Probing the formation of distant clusters with NIKA2 SZ observations

Rémi Adam (Lagrange - OCA, CNES)
on behalf of the NIKA collaboration

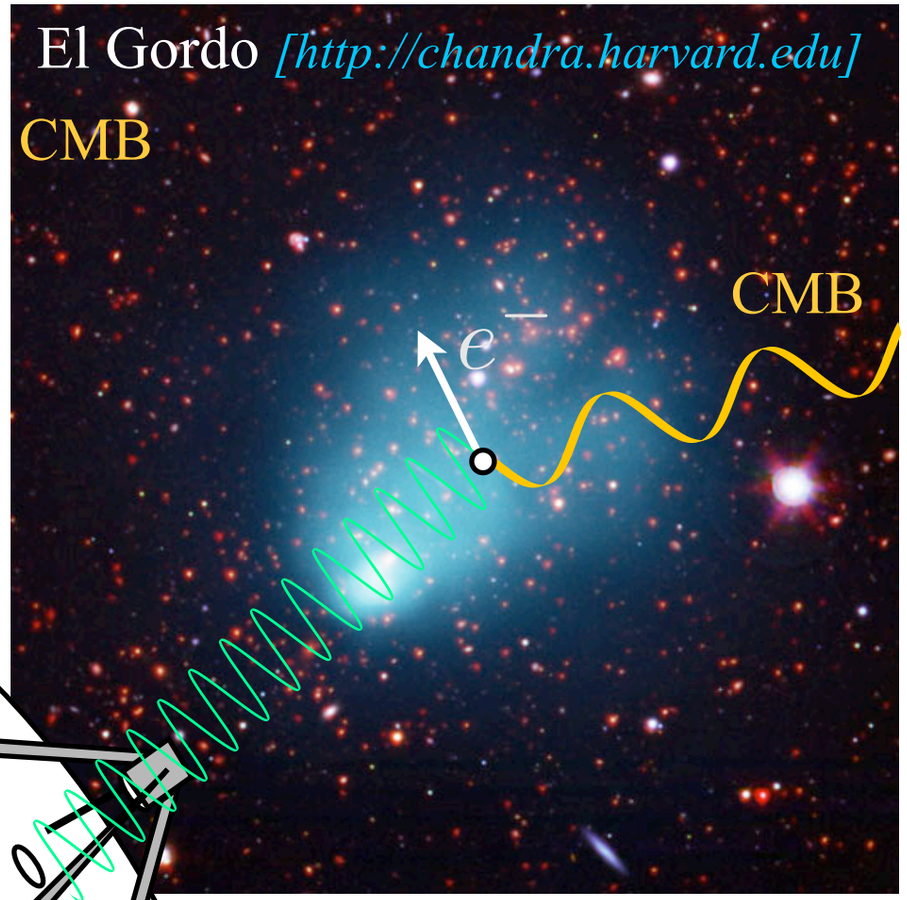
GCF conference
Garching - 18/07/2017

Looking at clusters using the SZ effects

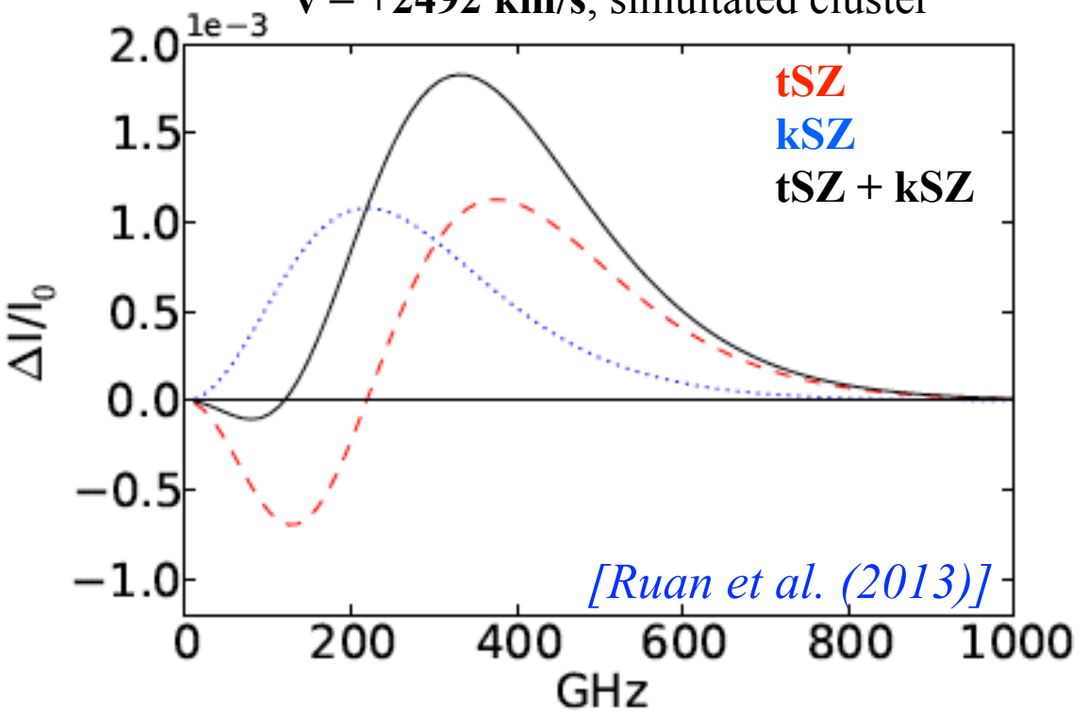
- **tSZ** = CMB spectral distortion from interaction with clusters' hot electrons
- **kSZ** = CMB Doppler shift from bulk motion of electrons (typically ~ tSZ/10)

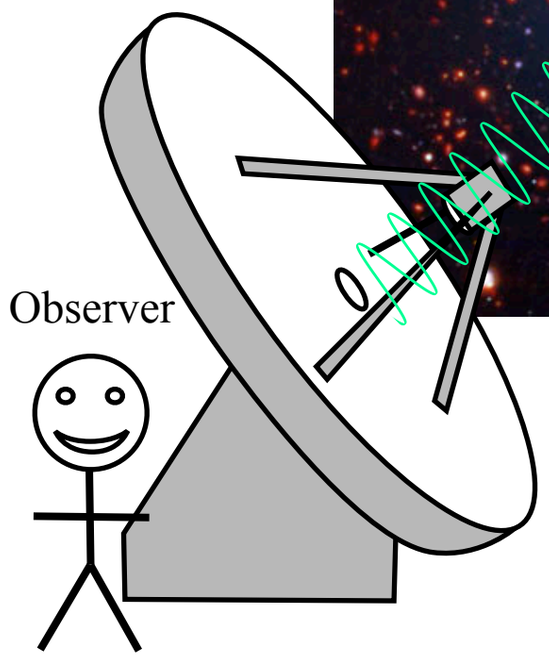
$$\frac{\Delta I_\nu}{I_0} = f_\nu \; y_{\rm tSZ} + g_\nu \; y_{\rm kSZ}$$

$$\begin{cases} y_{\rm tSZ} = \dfrac{\sigma_{\rm T}}{m_e c^2} \displaystyle\int P_e d\ell \quad \Rightarrow \text{ Pressure (density x temperature)} \\ y_{\rm kSZ} = \sigma_{\rm T} \displaystyle\int \frac{-v_z}{c} n_e d\ell \quad \Rightarrow \text{ Velocity x density} \end{cases}$$



v = +2492 km/s, simultated cluster



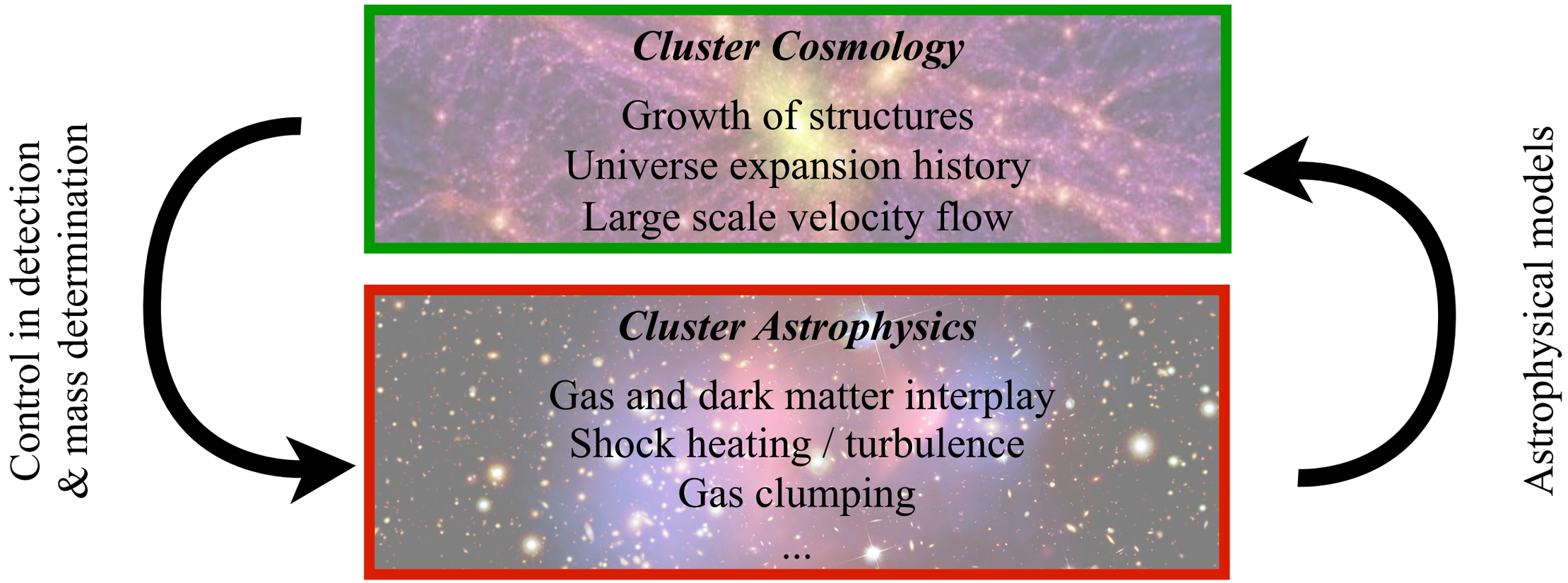


No redshift dimming!

