Final Report

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Title: Cluster Observations for Combined X-ray and Sunyaev-Zel'dovich Estimates of Peculiar Velocities and Distances

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Summary of Activities and Anticipated Results

Measurements of the peculiar velocities of galaxy clusters with respect to the Hubble flow allow the determination of the gravitational field from all matter in the universe, not just the visible component. The Sunyaev-Zel'dovich (SZ) effect (the inverse-Compton scattering of cosmic microwave background photons by the hot gas in clusters of galaxies) allows these velocities to be measured without the use of empirical distance indicators. Additionally, because the magnitude of the SZ effect is independent of redshift, the technique can be used to measure velocities out to the epoch of cluster formation. The SZ technique requires a determination of the temperature of the hot cluster gas from X-ray observations, and measurements of the SZ effect at millimeter wavelengths to separate the contribution from the thermal motions within the gas from that of the cluster peculiar velocity. We have constructed a bolometric receiver, the Sunyaev-Zel'dovich Infrared Experiment (SuZIE, see Holzapfel et al., 1997a), specifically to make measurements of the SZ effect at millimeter wavelengths in order to apply the SZ technique to peculiar velocity measurements. This receiver has already been used to set limits to the peculiar velocities of two galaxy clusters at $z \sim 0.2$ (Holzapfel et al., 1997b)

As a test of the SZ technique, the double cluster pair Abell 222 and 223 was selected for observation. Measurements of the redshifts of the two components suggest that, if the clusters are gravitationally bound, they should exhibit a relative velocity of $1000\,\mathrm{km\,s^{-1}}$, well above the expected precision of $200\,\mathrm{km\,s^{-1}}$ (set by astrophysical confusion) that is expected from the SZ method. The temperature can be measured from ASCA data which we obtained for this cluster pair. However, in order to ensure that the temperature estimate from the ASCA data was not dominated by cooling flows within the cluster, we requested ROSAT HRI observations of this cluster pair.

Analysis of the X-ray properties of the cluster pair is continuing by combining the ROSAT observations funded under this proposal, archival PSPC data and our own PI ASCA data. The spectral analysis shows that both clusters have typical X-ray temperatures for objects of their luminosity ($6.0^{+1.5}_{-0.9}$ and $5.8^{+1.2}_{-0.7}$ keV respectively). The imaging data shows that neither cluster has a strong cooling flow, although A223 is the more compact of the two components. A223 also has a sub-cluster projected 1 Mpc to the North.

The observed properties of this cluster pair are strikingly similar to those of the well-studied pair of A399 and A401 which are widely believed to be interacting and are in the initial stages of merging. This strengthens our selection of this cluster pair as a test for cluster peculiar motions. Combining these X-ray observations with SuZIE measurements of the SZ effect will provide important constraints on cluster merger models. This part of the program has been heavily delayed by bad weather at Mauna Kea, however SZ observations were obtained in November 1997 as part of a separately funded effort. These data are currently being analyzed.

W.L. Holzapfel, T.M. Wilbanks, P.A.R. Ade, S.E. Church, M.L. Fisher, P.D. Mauskopf, D.E. Osgood & A.E. Lange, "The Sunyaev-Zel'dovich Infrared Experiment: A Millimeter-wave Receiver for Cluster Cosmology", 1997a, *ApJ*, **479**, 17

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Funding:

Papers: 1