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BVRI CCD Photometry of Galaxies in Abell Clusters: Hubble Types From Undersampled Data

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Abstract. We have obtained BVRI CCD frames of the inner Abell radius of 14 Abell clusters as part of a survey that will eventually include 45 clusters with $0.03 < z < 0.08$. We report on how the colours and surface brightness profiles can be used to identify galaxy Hubble type despite having rather large (2.1 arcsec) pixels and small images.

1. Introduction

Virtually any analysis of galaxy cluster phenomena benefits from knowing the positions, redshifts, magnitudes, colours and morphologies of the cluster members. Much effort is going into obtaining redshifts of cluster members (Dressler & Schectman 1988, Huchra et al. 1990, Teague et al. 1990, Struble & Rood 1991). However, the growth of basic photometric and morphological data is lagging behind. Photometric surveys similar to the redshifts surveys are needed to make the redshift data more meaningful (cf. Sandage 1988; Huchra 1990). Single colour photographic surveys that examine galaxy luminosity functions have been done (e.g. Dressler 1978, 1980; Lugger 1986, Oegerle & Hoessel 1989; Colless 1989), but multicolour CCD photometric surveys are just now being undertaken. Schmidt telescopes equipped with CCDs are ideal for this task even if the fields of view are restricted by small CCD sizes. Multicolour photometry of rich galaxy clusters is an important future use of Schmidt telescopes.

We have undertaken a CCD BVRI photometric study of galaxies in 45 relatively close ($0.03 < z < 0.08$) Abell clusters. The goals of this study are to see how multicolour optical photometric measurements of individual cluster galaxies relate to: (i) the Rood-Sastry (RS) cluster morphological classification, (ii) a cluster's position within a supercluster, and (iii) the cluster X-ray morphology. The ultimate goal is to learn more about the nature and past history of rich clusters by seeing how their individual galaxies are similar and/or different. Our survey builds upon previous data that are already obtained or are being obtained. For example, we are using the Hubble types compiled by Dressler (1980) as morphological standards, we use the Minnesota APS scans of the Palomar survey for positions and, when possible, we use redshifts from the literature to verify cluster membership.

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2. Survey Data

We are using the CWRU/NOAO 24/36″ Burrell Schmidt telescope located at Kitt Peak Arizona to obtain the data. This telescope was retrofitted in 1990 with a CCD mounted at the Newtonian focus. We use the S2KA CCD 2048 × 2048 detector and a Bessell (1990) filter set. The S2KA detector gives a resolution of 2.1 arcmin/pixel and a circular unvignetted field of approximately 1° in diameter. When the vignetting problem is fixed in the spring of 1994, the total usable area will be 1.2 square degrees.

We take our data in five settings per cluster. One frame is centred on the cluster and the four others form the quadrants of a square also centred on the cluster. Our total areal coverage per cluster is a square that is 100 arcmin on a side. The centre frame is taken under photometric conditions but the peripheral frames need not be since they can be calibrated from the overlap with the centre frame. This way we can obtain absolute photometry for the entire cluster while requiring that just 20 % of the nights be photometric. In addition to serving as the photometric calibrator, the centre frame assures that the cluster centre will be measured on the best portion of the chip. The defined size of an Abell radius is 1.7′/z or 2.3 Mpc for $H_0 = 75\ km\,s^{-1}\,Mpc^{-1}$. For clusters at a redshift of 0.03 this is 56.7′. Our areal coverage extends to an Abell radius for all but 4 of the 45 clusters.

Data are taken in sets of VRI and sets of BV giving a double exposure in V. This scheme assures that most cluster members are observed four times in V (twice with a centre frame and twice with a periphery frame) which enables us to test the reproducibility of our photometry and profile fitting and obtain an accurate estimate of errors. We expose 20 minutes in each filter except B which is twice as long. We estimate that our frames are complete to V = 19 mag.

