SF2A 2011
G. Alecian, K. Belkacem, R. Samadi and D. Valls-Gabaud (eds)

PLANCK SZ CLUSTERS

M. Douspis[1, 2]

Abstract. We present here the first results on galaxy clusters detected by the *Planck* satellite through the Sunyaev–Zeldovich (SZ) effect from its six highest frequencies. We show the properties of the first all sky SZ sample (Planck Early SZ sample, ESZ) and how the new discovered clusters are mostly morphologically disturbed. Finally, we present results on the scaling relations between SZ and X-ray or optical cluster properties.

Keywords: Cosmology, Galaxy clusters

1 Introduction

In January 2011, Planck* delivered to the community the first data and accompanying papers. The Early Release Compact Source Catalogue (ERCSC, Fig. 1) contains three type of samples: the first type consists in a sample of compact sources per frequency (from 30 GHz to 857 GHz), the second one is the Early Cold Core (ECC) sample, and the last one in the Early SZ (ESZ) cluster sample. On top of the technological, spatial, and human achievement, *Planck* is also a scientific success with the publication of 20 articles so far, based only on 10 months of observations.

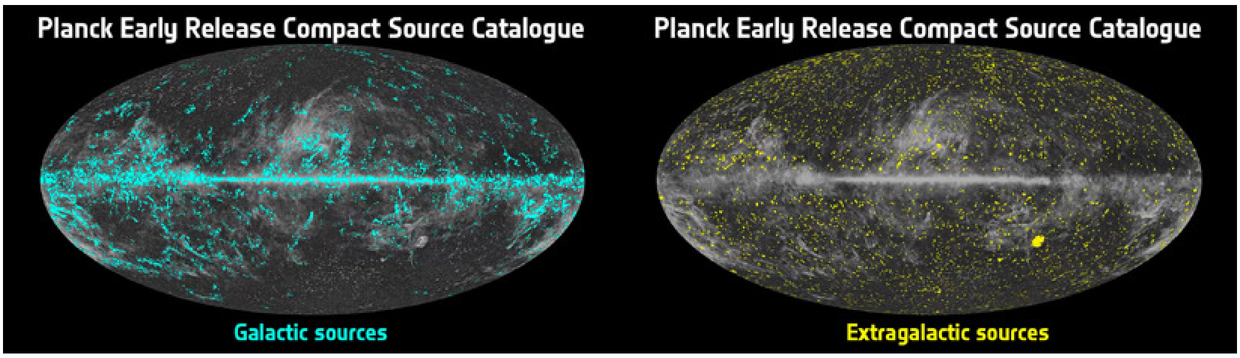

Fig. 1. Left: Planck ERCSC galactic sources. **Right:** Planck ERCSC extragalactic sources.

Among the Planck early papers on extragalactic science, five are presenting results on galaxy clusters (Planck Collaboration 2011b,c,d,e,f) including the description of the ESZ and new XMM confirmed clusters, SZ/X-ray and SZ/optical scaling laws.

[1] IAS, Université Paris Sud 11, CNRS, 91400 Orsay, France
[2] on behalf of the Planck Collaboration, `www.rssd.esa.int/`

* *Planck* (http://www.rssd.esa.int/Planck) is a project of the European Space Agency (ESA) with instruments provided by two scientific consortia funded by ESA member states (in particular the lead countries France and Italy), with contributions from NASA (USA) and telescope reflectors provided by a collaboration between ESA and a scientific consortium led and funded by Denmark.

2 Clusters and SZ effect

The clusters of galaxies are the largest virialized structures of the universe and are thus very sensitive to the primordial fluctuations and the evolution of the universe. They are composed of dark matter ($\approx$ 80%), hot gas ($\approx$ 15 %), and stars (galaxies). The dark matter component is responsible for most of the potential well with the gas component. The latter is the source of the X-ray and SZ emissions, enabling the observation of the clusters. The smallest component, galaxies and stars, revealed the existence of clusters through the first means of observation in visible wavelengths. Galaxy counts enable the characterization of clusters even today.

