Observations of the Sunyaev-Zel'dovich effect from galaxy clusters

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IAS Orsay - 24/11/2016

Outline

1. **The Sunyaev-Zel'dovich effect in the Planck era**

2. **Pushing observations at high resolution and high z**

3. **Next step at the IRAM 30m telescope with NIKA2**

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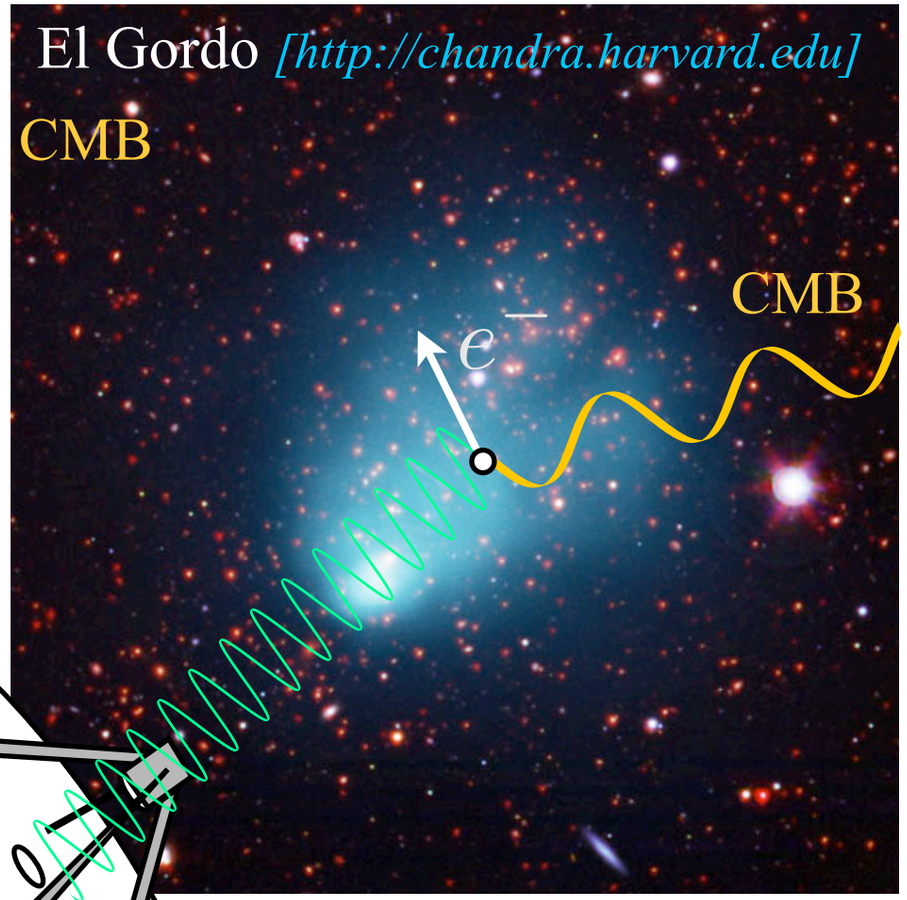
Looking at clusters using the SZ effects

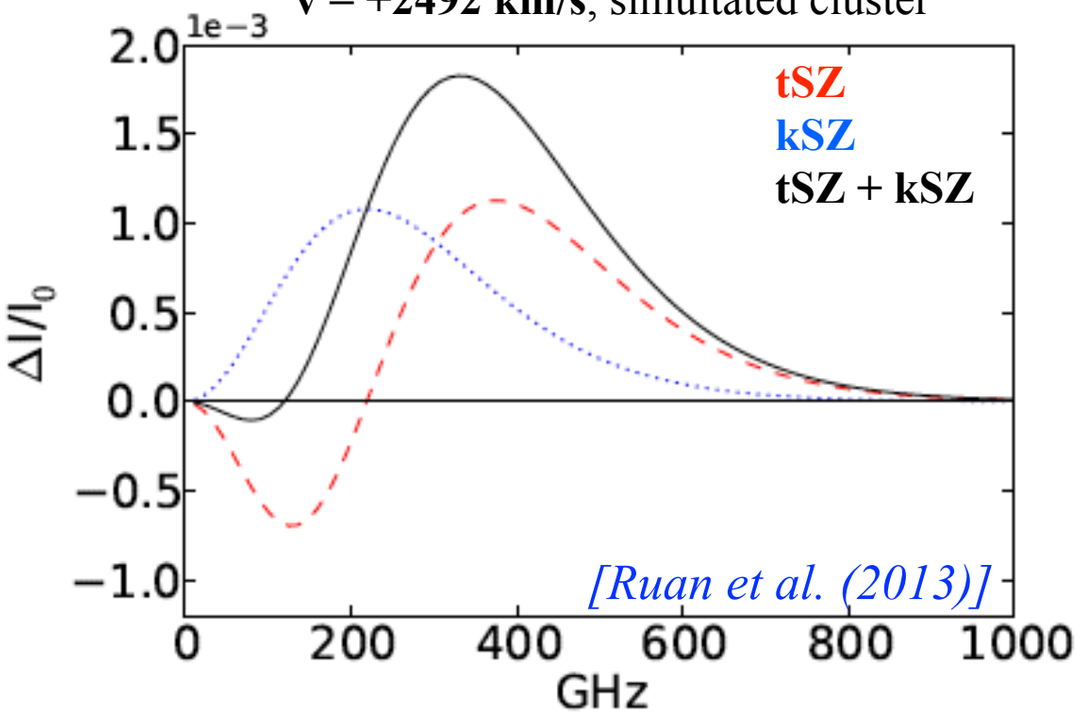
- **tSZ** = CMB spectral distortion from interaction with clusters' hot electrons
- **kSZ** = CMB Doppler shift from bulk motion of electrons (typically ~ tSZ/10)

