Detecting Clusters of Galaxies at High Redshift with the
*Spitzer* Space Telescope

Gillian Wilson, Adam Muzzin, Mark Lacy & the FLS Team

*Spitzer Science Center, University of Toronto, Spitzer Science Center*

**Abstract.**

We present an infrared adaptation of the Cluster Red-Sequence method. We modify the two filter technique of Gladders & Yee (2000) to identify clusters based on their $R - [3.6]$ color. We apply the technique to the 4 degree$^2$ *Spitzer* First Look Survey and detect 123 clusters spanning the redshift range $0.09 < z < 1.4$. Our results demonstrate that the *Spitzer* Space Telescope will play an important role in the discovery of large samples of high redshift galaxy clusters.

1. **Introduction**

Early type (elliptical) galaxies in any given cluster have a similar color almost independent of their magnitude. If a color-magnitude diagram is constructed using two filters that span the rest-frame 4000Å break, cluster early-types form a distinctive red sequence comprised of the brightest, reddest galaxies at a given redshift. Clusters can therefore be detected as overdensities in a simultaneous projection of galaxy angular position, color and magnitude. Furthermore, the color of the red sequence itself provides a precise estimate of the redshift of the detected cluster (Gladders & Yee 2000). The Cluster Red-Sequence (CRS) technique is extremely insensitive to projection effects, because random projections do not exhibit the necessary red sequence signature in the color-magnitude plane. Cluster surveys employing the CRS algorithm have traditionally been carried out using an $R - z'$ combination (Gladders & Yee 2005).

Applying the CRS technique to higher redshift is an obvious next step. At $z = 1.2$, the $z'$ filter is no longer redward of the rest-frame 4000Å break. Therefore, to detect early-types at higher redshift, a redder filter must be employed. Covering large areas of sky in the NIR from the ground is a daunting proposition because of the bright NIR sky background and current dearth of large format NIR cameras. The *Spitzer* Space Telescope offers a promising alternative. Here we present results from the First Look Survey (FLS) utilizing an $R - [3.6]$ filter combination.

**Color-Magnitude Relation**

As an illustration of the overall depth of the FLS, and the expected colors of early-type galaxies, Figure 1 shows the $R - [3.6]$ color-magnitude diagram for all galaxies in the 4 degree$^2$ Main Field. The IRAC component of the FLS totals 60s of coverage, reaching a survey depth of about $[3.6] = 18.5$ on the Vega...
magnitude scale. The R-band component was obtained at the Kitt Peak 4m Mayall Telescope (Fadda et al. 2004).

The solid lines show the expected colors of early-types from models generated using the code of Bruzual and Charlot (2003). The slight slope is a reflection of the well-known color-mass-metallicity effect; fainter, less massive galaxies appear bluer in color.

**Photometric Redshift Accuracy**

Figure 2 shows the photometric redshift (inferred from the $R - [3.6]$ color) versus the spectroscopic redshift, for each of 26 clusters for which a spectroscopic redshift of a red-sequence galaxy was available. The key shows the source of each of the spectra. The large symbols indicate clusters for which more than one spectroscopic redshift was measured.

The photometric and spectroscopic redshifts are in excellent agreement, with an r.m.s. dispersion of $\delta z = 0.07$. This is an accuracy comparable to the best four (or more) passband photometric studies. The advantage here is, of course, that one is determining a photometric redshift for each cluster by calculating a mean color, averaging over many early-type galaxies with intrinsically similar color at the same redshift.

**Cluster Examples**

Figure 3 shows an example of a cluster detected at $z = 0.55$. Clockwise from upper left the four panels show the $R$ image, the $[3.6]$ image, the $R - [3.6]$ color-magnitude diagram, and the MIPS $[24]$ image.

For comparison, Figure 4 shows an example of a cluster at $z = 1.12$. *Spitzer* will be able to detect clusters to even higher redshift using deeper datasets and alternate filter combinations. In collaboration with the SWIRE Legacy Team we are now applying the CRS technique to the 50 degree$^2$ SWIRE Legacy Fields.

**Further Reading**

This paper presented an IR adaptation of the CRS technique for detecting clusters at high redshift. More details about the IRAC component of the FLS may be found in Lacy et al. (2005). A study of the evolution of the 3.6$\mu$m cluster luminosity function may be found in Muzzin et al. (this volume) and Muzzin et al. (2005a), and a study of cluster 24$\mu$m sources in Muzzin et al. (2005b).

**References**

Bruzual, G., & Charlot, S. 2003, MNRAS, 344, 1000
Fadda, D., Jannuzi, B. T., Ford, A., & Storrie-Lombardi, L. J., 2004, A.J., 128, 1
Gladders, M. D., & Yee, H. K. C. 2000, A.J., 120, 2148
Gladders, M. D., & Yee, H. K. C. 2005, in press (astro-ph/0411075)
Lacy, M., Wilson, G., Masci, F., Storrie-Lombardi, L. J., et al., 2005, Ap.J.S., in press
Muzzin, A., Wilson, G., Lacy, M., et al., 2005a, in prep
Muzzin, A., Wilson, G., Lacy, M., et al., 2005b, in prep
Figure 1. Color-magnitude diagram for all galaxies in the First Look Survey. The predicted $R - [3.6]$ color of an early type galaxy at each redshift is shown by the solid lines.

Figure 2. Plot of photometric versus spectroscopic redshifts. The large symbols indicate clusters for which more than one spectroscopic redshift was measured. The one-color $R - [3.6]$ photometric redshifts are in excellent agreement with the spectroscopic redshifts with an r.m.s. dispersion of $\delta z = 0.07$. 
Figure 3. A cluster at $z = 0.55$ detected in the First Look Survey using the CRS technique. Clockwise from upper left the four panels show the $R$ image, the [3.6] image, the $R - [3.6]$ color-magnitude diagram, and the MIPS [24] image. The f.o.v. is 500 kpc at the cluster redshift.

Figure 4. As for Figure 3, but for a cluster at $z = 1.12$. 