The SZ structure of high-z galaxy clusters with NIKA
A pathfinder for NIKA2

Rémi Adam
on behalf of the NIKA collaboration

SnowCluster 2015
Snowbird, Utah - 17/03/2015
1. **NIKA** in a nutshell
2. The **first SZ** observation with NIKA
3. Looking at:
   1. **high-z** cluster
   2. **relaxed point source contaminated** cluster
   3. heavily **disturbed** cluster
4. Follow-up of **Planck discovered** clusters
5. **NIKA2** SZ prospects
NIKA, a prototype camera for NIKA2

The IRAM 30m telescope:
• 12” resolution at 260 GHz
• 17” resolution at 150 GHz

The two KID arrays:
• 2x2000 (224) KIDs at 260 GHz
• 1000 (132) KIDs at 150 GHz
• State-of-the-art sensitivity

The dilution cryostat:
• operates at ~100 mK

The dedicated optics:
• 6.5’ (1.8’) field of view
• Beam splitting in two bands
• Filters + mirrors + lenses

The NIKEL readout electronics
[O. Bourrion et al. (2012)]

NIKA2 and its prototype

NIKA is a KID based camera which we use for SZ pilot studies for NIKA2
[http://ipag.osug.fr/nika2/Welcome.html]
The need for high angular resolution SZ observations

• SZ surveys (Planck/SPT/ACT) are amazing but high z clusters are not resolved
• NIKA resolution is ~ 30 times better than Planck

With resolved observations we could investigate
• redshift dependence of the pressure profile
• pressure distribution in cluster cores
• mass bias versus radius and redshift
• ...

This is necessary for reducing systematic effects in cluster mass-observable relations

➡ High-resolution SZ observations are required (+ multi-wavelength)
First observation of the tSZ effect with NIKA on RX J1347.5-1145
The first NIKA tSZ observation
RX J1347.5+3745 (z=0.45)

- The ideal test cluster: RXJ1347.5+3745, well known, compact and bright
- Technical time observation of November 2012
- Integration time: 5h47min
- Atmospheric removal using the 240 GHz channel as a template

\[ y_{\text{max}} \approx 10^{-3} \]

The first tSZ observation with KIDs, using the NIKA prototype
[R. Adam, B. Comis, J. F. Macías-Pérez et al. (2014)]
Complementarity of resolved (sub)millimeter, X-ray, radio and optical data

- The X-ray emission is due to bremsstrahlung from hot electrons

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

\[ \text{SZ} \propto P_e \propto n_e T_e \]

- tSZ is well adapted for the characterization of shocks

- RX J1347.5-1145 is an ongoing merger (strong SE extension)

- Multiwavelength observations provide a complete picture of the cluster

- NIKAA agrees well and complements other SZ observations

⇒ Detection and SZ mapping achieved

Radio halo at the shock location

[C. Ferrari et al. (2011)]
Observations at high redshift with CL J1226.9+3332
Looking at high redshift clusters
CL J1226.9+3332 (z=0.89)

- First NIKA Open Pool (February 2014): 7.8 hours

- Sub-mm point source identification using the 260 GHz band
- SZ detection within the two bands with tSZ expected flux ratio
- Single-band method: accurate signal mapping at ~ 20” - 3’ (0.1 - 1 $R_{500}$ at $z \sim 0.9$)

$\Rightarrow$ Dual-band SZ resolved mapping at high redshift
Looking at high redshift clusters
CL J1226.9+3332 (z=0.89)

- First NIKA Open Pool (February 2014): 7.8 hours

- **Sub-mm point source** identification using the 260 GHz band
- SZ detection within the two bands with tSZ expected flux ratio
- Single-band method: accurate signal **mapping at ~ 20” - 3’** (0.1 - 1 R\(_{500}\) at z ~ 0.9)
- Relaxed on large scales + disturbed core

➡ **Dual-band SZ resolved mapping at high redshift**
NIKA+Planck (pressure) + X-ray (ACCEPT density, [K. Cavagnolo et al. (2009)]) give temperature and mass profiles.

\[ M_{500} = 5.96^{+1.02}_{-0.79} \times 10^{14} \, M_\odot \]

NIKA provides accurate pressure profile reconstruction at high z.
High-z prospect for NIKA2 with CL J1226.9+3332 (z=0.89)

Our single high-z cluster can be compared to lower redshift clusters:

1. In term of pressure profile

   ![Pressure Profile Graph]

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

2. Or Mass/tSZ flux calibration

   ![Mass/tSZ Flux Calibration Graph]

   - Planck calibration
   - CL J1226.9+3332

→ With more high-z clusters, NIKA(2) can constrain redshift evolution
The relaxed cluster
MACS J1423.8+2404
Looking at a point source contaminated relaxed cluster MACS J1423.8+2404 (z=0.54)

- First NIKA Open Pool (February 2014): only **1.5 hours** unfortunately
- **Sub-mm point sources** are observed
- A **radio point source** sits at the cluster center

→ Radio and IR point sources contamination can be a problem
Multiwavelength data set
MACS J1423.8+2404 (z=0.54)

