

Deep, Wide-Field, Multi-Band Imaging of $z \approx 0.4$ Clusters and Their Environs

David R. Silva and Michael J. Pierce (NOAO/KPNO)

The existence of an excess population of blue galaxies in the cores of distant, rich clusters of galaxies, commonly referred to as the "Butcher-Oemler" effect (Butcher and Oemler 1978,1984) is now well established. Spectroscopy of clusters at $z = 0.2-0.4$ has confirmed that the luminous blue populations comprise as much as 20% of these clusters (Dressler & Gunn 1983; Dressler, Gunn, & Schneider 1985; Lavery & Henry 1986,1988; Couch & Sharples 1987). This fraction is much higher than the 2% blue fraction found for nearby rich clusters, such as Coma, indicating that rapid galaxy evolution has occurred on a relatively short time scale.

Spectroscopy has also shown that the "blue" galaxies can basically be divided into three classes: "starburst" galaxies with large [OII] equivalent widths, "post-starburst" E+A galaxies (i.e. galaxies with strong Balmer lines shortward of 4000\AA but elliptical-like colors), and normal spiral/irregulars. Unfortunately, it is difficult to obtain enough spectra of individual galaxies in these intermediate redshift clusters to say anything statistically meaningful. Thus, limited information is available about the relative numbers of these three classes of "blue" galaxies and the associated E/SO population in these intermediate redshift clusters.

More statistically meaningful results can be derived from deep imaging of these clusters. However, the best published data to date (e.g. MacLaren *et al.* 1988; Dressler & Gunn 1992) are limited to the cluster cores and do not sample the galaxy luminosity functions very deeply at the bluest wavelengths. Furthermore, only limited spectro-energy distribution data is available below 4000\AA in the observed cluster rest frame providing limited sensitivity to "recent" star formation activity.

To improve this situation, we are currently obtaining deep, wide-field UBRI images of all known rich clusters at $z \approx 0.4$. Our main objective is to obtain the necessary color information to distinguish between the E+S0, "E+A", and spiral/irregular galaxy populations throughout the cluster/supercluster complex. At this redshift, UBRI correspond to rest-frame $2500\text{\AA}/\text{UVR}$ bandpasses. The rest-frame UVR system provides a powerful "blue" galaxy discriminator given the expected color distribution. Moreover, since "hot" stars peak near 2500\AA , that bandpass is a powerful probe of recent star formation activity in all classes of galaxies. In particular, it is sensitive to ellipticals with "UV excess" populations (MacLaren *et al.* 1988).

By going deep ($S/N = 10$ at $B = 23.5$), we are sampling the luminosity function of the elliptical, S0, and spiral galaxies well enough to investigate population differences within a class as a function of luminosity/mass. Given the extreme density contrast of these clusters and a 23 arcmin field-of-view, purely statistical arguments can be used to establish cluster membership. The large field-of-view also allows the investigation of the extended cluster/super-cluster associated with the observed cluster cores. These "field" data are directly relevant to issues regarding the evolution of faint blue galaxies.

Selected results for CL0939+4713 ($z = 0.41$) are presented on the next page. These data were acquired on 1992 Feb 28 UT at the KPNO 0.9m with a thinned Tektronix 2048² CCD (T2KA). The U, B, and R total integration times and 2.5σ detection limits were 7.5 hours/26 mag, 3 hours/25 mag, and 1.25 hours/26 mag, respectively. Only data from the central 12x12 arcmin (5×5 Mpc; $H_0 = 100$, $q_0 = 0.1$) field are discussed here. The central wavelengths of these U, B, and R data correspond to approximately 2550\AA , 3070\AA , and 4640\AA , respectively, in the rest-frame of this cluster. The raw data was processed using standard IRAF reduction tasks. Galaxy/star discrimination and photometry were done with FOCAS.