SZ = probe for intracluster gas

Cosmology and astrophysics with the SZ effects

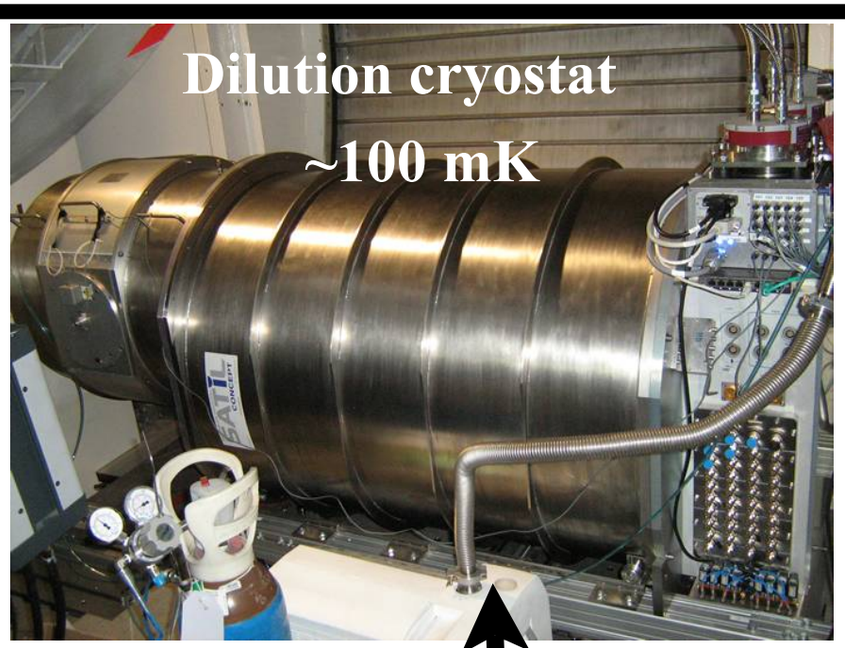
The gas is an excellent tracer of the matter:
➡ tSZ pressure ~ total mass & temperature
➡ kSZ momentum ~ velocity

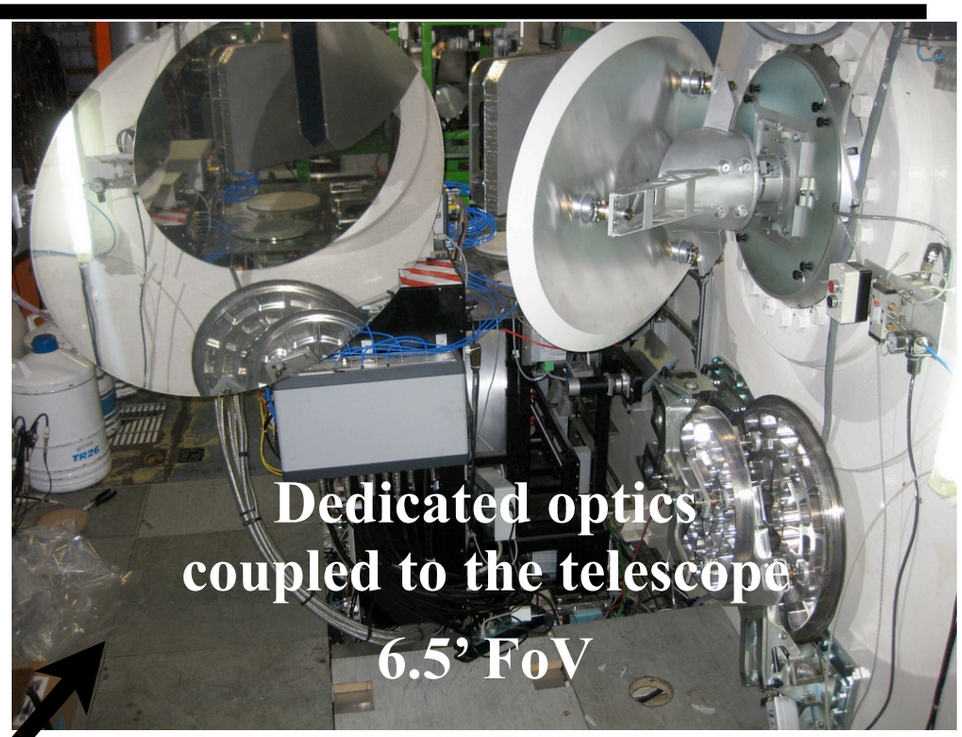


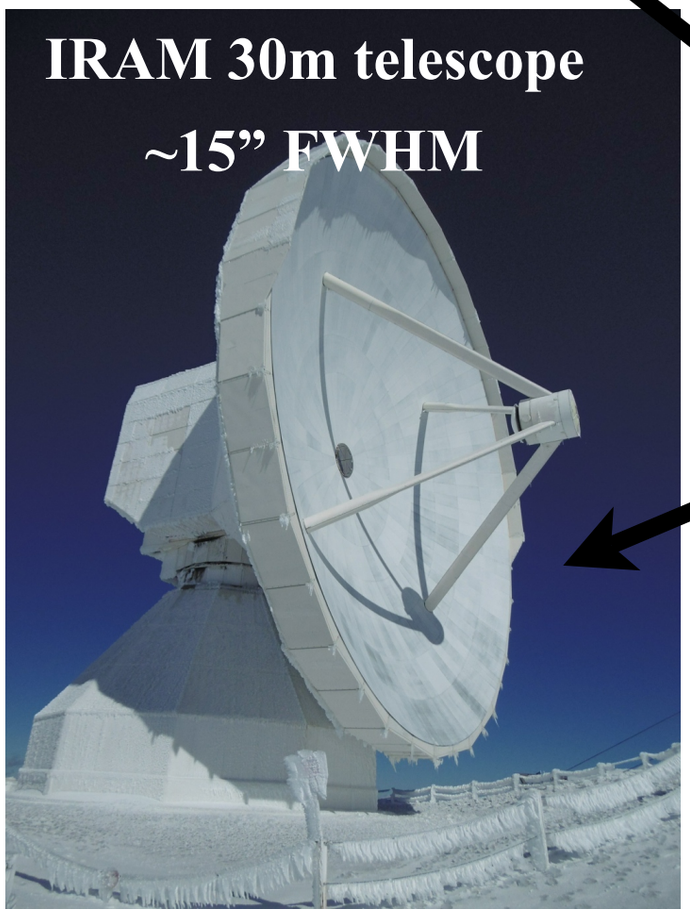
➡ Next step after SZ surveys: exploring the **inner structure** & **high z** with high angular resolution dedicated follow-up

Cluster formation & robust cosmological probe

NIKA2: next generation millimeter wave continuum instrument at the IRAM 30m telescope





