Spectral Measurements of the S-Z Effect in Clusters of Galaxies with SuZIE,
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Introduction
The Cosmic Microwave Background (CMB) acts as a uniform backlight to the rest of the observable universe. Inverse Compton scattering of CMB photons by hot intra-cluster gas (ICG) residing in clusters of galaxies is the gravitational potential wells of clusters of galaxies is known as the S-Z effect. The SuZIE (Z薇l) experiment has two components, the thermal effect, due to the random thermal motions of the scattering electrons, and the kinematic effect, due to the bulk motion of the ICG relative to the CMB. For typical clusters, the kinematic effect is expected to be much smaller than the thermal effect (see Figure 1). In practice, separation of the two is most easily achieved with instruments at millimeter wavelengths because of the distinct spectral shape of the thermal effect.

What is SuZIE?
The Sunyaev-Z薇ldovich Infrared Experiment (SuZIE) is an experiment at the Caltech Sub-millimeter Observatory (CSO) (see Figure 2) designed to measure the thermal effect in immediate redshift (z = 0.15 to 0.8) clusters of galaxies. The SuZIE II (see Figure 3) is a 2 by 2 array of 3 color photometers that observe the sky simultaneously in each frequency band, with band centers of 145, 221, and 355 GHz. Each photometer is of the same type and is sensitive to the same frequency. Each photometer defines a 1.5' FWHM beam, with each row separated by 2.3' and each column by 5' on the sky (see Figure 4).

Atmospheric Subtraction
There are two sources of residual atmospheric noise in SuZIE data, with different temporal spectra. The first is incomplete subtraction of the signal that is common to each beam because of the finite common mode rejection ratio (CMRR) of the electronic differential. The second is a fundamental limitation introduced by the fact that the two beams being differentiated are passed through slightly different columns of atmosphere; consequently, there is a percentage of atmospheric emission that cannot be removed by differencing. By forming a linear combination of our frequency channels which contains no S-Z signal we are able to achieve a significant improvement in the performance at each frequency (see Figure 5).

Sub-millimeter Point Source Confusion
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Results
An overview of our entire analysis routine can be found in Benson et al. 2003. In Figure 5 we show the S-Z spectra measured with the 2nd generation of SuZIE. For each cluster, the solid black line is the best-fit S-Z spectrum, the dashed red line is the best-fit thermal spectrum, and the dotted blue line is the best-fit kinematic spectrum.

In Figure 7 we show the precision to the radial component of each cluster’s peculiar velocity, plotted against the redshift of the cluster. We include previous peculiar velocity measurements of the clusters A1689 and A2163 observed with the SuZIE II by Holzapfel et al. (1997). The cross-hatched region shows the region of redshift space that has been probed by existing optical surveys.

Comparing the Comptonization Results from SuZIE to OVRO/BIMA
Beceo et al. 2002 have an impressive catalog of S-Z observations taken with the OVRO and BIMA interferometers at 30 GHz. A total of 10 clusters have been measured by both SuZIE and OVRO/BIMA. A comparison of the central Comptonization, \( y_\text{tot} \), derived from OVRO/BIMA data to that from SuZIE reveal an interesting trend (see Figure 8). The sample of non-cooling flow clusters show good agreement, however SuZIE measured significantly lower central \( y_\text{tot} \). We note that the Comptonization plotted in Figure 8 is calculated from the SuZIE II 150 GHz channel only, with an assumed peculiar velocity. The comparison with the OVRO results), to reduce biases from possible sub-mm point source contamination that are present when the high-frequency data are included. In Figure 9 we plot 2-d likelihood contours of two representative clusters (one cooling flow and one non-cooling flow) to show that even when peculiar velocities are included in the fit, the fits disparities still exist derived optical depths for cooling flow clusters.

The Temperature of the CMB vs. Redshift
The spectrum of the S-Z effect can also be used to measure the temperature of the CMB as a function of redshift. Taking ratios of the difference intensity at multiple frequencies to measure the temperature of the CMB was suggested by Rephaeli (1980). This method has the desirable property that it would be independent of cluster Comptonization.

In calculating Figure 10 we have ignored several important systematic effects, the most important of which are peculiar velocity and sub-mm point source confusion. The derived temperature is highly degenerate with the cluster peculiar velocity and the S-Z (z薇l) frequency (range). In Figure 11, in addition, sub-mm point sources can cause significant confusion in measurements of the CMB temperature. In Figure 12 we plot the effect of sub-mm point source confusion in measuring the CMB temperature for A202. We note that SCUBA measurements of 850 microns in one of the field of view of A202 detected two sub-mm point sources, resulting 49.2 K lower.

Conclusions
Spectral measurements of the S-Z effect with SuZIE have been made in 13 clusters of galaxies. These results have been used to calculate the peculiar velocity and central Comptonization in each cluster. An overall average negative peculiar velocity may be indicative of sub-mm point source contamination in our observations. A comparison of the derived central Comptonization to that from the OVRO/BIMA interferometers indicates a systematic discrepancy in cooling flow clusters, which may be evidence for an inadequate model of the IC gas. The CMB measurements have also been used to measure the CMB temperature at zero redshift assuming a zero peculiar velocity. The 68.3% and 95.4% confidence regions are shown in each plot.

Literature cited

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