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

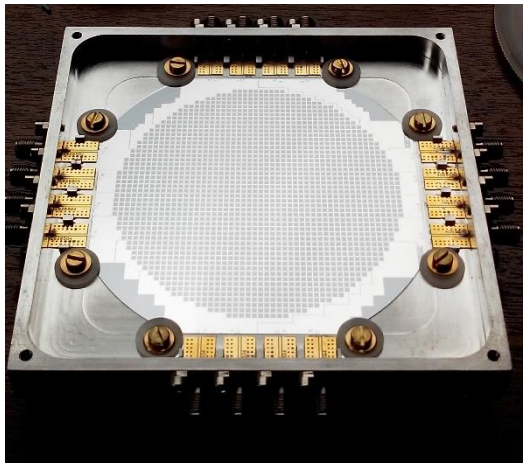
2. Why high-resolution SZ cartography of clusters ?

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

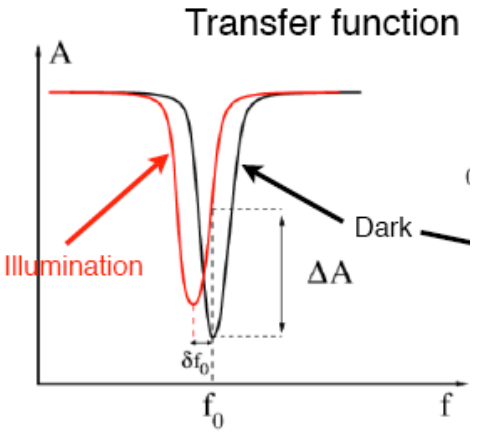
NIKA2 LEKID array (260 GHz)

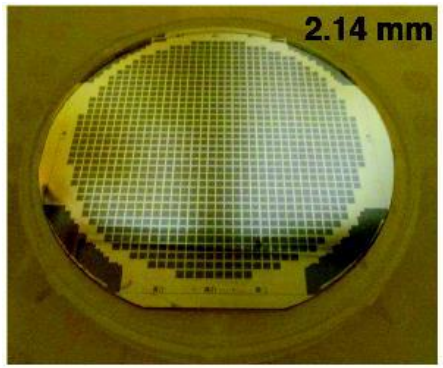


The NIKA2 camera

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



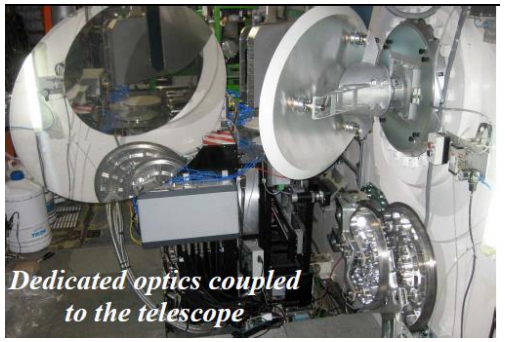


NIKA

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

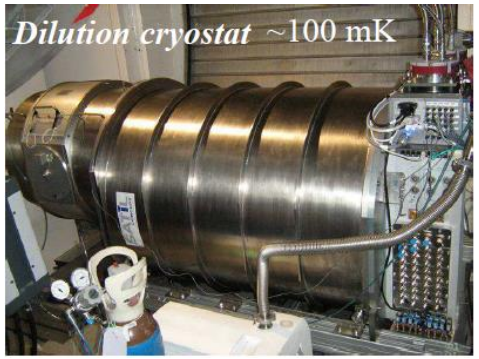
The NIKA2 camera

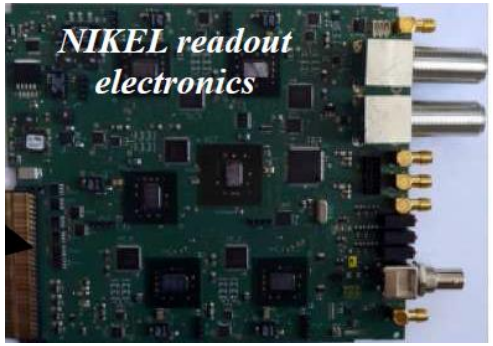
IRAM 30-m telescope
at Pico Veleta (Spain)