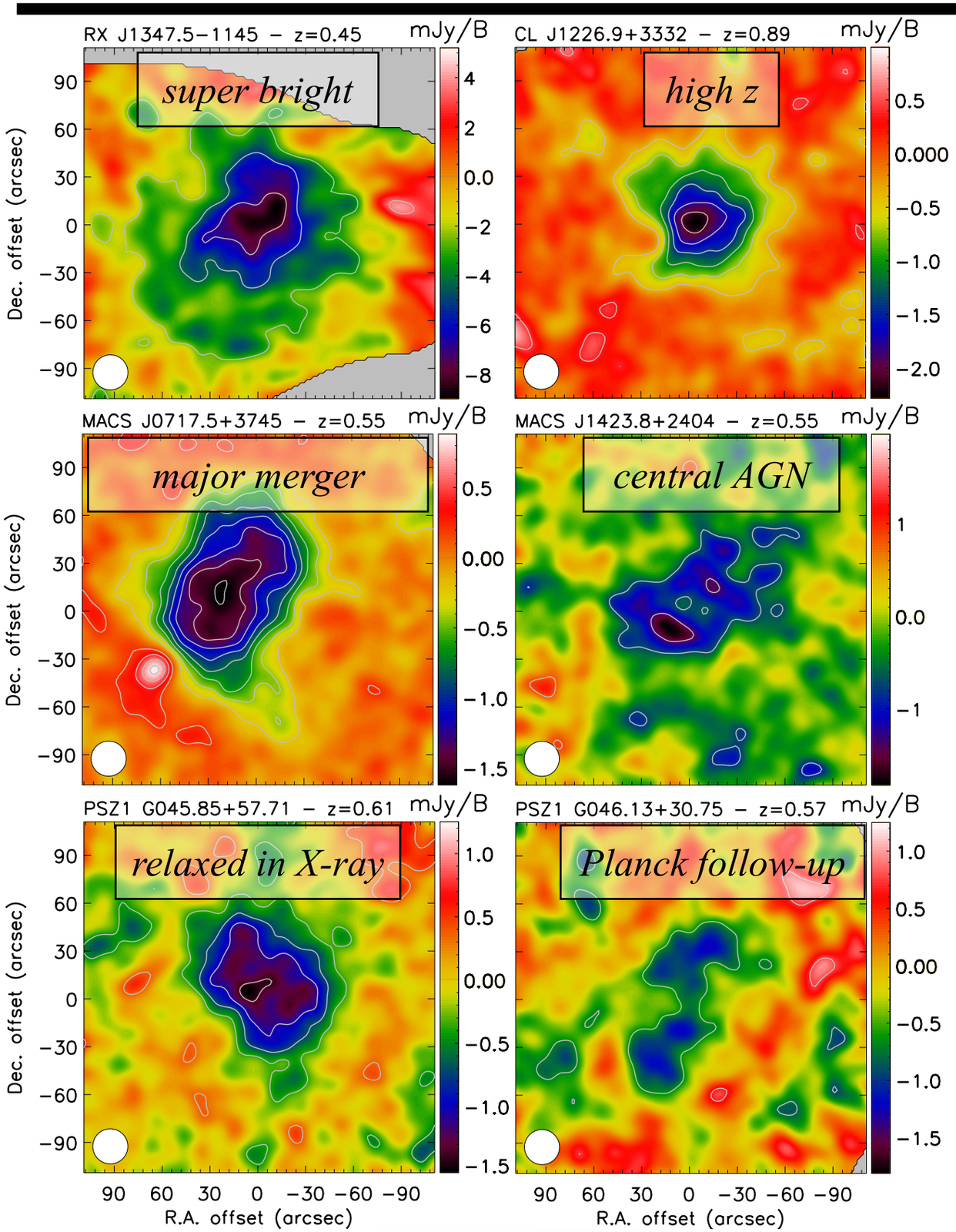


NIKA2

[NIKA collab. (2017)]

Large FoV+high resolution+SZ bands: ideal for high z clusters

The NIKA pathfinder cluster sample (at 150 GHz)



A pilot sample to prepare the NIKA2 observations

- ☑ First SZ observation with KIDs detectors *[Adam et al. (2014)]*
- ☑ High z thermodynamics reconstruction with tSZ+X-ray *[Adam et al. (2015, 2016), Ruppin et al. (2017)]*
- ☑ Dealing with astrophysical contaminants *[Adam et al. (2016)]*
- ☑ Detection and follow-up of high z lensed galaxies *[Adam et al. (2015, 2017a)]*
- ☑ A first image of the kSZ effect *[Adam et al. (2017a)]*
- ☑ A first temperature mapping from tSZ+X-ray imaging *[Adam et al. (2017b)]*
- ☑ Merger detection: NIKA vs RHAPSODY-G simu. *[Adam et al. (in prep.)]*

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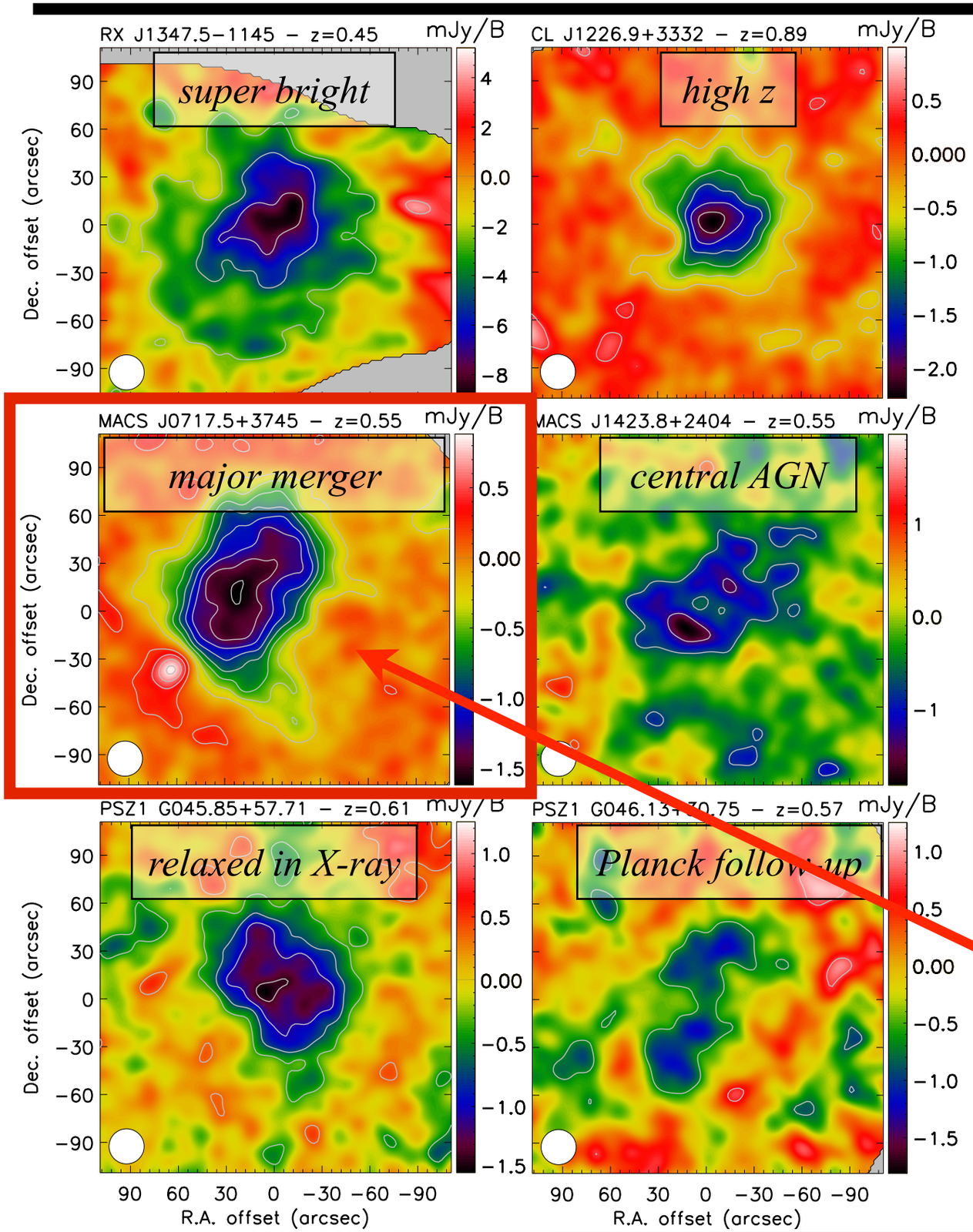

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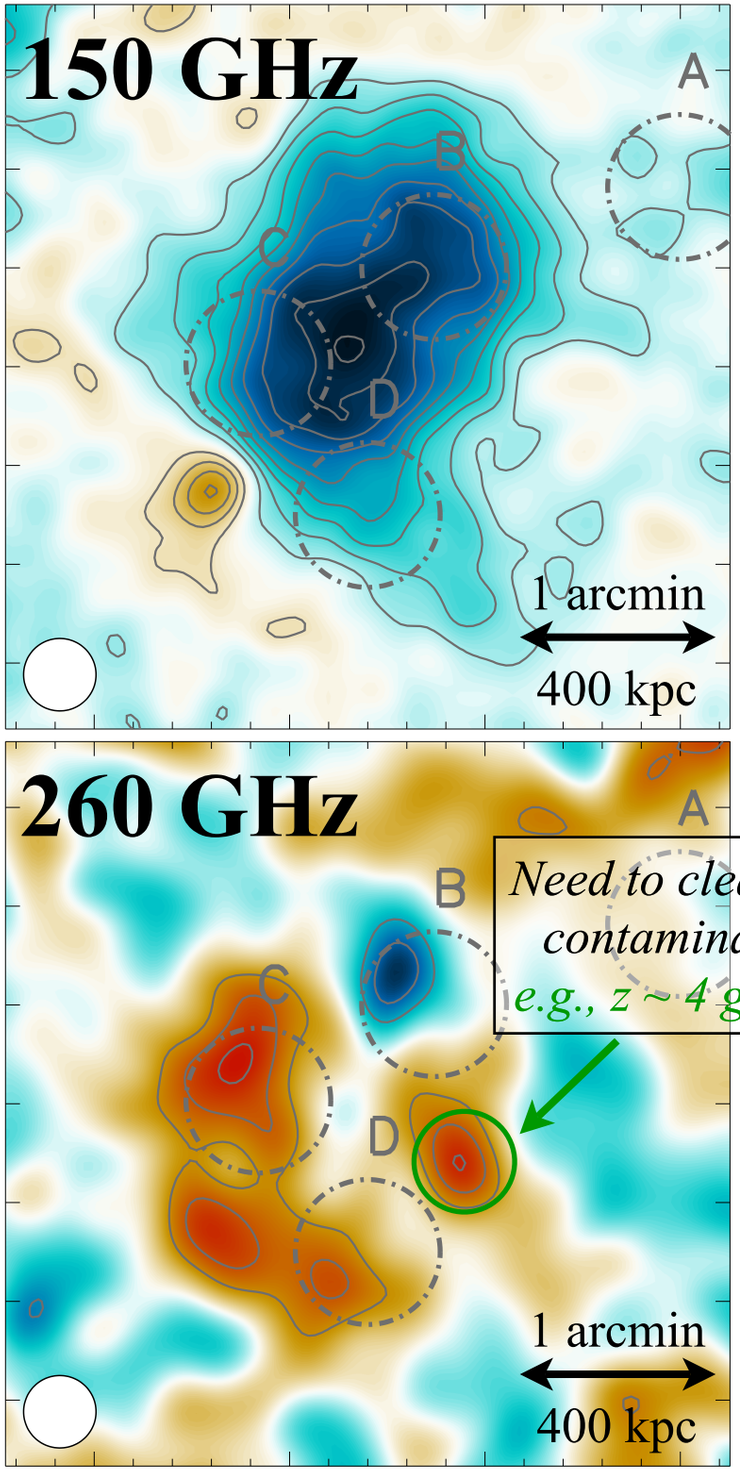
MACS J0717.5+3745 (z=0.55)