The Sunyaev-Zeldovich effect emerges when light of the CMB travels through hot gas in clusters of galaxies. It is caused by the inverse Compton effect, where the electrons of the hot gas interact with (scatter) the CMB photons. This interaction has a very specific signature in the microwave spectrum, predicted already by Sunyaev & Zeldovich (1972); Sunyaev & Zeldovich (1980), showing up as a distortion of the blackbody spectrum that translates into a "hole in the sky" at frequencies below 217 GHz and a "bump" above this frequency. The frequencies of *Planck* channels were specifically chosen to observe this effect. Figure 2 shows a cluster (Abell 2319) as seen by *Planck* between 44 GHz and 545 GHz. Note the negative (resp. positive) signal below (resp. above) 217 GHz. At the latter frequency, the SZ signal is expected to be null.

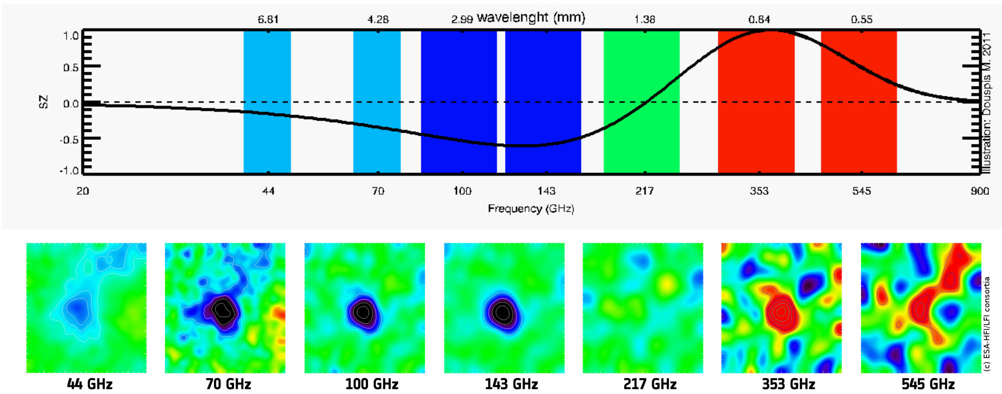

Fig. 2. Abell 2319 seen by *Planck* between 44 GHz and 545 GHz.

3 Planck SZ clusters

Using this specific SZ signature, *Planck* was designed to be able to detect numerous clusters (Aghanim et al. 1997). Unfortunately, not all are showing up as Abell 2319. The signal is indeed quite weak and is contaminated by foregrounds (our Galaxy, and nearby radio/IR galaxies) and backgrounds (CMB and CIB). As described later, the published Planck clusters have a signal–to–noise ratio (S/N) greater than 6. This means that the S/N per frequency is of the order of 1. This has lead us to develop a specific approach for detecting, validating and confirming clusters.

We use a multi-matched filter (MMF) method (Melin et al. 2006) to detect the clusters. It is taking advantage of the spectral signature (SZ signature without relativistic effects) *and* the spatial signature (universal spherical profile from X-ray observations, Arnaud et al. 2010) of the clusters detected by Planck. As optimal as the method can be, a process of validation is still necessary to remove false detections. This is done in two steps. First a cross-check with internal Planck catalogues (cold cores, solar system objects, bad pixels) is performed, then cross-checks with existing external catalogues and data (SDSS, RASS) are performed to classify the known clusters and the new candidate clusters. Finally, follow-up observations has been done in optical, SZ and mainly in X-ray with XMM-Newton, to confirm our candidate clusters.

3.1 Planck Early SZ cluster sample

These detection, validation, and confirmation steps have lead to the production of the Planck Early SZ Cluster sample (ESZ). It contains 199 clusters, 10 of which, confirmed by XMM-Newton have a S/N <6. The 189 clusters with S/N greater than 6 are divided in 169 known clusters (in X-ray, optical or SZ) and 20 new Planck clusters. At the time of the release only 11 were confirmed by XMM-Newton. Since then, 6 more have been confirmed by

SPT and AMI (Story et al. 2011; AMI Consortium et al. 2011). The sample is available as part of the Planck Early Release Compact Source Catalogue (ERCSC, Planck Collaboration 2011a) at `rssd.esa.int/Planck`. The distribution on the sky of these clusters is shown in Fig. 3.

