

The Néel IRAM KID Arrays (NIKA)

A. Monfardini, A. Benoit, A. Bideaud, N. Boudou, M. Calvo, P. Camus, C. Hoffmann

Institut Néel, CNRS & UJF, 25 rue des Martyrs, 38042 Grenoble, France

F.-X. Désert

IPAG, UJF & CNRS-INSU, Grenoble Campus, Grenoble F-38041, France

S. Leclercq, M. Roesch, K. Schuster

IRAM, Saint Martin d'Hères F-38406, France

P. Ade, S. Doyle, P. Mauskopf, E. Pascale, C. Tucker

School of Physics & Astronomy, Cardiff University, Cardiff CF24 3AA, UK

A. Bourrion, J. Macias-Perez, C. Vescovi

LPSC, UJF & CNRS/IN2P3 & INPG, F-38026 Grenoble

A. Barishev, J. Baselmans, L. Ferrari, S.J.C. Yates

SRON, 3584 CA Utrecht and 9700 AV Groningen, The Netherlands

A. Cruciani, P. De Bernardis, S. Masi

Dipartimento di Fisica, Università di Roma La Sapienza, 00185 Roma, Italy

C. Giordano, B. Marghesin

Fondazione Bruno Kessler, I-38123 Povo (TN), Italy

H.G. Leduc, L. Swenson

JPL-Caltech, Pasadena, California 91109, USA

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We are developing an instrument based on Kinetic Inductance Detectors (KID) known as the Néel IRAM KID Array (NIKA). Leveraging the experience gained from the first generation NIKA in 2009, an improved, dual-band (150 GHz and 240 GHz) instrument has been designed and tested at the Institut of RadioAstronomie Millimetrique (IRAM) 30-meter telescope in October 2010. The performances, in terms of sensitivity on-the-sky at 150 GHz, are already comparable to existing state-of-the-art bolometer-based instruments. NIKA represents thus the first real prove that KID are a viable technology for ground-based Astronomy. We will describe the instrument, the most recent results and the future plans for building a large resident mm-wave camera.

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1. INTRODUCTION

Millimeter and sub-millimeter Astronomy, i.e. where the radio meets the IR, is traditionally tricky from the instrumental point-of-view. The real boost for specifically developing mm-wave instrumentation came from the famous Cosmic Microwave Background (CMB) discovery in 1965 and, five years later, the first observation of the 2.6 mm CO molecular lines in the Galaxy. Among the most challenging requirements, when compared to longer wavelengths radio instruments, we have very fast receivers, accurate optical surfaces, need for exceptional observational sites due to the atmospheric (variable) absorption. Complementary to the more classical heterodyne, narrow-band techniques, we have the so-called mm-wave “continuous” observations, in which, in order to detect even fainter sources, a larger band is integrated. In particular, three main areas motivate millimeter and sub-mm continuum research:

1. The study of star forming regions in the Galaxy. The pre-stellar phases in molecular clouds are hidden by cold dust (around 10 K) which can only be observed at sub-millimeter wavelengths.

2. The investigation of high redshift galaxies. The redshift effect, at sub-millimetre wavelengths, counteracts the distance dimming.

3. The measurement of CMB temperature anisotropies. Of particular interest is the Sunyaev-Zel’dovich (SZ) effect, which distorts the CMB spectrum at millimeter and radio wavelengths and can be used to map the distribution of hot gas in clusters of galaxies.

Throughout the previous decade, instruments utilizing up to hundreds of individual bolometers in focal plane arrays have dominated continuum sub-millimeter and millimeter astronomy (e.g. BOOMERANG balloon,

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Archeops balloon, Planck satellite, MAMBO2 at the IRAM 30-m telescope, BOLOCAM at the Caltech Sub-millimeter Observatory). A number of full-sampling arrays with up to thousands of pixels in a single array are now being proposed or reaching maturity, offering increased mapping speed and decreased per-pixel manufacturing costs (e.g. Apex-SZ, South Pole Telescope, SCUBA2, LABOCA, MUSIC at CSO, GISMO at IRAM). Despite these advances, further scaling is limited by the multiplexing factor of the readout electronics. That represented our main driver for developing intrinsically multiplexable detectors, preserving the high sensitivity of photon-noise limited observations.