3. Data Analysis

We have completely surveyed 14 clusters to date. IRAF is used to obtain a sequence of magnitude versus aperture radius in steps of 1.03 arcsec for each galaxy brighter than V = 19. These data are extrapolated to obtain an asymptotic magnitude. The magnitude data are transformed to counts/arcsec^2 and fit with a surface brightness relation given by

$$log_{10}[\Sigma(r)/\Sigma_0] = -(r/r_s)^{1/\beta}$$

where $\Sigma(r)$ is surface brightness as a function of radius, Σ_0 is the central surface brightness, r is the radius from the centre, and r_s is a core radius. This relation has been used to approximate the surface brightness of spiral or elliptical galaxies by choosing an appropriate β and fitting Σ_0 and r_s respectively (Mihalas & Binney 1981). However, we let β as well as Σ_0 and r_s be free parameters in the fit. The magnitude within a 25 mag/arcsec^2 circular aperture ($m25$) is found from the actual data. The fit is used to calculate an asymptotic magnitude (m_a) and the magnitude (mr_s) within the core radius r_s.

We currently use circular apertures for all objects regardless of ellipticity. This should cause inclined spirals to have smaller values than face-on spirals because at large radii, the measured surface brightness falls off quickly as much of the aperture fills with sky and not object. This effect should cause the $m25$ but not the m_a values to be affected by inclination. In practice the $m25$ values correlate closely to the m_a values because 25 mag/arcsec^2 is essentially at the edge of the objects. Still, for our analysis we use m_a. One sigma errors in m_a and mr_s, as judged by their reproducibility in V, are 0.04 mag at V = 15.5 increasing to 0.14 mag at V = 18.5. The errors in β are approximately 15%.

The values for β correlate with Hubble type but there is considerable overlap. Fig. 1(a) is a plot of β(V) versus β(R) for 71 galaxies in Abell 2657. Symbols represent the galaxy Hubble types published by Dressler (1980) in accordance with the legend. Assuming no error in the Dressler values, this figure shows that the β values in V and R are essentially equivalent and either value is about 65% effective at separating ellipticals and S0s from spirals. Ellipticals are mingled with the S0s although the ellipticals tend to have the smallest β values as expected and the general trend is from elliptical to S0 to spiral as β increases. However, β by itself is not very useful as a Hubble-type delineator.

Fig. 1(b) is a plot of B−I versus β(V). The addition of colour information improves the spiral separation success rate to 90% if the objects at $1.9 < \beta < 2.1$ are regarded as S0/spirals. The two S0s in the spiral region are both interacting with nearby companions. It is possible that tidally stripped debris (causing an increase in β) together with an elevated star formation rate (causing a decrease in B−I) may be responsible for moving them to the lower right of the graph. The elliptical in the S0/spiral region is also interacting with a companion and may also have an unusually large β as a result. The one elliptical galaxy with B−I = 1.4 is too blue for an elliptical and either has very large [OII] emission or should be classified as a blue compact object. It is near the cluster centre and may have been altered by gas infall or some other effect from being in a rich, collision-prone environment. Likewise, the spiral with B−I = 3.1 and $\beta = 1.57$ is very red and compact for a spiral and is either mistyped or significantly altered by the environment.

Ellipticals stay intertwined with S0s on this plot. However, their ellipticities generally are smaller than the S0 ellipticities and some further separation may be made this way.

4. Conclusions

Many of the galaxies for which we have fits are very small, having diameters of only 6–10 pixels. Yet the scatter in their β values from filter to filter or night to night is only on the order of 15%. Spatially undersampling is an advantage in that it compensates for variable seeing causing the β values to be more stable. For spirals and S0s, the correlation between Hubble type and β versus colour is quite good. It is not 100% but this is not expected since all galaxies simply do not fit nicely into morphological bins. The scatter in Figs 1(a) and 1(b) reflect this. Our goal is not to reproduce the Hubble sequence but, rather, to discover a statistic that can be used to explore the nature of galaxies at various locations inside a cluster and between different clusters. Plots of β versus colour look very promising as such a statistic and may, in fact, be more meaningful than a traditional Hubble type assignment since it requires no subjective judgements.

