Photometric Redshifts of SZ Clusters with Targeted Multiband Imaging

Abstract

The upcoming set of cluster-hunting surveys using the SZ effect require optical determination of cluster redshifts, to complement the measurements made at CMB wavelengths. We assert that the most effective way to obtain these redshifts, in terms of telescope efficiency and instrument costs, is to obtain *simultaneous* broadband images over a modest (few arcminute) field of view. If these images are fed to an on-line analysis code, which measures the photo-z of the cluster galaxies in real time, with uncertainties, we can optimize the integrations to neither over nor underexpose on *each* cluster. With an anticipated sky density of perhaps 8-10 per square degree, from the standpoint of obtaining photo-z's this approach is superior to obtaining deep wide-field images over the entire survey region.

We are constructing a multiband camera (PISCO, the Parallel Imager for Southern Cosmological Observations) for use on the 6.5 meter Magellan telescope, motivated by the upcoming SZ surveys. We expect the camera to be ready for use by Dec 2006, in time for first light on the South Pole Telescope SZ survey.

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1. Introduction

We are confident that the Dark Energy Task Force will receive submissions that stress the importance of measuring the abundance of galaxy clusters with redshift as a probe of the nature of Dark Energy. We will not repeat those arguments here, except to highlight the importance of obtaining redshifts for the clusters that will be detected through the SZ effect.

There are multiple ways to determine cluster redshifts. Spectroscopy provides the most secure redshifts, at the expense of large investments of telescope time. The community is placing much confidence in the use of broadband photometry to determine photometric redshifts, as spectral features move across the imaging passbands the apparent color of galaxies changes.

We stress that the measurement of cluster redshifts is much easier than the redshift determination for a single galaxy. First there is the gain of $\sqrt{N}$ statistics from having many galaxies, and second we can reject obvious outliers. One approach to obtaining photometric redshifts for SZ clusters is to image the entire SZ survey region in a set of broad passbands. This suffers from a number of challanges:

- *Each* image must be deep enough to detect the faintest objects desired,
- Most of the photons that strike the primary mirror are ignored, as they fall outside the passband of the moment,
- The survey images must be obtained under photometric conditions, and
- The photometric zeropoints (i.e. flux calibrations) must eventually all be tied together.

We advocate an alternative approach, in which we exploit the fact that the locations of the SZ clusters will be known. By making targeted observations over a modest field of view, we can image the specific regions of sky that contain cluster galaxies of interest. Furthermore, this approach allows us to 'tune' the exposures on a cluster-by-cluster basis. Most of the SZ clusters will reside at modest redshifts, half of them are closer than z=0.5. We have arranged with the South Pole Telescope team (PI John Carlstrom) to support their SZ survey with optical followup observations using this system.

Our instrument, shown in Figure 1 below, uses 4 focal planes and an arrangement of dichroic beamsplitters to obtain simultaneous images in the g,r,i and z bands. The simultaneous acquisition is important not only for photon efficiency but also allows us to determine the *color* (i.e. flux ratios) of each galaxy regardless of even patchy cloud cover. Table I shows a list of system characteristics.

By feeding the multiband images to a real-time photo-z analysis code, we can tune the exposure times to optimize the use of allocated telescope time. SInce so many of the clusters are fairly nearby, we can rapidly acquire many cluster redshifts, saving the long integration times for the more distant objects (and even saving them up for observations under optimal conditions...). Table II shows the integration times needed to reach L* early type galaxies as a function of redshift. Table III shows how the investment of Magellan time increases with cluster redshift.

We can obtain cluster redshifts much more effectively (both in terms of telescope time and instrument cost) with this approach than can be accomplished with a full-field multiband survey. The latter does provide potential for weak lensing and supernovae, of course, but those are secondary goals.

With this approach we can obtain redshifts for 3000 clusters (10% of the total expected from the SPT project) in roughly 10 nights on Magellan, with an instrument that is much more cost-effective than than building a wide field imager.

