

The Toronto Red-Sequence Cluster Survey: First Results

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Abstract. The Toronto Red-Sequence Cluster Survey (TRCS) is a new galaxy cluster survey designed to provide a large sample of optically selected $0.1 < z < 1.4$ clusters. The planned survey data is 100 square degrees of two color (R and z') imaging, with a 5σ depth ~ 2 mag past M^* at $z = 1$. The primary scientific drivers of the survey are a derivation of Ω_m and σ_8 (from $N(M, z)$ for clusters) and a study of cluster galaxy evolution with a complete sample. This paper gives a brief outline of the TRCS survey parameters and sketches the methods by which we intend to pursue the main scientific goals, including an explicit calculation of the expected survey completeness limits. Some preliminary results from the first set of data (~ 6 deg²) are also given. These preliminary results provide new examples of rich $z \sim 1$ clusters, strong cluster lensing, and a possible filament at $z \sim 1$.

1. The TRCS

The Toronto Red-Sequence Cluster Survey (TRCS) is a major new observational effort designed to identify and characterize a large sample of galaxy clusters to redshifts as high as $z \sim 1.4$. When completed, the TRCS will be the largest imaging survey ever completed on 4m telescopes, and will provide a large and homogeneous sample of galaxy clusters for detailed follow-up study. The basic survey is envisioned as 100 deg² of 2 filter (R and z') imaging, to a depth which is ~ 2 mag past M^* at $z = 1$ in both filters. The design of the survey is based on a new method for identifying galaxy clusters (Gladders & Yee 2000a) developed specifically for the TRCS. In brief, this method searches for clustering in the 5-D space of: x-y positions, $R - z'$ color, z' mag, and morphology in the form of a concentration index. The x-y positions provide the surface density enhancement. A color slice in the color-mag plane provides separation in z space via the *red sequence* of early-type galaxies in clusters (Figure 1) and increases the S/N of density enhancements. Morphology allows us to key onto early-type galaxies, the primary population in cluster centers.

1.1. Scientific Goals

The TRCS is being driven by two major scientific goals. The first is based on the theoretical prediction that the evolution of the mass-spectrum of galaxy clusters with redshift, $N(M, z)$, should be a strong function of two cosmological parameters, Ω_m and σ_8 (Figure 2). The goal is to use the clusters identified in

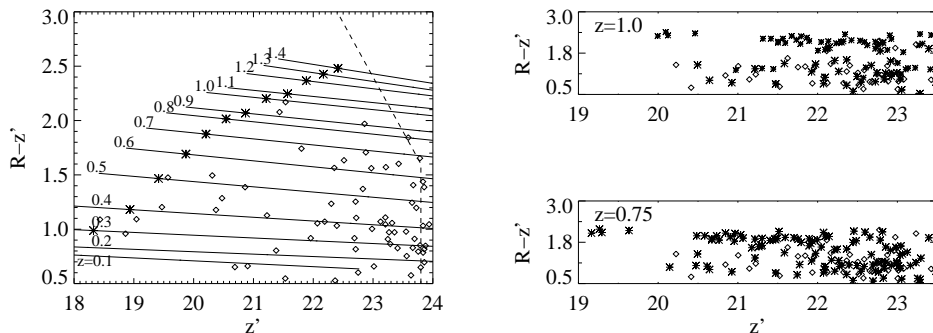


Figure 1. Modeled cluster CMDs to $z=1.4$ (left panel, solid lines), from Kodama & Arimoto (1997). Diamonds indicate simulated field galaxies for a 1 arcmin^2 FOV. The *s show M^* for each redshift. The TRCS photometric completeness limits are shown (dashed line). We also show real CMDs (right) for CL1322+3114 at $z = 0.75$ and k -corrected to $z = 1.0$. These data are from HST images degraded to TRCS seeing and depth. Cluster image objects (*) and field image objects (\diamond) are shown. Note the visibility of the cluster red sequence.

the survey to measure $N(M, z)$ directly from the survey data. Redshift can be estimated from the color of red sequence (e.g., López-Cruz & Yee 2000), and the mass of each cluster can be estimated from its richness, as measured by the parameter B_{gc} (e.g., Yee & López-Cruz 1999). The second major scientific goal is a study of the cluster galaxy populations, which can be done using the TRCS for the first time with a complete sample. The definition of a complete, or volume limited, sample is derived from extensive simulations of the survey selection functions.

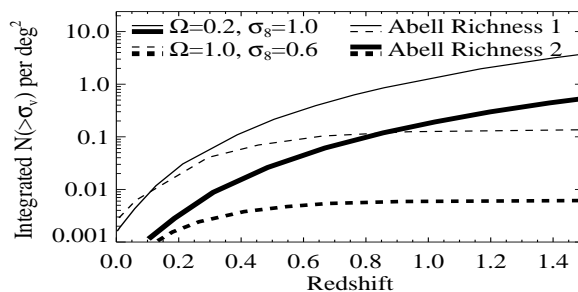


Figure 2. The expected cumulative counts of clusters per deg^2 for two cosmologies, for Abell Richness Class (ARC) 1 and 2. The 100% completeness redshift for ARC 1 is ~ 1.1 , and ~ 1.3 for the richer, rarer ARC 2 clusters.

