The Planck Survey Early Release SZ sky

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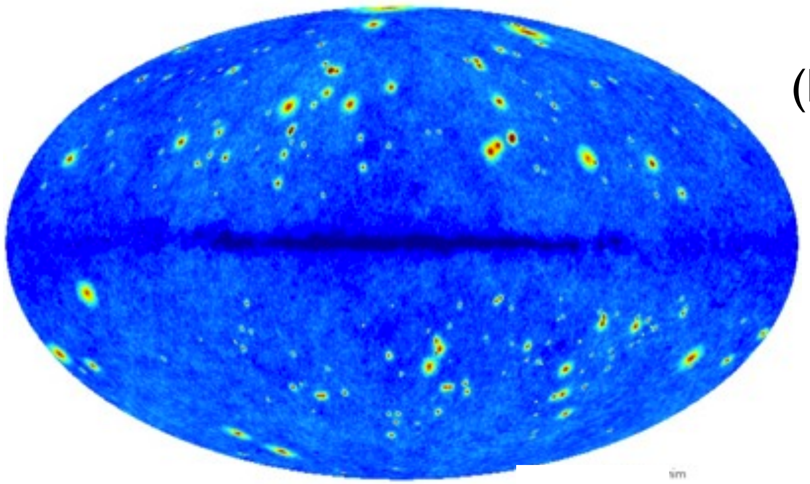
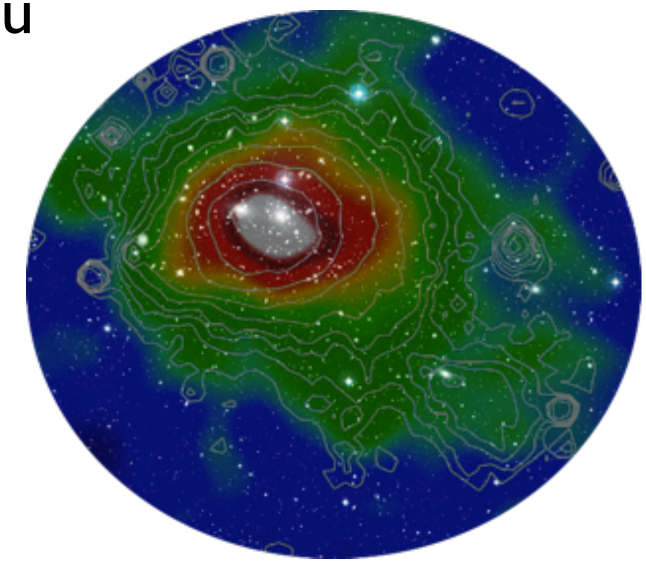
on behalf of the Planck Collaboration





189 Planck sources in the early release SZ sample

- *Planck* Early Results: The all-sky Early Sunyaev-Zeldovich cluster sample *(arXiv:1101.2024)*
- *Planck* early results: XMM-Newton follow-up for validation of Planck cluster candidates *(arXiv:1101.2025)*
- *Planck* early results: statistical analysis of SZ scaling relations for X-ray galaxy clusters *(arXiv:1101.2043)*
- *Planck* Early Results: Cluster SZ-Optical Scaling Relations *(arXiv:1101.2027)*
- *Planck* Early Results: Calibration of the local galaxy cluster Sunyaev-Zeldovich scaling relations *(arXiv:1101.2026)*

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PLANCK Early Results

The all-sky Early Sunyaev-Zeldovich cluster sample

Planck Collaboration

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Introduction

Thanks to its all-sky coverage and to its frequency range spanning the Sunyaev-Zeldovich (SZ) decrement and increment, *Planck* was specifically designed to measure the SZ effect [2]. It provides us with the very first all-sky signal-to-noise (S/N) selected sample of clusters detected blindly through the SZ effect [1].

This Early SZ (ESZ) sample of 189 high-reliability SZ candidates (S/N from 6 to 29) was constructed using a matched multi-filter detection technique over the six highest frequencies of *Planck*.

The ESZ high reliability (purity above 95%) is further insured by an extensive validation process based on *Planck*-internal quality assessment, cross-identification with external X-ray and optical data, and a multi-frequency follow-up programme for confirmation relying mostly on XMM-Newton snapshot observations.

With the ESZ, *Planck* provides the first measurement of SZ signal for about 80% of the 169 ESZ known clusters. *Planck* releases in t
Twenty of them are within the ESZ with eleven confi M-
Newton observations. (Ten candidates with S/N<6
released separately

The ESZ clusters are mostly at moderate redshifts
They span over a decade in mass, up to the rarest s
with masses above 10 × 1

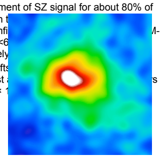


Fig. 1 *Planck* reconstructed y-map of Coma on a ~3°x3° patch

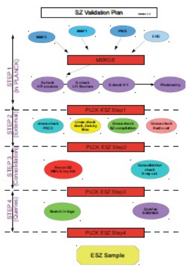
Construction and Validation of the *Planck* cluster sample
B- Validation process

The filtering by MMF3 optimises cluster detection but is not immune to contamination by false, non-SZ detections. To ensure that
extensive validation process is performed:

- **Internal validation steps based on *Planc***
  - search for and rejection of associations w
  - rejection of sources with rising spectral e
  - cross-check with other *Planck* source c
    with cold cores [5] and other Galactic sou
  - redundant detections of the candidates b
- **Candidate identification steps based on**
  - identification of SZ candidates with know
    [7], SZ catalogues and lists [8]
  - search in NED and SIMBAD databases.

