

DETECTION OF THE TSZ EFFECT WITH THE NIKA CAMERA

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Abstract. We present the first detection of the thermal Sunyaev-Zeldovich (tSZ) effect from a cluster of galaxies performed with a KIDs (Kinetic Inductance Detectors) based instrument. The tSZ effect is a distortion of the black body CMB (Cosmic Microwave Background) spectrum produced by the inverse Compton interaction of CMB photons with the hot electrons of the ionized intra-cluster medium.

The massive, intermediate redshift cluster RX J1347.5-1145 has been observed using *NIKA* (New IRAM KIDs arrays), a dual-band (140 and 240 GHz) mm-wave imaging camera, which exploits two arrays of hundreds of KIDs: the resonant frequencies of the superconducting resonators are shifted by mm-wave photons absorption.

This tSZ cluster observation demonstrates the potential of the next generation *NIKA2* instrument*, being developed for the 30m telescope of IRAM, at Pico Veleta (Spain). *NIKA2* will have 1000 detectors at 140GHz and 2x2000 detectors at 240GHz, providing in that band also a measurement of the linear polarization. *NIKA2* will be commissioned in 2015.

Keywords: Superconducting Detectors, thermal Sunyaev-Zeldovich effect, high resolution observations

1 Introduction

The important role of millimeter wave astronomy for both cosmology and astrophysics is today well established. However, the standard technology for these wavelengths, low-temperature bolometers, requires complex cryogenic readout electronics, which limits the reachable multiplexing ratios well below a hundred. In order to increase the focal plane area and pixel number, an alternative technology intrinsically suited for frequency domain multiplexing, able to provide multiplexing ratios greater than a thousand, looks extremely interesting. It is therefore worth studying and employing Kinetic Inductance Detectors (KIDs) as a promising alternative to bolometers.

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The New IRAM KIDs Array (*NIKA*) is a dual-band (140 and 240 GHz) KIDs camera developed in Grenoble to work at the IRAM 30m telescope. The first four *NIKA* commissioning campaigns at the IRAM 30 m telescope (Monfardini et al. 2010, 2011; Calvo et al. 2013) have allowed us to demonstrate performances comparable to state-of-the-art bolometer arrays, working at the same wavelengths (e.g. GISMO, Staguin et al. 2008, observing only at 2 mm).

We report here the first KID-based observation of a galaxy cluster via the thermal Sunyaev-Zeldovich (tSZ) effect, RX J1347.5-1145 has been imaged using the *NIKA* prototype (Adam & *NIKA* Collaboration 2013) during the fifth observing run (November 2012, *NIKA* Collaboration 2013). When observed through the tSZ effect, clusters of galaxies show up as weak extended sources. In fact, this effect is a small spectral distortion (of the order of one-thousandth) of the cosmic microwave background (CMB) intensity, and its detection and mapping have been hard challenges. However, recently, tSZ-selected cluster catalogues containing hundreds of candidates with arcmin resolution have finally been produced (SPT – Reichardt et al. 2013, ACT – Hasselfield & ACT Collaboration 2013 and the Planck Satellite – Planck Collaboration et al. 2013). Consequently, high-resolution tSZ observations and follow-ups are now necessary to deeply explore the cluster internal structure. The *NIKA* camera at the IRAM 30 m telescope is a well-suited instrument for such observations and follow-ups, given its resolution, its sensitivity and the two observing frequencies.

2 The *NIKA* camera

Located on Pico Veleta, in a dry and high (2850 m a.s.l.) area, the IRAM 30-m telescope is one of today’s largest and most sensitive for mm wavelengths. In order to completely exploit its angular resolution and the entire field of view, large arrays of (thousands) detectors are needed. For this reason it is worth to develop a camera based on an alternative technology with respect to bolometers, the Kinetic Inductance Detectors. KIDs are superconducting resonators whose resonance frequency changes with the absorbed optical power. The resonant frequencies of the individual resonators can be easily controlled geometrically during array design (Monfardini et al. 2010) and a very large number of pixels, of the order of thousands, can be multiplexed on a single transmission line. Compared to bolometers, KIDs also offer further advantages. They are significantly less sensitive to temperature fluctuations, microphonic noise and magnetic field fluctuations (with respect to Transition Edge Sensor Bolometers).

