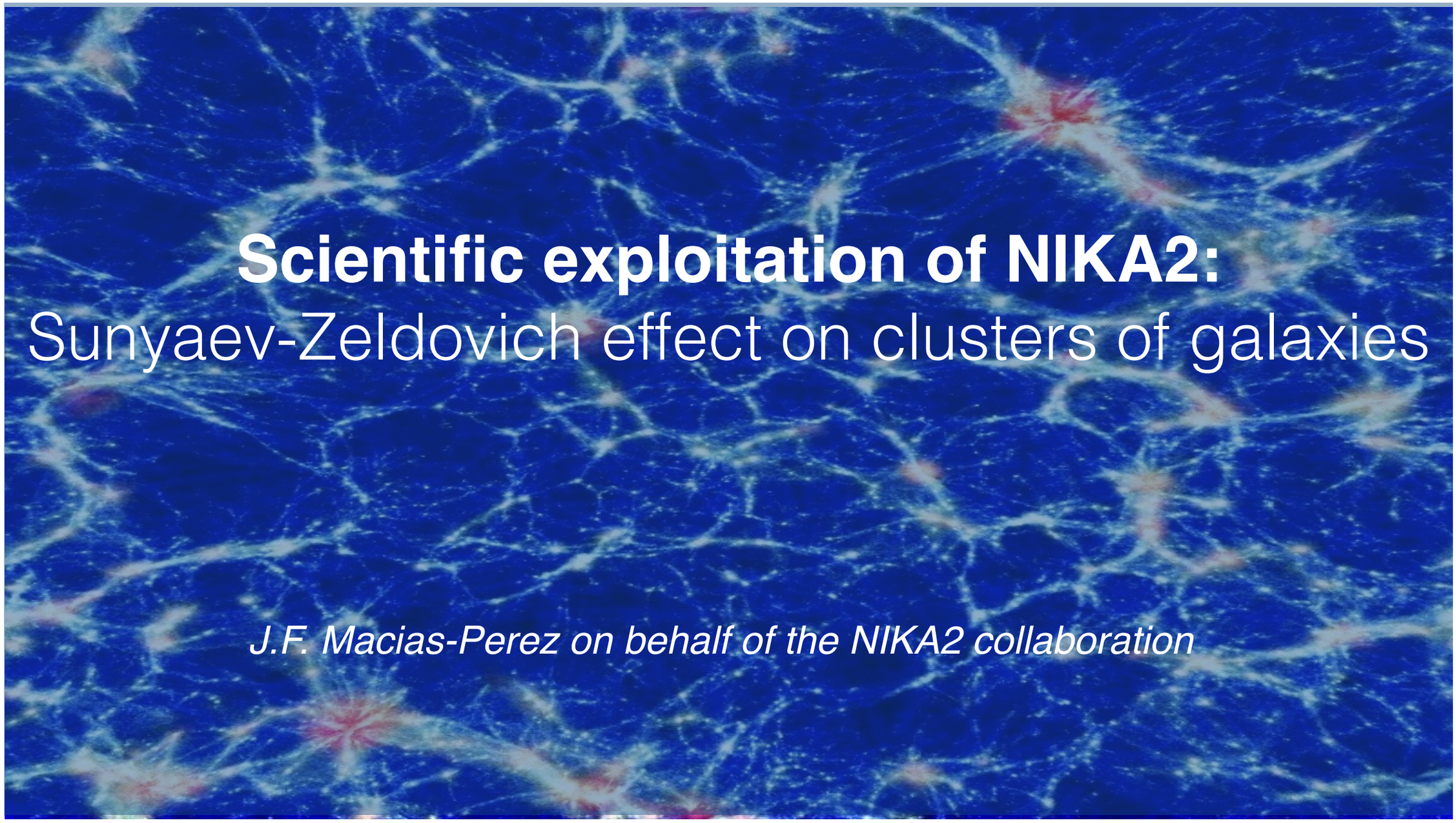


Scientific exploitation of NIKA2:
Sunyaev-Zeldovich effect on clusters of galaxies

J.F. Macias-Perez on behalf of the NIKA2 collaboration

NIKA2 scientific objectifs

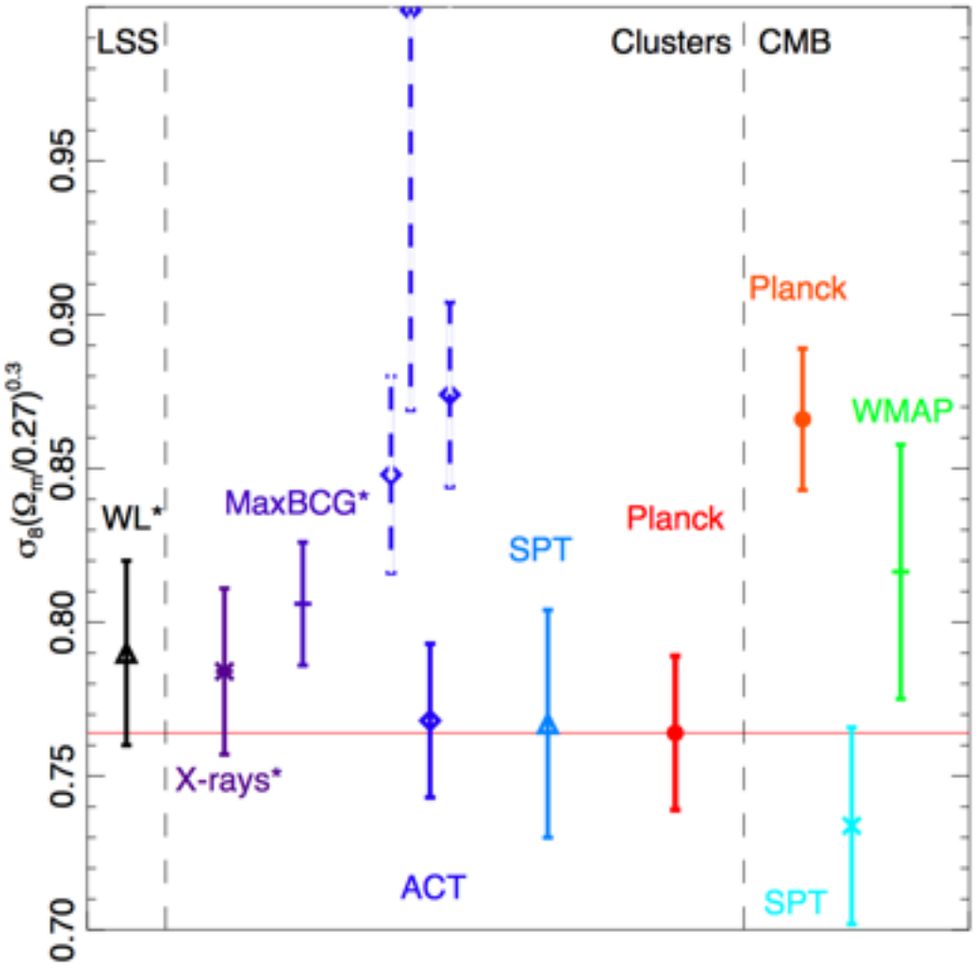
- **Resident multipurpose** instrument at the IRAM 30 m telescope

+

- **NIKA2 Large programs**:
  - ***thermal Sunyaev-Zeldovich (SZ)*** effect on high redshift clusters
  - deep cosmological survey
  - early stage of star formation in the galaxy
  - study of nearby galaxies
  - polarisation

Cosmology with clusters and SZ

clusters and their SZ signal are becoming increasingly used to derive cosmological constraints



Planck 2013 results. XX, XXI (2013)

based on the assumption that

- clusters are a self-similar population of objects
- the baryonic gas component is a good tracer of the DM distribution (hydrostatic equilibrium)

mass calibration uncertainty still limits recent cluster based cosmological results

systematic uncertainties in the Y-M relation must be controlled

Clusters self-similarity

clusters are a self-similar population of objects

but

non-negligible systematic/calibration uncertainties remain (limiting recent cluster based cosmological results)

$Y - M_{tot}$

$P(r)$

bias
scatter
evolution

vs

dynamics
z

→ **more robust calibration of the mass/observable scaling**
→ **robust z-evolution**

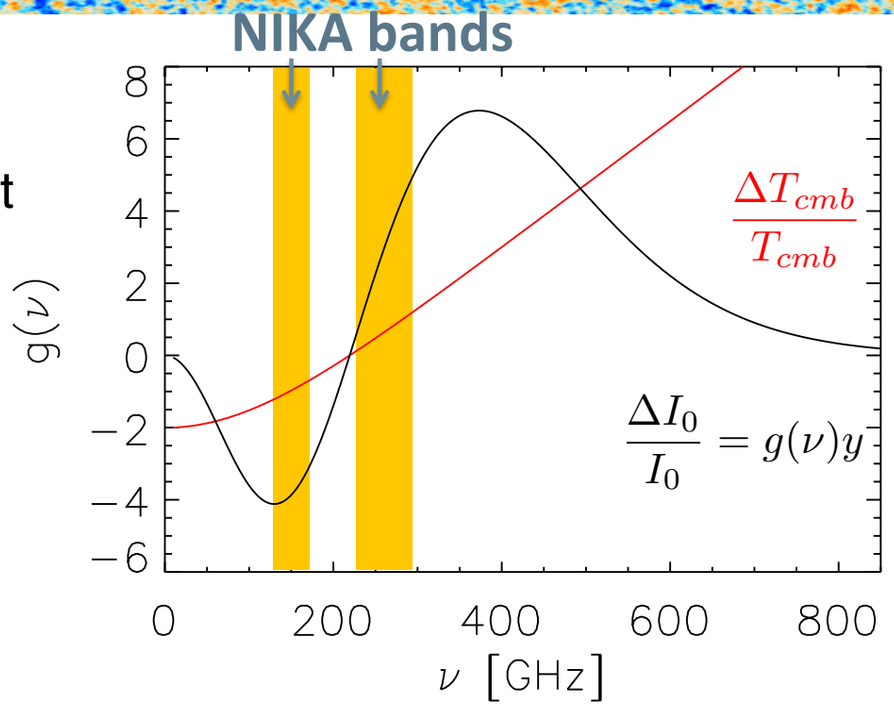
High angular resolution tSZ observations and follow-ups are now necessary to deeply explore the cluster internal structure and to better address the physics at play, especially when dealing with intermediate and high z objects.

NIKA2 for SZ

NIKA2 is well adapted for these observations

- large number (thousands) of high sensitive detectors at two frequency bands (150 and 260 GHz)
- large field of view (6.5 arcmin, $\lesssim r_{500}$ at z > 0.5)
- the 30 m resolution (20 and 12 arcsec for the NIKA2 frequencies)

→ **resolution and quality comparable with X-ray (XMM)**



300h GT LP dedicated to SZ → to observe a large sample (50) of clusters of galaxies with redshift > 0.5

→ **P(r) vs z & morphology**

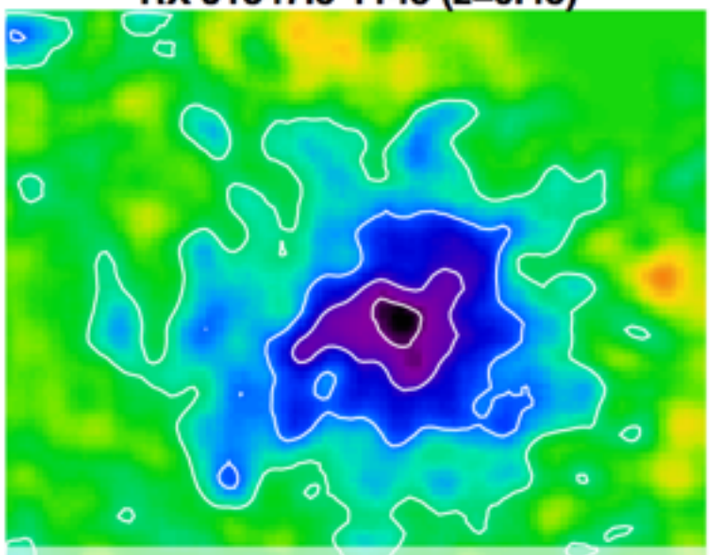
→ **T(r) & K(r) vs z & morphology**

→ **Y - M_{tot} vs z & morphology**

} NIKA2 + ancillary data (including X-rays, optical and radio observations)

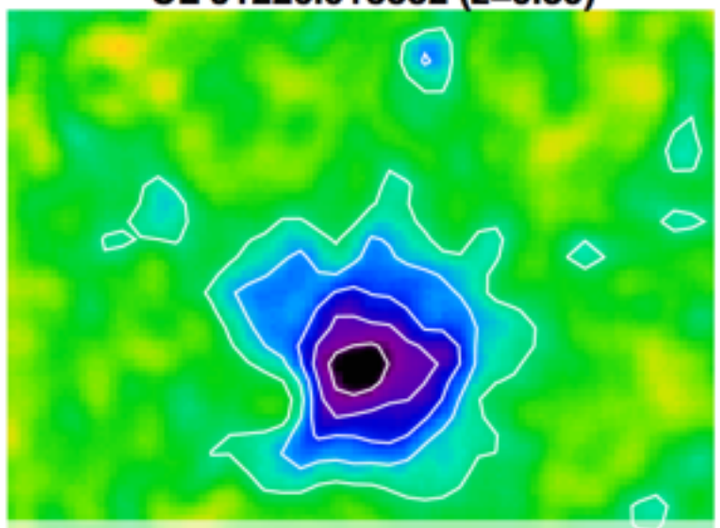
NIKA2 tSZ pilot study

RX J1347.5-1145 (z=0.45)



☑ First SZ obs. with KIDs
[R. Adam et al. (2014)]

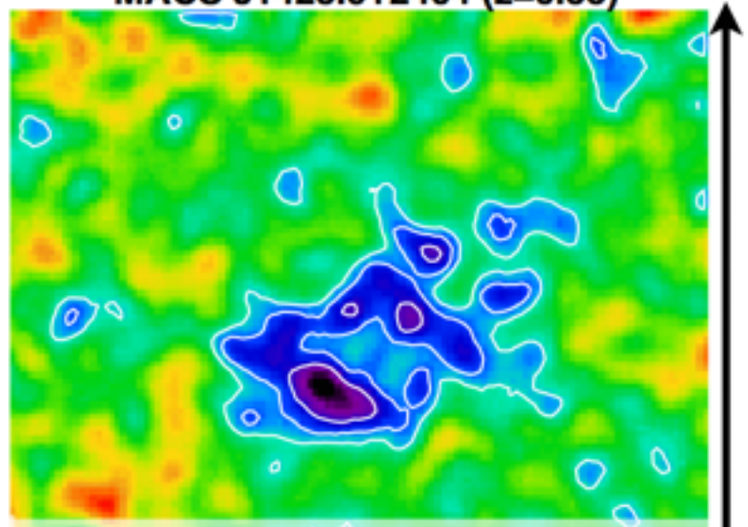
CL J1226.9+3332 (z=0.89)



☑ Pressure profile at high z
[R. Adam et al. (2015)]

☑ tSZ/X-ray radial thermodynamics+matter reconstruction

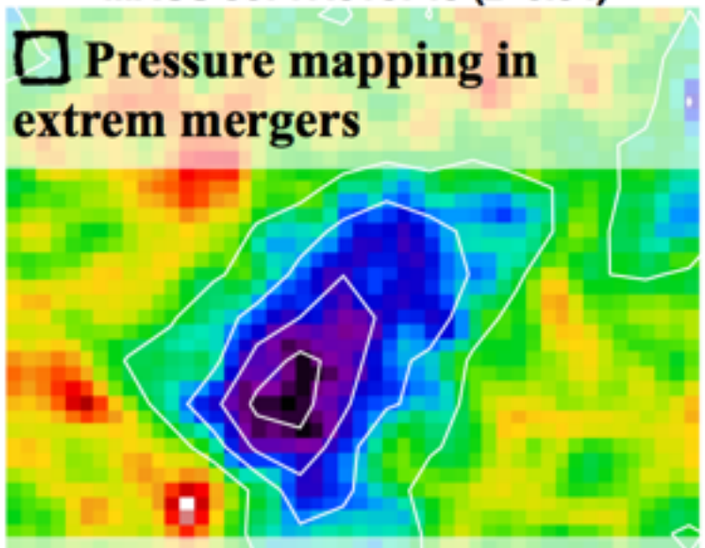
MACS J1423.9+2404 (z=0.55)



☑ Radio/IR contamination
[R. Adam et al. (submitted)]

4'x4'

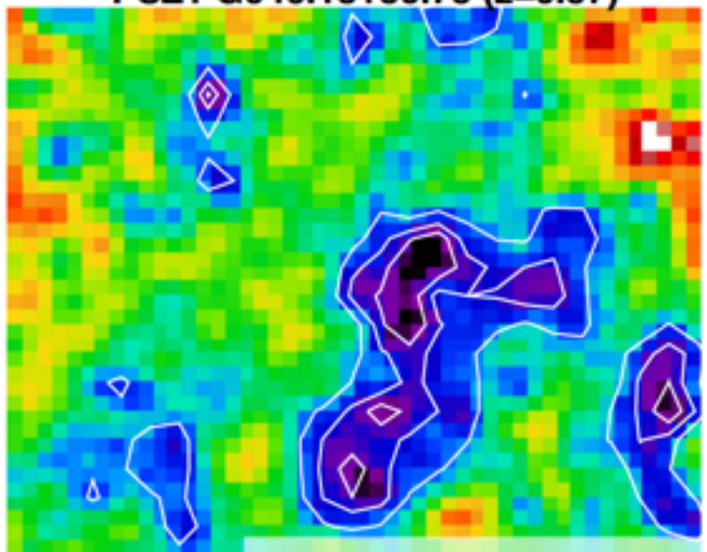
MACS J0717.5+3745 (z=0.54)



☐ Pressure mapping in extrem mergers

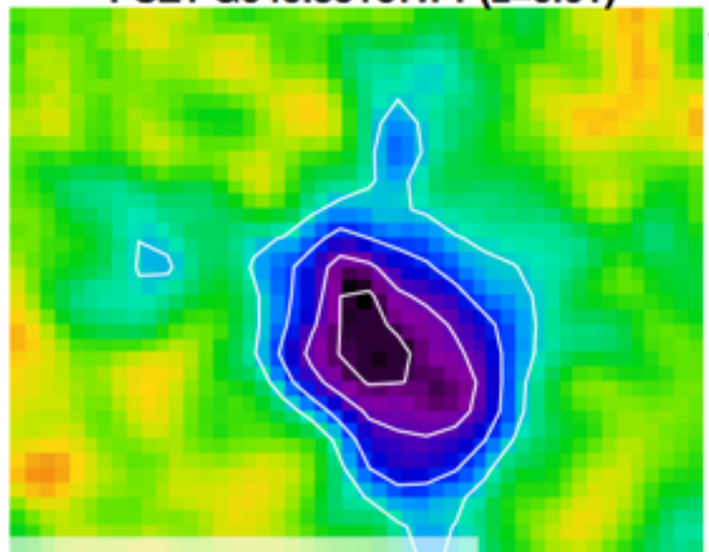
☐ Gas velocity mapping from kinetic SZ?

