxies with redshifts and for all BB galaxies is similar. In particular, brighter BB galaxies are only slightly overrepresented among galaxies with redshifts. Therefore, we conclude that roughly 88%, or 40, of the Blue Blob galaxies are likely members of the Coma cluster.

In examining the original redshift sources, we found that some came from the Caldwell *et. al.* (1993) spectroscopic study of early-type galaxies in Coma and the N4839 group. This study found a large population of starburst and post-starburst galaxies associated with the N4839 group. Of the 4 BB galaxies observed by Caldwell *et. al.*, 3 had starburst or post-starburst spectra; the remaining spectrum was too weak for a detailed analysis. Another 3 BB galaxies were among the 6 blue Coma galaxies studied by Bothun & Dressler (1986), all of which have starburst spectra.

Thus, in every instance for which spectra were published or analyzed in detail, galaxies in the BB were found to have starburst or post-starburst spectra. Given that only 16% of the Caldwell *et. al.* sample have abnormal spectra, this is unlikely to occur by chance. Extrapolation to the remainder of the sample indicates that the O-E ≤ 1.28 color selection is picking out starburst or post-starburst galaxies. Taken together, the redshifts, spectra, and imaging data allow a more complete discription of the BB as a population of starburst or post-starburst galaxies of predominantly early-spiral morphology forming a spatially coherent structure within, but offset from the center of, the Coma cluster.

Given that the BB is offset from Coma on the sky, we looked for evidence for a difference between the redshift distribution of Coma galaxies and those BB galaxies having redshifts. The BB galaxies were tested against two redshift samples using the Kolmogornov-Smirnov statistic. The first comparison sample was comprised of all ZCAT galaxies with $4000 \leq cz \leq 10000$ km s^{-1} within an 0.83×0.83 degree box centered on Coma. The second was the faint redshift sample of Biviano *et. al.* in the central $48' \times 25'$ of Coma covering the same redshift range.

TABLE I K-S Test of Redshift Distributions

Samples Compared	N Total	N Common to Both	– KS Results – D	$P(D)$
Blue Blob vs. ZCAT	166	12 (of 14)	0.29	0.21
Blue Blob vs. Biviano	213	2 (of 14)	0.36	0.05
Biviano vs. ZCAT	...	...	0.09	0.45

The results of these tests are given in Table I. Listed are the samples compared, number of galaxies in the non-BB sample, number of BB galaxies common to both samples, followed by the KS test results – the maximum difference in the cumulative distribution, D, and the probability, $P(D)$, that such a large value of D would occur by chance. The result is that the velocity distribution of those BB galaxies with redshifts is consistent with membership in the Coma cluster. The comparison between the BB and Biviano *et. al.* redshift distribution is on the verge of showing disagreement. However, caution is necessary as the Biviano sample is faint and may contain some galaxies not in the sample of OA95. We checked for evidence of a difference between the Biviano and ZCAT samples; most of our redshifts come from ZCAT so if the two redshift samples are different it could explain the poor agreement between the BB and Biviano redshift distribution. As the value of $P(D)$ in the last line of Table I shows, there is no disagreement between the redshift distributions of the Biviano and ZCAT samples. Presently the BB redshift sample is small – once redshifts are available for the remainder of the galaxies, differences in redshift distributions may emerge.

DISCUSSION

Inspection of the deep X-ray map of White *et. al.* (1993) fails to show any feature coincident with the BB. This, and the velocity concurrence of the BB with Coma, argues that the BB is not an infalling group. If the BB were an infalling structure of any consequence it would perturb the cluster potential and hence the X-ray surface brightness. Its orbit, if along the axis of the BB, would need considerable angular momentum to pass so far from the center of Coma. The X-ray extension from Coma to the N4839 group, and the enhanced population of starburst and post-starburst galaxies around N4839, may be the by-product of a recent collision or on-going merger (Burns *et. al.* 1994). However, the offset and misalignment of the BB with both the Burns *et. al.* trajectory of the N4839 group through Coma and the main group of the Caldwell *et. al.* star-forming galaxies suggests that the BB is unrelated to a putative N4839 collision/merger. If the blue galaxies are "sparked up" in the process of ram pressure stripping it seems that some correlation of the blue galaxies and the X-ray halo would occur, but this is not seen. A more quantitative analysis is required to determine whether this is a very strong constraint. In the case of galaxy interactions, both the density and relative velocities are important in setting the frequency and strength of interactions. Thus, under a merger scenario, the relative spatial distribution of BB and Coma galaxies offers little insight. For galaxy interactions, imaging data is more telling; the photographic and CCD images presently in-hand show no evidence that these galaxies are involved in mergers. Further interpretation is hampered by the small number of redshifts and the low-resolution ($3''$) of our imaging data. Additional observations should lead to a more satisfactory explanation for the BB. The ability to study the blue galaxy population in a nearby rich cluster should prove valuable in understanding substructure and the blue galaxy fraction in high redshift clusters.

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