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

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



v = +2492 km/s, simultated cluster



➡ **SZ = probe for intracluster gas**

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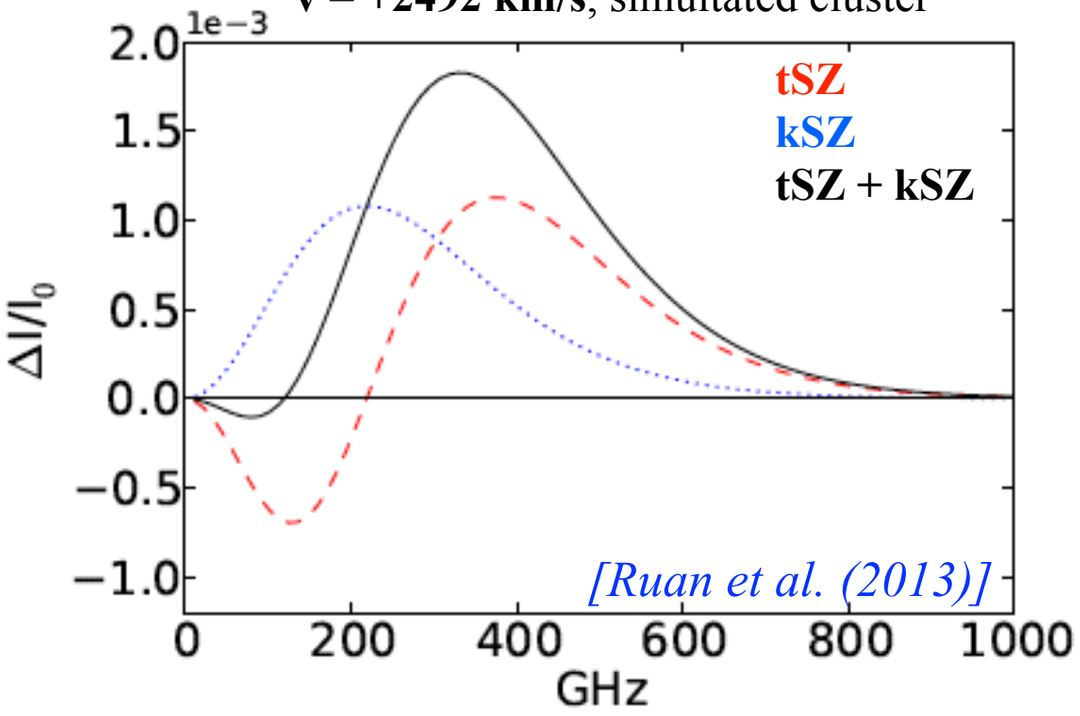
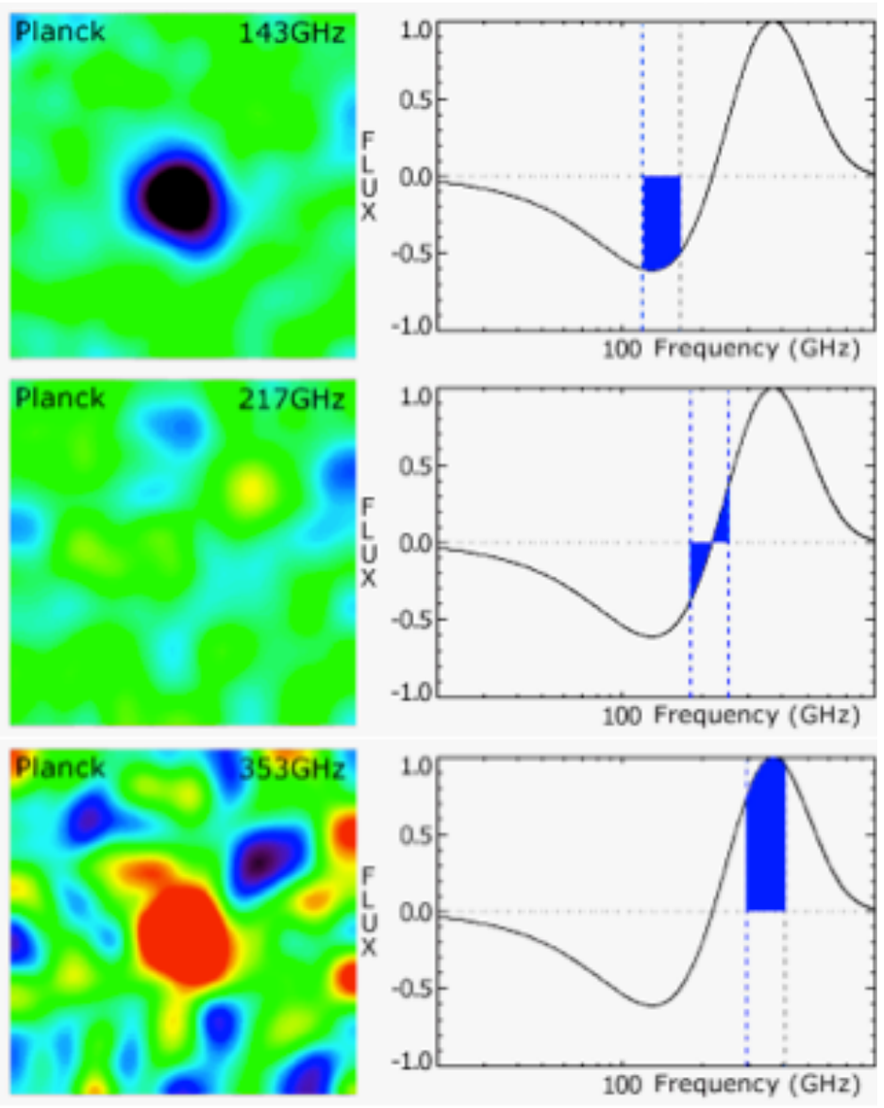