The NIKA2 camera has been built by the NIKA2 Collaboration

- 14 laboratories
- 110 members of the collaboration





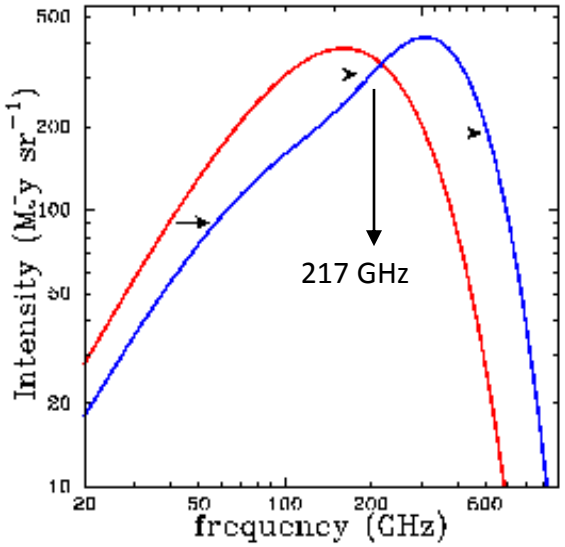
The NIKA2 camera

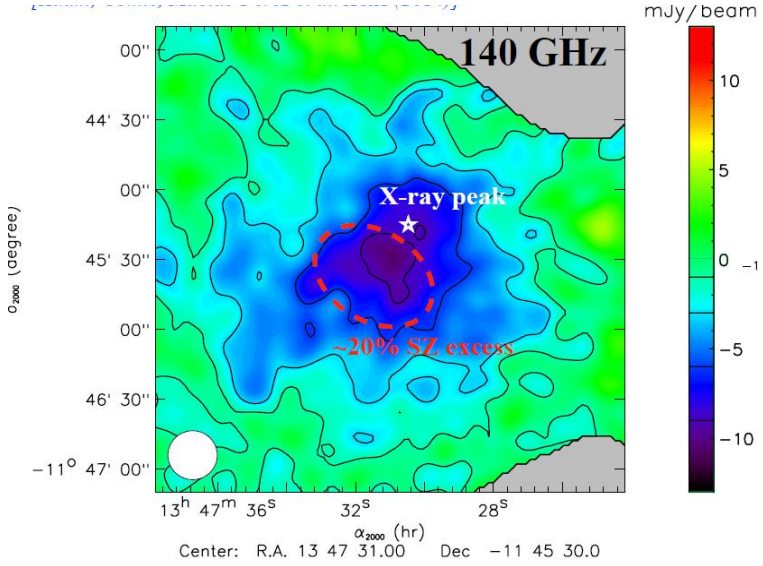
→ has been installed in Sep. 2015 at the **IRAM-30m telescope**

→ has given its **first light** in Oct. 2015

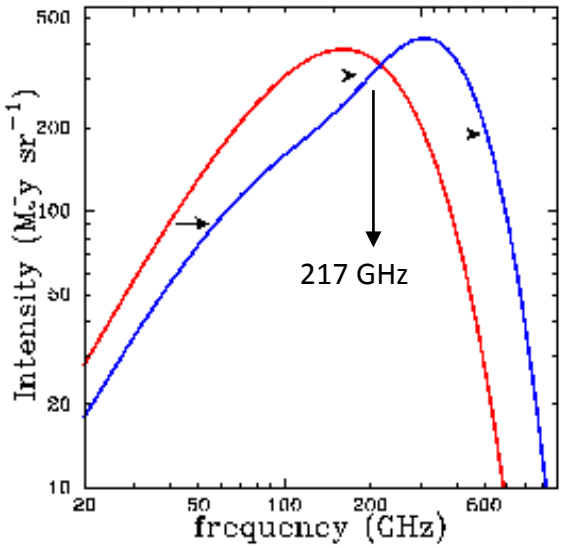
→ will be **open to the scientific community for the next decade**

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 effet (SZ)

→ inverse Compton scattering of CMB photons on hot electrons of the intra-cluster medium (ICM)

→ spectral distorsion of the CMB spectrum

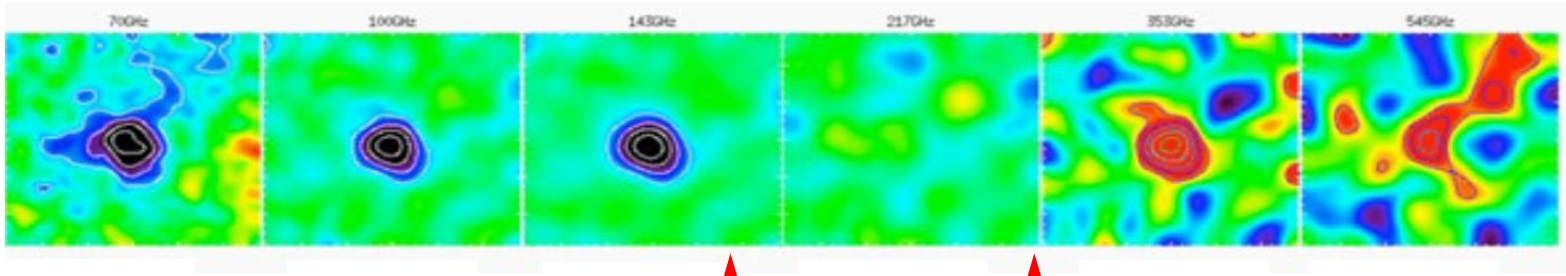
→ SZ effect is redshift-independant

→ observation of high-z cluster

→ Compton parameter $y \propto \int P_e dl$

→ Characterization of the electronic pressure (shocks)

A 2319 (Planck)



70 MHz — 100 GHz — 145 GHz — 217 GHz — 343 GHz — 545 GHz → Frequency

NIKA 150 NIKA 260

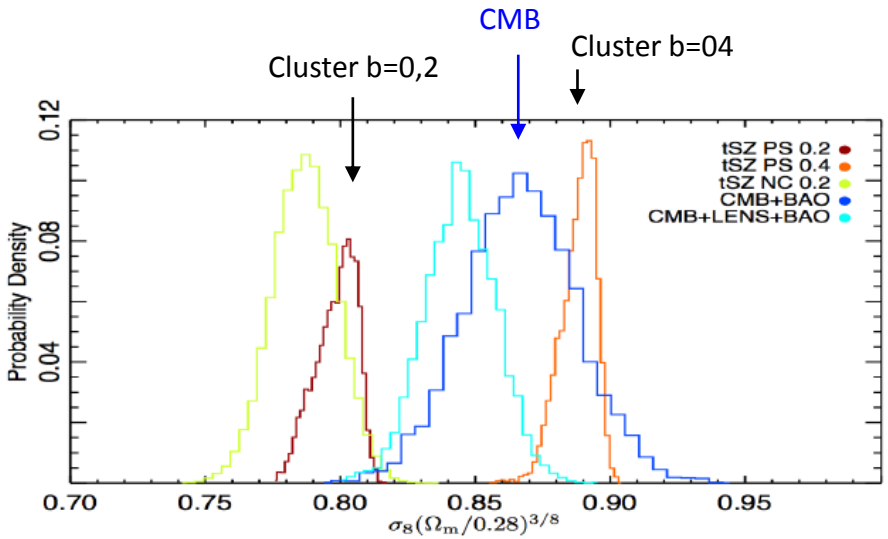
Why high-resolution SZ cartography of clusters ?