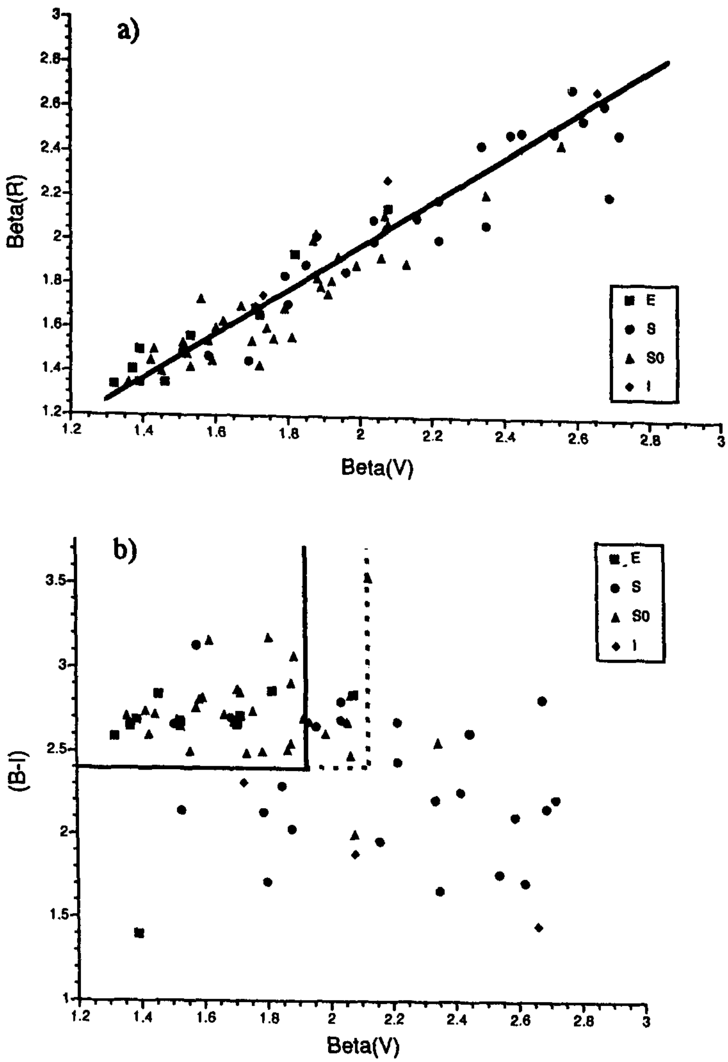

Figure 1. (a) Plot of V vs R for 71 galaxies from Abell 2657. Hubble types are according to the legend. The line has a slope of 1.0. (b) V vs B−I for the same galaxies. The upper left box delineates the realm of ellipticals and S0s. The dashed box delineates the spiral/S0 transition region.

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It is also an effective way of identifying unusual objects for further study such as the blue compact object and the interacting S0s.

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Discussion

Armandroff: The nebula around the Abell cluster that you've found is very interesting. One point that I failed to note in my talk: Cutri and Guhathakurta, who are studying high-latitude dust clouds using Schmidts and CCDs, find them to be very common and argue that they may limit deep studies of extragalactic objects.

Moody: They may well be correct. Our survey found this one nebula covering one half of Abell 2657 at $b = 50°$ in an area of the sky that the Burstein Heiles maps say should only have a reddening of 0.01 mag. I would guess that the reddening here is clearly greater than that.

Drinkwater: Can you comment on the prospects of using your parameterisation of morphological type with photographic Schmidt data.

Moody: The prospects are excellent. Any two colours will work, although B−I is best because it is least sensitive to emission lines. Of course, you must digitize one of the plates to get β values.