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Sunyaev-Zel'dovich effect at supercluster scales with Planck

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A significant fraction of the baryons in the low redshift Universe is expected to be in a warm-hot phase (WHIM) with temperatures of the order of 10^5-10^7 K, and with moderate overdensities $\delta \sim$ 10-100 (Cen & Ostriker 1999). This WHIM would be associated to a network of filaments connecting the regions where clusters of galaxies are located. In this work, we have explored the possibility of detecting this WHIM phase with PLANCK, by means of the Sunyaev-Zel'dovich effect (SZE) associated to regions containing superclusters. We have used hydrodynamic simulations including the gas physics, to identify those regions which are similar to present-day superclusters. Six maps of the Comptonization parameter (y) at PLANCK resolution have been prepared from these regions centered in a supercluster. For their analysis, we have excluded those regions in the maps which are associated to identified clusters in the simulation, studying only the SZ signal produced by the remaining gas in the supercluster. We find that the most intense features in these proccesed maps are produced by small haloes (clumps in the simulations which are not identified as clusters), although these clumps are part of filaments. PLANCK should be able to detect at least one intense feature ($y > 8 \times 10^{-6}$) not associated to a cluster for every 8 superclusters. The probability of observing those features is a strong function of the elongation of the supercluster along the line of sight, so detections are most probable in highly elongated superclusters.

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1. Introduction

The distribution of baryons in the local Universe remains one of the open questions in Cosmology. As pointed out by Fukugita, Hogan & Peebles [1], the baryon fraction detected in the low redshift Universe can account only for one half of the total fraction which is determined at higher redshifts by three independent methods: the Lyα forest at $z \sim 2$ [2]; the Cosmic Microwave Background [3]; and the results of Big-Bang nucleosynthesis [4]. Hydrodynamic simulations of structure formation in the Universe [5, 6] suggest that these "missing-baryons" should be found in a warm-hot phase with temperatures in the range of 10^5-10^7 K, and in regions with moderate overdensities ($\delta \sim 10$ -100). This is the so called Warm-Hot Intergalactic Medium (WHIM). Detection of this warm/hot gas is challenging. As originally suggested by Cen & Ostriker [5], there are several signatures of this WHIM which could be used for its detection, such as soft X-ray emission; absorption lines in X-ray and UV quasar spectra (e.g., O VI (1032, 1038) Å lines, O VII 574 eV line); strong emission lines (e.g., O VIII 653 eV line); low-redshift, broad, low column density Lyα absorption lines; and the thermal Sunyaev-Zel'dovich effect (SZE) on CMB photons. We shall concentrate in this last possibility for this work.

The physical picture shown by simulations is the following. The WHIM is associated to regions with moderate overdensities, which correspond with filaments connecting the high-overdensity regions where clusters appear. Therefore, in order to detect this signal it is reasonable to observe regions with superclusters, where one expects a larger number of these filaments. A simple estimate using the typical parameters describing the WHIM (electron temperatures of the order of 0.1 keV, overdensities of 100 and scales of few Mpc) shows that the amplitude of the expected signal is of the order of few micro-kelvins. These signals could be detected by PLANCK using cross-correlations with galaxies, clusters or superclusters catalogues.

2. Previous searches for signatures of WHIM with tSZE

Although there are some tentative detections of a WHIM signature using absorption or emission lines, we will focus here in those studies related to SZ observations, searching for signatures of SZE signals at superclustes scales. Most of those studies were based on statistical detections of the signal [7, 8, 9], but we shall concentrate here in one case of a tentative direct detection.

Génova-Santos et al. [10] presented observations with the Very Small Array[1] of the Corona Borealis Supercluster (CrB-SC), covering an area of 24 deg^2 with 11 arcmin resolution and a sensitivity of 12 mJy/beam. The main outcome of that paper is the detection of a negative feature in the final map (called spot H) with temperature -230 ± 23 μK, located in a region with no known clusters of galaxies, and near the centre of the supercluster. The analyses revealed that this spot can not be explained in terms of a primordial CMB fluctuation (probability smaller than 0.38%). A Gaussianity analysis [11] reveals a strong non-Gaussian deviation (99.8% CL) in this map. Using the R6 ROSAT All-Sky survey, Génova-Santos et al. do not find evidence for emission in X-rays. Using this constraint, they can infer that the most reasonable explanation for this spot is a combination of primordial CMB and SZ signal. In order to test this possibility, Battistelli et al. [12] have performed observations using the MITO telescope in the region associated to this negative

[1] http://www.iac.es/project/cmb/vsa

spot. The results of these observations are discussed in the poster "Millimetric observations of SZE towards Corona Borealis Supercluster", by Gemma Luzzi et al.

