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The NIKA2 instrument at 30-m IRAM telescope: performance and results

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Abstract The New IRAM KID Arrays 2 (NIKA2) consortium has just finished installing and commissioning a millimetre camera on the IRAM 30 m telescope. It is a dual-band camera operating with three frequency multiplexed kilo-pixels arrays of Lumped Element Kinetic Inductance Detectors (LEKID) cooled at 150 mK, designed to observe the intensity and polarisation of the sky at 260 and 150 GHz (1.15 and 2 mm). NIKA2 is today an IRAM resident instrument for millimetre astronomy, such as Intra Cluster Medium from intermediate to distant clusters and so for the follow-up of Planck satellite detected clusters, high redshift sources and quasars, early stages of star formation and nearby galaxies emission. We present an overview of the instrument performance as it has been evaluated at the end of the commissioning phase.

Keywords Millimetre Astrophysics, Detectors LEKID

1 Introduction

New frontiers in millimetre astronomy require high sensitivity and high resolution instruments. These goals demand the development of large-format instruments with arrays of detectors. The technological solution that we have chosen uses Lumped Element Kinetic Inductance Detectors (LEKID). It allows for a large multiplexing factor frequency domain readout and an accessible manufacturing. This technological solution has been selected for the NIKA project which represents the first demonstration of LEKID performance using kilo-pixel arrays for scientific observations at millimetre wavelength [1,2]. The camera has been permanently installed at the IRAM 30 m telescope in October 2015, and it is available for the general community since summer semester 2017.

The NIKA2 consortium is responsible for the design, the construction, and the commissioning of the instrument. In addition, NIKA2 consortium takes the pledge to provide technical support for the 10 years of foreseen life time of the instrument. This contribution is rewarded with 1300 hours of guaranteed time distributed in five large programs over 4 years :

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- Clusters of galaxies via the Sunyaev Zel'dovitch effect
- Deep surveys (mapping large areas at a depth close to the confusion limit)
- Mapping the insterstellar medium
- Nearby Galaxies
- Polarization measurements of Galactic regions

In this paper we report the performance obtained at the end of the commissioning in terms of instrumental noise equivalent flux density (NEFD) calculated on point-like sources. This work has been extensively discussed in a recent NIKA 2 paper[3]

2 NIKA2 instrument and the whole calibration process

We can separate NIKA2 into four main sub-systems:

- **Optics:** the instantaneous field-of-View is 6.5 arcmin. Being M1 and M2 the primary 30 m mirror and M2 the sub-reflector, the whole optical chain consists of several mirrors at room temperature (M3, M4, M5 and M6) and cold optics inside the cryostat (see Fig. 1). The cold optics consists of aluminium mirrors (M7 and M8 cooled at 80 K) and cold refractive optics (high density polyethylene - HDPE lenses placed from the 1 K stage to the 100 mK stage). The rejection of out-of-band emission from the sky and the telescope is achieved by using a series of low-pass metal mesh filters, placed at different cryogenic stages in order to minimize the thermal loading on the detectors. The band splitting between 2 and 1.15 mm channels is achieved by a dichroic installed at the 100 mK stage (see the full list of NIKA2 optical filters in Tab. 1). The polarisation facilities consist of a multi-mesh hot-pressed Half-Wave-Plate (HWP)[4] mounted in front of the NIKA2 cryostat window in a mechanical modulator performing the rotation thanks to a step motor. Since the LEKID design used in the NIKA2 instrument is sensitive to both linear polarisations, the beam is further split by a wire grid polariser at 100 mK cryogenic stage in order to analyse the modulated linear polarisation into two arrays observing at 1.15 mm without any waste of signal.
- **Cryostat:** The nominal working temperature of 150 mK is achieved by two 4 K cryocooler and a closed-cycle ^3He-^4He dilution fridge. The cool-down process is remotely controlled and does not require cryogenics liquids. The whole process lasts about 5 days with four full days of pre-cooling and about one day of dilution cool-down. The fluctuation of the detectors temperature is of the order of 0.1 mK RMS over the duration of a typical scan (15 minutes).
- **Detectors:**
  NIKA2 Lumped Element Kinetic Inductance Detectors (LEKIDs) are composed of an interdigitated capacitor and a meander inductor acting as an absorber. The mask is designed with an Hilbert pattern to absorb both polarisations[5,6]. Each array is fabricated on a single 4-inches high-resistivity silicon wafer (thickness equal to 250 and 300 μm for the 1.15 mm and 2 mm arrays respectively). The pixels pattern is wet etched from a thin aluminium film (18 nm) deposited by e-beam evaporation. The use of thin aluminium film has several advantages: a better match with free space impedance of the incoming photons and a high kinetic inductance. This kind of film has been largely