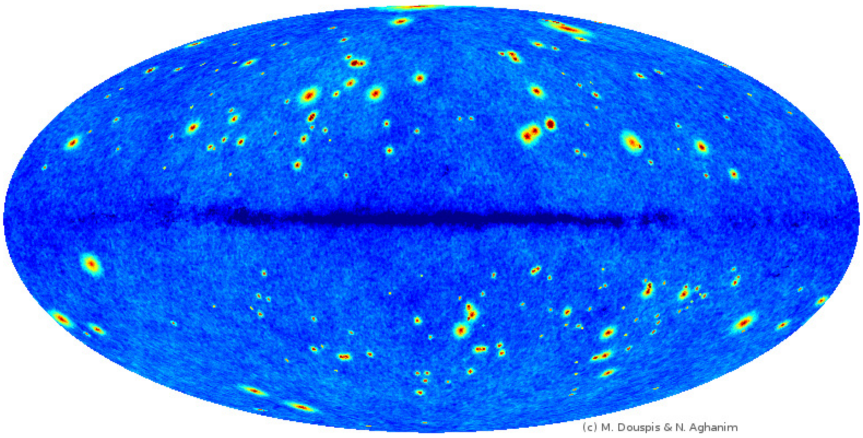

Fig. 3. Distribution on the sky of the Planck ESZ clusters (the signal has been amplified to be seen).

The ESZ clusters have relatively low redshift; 86% of them have $z < 0.3$. Their masses span more than a decade up to $1.5 \cdot 10^{15} M_{sol}$, and a large fraction of new Planck detected clusters are massive ($> 9 \cdot 10^{14} M_{sol}$). Planck has thus a unique capability to detect the rarest and most massive clusters over the full sky.

3.2 SZ clusters properties

Observing galaxy clusters in SZ opens a new observational window to understand not only the clusters themselves but also the evolution of our Universe. As described earlier, Planck has detected new clusters, sometimes massive. Why have they not been detected already in X-ray ? Is this a new population of clusters, or the gas (responsible for both X-ray and SZ emissions) properties differ from what we think ? As massive objects, clusters are sensitive to cosmological initial conditions and cosmic evolution. To use clusters for cosmological studies we need to relate their mass to our observation (SZ effect or Y-parameter). But is SZ effect a good proxy for the mass ? How does the SZ signal relates to the X-ray luminosity, to the richness of clusters ? The Planck ESZ clusters and Planck data are and will help in answering these questions.

3.3 New Planck clusters

The new Planck confirmed clusters have been compared with REXCESS X-ray detected clusters. *Planck* clusters show a more complex morphology, being sometimes really diffuse, extended, disturbed, and also double or triple. For the same given mass, they are also sub-luminous in X-ray compared to the REXCESS ones. Their electronic density profiles is on average lower in the center than the REXCESS ones (see Fig. 4).

Multiwavelenght studies will help understand these properties. For example, Bagchi et al. (2011) have observed one the XMM confirmed Planck new clusters and found radio arcs. Such findings, revealing shocks and/or merger, would imply higher temperature areas, that could enhance the SZ signal and explain why these clusters are seen in SZ and not in X-ray. More dedicated multiwavelenght studies are thus needed to better understand these clusters.

3.4 Scaling relations

In order to use clusters as cosmological probes, one needs to relate the observed properties (being X-ray luminosity, optical richness, or obviously SZ signal) to the mass of the clusters. It is usually assumed that X-ray luminosity is a good proxy for the mass. We thus looked at the relation between SZ signal and X-ray luminosity

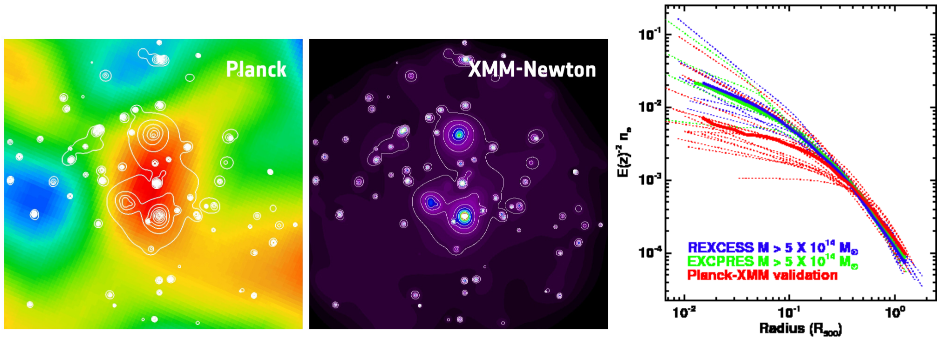

Fig. 4. Left: Planck SZ and XMM X-ray images of PLCKG214.6+37.0 **Right:** electronic density profiles of Planck and REXCESS clusters

on one side and SZ signal and optical richness on the other side. For this, we used two cluster catalogues. The first one is a meta-catalogue of $\sim$ 1600 homogenized X-ray clusters (Piffaretti et al. 2010). The other one is an optical catalogue based on SDSS of $\sim$ 13000 clusters between $0.1 < z < 0.3$. From these two catalogues, using the universal pressure profile, we computed the expected SZ signal per bin in X-ray luminosity or richness. We then compared these expected values with the ones observed by Planck at the positions of the catalogues clusters. The results are shown in Fig. 5.