PSZ1 G046.13+30.75 (z=0.57)



☐ Planck follow-ups: joint tSZ/X-ray thermodynamics mapping

PSZ1 G045.85+57.71 (z=0.61)

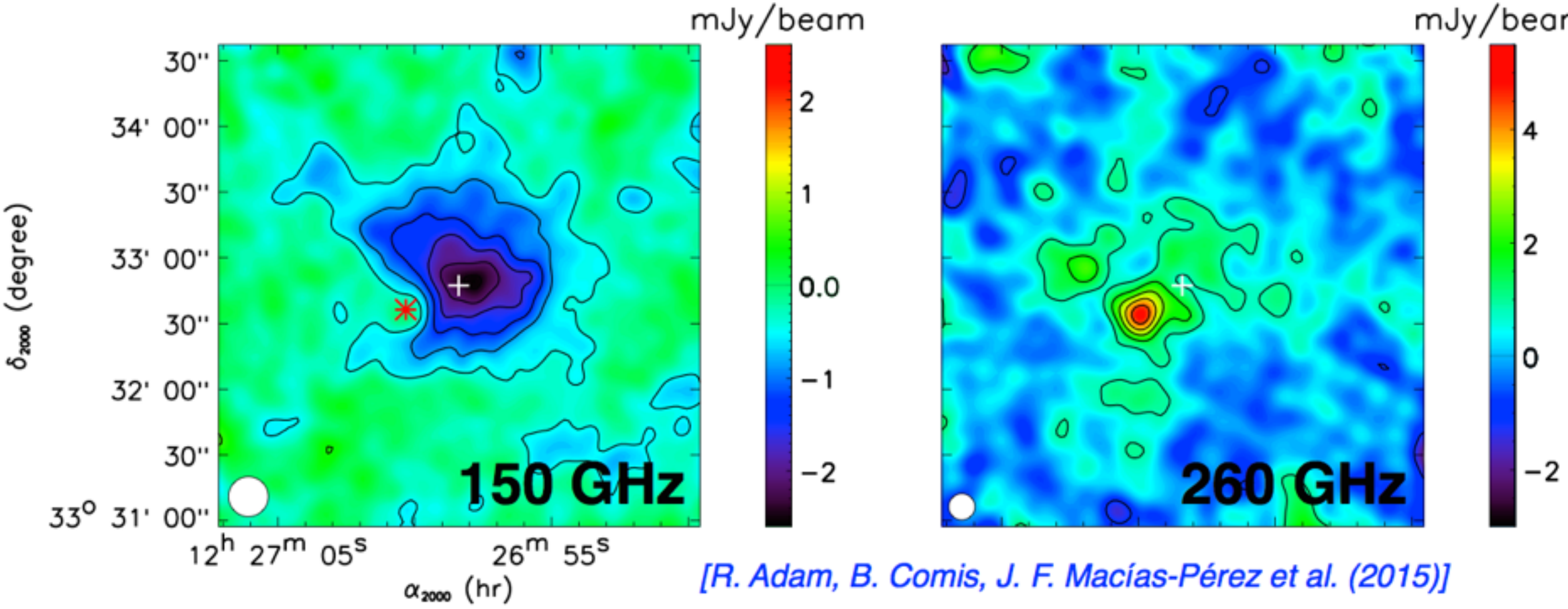


4'x4'

➡ **NIKA2 pilot studies: construction and exploitation of a unique cluster sample**

High redshift cluster: CL1226.9+3332 (z=0.89)

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



[R. Adam, B. Comis, J. F. Macías-Pérez et al. (2015)]

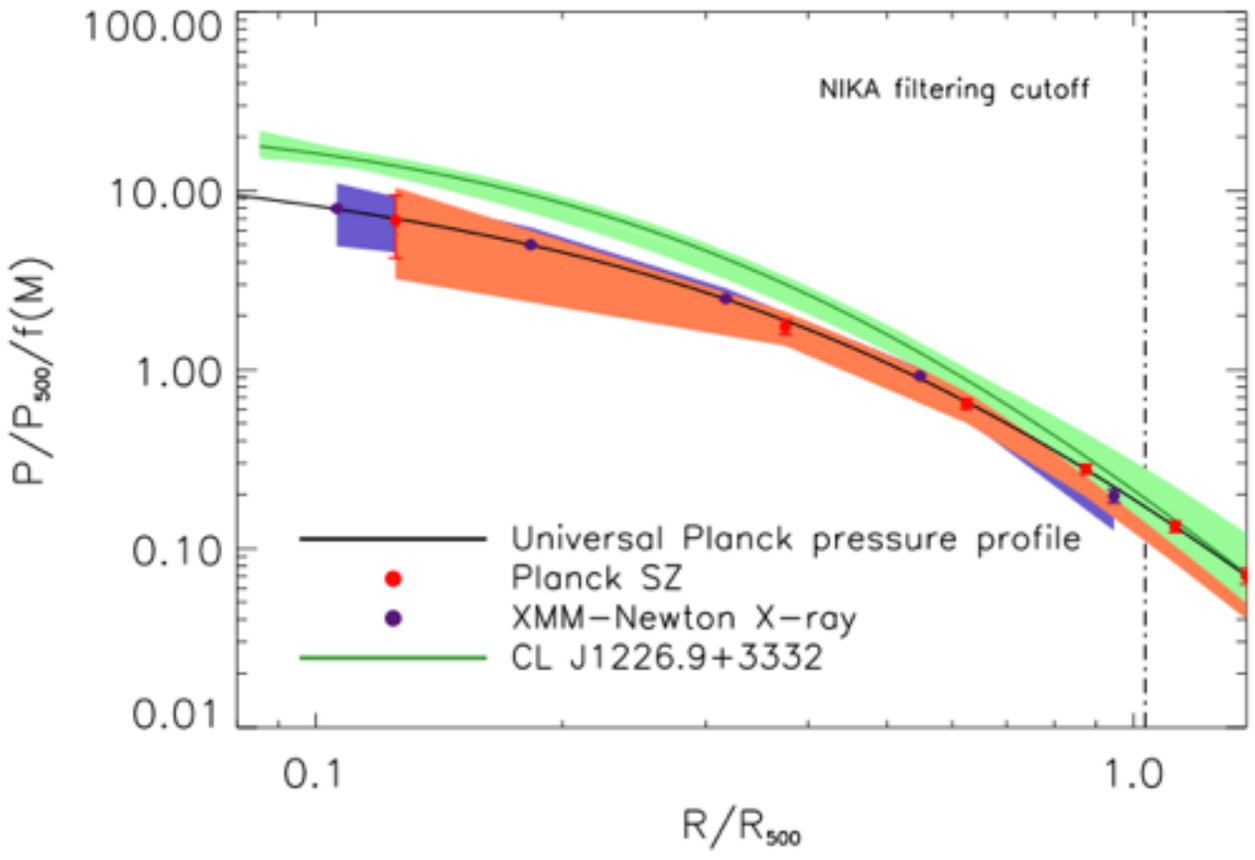
- **Sub-mm point source** identification using the 260 GHz band
- SZ detection within the two bands with tSZ expected flux ratio
- Single-band method: accurate signal **mapping at ~ 20" - 3'** (0.1 - 1 R_{500} at z ~ 0.9)

➡ **Dual-band SZ resolved mapping at high redshift**

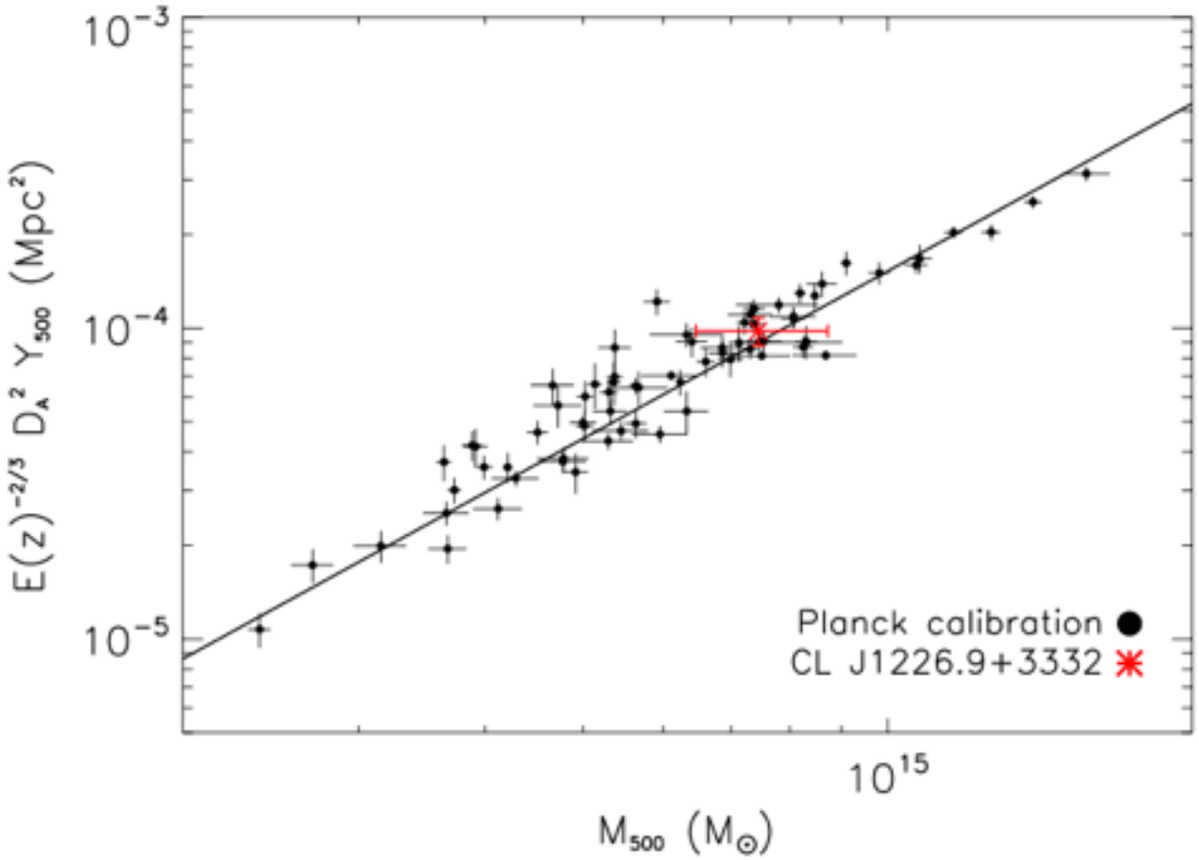
Radial distribution and mass

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

1. In term of pressure profile



2. Or Mass/tSZ flux calibration

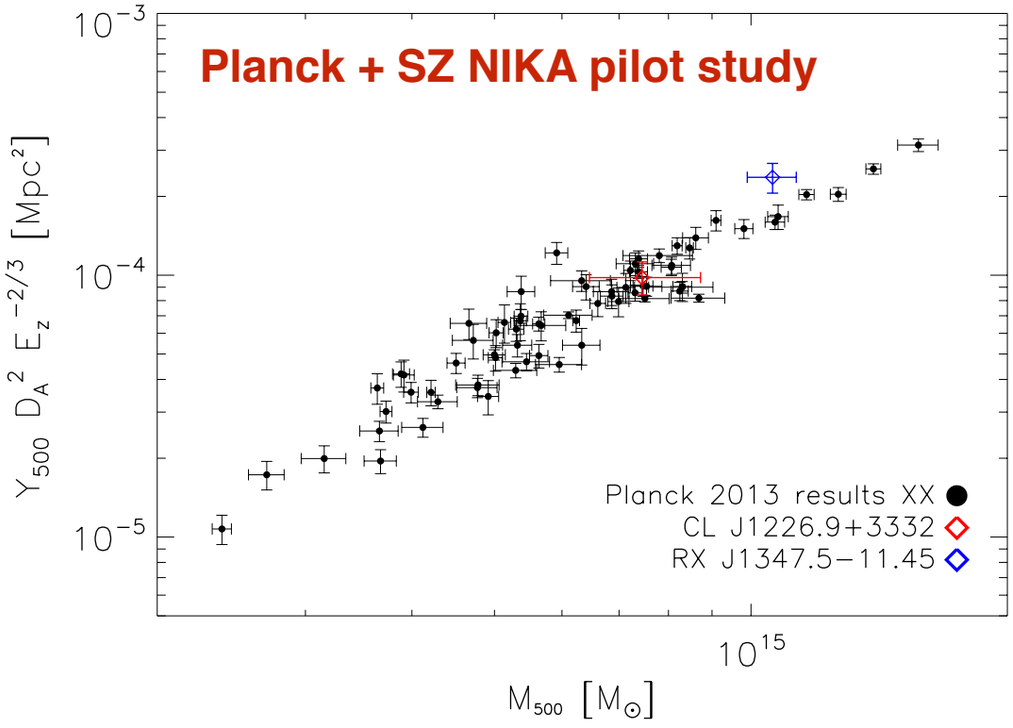


➡ **With more high-z clusters, NIKA(2) can constrain redshift evolution**

Conclusions

What are the questions related to sub-arcmin resolution with SZ?

