1 Abstract

We propose to observe two of the Planck tSZ discovered clusters of galaxies as a pilot project to test the feasibility of lensing studies with the GTC. The clusters proposed here, PSZ1 G045.85+57.71 and PSZ1 G046.13+30.75, have been recently observed in SZ (at 150 and 260 GHz) with the NIKA camera, at the IRAM 30 m telescope. NIKA complements Planck observations with an high angular resolution follow-up (20 arc sec at 150 GHz). The same clusters are also part of an XMM program, and we then also dispose of high-quality X-ray data for them. The tSZ and X-ray signals probe the diffuse baryonic gas component of galaxy clusters. Under the hypothesis of hydrostatic equilibrium, we can use these baryonic tracer to recover the cluster total mass. Through gravitational lensing we can instead directly explore the distribution of the dark matter component, which largely dominates the cluster total mass. The goal of this proposal is then to test the GTC lensing capabilities, and the complementarity with NIKA observations, in view of the NIKA2 large program aiming at observing 50 objects, to explore the properties of the cluster population beyond the local Universe (z > 0.5). The complementarity of the tSZ and gravitational lensing can in fact allow studying how does the distribution both dark matter and gas evolve with redshift and the complex interplay between the gravitational and non-gravitational processes governing the cluster astrophysics.

2 Scientific justification

Clusters of galaxies provide valuable information concerning the evolution and composition of the Universe, and the formation of large scale structures. The observable properties of clusters reflect their formation through hierarchical gravitational collapse, by accretion and merging of smaller sub-clusters and groups, as well as the contribution of non-gravitational processes (e.g. AGN feedback and supernova-driven galactic winds) that can affect their observed properties to a large extent (e.g. Sembolini et al. 2014). Consequently, a detailed characterization of the both the dark matter (mainly governed by gravity) and baryonic (governed by both gravity and radiative processes) components is a mandatory step to achieve a better control on the astrophysical systematics that represent the limit of cluster derived cosmological constraints. In order to use any cluster catalog to put constraints on the Universe content and evolution, we need an observable to mass relation. And at present we are limited by systematic uncertainties in the mass normalization of the baryonic mass proxies provided by X-ray and SZ, as recently shown by Planck Collaboration (2015).

By using the high angular resolution of the NIKA (and the future NIKA2) camera we can explore the details of the pressure distribution within clusters, which means the details of the distribution of the ICM thermal energy. This will for example allows us to study the impact of shocks due to merging events on the tSZ global properties (i.e. the integrated SZ signals, Y), that is used as a mass proxy for cosmological purposes. But SZ and X-ray mass estimates are based on a strong assumption about how the dark matter and ICM baryonic component are related. This is the hydrostatic equilibrium hypothesis, which might provide biased mass estimates, as lensing based studies have shown (e.g. von der Linden et al. 2014). Gravitational lensing provides in fact a completely independent measure of the cluster total mass, being directly sensitive to the whole mass of the structure, along the line of sight. While baryonic observables provide low scatter proxies, the advantage of gravitational lensing mass estimates is that of being unbiased. Therefore, only the the unique complementarity of multi-wavelength observations from optical, X-ray, and millimeter-wavelength via the tSZ effect, can provide a clear picture of the ongoing physics and help breaking degeneracies and systematic effects associated to each probe, which in turn affects any cosmological interpretation.

In addition to the galaxy distribution, valuable in itself, optical data can be used to infer strong lensing (SL) or/and weak lensing (WL) maps which are sensitive to the projected total mass of the cluster, $\Sigma \propto \int \rho \, dl$, along the line-of-sight (see Hoekstra et al. 2013, for a review). While SL modeling allows for a precise characterization of the mass distribution in the inner parts of the cluster, WL can be used at larger radii so that high-fidelity mass mapping is achievable over the entire cluster extension, up to the virial radius. X-ray and tSZ probe the gas physics, itself strongly related to the total mass distribution. The X-ray surface brightness is proportional to the projected electronic density (n_e), with a small temperature (T_e) dependance, as $S_X \propto \int n_e^2 \sqrt{T_e} dl$. The X-ray spectral analysis also provides temperature estimates but rapidly becomes expensive with increasing redshift, due to the large photon count required. The tSZ surface brightness is related to the integrated pressure along the line-of-sight as $\Delta I \propto f(\nu) \int n_e T_e dl$ with a characteristic spectral dependance $f(\nu)$. Conversely to X-ray, it does not suffer from cosmological dimming and it is only limited by the resolution and sensitivity of the observations. These observables provide an independent and complementary insight into the physics of galaxy clusters.

Cluster	R.A.	Dec.	z	Y_{500} (arcmin^2)	Comment
PSZ1 G045.85+57.71	15:18:20.8	+29:27:37	0.61	0.82×10^{-3}	Elongated but fairly relaxed in X-ray. Observed with Subaru. tSZ peak at about 5 mJy/beam.
PSZ1 G046.13+30.75	17:17:05.8	+24:04:25	0.57	0.77×10^{-3}	Compact in X-rays. Observed with Subaru. tSZ peak at about 4 mJy/beam.

Table 1: Brief characteristics of the proposed clusters.

