New Territory: SZ Cluster Surveys

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Abstract. The potential of the Sunyaev-Zel’dovich (SZ) effect for cluster studies has long been appreciated, although not yet fully exploited. Recent technological advances and improvements in observing strategies have changed this, to the point where it is now possible to speak of this subject at a meeting devoted to surveys in Cosmology. We will discuss SZ surveys by distinguishing what may be called pointed surveys, dedicated to pre-selected clusters, from blind surveys, those searching for clusters in blank fields. Surveys of the former type already have significant numbers of clusters with very good signal-to-noise images; surveys of the second type are currently possible, but as yet not undertaken. The discussion will focus on the kind of science that can be done in this “new territory”.

1 Introduction

Cluster studies based on the Sunyaev–Zel’dovich (SZ) effect\textsuperscript{[15]} have had a long and hard history of learning about systematic effects. Benefiting from these early efforts and thanks to new technologies (bolometers) and observing techniques (interferometry), the field is now in rapid expansion. At one time the issue was simply one of detection; today, we speak of several tens of clusters with high signal-to-noise SZ maps. The change has been revolutionary in its rapidity, and it has taken place somewhat unbeknownst to those outside the field.

In this contribution, we will summarize what is happening by discussing the kind of astrophysics one can do with the SZ effect and the impact of current observations. By far, the best and most complete recent review of the subject is given by Birkinshaw\textsuperscript{[5]}. We have been inspired both by this review and by the review given by Lange\textsuperscript{[11]}. We begin with a few general remarks concerning the SZ effect.

2 Properties of the SZ effect

There are some aspects of the SZ effect particularly worth emphasizing. Recall that the effect is a distortion of the cosmic microwave background (CMB) spectrum that may be expressed as $\delta i_\nu = y(\bar{\theta}) j_\nu$, where $\delta i_\nu$ is the change in
surface brightness of the CMB at position $\vec{\theta}$ on the cluster face relative to the unperturbed CMB spectrum. The quantity $j_\nu$ gives the spectral shape of the distortion and is only a function of frequency. The magnitude is set by the Compton $y$-parameter, an integral of the electron pressure along the line–of–sight:

$$y \equiv \int dl \frac{kT_e}{m_e c^2} n_e \sigma_T \quad (1)$$

Here, the electron temperature, mass and density are $T_e$, $m_e$ and $n_e$, respectively, and $\sigma_T$ is the Thompson cross section. Integrating over the cluster face, we find the total SZ flux density:

$$S_{sz} = \int d\Omega \, i_\nu(\vec{\theta}) = j_\nu D_a^{-2} (z) \int dV \frac{kT_e}{m_e c^2} n_e \sigma_T \quad (2)$$

where $D_a$ is the angular–size distance. There are two important observations to make: 1/ $D_a = (1 + z)^{-2} D_l$, i.e., the effect falls off with redshift much more slowly than does, say, an X–ray flux, which is simply the well known fact that the surface brightness of the effect is independent of redshift for a fixed cluster; 2/ we may rewrite the expression as $S_{sz} \sim f_{gas} M_{tot} < T_e >$ in terms of $f_{gas}$, the hot gas mass fraction, $M_{tot}$, the total virial mass of the cluster, and an average temperature defined by this expression, $< T_e > \sim (1/N_e) \int dV \, n_e T_e$, where $N_e$ is the total number of electrons in the cluster. This is an important aspect of the SZ effect, because the average temperature involved is truly the mean temperature of the electrons in the gas, as opposed, say, to the emission–weighted, X–ray measured temperature. The SZ–defined temperature is directly related to the total energy of the electrons gained during collapse and totally insensitive to the spatial distribution of the hot gas in the cluster. These two points distinguish the SZ distortion from the X–ray flux of a cluster and can be used to advantage in cluster studies.

3 Pointed Surveys

As discussed by Birkinshaw [5], there are three techniques used to observe the SZ effect: traditional single–dish observations (see, e.g., [12]), bolometers (see, e.g., [7]) and interferometry (see, e.g., [6] and [14]). Interferometric observations now routinely produce SZ maps at more than 20 $\sigma$ at the center. Bolometer observations have also detected the SZ effect in emission [11].

Such observations can be used to deduce cluster baryon fractions [12], constrain (eventually detect) cluster peculiar velocities [1], [8], and to trace total cluster mass profiles. In the former and latter cases, the density insensitivity of the SZ effect is a pertinent advantage over X–ray studies (SZ varies linearly with $n_e$). Combined X–ray and SZ observations lead to distance estimates and a Hubble diagram. Figure 1 shows such a diagram from data we gleaned from the literature (the diagram was inspired by Birkinshaw [5], although the data is not exactly the same).
4 Blind Surveys

Here we refer to purely SZ surveys where clusters are selected from “blank” sky solely on the basis of their SZ flux density. Such surveys are just feasible today. Surveys of this kind should be viewed as totally analogous to X–ray surveys (e.g., [3]): one can study SZ luminosity functions and their evolution (closely related to the amount and evolution of the intracluster medium), the cluster contribution to the mean background (mean distortion of the CMB spectrum) and to the background anisotropies, and redshift distributions. As discussed in [2], [4], the latter can be used to constrain the density parameter, \( \Omega \). Particularly enticing are the reports of SZ decrements with no optical or X–ray counterparts [9], [13]. If truly due to clusters, these must be at very large redshifts (\( z > 1 \)), a fact difficult to account for in a critical Universe [4] (see Figure 2).

5 Conclusion

We are now in a position to reap the potential of SZ observations. Catalogs of pre–selected clusters observed in SZ (pointed surveys) already count several tens of entries, permitting for the first time statistical studies. True blank field surveys will soon be undertaken over small patches of sky with interferometers and, eventually, with large bolometer arrays [11]; over the longer term, one anticipates a SZ–selected catalog of more than 10,000 sources from the Planck Surveyor [1], a remarkable opportunity.
Figure 2: SZ source counts confronted with the two possible SZ clusters found by the VLA [13] and Ryle Telescope [9]. If the decrements are truly clusters, they must be at $z > 1$ to satisfy the X-ray flux upper limits; this would be difficult to explain in an $\Omega = 1$ Universe. This figure was taken from [4].

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