A first kSZ mapping towards a galaxy cluster

[Adam et al. (2017a)]



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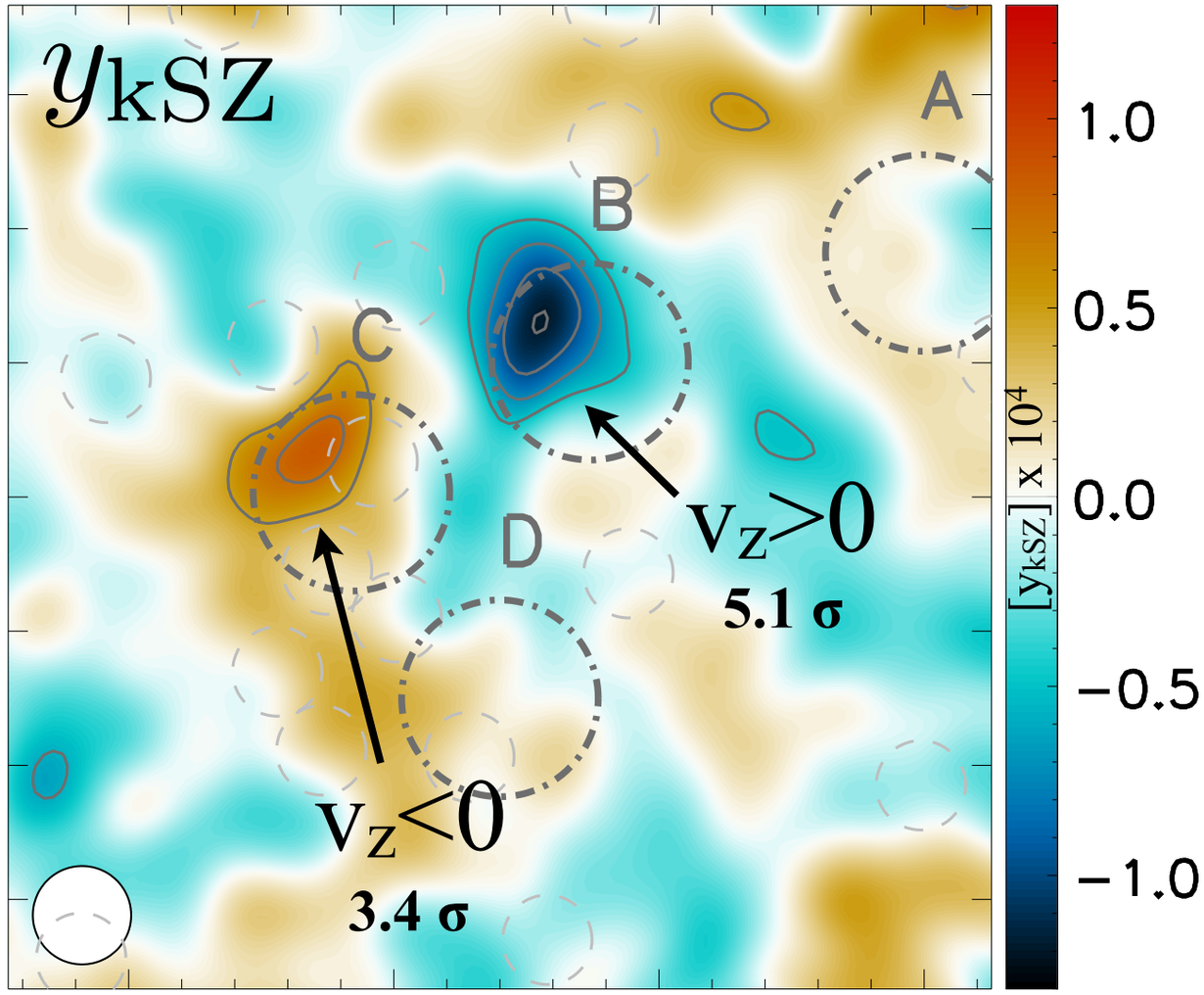
spectral dependencies

gas pressure

gas density+velocity



➡ **Separate kSZ from tSZ with 2 frequencies**

See also the first detection by Bolocam

[Mroczkowski et al. (2012) & Sayers et al. (2013)]

A first kSZ mapping towards a galaxy cluster

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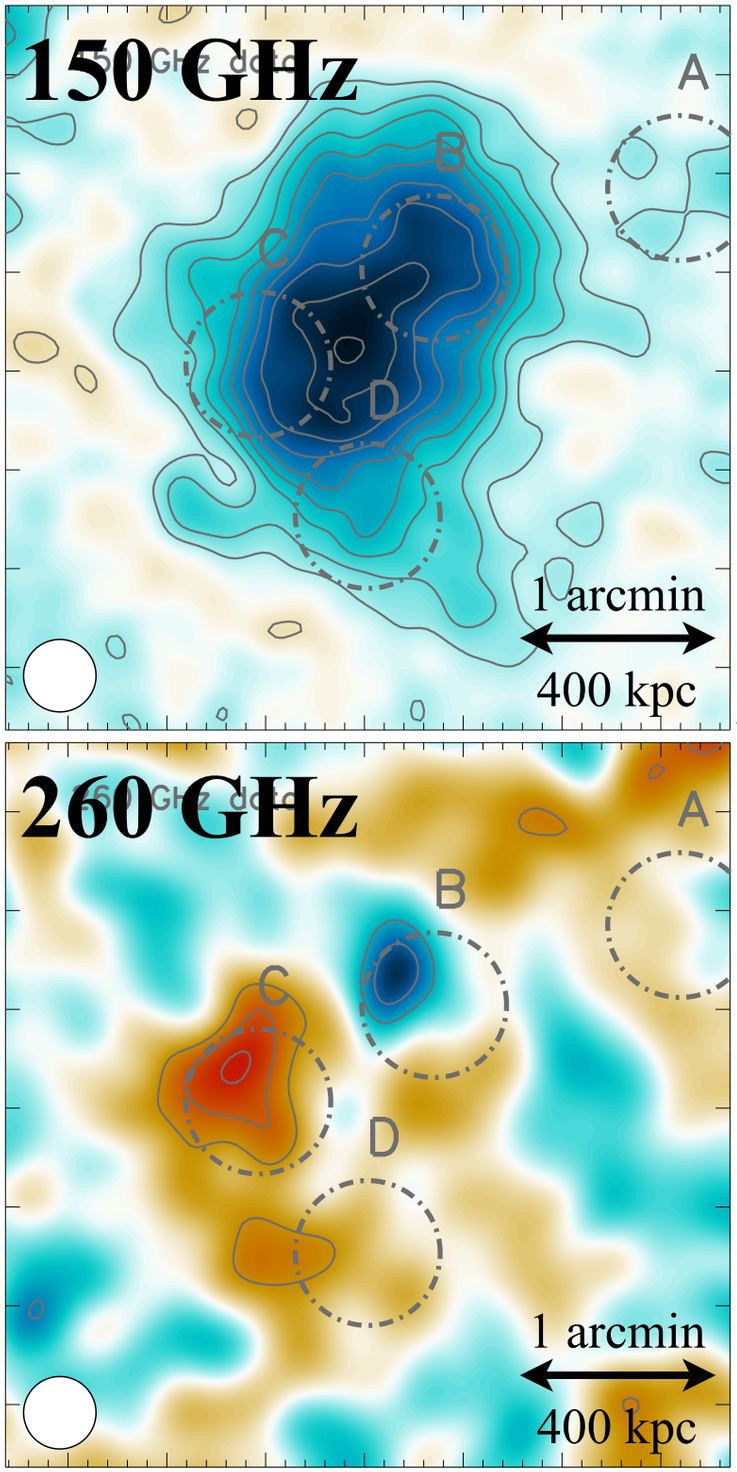