- cluster derived cosmological constraints are limited by our understanding of the impact of the details of cluster astrophysics
- NIKA2 is well adapted to explore the cluster population at intermediate and high redshift, at r_{500} (self-similar scales), at $r > r_{500}$ (non-eq. regions)
- this kind of study is mandatory to achieve cluster derived precision cosmology



NIKA2: 2h - 10h per cluster

Statistically significant, representative **NIKA2 sample of ≈ 50 clusters @ z > 0.5**

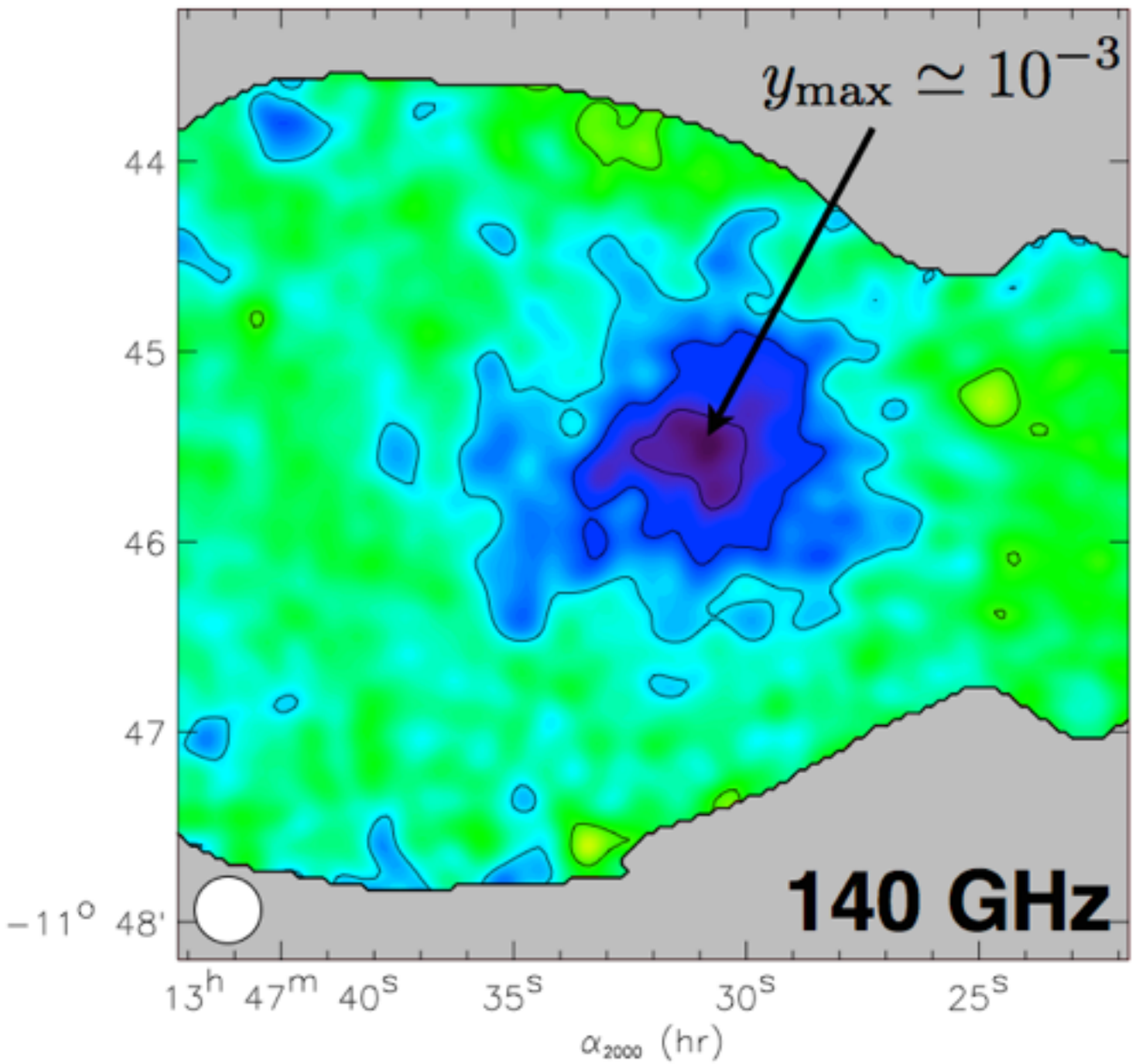
- study of the calibration of the **SZ flux as a mass proxy, its evolution with redshift and cluster dynamics**
- **redshift evolution** of the universal cluster pressure profiles, as well as deviations from its mean behavior due to cluster complex astrophysics and thermodynamical history

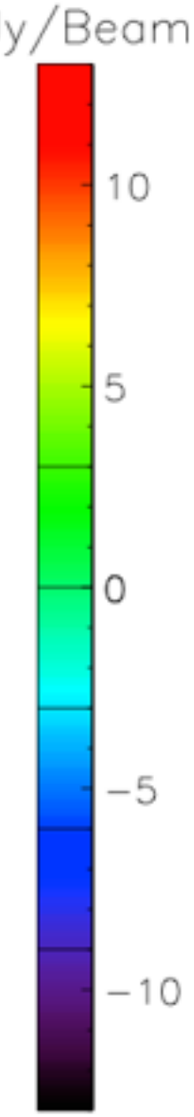
http://ipag.osug.fr/nika2

R. Adam, A. Adane, P. Ade, P. André, A. Beelen, B. Belier, A. Benoît, A. Bideaud, N. Billot, N. Boudou, O. Bourrion, M. Calvo, A. Catalano, G. Coiffard, B. Comis, A. D'Addabbo, F.-X. Désert, S. Doyle, J. Goupy, C. Kramer, S. Leclercq, J. F. Macias-Perez, J. Martino, P. Mauskopf, F. Mayet, A. Monfardini, F. Pajot, E. Pascale, L. Perotto, E. Pointecouteau, N. Ponthieu, V. Revéret, L. Rodriguez, F. Ruppin, G. Savini, K. Schuster, A. Sievers, C. Tucker, R. Zylka

also financed by

First NIKA tSZ detection





- 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

➡ **The first tSZ observation with KIDs, using the *NIKA* prototype**

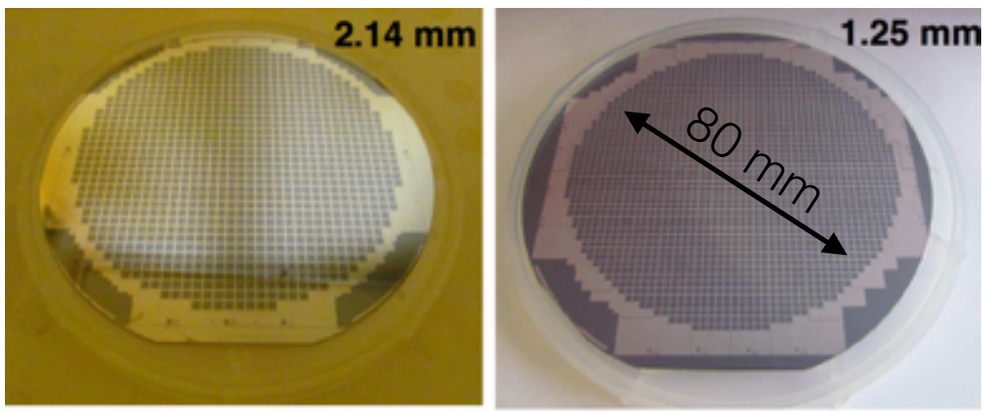
[R. Adam, B. Comis, J. F. Macías-Pérez et al. (2014)]

NIKA2

dual-band imaging capabilities (150 GHz and 260 GHz), it will be able to measure the linear polarization of the targeted sources at 260 GHz

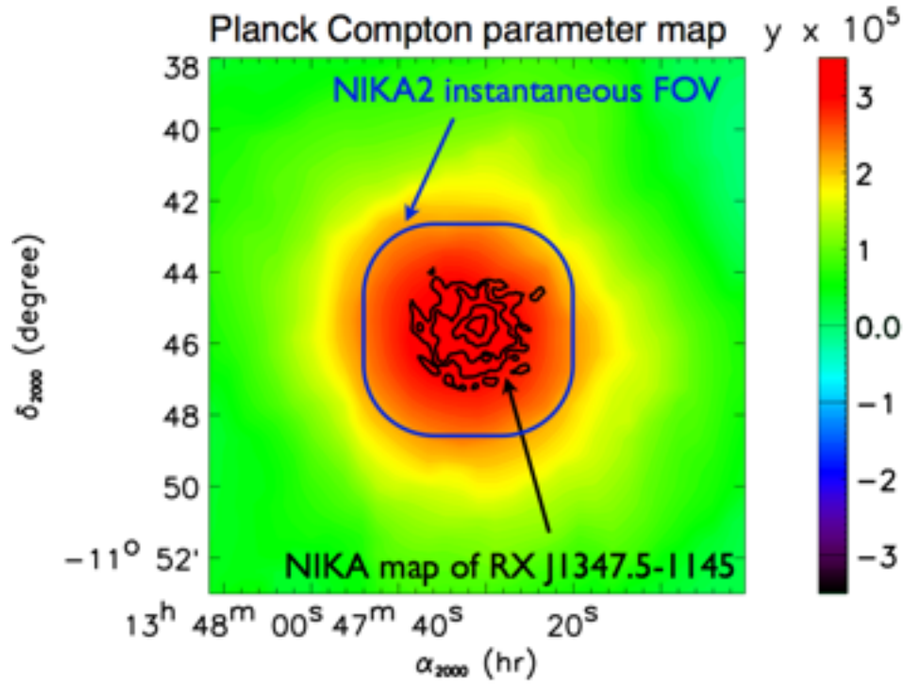
NIKA	260 GHz	150 GHz
beam (FWHM)	12.5”	18.5”
# of det	224	132
fov eff. diameter	1.8’	2.0’
sensitivity	35 mJy*s$^{1/2}$	14 mJy*s$^{1/2}$

NIKA2	260 GHz	150 GHz
beam (FWHM)	12” (10’’)	18” (16’’)
# of det	2x2000	1000
fov eff. diameter	6.5’	6.5’
sensitivity	30 mJy*s$^{1/2}$ (15 mJy*s$^{1/2}$)	20 mJy*s$^{1/2}$ (10 mJy*s$^{1/2}$)



1020 KIDs array for 2mm band

1932 KIDs array for 1.2mm band



External data

Great added value using external data:

- X-rays:
  direct measurement of the electron density
  spectroscopy temperature

- Galaxy velocities, weak and strong lensing:
  distribution of dark matter

- Radio data:
  radio relics and emission on shocks

* Complete characterisation of radial properties of clusters: pressure, density, temperature, entropy
* Multiple scaling relations for cosmology

NIKA2: SZ large program

NIKA2 will start observing in 2016

300 h GT SZ Large Program

J.F. Macías-Pérez (LPSC), R. Adam (LPSC), N. Aghanim (IAS), M. Arnaud (CEA), B. Comis (LPSC), F.X. Desert (IPAG), M. Douspis (IAS), F. Mayet (LPSC), J.B. Melin (CEA), E. Pointecouteau (IRAP), G. Pratt (CEA), J. A. Rubiño-Martín (IAC, Tenerife)

Main goal: **high angular resolution SZ follow-up of clusters of galaxies, at intermediate and high redshift**

We intend to observe a large (~50), representative sample of clusters of galaxies with redshift > 0.5 to study the properties of the cluster population

NIKA2 Workshop, Oct. 2013

SZ tools

SURVEY

Planck:
full sky (satellite)
30’ – 5’ (7’-10’ for SZ)@
30- 857 GHz = 9 channels

SPT:
720 deg^2 + 2500 deg^2
95, 150, 220 GHz (1.1’@150GHz)

ACT:
504 deg^2 + 455 deg^2
148, 218, 277 GHz (1.4’@148GHz)

AMI: two interferometer arrays (10+8), a frequency range 13.5-18 GHz

Bolocam: 144 bolometers array the 10-m CSO, 140 or 268 GHz, it provides resolutions of 58’’ and 31’’, respectively, over an 8’ f.o.v. (BolocamII @LMT: 12’’ vs 2’ f.o.v.)

Mustang/GBT: 64 element bolometer array operating at 90 GHz on the 100-m GBT with a resolution of 8.5’’

CARMA: 23-element multi-frequency interferometer, at 31 GHz, 86 GHz and 90 GHz

AMiBA: 19-elements interferometer, at 90GHz

APEX-SZ: 12-m telescope, 280 TES bolometers, at 150 GHz, 1’, 22’ f.o.v.

NIKA: hudreds of KIDs arrays
at 140 and 240 GHz (**dual-band** observation)
12.5’’ and 18.5’’ (1’, 1.8’ f.o.v.)

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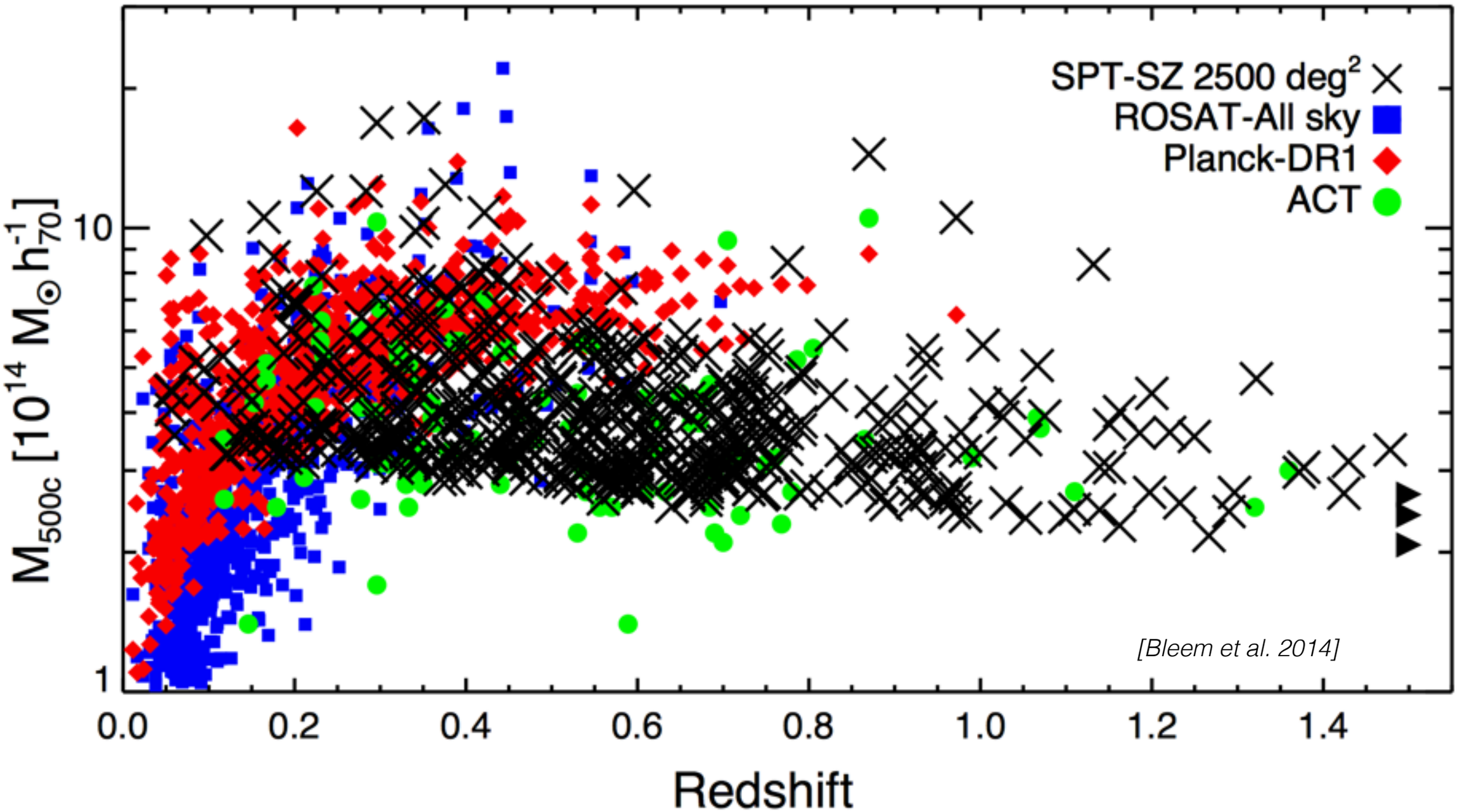
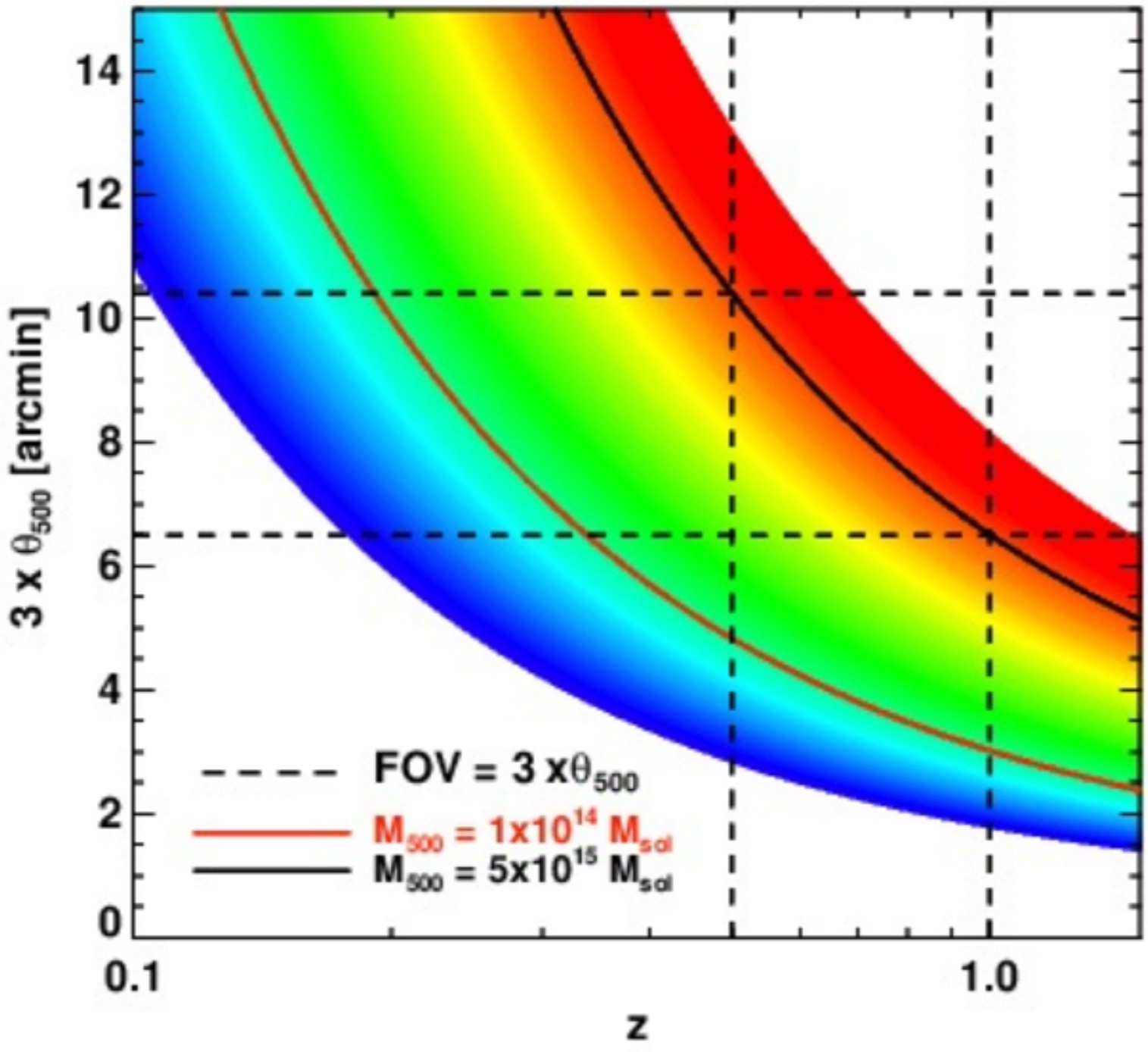
at 140 and 240 GHz (**dual-band** observation)
12’’ and 18’’ (6.5’ f.o.v.)