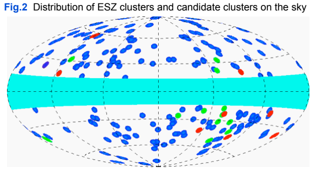
- **Follow-up programmes** for verification a
mostly on observations with XMM-Newton m
[9].

The ESZ sample, distributed over the whol
candidates: 169 known clusters (blue) and
confirmed (11 by XMM-Newton, 1 by AMI/\
confirmed (red).



ESZ sample		189
Known clusters		169
	X-ray only	30
	Optical only	5
	NEDSimbad only	1
	X-ray + Optical	128
	X-ray + SZ	1
	SZ + Optical	1
	X-ray + Optical +SZ	3
New *Planck* clusters		20
	XMM confirmed	11
	AMI confirmed	1
	Candidate new clusters	8

Fig.2 Distribution of ESZ clusters and candidate clusters on the sky



Construction and Validation of the *Planck* cluster sample
A- Detection of SZ candidates

The ESZ sample is the result of a blind multi-frequency search in the six all-sky *Planck*-HFI maps. No prior positional information on detected known clusters was used as input to the algorithm. The ESZ sample is produced by running an all-sky extension of the matched multi-frequency filter algorithm, MMF3 [3]. In order to enhance the SZ contrast over the contaminating signals, MMF3 incorporates prior assumptions on the cluster signal, its spectral and spatial [i.e., the shape of the Intra-Cluster Medium pressure profile] characteristics. The baseline pressure profile used is the standard `universal' profile [4] and the SZ spectrum is the non-relativistic one. For each of the 504 overlapping 10°x10° patches, the position and the scale radius (chosen to be $5{\times}R_{500}$) of the cluster profile are varied to maximise the S/N of each detection. The algorithm hence assigns to each detected source a position, an estimated cluster size, $5{\times}\Theta_{500}$, and an integrated Compton parameter, Y_{5R500}.

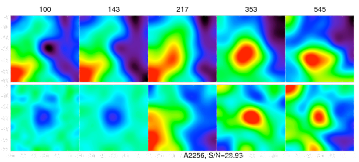


Fig. 3 *Planck* observation of A2256 (S/N~29). The upper panel shows the raw (1°x1°) maps at 100, 143, 217, 353, and 545GHz. The lower panel shows the corresponding cleaned maps.

ESZ sample properties

- The S/N of the ESZ clusters range between 6 and 29 with a median of about 8. Six clusters, including A2163 with S/N = 26 and Coma with S/N = 22, are in the tail of the distribution with S/N>20.

- *Planck* provides us with measures of the integrated Compton parameter within a $5{\times}R_{500}$ sphere, $5{\times}Y_{500}$, for 189 clusters. For about 80% of the known clusters in the ESZ, this is the very first SZ measure performed in their direction. The SZ signal of the whole sample extends over about two orders of magnitude from ~ 1.5×10^{-3} to 117×10^{-4} arcmin^2

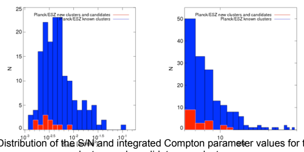


Fig.4 Distribution of the S/N and integrated Compton parameter values for the ESZ clusters and candidate new clusters

- Using X-ray derived mass-proxies, we estimate masses, M_{500}, for 167 clusters out of the 189 of the ESZ clusters. The masses of the ESZ clusters span over a decade ranging from 0.9 to 15×10^{14} M_{sol}. In surveying the whole sky, *Planck* has a unique capability to detect rarest and most massive clusters. Among the 21 newly discovered clusters confirmed by XMM-Newton in total 3 have total masses of 10×10^{14} M_{sol} or larger. The ESZ clusters with masses above $M > 9 \times 10^{14}$ M_{sol} represent 90% of the RASS clusters.

Using the redshift information (compiled in the MCXC, retrieved from NED/SIMBAD and estimated from XMM-Newton follow-up observations), we gather the redshifts for 175 clusters of the ESZ sample. They are distributed in the range of small to moderate redshifts with a median z of 0.15 (86% of the ESZ clusters are lying below z=0.3).

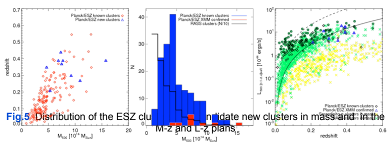


Fig.5 Distribution of the ESZ clu ndidate new clusters in mass and in the M-z and L-z plans

Gallery of ESZ clusters

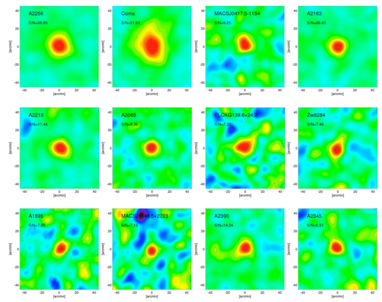


Fig. 6 Illustrations of reconstructed y-maps (1.5°x1.5°, smoothed to 13 arcmin) for clusters spanning S/N from 29 to 6, from the upper left to the lower right.