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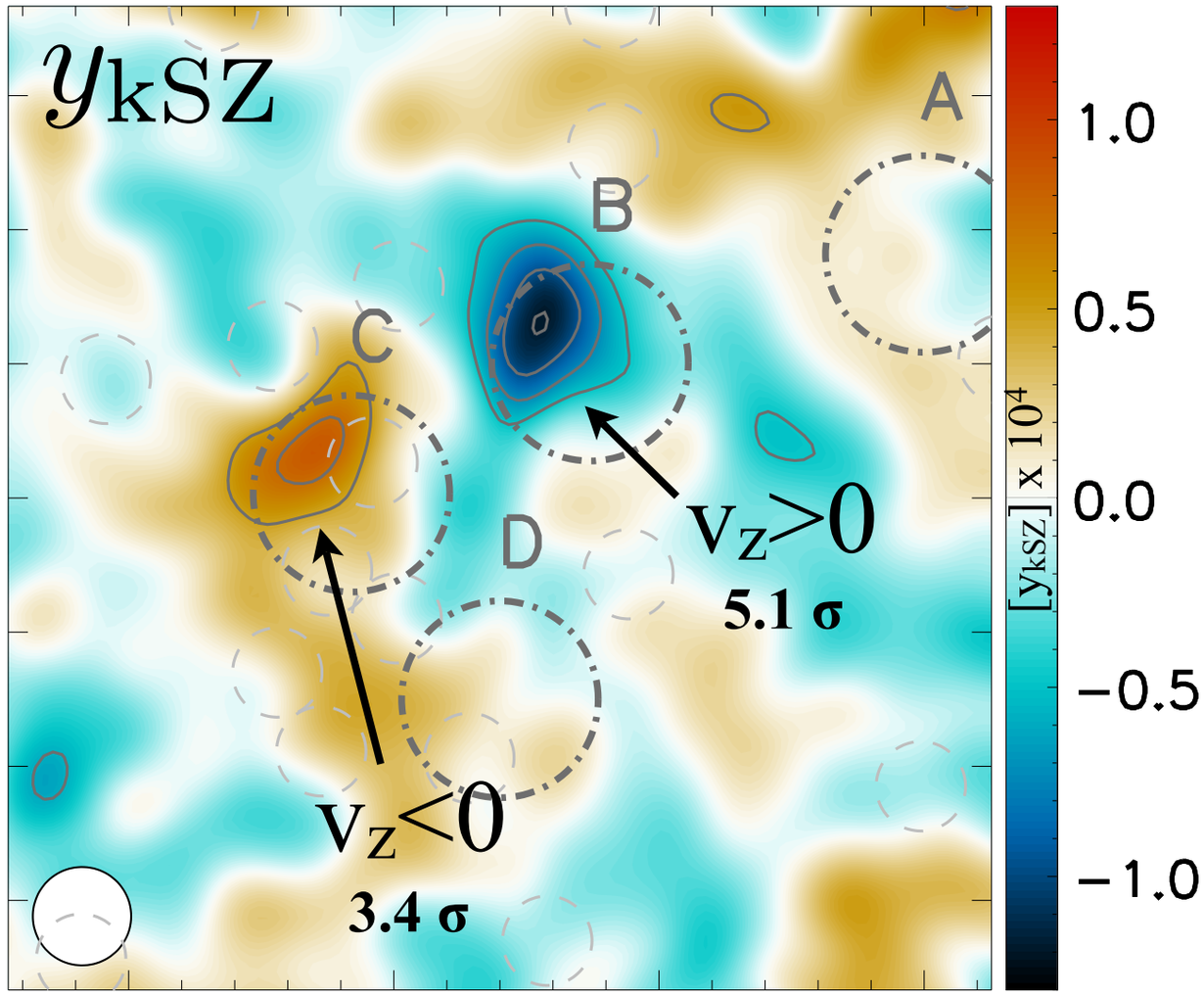

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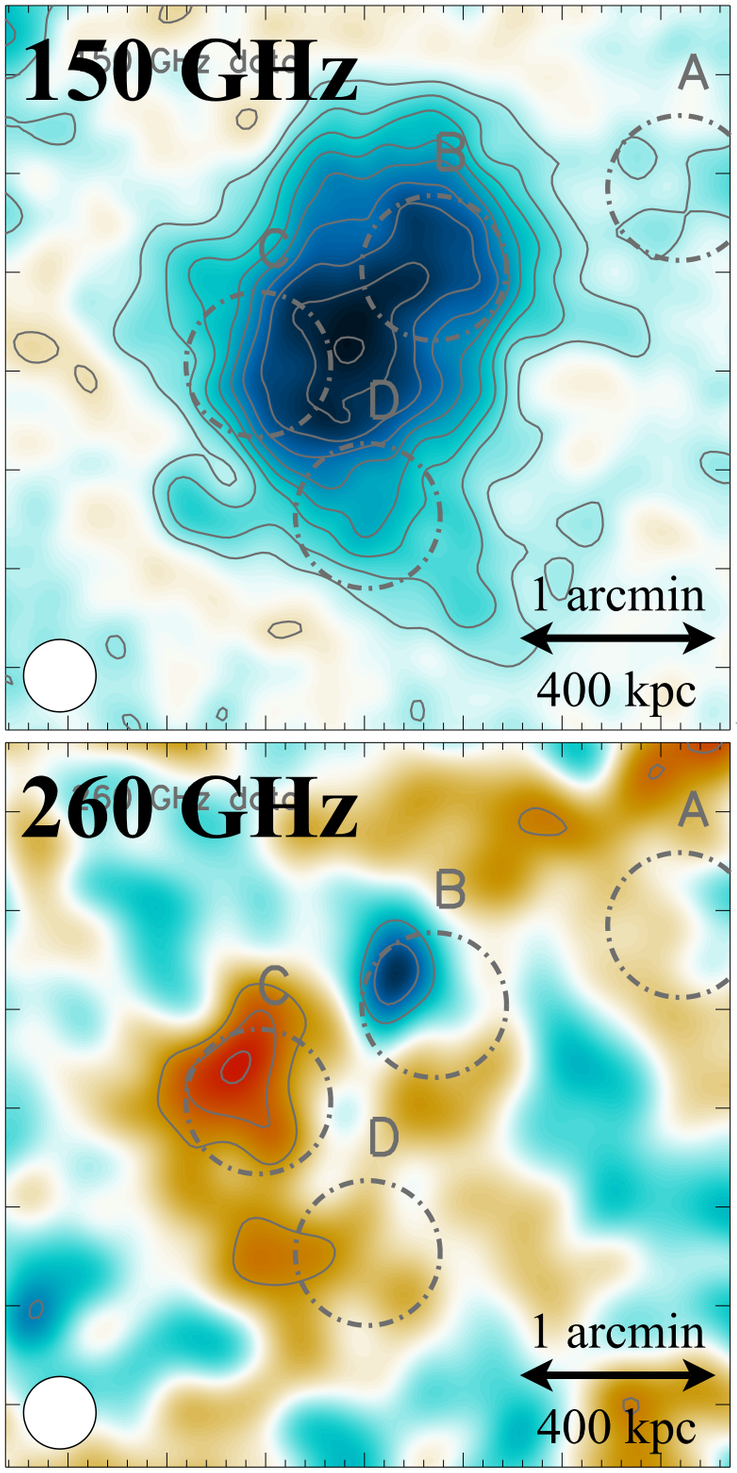
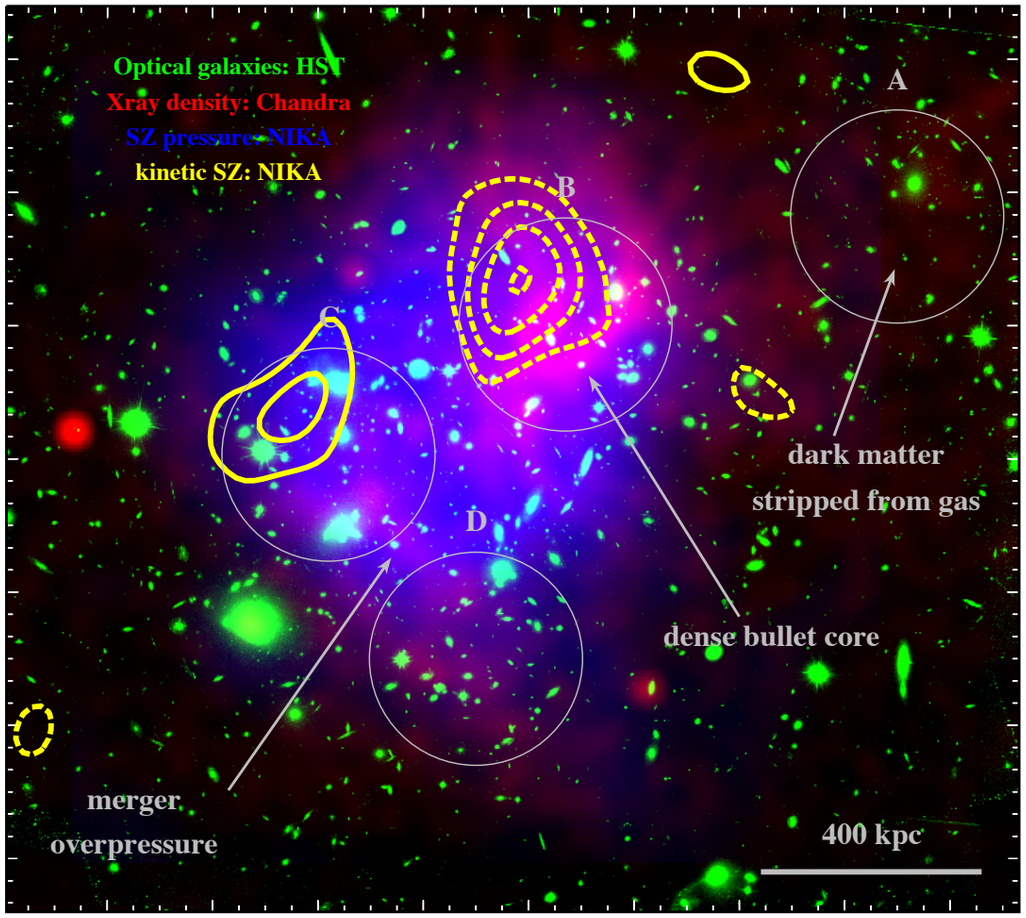


