The Arcminute MicroKelvin Imager: AMI

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The Arcminute MicroKelvin Imager (AMI)is an instrument planned to make a deep survey of the microwave sky at high angular resolution. One key product of such a survey would be a catalogue of galaxy clusters selected by mass with almost no bias due to distance. The number counts of these clusters are strongly dependent on the underlying cosmology, and with optical and X-ray follow up would allow for the measurement of several key cosmological parameters. AMI will also be used to make detailed images of moderate-redshift clusters, and to search for reionization-era effects, as well as topological defects.

1 The need for cluster SZ surveys

The importance of galaxy clusters as tracers of the development of structure in the Universe has long been recognised, and both optical (e.g.[1]) and X-ray (e.g.[2]) surveys have attempted to study the evolution of galaxy clusters. This evolution is controlled by factors such as the matter density parameter $\Omega_{\rm M}$, the initial fluctuation amplitude, and the universal baryon fraction, which we could thus hope to measure. However, the difficulty of observing clusters in either light or X-rays at high redshift due to confusion and the cosmological dimming of surface brightness makes these studies uncertain and prone to observational selection biases.

The Sunyaev-Zel'dovich effect[3] offers the means of bypassing these problems, as the surface brightness of the effect depends only on the intrinsic properties of the cluster and not on its redshift. Indeed, the scaling relations between mass and temperature expected for clusters heated by their own gravitational collapse predict that the total SZ flux density observed should be nearly proportional to the mass of the cluster, and this is confirmed by numerical simulations[4]. This redshift-independent selection based on just mass results in very different predictions for the number of observable SZ clusters in different cosmologies[5], for which the X-ray observables are rather similar (Figures 1, 2). Detection of a statistically significant number of clusters in an SZ survey, with some X-ray and optical follow up, would allow measurement

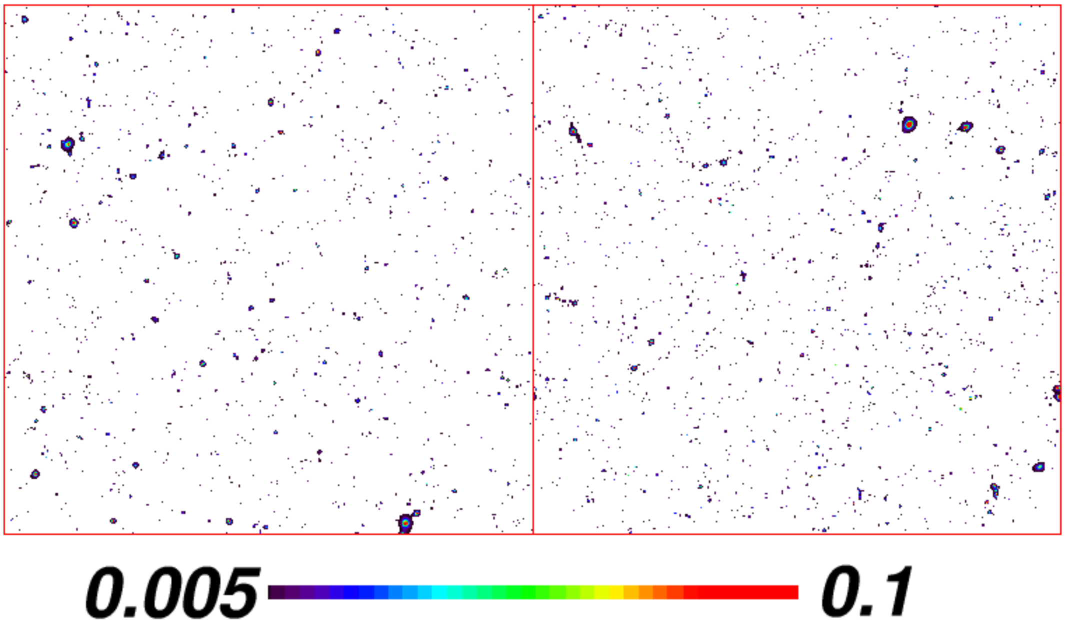

Figure 1: Simulations of a medium-deep XMM $5° \times 5°$ survey in (left) $\Omega = 1.0$, (right) $\Omega = 0.3$ cosmologies. Units are XMM EPIC counts / s (0.5–2.0 keV). Since both surveys are dominated by low-redshift clusters, to whose abundance they are normalised, the number counts are very similar—compare Figure 2

of $\Omega_{\rm M}$, the baryon fraction (and its evolution in clusters) and the overall normalisation of the amplitude fluctuations (usually parameterised as σ_8), as well as directly testing the theories of structure formation (see also R. Kneissl, this volume).

