High-resolution SZ cartography of clusters of galaxies with NIKA at the IRAM 30-m telescope

F. Mayet on behalf of the NIKA Collaboration
Outline

1. The NIKA2 camera and the NIKA prototype

2. Why high-resolution SZ cartography of clusters?

3. First SZ observations with NIKA
   - well-known cluster
   - high-z cluster
   - Planck-discovered cluster

4. The NIKA2 SZ large program (2016-2021)
   → follow-up of Planck-discovered clusters
High-resolution SZ cartography of clusters of galaxies with the NIKA camera at the IRAM 30-m telescope
The NIKA2 camera

NIKA2
- KID-based camera
  → Kinetic Inductance Detectors = High quality factor superconducting resonator
    *Frequency shift proportional to the incoming optical power*
- Operated at 100 mK
- Dual-band: 150 and 260 GHz
- Wide field of view: 6.5 arcmin (spec.) up to 5000 detectors
- High-angular resolution: 18 and 12 arcsec (spec.)
- State-of the art sensitivity : 20 and 30 mJy.s^{1/2} (spec.)
- Polarization capabilities at 260 GHz

NIKA
- a prototype of NIKA2
- operated at IRAM-30m telescope from 2014 to 2015
- Field of view: 1.8 arcmin (356 detectors)
The NIKA2 camera

The NIKA2 camera has been built by the NIKA2 Collaboration
- 14 laboratories
- 110 members of the collaboration

The NIKA2 camera
- has been installed in Sep. 2015 at the IRAM-30m telescope
- has given its first light in Oct. 2015
- will be open to the scientific community for the next decade

IRAM 30-m telescope at Pico Veleta (Spain)
High-resolution Sunyaev Zel’dovich cartography of clusters of galaxies with NIKA at the IRAM 30-m telescope
Sunyaev Zel’dovich (SZ) Effect

Thermal Sunyaev Zel’dovich effect (SZ)
- inverse Compton scattering of CMB photons on hot electrons of the intra-cluster medium (ICM)
- spectral distortion of the CMB spectrum
  - SZ effect is redshift-independent
  - observation of high-z cluster
- Compton parameter
  \[ y \propto \int P_c \, dl \]
- Characterization of the electronic pressure (shocks)
Why high-resolution SZ cartography of clusters?

- Clusters of galaxies are widely used for cosmological studies
- Catalog of ~2000 galaxy clusters identified by their SZ signal by Planck, ACT and SPT

  → NIKA2 resolution is ~30 times better than Planck’s one
  → high-resolution cartography
  → Study of the intra-cluster medium (ICM)

- Tension between CMB and Cluster estimation of cosmological parameters ...
  most probably due to the estimation of the total mass of the cluster

\[ M_{tot} = (1 - b) M_{HSE} \quad \text{where } b \text{ is the hydrostatic bias} \]

High-resolution observations would allow us to study
- the hydrostatic bias
- the pressure distribution within the inner part of the cluster
- the redshift dependence of the pressure profile

→ Combined with other probes (X-ray, lensing) = multi-probe analysis of clusters
→ this will open a new era for the use of clusters to study cosmology.
First SZ observations with NIKA

- **RXJ1347**: well-known
- **CLJ1227**: high-z
- **PSZ1G045**: Planck catalog
- **MACSJ1424**
Well-known cluster: RX J1347 (z=0.45)

- **RXJ1347**
  - the most luminous X-ray cluster
  - strong SZ signal (Diabolo, Mustang, Carma)

**Data analysis: Single-band method**

Atmospheric noise removal performed by using the 260 GHz data as a template *(as the expected SZ signal is small)*

- 10σ detection
- First observation of SZ effect with a KID-based camera (NIKA)
- NIKA2 field of view = Planck beam

→ The combination of Planck and NIKA data allows us to map all scales (core and outskirts)
Well-known cluster: RX J1347 (z=0.45)

Multi-probe study: X, radio, optical

\[ X \text{ ray } \propto n_e^2 \sqrt{T_e} \]
\[ \text{SZ } \propto P_e \propto n_e T_e \]

→ SZ used to characterize shocks

Conclusions:
→ X-ray peak well aligned on central AGN
→ SZ peak shifted toward South-East
   & agrees with radio halo
→ RXJ1347 is an on-going merger