tSZ only here *[ESA HFI/LFI consortia]*



➡ **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

➡ kSZ momentum ~ velocity

Cluster Cosmology

Growth of structures
Universe expansion history
Large scale velocity flow

Control in detection & mass determination

Astrophysical models

Cluster Astrophysics

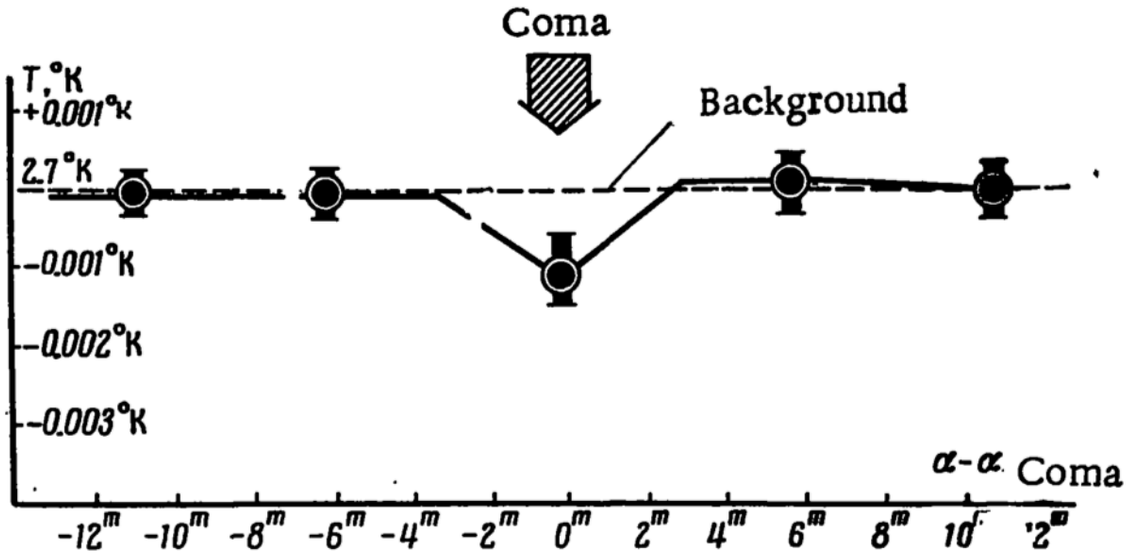
Gas, galaxies and dark matter interplay
Shock heating / turbulence
Feedback
Gas clumping
...