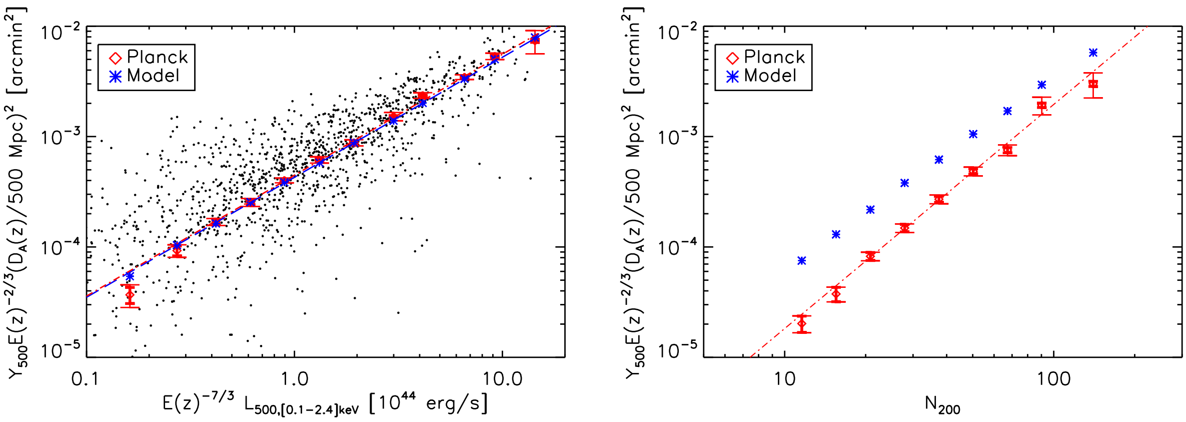

Fig. 5. Left: Scaling relation between X-ray luminosity and *Planck* SZ flux **Right:** Scaling relation between the optical richness (N_{200}) and *Planck* SZ flux

The first result shown in these figures is that the SZ signal is observed and detected for the first time at really low masses $\sim 5 \cdot 10^{13} M_{sol}$, with a precision 10 times better than WMAP.

It is also shown that the predicted signal inferred from X-ray luminosity is in perfect agreement with that observed by Planck. This agreement, expected by the fact that the gas is responsible for both signals, is furthermore good at all masses (luminosity). It has also been checked with several catalogues and ESZ sub-samples (Planck Collaboration 2011e). This comforts us in the fact that the X-ray luminosity is a good mass proxy for clusters. The good quality of the data allows us now to study the dispersion and evolution with redshift of the X-SZ relation.

A good correlation is also found between the SZ signal and the optical richness of clusters. But, besides this good correlation, the expected signal inferred from the richness is a factor of 2 higher (at $N_{200} = 50$) than that observed. This disagreement remains unexplained, and studies are ongoing to understand the role of selection effects, the disagreement between X-ray and lensing masses, or any other explanation.

4 Conclusions

Planck has delivered a unique all sky sample of 199 galaxy clusters observed in SZ. This is the most complete and homogeneous sample of massive SZ clusters at moderate redshift (z<0.5). For 80% of the sample, this is the first SZ measure, increasing by a factor 2 the number of observed clusters in SZ.

Planck offers thus a new window for the study of galaxy clusters. The newly discovered clusters seem to have a more complex morphology and a lower luminosity than the usual X-ray clusters.

The predicted signal inferred from X-ray observations is in very good agreement with the observed SZ signal, even to lower masses, leading to a good understanding of the gas properties in clusters. Conversely, the optical richness of clusters does not seem to probe correctly the SZ signal. This discrepancy is still under study by both optical and SZ clusters communities.

The next release of Planck data will occur in January 2013. The SZ cluster sample will obviously be expanded, especially towards higher redshift (see e.g. Planck Collaboration et al. (2011), and Fig. 6). It will be used for cosmology, studies of the diffuse SZ, and more detailed studies of particular clusters.