The New IRAM KIDs Array (*NIKA*) is a dual-band KIDs camera custom designed for the IRAM 30-m Nasmyth-focus telescope, whose detectors are cooled down to ~ 100 mK with a $^4\text{He} - ^3\text{He}$ dilution cryostat. *NIKA*, a prototype of the final camera *NIKA2*, consists of two arrays of Kinetic Inductance Detectors (KIDs) with maximum transmission at about 140 and 240 GHz and respective angular resolutions (FWHM) of 18.5 and 12.5 arcsec and fields of view of 2.0 and 1.2 arcmin. During the test run of November 2012, the 140 GHz band was used with 126 detectors with mean effective sensitivity of $31 \text{ mJy.s}^{1/2}$ per beam. Concerning the 240 GHz channel, despite the disfunction of a cold amplifier during this campaign, 91 detectors with mean effective sensitivity of $81 \text{ mJy.s}^{1/2}$ per beam were used, recovering the expected mean effective sensitivity of $32 \text{ mJy.s}^{1/2}$ per beam by using only eight detectors. More details on the *NIKA* prototype setup (Run5) can be found in *NIKA* Collaboration (2013).

3 First tSZ results: mapping of RX J1347.5-1145

Clusters of galaxies are the largest gravitationally bound structures observable in our Universe. They are mainly ($\sim 80\%$) constituted of dark matter, while most of the baryons are in the form of a hot ionized gas, the so-called intra-cluster medium (ICM). The ICM is responsible for the Bremsstrahlung X-ray emission but also for the tSZ effect, a distortion of the black body CMB spectrum produced by the inverse Compton interaction of CMB photons with the hot electrons of the ICM (Sunyaev & Zel’dovich 1972, 1980). This interaction produces a unique spectral signature, a decreased CMB intensity at frequencies lower than ~ 217 GHz, and an increase at higher frequencies, making the *NIKA* channels particularly interesting for SZ studies. While the frequency behavior is specific of the effect, the amplitude of the signal is defined by the Comptonization parameter

$$y = \frac{\sigma_T}{m_e c^2} \int P_e dl \quad (3.1)$$

(with m_e the electron rest mass, c the light speed, σ_T the electron Thomson scattering cross-section), which is then a measure of the integrated electronic pressure P_e along the line-of-sight, \vec{l} .