➡ **Deep astrophysical understanding needed for cosmology**

The beginning of Sunyaev-Zel'dovich observations

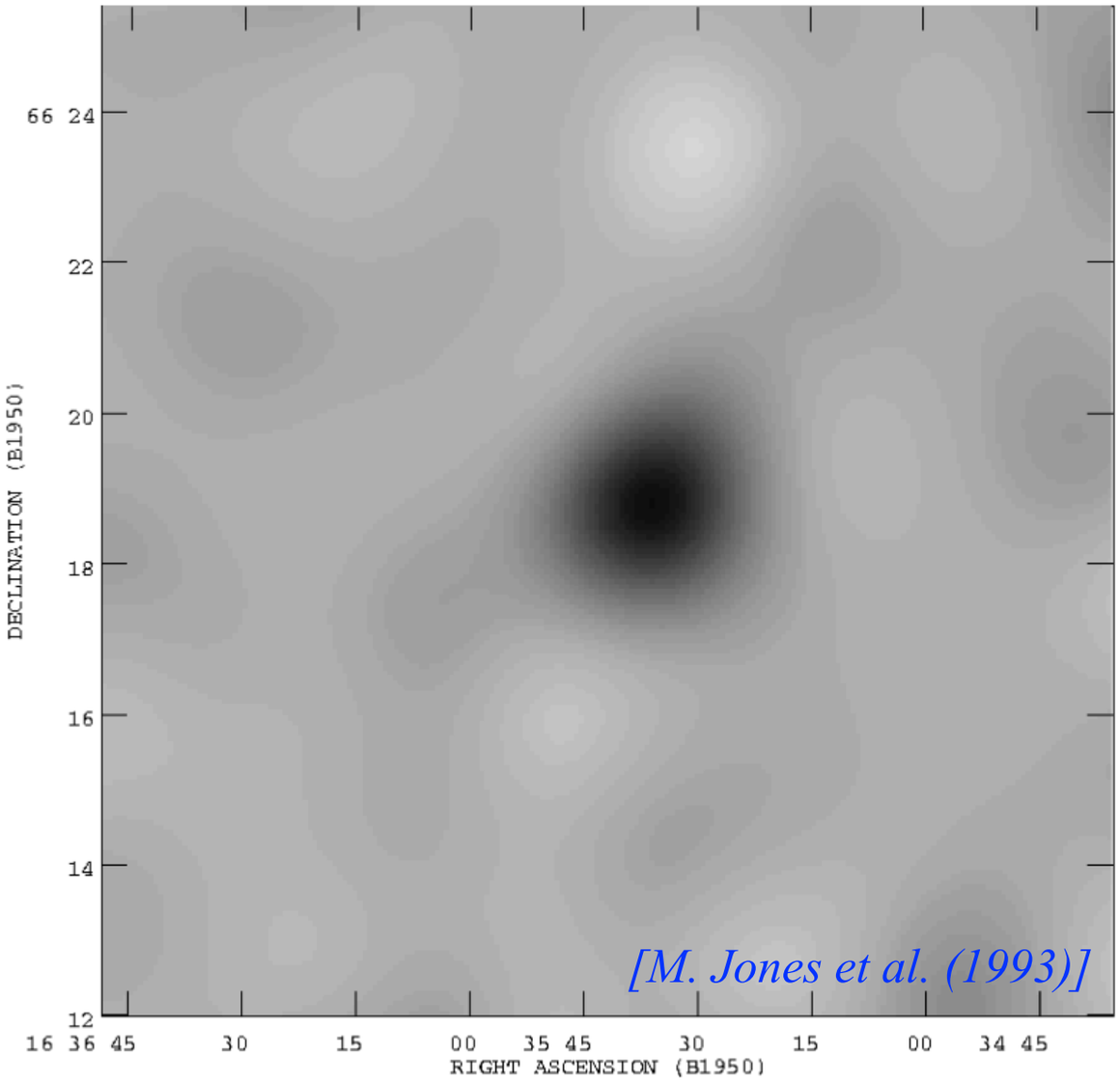
- Formalism early 70's *[Sunyaev & Zel'dovich (1970)]*
- First tSZ detections in the 70's

First tentative detection with the Pulkovo telescope at 7.5 GHz [Pariiskii (1973)]



- Several measurements from the 90's
- First kSZ detections in 2012

A first image (interferometric): Abell 2218 with the Ryle Telescope at 15 GHz and 6' FWHM



[M. Jones et al. (1993)]