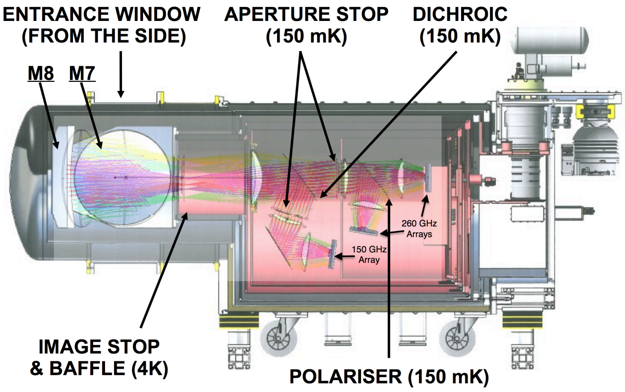

Fig. 1 Cross-section of the NIKA2 cryostat with the whole cold optical chain [3].

adopted for NIKA and in general for all the applications in our laboratory [7,8]. In order to exploit all the angular resolution of the IRAM 30 m telescope, the pixel sizes have been set to 2 mm for the 1.15 mm arrays and 2.3 mm for 2 mm array. This corresponds to a pixel size in units Fλ (λ = wavelength and F= f-number or relative aperture) equal to 1 for all the arrays. The geometrical coupling between pixels and the corresponding feed-line is made with a microstrip readout line. The consequence of this geometry is that the detectors must be front-illuminated. More details about the design and fabrication of NIKA detectors can be found in [3,7,5].

– **Readout electronics:** The readout comprises coaxial cables connected from 300 K to the base temperature, 20 low-noise cryogenics amplifiers (LNA) in-

Common Filters	Working Temperature [K]
Thermal filter CT15	300
Thermal filter CT15	150
Thermal filter CT30	80
Thermal filter CT30	80
W1924 13cm-1 LPE	80
W1923 12cm-1 LPE	4
W1922 11cm-1 LPE	1
dichroic 6.1cm-1 HPE	0.1
W1924 13cm-1 LPE at 80K	80
Band-defining Filters	
K1931 5.65cm-1 LPE	0.1 (on 2mm)
K1670 4.0cm-1 HPE	0.1 (on 2mm)
K1930 10.15cm-1	0.1 (on 1mm)
W2217 6.5cm-1	0.1 (on 1mm)

Table 1 List of NIKA2 optical filters.

Wavelength [mm]	2	1.15
Average KID per feed-line [#]	255	142.5
Board count [#]	4	16
Total Power consumption [W]	370	1220
Tone tuning resolution [Hz]	953	953
Frequency range [GHz]	1.3-1.8	1.9-2.4

Table 2 Main characteristics of the NIKA2 readout.

stalled in the 4 K stage, and warm electronics. The latter is constituted by readout boards named New Iram Kid ELectronic in Advanced Mezzanine Card format (NIKEL_AMC), central, clocking and synchronisation boards (CCSB) mounted on the MicroTCA Carrier Hub (MCH) and one 600 W power supply. These boards are distributed in three micro-Telecommunication Computing Architecture (MTCA) crates. In order to readout 2896 pixels, NIKA2 is equipped with 3 crates hosting 20 boards (8X2 for arrays at 1.15 mm and 4x1 for 2 mm array). In Tab. 2 are presented the main characteristics of the NIKA 2 readout. For a full description of the readout electronics please see for example[9].

3 The commissioning phase: a summary of the performance

The NIKA camera was commissioned between September 2015 and April 2017. In that period we performed several technical observing campaigns observing point like sources, in order to assess the NIKA photometry, and extended sources to demonstrate the possibility to reconstruct angular scales up to several arcminutes.

Table 3 summarises the main NIKA characteristics and performance as measured on the sky. We obtained a sensitivity (averaged over all valid detectors) of 33 and 8 mJy$\cdot\sqrt{s}$ for the best weather conditions for the 1.15 mm (A1&A3) arrays and for 2 mm (A2) array respectively, estimated on point-like sources.