Summary

- The high-purity (above 95%) ESZ sample comprises 189 candidates, of which 20 are candidate new clusters. Twelve candidate clusters have already been confirmed. One candidate was confirmed by AMI and WISE. Eleven were confirmed by XMM-Newton, including two candidates found to be double clusters on the sky.

- The remaining 169 ESZ candidates 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 known ESZ clusters and hence homogeneously measured SZ signal.

- A significant fraction of the ESZ clusters have good archival data. The ESZ should motivate follow-up efforts. The ESZ will hence serve as a valuable reference for studies of cluster physics at moderate redshifts (e.g., galaxy properties versus intra-cluster gas physics, metallicities, dynamical state and its evolution, etc). These studies will require multi-wavelength observations including further SZ observations at higher spatial resolution and observations in X-rays (with XMM-Newton, Chandra, and Suzaku), in the optical (imaging and spectroscopy), and in the radio (e.g., with LOFAR).

- The clusters in the ESZ sample are mostly at moderate redshifts lying between z=0.01 and z=0.55, with 86% of them below z=0.3. The ESZ-cluster masses span over a decade from 0.9 to 15×10^{14} M_{sol}, i.e. up to the highest masses.

- Thanks to its all-sky coverage, *Planck* has a unique capability to detect the rarest and most massive clusters in the exponential tail of the mass function. As a matter of fact, two of the newly-discovered clusters in the ESZ and confirmed by XMM-Newton have estimated total masses larger than 10^{15} M_{sol}.

- *Planck* is detecting new clusters, in a region of the mass-z plane that is sparsely-populated by the RASS catalogues. Furthermore, as indicated by XMM-Newton, most of the new clusters have low luminosity and a disturbed morphology, suggestive of a complex dynamical state. *Planck* may have started to reveal a non-negligible population of massive dynamically perturbed objects, that is under-represented in X-ray surveys.

Bibliography

- [1] *Planck* Collaboration 2011e, *Planck Early Results: The all-sky Early Sunyaev-Zeldovich cluster sample*
- [2] Aghanim, N., de Luca, A., Bouchet, F. R., Gispert, R., & Puget, J. L. 1997, A&A, 325, 9
- [3] Melin, J., Bartlett, J. G., & Delabrouille, J. 2006, A&A, 459, 341
- [4] Arnaud, M., Pratt, G. W., Piffaretti, R., et al. 2010, A&A, 517, A92
- [5] *Planck* Collaboration. 2011w, *Planck Early Results: The Galactic Cold Core Population revealed by the Planck first all sky survey*
- [6] Piffaretti, R., Arnaud, M., Pratt, G. W., Pointecouteau, E., & Melin, J. 2010, arXiv:1007.1916
- [7] Abell, G. O. 1958, ApJS, 3, 211 & Zwicky, F., Herzog, E., & Wild, P. 1961
- [8] Douspis, M., Aghanim, N., Evrard, L., & Langer, M. 2011, in preparation
- [9] *Planck* Collaboration 2011f, *Planck Early Results: XMM-Newton follow-up for confirmation of Planck discovered clusters*

Planck (http://www.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.

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PLANCK Early Results

The Planck Mission: XMM-*Newton* follow-up for validation of *Planck* cluster candidates

Planck Collaboration

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Overview

The *Planck* collaboration has undertaken a follow-up with the XMM-*Newton* satellite to confirm the cluster candidates detected in the *Planck* survey.

▪ Cluster Candidate Selection

- **MMF (Melin et al 2006) blind search ;** internal & external (rass) quality assessment ; cross-identification with ancillary catalogues, data & DB (ID of known clusters). See Planck Collaboration 2011e
- ⇒ list of *Planck* SZ cluster candidates with $S/N > 4$ (here) for confirmation follow-up.
- Must not fall in a Chandra/XMM/Suzaku pointing (performed or accepted)

▪ ***XMM-Newton* validation programme to date**

•Snapshot (~10 ksec) exposures.

•Pilot programme to sample the lower range of signal-to-noise ($4 < S/N < 6$)

•High S/N programme: sub-sample of 15 ($S/N > 5$) candidates starting from the highest S/N

▪ **Outcomes of the validation programme**

•21 candidates are confirmed as extended X-ray sources (100% for $S/N > 5$)

•17 single clusters, the majority of which are found to have highly irregular and disturbed morphologies.

•2 double clusters, one of which is a projection of two physically independent clusters at different redshifts.

•2 newly-discovered triple systems that were not resolved by Planck. One of these is at confirmed z~0.45, likely to form the core of a supercluster, the first such object discovered via the SZ effect.

•17 clusters have redshift estimate from the X-ray Fe K line spectroscopy. spawning in the range $0.09 < z < 0.54$ with a median redshift of z~0.37.

▪ **Conclusions and perspectives**

•Clear demonstration of the efficiency of *XMM-Newton* for *Planck* candidate validation: sensitivity and spatial resolution of XMM-Newton allows unambiguous discrimination between clusters and false candidates (Fig 1)

•The validation programme has helped to optimise the *Planck* candidate selection process.

•Clear added value to simple candidate confirmation from XMM observations.