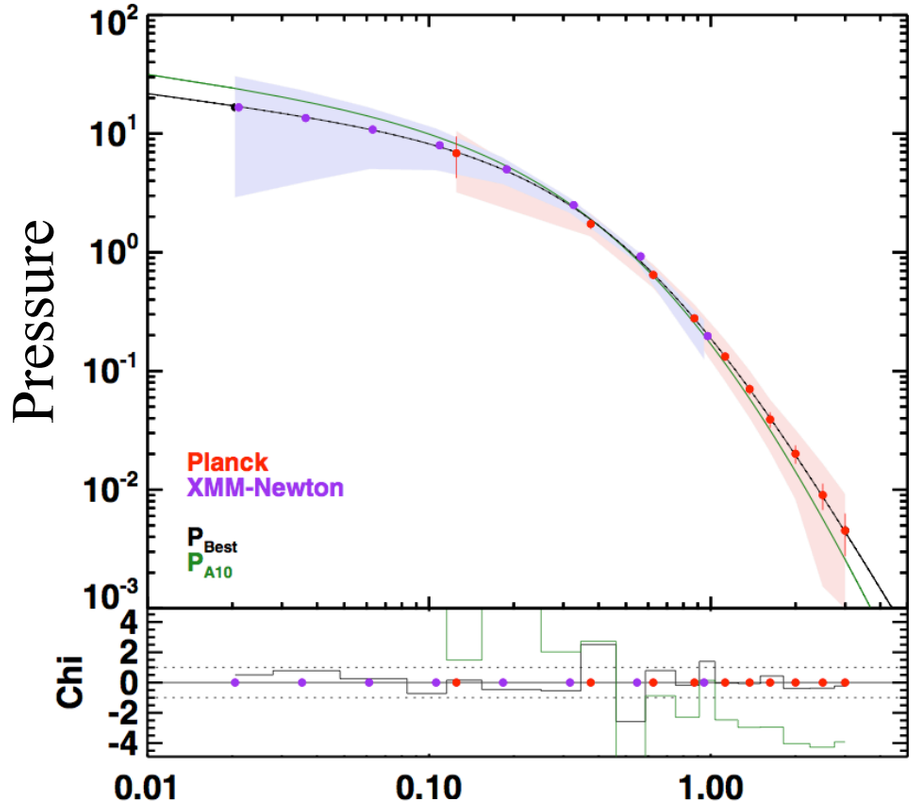
SZ status after Planck (and other surveys)

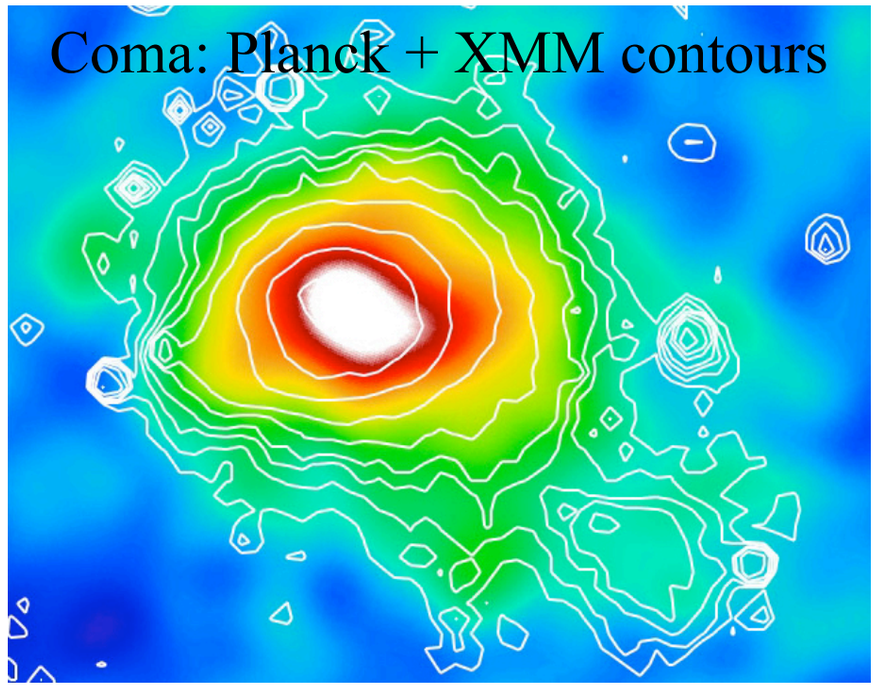
- Pressure profile of nearby clusters *[Planck V (2013)]*
- Detailed study of nearby clusters (e.g., Coma *[Planck X (2013)]*, filaments *[Planck VIII (2013)]*)
- All-sky SZ catalog of 1653 clusters *[Planck XXIX (2013), XXVII (2015)]*
- Full sky y-map *[Planck XXII (2015)]*
- Number count *[Planck XXIV (2015), Planck XX (2013)]*
- ...

- See also results by SPT, ACT, ... (e.g., statistical detection of kSZ signal *[Hand (2012), Soergel (2016)]*)