- 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

$$M_{tot} = (1-b)M_{HSE}$$ *where b is the hydrostatic bias*

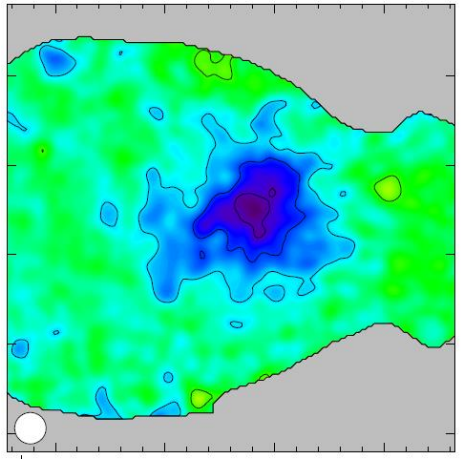


High-resolution observations would allow us to study
- the hydrostatic bias
- the pressure distribution within the inner part of the cluster
- the redshift dependence of the pressure profile

→ 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.

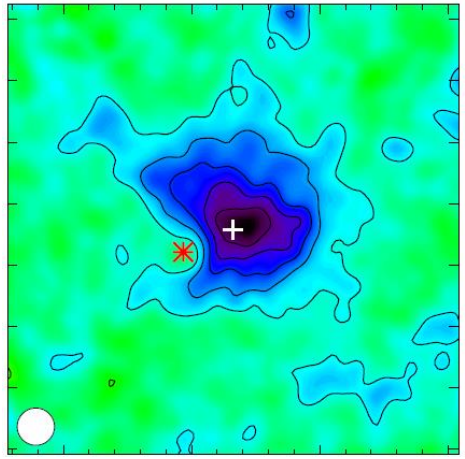
First SZ observations with NIKA

RXJ1347



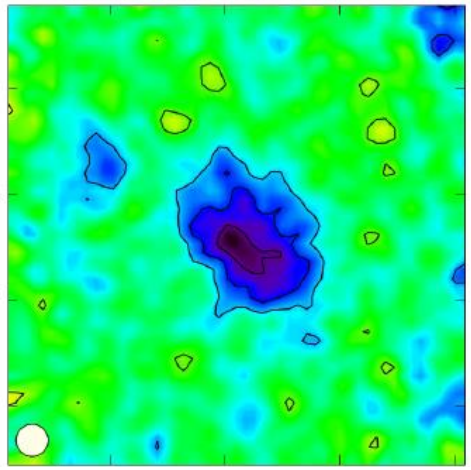
well-known

CLJ1227



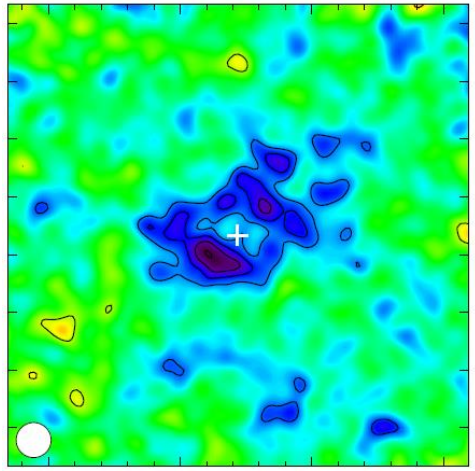
high-z

PSZ1G045

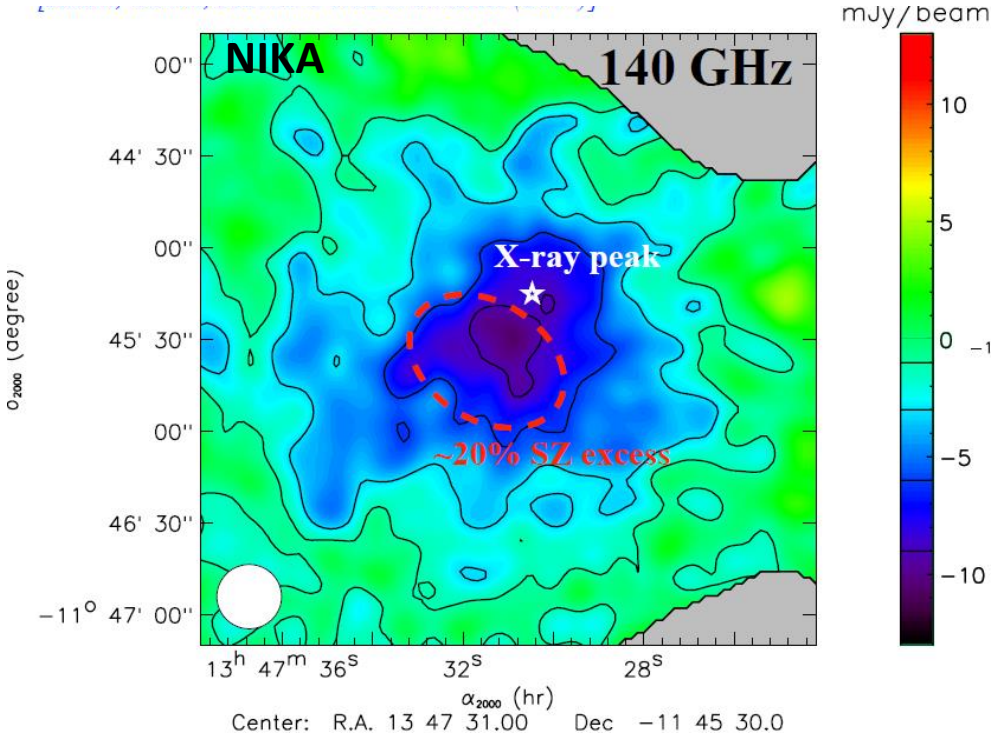


Planck catalog

MACSJ1424



Well-known cluster: RX J1347 (z=0.45)