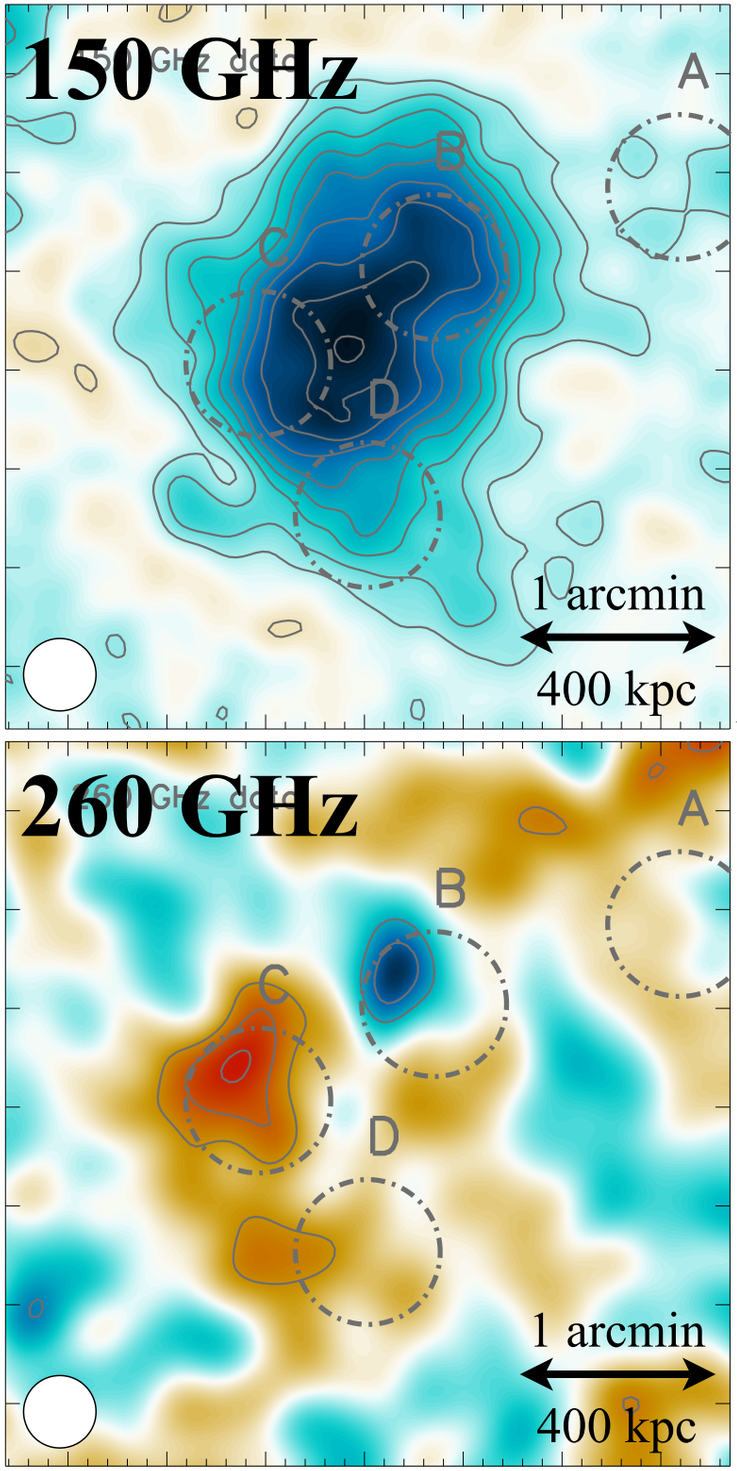
To be compared with multi-wavelength data



➡A bimodal kSZ structure associated with the two main sub-clusters

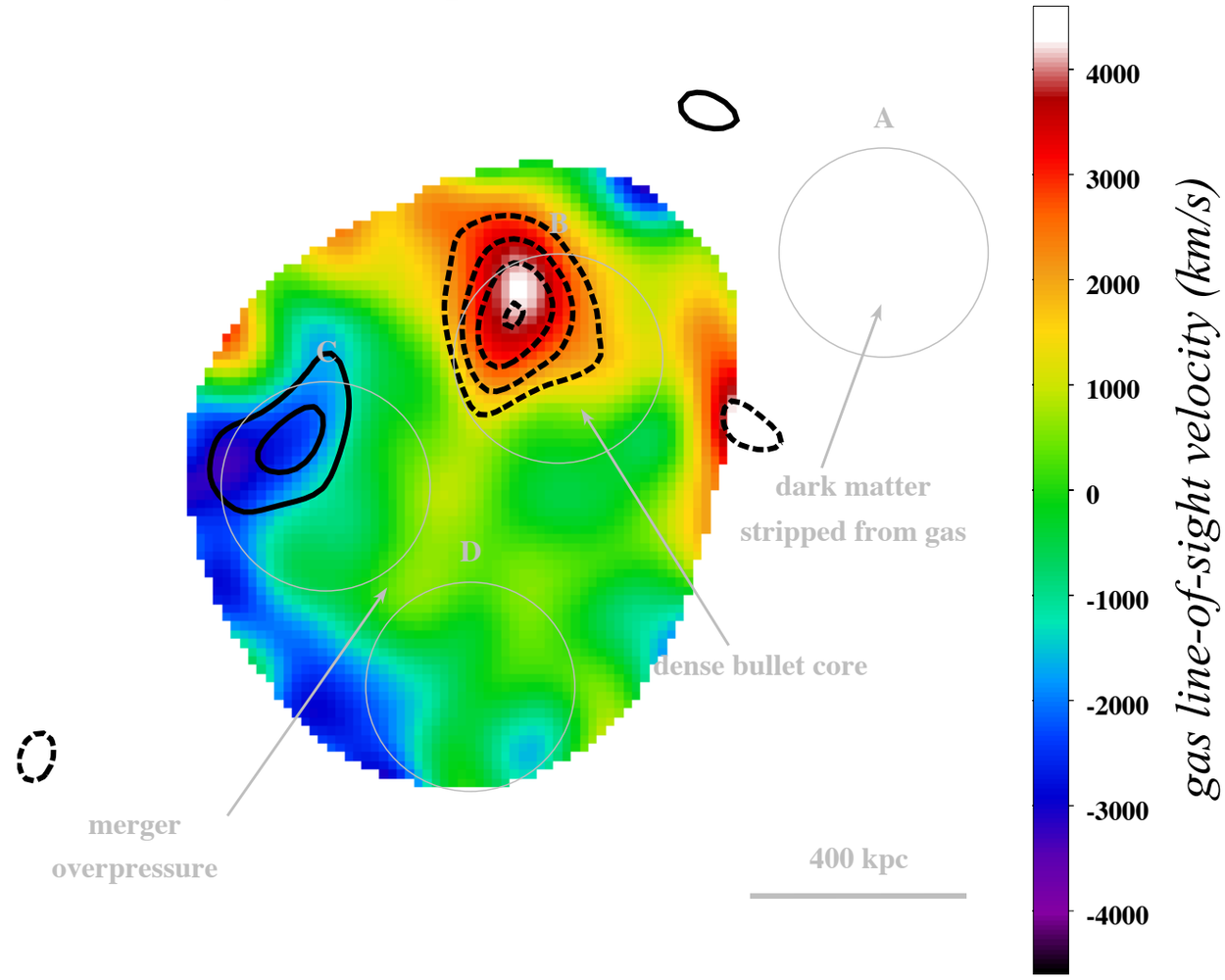
A first kSZ mapping towards a galaxy cluster

[Adam et al. (2017a)]



$$v_z \equiv -\frac{y_{\rm kSZ}}{\int n_e d\ell} \quad \text{(using X-ray)}$$

(Warning: model dependent & n_e-v_z correlations)

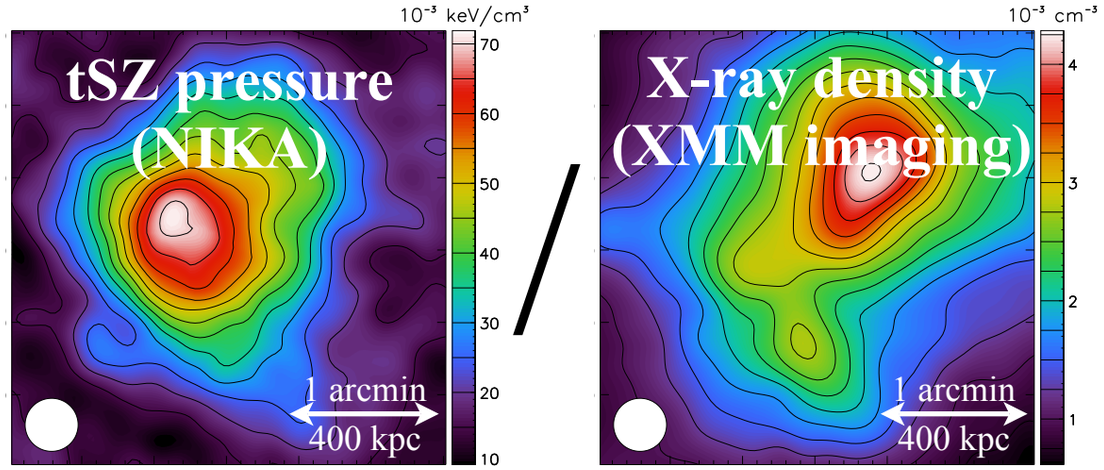


➡ **Also extract the velocity using a gas model**

A new method to map the hot gas in galaxy clusters from tSZ+X-ray imaging

[Adam et al. (2017b)]

X-ray spectro. temperatures are fundamental for astro. & cosmo.,
but are challenging to obtain at high z and may suffer from systematics