- ⇒ Refine SZ flux (Y_{SZ}) estimate knowing X-ray size+position
- ⇒ X-ray flux measurement and refined position is essential information for optimisation of deeper X-ray (and optical) follow-up

•A preview of the new SZ cluster properties (see Fig 2):

- From first estimates of cluster properties, these SZ-selected objects have, on average, lower luminosities, flatter density profiles, and a more disturbed morphology than their X- ray selected counterparts.
- The Planck SZ survey has already started to complete existing X–ray surveys, particularly above z~0.3

⇒ *Planck* may have started to reveal a non-negligible population of massive dynamically perturbed objects that is under-represented in X-ray surveys.

Continuation of the validation of Planck candidates and the characterisation of the Planck selection function constitutes a major effort, and requires a good understanding of the properties of the newly-discovered clusters. XMM-Newton can play a major role in this process. The XMM-Newton validation program is presently on going. It is currently focussed on detections both in the S/N > 5 range and at lower S/N, thus potentially leading to the discovery of more distant clusters.

Acknowledgments: **The Planck Collaboration warmly thanks Norbert Schartel for his support of the validation programme and granting discretionary time for the observations.**

References

- Arnaud, M., Pratt, G. W., Piffaretti, R., et al. 2010, A&A, 517, A92
- Melin, J., Bartlett, J. G., & Delabrouille, J. 2006, A&A, 459, 341
- Planck Collaboration. 2011e, Proj. Ref. 5.1: Physical properties of the ESZ cluster sample (ArXiv Astrophysics e-prints)
- Planck Collaboration. 2011g, Proj. Ref. 5.2: Calibration of the local galaxy cluster SZ scaling relations with the Planck survey (ArXiv Astrophysics e-prints)
- Pratt, G. W., Croston, J. H., Arnaud, M., & Böhringer, H. 2009, A&A, 498, 361

XMM-Newton validation procedure

- Identification of an extended X-ray source within the SZ source position error box and check that the SZ and X–ray flux are consistent.
- The redshift estimated via the X-ray spectral fit using a maximum likelihood investigation within the [kT-z] plane.

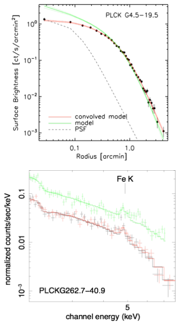


Fig. 1a Illustration of the results of the XMM-*Newton* validation procedure for confirmed candidate:

Confirmation of the extended nature of PLCK G4.5-19.5 (highest z cluster) from comparison of XMM-Newton surface brightness with PSF (dotted line)

Illustration of X-ray redshift estimate from thermal model fit to MOS1&2 (red and black) and pn (in green) spectra. The position of the redshifted Fe K line is marked.

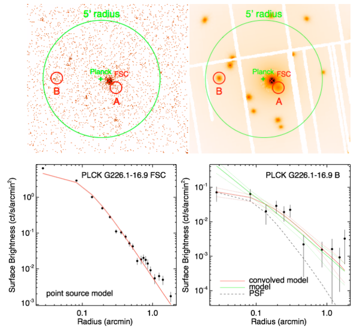


Fig. 1b Illustration of the results of the XMM-*Newton* validation procedure for a false candidate:

Raw MOS&pn image (left) and reconstructed pn image (right) in the soft band. The circle of 5′ in radius centred on the *Planck* position (green cross) corresponds to the conservative position error box.

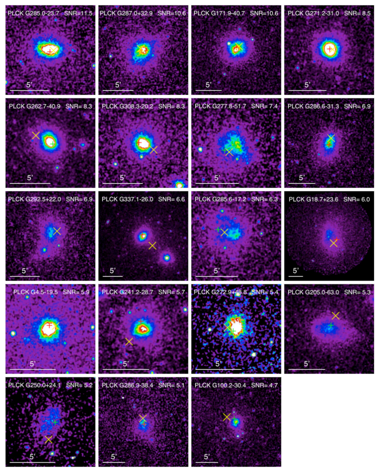
The RASS/FSC source (which could have been the X-ray counterpart) is revealed by XMM to be a point source (Fig bottom left showing comparison of profile with PSF). Its spectrum is also a power law; It is likely an AGN

Two extended sources (A & B) are detected in the error box. However both have an X-ray flux much smaller than expected from the SZ signal for any cluster redshift up to z=1.5

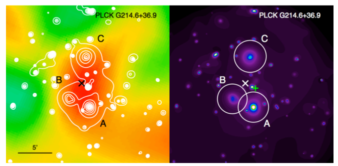
⇒ This is a false candidate

XMM-Newton image Gallery of confirmed (single or double) cluster candidates

Image are in [0.3–2] keV energy band and with sizes of $3\theta_{500}$ on a side, where θ_{500} is estimated from the M_{500}–Y_X relation. Images are corrected for surface brightness dimming with z, divided by the emissivity in the energy band and scaled according to the self-similar model. The images would be identical if clusters obeyed strict self-similarity. The majority of the objects show evidence for significant morphological disturbance. Yellow cross : Planck position; red/green plus sign: position of a RASS-BSC/FSC source.



Multiple systems



Example of the triple system PLCK G214.6+37.0. *Planck* Y_{SZ} *map (left)* with contours from the *XMM-Newton* wavelet filtered [0.3 − 2] keV image (right) overlaid in white. Extended components found in the *XMM-Newton* image are marked with letters. The circles in each *XMM-Newton* image denote the estimated R_{500} radius for each component.