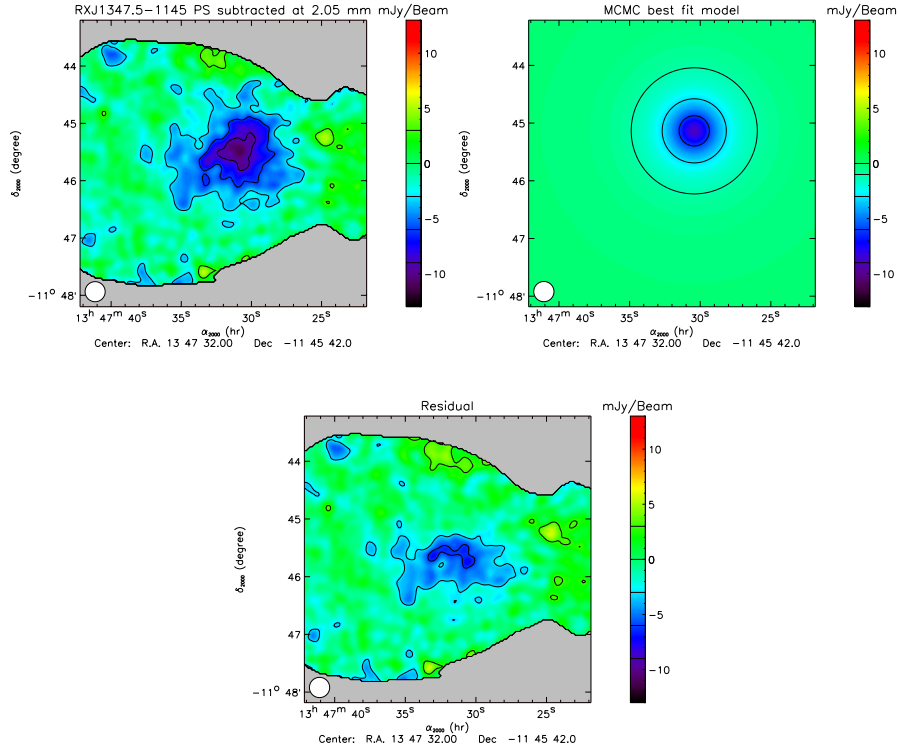


Fig. 1. Upper left: RX J1347.5-1145 reconstructed tSZ map (at 140 GHz), the central radio point source (4.4 mJy) has been subtracted. **Upper right:** Map of the best fitting model for the relaxed cool-core like region, obtained by masking the shock area. **Bottom:** Residuals obtained by subtracting the fitted model to the original map. As expected, the model accounts well for the cluster profile except in the southern shocked area.

RX J1347.5-1145 is one of the most extensively studied clusters. Located at intermediate redshift ($z = 0.451$), it represents a particularly well-suited candidate for the *NIKA* 5th run, being both compact and strong enough for the prototype f.o.v. and sensitivity, as estimated by exploiting the best fitting $P_e(r)$ obtained for the work of Comis et al. (2011) from the X-ray derived pressure profiles of the *ACCEPT* catalogue (Cavagnolo et al. 2009). Furthermore, this cluster is a perfect illustration of the complementarity of tSZ effect and X-ray signals: initially thought to be a well-relaxed (cool-core) object according to its first X-ray data (Schindler et al. 1997), later tSZ observations showed a substructure located at $\sim 20''$ from the center towards the SE region (Komatsu et al. 1999; Pointecouteau et al. 1999). This has been interpreted as a hotter, over-pressured component resulting from a merging event. The non-trivial morphology makes this cluster an ideal target to test *NIKA* capabilities of probing the details of ICM physics.

In Fig. 1 (upper left panel) we report the 140 GHz tSZ map obtained during the *NIKA* 5th run, with a total (unflagged) observing time of 5h 47min (scans of 6min 20s). The analysis used 81 detectors at 140 GHz and 45 at 240 GHz (for the dual-band decorrelation of the atmospheric noise, further details in Adam & NIKA Collaboration 2013).

In order to extract the signal from the shock, produced by the ongoing merger, we have modeled the relaxed region by considering a generalized Navarro, Frenk and White (gNFW, Nagai et al. 2007) pressure profile

$$P(r) = \frac{P_0}{\left(\frac{r}{r_s}\right)^\gamma \left[1 + \left(\frac{r}{r_s}\right)^\alpha\right]^{\frac{\beta-\gamma}{\alpha}}}, \quad (3.2)$$

centered at the X-ray position of the system. P_0 is a scalar normalization of the pressure profile, while the parameters α , β , γ are respectively the slopes for intermediate radii ($r \sim r_s$, a scale radius), the outer region ($r \gg r_s$) and the core region ($r \ll r_s$). The intermediate, outer and inner slopes have been set equal to the cool-core best fitting values of Arnaud et al. (2010), ($\gamma = 0.7736$, $\beta = 5.4905$, $\alpha = 1.2223$). The free parameters