Table 3 Summary of the principle characteristics and performance of the NIKA2 instrument[3]. Beam efficiency here is defined as the ratio between the main beam power and the total beam power up to a radius of 250″.

Channel	260 GHz 1.15 mm			150 GHz 2 mm
Arrays	A1	A3	A1&3	A2
Number of designed detectors	1140	1140		616
Number of valid detectors	952	961		553
FOV diameter [arcmin]	6.5	6.5	6.5	6.5
FWHM [arcsec]	11.3 ± 0.2	11.2 ± 0.2	11.2 ± 0.1	17.7 ± 0.1
Beam efficiency [%]	55 ± 5	53 ± 5	60 ± 6	75 ± 5
rms calibration error [%]	4.5	6.6		5
Model absolute calibration uncertainty [%]	5			
RMS pointing error [arcsec]	< 3			
NEFD [mJy.s$^{1/2}$]			33 ± 2	8 ± 1

The sensitivity at 1.15 mm is limited by sky noise decorrelation techniques (this will be investigated in forthcoming articles Perotto et al. 2018, Ponthieu et al. 2018) and a still unidentified optical problem reducing considerably the illumination on the array A1. This issue is under investigation and will be addressed in a forthcoming publication.

In april 2017 we performed a science verification run in order to summarise the capability of NIKA 2 camera to recover large angular scales with high mapping speed. The choice of the source was on the high redshift cluster of galaxy PSZ2-G144.8 observed via the Sunyaev Zel'dovitch effect. The analysis of this cluster is still in progress and it will be published in a dedicated paper in the incoming months.

4 Conclusion

NIKA2 has been successfully installed at the IRAM 30-m telescope in october 2015 as planned. The commissioning phase for the intensity observations is achieved. Acceptance meeting scheduled in early September 2017 made official the beginning of the NIKA 2 instrument as a open tool available for astronomers

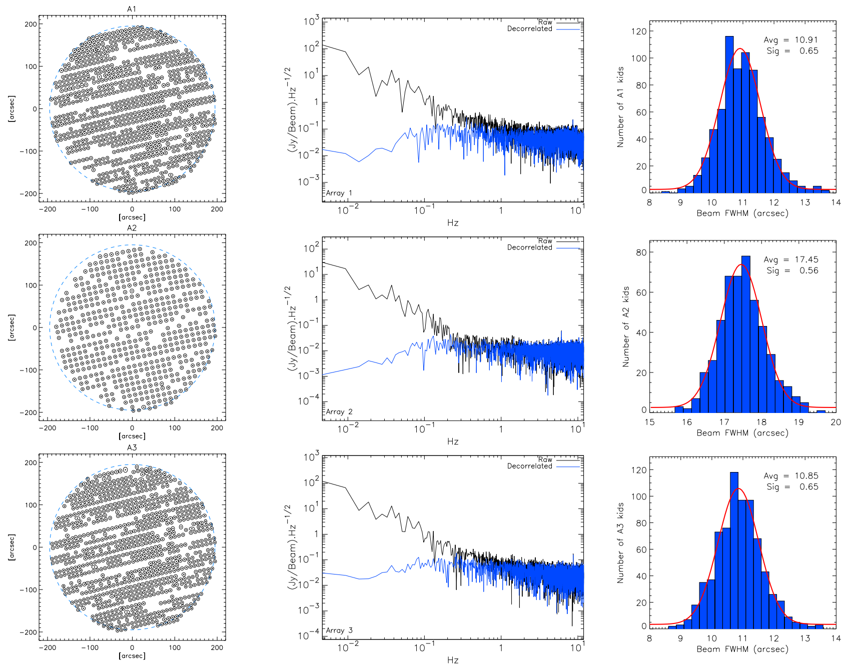

Fig. 2 From top to bottom left column: detectors positions for arrays A1 (260 GHz-H), A2 (150 GHz) and A3 (260 GHz-V). Central column: power spectra of the NIKA2 time ordered data before (black) and after (blue) subtraction of atmospheric fluctuations, which show-up at frequencies below 1 Hz. Right column: main beam FWHM distribution of all valid KID detectors of arrays A1, A3, and A2[3].

since summer semester 2017.
Recent results can be found on http://lpsc.in2p3.fr/NIKA2LPSZ/nika2sz.release.php. Finally, commissioning for polarisation shows encouraging results, the work will continue over the incoming months.

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