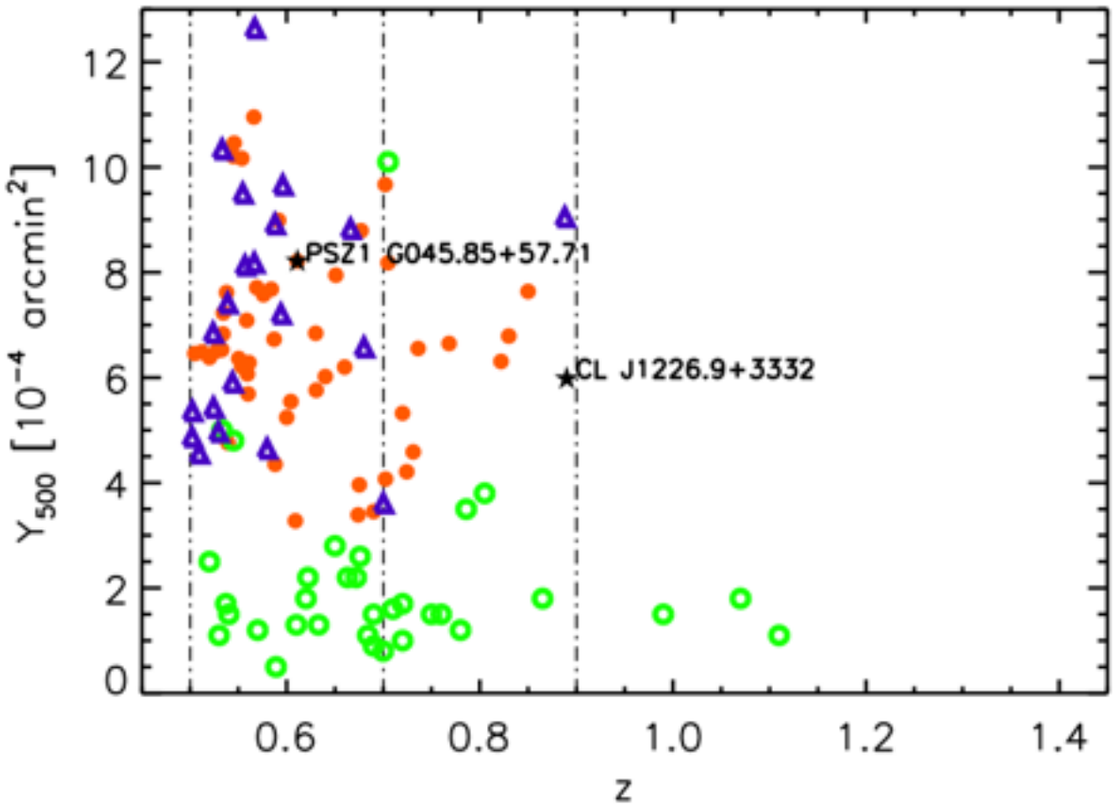
NIKA2 cluster sample

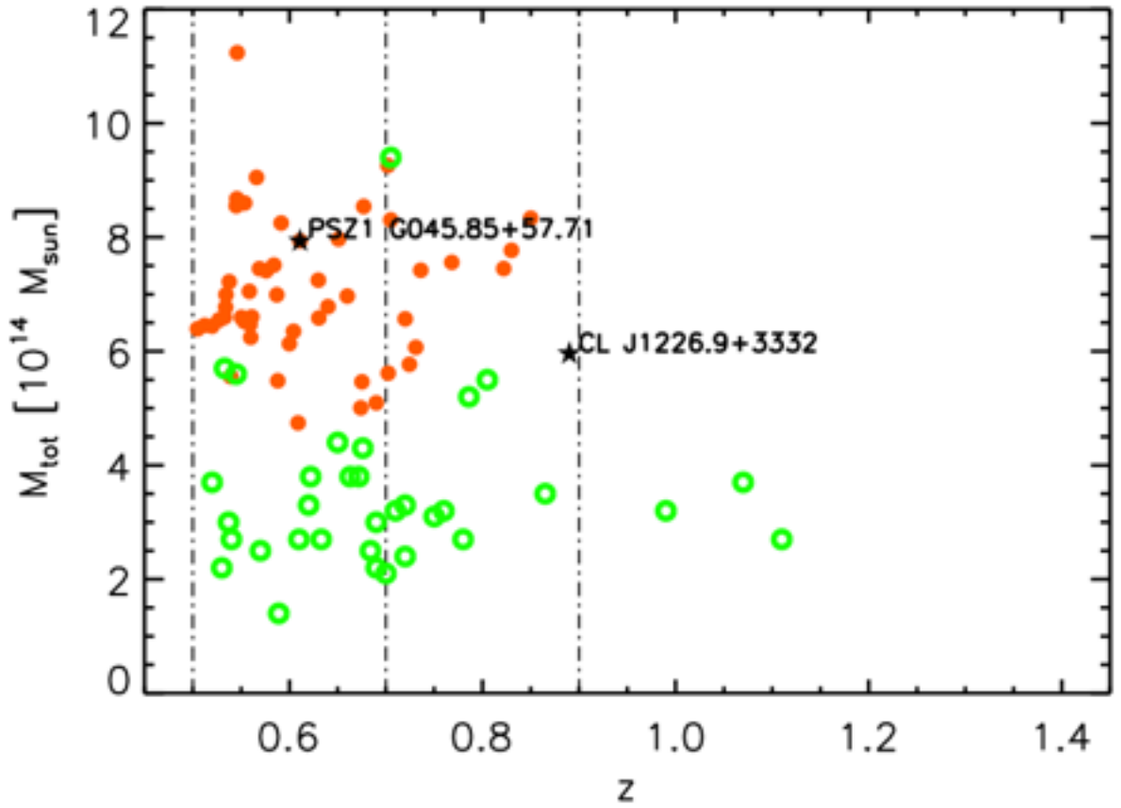


Expected size of the clusters



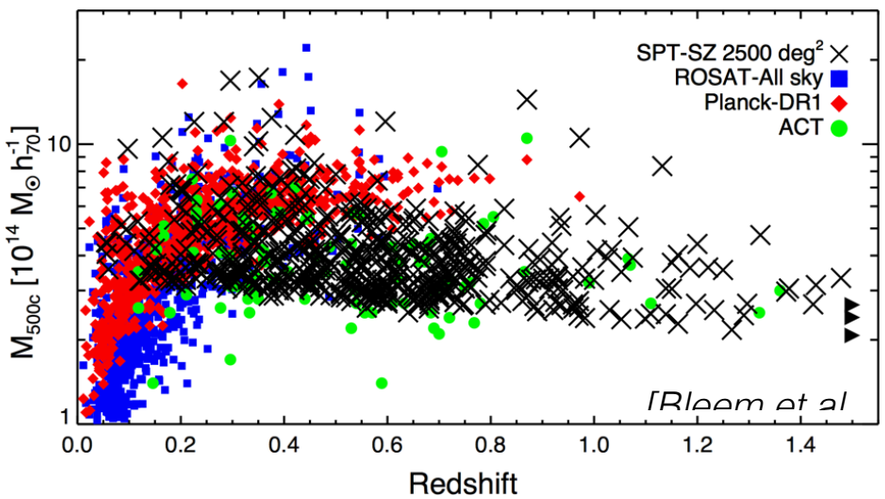
NIKA2 cluster sample





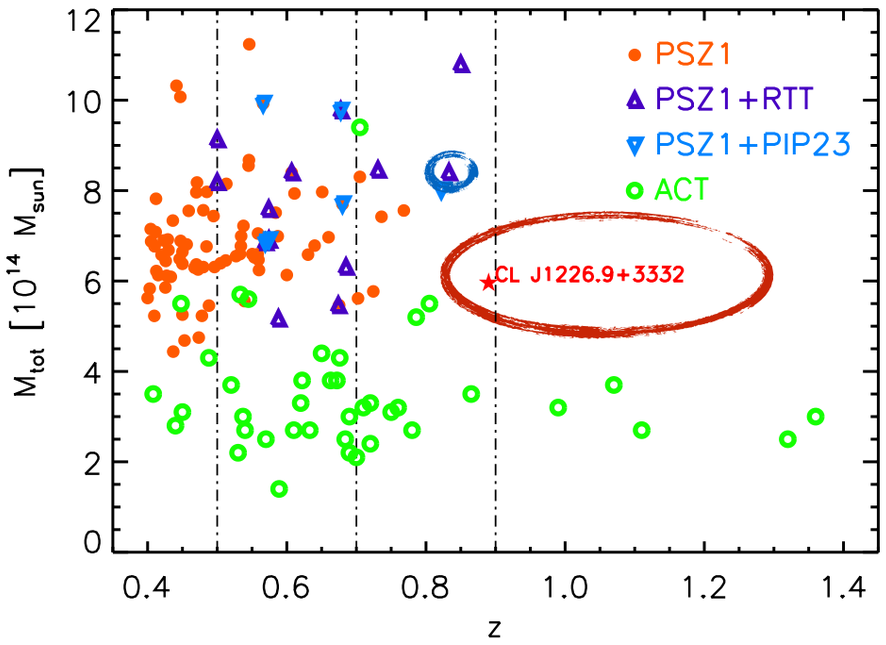
dec > -11

	0.5 ≤ z < 0.7	0.7 ≤ z < 0.9	0.9 ≤ z < 1.1	no z available
PSZ1	40	11	-	153
PSZ2	21	2	-	150
ACT	19	11	2	



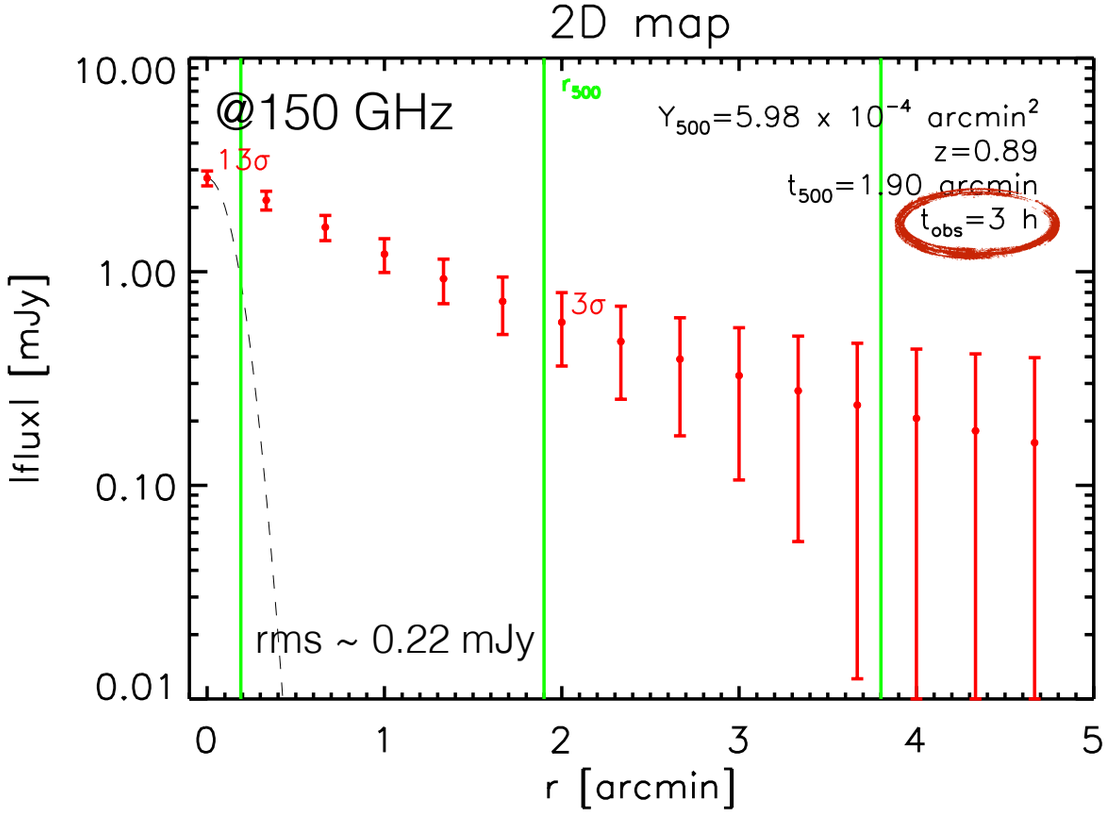
PSZ1, PSZ2 - *Planck 2013 results. XXIX, Planck intermediate results. XXVI, Planck intermediate results in preparation*
ACT - *Hasselfield et al. 2013*