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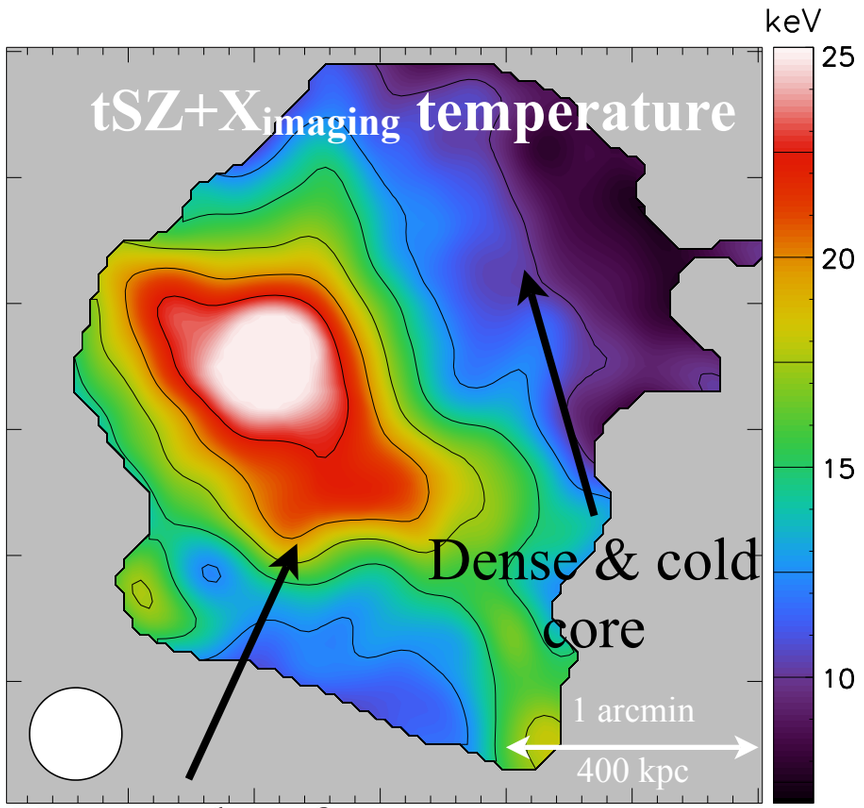
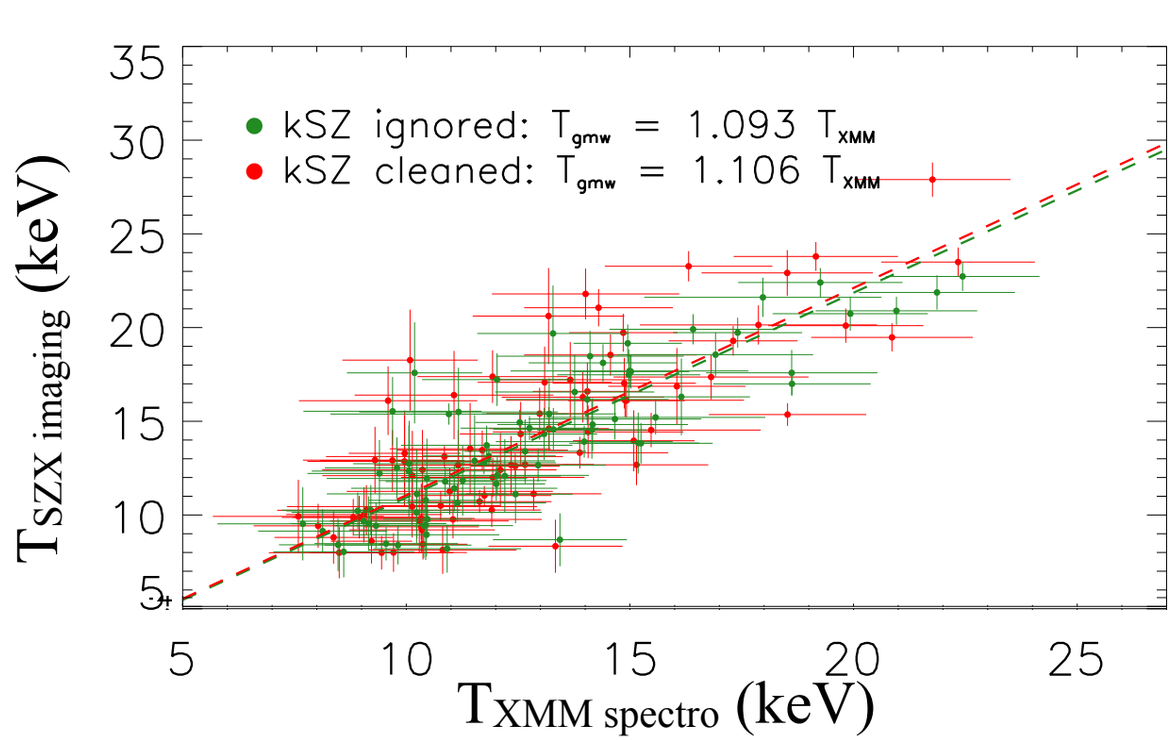


Hot gas bar from merger compression

Alternative: $T_{\rm SZX} \equiv \frac{\int T_e n_e d\ell}{\int n_e d\ell} \propto y_{\rm tSZ} / \sqrt{\ell_{\rm eff} S_{\rm X}}$

- Smaller errors despite obs. time reduced by x3
- Overall agreement with $X_{spectro}$
- Comparison limited by cluster complexity

(cluster geometry, kSZ, clumping, ...)

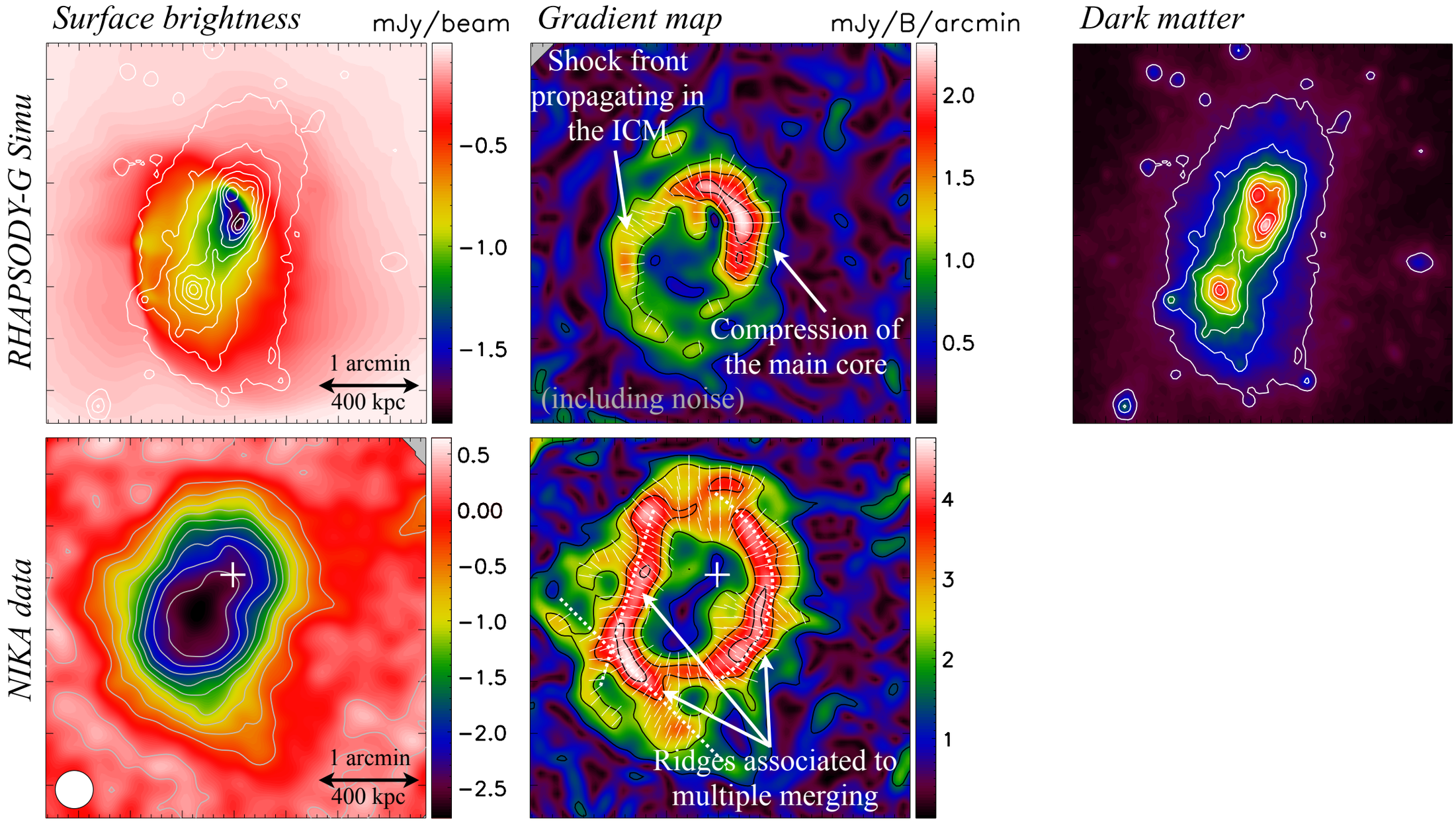


➡ Excellent alternative to probe the gas temperature at high z: understanding cluster assembly

