# 1 Determination of Cluster Masses, and Dark Energy

The number of clusters of galaxies as a function of mass and redshift provides a powerful alternative probe of the cosmology thanks to its sensitivity to the comoving volume *and* the growth of large scale structure. The rare, massive clusters at high redshifts provide most of the discriminating power of the experiment, requiring large surveys of the sky to search for these systems. A number of large cluster surveys are underway (e.g., Red-sequence Cluster Survey) or imminent (e.g., South Pole Telescope Sunyaev-Zeldovich Survey, Dark Energy Survey) with this dark energy measurement as a key goal, but all require estimates for the cluster masses in order to successfully constrain cosmological parameters.

The observations proposed here will provide the most accurate calibration of the masses of high redshift clusters for years to come and will serve as the necessary reference to ensure that the next generation cluster surveys can reliably use clusters beyond $z \sim 1$ to constrain $w$ to better than $5 - 10\%$. The recent work of Majumdar & Mohr (2003;2004) on "self-calibration" shows that only a moderate sample of clusters (such as that proposed here) needs to be studied in detail to reach those goals. The combination of weak and strong lensing measurements, along with X-ray and SZ imaging of these clusters would provide much needed information for understanding the properties of the ICM at very high redshifts and therefore the role of clusters in cosmology.

## 1.1 Weak lensing measurements of cluster masses.

Weak gravitational lensing of background galaxies is now a well-established technique for providing a *direct* measurement of the projected cluster mass, without any assumptions about the geometry or dynamical state of the cluster. The $z = 1 - 1.5$ range is of particular interest as it is the era where much of the cluster assembly is thought to occur. The sample studied here is 4 times larger than previous work, and targets clusters at higher redshifts. The additional Cycle 15 data will increase the effective number density of sources from $\sim 100$ to $\sim 165$ arcmin$^{-2}$, reducing the uncertainty in mass to 23% for the average cluster in our sample $(M = 5 \times 10^{14} M_{\odot})$. These numbers are corroborated by preliminary weak lensing analysis of Cycle 14 data in hand.

The proposed observations enable us to determine the zero-point in the massobservable relations to better than $10-15\%$ in each of four independent redshift bins. These data will complement archival data and ground based efforts at lower redshifts (e.g., the Canadian Cluster Comparison Project, the CFHT Legacy Survey) that are undertaken by members of our team. Consequently, we will be able to study the evolution in the properties of clusters from the present day out to $z\sim 1.5$.

## 1.2 Strong lenses at $z \gtrsim 1$.

Observations by ACS show image quality that dramatically increases the number of faint, low surface brightness strongly lensed arcs and image families detectable – particularly with multicolor data as we propose for Cycle 15. Our cycle 14 sample already contains 3 new giant arc systems lensed by $z \gtrsim 1$ clusters, doubling the number known, including a giant arc lensed by a cluster at $z = 1.39$ which is the highest redshift lensing cluster to date. These are in addition to the known high redshift lensing cluster on our cycle 15 target list. A single arc in a high redshift cluster determines the mass interior to the Einstein radius ($\sim 100$ kpc/$h$), and when combined with our complementary larger scale weak lensing analysis will measure the concentration parameter of the dark matter halo. In addition, comparison with results at lower redshifts enables us to follow the evolution of strong lensing cluster abundances and characteristics, and test CDM predictions (Hennawi *et al.* 2006). Our unprecendented deep imaging survey of high redshift clusters will allow us to place the first constraints on the profiles of dark matter halos at $z \gtrsim 1$.

## 1.3 X-ray and SZ cluster synergy.

We have been successful in getting XMM and Chandra time for the cluster observations and have agreements with the PI of SPT and SZ Array, John Carlstrom, to obtain Sunyaev-Zeldovich measurements. This multiwavelength strategy of determining cluster masses through lensing, X-ray, and SZ enables significant advances in understanding cluster physics and formation.