- See also many results using SZ selected samples

➡ **Huge astro/cosmo progress & new fundamental questions**





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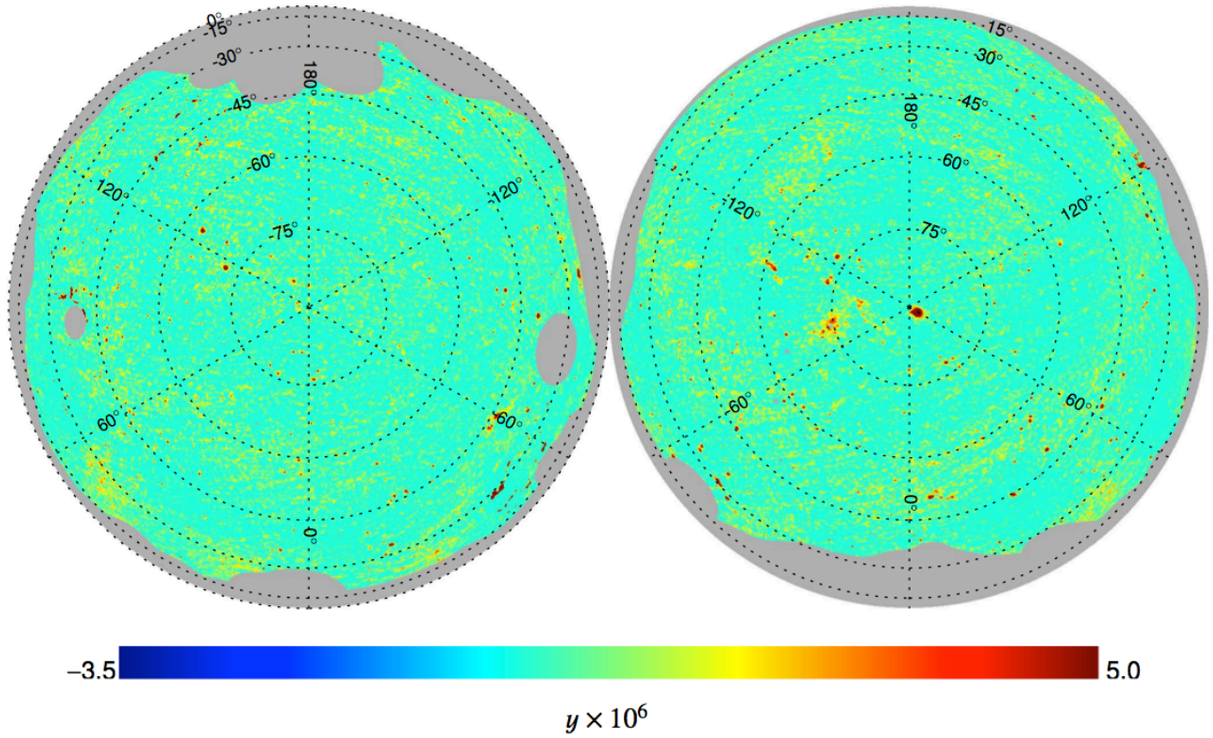