Nov. 2012
Obs. time: 5.5 h
R. Adam *et al.*, A&A 2014

RXJ1347

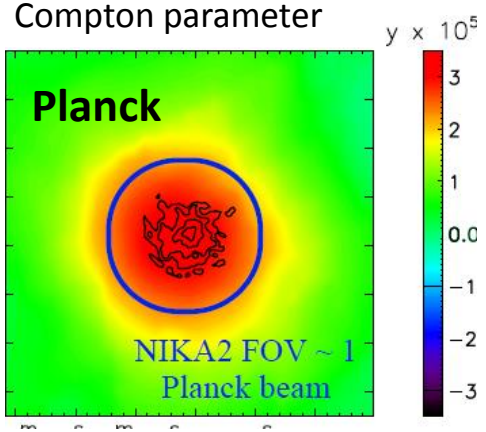
- the most luminous X-ray cluster
- strong SZ signal (Diabolo, Mustang, Carma)

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)*

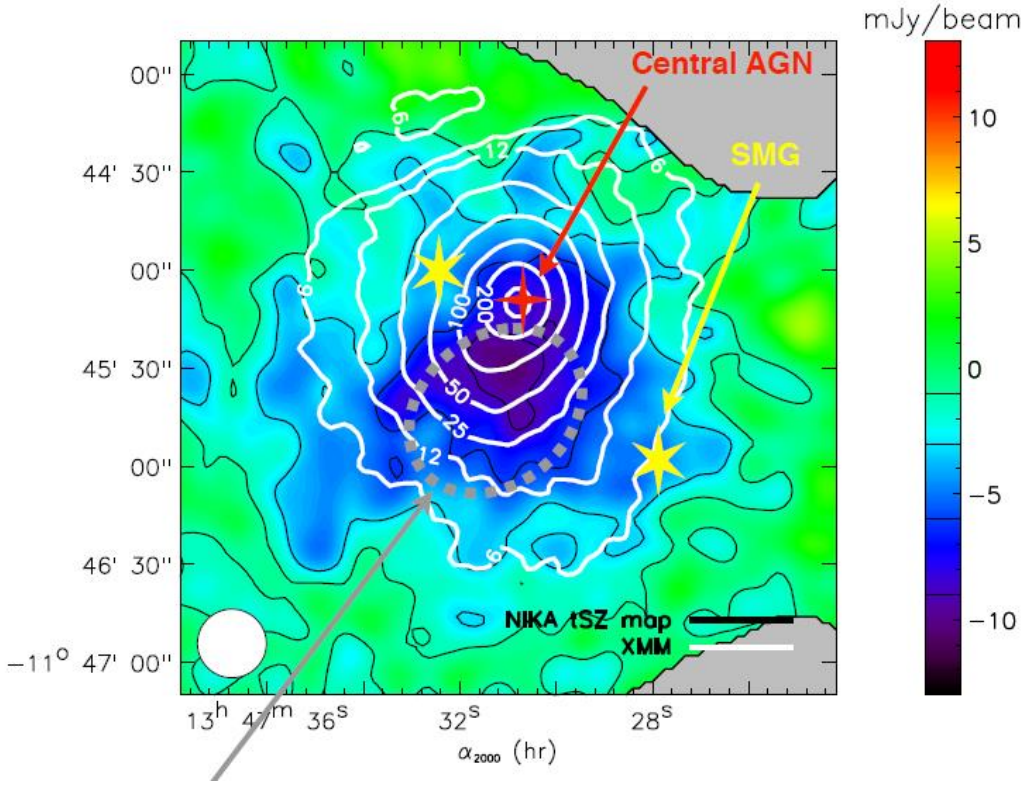
→ 10σ detection
→ First observation of SZ effect with a KID-based camera (NIKA)
→ NIKA2 field of view = Planck beam

Compton parameter



→ The combination of Planck and NIKA data allows us to map all scales (core and outskirts)

Well-known cluster: RX J1347 (z=0.45)



Radio halo (C. Ferrari et al. 2011)

Nov. 2012
Obs. time: 5.5 h
R. Adam *et al.*, A&A 2014

Multi-probe study: X, radio, optical

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

$$\text{SZ} \propto P_e \propto n_e T_e$$

→ SZ used to characterize shocks

Conclusions:

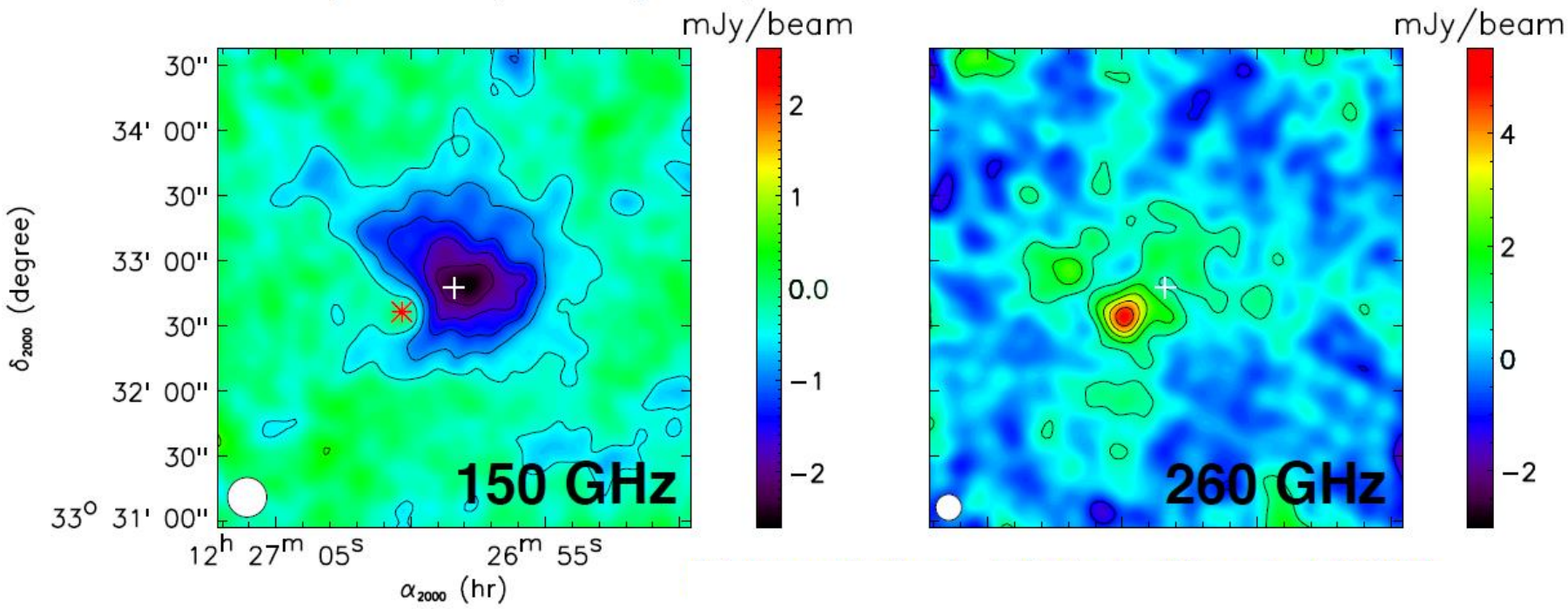
→X-ray peak well aligned on central AGN

→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

High-z cluster: CL J1227 (z=0.89)



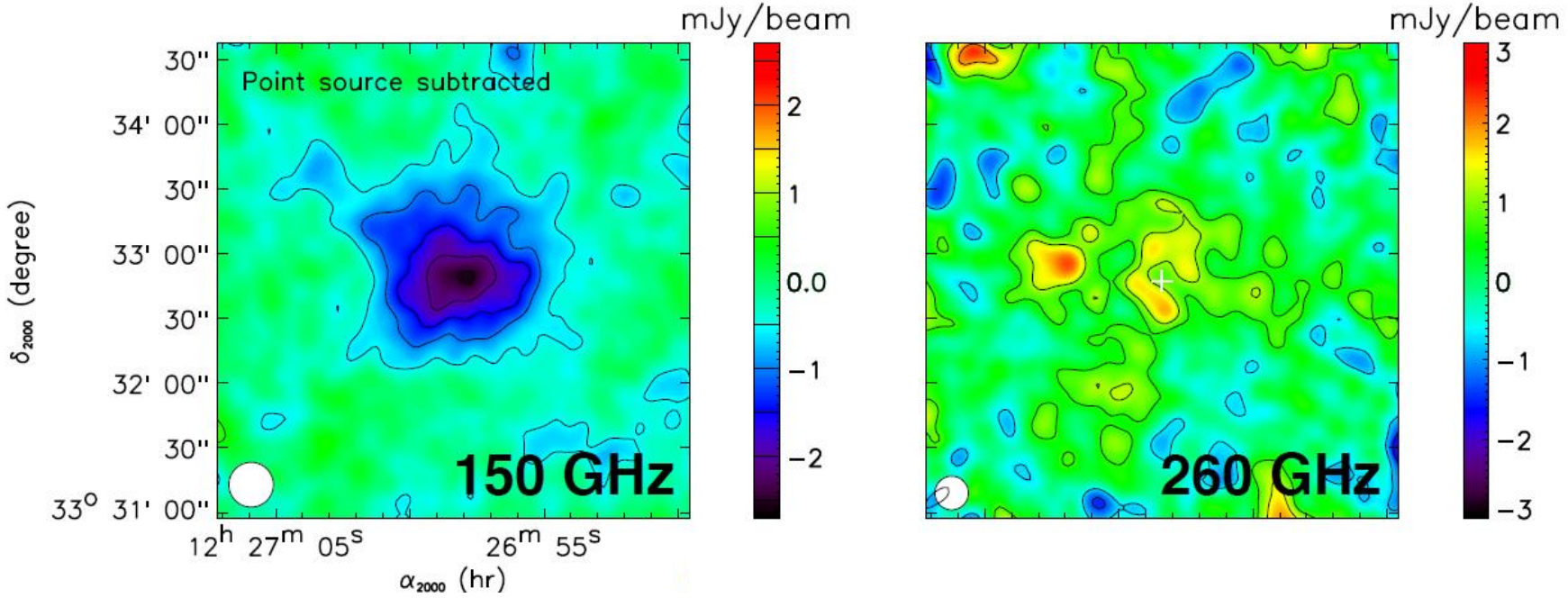
Feb. 2014
Obs. time: 7.8 h
R. Adam *et al.*, A&A 2015

- 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 substraction**

High-z cluster: CL J1227 (z=0.89)

Point source substracted



Feb. 2014
Obs. time: 7.8 h
R. Adam *et al.*, A&A 2015

- SZ detected in the 2 bands with expected ratio
- To further remove atmospheric noise, a single-band method can be used
  → accurate mapping from 20'' to 3' (0,1 to 1 R_{500} at z=0,9)