2. THE NIKA INSTRUMENT: 2009 AND 2010 PROTOTYPES

NIKA is a relatively new project, which started officially as late as November 2008. The final goal is to develop a large field-of-view camera to equip the focal plane of the 30-m IRAM telescope at Pico Veleta (2850 m.s.l.), near Granada. The 30-m telescope is today the largest telescope able to operate at sub-millimeter wavelengths. The instrument is exploiting the intrinsically multiplexable Kinetic Inductance Detectors (KID)^{1,2}. A single KID pixel is a superconducting resonator coupled to a properly designed microwave feedline. A number of LC resonators, properly tuned to resonate at different frequencies, can be attached to the same feedline, sharing thus common readout electronics. The incoming radiation changes the surface impedance (kinetic inductance) of the superconductor films, resulting in a measurable signal. Please refer to the bibliography for further details. The NIKA prototype is based on a continuous dilution cryostat specifically designed for the IRAM 30-m telescope and able to reach a base temperature of about 70 mK.

During 2009, in the framework of the preparation of the first NIKA observational run, we have first demonstrated the potential of the new Lumped Element KID proposed in 2007 by the University of Cardiff³. In particular, we have demonstrated good imaging quality despite the EM interaction between the lumped LC resonators. The first NIKA prototype consisted in a single band instrument optimized for the so-called “2 mm atmospheric window” (130-170 GHz). We were granted six half-days technical time, during daytime, and tested two arrays on the sky: one 30 pixels (5×6 array) LEKID and one 42 pixels (6×7 array) antenna-coupled array with individual sapphire microlenses attached to each pixel. Performances were more than acceptable for a very first prototype, with a sensitivity approaching, for the LEKID array, 120 mJy·s^{0.5} per beam, a factor of 10 worse than the final goal but still the best KID-based instrument at that time. We present in figure 1 the pixels designs of both arrays tested on the

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sky in October 2009, and one example of a typical point-like, galactic source observed with NIKA. More details concerning the first NIKA run are reported in the reference⁴.

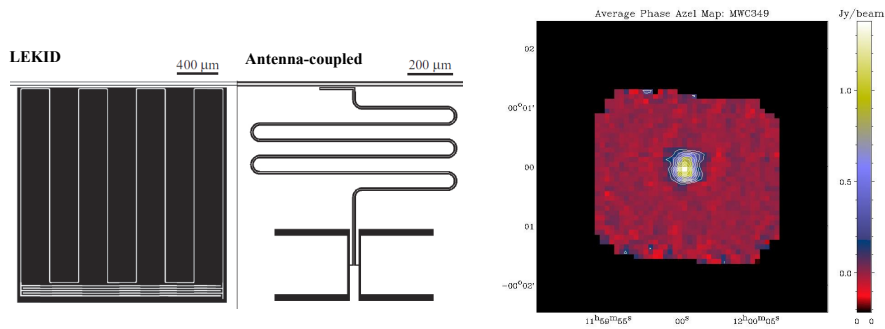


Fig. 1. NIKA first run (October 2009). Left: LEKID and antenna-coupled single pixels designs. Right: MWC349 secondary calibrator (~ 1.5 Jy).

In preparation of the second run, that took place in October 2010, we have improved the NIKA prototype instrument to accommodate a dual-band (150 GHz and 240 GHz) optics, and two larger arrays. The beam is splitted by a grid polarizer placed at the coldest stage. The image is then formed by two HDPE lenses, one per array, placed in front of the detectors. For the 150 GHz channel we have used an Al LEKID 144 pixels array. Among the most important design optimizations, we have changed the resonator impedance in order to reduce the phase noise, and increased the kinetic inductance fraction (ratio between the kinetic and the geometric inductance) by reducing the Al film thickness down to 20 nm. On the 240 GHz channel, we have mounted a hybrid NbTiN/Al antenna-coupled matrix with 256 pixels and a micro-fabricated Si microlenses array. The two arrays, observing simultaneously a common portion of the sky (2 arc-min diameter), are read-out by a couple of independent ROACH boards developed by the CASPER group⁵, and adapted for KID by the Open Source Readout collaboration⁶. The FPGA program and the up/down converter, allowing handling up to 112 resonators spread over 230 MHz of band, has been developed in house by the NIKA collaboration. In figure 2 we present pictures of both arrays and a nice example of the instrument imaging capabilities. The sensitivity of the LEKID array, when compared to the first technical run, has improved by about a factor of 4, being around $30 \text{ mJy}\cdot\text{s}^{0.5}$ per beam, on average. The best pixels already approach the target sensitivity, and are thus basically photon-noise limited. The antenna-coupled array, at 240 GHz, had a sensitivity of

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about $300 \text{ mJy}\cdot\text{s}^{0.5}$, acceptable for a first KID prototype working at those frequencies. For more details concerning the NIKA 2010 prototype performances and testing procedure, see the reference⁷.