3. Hydrodynamical simulations

We have used a high-resolution adiabatic SPH cosmological simulation [13] to study the observability of the WHIM with the PLANCK satellite data. The main question we have addressed here is: what is the probability of finding SZ signatures in a supercluster which are not associated to clusters of galaxies? The details of the simulation are: a cube of 500 h^{-1} Mpc a side, and resolution of 15/h kpc with 2×512^3 particles. Almost 200,000 objects with masses above $2 \times 10^{12} M_{\odot}$ are identified. The cosmology adopted is Λ-CDM model with $\Omega_\Lambda = 0.7$, $\Omega_m = 0.3$, $\Omega_b = 0.045$ and reduced Hubble constant $h = 0.70$. From this simulation, we identified 6 sub-volumes of $50 \times 50 \times 50$ Mpc^3 containing a supercluster, defined with the following criteria: the total mass in each region is higher than 10^{15} M$_{\odot}$, and more than 6 clusters with masses higher than 5×10^{13} M$_{\odot}$ are found. These characteristics are chosen to mimic the physical properties of the Corona Borealis supercluster. From these 6 sub-volumes, we generated y- parameter maps of 10 degrees on a side, and with an angular resolution of 1.2 arcmin. These maps are then convolved to the highest resolution of PLANCK (5 arcmin), as shown in Fig. 1.

3.1 Cluster removal algorithm

Cluster removal is a key point in our analysis. We can not delete a cluster directly from y-parameter map because we can not distinguish cluster contribution from diffuse gas. Therefore, we deleted each cluster from the hydrodynamical simulation before integrating along the line of sight. For removing each cluster, we used a numerical model following this procedure. The central coordinates of the cluster are identified in the simulation by selecting the highest density value. Then, we use a β-polytropic model for fitting the cluster. Using the entropy-driven model [14], it is possible to find a simulation cut-off as a function of the redshift and cluster total mass [15].

4. Preliminary Results and Conclusions

Once the y-parameter maps have been prepared removing the clusters, we identified all the resolution elements with a value of the Comptonization parameter larger than or equal to the y-parameter measured in CrB by the MITO experiment: $y = 7.8 \times 10^{-6}$.

Our results show that the probability of finding one or more spots like the one in CrB in a 3 by 3 degree square centered in a supercluster is 13% for PLANCK. In order to explore which orientations are most favourable for detecting this signal, we considered each one of the 6 sub-volumes containing superclusters and we rotated then in all possible directions. To achieve a detection, the best orientations are found to be those in which the apparent (projected) positions of the clusters are very close to each other and, simultaneously, when they have a large redshift separation along the integration line of sight (i.e when the supercluster is elongated along the line of sight). The strongest signals we find are usually associated to small clumps in the simulations, which are not identified as clusters, but they lie inside a filament. In general, those intense spots are placed between two clusters which are close in projected (angular) coordinates, but they are well separated

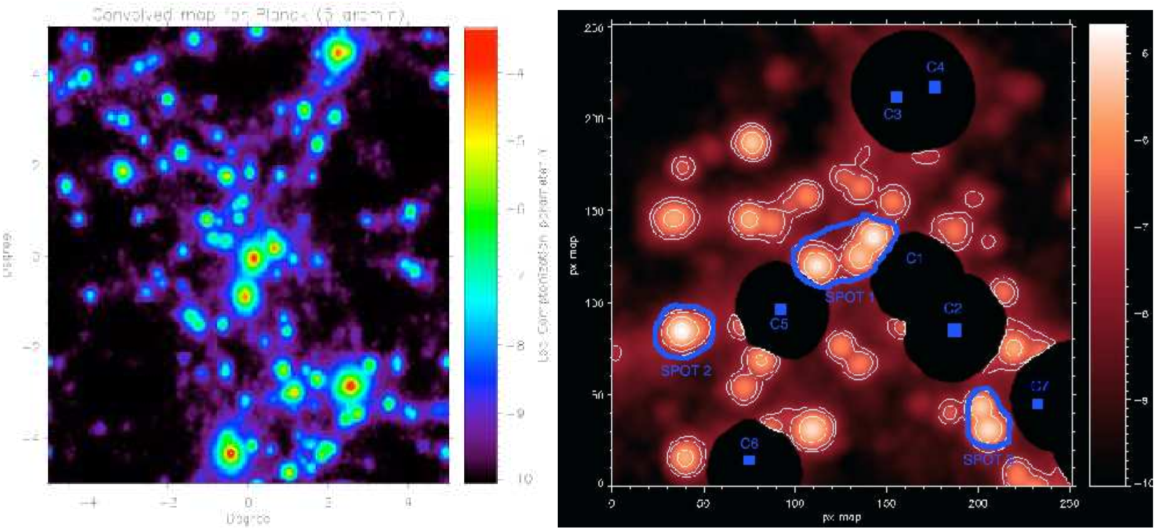

Figure 1: Left: Example of one y-parameter map obtained in this work, convolved to the highest resolution of PLANCK ($5'$). Right: A y-map with clusters excluded. Cluster positions are marked with letter C. We used the Sextractor algorithm to idenfity peaks in these "cleaned" maps. Those structures are marked in blue.

in redshift. This is in agreement with the case of CrB-SC, which is found to be elongated along the line of view. The spot H is placed between clusters A2069 and A2073, which are separated by $\Delta z = 0.06$. This is exactly the largest separation found between two members of the Corona Borealis SC.

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