As yet, no such surveys have been made because of the difficulty of observing large areas of sky at sufficient brightness sensitivity and resolution. However, the technique of interferometric observation of individual, X-ray selected clusters[6,7] is sufficiently advanced that it is now possible to design specialised SZ survey telescopes, capable of detecting many hundreds of clusters, at modest cost. Interferometry is the preferred technique due to its efficient rejection of the atmosphere and other systematics, allowing ground-based observations to reach the high sensitivities required (a $10^{13} M_\odot$ cluster has a maximum Rayleigh-Jeans brightness temperature of $\sim 5\mu$K).

2 The Arcminute MicroKelvin Imager

The existing interferometers used for SZ observations (the Ryle Telescope and the OVRO and BIMA arrays) have fields of view of 4–6 arcmin, and minimum baselines around 1000 λ. These are badly suited to an SZ survey, since many hundreds of pointings are required to cover a sufficient sky area, and the signal from a moderate-to-high redshift cluster is mostly resolved out on such long baselines. The Arcminute MicroKelvin Imager (AMI) will rectify these problems. AMI will have an array of ten 3.7-m antennas operating in the 12–18 GHz band. This will allow baselines as short as 150 λ, on which the observed flux density from a cluster will be typically ten times higher than on a 1000-λ baseline. The field of view is also increased by an order of magnitude compared with the Ryle. Using the full 6 GHz bandwidth increases the sensitivity yet further compared to existing instruments. The combination of these effects means that AMI will be able to survey to a given depth over a thousand times faster than the Ryle.

The main foreground contamination at cm wavelength and arcminute resolution is extragalactic radio sources. In order to remove the effects of these sources it is necessary to have

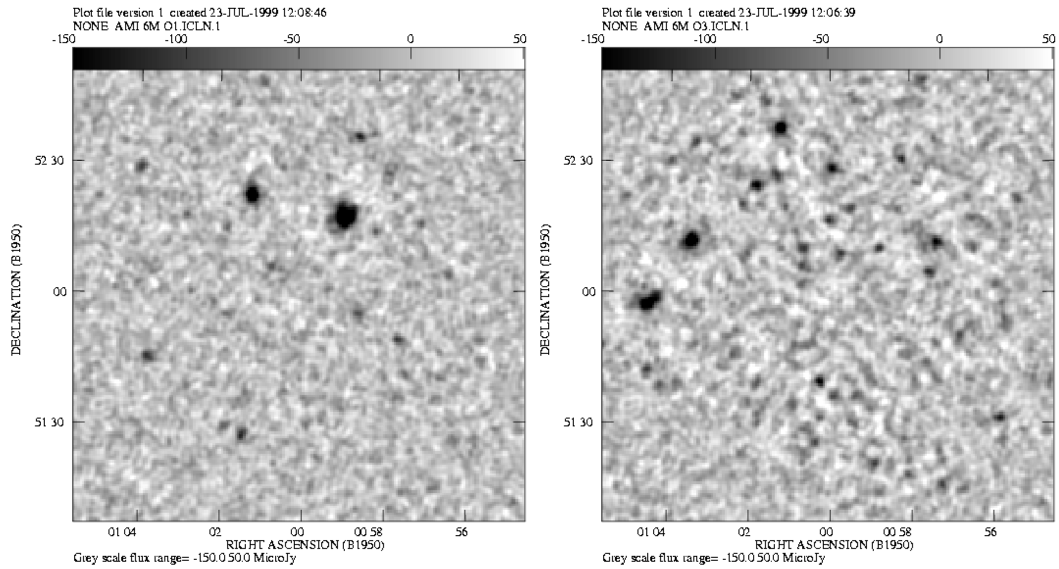

Figure 2: Simulations of AMI observations in (left) $\Omega = 1.0$, (right) $\Omega = 0.3$ cosmologies. Many more high-redshift clusters are visible in the low-density universe.

