SUNYAEV-ZEL'DOVICH EFFECT WITH PLANCK SURVEYOR

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ABSTRACT

We will present the simulations of the Sunyaev-Zeldovich effect that have been performed during Planck Surveyor scientific preparation and the subsequent predictions made for the detection of galaxies clusters through the unique spectral signature of the SZ effect. Indeed, we predict that Planck Surveyor should lead to the detection of many thousands of rich clusters. This complete catalogue will allow to study the properties and evolution of clusters in conjunction with X-ray observations, to detect high redshift clusters (up to about 1), and hence test the theories of structure formation, and to measure the deviations from the Hubble flow and the coherent large scale peculiar motions.

1.

The Planck Surveyor ESA's satellite will achieve an all-sky multi-frequency measurement of the Cosmic Microwave Background (CMB)

anisotropies at all scales larger than about 5 arcminutes, with an accuracy ($\Delta T/T \simeq 2.\,10^{-6}$) limited only by the photon noise and the astrophysical foregrounds.

In order to assess the capabilities of the Planck Surveyor we have performed complete simulations of the millimetre and submillimetre sky (Bouchet et al. 1995) which take into account both expected astrophysical components (zodiacal, Galactic and extragalactic) and the instrumental characteristics of the future space mission.
In particular, we have simulated maps of the large scale distribution of Compton parameters (y) and temperature anisotropies ($\Delta T/T$) induced by clusters of galaxies through respectively the thermal and kinetic Sunyaev-Zeldovich (SZ) effects (Sunyaev & Zel'dovich 1972). The former arises form the inverse Compton scattering of the CMB photons off the free electrons of the hot ionised intracluster medium. The kinetic SZ effect is a Doppler effect resulting from the bulk motion of the intracluster medium with respect to the CMB rest frame.
The wide frequency coverage of Planck Surveyor will enable a spectral separation, and thus a measurement, of the astrophysical foregrounds, among which the SZ effect which is expected to be the dominant secondary distortion of the CMB. The observations of the simulated sky were separated into physical components as a "recovered map" for each astrophysical process.
The recovered maps of the thermal SZ effect have been analysed. We detect clusters above a