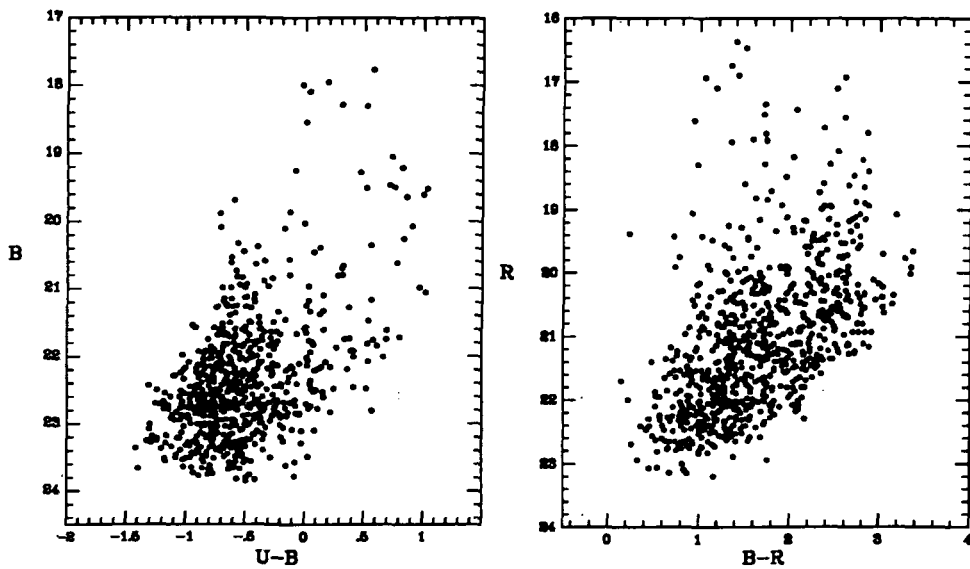


Figure 1 Color-Magnitude Diagrams. CMDs for all objects classified as galaxies by FOCAS with color uncertainties less than 0.2 mag. While some of the brighter galaxies are clearly foreground objects, the majority of the galaxies shown must be at the redshift of the cluster (see the radial distribution plot below). The galaxy colors are uncorrected for redshift or reddening. The "zones of avoidance" in the lower right corner are due to the adopted photometry cutoff in the bluer filter in each diagram. A large population of faint, blue galaxies is evident in both figures.

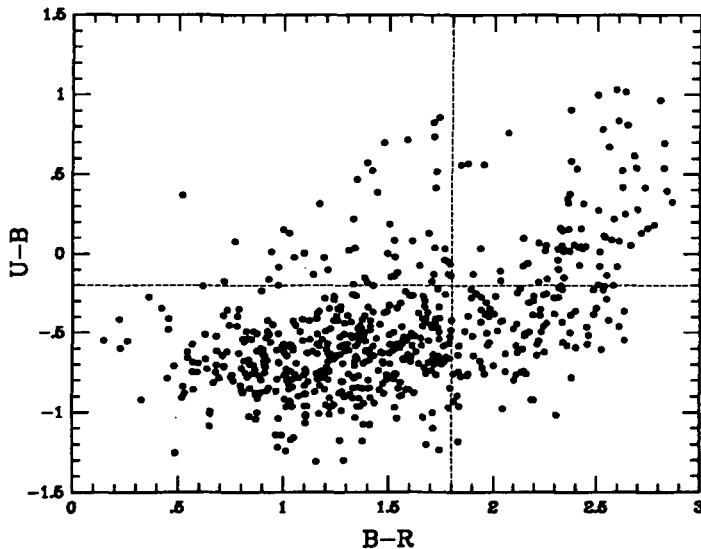


Figure 2 Two Color Diagram. U-B vs. B-R diagram of all galaxies with color uncertainties less than 0.2 mag. The dashed lines indicated the color criteria used to construct the radial density distribution plot below. Galaxies in the upper left "box" are likely to be in the foreground of the cluster. Galaxies in the lower right "box" are counted as both "blue" and "red" galaxies in the radial density distributions below. Note that the incompleteness obvious in the CMDs in Figure 1 is less obvious here but is a function of galaxy luminosity since only galaxies with $S/N \geq 5$ in all three bands are shown.

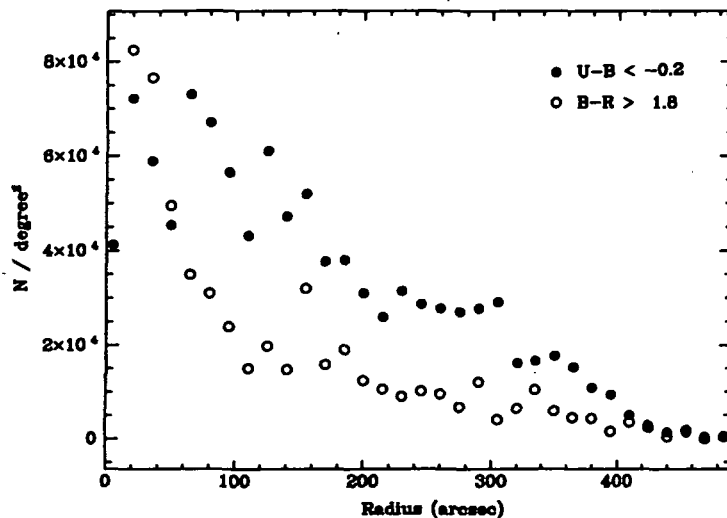


Figure 3 Radial Density Distributions. The radial density distributions of the bluest ($U-B < -0.2$) and reddest ($B-R > 1.8$) galaxies are shown here. Only galaxies with color uncertainties less than 0.2 mag were used. The "red" galaxies are significantly more centrally concentrated than the "blue" galaxies (cf. Thompson 1986). Furthermore, the extended nature of the blue galaxy density distribution suggests that the cluster blue galaxy distribution dominates the field blue galaxy distribution to the edge of the field analyzed. The smooth fall off in both distributions implies that most of the galaxies in the central 12×12 arcmin are associated with CL0939+4713.