Preview of the SZ and X-ray properties

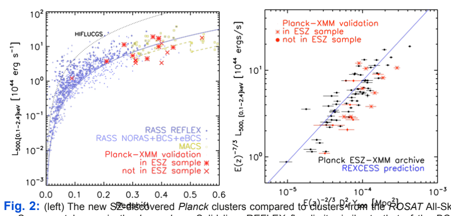


Fig. 2: (left) The new SZ-discovered *Planck* clusters compared to clusters from the *ROSAT* All-Sky Survey catalogues in the L_X–z *plane*. Solid line: REFLEX flux limit, similar to that of the BCS +eBCS catalogues. Dotted line: HIFLUCGS flux limit. Dashed line: MACS flux limits.
(right) L_X– Y_{500} relation for the 17 new confirmed single-component clusters (red symbols). Black points show clusters in the *Planck*-ESZ sample with *XMM-Newton* archival data (Planck Collaboration 2011g). The blue line in the bottom left panel is the Malmquist bias corrected *M–L* relation from REXCESS sample (Pratt et al. 2009; Arnaud et al. 2010).

Planck (http://www.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.

Planck2011a

PLANCK Early Results

Statistical Analysis of SZ Scaling Relations for X-ray Galaxy Clusters

Planck Collaboration

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Introduction

We combine all-sky data from the *Planck* survey and the Meta-Catalogue of X-ray detected Clusters of galaxies (MCXC) to investigate the relationship between the thermal Sunyaev-Zeldovich (SZ) signal and X-ray luminosity. The sample comprises 1600 X-ray clusters with redshifts up to ~1 and spanning a wide range in X-ray luminosity.

- The relation between SZ signal and X-ray luminosity is investigated and the measured SZ signal is compared to values predicted from X-ray data.
- We explore the redshift evolution of the Y-M relation
- We measure, for the first time, the intrinsic scatter in the scaling relation between SZ signal and X-ray luminosity

Data Sets

MCXC: the Meta-Catalogue of X-ray detected Clusters of galaxies (Piffaretti et al. 2010)

- Compilation of publicly available ROSAT All Sky Survey-based (NORAS, REFLEX, BCS, SGP, NEP, MACS, and CIZA) and serendipitous (160SD, 400SD, SHARC, WARPS, and EMSS) cluster catalogues.
- About 1800 clusters with homogenised luminosities L_{500}, redshift, position, mass M_{500}, and size R_{500} (from the representative REXCESS L_{500}-M_{500} relation by Pratt et al. (2009)).

***Planck* data**

- 6 highest frequency intensity maps (100-857 GHz)
- First 10 months of observing, covering complete sky
- After masking the Galactic plane and point sources, observations of over 1600 X-ray clusters (virtually all known X-ray clusters in the sky region of interest)

SZ Measurements

We apply a matched multi-frequency SZ filter (Melin et al. 2006) centered on each MCXC cluster:

- Optimizes the signal-to-noise of SZ clusters over the six *Planck* frequency bands
- Uses the universal pressure profile (Arnaud et al. 2010) as spatial template
- Filter size set by R_{500}
- Individual measurements of low S/N. Bin by luminosity, mass or redshift to maximise signal detection (Figure 1)

Summary

Figures 1 summarises our main results:

- Highly significant detection of the SZ signal.
- Detection over more than two decades in luminosity
- *Planck* measurements and X-ray based predictions in excellent agreement

Figure 2 investigates the redshift evolution of the Y-M relation. We detect no deviation from standard evolution.

Figure 3 shows the estimated intrinsic dispersion in the SZ-luminosity scaling relation. It is consistent with the 42% estimated dispersion in the predicted Ysz-M relation (Arnaud et al. 2010) and the 33% dispersion estimated in the *Planck* local cluster sample.

Figure 4 illustrates a remarkable agreement between the model, the SZ signal and X-ray luminosities for both the MCXC and the maxBCG clusters.

Our study shows that there is no evidence for a deficit in SZ signal strength in *Planck* data relative to expectations from the X-ray properties of clusters, underlining the robustness and consistency of our overall view of intra-cluster medium properties.

The Scaling Relation

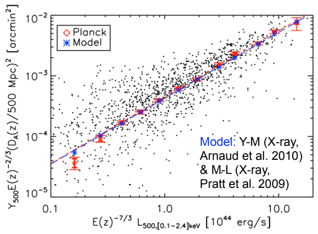
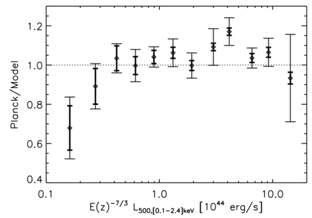


Figure 1: *TOP:* Scaling relation between *Planck* SZ measurements and X-ray luminosity for ~1600 clusters from the MCXC (Meta-Catalogue of X-ray detected Clusters of galaxies, Piffaretti et al. 2010). Both quantities are intrinsic and scaled assuming standard evolution. Individual measurements are shown by the black dots and the corresponding bin averaged values by the red diamonds. Thick bars give the statistical errors, while the thin bars are bootstrap uncertainties. The bin-averaged SZ cluster signal expected from the X-ray based model (Y-M, Arnaud et al. (2010) & M-L, Pratt et al. (2009)) is shown by the blue stars. The X-ray predicted scaling law is shown by the dashed blue line while the red dot-dashed line shows the best fit power-law to the data. *BOTTOM:* Ratio between data and model bin averaged values shown in the top panel.



