PROCEEDINGS OF SCIENCE

The all-sky early Sunyaev-Zeldovich cluster sample from the PLANCK experiment

G.Hurier* **On behalf of the PLANCK Collaboration.**
Laboratoire de Physique Subatomique et de Cosmologie, CNRS/IN2P3, Université Joseph Fourier Grenoble I, Institut National Polytechnique de Grenoble, 53 rue des Martyrs, 38026 Grenoble cedex, France

E-mail: ghurier@lpsc.in2p3.fr

We present the first all-sky sample of galaxy clusters detected blindly by the PLANCK satellite through the Sunyaev-Zeldovich (SZ) effect from its six highest frequencies. This early SZ (ESZ) sample consists of 189 candidates, which have a high signal-to-noise ratio ranging from 6 to 29. Its high reliability (purity above 95%) is further ensured by an extensive validation process based on PLANCK internal quality assessments and by external cross-identification and follow-up observations. PLANCK provides the first measured SZ signal for about 80% of the 169 previously-known ESZ clusters. PLANCK furthermore releases 30 new cluster candidates, amongst which 20 meet the ESZ signal-to-noise selection criterion. At the submission date, twelve of the 20 ESZ candidates were confirmed as new clusters, with eleven confirmed using XMM-Newton snapshot observations, most of them with disturbed morphologies and low luminosities. The ESZ clusters are mostly at moderate redshifts (86% with z below 0.3) and span more than a decade in mass, up to the rarest and most massive clusters with masses above $1 \times 10^{15} M_{\odot}$.

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*Speaker.

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1. Introduction

Galaxy clusters provide valuable information on cosmology, from the nature of dark energy to the physics that drives galaxy and structure formation. The main baryonic component in these dark matter dominated objects is a hot, ionised intra-cluster medium (ICM). The ICM can be studied both in the X-ray and through the Sunyaev-Zeldovich effect (SZ) [16, 15], a fairly new and highly promising technique that has made tremendous progress in recent years since its first observations [3]; see also [14, 2, 5].

The SZ effect is caused by the inverse Compton interaction between the cosmic microwave background (CMB) photons and the free electrons of the hot ICM. It can be broadly subdivided into the thermal SZ (TSZ) effect, where the photons are scattered by the random motion of thermal electrons, and the kinetic SZ (KSZ) effect caused by the bulk motion of the electrons. In the former case, the scattered CMB photons have a unique spectral dependence, whereas the final spectrum remains Planckian in the case of the KSZ effect.

The SZ effect offers a number of advantages for cluster studies. First, the Compton y parameter, which measures the integral of the gas pressure along the line of sight and sets the amplitude of the SZ signal, does not suffer from cosmological surface-brightness dimming. This implies that the SZ effect is an efficient method for finding high-redshift clusters. Second, the total SZ signal Y, integrated over the cluster's angular extent, directly measures the total thermal energy of the gas and as such is expected to correlate closely (i.e., with a tight scatter in the scaling relation) with total cluster mass. This fact is borne out both by numerical simulations [4, 6, 9, 11] and indirectly from X-ray observations [10, 1, 17] using Y_X, the product of the gas mass and mean temperature giving an X-ray analogue of the integrated SZ Compton parameter first introduced by [8].

The present article details the process by which PLANCK ESZ sample was validated [13].

2. The ESZ sample

The ESZ sample was constructed out of the PLANCK channel maps of the HFI instrument, as described in detail in [12]. These maps correspond to the observations of the temperature in the first ten months of the survey by PLANCK, which give complete sky coverage. Raw data were first processed to produce cleaned time-lines (time-ordered information, TOI) and associated flags correcting for different systematic effects. This includes a low-pass filter, glitch treatment, conversion to units of absorbed power, and a decorrelation of thermal stage fluctuations.