→ This first observation highlights the interest of high-resolution cartography with NIKA

Radio halo (C. Ferrari et al. 2011)
High-z cluster: CL J1227 (z=0.89)

- SZ detection at 18σ
- SZ peak well aligned on X-ray center (white cross)
- Point source identified at 260 GHz map
  - induces a deformation of the map at 150 GHz
  - Point source subtraction

Feb. 2014
Obs. time: 7.8 h
R. Adam et al., A&A 2015
High-z cluster: CL J1227 (z=0.89)

- SZ detected in the 2 bands with expected ratio
- To further remove atmospheric noise, a single-band method can be used
  \( \rightarrow \) accurate mapping from 20'' to 3' (0.1 to 1 R_{500} at z=0.9)

\( \rightarrow \) CLJ1227 is relaxed on large scales but with a disturbed core
High-z cluster: CLJ1227 (z=0.89)

**Combined analysis:** Planck+NIKA+Chandra

Multi-probe study allows us to study the thermodynamic properties of the intra-cluster medium

<table>
<thead>
<tr>
<th>Model</th>
<th>$a$</th>
<th>$b$</th>
<th>$c$</th>
</tr>
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<tbody>
<tr>
<td>PPC</td>
<td>1.33</td>
<td>4.13</td>
<td>0.014</td>
</tr>
<tr>
<td>NNN</td>
<td>0.9</td>
<td>5.0</td>
<td>0.4</td>
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<tr>
<td>FPC</td>
<td>free</td>
<td>4.13</td>
<td>0.014</td>
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</table>

Summary of CLJ1227 main properties

<table>
<thead>
<tr>
<th>PPC pressure profile</th>
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<tbody>
<tr>
<td>$M_{500}$</td>
</tr>
<tr>
<td>$9.30^{+0.30}<em>{-0.19}$ $10^{14}$ $M</em>{\odot}$</td>
</tr>
<tr>
<td>$R_{500}$</td>
</tr>
<tr>
<td>1.93^{+0.10}_{-0.09} arcmin</td>
</tr>
<tr>
<td>$f_{500}$</td>
</tr>
<tr>
<td>0.146^{+0.041}_{-0.039}</td>
</tr>
<tr>
<td>$\gamma_{500}$</td>
</tr>
<tr>
<td>0.598^{+0.063}_{-0.060} $10^{-3}$ arcmin$^2$</td>
</tr>
</tbody>
</table>

**code code:** slope parameters of the gNFW model
High-z cluster: CL J1227 (z=0.89)

Comparison with the characteristics of low-redshift clusters

**Pressure Profile**

- Universal Planck pressure profile
- Planck SZ
- XMM-Newton X-ray
- CL J1226.9+3332

**Mass/SZ flux scaling law**

- No conclusion can be drawn with a single high-redshift cluster
- One of the goals of NIKA2 SZ Program
- Redshift evolution of Pressure profiles and Mass/SZ relation
Planck-discovered cluster: PSZ1G045

In preparation of the NIKA2 SZ program, we have observed with NIKA one cluster of the Planck catalog

- NIKA : SZ peak at 7σ
- **Multi-probe study** : NIKA+PLANCK+XMM → study of the ICM thermodynamics

\[
R_{500} = (956 \pm 62) \text{ kpc}
\]

\[
M_{HSE,500} = 4.61^{+0.96}_{-0.84} \times 10^{14} M_\odot
\]

\[
Y_{tSZ}(R_{500}) = 5.15^{+0.80}_{-0.73} \times 10^{-4} \text{ arcmin}^2
\]

→ a pilot study done with NIKA to prepare the NIKA2 SZ program
The NIKA2 SZ large program (2016-2021)

• one of the Large Programs of the NIKA2 Guaranteed time
  → 300 hours of observations
  → 50 clusters up to z=1 from Planck & ACT catalogs
  → XMM follow-up

Goals:
• in-depth study of the intra-cluster medium
• Combination with ancillary data (X, lensing)
  → pressure, density, temperature, entropy, mass

Expected outputs:
  → Redshift evolution of pressure profile
  → Scaling law and the hydrostatic bias
  → Cluster properties as function of dynamical states (mergers)
  → Morphology (sphericity)

→ Significant improvements on the use of clusters of galaxies to draw cosmological constraints