Detecting sub-structures in the pressure distribution with tSZ imaging

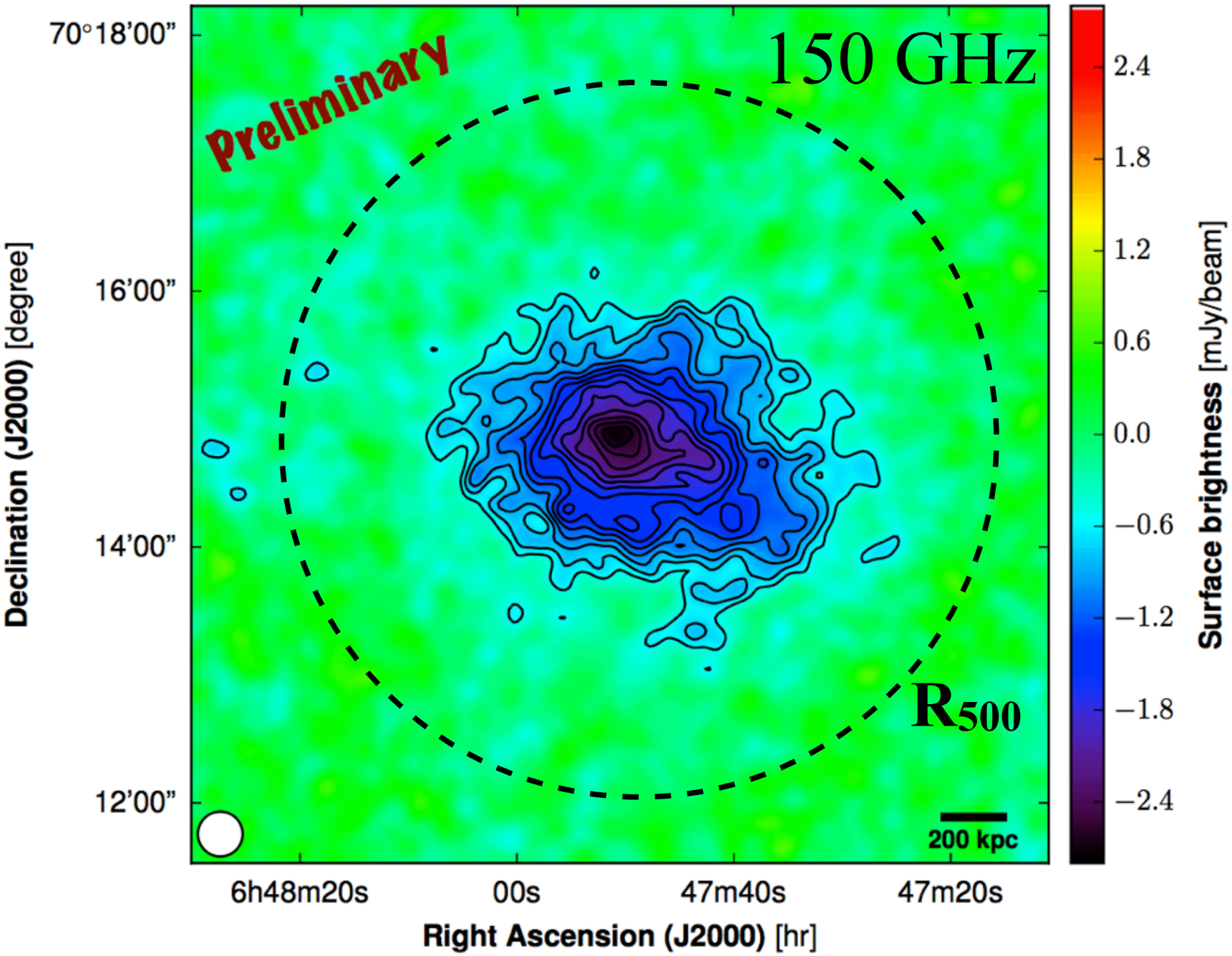
[Adam et al. (in prep)]

The Gaussian Gradient Filtering allows us to extract pressure ridges in tSZ images



➡ tSZ imaging has now reached the sensitivity and resolution to explore the details of pressure sub-structure

First tSZ observations with NIKA2
PSZ2 G144.83+25.11 (i.e., MACS J0647+7015)



- z = 0.58
- $M_{500} \sim 7 \times 10^{14}\ M_{sun}$

- 11 hours under poor weather conditions
- > 10 σ/beam at the peak
- Mapping over >1Mpc

[Ruppin et al. (in prep.)]

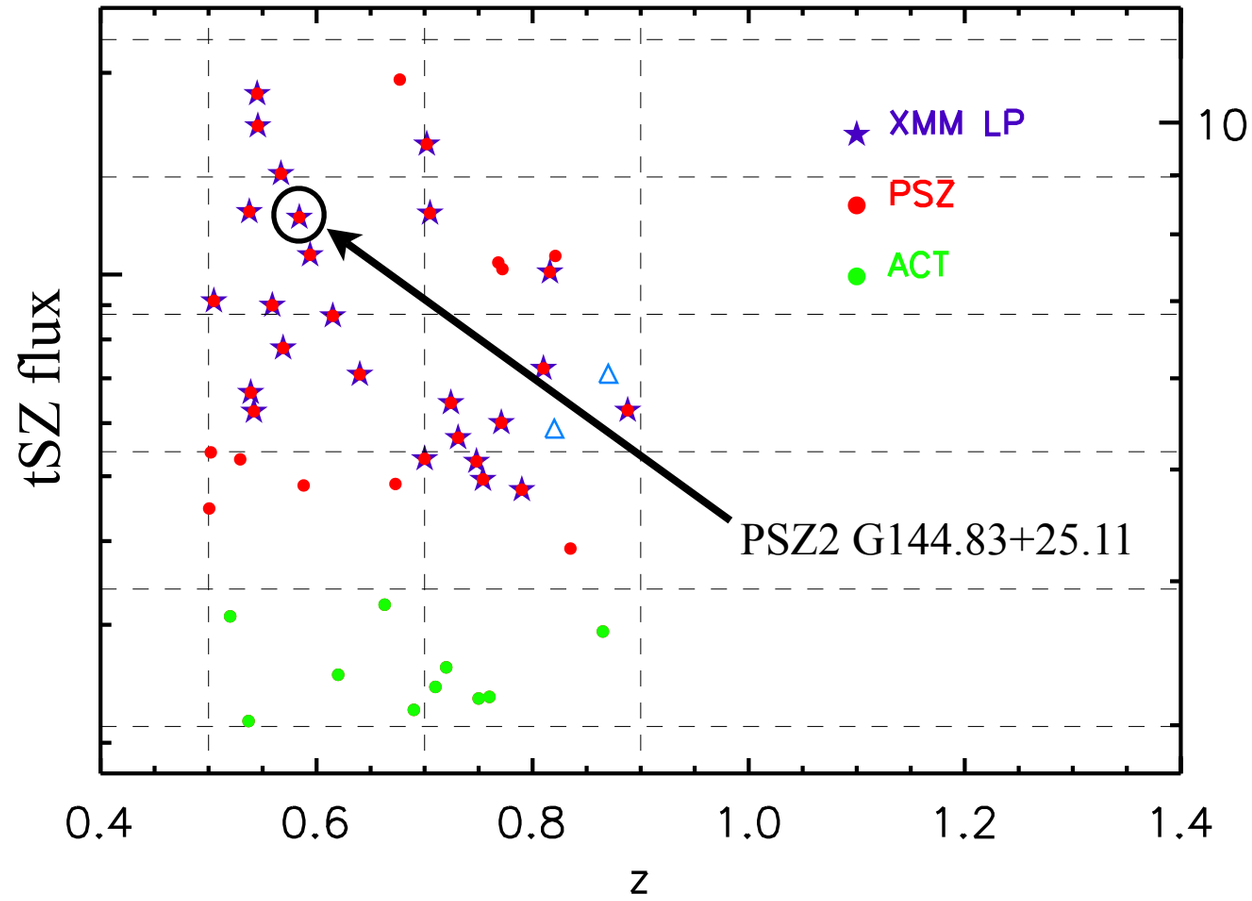
NIKA2 capabilities are much better than expected

The NIKA2 SZ large program

NIKA2 is **opened** to the community

SZ large program

- **300 hours** dedicated for SZ
- ~ **50 clusters** at **0.5 < z < 1**
- Planck/ACT clusters: **representativity**
- Combine NIKA with **Planck**, **X-ray,** optical, radio, submm and other datasets



Main goals

- Calibrating the **tSZ flux** as a **mass** proxy and its **evolution** with redshift
- Pressure profile evolution with redshift
- Characterize the **structural properties** and clusters dynamical state

NIKA2 observations (LP+external) are about to start

Conclusions

The SZ effect in the Planck era

- The SZ effects are excellent astro. & cosmo. probe
- Now need high resolution follow-up: substructure, high z

Status of SZ imaging

- The NIKA pathfinder has established tSZ & kSZ capabilities
- SZ imaging: test case demonstration and nice results

Next steps

- NIKA studies to be applied on NIKA2 cosmological sample
- Mutli-wavelength synergies being developed

R. Adam, A. Adane, P. Ade, P. André, A. Andrianasolo, M. Arnaud, H. Aussel, I. Bartalucci, A. Beelen, B. Belier, A. Benoît, A. Bideaud, N. Billot, G. Blanquer, N. Boudou, H. Bourdin, O. Bourrion, A. Bracco, M. Calvo, A. Catalano, G. Coiffard, B. Comis, A. Cruciani, A. D'Addabbo, M. De Petris, J. Démoclès, F.-X. Désert, S. Doyle, E. Driessen, E. Egami, R. Evans, C. Ferrari, J. Goupy, O. Hahn, B. Hasnoun, I. Hermelo, C. Kramer, G. Lagache, S. Leclercq, J. P. Leggeri, J. F. Lestrade, J.-F. Macías-Pérez, G. Martinez-Aviles, J. Martino, D. Martizzi, A. Maury, S. Maurogordato, P. Mauskopf, F. Mayet, A. Monfardini, T. Mroczkowski, S. Navarro, F. Pajot, E. Pascale, L. Perotto, G. Pisano, E. Pointecouteau, N. Ponthieu, G.W. Pratt, V. Revéret, M. Ricci, A. Rigby, A. Ritacco, L. Rodriguez, C. Romero, H. Roussel, F. Ruppin, G. Savini, K. Schuster, A. Sievers, S. Triqueneaux, C. Tucker, H.-Y. Wu, M. Zemcov, R. Zylka