The ESZ validation process, is an integrated HFI-LFI effort within PLANCK Working Group 5 (WG5[1]) "Clusters and Secondary anisotropies". It has been established in order to validate the full SZ candidate lists obtained from the extraction methods developed by the PLANCK collaboration. It relies mainly on a three-stage process detailed in the following subsections:

- **Internal validation** steps based on PLANCK data:
  - search for and rejection of associations with SSOs (Solar System Objects) and artefacts;
  - rejection of sources with rising spectral energy distribution in the high HFI frequency bands;

[1] http://www.ita.uni-heidelberg.de/collaborations/planck/

  - cross-check with other PLANCK source catalogues to reject SZ candidates identified with cold cores (CC) and other Galactic sources; and
  - redundant detections of the same candidates by methods other than the reference one.

- **Candidate identification** steps based on ancillary data:
  - identification of SZ candidates with known clusters from existing X-ray, optical/near infrared (NIR), and SZ catalogues and lists; and
  - search in NED and SIMBAD databases.

- **Follow-up programmes** for verification and confirmation of SZ candidates.

3. Construction of y maps for internal validation

We produced maps of the Compton parameter y using different cleaning approaches developed by the PLANCK collaboration, for each of the ESZ sample clusters, in order to ensure convergence and redundancy in the derived conclusions in the context of the validation process described above. One of these methods is based on the Modified Internal Linear Combination Algorithm (MILCA, [7]).
The MILCA algorithm search for the best linear combination of the input maps to extract the tSZ signal, which minimize both the instrumental noise level and the contamination by other physical emissions in the reconstructed y map. It can be divided in three main steps. First we use the Electromagnetic spectrum of the known components to constrain the weights of the linear combination that extract the tSZ effect Then, we minimize the the variance of the reconstructed y map in the subspace of physical components. Finally, we use remaining degrees of freedom to minimize the noise contribution in the y map

The Figure 1 shows an example of y map obtained for the Coma cluster.

4. Summary

Thanks to its all-sky coverage and to its frequency range spanning the SZ decrement and increment, PLANCK provides us with the very first all-sky S/N-selected SZ sample. This early release sample of high-reliability SZ clusters and candidates (S/N from 6 to 29) was constructed using a matched multi-filter detection technique. It was validated using PLANCK-internal quality assessment, external X-ray and optical data, and a multi-frequency follow-up programme for confirmation relying mostly on XMM-Newton snapshot observations. The ESZ sample comprises 189 candidates, of which 20 are candidate new clusters and 169 have X-ray or optical counterparts. Of these, 162 were observed in X-ray. PLANCK provides for the first time SZ observations for about 80% of the ESZ clusters and hence a homogeneously measured SZ signal. Twelve candidate clusters in total, out of the 20, have been confirmed. One candidate was confirmed by AMI and WISE. Eleven were confirmed with XMM-Newton, including two candidates found to be double clusters on the sky.

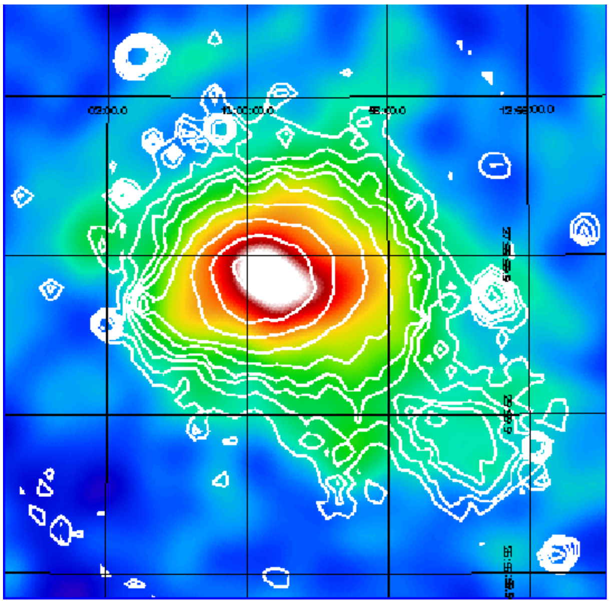

Figure 1: PLANCK y-map of Coma on a $\sim 3\,\mathrm{deg} \times 3\,\mathrm{deg}$ patch with the *ROSAT-PSPC* iso-luminosity contours overlaid.

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