In the future, with the NIKA2 cluster sample (50 objects at z > 0.5), this kind of study will finally permit: **1)** To test the hydrostatic equilibrium assumption (i.e. the hydrostatic mass bias) against redshift and as a function of cluster centric distance. This can be done combining resolved mass profiles from lensing (independent of the gas physics) and SZ+X-ray which assumes hydrostatic equilibrium. **2)** To quantitatively probe the amount of non-thermal support as a function of the dynamical state of the systems and along with redshift. **3)** To constrain the spatial distribution of dark matter versus the stellar content and its interplay with the baryonic mass component which will allow us to study the formation process and evolution of clusters. **4)** To constrain cluster triaxiality, as the combining of SZ, X-ray and lensing is sensitive to the line-of-sight elongation, thanks to their different sensitivities to the ICM physics. While numerical simulations suggest that clusters are triaxial, they are generally assumed to be spherically-symmetric due to the difficulty to probe the three-dimensional shape. This can lead to biases and scatters in cosmological constraints. See e.g. Limousin et al. (2013) and the results by Morandi et al. (2012) on a nearby cluster.

ADD DISCUSSION ON THE 2 CLUSTERS PROPOSED: X-ray morphology vs SZ, PSZ1 G046 in SZ is less spherical than in X, but seems to better trace the galaxy distribution.

3 Supporting material

PSZ1 G045.85+57.71

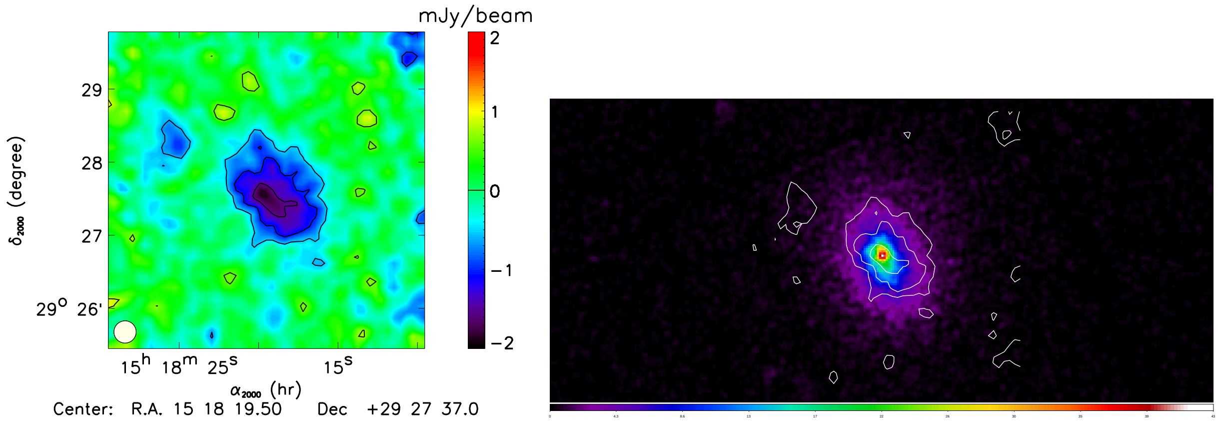

Figure 1: Left: NIKA tSZ map, at 150 GHz. Right: The NIKA tSZ contours (in white) are over-plotted on the X-ray photon counts map, obtained with XMM for the same cluster.

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PSZ1 G046.13+30.75

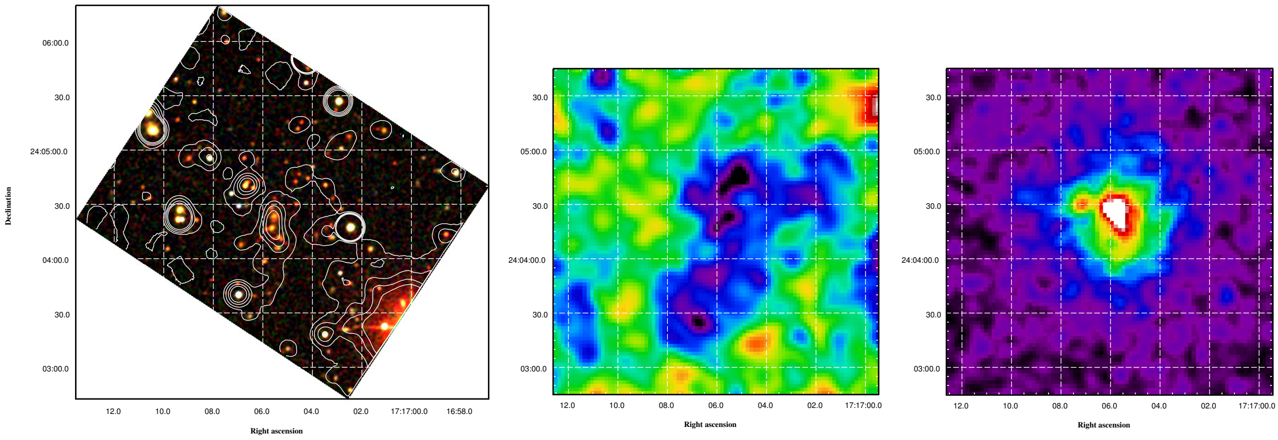

Figure 2: Left: SDSS i, r, and g bands composite image towards PSZ1 G046.13+30.75. The white contours provides a 5 arcsec smoothed brightness distribution in the red band, which gives an indication of the cluster galaxy distribution. Middle: NIKA tSZ map. All the data indicate an elongated morphology. Right: XMM X-ray photon count.

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