MULTICOLOR PHOTOMETRY: A TOOL IN THE MORPHOLOGICAL CLASSIFICATION OF CLUSTER GALAXIES

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ABSTRACT.

We show that color-magnitude diagrams are a useful tool in estimating the morphological composition of clusters of galaxies with redshifts up to 0.7. Misclassifications between early and late type galaxies can be contained within 10% for Virgo-like or Coma-like morphological compositions and normal quality photometry.

1. INTRODUCTION

The study of the properties of distant clusters of galaxies (z>0.2−0.3) is hampered by the difficulty in obtaining redshifts for galaxies fainter than M*, and by the quality of the obtainable images, which preclude the morphological classification of most galaxies in the field. An improvement in this situation came with the advent of the *Space Telescope*: thanks to its higher angular resolution, it is now possible to get high quality images of distant clusters (Dressler 1993). Unfortunately this opportunity cannot be exploited in the study of large samples of clusters since such observations require long exposure times.

This work addresses the problem of the morphological composition of clusters of galaxies with the aim of assessing the reliability of the use of multicolor photometry obtainable with medium size telescopes to derive the relative populations of early and late type galaxies making up a cluster of known redshift.

The targets of our analysis are: (1) to give quantitative criteria to discriminate between early (i.e. E+S0+S0a) and late type galaxies (i.e. Sa+Sb+Sc+Irr), (2) to estimate our classification errors and (3) to predetermine the best filter set to use according to the cluster redshift in order to improve the classification.

To such purposes, we used a reference sample of morphologically classified nearby cluster galaxies and the computed k-corrections available in the literature to simulate clusters at different distances. The reference sample and the k-corrections employed are described in section 2, section 3 deals with galaxy morphological classification, while in section 4 our results are discussed.

2. THE REFERENCE SAMPLE

2.1 The Data

This work is based on a collection of galaxies taken from the CGCG catalogue (Zwicky et al. 1961-68) in the Coma cluster region (within a projected distance of 2 degrees from the X-ray center of the cluster taken at α=$12^h57^m30^s$; δ=+28°15′00") and in the Virgo cluster region (in the rectangular region $12^h<\alpha<13^h$; $0°<\delta<+18°$). 191 galaxies brighter than m_{pg}=15.7 were found in the Coma cluster and 164 brighter than m_{pg}=14.5 in Virgo. A higher threshold was chosen in the Virgo cluster in order to reject dwarf galaxies. 171 and 161 of these galaxies respectively have well defined morphological type from E to Irr. We searched in the literature (De Vaucouleurs et al. 1991 (RC3), Bothun et al. 1985 and Gavazzi, Boselli & Kennicutt 1991) the available photometry in the UBV system (Johnson & Morgan 1953) and we found data in the three bands for 70/171 and 102/161 objects respectively. The completeness is therefore 41% for Coma and 61% for Virgo, but this should not introduce any serious selection effect that could bias the results of our analysis. Total U,B,V uncorrected magnitudes are used throughout this work. The correction for extinction in our Galaxy is negligeable due to the high galactic latitude of Virgo and Coma. The K correction is also negligeable at the distance of these clusters (z=0.0037 and z=0.0232). No correction for internal extinction was applied. This choice is motivated by the fact that the aim of the following analysis is that of using nearby objects to simulate color-magnitude relationships in clusters at high (0.05–0.7) z. Due to the limited spatial resolution of the available observations, the inclination and the Hubble type of most of the faint members of such clusters cannot be confidently determined, making it impossible to correct magnitudes for internal extinction. Using the total B magnitude instead of the photographic one implies that the limiting magnitudes of our reference sample become m_B=14.2 and m_B= 16.3 respectively for Virgo and Coma cluster members. Assuming a distance modulus of 31.73 and 35.73 for Virgo and Coma ($H_\circ$=50 km s^{-1} Mpc^{-1}), these limits correspond to M_B=−17.5 and M_B=−19.4 respectively, i.e. 3.5 mag and 1.6 mag fainter than the typical M*.

2.2 K-Corrections

The k-correction is the magnitude difference between a redshifted and a non-redshifted spectral energy distribution when observed through a fixed spectral interval. K-corrections in the UBV photometric system were calculated, for different morphological galaxy types, by Pence (1976) and by Coleman et al. (1980).