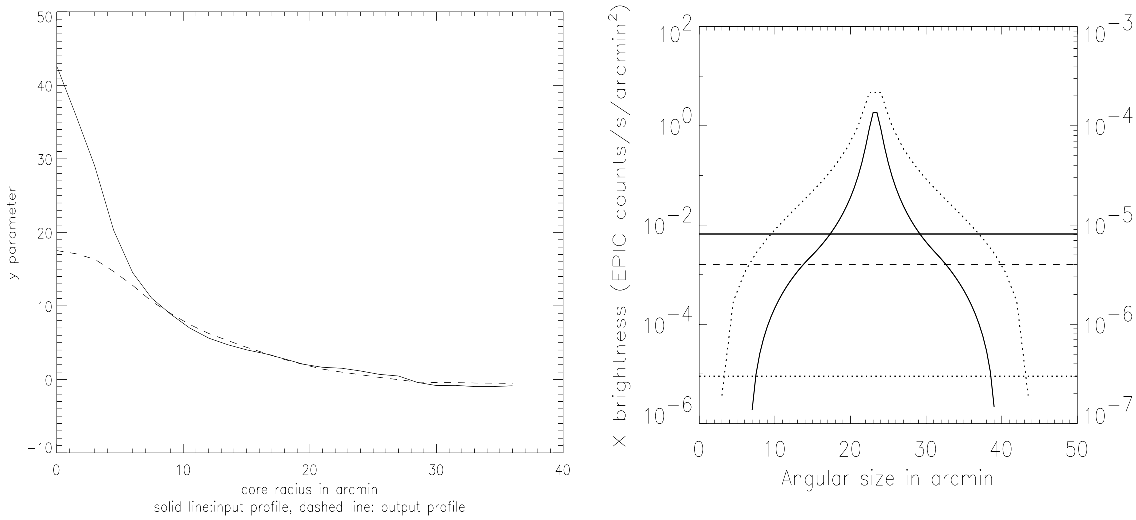

Fig. 1.— **Left panel:** Input (solid line) and recovered (dashed) profiles of the Compton parameter y as a function of the distance to center in arcminutes. The integrated y parameter is recovered with an accuracy of about 2%. **Right panel:** Comparison between X-ray brightness (solid line) and the y parameter (dotted line) for an A496-like cluster with XMM-EPIC and Planck Surveyor resolutions. Left axis: X-ray brightness in EPIC counts/s/arcmin^2; right axis: y parameter, versus angular size in arcminutes. The solid horizontal line stands for the X-ray background, the sensitivity limit of the XMM instrument for an integration time of 20 hours is indicated by the dashed horizontal line whereas the dotted line is for the Planck sensitivity limit.

threshold of $y_0 = 2.\,10^{-6}$. Assuming spherical symmetry, we compute the radial profile of their Compton parameter y, by averaging the signal within rings of equal width. We also compute the integrated y parameter, Y, over the profile for each recovered cluster. The left pannel of the figure 1 is an illustration of what can be achieved, in terms of y profile reconstruction, for a cluster 10 times nrighter than typical observed ones ($y_0 \simeq 10^{-4}$). We note that the central part of the cluster suffers from the beam dilution, whereas the outskirts of the profile are well recovered.

Using the Press-Schechter formalism (Press & Schechter 1974) to predict the number counts of clusters, we expect that Planck Surveyor will detect about 10^4 clusters with $\mathrm{Y} > 5.\,10^{-4}\,\mathrm{arcmin}^2$ and completeness better than 68%. These numbers could increase by a factor 3 for cosmological models with low Ω_0 due to the existence of distant clusters ($z > 0.5$) (Barbosa et al. 1996).

Complementary information on the intracluster gas profile are provided by joint observations of its SZ effect and X-ray emission. The thermal SZ effect is less dependent on the electronic density than the X-ray emission, it is expected to be a suitable tool for observing the outskirts of the gas profile. We illustrate this point in the right pannel of the figure 1 in which we draw, for the same cluster (A496-like cluster: $T_{e0} = 4$ keV at $z = 0.2$), the sensitivity limits of both XMM and Planck Surveyor. The mapping of the intracluster gas distribution up to about 15 core radii will be possible with Planck Surveyor and XMM.

2. Radial peculiar velocity of galaxies clusters

Measuring the radial peculiar velocities of clusters by combining measurements of both thermal and kinetic SZ effects has been suggested by Sunyeav & Zel'dovich (1980). The velocity is given by:

$$v_r = \frac{ck}{m_e c^2} \times T_e \frac{\Delta T/T}{y},$$

where c is the speed of light, k the Boltzmann constant, $m_e c^2$ the electron's rest mass and T_e the electronis temperature of the intracluster gas. We have constructed and optimized a geometrical filter, adapted to each cluster, for the velocity measurement. We evaluate the rms uncertainty on the velocity determination using the recovered maps of both y and $\Delta T/T$, results are shown figure 2. The uncertainty is due to the instrumental noise and to all the astrophysical components that contribute to the signal. In fact even after the component separation, a residual spurious contribution is very likely to remain in the signals of interest ($\Delta T/T$ and y). Nevertheless, due to spectral confusion with the kinetic SZ effect, the contamination associated with the CMB is the dominant one. It increases with the size of the cluster, as more contribution from the first Doppler peak is included in the geometrical filter. This explains the rise of δv_{rms} from $2-3$ arcminutes upwards (Fig. 2). For clusters with core radii smaller than 2 arcminutes, the beam dilution leads to a fast degradation of the velocity determination, and thus to an increase of δv_{rms}.

2.1. Generalisation to the bulk velocity

A survey of the sky, in the SZ effect, followed by a redshift survey of the detected clusters should give the possibility of measuring the overall bulk velocity in typical volumes of about $100h^{-1}$ Mpc scale, through the measurement of the individual radial peculiar velocities of the clusters present in these volumes.

We find that the overall accuracy of the velocity in the local volume ($0 < z < 0.05$) is about 60 km/s. It goes through a minimum around $z = 0.1$ and remains lower than 100 km/s for $0.5 < z < 0.7$. At higher redshifts, the overall accuracy in the peculiar velocity determination is degraded; it reaches about 200 km/s at $z \simeq 1$.