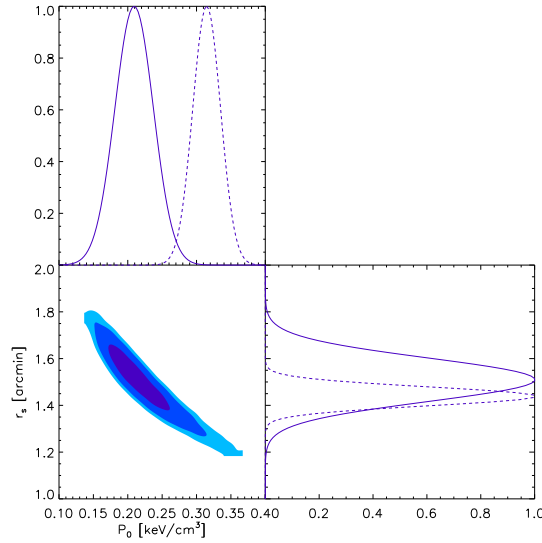


Fig. 2. Posterior likelihood of the MCMC pressure profile fit in the plane $P_0 - r_s$. From dark to light blue, the colors correspond to 68.2%, 95.4% and 99.7% confidence levels. The top and right curves show the marginalized normalized likelihood of P_0 and r_s respectively. The dashed lines allow comparison with the marginalized distribution obtained when no mask is applied to the map.

P_0 and r_s have been constrained through a Markov Chain Monte Carlo (MCMC) approach, masking the South East extension with a half ring, centered on the X-ray peak, with inner and outer radii set to 10 and 80 arcsec. The values obtained are $P_0 = 0.208 \pm 0.028 \pm_{0.032}^{0.052} \text{ keV/cm}^3$ and $r_s = 1.510 \pm 0.093 \pm_{0.00}^{0.30} \text{ arcmin}$. The systematic uncertainties have been computed using the calibration uncertainty and taking into account bias filtering effects of the analysis estimated from the difference in the input and output simulated profiles (Adam & NIKA Collaboration 2013). Fig. 1 allows comparison between the *NIKA* prototype tSZ map (upper left panel), the best fitting model obtained for the relaxed component (upper right panel), and the residual (bottom panel). The model represents well the northern part of the tSZ map but the southern side cannot be explained without including an overpressure component, that is known to be due to the merging of a sub-cluster (Cohen & Kneib 2002; Allen et al. 2002; Miranda et al. 2008). In Fig. 2 the posterior likelihood of the model parameters is given. Note that in the case of no mask being applied to the map, r_s is still compatible with the value given above (Fig. 2, dashed line).

4 Conclusions

Past NIKA runs have demonstrated the potential for KIDs to provide large pixel arrays for ground-based millimeter astronomy. Now we have also shown the tSZ capabilities of a KIDs-based camera.

The agreement with DIABOLO observations of RX J1347.51145 (Pointecouteau et al. 1999, 2001), performed at the same telescope and with similar resolution and frequency coverage, has been used to validate the *NIKA* tSZ map (Adam & NIKA Collaboration 2013). In addition, the *NIKA* prototype map agrees also with state-of-the-art sub-arcminute resolution tSZ observations, MUSTANG (Kornigut et al. 2011, 90 GHz and 8 arcsec resolution) and *CARMA* (Plagge et al. 2012, 30 90 GHz and ~ 15 arcsec resolution).

NIKA 5th run has proven that KID arrays are competitive detectors for millimeter wave astronomy and in particular for the observation of galaxy clusters via the tSZ effect. The prototype *NIKA* is now fully operational and will be open to the science community strating from the next Winter (2013/14). The second generation instrument, *NIKA2* (<http://ipag.osug.fr/nika2>), will be made of about 1000 detectors at 140 GHz and 4000 at 240 GHz with a field of view of ~ 6.5 arcmin. With these characteristics, *NIKA2* will be able to provide larger f.o.v., high resolution mapping of clusters. Therefore a perfect instrument for high resolution observations and follow-ups of medium and high redshift cluster. *NIKA2* will be installed for commissioning in 2015.

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