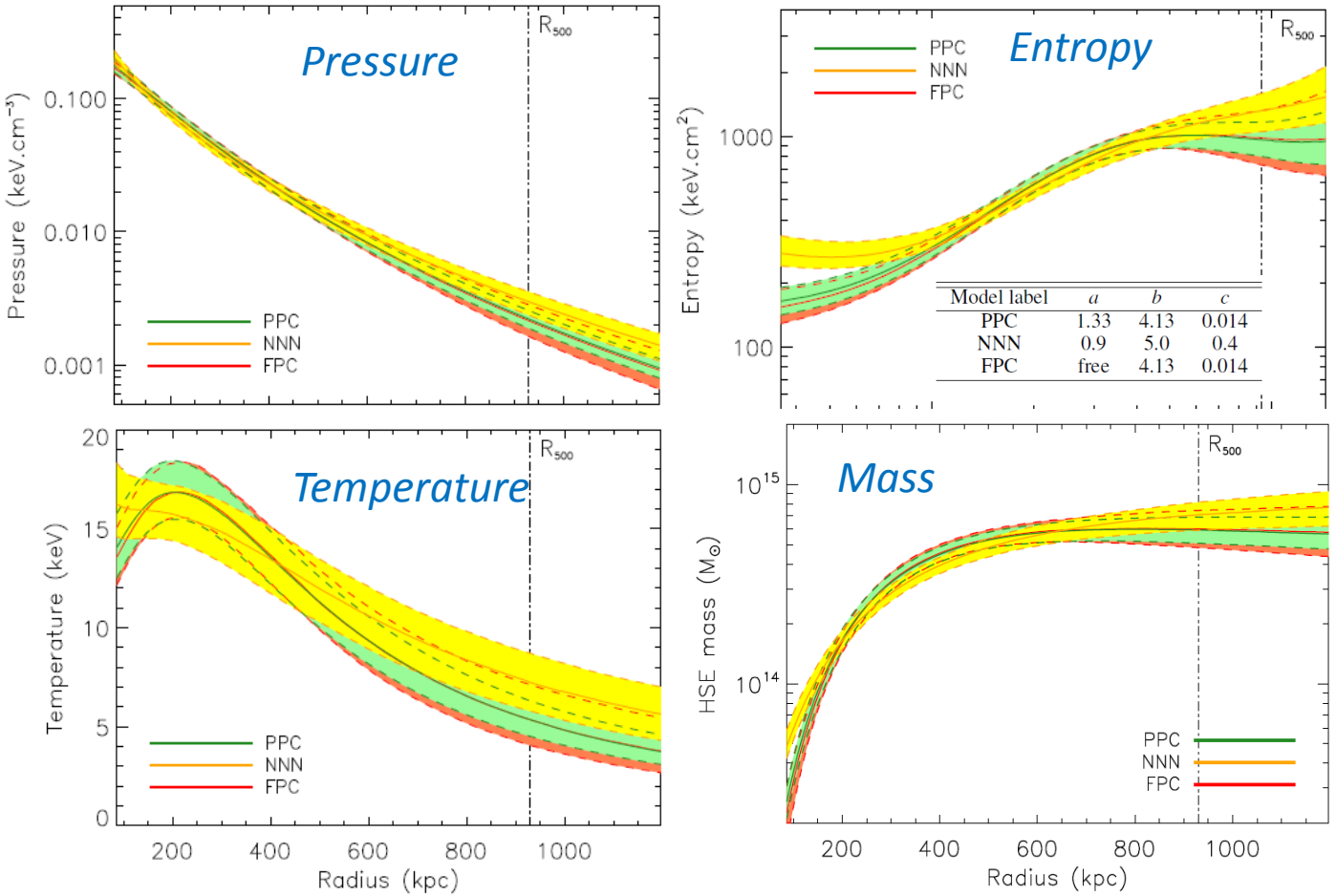
→ CLJ1227 is relaxed on large scales but with a disturbed core

High-z cluster: CL J1227 (z=0.89)

Combined analysis: Planck+NIKA+Chandra

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

Feb. 2014
Obs. time: 7.8 h
R. Adam *et al.*, A&A 2015



Summary of CLJ1227 main properties

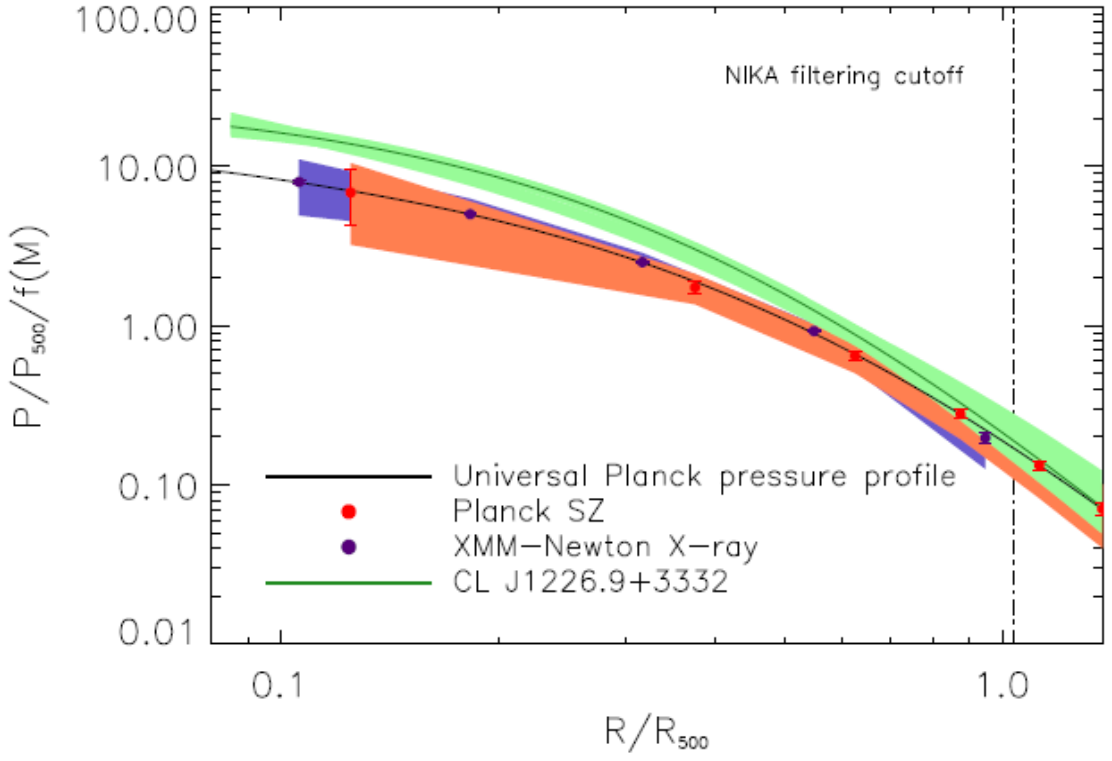
PPC pressure profile	
M_{500}	$5.96^{+1.02}_{-0.79} \times 10^{14}\ M_\odot$
R_{500}	930^{+50}_{-43} kpc
θ_{500}	$1.93^{+0.10}_{-0.09}$ arcmin
$f_{gas}(R_{500})$	$0.146^{+0.041}_{-0.030}$
Y_{500}	$0.598^{+0.063}_{-0.060} \times 10^{-3}$ arcmin^2