We have requested that DOE support the development of this instrument, through their ongoing grant to the Harvard Laboratory for Particle Physics and Cosmology, and a word from the task force would be welcome in this regard.

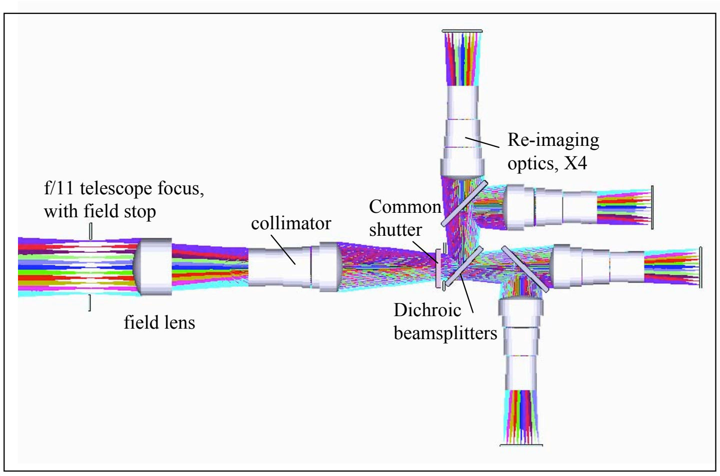

Figure 1. Conceptual Design. The system uses a single common shutter in conjunction with 3 dichroic beamsplitters to simultaneously illuminate focal planes in the g, r, i and z passbands. The first beamsplitter passes wavelengths $\lambda > 7000$ A, and the other two have transition wavelengths of 5500 A and 8500 A. The system is readily baffled at both field and pupil stops. The common shutter allows for the determination of flux ratios for photometric redshifts and transient followup, even with patchy cloud cover. Each focal plane spans 4.7 x 4.7 arcminutes. The instrument will be mounted at an *f/11* focus on the 6.5m Magellan telescope.

Optical Passbands	g, r, i, z simultaneous imaging
Plate Scale	0.12 arcsec per binned 30 micron pixel
Field of View	4.7 arcmin x 4.7 arcmin (corresponds to 800 kpc at z=0.3)
Detectors	Two Lincoln Labs 2K x 4K CCDs per focal plane Read noise <5 e rms Optimal AR coating for each passband Deep depletion CCDs for i, z bands
Readout time	< 8 seconds
80% encircled energy radius	0.2 arcseconds
Optical surfaces	One aspherical surface in field lens, rest are all spherical 6 inch dia lenses.

Table I: Summary of System Characteristics.

mAB	g	r	i	z	Median z
23	35	86	320	870	0.5 to 23rd
23.5	78	210	800	2200	0.73
24	180	500	1900	5500	0.85
24.5	450	1200	4900	13000	1.01

Table II: Exposure times (seconds) to achieve SNR=10. The table assumes galaxy flux integrated in a 2.2 arcsec diameter aperture, in seeing of 0.8 arcsec at an airmass of 1.2 in dark time. The numbers assume deep depletion detectors in the z and i bands. The right hand column (from Brodwin et al 2003) shows the median galaxy redshift in the relevant magnitude bin. The fact that the early type galaxies have red colors produces balanced SNRs for a common exposure time.

z range	N clusters	time (seconds)
0.0 0.2	15	15 * 60 = 900
0.2 0.4	30	30 * 60 = 1800
0.4 0.6	30	30 * 60 = 1800
0.6 0.8	15	15 * 200 = 3000
0.8 1.0	10	10 * 600 = 6000
1.0 1.2	9	} 15 * 1000 = 15000
1.2 1.4	4	
1.4 1.6	2	
Totals		4 hours for 100 clusters to z=1 4.2 add l hrs for 15 at z > 1

Table III. Time needed to obtain 100 cluster redshifts, in good conditions.