Redshift Evolution

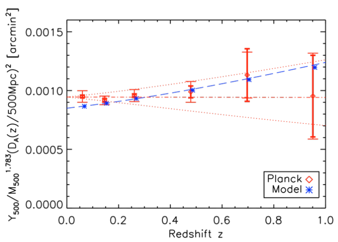


Figure 2: The *Planck* data (red diamonds) and the SZ cluster signal expected from the X-ray based model (blue stars) are shown together with the expected $[H(z)/H_0]^{2/3}$ standard redshift evolution (dahed line). The best fitting model is shown by the dot-dashed line and the 1σ confidence region is limited by the dotted lines.

Dispersion Analysis

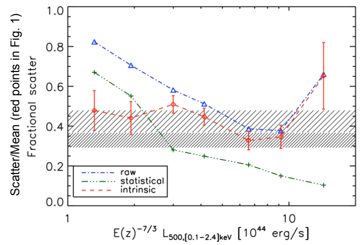


Figure 3: Fractional raw (dot-dashed blue line and triangles), statistical (dot-dot-dashed green line and plus signs), and intrinsic (dashed red line, diamonds, and error bars) scatter on the Y_{500} – L_{500} relation. The coarse/fine-hatched regions corresponds to the 1 σ uncertainties on the intrinsic scatter reported in Arnaud et al. (2010) and the *Planck* SZ local scaling relation study, respectively.

Comparison with SZ-Optical Scaling Relations

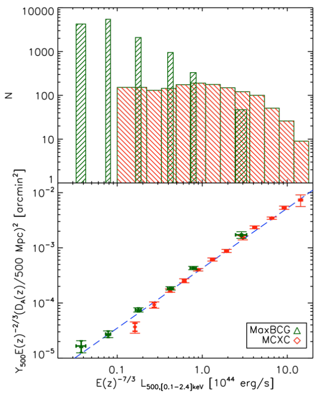


Figure 4: *BOTTOM:* Comparison between our results (red diamonds, as in top panel Figure 1 and those obtained in the *Planck* SZ – optical study (green triangles), where MaxBCG clusters (Koester et al. 2007) are investigated. X-ray luminosities for the MaxBCG clusters are based on the analysis of Rykoff et al. (2009). Error bars are as in Figure 1 and the X-ray prediction is shown by the dashed blue line.
TOP: The X-ray luminosity histograms of the MCXC (red) and MaxBCG (green) samples highlight the complementarity of our analysis and the companion *Planck* SZ – optical study.

References

Arnaud, M., Pratt, G. W., Piffaretti, R., et al. 2010, A&A, 517
Koester, B. P., McKay, T. A., Annis, J., et al. 2007, ApJ, 660, 239
Melin, J.-B., Bartlett, J. G., & Delabrouille, J. 2006, A&A, 459, 341
Piffaretti, R., Arnaud, M., Pratt, G. W., et al. 2010, ArXiv e-prints
Pratt G. W., Croston J. H., Arnaud M., et al. 2009, A&A, 498, 361
Rykoff, E. S., McKay, T. A., Becker, M. R., et al. 2008b, ApJ, 675, 1106

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Planck2011a

PLANCK Early Results

Cluster SZ-Optical Scaling Relations

Planck Collaboration

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Introduction

We measure, for the first time, the Sunyaev-Zeldovich (SZ) – richness relation using more than 13,000 clusters from the maxBCG catalog. This is possible thanks to the all-sky coverage afforded by the Planck survey.

Relations between the gas and galaxy properties of optically selected clusters are valuable because:

- Optical cluster catalogs can cover a larger mass range, including poor systems, than X-ray catalogs
- They tell us about the interplay between the hot (gas) and cold (stellar) baryonic cluster components, an important element of galaxy evolution
- They connect two distinct facets of the cluster population

Data Sets

Optical catalog: public maxBCG from the Sloan Survey (Koester et al. 2007)

- 13,823 clusters detected as red-galaxy over-densities around bright central galaxies (BCG).
- 7,500 square degrees in the Northern Hemisphere.
- A richness measure, N200
- Weak-lensing calibrated mass-richness relations by Johnston et al. (2007) and Rozo et al. (2009).

Planck data

- 6 highest frequency intensity maps (100-857 GHz)
- First 10 months of observing, covering complete sky
- After masking, observations of over 13,000 maxBCG clusters

SZ Measurements

We apply a matched multi-frequency SZ filter (Melin et al. 2006) centered on each maxBCG cluster:

- Optimizes the signal-to-noise of SZ clusters over the six Planck frequency bands
- Uses the universal pressure profile (Arnaud et al. 2010) as spatial template
- Filter size set by mass-richness relation from weak-lensing calibrations (Johnston et al. 2007, Rozo et al. 2009)
- Individual measurements of low S/N. Bin by richness to detect signal (Figure 1)

Summary

Figures 1 & 2 summarize our main results:

- Highly significant detection of the SZ signal (difference between the red and green points).
- Detection over entire richness range
- A power law describes the observed SZ-richness relation well
- Model predictions disagree with the observations, which have a notably lower SZ signal than predicted at given richness

Figure 3 shows the estimated intrinsic dispersion in the SZ-optical richness scaling relation. At high richness, it is consistent with the 45% estimated dispersion in the M-N_{200} relation (Rozo et al. 2009) being the dominant source. The dispersion becomes large at low richness.