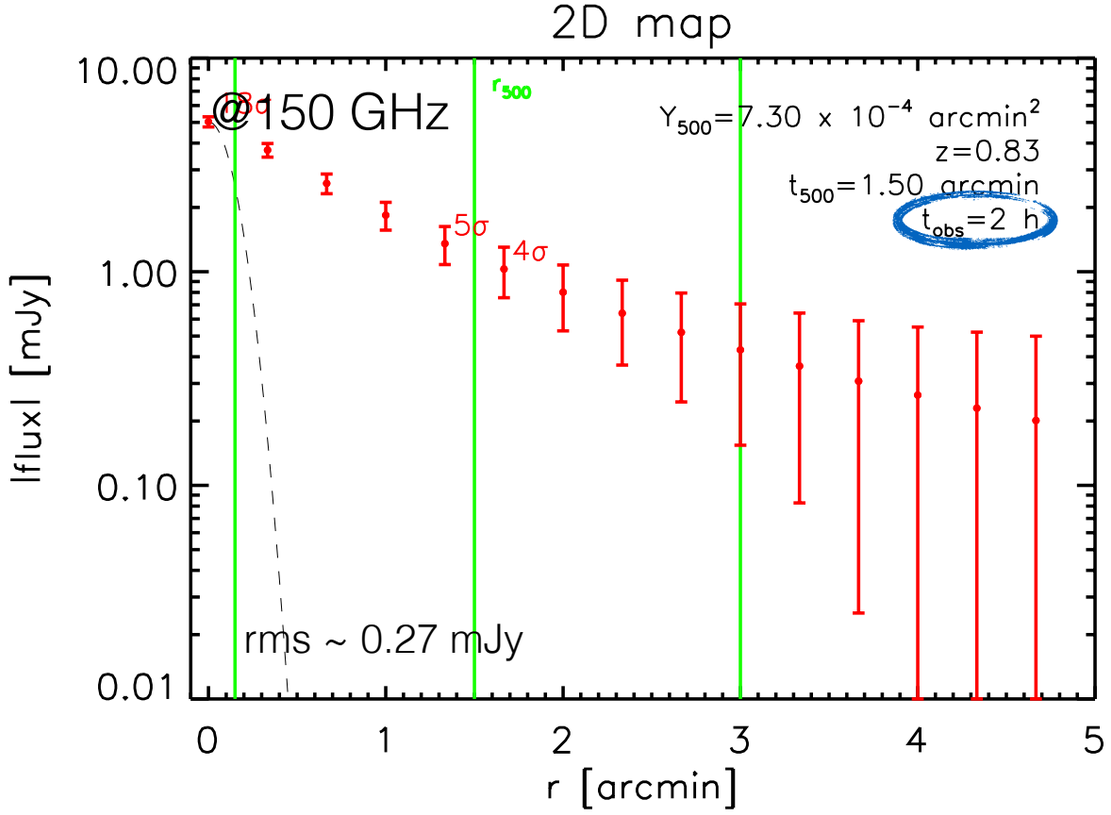
NIKA2 cluster sample



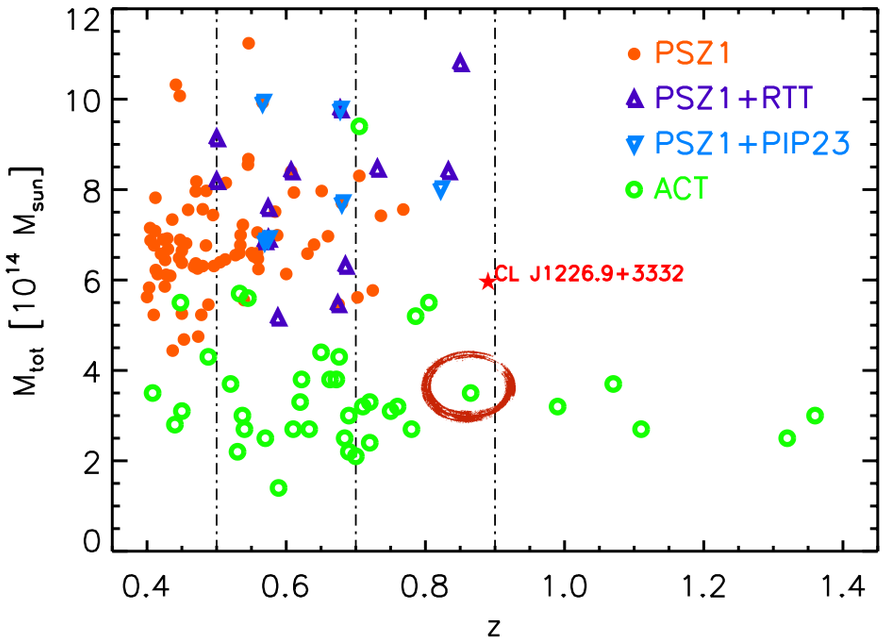
2D maps: 10' x 10' ~ $3r_{500}$

sensitivity ~ 18 mJy/s$^{1/2}$





NIKA2 cluster sample



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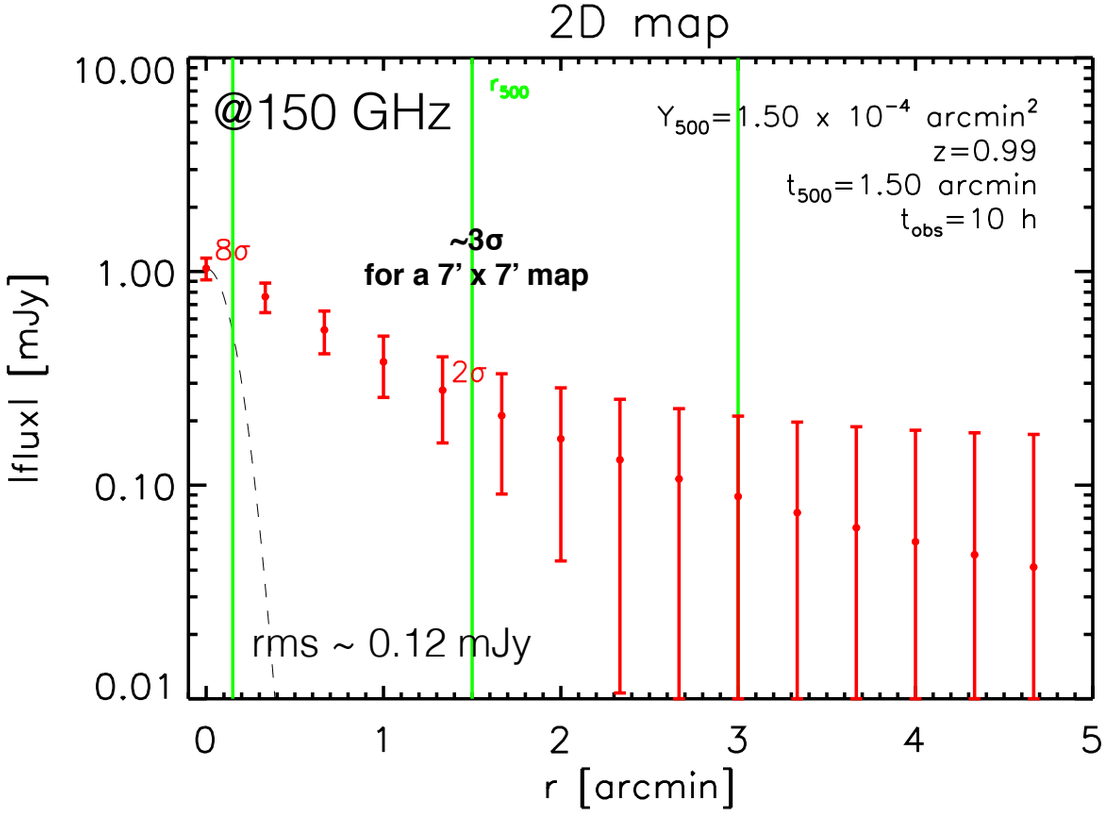
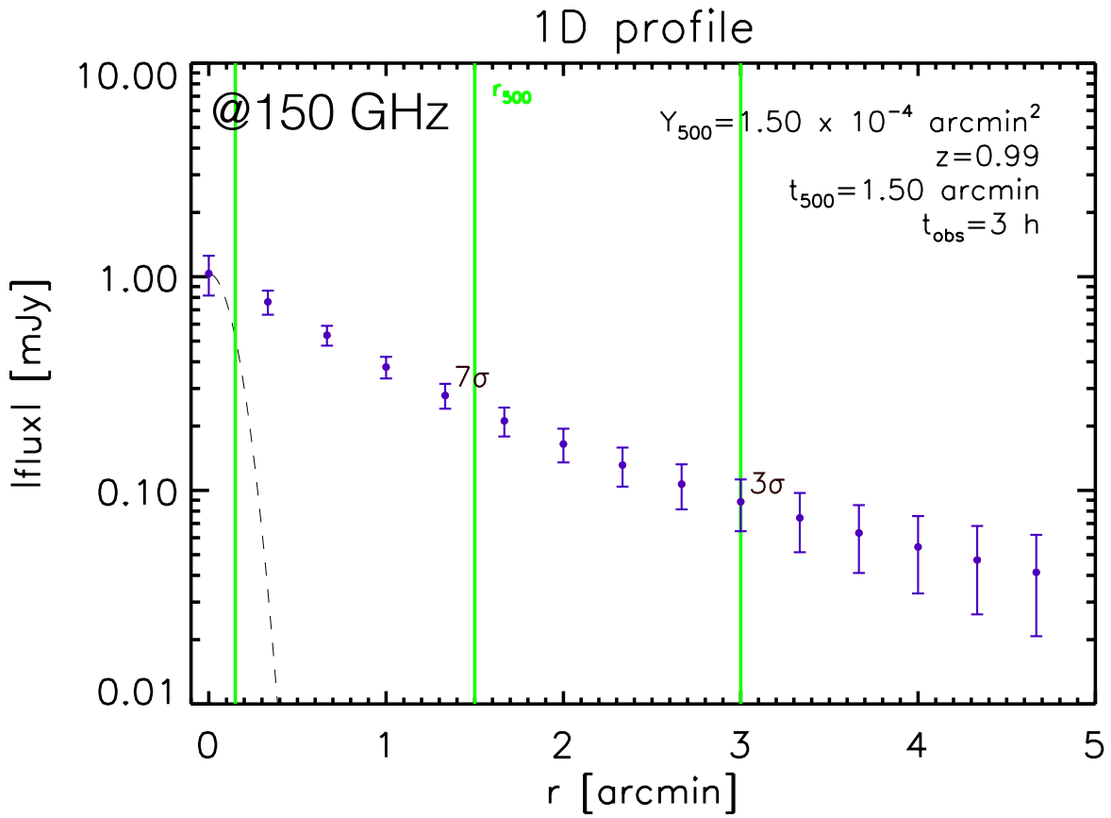




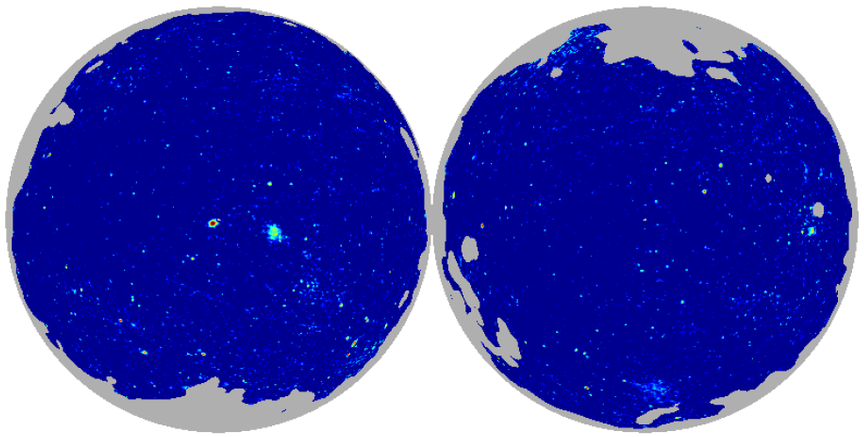
Current SZ surveys

Planck:
full sky (satellite)
30’ – 5’ (7’-10’ for SZ)
@30 - 857 GHz = 9 channels

SPT:
720 deg^2 + 2500 deg^2
95, 150, 220 GHz (1.1’@150GHz)

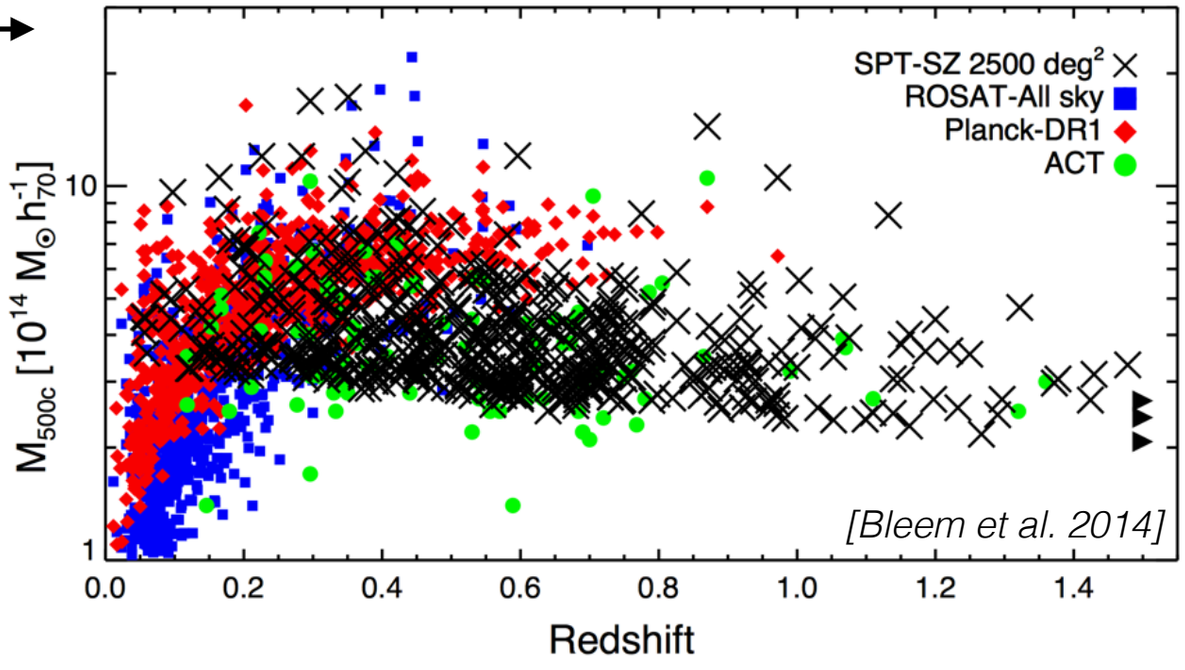
ACT:
504 deg^2 + 455 deg^2
148, 218, 277 GHz (1.4’@148GHz)

full-sky reconstruction of the SZ emission (10’ FWHM)



Planck 2013 results. XXI (2013), Planck 2015 results

tSZ selected cluster catalogues, containing thousands of tSZ detected clusters



Planck *[Planck Early Results VIII, Planck 2013 results XXIX, Planck 2015 results]*

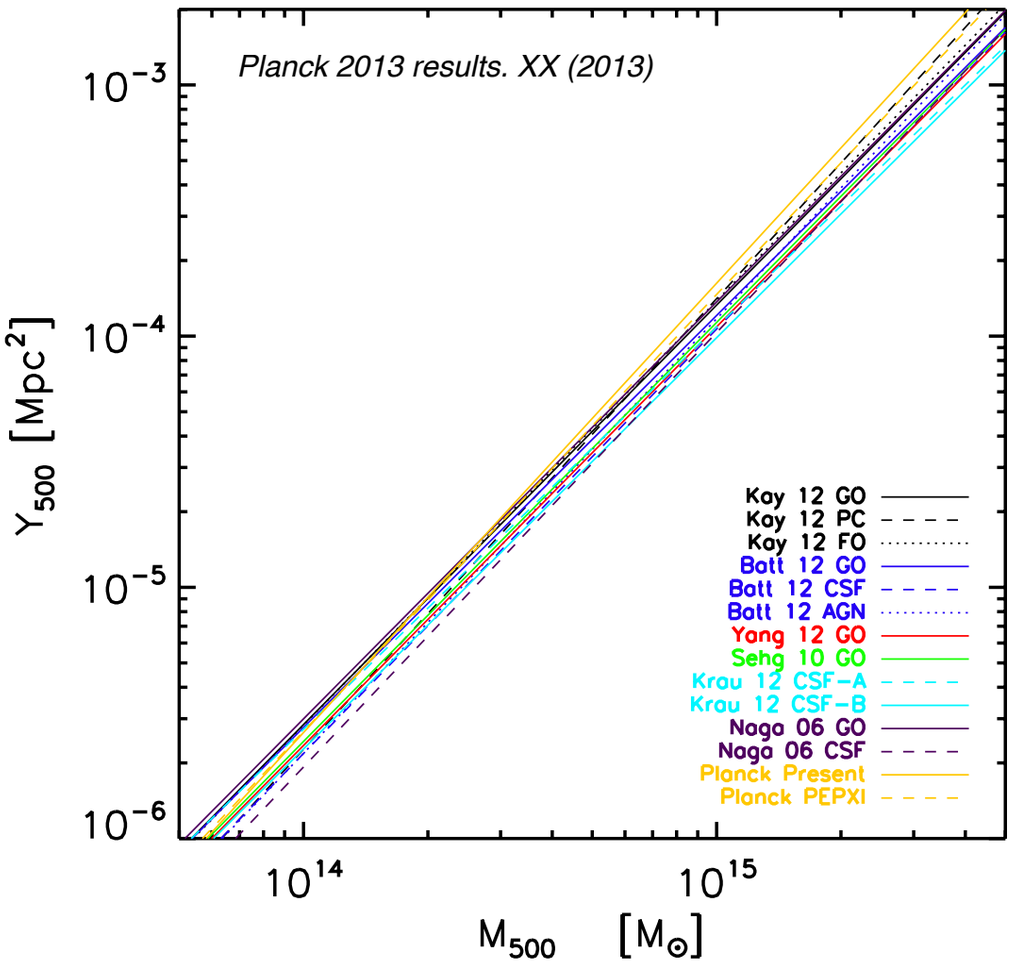
SPT *[Staniszewski et al. 2009, Williamson et al. 2010, Reichardt et al. 2013]*

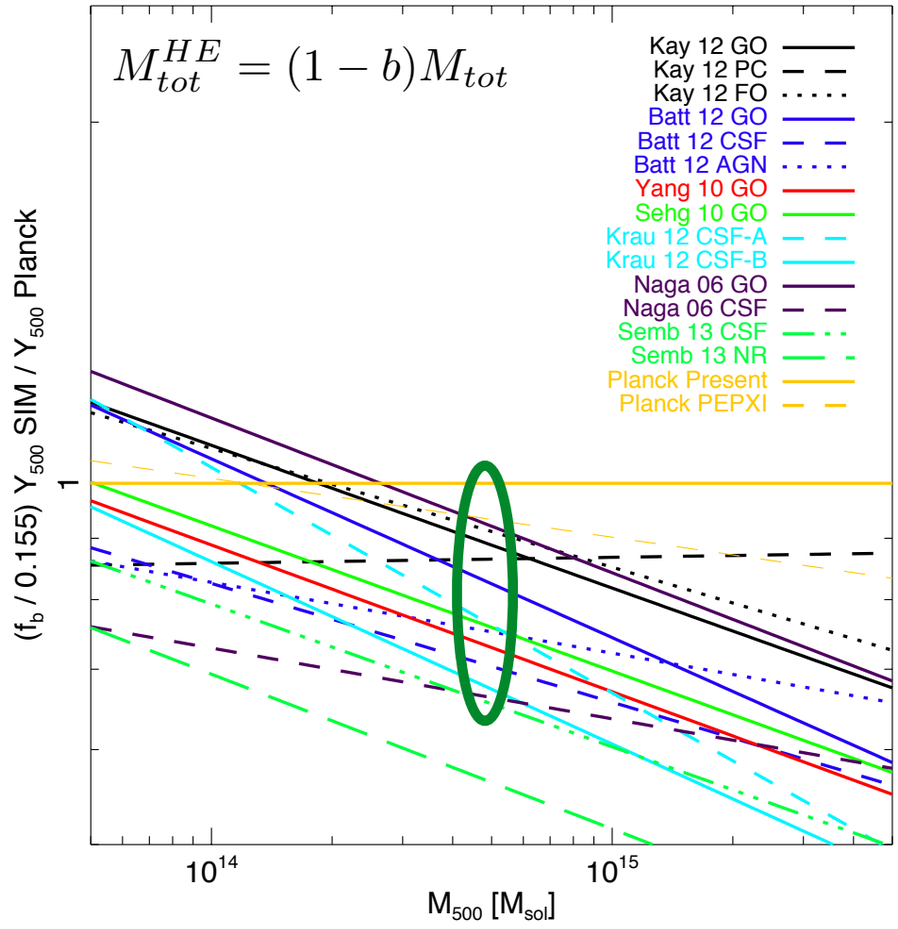
ACT *[Marriage et al. 2011, Menanteau et al. 2010, Hasselfield et al. 2013]*