code code: slope parameters of the gNFW model

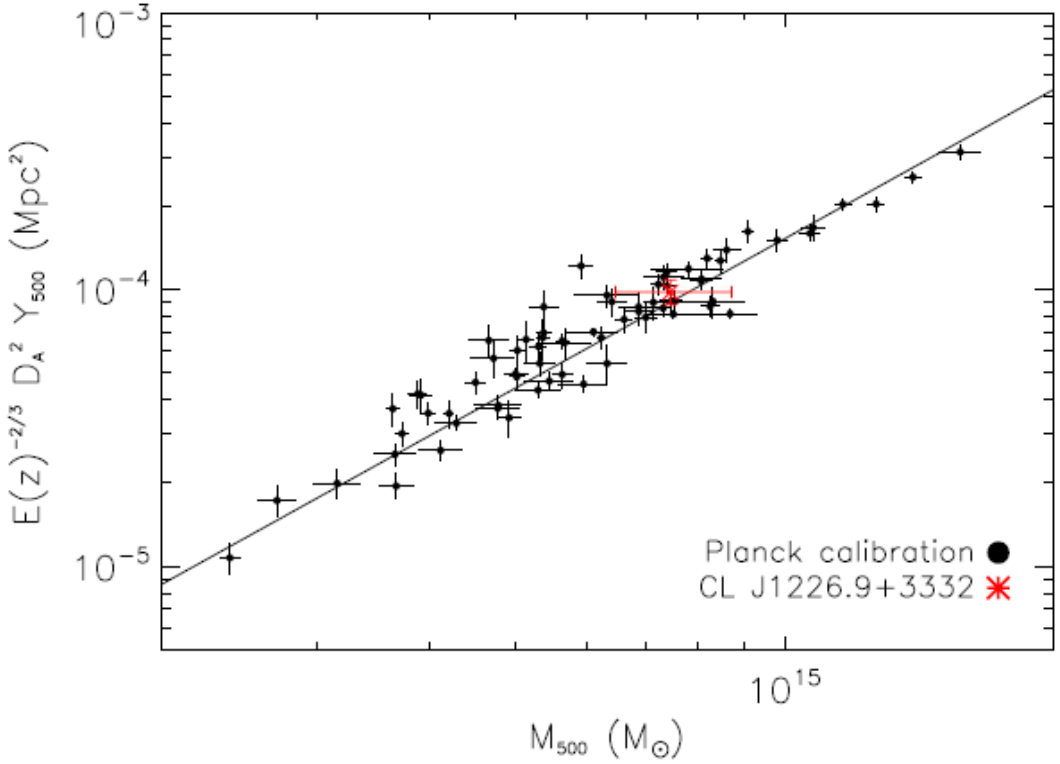
High-z cluster: CL J1227 (z=0.89)

Comparison with the characteristics of low-redshift clusters

Pressure Profile



Mass/SZ flux scaling law

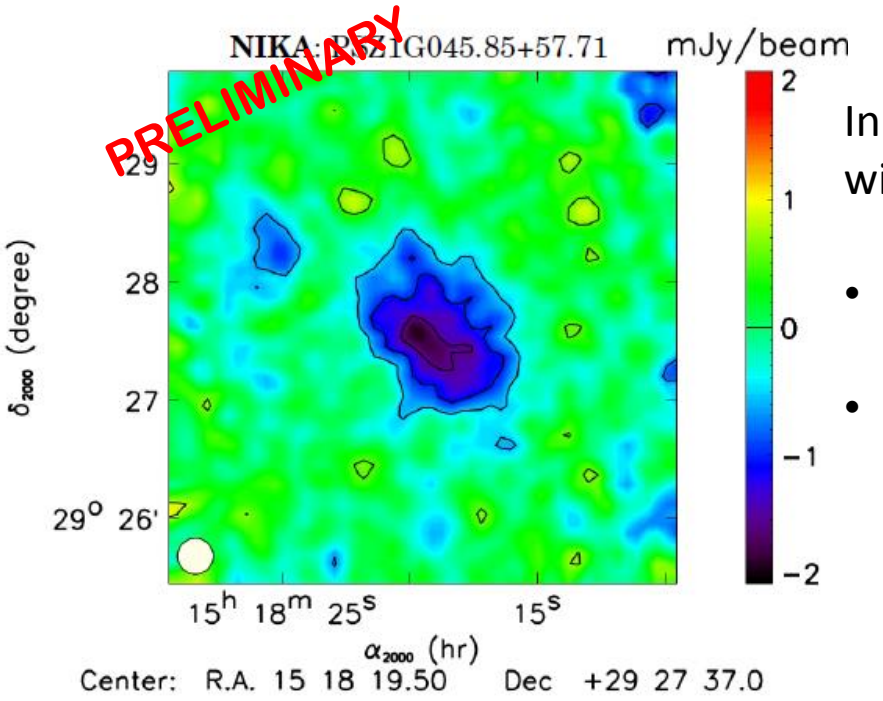


→No conclusion can be drawn with a single high-redshift cluster

→ 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

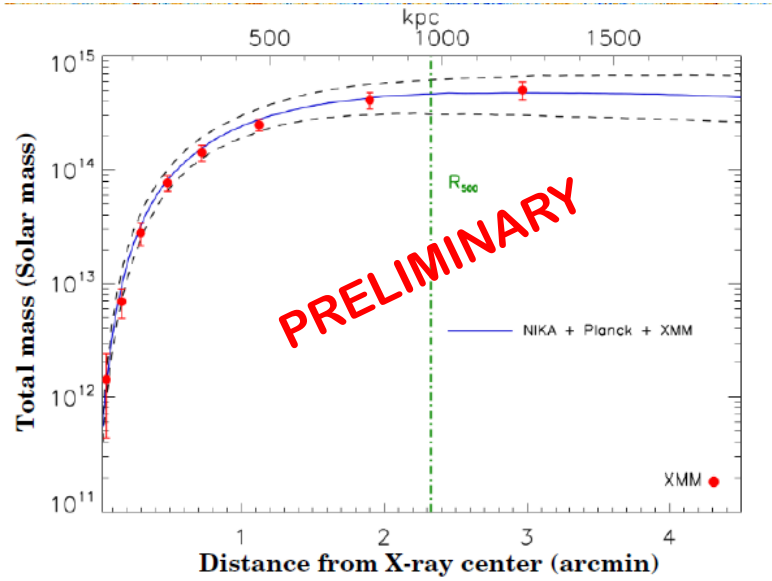
Nov. 2014
Obs. time: 5.5 h
to be published