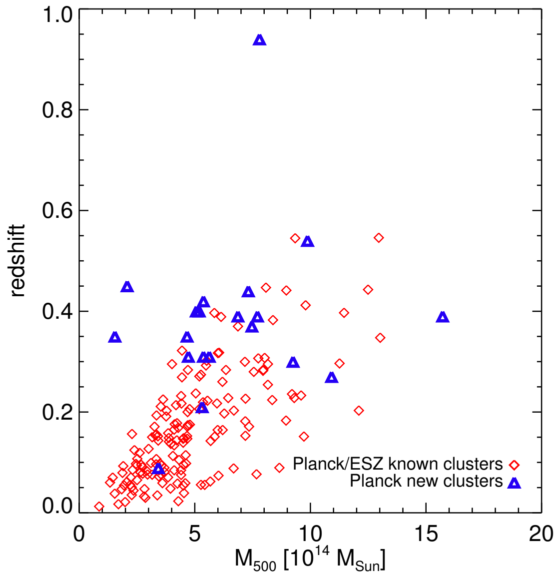

Fig. 6. Redshift–mass distribution of the ESZ sample as well as the new $z \sim 1$ clusters of Planck Collaboration et al. (2011)

The authors thank N. Schartel, ESA XMM-Newton project scientist, for granting the Director Discretionary Time used for confirmation of SZ Planck candidates. This research has made use of the following databases: SIMBAD, operated at CDS, Strasbourg, France; the NED database, which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration; BAX, operated by the Laboratoire d'Astrophysique de Tarbes-Toulouse (LATT), under contract with the Centre National d'Etudes Spatiales (CNES), SZ repository operated by IAS Data and Operation Center (IDOC) under contract with CNES. The authors acknowledge the use of software provided by the US National Virtual Observatory. A description of the Planck Collaboration and a list of its members, indicating which technical or scientific activities they have been involved in, can be found at `http://www.rssd.esa.int/Planck`.

References

Aghanim, N., de Luca, A., Bouchet, F. R., Gispert, R., & Puget, J. L. 1997, A&A, 325, 9

AMI Consortium, Hurley-Walker, N., Brown, M. L., et al. 2011, MNRAS, 414, L75

Arnaud, M., Pratt, G. W., Piffaretti, R., et al. 2010, A&A, 517, A92

Bagchi, J., Sirothia, S. K., Werner, N., et al. 2011, ApJ, 736, L8+

Melin, J., Bartlett, J. G., & Delabrouille, J. 2006, A&A, 459, 341

Piffaretti, R., Arnaud, M., Pratt, G. W., Pointecouteau, E., & Melin, J. 2010, arXiv e-print, `arXiv:1007.1916`

Planck Collaboration. 2011a, Planck early results 07: The Early Release Compact Source Catalogue (Submitted to A&A, [arXiv:astro-ph/1101.2041])

Planck Collaboration. 2011b, Planck early results 08: The all-sky early Sunyaev-Zeldovich cluster sample (Submitted to A&A, [arXiv:astro-ph/1101.2024])

Planck Collaboration. 2011c, Planck early results 09: XMM-Newton follow-up for validation of Planck cluster candidates (Submitted to A&A, [arXiv:astro-ph/1101.2025])

Planck Collaboration. 2011d, Planck early results 10: Statistical analysis of Sunyaev-Zeldovich scaling relations for X-ray galaxy clusters (Submitted to A&A, [arXiv:astro-ph/1101.2043])

Planck Collaboration. 2011e, Planck early results 11: Calibration of the local galaxy cluster Sunyaev-Zeldovich scaling relations (Submitted to A&A, [arXiv:astro-ph/1101.2026])

Planck Collaboration. 2011f, Planck early results 12: Cluster Sunyaev-Zeldovich optical Scaling relations (Submitted to A&A, [arXiv:astro-ph/1101.2027])

Planck Collaboration, Aghanim, N., Arnaud, M., et al. 2011, ArXiv e-prints, [arXiv:1106.1376]

Story, K., Aird, K. A., Andersson, K., et al. 2011, ApJ, 735, L36+

Sunyaev, R. A. & Zeldovich, I. B. 1980, ARA&A, 18, 537

Sunyaev, R. A. & Zeldovich, Y. B. 1972, Comments on Astrophysics and Space Physics, 4, 173