These two sets of k-corrections agree only to the first order over the common range, because of the conceptual differences in the procedures followed by the different authors. Because of the difficulty in determining the ultraviolet spectral energy distribution of early type galaxies, Pence observed late F dwarf stars. On the contrary, Coleman et al. observed nuclear bulges of near and bright spiral galaxies (M31 and M81); this accounts for the differences in the k-corrections for early type galaxies. K-corrections for late type ones also differ somewhat in the two sets of data at the high redshift range. Although Coleman's corrections extend to higher redshifts (up to z=1), we preferred to use Pence's ones, as they are also computed for Sa-Sab galaxy types. In the last section, we will discuss how the alternative choice would have affected our results.

3. COLOR BASED MORPHOLOGICAL CLASSIFICATION

Since field and clusters show a different galactic population, any morphological classification of cluster galaxies without isolating them from the field yields results which approximate the real cluster composition only if the density contrast is quite strong (i.e., the rich cluster core regions). On the other hand, the use of field galaxy counts to evaluate field contamination (Thompson & Gregory 1980; Oegerle, Hoessel & Ernst 1986; Oegerle, Hoessel & Jewinson 1987; Lugger 1989) implies: (1) the more distant the cluster is, the lower the ratio of cluster to field galaxies becomes for equal limiting absolute magnitude of the cluster galaxies; (2) field galaxies can only be statistically removed, so that many interesting cluster properties may be strongly diluted. As in computing the Butcher-Oemler effect (1984), also in evaluating the cluster morphological composition, a method which allows to separate cluster and field galaxies on a one-to-one basis is highly preferable. Apart from measuring large numbers of redshifts, only the analysis of color-color diagrams provides a such a tool. Other authors (Garilli, Maccagni & Vettolani 1991; Garilli et al. 1992; Dressler & Gunn 1992) have already shown that cluster galaxies concentrate along a line representing the Hubble sequence in a color-color plane while field galaxies are much more spread in the same plane. This has been confirmed by simulating a field with the galaxies of our reference sample redshifted between z=0 and z=0.5 and comparing their positions on a color-color plane with the positions of a Virgo-like cluster at z=0.2. Thus subtraction of the field galaxies through the inspection of the color-color diagram (for instance, as described in Garilli et al. 1992), though leaving some residual contamination difficult to evaluate quantitatively, is the only viable method for the analysis of the cluster morphological composition, in the sense that it certainly allows us to work with all the cluster galaxies.

We know that early type galaxies are statistically redder than late type ones, but we cannot quantify the reliability of a classification based on this qualitative statement. Fig. 1, relative to early and late type galaxies of the Virgo and Coma cluster together, shows that the color overlap of these two classes of galaxies is quite large. The distinction between early and late type galaxies is more evident if two colors are simultaneously considered as in Fig. 2. Unfortunately, because of the color-magnitude effect, hereafter c-m effect (Visvanathan & Sandage 1977), the degree of mixing between the two classes of galaxies depends on the magnitude limit of the sample. In fact, as a consequence of the c-m effect, faint early type galaxies are bluer than bright ones; so, at faint magnitudes, a higher number of early type galaxies have the same colors as the bright late type ones. For this reason we chose to use color vs. magnitude diagrams in our classification method. Fig. 3 to 6 show $U-B$ or $B-V$ colors vs. B magnitude diagrams for the Virgo and Coma cluster galaxies when placed at different redshifts. In these diagrams, line a is the linear regression of the mode of the entire galactic population calculated in each magnitude bin. This line is representative of the early type galaxy locus. Line b, in Fig. 3 to 6, is 1σ bluer (the reference sample errors are ~ 0.1 mag in B and V and ~ 0.2 mag in U) than line a and can be used as the division criterium between the two morphological galaxy classes: galaxies which are above line b are considered early type ones, galaxies which are below are considered late type ones.

The use of this simple classification criterion, i.e. early type galaxies are the ones above line b, yields quite acceptable morphological classifications of clusters. In Table 1 we give the percentage of misclassified galaxies of our reference sample: column (1) is the cluster redshift; columns (2) and (3) indicate the percentage of misclassification for a Virgo-type cluster using respectively the $U-B$ and $B-V$ colors; columns (4) and (5) are as columns (2) and (3) but relative to a Coma-like cluster.