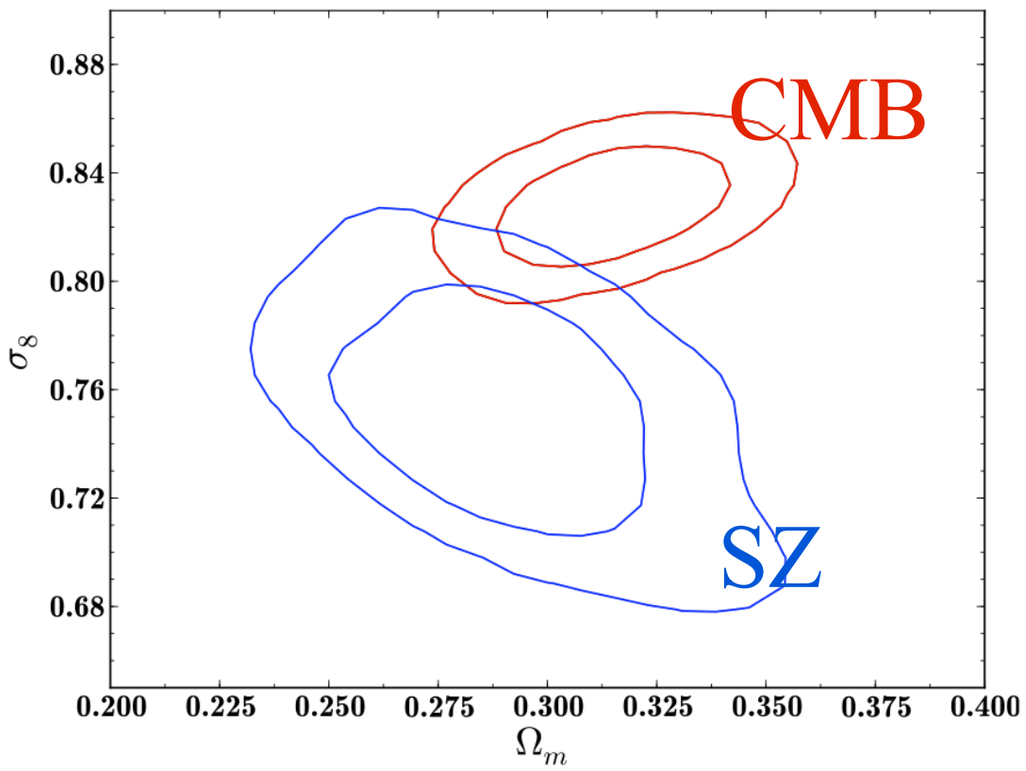

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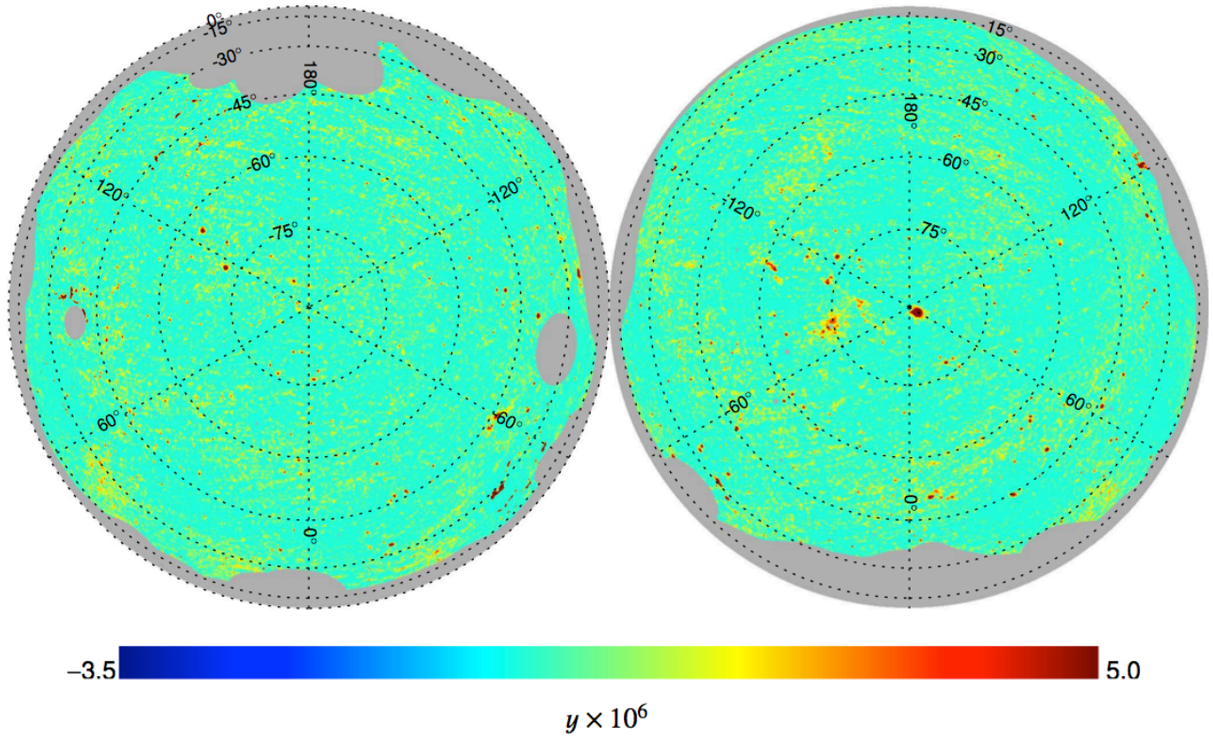