• NIKA and Herschel data [provided by K. Dassas and B. Hasnou] are highly complementary for sub-mm sources study
  • in terms of frequency coverage
  • and angular resolution

⇒ NIKA+Herschel can be used to constrain IR sources SED
The best fit SED can be used to predict the contamination at
  - the map level for morphological studies
  - the profile level for ICM radial reconstruction

⇒ The impact of point sources on the ICM reconstruction is under investigation in the context of NIKA2
The disturbed cluster
MACS J0717.5+3745
Looking at spectacular mergers
MACS J0717.5+3745 (z=0.55)

An exceptionally disturbed cluster

- Triple merger
- 4 optically identified groups with $v_z \sim 3000$ km/s (B)
- Temperature up to 30 keV

⇒ SZ mapping of (one of?) the most complex system
What about kSZ with NIKA in MACS J0717.5+3745 (z=0.55), PRELIMINARY

- kSZ is detected by Bolocam from the difference between their two maps [T. Mroczkowski et al. (2012), J. Sayers et al. (2013)]

- NIKA shows already strong hints for kSZ at high angular resolution
- More data obtained in Feb. 2015 which might provide a kSZ/tSZ map and possibly $v_z$

⇒ Hint for kinetic SZ signal, as detected by Bolocam. Analysis in progress
Follow-up of Planck discovered clusters
Looking at 2 Planck discovered clusters followed-up by XMM, PRELIMINARY

PSZ1 G046.13+30.75 at z=0.57

Interesting features are observed. Analysis in progress

PSZ1 G045.85+57.71 at z=0.61

NIKA 150 GHz

NIKA 260 GHz

XMM (P.I. M. Arnaud)
NIKA2
NIKA2: the status

NIKA2 (NIKA prototype)

- 5000 (300) detectors at SZ frequencies: 150 and 260 GHz (similar)
- 6.5 (2) arcmin instantaneous field-of-view
- State-of-the-art sensitivities (similar)
- High angular resolution: 17.5” and 12” (similar)

The NIKA2 cryostat

1000 pixels 150 GHz KIDs array
(2000 pixels 260 GHz also available)

- NIKA2 cryostat fully built
- The assembling of optics and wiring is done
- The >1000 pixels arrays are currently tested

⇒ NIKA2 will be definitely installed at IRAM in June 2015 and commissioned before 2016
NIKA2
Large Sunyaev-Zel’dovich programs

SZ large program
• 300 hours dedicated for SZ
• Observe ~ 50 clusters in the range $z = 0.5 - 1.5$
• Planck/ACT clusters are a working baseline to define a representative sample
• Combine NIKA with Planck, X-ray, optical, radio, submm and other datasets

Goals
• Calibrating the SZ flux as a mass proxy and its evolution with redshift
• Pressure profile evolution with redshift
• Characterize the structural properties and clusters dynamical state
• Measure the kSZ effect in individual clusters

⇒ The future of high resolution SZ observation with NIKA2 is promising
Summary and conclusions

• Nov. 2012: first tSZ observation with NIKA
  • NIKA can map the tSZ effect

• Feb. 2014: observation of high-z, disturbed and relaxed clusters
  • NIKA can measure the pressure profile at high-z and map the tSZ signal

• Nov. 2014: pilot follow-up program of Planck discovered clusters
  • Ongoing analysis

• Feb. 2015: detect kSZ? obtain a tSZ/kSZ map?
  • Ongoing analysis

➡ A lot of progress has been achieved since SnowCluster 2013
➡ 6 clusters are available to explore the SZ capabilities of NIKA2
➡ NIKA2 should be a powerful SZ instrument starting from 2016
http://ipag.osug.fr/nika2

The Kinetic Inductance Detectors (KIDs)

- KIDs are high-Q superconducting RLC resonators
- Absorbed photons change the kinetic inductance by breaking Cooper pairs (charge carriers)

\[ \delta f_0 \propto \delta L_k \propto P_{\text{opt}} \]

KIDs probe optical power via the shift of their resonance frequencies

Single KID (aluminum on silicon wafer)  
[A. Monfardini et al. (2010)]

Transfer function of a single KID

\[ \Delta A \]
The two reduction methods

1. Per frequency band independently
   - Large scale signal is filtered
   - Small correlated noise residual
   - Maps available at both frequencies

2. Estimated at 260 and removed at 150 GHz
   - Large scales are better recovered
   - Large correlated noise residual (elec.)
   - Only one map at 150 GHz

The reduction method is chosen depending on the cluster extension and the scientific goal.
We fit the relaxed North region of RX J1347.5-1145 using a gNFW pressure profile parametrization [D. Nagai et al. (2007)]

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

Slopes fixed to:

- \( \alpha = 1.2223 \)
- \( \beta = 5.4905 \)
- \( \gamma = 0.7736 \)
SZ characterization of the merger overpressure

We fit the relaxed North region of RX J1347.5-1145 using a gNFW pressure profile parametrization [D. Nagai et al. (2007)]

NIKA data

X-ray centered best fit model

Residual

→ RX J1347.5-1145 is well described by a relaxed cool-core + merger (~20% of the signal)