Figure 4 repeats Figure 1 for an X-ray subsample of the maxBCG catalog taken from the MCXC compilation by Piffaretti et al. (2010). The model matches this subsample much better, hinting at the presence of subpopulations within the catalog.

Figure 5 illustrates a remarkable agreement of the model with the observed relation between the SZ signal and X-ray luminosities for the clusters, despite the discrepancy between SZ and optical properties.

The Scaling Relation

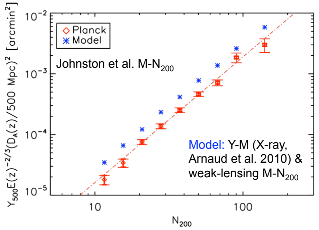
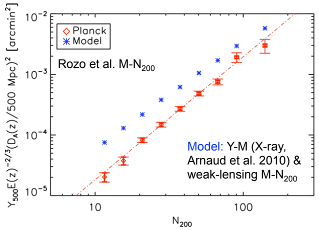


Figure 1: Planck SZ measurements (red diamonds) binned by maxBCG richness for the Johnston et al. (above) and Rozo et al. (below) mass-richness relations. Solid error bars show the measurement error, while the thin error bars are from a bootstrap analysis. The blue points show predictions from a model based on X-ray calibrated Y-M (Arnaud et al. 2010) and the weak-lensing M-N_{200} relations.



Detection Significance: Null test

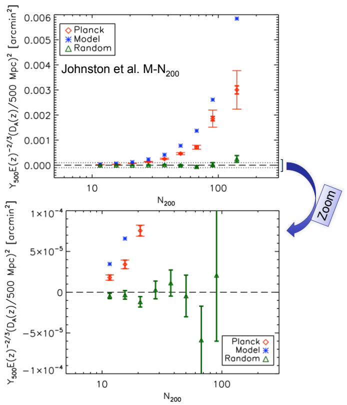


Figure 2: The red and blue points repeat the results from Figure 1. Green triangles show the SZ measurements for the same SZ filter set, but with randomized positions, all consistent with zero.

Dispersion Analysis

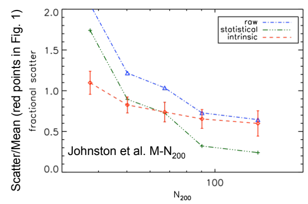


Figure 3: Blue curve: measured fractional scatter by richness bin. Green curve: calculated SZ signal measurement uncertainty. Red curve: estimated intrinsic fractional scatter by richness bin.

Comparison with X-rays

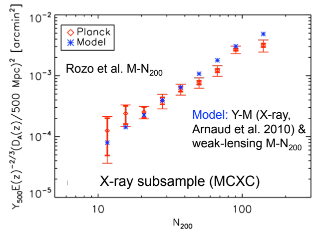


Figure 4: Same as Figure 1 for an X-ray subsample of the MaxBCG catalog (taken from the MCXC, Piffaretti et al. 2010)

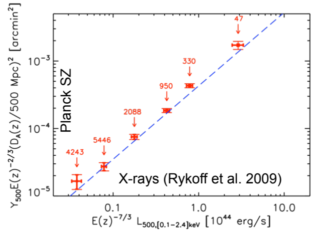


Figure 5: Planck SZ signal vs mean X-ray luminosity (Rykoff et al. 2008). Numbers indicate the number of clusters per bin. Dashed blue line: model Y-Lx relation from Arnaud et al. (2010)

References

Arnaud, M., Pratt, G. W., Piffaretti, R., et al. 2010, A&A, 517
Johnston, D. E., Sheldon, E. S., Wechsler, R.H., et al. arXiv0709.1159
Koester, B. P., McKay, T. A., Annis, J., et al. 2007, ApJ, 660, 239
Melin, J.-B., Bartlett, J. G., & Delabrouille, J. 2006, A&A, 459, 341
Piffaretti, R., Arnaud, M., Pratt, G. W., et al. 2010, arXiv1007.1916
Rozo, E., Rykoff, E. S., Evrard, A., et al. 2009, ApJ, 699, 768
Rykoff, E. S., McKay, T. A., Becker, M. R., et al. 2008, ApJ, 675, 1106

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Planck2011g

PLANCK Early Results

Calibration of the local galaxy cluster SZ scaling relations

Planck Collaboration

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Abstract

We present precise Sunyaev-Zeldovich (SZ) effect measurements in the direction of 62 nearby galaxy clusters (z <0.5) detected at high signal-to-noise in the first Planck all-sky dataset. The sample spans approximately a decade in total mass, 10^{14} M$_\odot$ < M_{500} < 10^{15} M$_\odot$, where M_{500} is the mass corresponding to a total density contrast of 500. Combining these high quality Planck measurements with deep XMM-Newton X-ray data, we investigate the relations between $D_A^2\, Y_{500}$, the integrated Compton parameter due to the SZ effect, and the X-ray-derived gas mass $M_{g,500}$, temperature T_X, luminosity L_X, SZ signal analogue $Y_{X,500} = M_{g,500} \times T_X$, and total mass M_{500}. After correction for the effect of selection bias on the scaling relations, we find results that are in excellent agreement with both X-ray predictions and recently-published ground-based data derived from smaller samples. The present data yield an exceptionally robust, high-quality local reference, and illustrate Planck's unique capabilities for all-sky statistical studies of galaxy clusters.