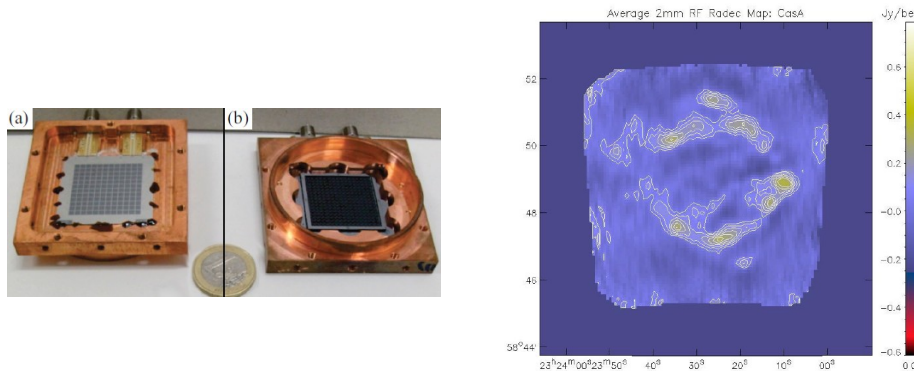


Fig. 2. NIKA second run (October 2010). Left : a) LEKID 144 pixels array (20 nm Al), resonators side; b) antenna-coupled array, microlenses side. Right: example of the Cas A supernova remnant (SNR) observed with NIKA in October 2010. Preliminary result taken from the NIKA wiki page⁸.

With NIKA approaching the target sensitivity, we could start investigating more subtle points, like the photometric accuracy. We have during the 2010 run linearly related the complex KID phase with an effective resonant frequency shift, which is expected being proportional to the incoming power for thin superconducting films⁹. Despite that, the photometric accuracy is still poor, of the order of 30%, compared to about 10% for the best bolometer-based instruments.

3. NIKA PLANS

Based on the very encouraging results obtained with the 2010 dual-band prototype, we have responded to the recent IRAM call for building a next generation, large field-of-view (6 arc-min) resident instrument at Pico Veleta. The mm-wave camera being designed will be largely inspired to the NIKA 2010 prototype, with an optimized dichroic for beam splitting at 70 mK and a pupil placed at the same temperature to efficiently suppress the stray light. The filters chain, including the dichroic, is made exclusively by multi-layer metallic meshes. The internal optics is based, for the baseline design, on HDPE (high-density polyethylene) corrugated components. The telescope diffraction spot, imaged on the focal plane, will be oversampled,

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resulting in a large number of pixels. The baseline design calls for about 1,000 pixels for the 150 GHz channel and 3,000 pixels for the 240 GHz. As far as sensitivity is concerned, and based on recent laboratory results, we think that a simple Al-based LEKID array will be sufficiently sensitive for the 150 GHz channel. At higher frequency, it is not clear if a single Al film can satisfy the requirements. We are thus investigating TiN LEKID, exhibiting larger kinetic fraction and thus improved sensitivity¹⁰. Preliminary results show optical NEP, in the astronomically interesting band 0.1-10 Hz, in the low 10^{-17} W/Hz^{0.5} for optical loading of less than 1pW per pixel. Further devices are being fabricated and tested, more adapted to the ~ 10 pW loading per pixel found during normal IRAM conditions at 240 GHz. Besides LEKID, antenna-coupled KID are rapidly improving¹¹, and remain a viable option. As far as electronics is concerned, we are developing in house an FPGA-based system, able to handle 256-384 channels over 500 MHz of band¹². Particular care will be put in the internal calibrator design, in order to reduce the photometric uncertainties at the goal level of about 5%. The time schedule for this project is particularly tight; the science grade instrument will be installed at the telescope by the end of 2014.

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