1.2. Survey Completeness and Selection Functions

Any detailed understanding of the cosmological or galaxy evolution results deriving from the TRCS requires a good understanding of the survey selection

functions. Specifically, we wish to know how well the cluster-finding algorithm finds clusters of various sorts (as described by various parameters). To this end, we have constructed a number of cluster and field simulations (Gladders & Yee 2000b) to directly test the algorithm. A large suite of possible clusters have been tested; the parameters describing the clusters are given in Table 1. The results of this process demonstrate that the TRCS should be complete for all reasonable clusters of Abell Richness Class ≥ 1 clusters ($\sigma_v \geq 750 \text{ km s}^{-1}$) to at least $z = 1.1$.

Parameter	Model Values	Notes
LF R -band M^*	-22.5, -22.25, -22.0	$\alpha = -1.0$
Abell Richness counts	35,44,56,72,93,120	Richness Classes 0-2
NFW core scale radius	0.1,0.2,0.3,0.4,0.5	in h^{-1} Mpc
ellipticity	0.0,0.2,0.4,0.6,0.8	measured at $1 h^{-1}$ Mpc
blue fraction	0.1,0.5,0.65,0.8,0.9	
red sequence age	9,10,11,11.5	lower limit of SF in Gyr
scatter in formation ages	0.5,1.0,max	tophat width in Gyr
cluster redshift	0-1.4	

Table 1. Cluster model parameters used to test the cluster finding algorithm as applied to the TRCS.

2. Some First Results

The first run for the TRCS occurred at CFHT in May, 1999. A total of 21 pointings were acquired with the CFH12K camera, with each pointing covering 0.272 deg^2 . The bulk of the images have seeing better than $0''.7$, with some as good $0''.5$. At the time of writing, the total TRCS dataset consists of about 35 deg^2 of data. However, the results presented below are based on only the first 6 deg^2 . Figure 3 shows a rich ($B_{gc} \sim 2000$), compact cluster at photometric redshift of $z \sim 0.95$ (left panel). The cluster appears to be embedded in a large filamentary structure ($\sim 10 h^{-1}$ Mpc long) traced out by red galaxies (center

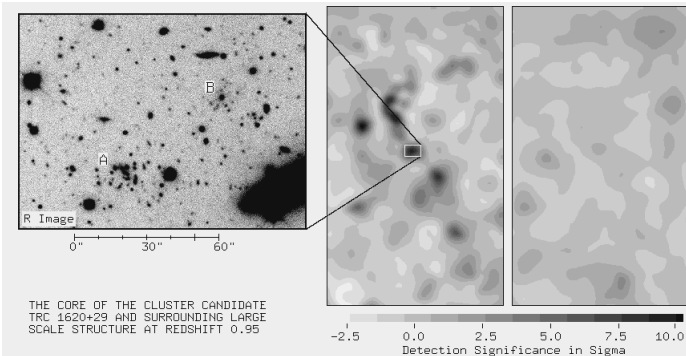


Figure 3. The image on the left shows the core of the cluster (A) and a possibly associated group (B). The central and right panels show the surface density of galaxies in a *much larger region* (roughly $20' \times 30'$) with and without a color cut.

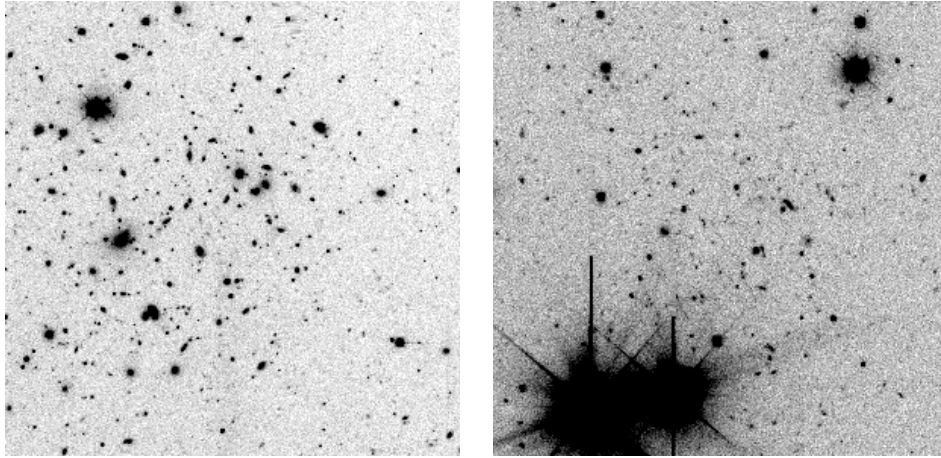


Figure 4. Two rich cluster candidates with estimated redshifts of 0.45 and 0.85 (left to right). Though not readily visible here, the cluster at 0.85 appears to have a gravitational arc, consistent with its richness of $B_{gc} \sim 2500$. Large color images of these clusters can be found at <http://www.astro.utoronto.ca/~gladders/TRCS/trcs1.html>

panel). The excess is undetectable without a color cut (right panel). The efficacy of color information in isolating high- z structures is obvious.

Figure 4 shows the cores of several other rich clusters, one of which appears to have a gravitational arc. The success of the TRCS in finding rich, high- z cluster candidates in the few degrees searched so far implies that the total survey will contain several hundred $z \geq 0.8$ cluster candidates, a preliminary result which is supportive of a low-density, high normalization cosmological model.

3. Secondary Projects

The TRCS dataset is also well suited for a number of other detailed studies. For example, preliminary work has already revealed a significant population of extremely red ($R - z' \geq 3.5$) point sources. Such objects are likely L and T dwarfs, with some contamination by $z \geq 5.5$ QSOs. Other studies are possible using the survey data, e.g. studies of cluster lensing (strong and weak), cosmic shear, halo structure, low surface brightness galaxies and early-type galaxy correlations.

References

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