Data set

The basic data set is the Planck Early Release Compact Source Catalogue SZ (ESZ) sample, described in detail in Planck Collaboration (2011e). This sample is derived from the highest signal-to-noise ratio detections (S/N > 6) in a blind multi-frequency search in the all-sky maps from observations obtained in the first ten months of the Planck survey. Cross-correlation of the ESZ subsample with the Meta Catalogue of X-ray Clusters (MCXC; Piffaretti et al. 2010) produced 158 matches with known X-ray clusters.

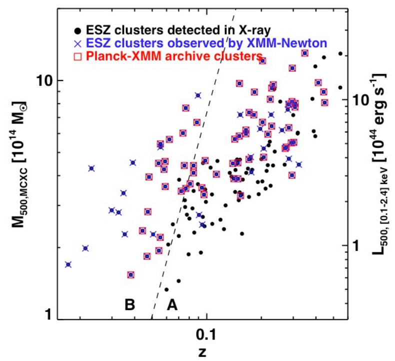

Figure 1.

The 158 Planck ESZ clusters already observed in X-rays. Masses are estimated from their X-ray luminosity as described in Piffaretti et al. (2010). The 62 clusters discussed here are indicated by the red squares. The dashed line represents the locus at which R_{500}~12 arcmin.

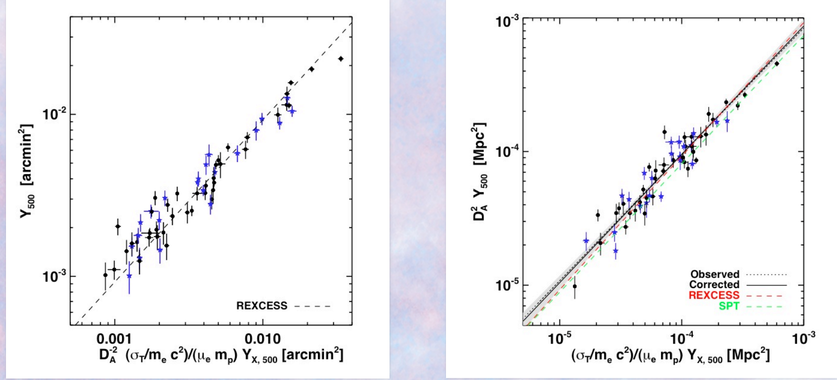

Figure 2. SZ vs X-ray, cool cores plotted in blue

Left panel: Relation plotted in units of arcmin². The dashed line is the prediction from REXCESS X-ray observations Arnaud et al. (2010).

Right panel: Relation plotted in units of Mpc². The SPT results are taken from Andersson et al. (2010).

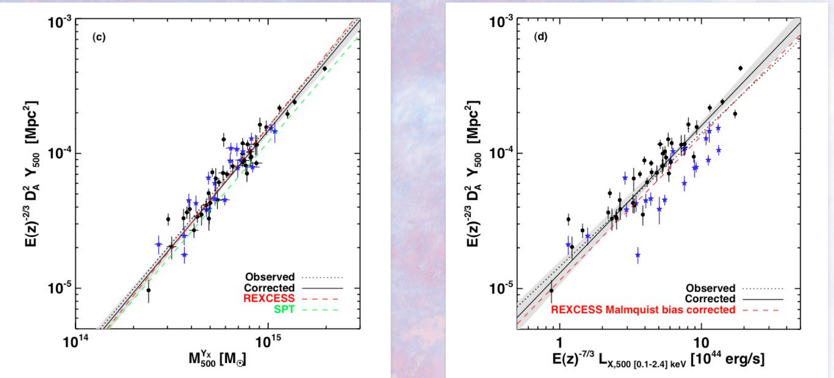

Figure 3. Y-M and Y-L relations, cool cores plotted in blue

Left panel: . $D_A^2\, Y_{500} - M_{500}$ relation, where M_{500} is determined from the M_{500}-$Y_{X,500}$ relation of Arnaud et al. (2010). The SPT results from Andersson et al. (2010) and the REXCESS prediction from Arnaud et al. (2010) are also shown.

Right panel: $D_A^2\, Y_{500} - L_{500}$ relation. REXCESS results are from Pratt et al. (2009).

Conclusion

The results are fully consistent with the predictions from X-ray observations (Arnaud et al. 2010) and with recent measurements from a smaller sample spanning a wider redshift range observed with SPT (Andersson et al. 2010). The results are also in excellent agreement with the statistical analysis undertaken at the positions of known X-ray clusters (Planck Collaboration 2011i). This excellent agreement between observed SZ quantities and X-ray-based predictions underlines the robustness and consistency of our overall view of ICM properties. The results presented here, derived from only 62 systems, provide a maximally-robust local reference for evolution studies or for the use of SZ clusters for cosmology. The agreement between the present results, ground-based results and X-ray predictions augurs well for our understanding of cluster astrophysics and for the use of clusters for cosmology.

References

Arnaud et al. 2010, A&A, 517, A92
Andersson et al. 2010, arXiv:1006.3068
Piffaretti et al. 2010, arXiv:1007.1916 (MCXC)
Planck Collaboration 2011e, arXiv (ESZ sample)
Planck Collaboration 2011i, arXiv (Stat-X paper)
Pratt et al. 2009, A&A, 498, 361

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