SZ mass proxy

$$\Delta I_{SZ} \propto Y_\Delta = \int_{r_\Delta} P_e(r) dV$$

$$YD_A^2 \propto f_{gas} M_{tot}^{5/3} E(z)^{2/3}$$ self-similar evolution





SPT (15 clusters, Anderson et al. 2009), **PLANCK** (PER, PIP, Planck 2013 results), **ACT** (dynamical masses, Sifon et al. 2013), **Bolocam** (45 clusters @ r_{2500}, Czakon et al. 14)

Universal pressure profile

$$YD_A^2 \propto f_{gas} M_{tot}^{5/3} E(z)^{2/3}$$

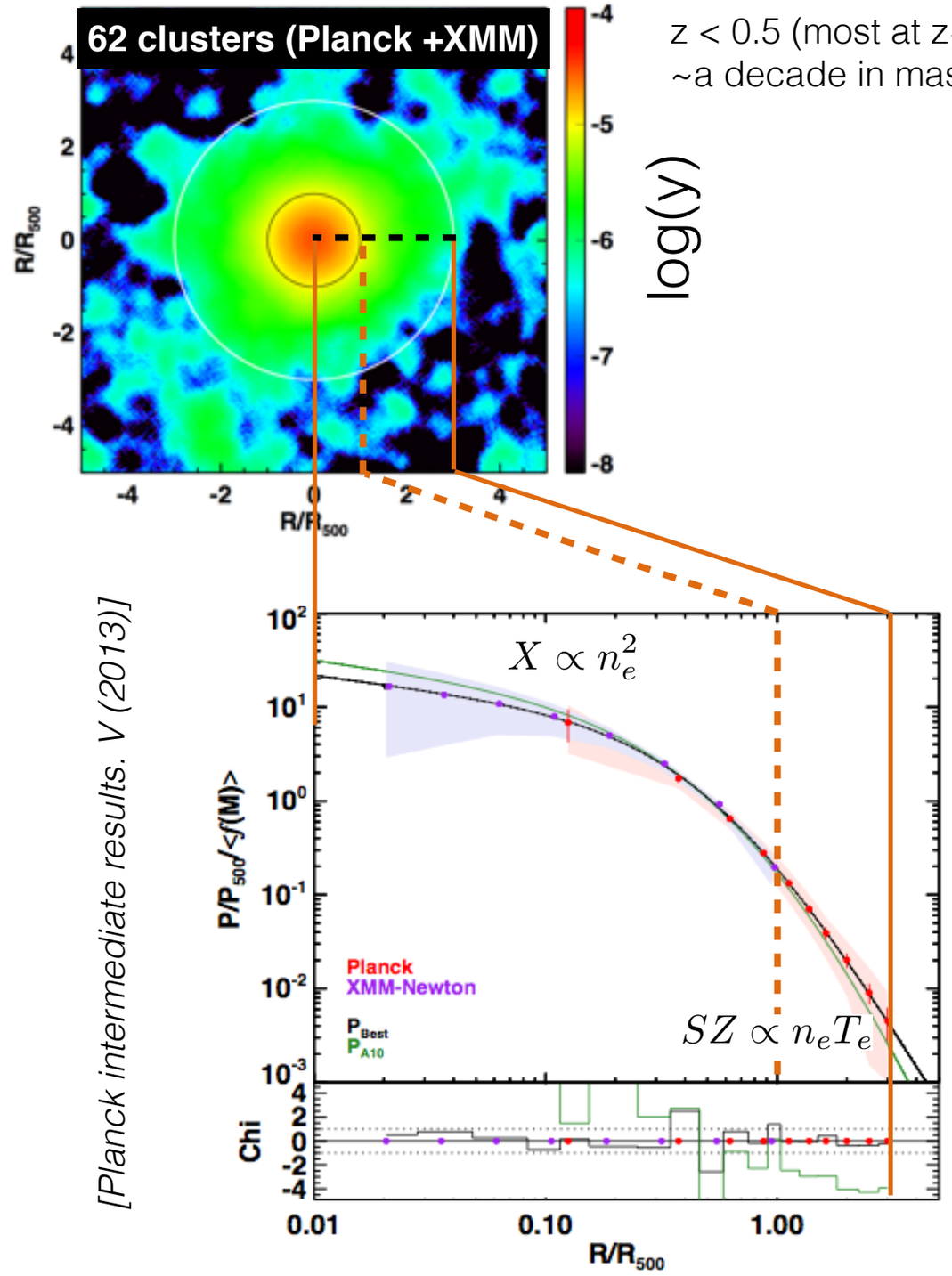
$$P(r) = \frac{P_0}{(\frac{r}{r_s})^{\gamma}[1+(\frac{r}{r_s})^{\alpha}]^{(\beta-\gamma)/\alpha}} \qquad \textbf{gNFW}$$

$$\Rightarrow \quad P(r) = P_{500} p\left(\frac{r}{r_{500}}\right) \qquad \textit{[Arnaud et al. (2010)]}$$

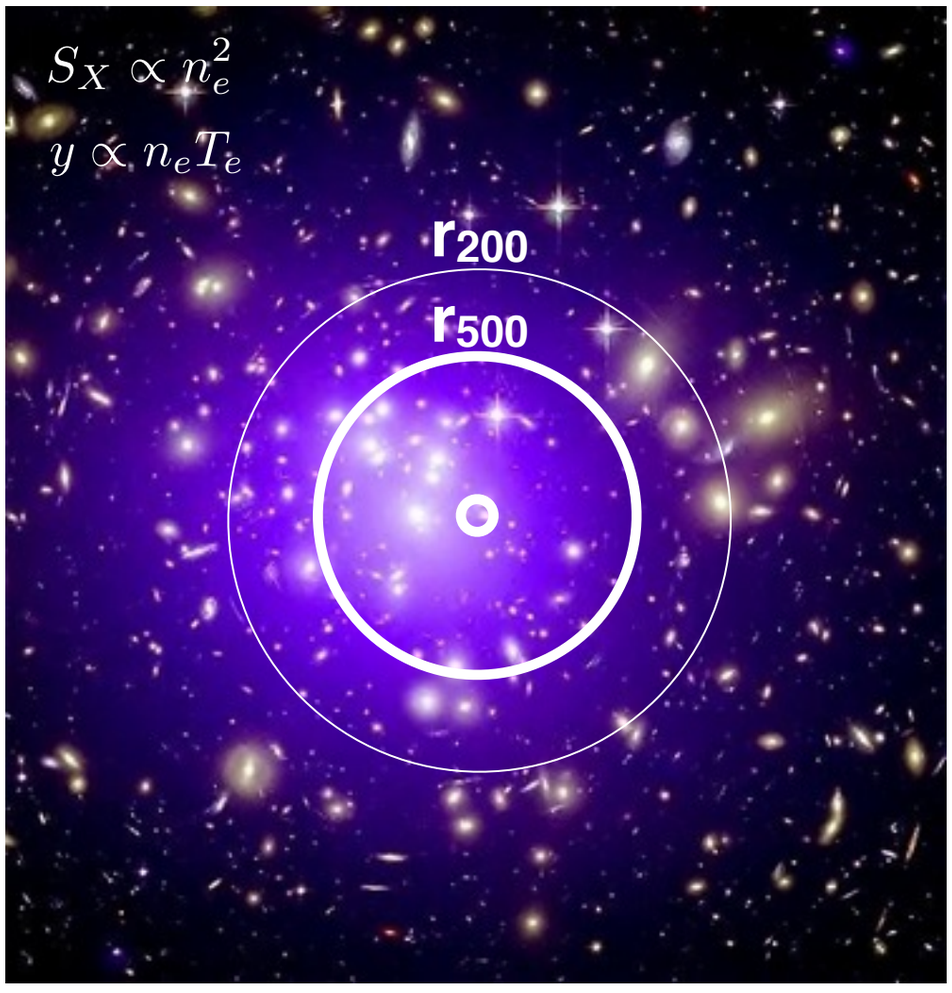
Planck (*Planck intermediate results. V 2013*)

SPT (15 clusters, *Plagge et al. 2010*)

Bolocam (BOXSZ 45 clusters, *Sayers et al. 2013*)



self-similarity vs radius



$r \lesssim 0.1 r_{500}$ baryonic physics

(e.g. cooling, feedback, affect the normalization)

$0.1 r_{500} \lesssim r \lesssim r_{500}$ gravity

$r \gtrsim r_{500}$ deviations from equilibrium, on-going formation

(e.g. non-thermal pressure support, affects the normalization)

From NIKA to NIKA2

NIKA 1 - Final Performance

Array	1.25 mm	2.14 mm
Valid Pixels	190 (196)	125 (128)
Field Of View (arcmin)	1.8	2.0
Band-Pass (GHz)	200-270	126-175
FWHM (arcsec)	12.5	17.5
Sensitivity (mJy·$s^{\frac{1}{2}}$)	35	14
Mapping Speed (arcmin^2/mJy^2/hour)	8	57

NIKA 2 - Nominal Performance

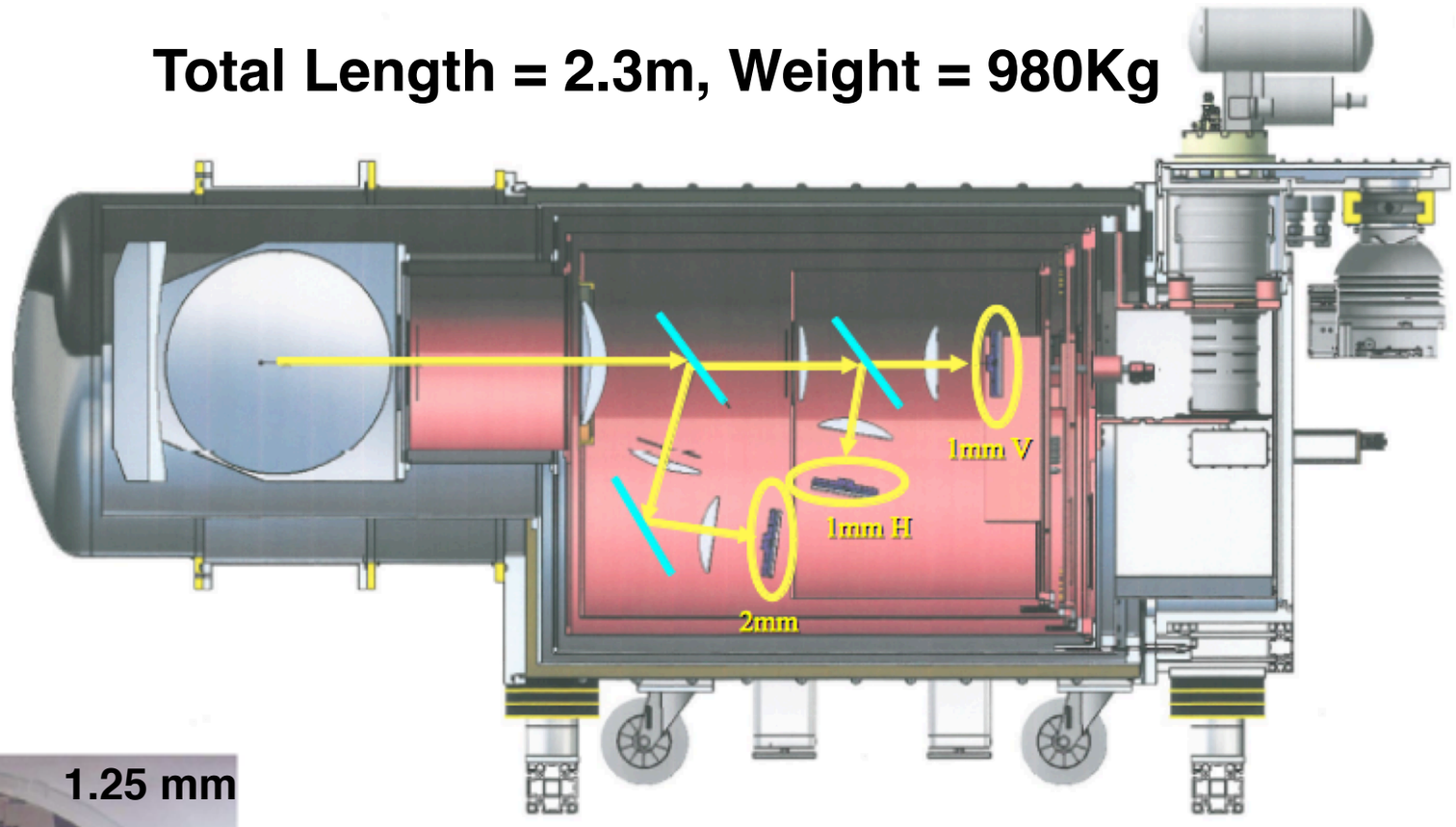
Array	1.25 mm	2.14 mm
Valid Pixels	2000x2	1000
Field Of View (arcmin)	6.5	6.5
Band-Pass (GHz)	220-270	137-172
FWHM (arcsec)	12.5	17.5
Sensitivity (mJy·$s^{\frac{1}{2}}$)	15	10
Mapping Speed (arcmin^2/mJy^2/hour)	676	1521

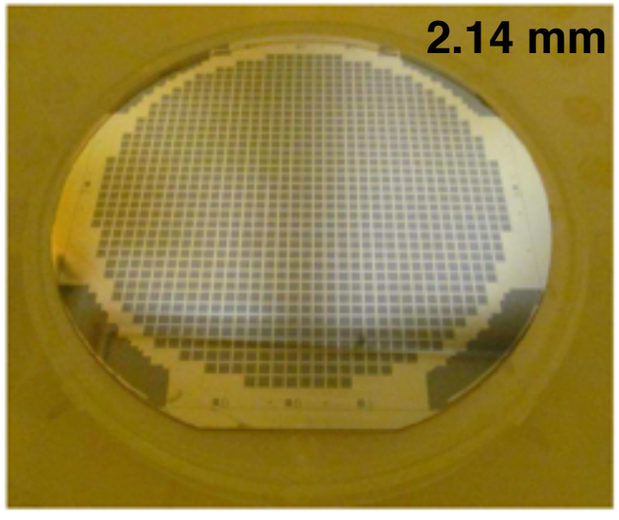
From NIKA to NIKA2

NIKA2 is officially selected by IRAM as the next generation continuum and polarisation instrument at the 30m telescope. It will be installed for Commissioning in 2015.

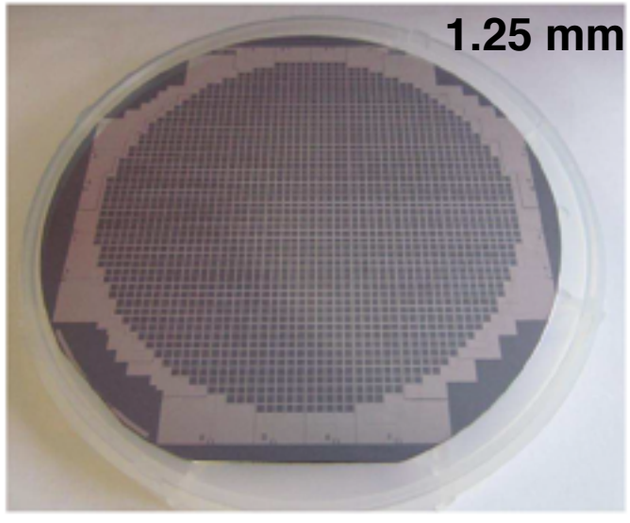
- **Cryostat :** 3He-4He dilution system (100 mK), with intermediate temperature stage using 2 cryorefrigerators.
- **Large LEKID arrays:** Total pixel count of 5000.
- **Warm electronics:** 20 NIKEL boxes, 40 cables between cryostat and electronics
- **Field-of-view :** 6.5 arcmin
- **Linear polarisation @1.25mm** : rotating HWP at 300K and wire grid at 100mK .
- **In-cabin calibration unit :** 300K black body.
- **Foreseen data rate :** 700 Gb/day at most.