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

$$R_{500} = (956 \pm 62)\ \mathrm{kpc}$$

$$M_{HSE,500} = 4,61^{+0,96}_{-0,84} \times 10^{14}\ \mathrm{M}_{\odot}$$

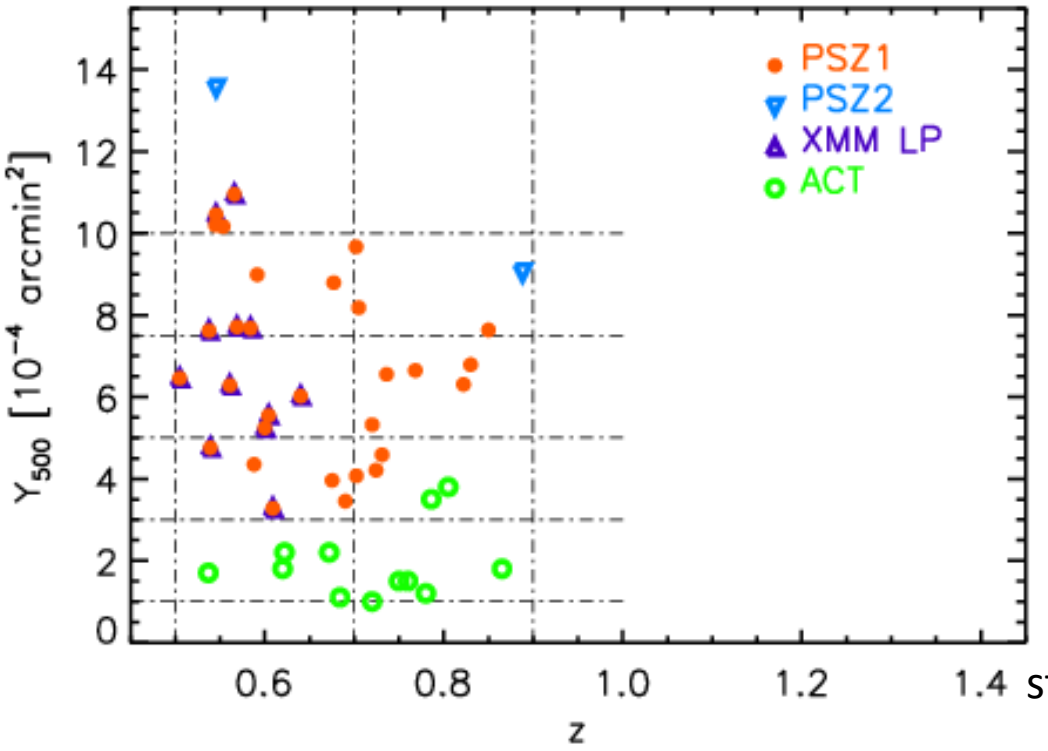
$$Y_{tSZ}(R_{500}) = 5,15^{+0,80}_{-0,73} \times 10^{-4}\ \mathrm{arcmin}^2$$



→ a pilot study done with NIKA to prepare the NIKA2 SZ program

The NIKA2 SZ large program (2016-2021)

NIKA2 cluster sample



- one of the Large Programs of the NIKA2 Guaranteed time
  → 300 hours of observations
  → 50 clusters up to z=1 from P*lanck & 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:

study of
- → 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**

A. Abergel, R. Adam, A. Adane, A. D'Addabbo, P. Ade, N. Aghanim, P. André, J. Angot, M. Arnaud, J. Aumont, H. Aussel, A. Bacmann, E. Barria, A. Beelen, B. Belier, A. Benoît, J-P. Bernard, M. Bethermin, A. Bideaud, N. Billot, F. Boulanger, O. Bourrion, A. Bracco, G. Bres, V. Buat, D. Burgarella, M. Calvo, E. Castillo, A. Catalano, C. Ceccarelli, G. Coiffard, B. Comis, A. Coulais, M. Cousin, E. Daddi, G. Dargaud, J. Davies, K. Demyk, F-X. Désert, H. Dole, G. Donnier-Valentin, M. Douspis, S. Doyle, P-A. Duc, S. Eales, D. Elbaz, O. Exshaw, F. Galliano, G. Garde, C. Geraci, J. Goupy, M. Grollier, F. Gueth, I. Hermelo, P. Hily-Blant, M. Hoaurau, A. Hugues, V. Konyves, C. Kramer, G. Lagache, V. Lebouteiller, S. Leclercq, J-P. Leggeri, J-F. Lestrade, F. Levy-Bertrand, J-F. Macias-Perez, S. Madden, J. Martino, A. Maury, P. Mauskopf, F. Mayet, J-B. Melin, J. Menu, A. Miniussi, A. Monfardini, L. Montier, F. Motte, S. Navarro, A. Omont, F. Pajot, D. Paradis, B. Parise, E. Pascale, A. Pelissier, N. Peretto, L. Perotto, M. de Petris, J. Pety, E. Pointecouteau, N. Ponthieu, G. Pratt, V. Revéret, I. Ristorcelli, A. Ritacco, L. Rodriguez, S. Roni, S. Roudier, H. Roussel, F. Ruppin, G. Savini, K. Schuster, J-P. Scordilis, A. Sievers, J. Soler, D. Tourres, S. Triqueneaux, C. Tucker, C. Vescovi, R. Zylka