higher-resolution observations with sufficient sensitivity to reduce the residual confusion noise below the thermal noise. This problem is worse at low frequencies where the sources are typically brighter and the CMB less intense; however it is not negligible anywhere in the cm wavelength range. A competing requirement is to minimise the system temperature, for which the contributions from the atmosphere and the receivers both increase with frequency. For AMI, the existence of the Ryle Telescope (with a suitably upgraded receiver system and correlator), with its large collecting area and high point-source sensitivity in the 12–18 GHz band, means that the optimum solution is to observe in that band from Cambridge, thus removing the need for a low-humidity site and an expensive array of new, larger antennas.

3 More science with AMI

Although a primary goal of AMI is to conduct a cluster survey, there are many other scientific possibilities for such an instrument. Other imprints on the CMB on arcminute scales include the Ostriker-Vishniac (OV) effect[8,9], the effect of topological defects, inhomogeneous reionization, the primary CMB spectrum, which may have significant power on the largest scales probed by AMI, and of course individual clusters at low enough redshift to be closely studied in other wavebands. The quality of SZ images of rich clusters at moderate redshift obtainable with AMI will perfectly complement the imaging and spectral data available from Chandra and XMM, allowing detailed studies of the gas dynamics and substructure of these objects.

The OV effect is essentially the combined thermal and kinetic SZ effects in the early stages of structure formation; its amplitude depends critically on the epoch of reionization, and its discovery would provide crucial evidence about the end of the ‘dark ages’.

Topological defects such as cosmic strings are predicted to imprint features on the CMB via distortions of the metric surrounding them. Moving cosmic strings produce sharp linear discontinuities in the CMB via the Kaiser-Stebbins effect[10]. Although these will be superimposed on the (probably) gaussian primordial background, with the high resolution observations provided by AMI the signature of a cosmic string of the canonical mass per unit length will be clearly detectable. Despite their current unpopularity as seeds of structure formation, topo-

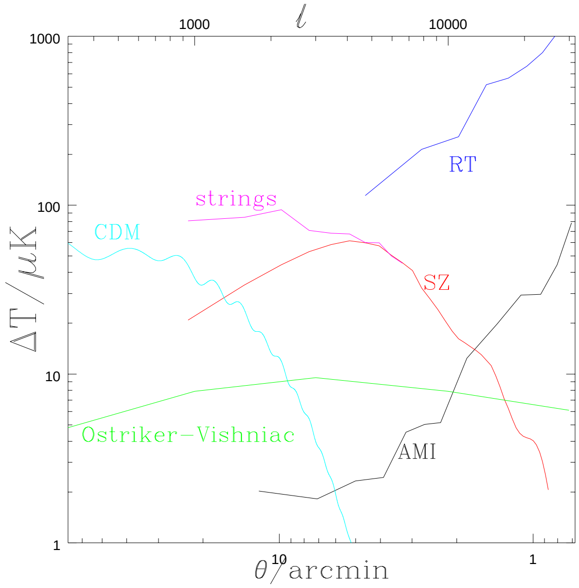

Figure 3: The temperature sensitivity of AMI in μK as a function of angular scale θ (and multipole index $l = 2\pi/\theta$), for a six-month observation over a 0.1 square-degree field. Also shown are the sensitivity of the Ryle Telescope; the S-Z signal from a $10^{14}M_\odot$ cluster at any redshift $z > 0.2$; the signal from an isolated cosmic string within AMI's field of view; a possible signal due to the Ostriker-Vishniac effect; the expected signal from primary CMBR anisotropies in the standard cold-dark-matter scenario.

logical defects are still predicted by all grand unified theories and their discovery would be of profound significance.

Acknowledgments

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