In Fig. 7 we give an example of the application of this method to the Abell cluster S0400 (z=0.32) after field galaxy subtraction (Garilli et al. 1992) and photometric transformation (Garilli, Maccagni & Vettolani 1991; Kent 1985) from the Gunn-La Silla (Pedersen 1988) to the Johnson photometric system. We find that early type galaxies are 61%, late type ones 39%, substantially as we already found (Garilli et al. 1992): the additional information is the degree of reliability of this morphological composition, since our simulations tell us that misclassifications are only 6%, in case of a galactic content similar to the Virgo one, or 1%, in case of a galactic content similar to the Coma one. The incompleteness in the reference sample should not affect these results: the reference sample is strongly biased towards late type galaxies, which are also the ones easier to be misclassified. Adding more ellipticals to the reference sample should, in principle, improve the reliability of the morphological classification method.

4. RESULTS AND DISCUSSION

The use of this simple classification criterion, i.e. early type galaxies are the ones above line b, yields quite acceptable morphological classifications of clusters. In Table 1 we give the percentage of misclassified galaxies of our reference sample: column (1) is the cluster redshift; columns (2) and (3) indicate the percentage of misclassification for a Virgo-type cluster using respectively the $U-B$ and $B-V$ colors; columns (4) and (5) are as columns (2) and (3) but relative to a Coma-like cluster.

We can not give a real demonstration that our tool is actually working for cluster of galaxies up to z=0.7; nevertheless, using Hubble Telescope data, we tested the reliability of our method at least in one case: CL0939+4713 (Dressler, 1993), cluster at z=0.4. According to Dressler's direct morphological classification, early type galaxies percentage is 46%, whereas our method applyed to his data yields a percentage of 58%. Our method (see Table 1) foresees that in doing this classification using the $B-V$ color for a Virgo type cluster we would missclassify 13.7%±3.7% of the galaxies (taking into account galaxy evolution). The percentage of misclassified galaxies is in fact 20.2±4.3. We believe this result to confirm the reliability of the proposed method in view of the substantial agreement with a direct morphological classification within the statistical errors and taking into consideration that we had to assume that the effect of the k-corrections is the same in the B,V and in the g,r systems. We further note that the reliability of a classification based on colors would improve using a bluer color (see Table 1).

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TABLE 1: Misclassification Percentages

(1) z	(2) VIRGO $U-B$	(3) VIRGO $B-V$	(4) COMA $U-B$	(5) COMA $B-V$
0.1	19%	7%	10%	0%
0.2	16%	7%	6%	0%
0.3	4%	6%	0%	1%
0.4	2%	12%	0%	4%
0.5	1%	7%	0%	1%
0.6	-	0%	-	0%
0.7	-	0%	-	0%

FIGURE CAPTIONS

Fig. 1: The distribution of the $U-V$ colors of the Virgo and Coma cluster galaxies in our reference sample, subdivided into late and early types.

Fig. 2: A color-color ($U-B$ vs. $B-V$) for the same galaxies: black dots are the early type galaxies.

Fig. 3: $U-B$ vs. m_B diagram for a Virgo-like cluster at different redshifts, when the morphology-dependent k-corrections are applied (see text). Black dots are the early type galaxies. Line a is the linear regression of the mode calculated over the entire galactic population in each magnitude bin, while line b is the same linear regression 1σ bluer. Note that in such a diagram the morphological types separate better as the redshift increases.

Fig. 4: Same as Fig. 3, but for the $B-V$ color.

Fig. 5: Same as Fig. 3, but for a Coma-like cluster.

Fig. 6: Same as Fig. 5, but for the $B-V$ color.

Fig. 7: Example of the application of the classification method illustrated in this paper to the cluster S0400: for all detected galaxies $B-V$ is plotted against m_B. Lines a and b have the same meaning as in Fig. 3.

Fig. 8: Differences in the color k-corrections (a) $U-B$, (b) $B-V$ between early and late type galaxies as a function of redshift, according to Pence (1976) and Coleman et al. (1980).