Total Length = 2.3m, Weight = 980Kg





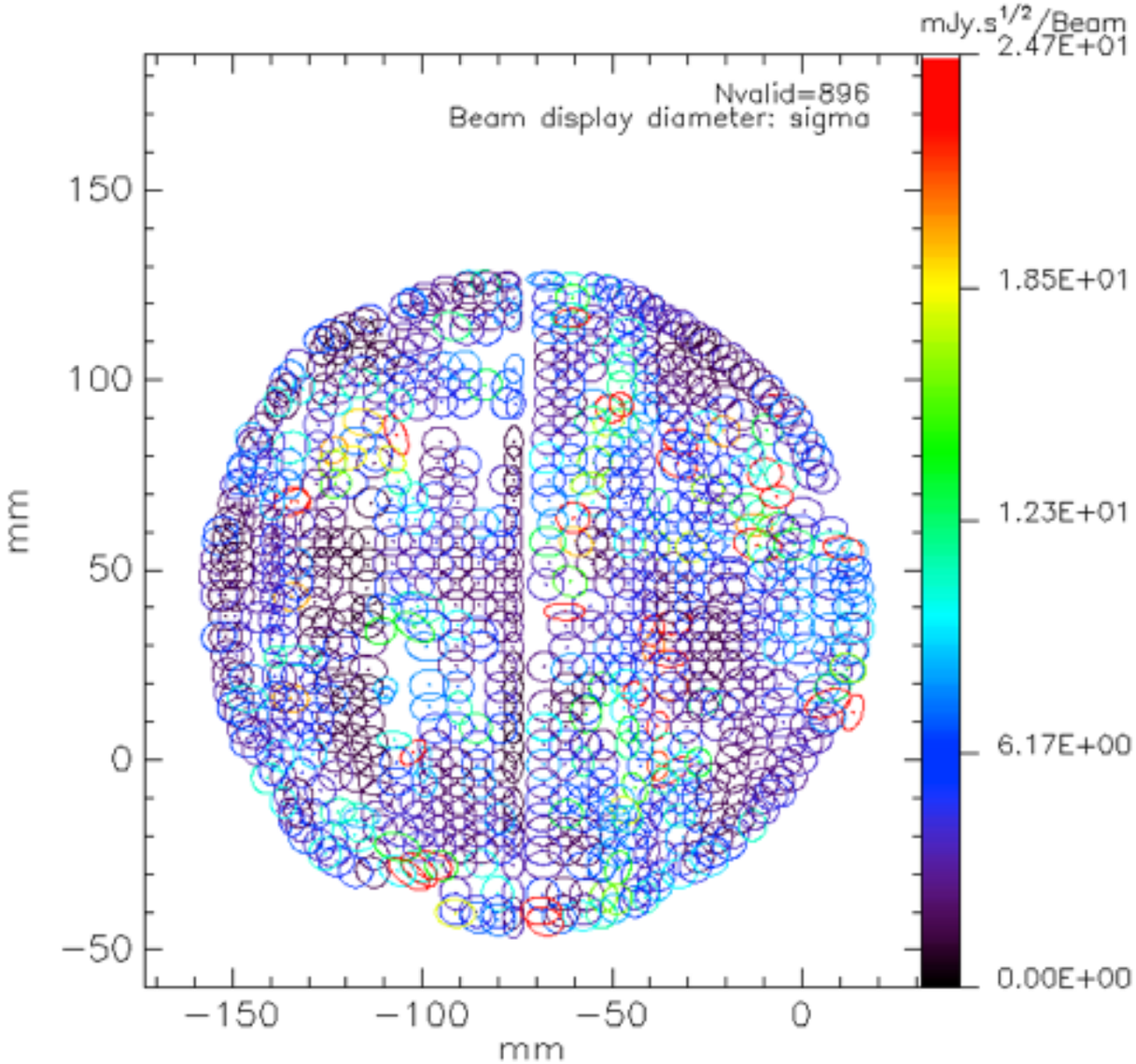
1020 KIDs array for 2mm band



1932 KIDs array for 1.2mm band

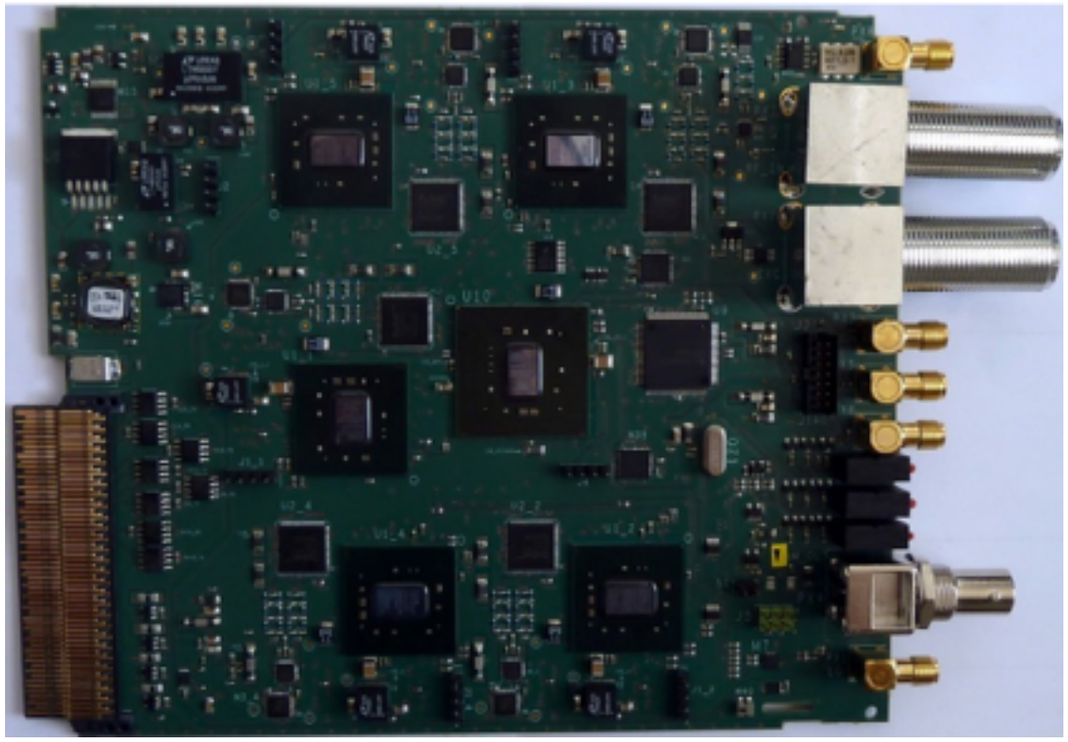
NIKA2 Cryostat cooled down at 100mK for the first time on May 2014 23rd in 3.5 days naked! Today 5 days with optics+arrays

NIKA2 First Performance (2mm - 1000 pixels)

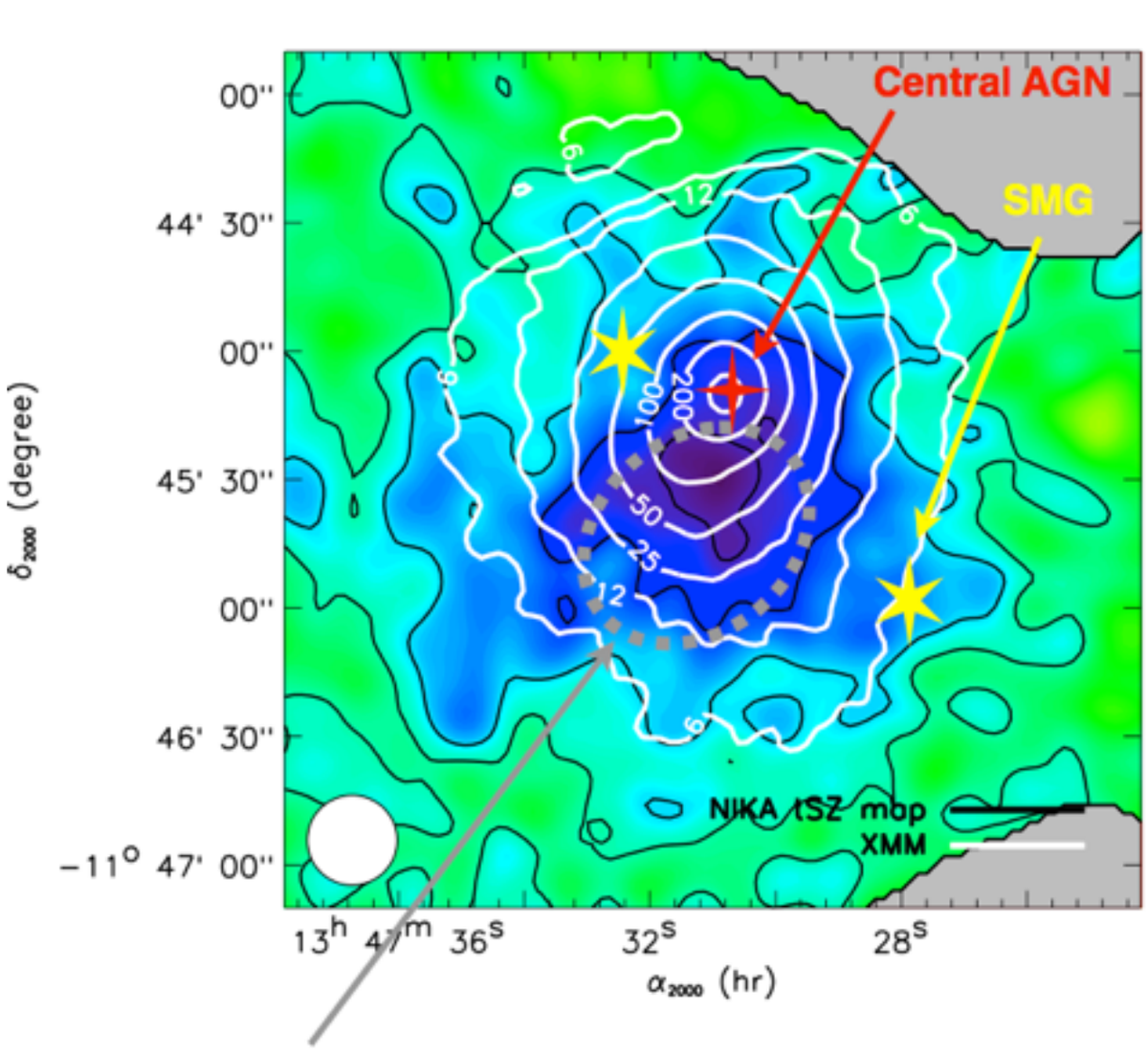


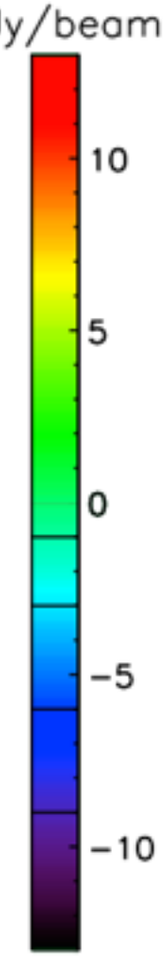
- The four feedlines are connected.
- The res. look at the right place (from 1.32-1.34GHz).
- The optical response seems OK (more than 100kHz between 0K and 300K.
- The noise (very preliminar) on the 300K is between 1 and 2Hz/sqrt(Hz) before any power optimisation.

tests on NIKEL_AMC going on...



First NIKA tSZ detection





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

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

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

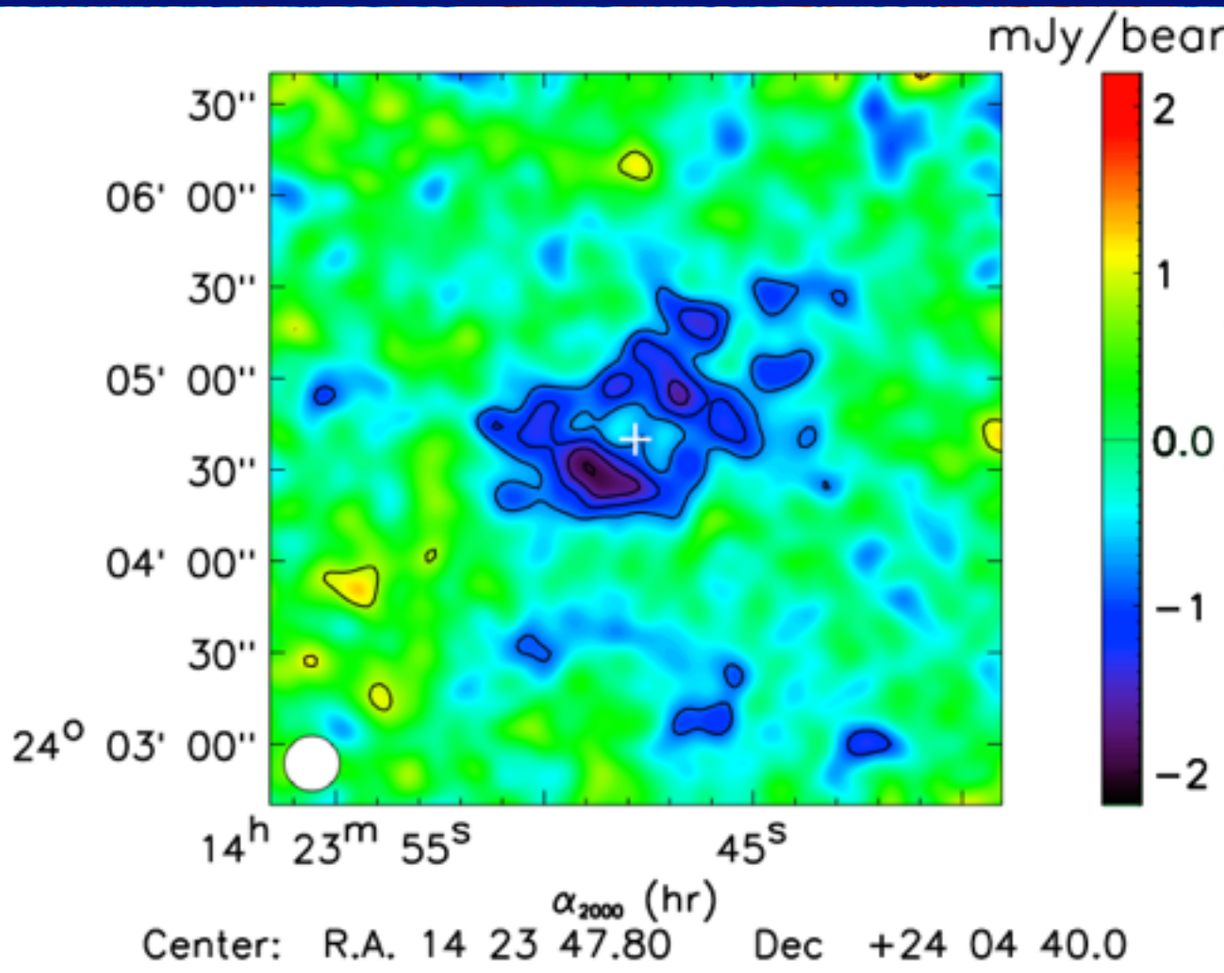
- tSZ is well adapted for the **characterization of shocks**
- RX J1347.5-1145 is an ongoing **merger** (strong SE extension)
- **Multiwavelength** observations provide a complete picture of the cluster
- NIKA agrees well and complements other SZ observations

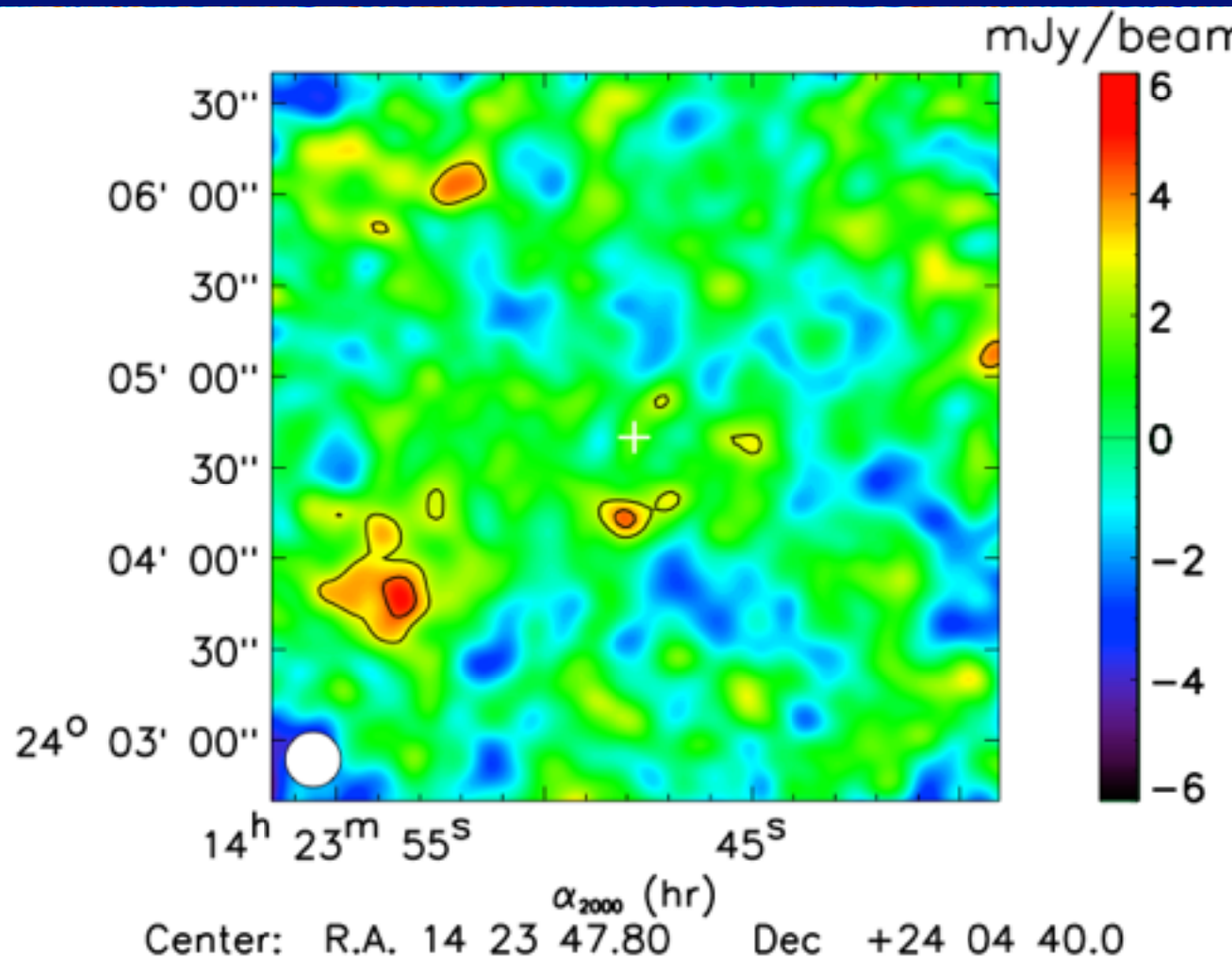
Radio halo at the shock location

[C. Ferrari et al. (2011)]