The application of the SZ effect measurements to the evaluation of the peculiar velocity of clusters of galaxies should become a very useful tool to map the large scale velocity fields and test and constrain theories of structure formation and evolution.

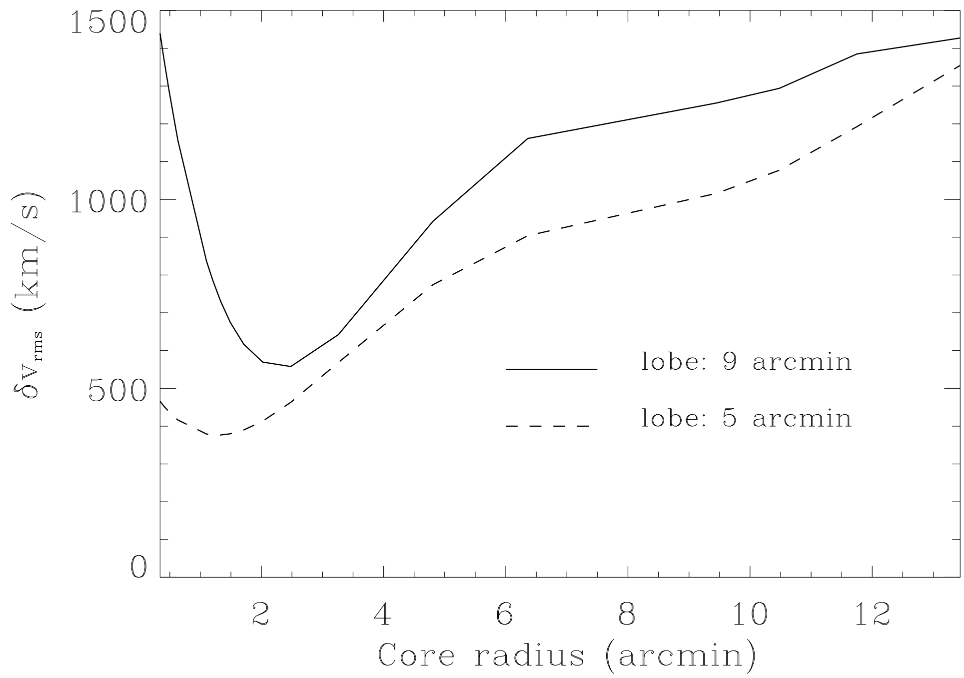

Fig. 2.— The *rms* velocity due to the contamination by astrophysical emissions (including CMB) and instrumental noise as a function of the core radius of the cluster. Results are obtained for a cluster with $y_0 \approx 10^{-4}$.

3. Conclusions

In the context of a multiwavelength CMB experiment, SZ effect can be easily separated from other astrophysical contributions through its peculiar spectral signature. This offers an exciting prospect for the observational cosmology. We have predicted the potential of Planck Surveyor mission in detecting clusters of galaxies and measuring their radial peculiar velocities (Aghanim et al. 1997).

• We expect that Planck mission will give a fairly complete catalogue of about 10^4 resolved galaxies clusters, up to a redshift of one or more.

• In the case of resolved clusters with central comptonisation parameter $y_0 > 2.\,10^{-6}$, it is generally possible to reconstruct their y profiles up to one degree radius for the strongest ones. The main limitation in the observation of the outer parts of the profile is due to the confusion with weaker clusters.

• We have shown that the measurement of the radial peculiar velocity of individual clusters is

possible, in principle, but it is strongly limited by the spectral confusion with, mainly, the CMB fluctuations. The *rms* uncertainty is in the best case of the order of 500 km/s for bright clusters.
• We have also shown that measuring the peculiar velocities for a large number of clusters, in boxes of equal volume (typical dimension $100\,h^{-1}$ Mpc), up to $z \simeq 0.6$ gives overall accuracies on bulk velocities better than 100 km/s.

The SZ effect is thus very promising as a tool for cosmology allowing the detection and study of individual clusters, and the mapping of the matter distribution and the large scale velocity fields in the Universe.

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