➡ **Detection and SZ mapping achieved**

Relaxed clusters: MACSJ1423.8+2404 (z=0.54)

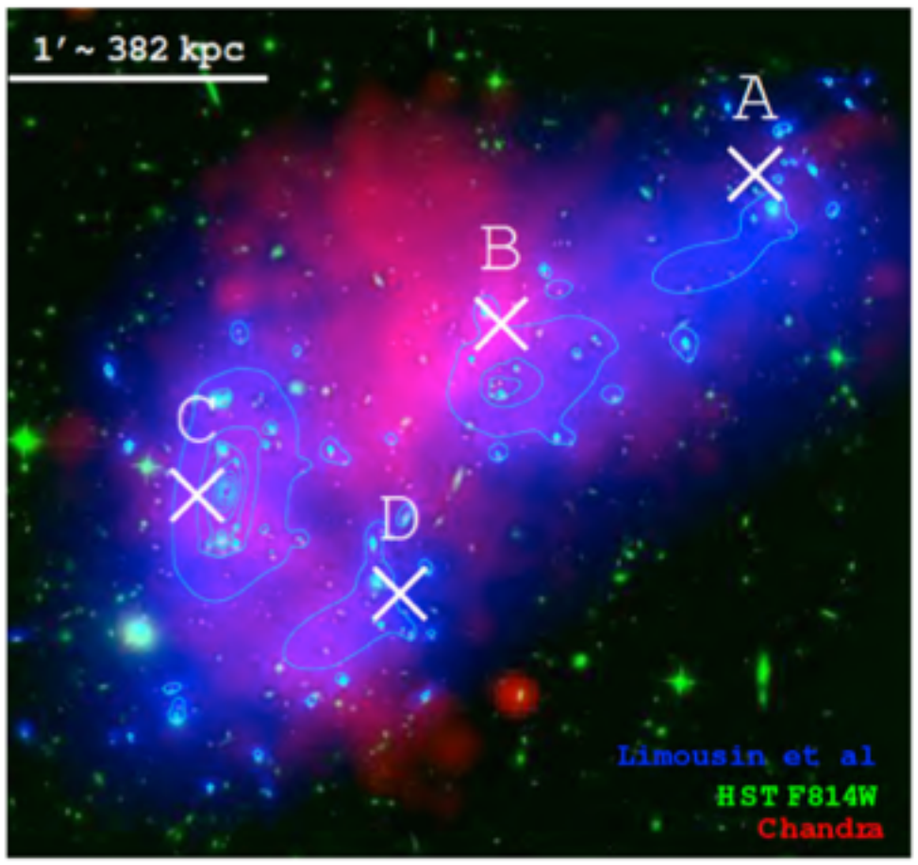




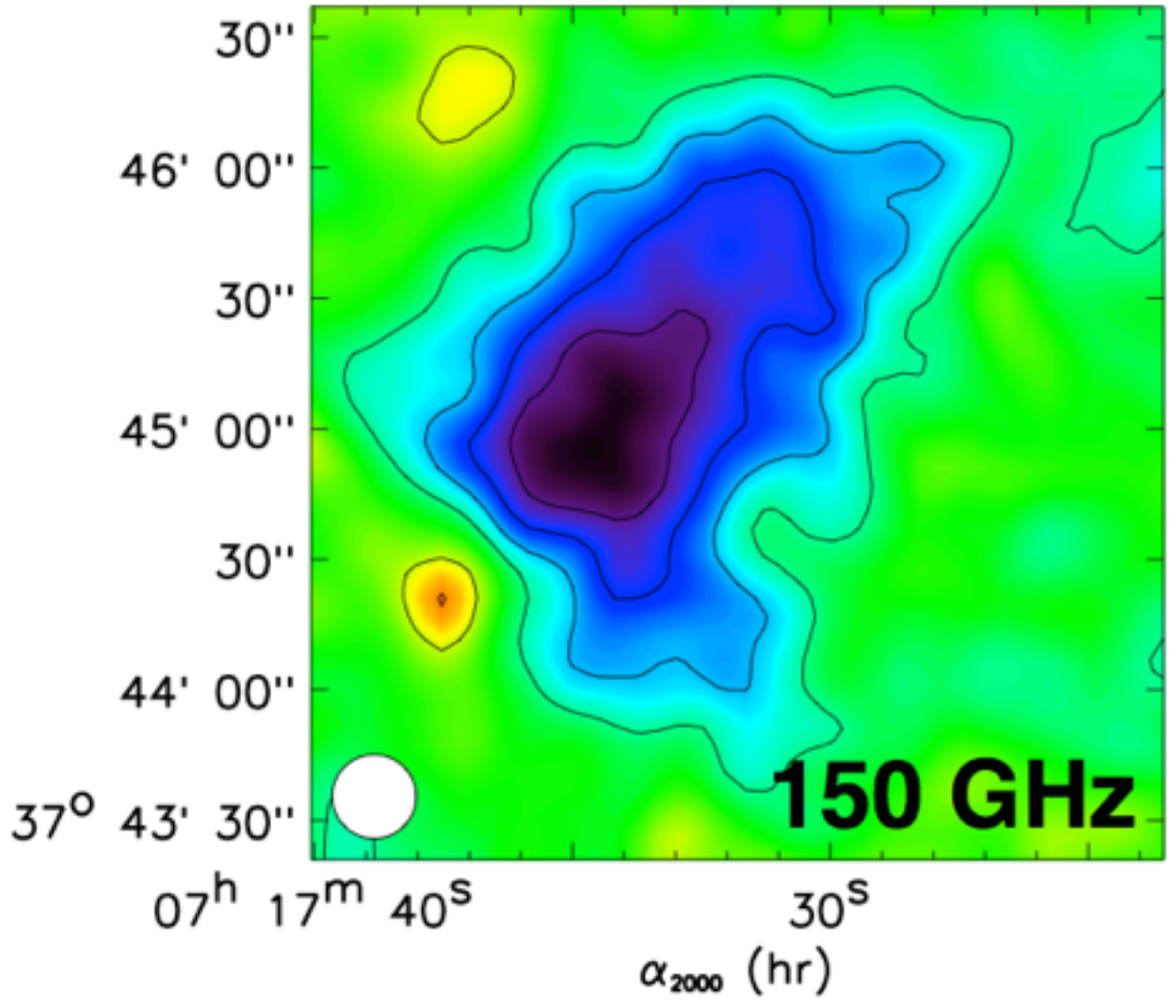
- First NIKA Open Pool (February 2014): **only 1.5 hours** unfortunately
- **Sub-mm point sources** are observed
- A **radio point source** sits at the cluster center

➡ **Radio and IR point sources contamination can be a problem**

Disturbed cluster: MACSJ0717.5+3745 (z=0.55)



[J. Sayers et al. (2013)]



An exceptionally disturbed cluster

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

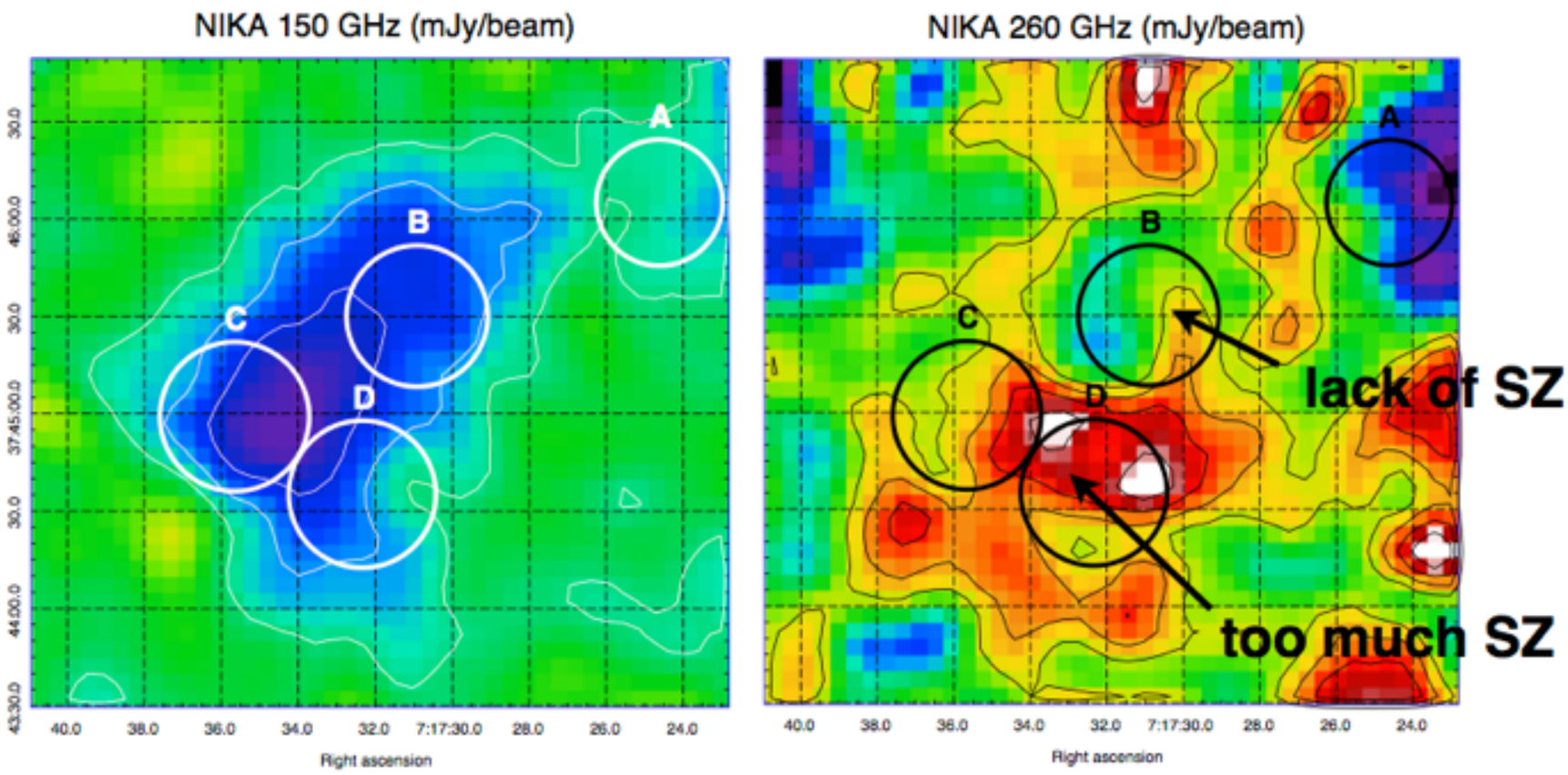
***NIKA* data**

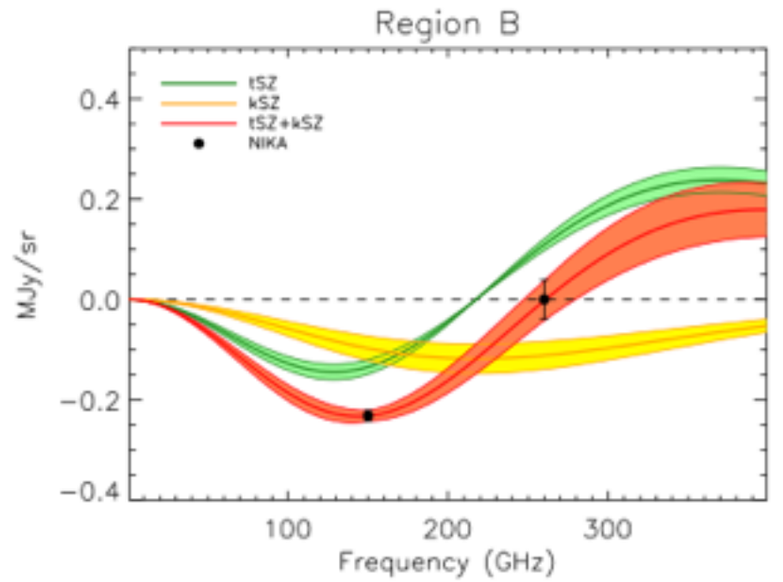
- First NIKA Open Pool (February 2014)
- **5.3h** on source shown here (signal/noise)

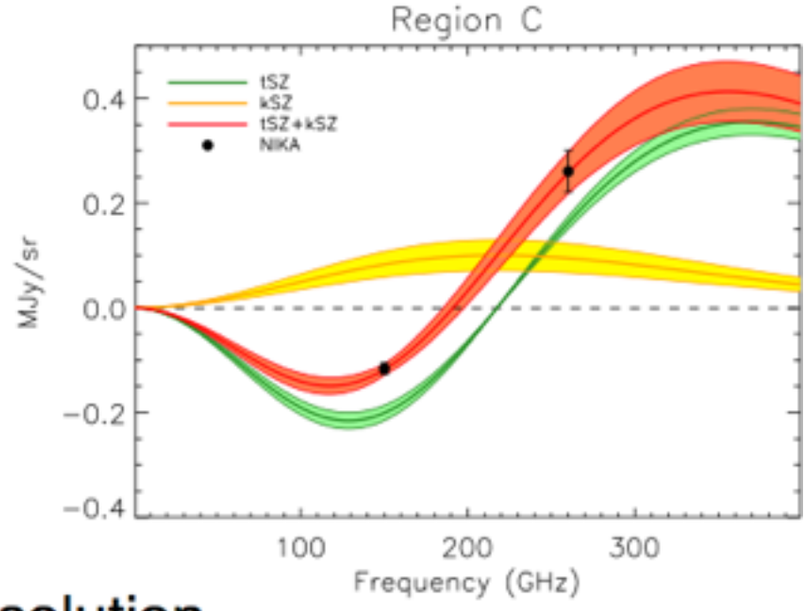
➡ **SZ mapping of (one of?) the most complex system**

MACSJ0717.5+3745, kSZ?

• **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

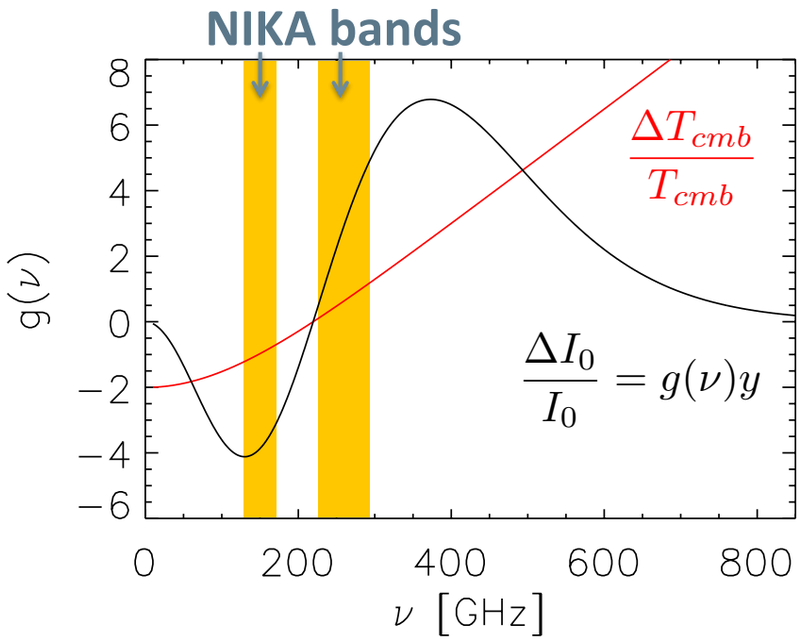
➡ **Hint for kinetic SZ signal, as detected by Bolocam. Analysis in progress**

NIKA2 for SZ

NIKA2 is well adapted for these observations

- large number of high sensitive detectors at two frequency bands (150 and 260 GHz)
- large field of view (6.5 arcmin, $\lesssim r_{500}$ at z > 0.5)
- the 30 m resolution (20 and 12 arcsec for the NIKA2 frequencies)

→ **resolution and quality comparable with X-ray (XMM)**



300h GT LP dedicated to SZ → We intend to observe a large sample (~ 50) of clusters of galaxies with redshift > 0.5 :

→ **P(r) vs z & morphology**

→ **T(r) & K(r) vs z & morphology**

→ **Y - M_{tot} vs z & morphology**

} NIKA2 + ancillary data (including X-rays, optical and radio observations)