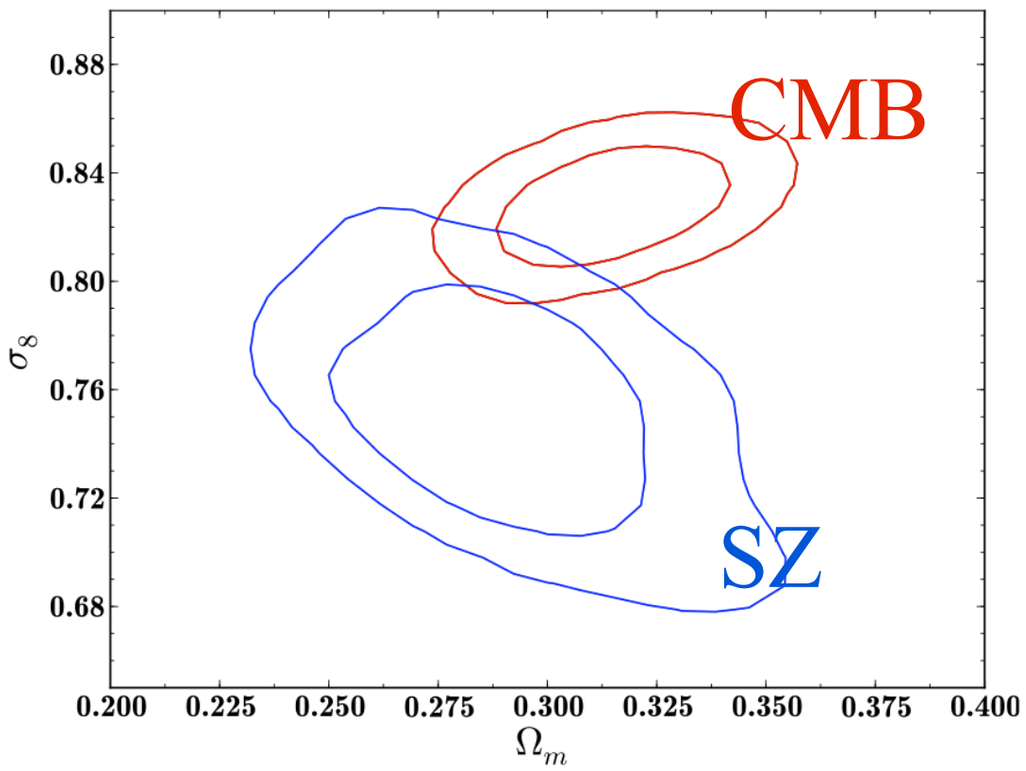

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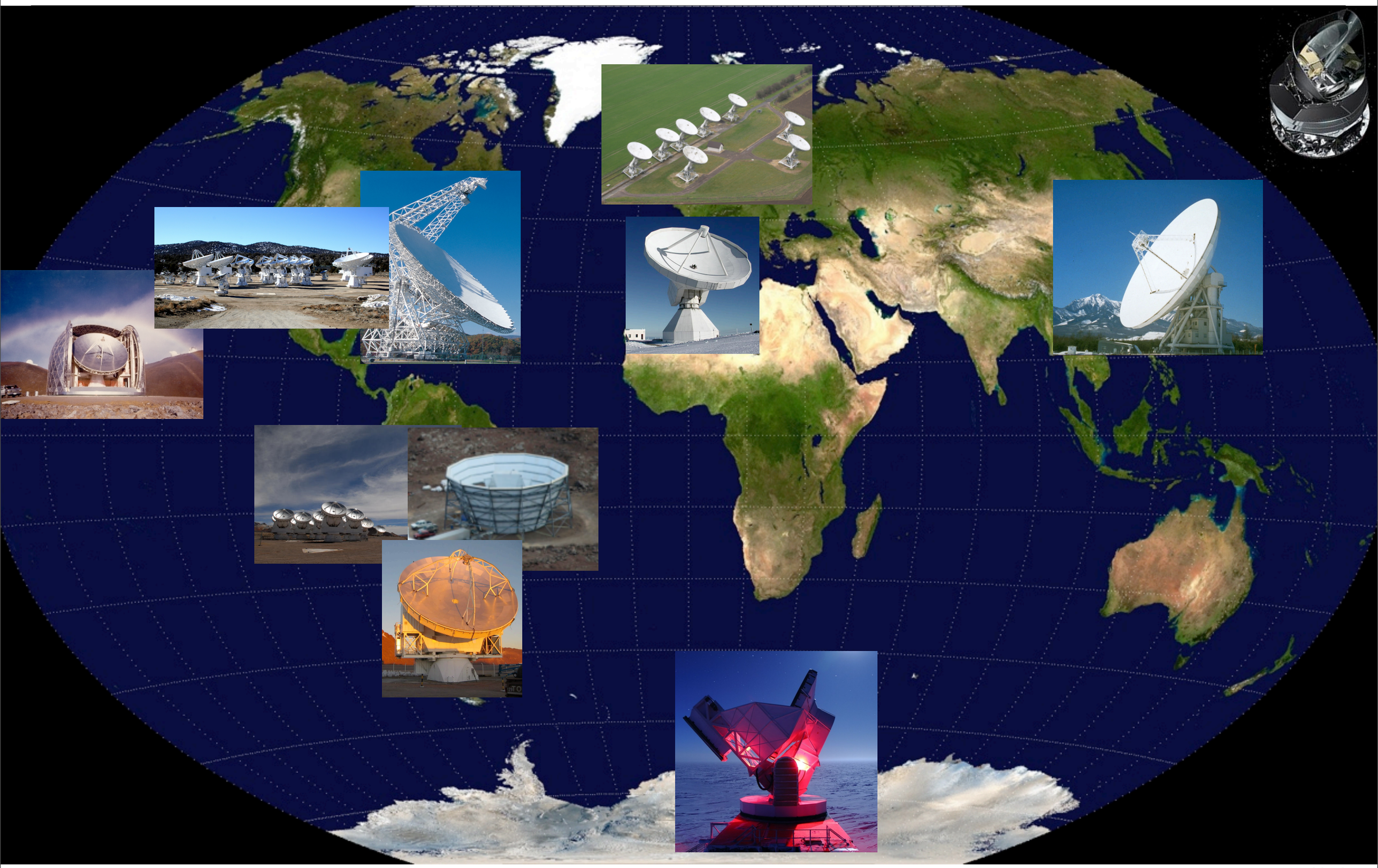
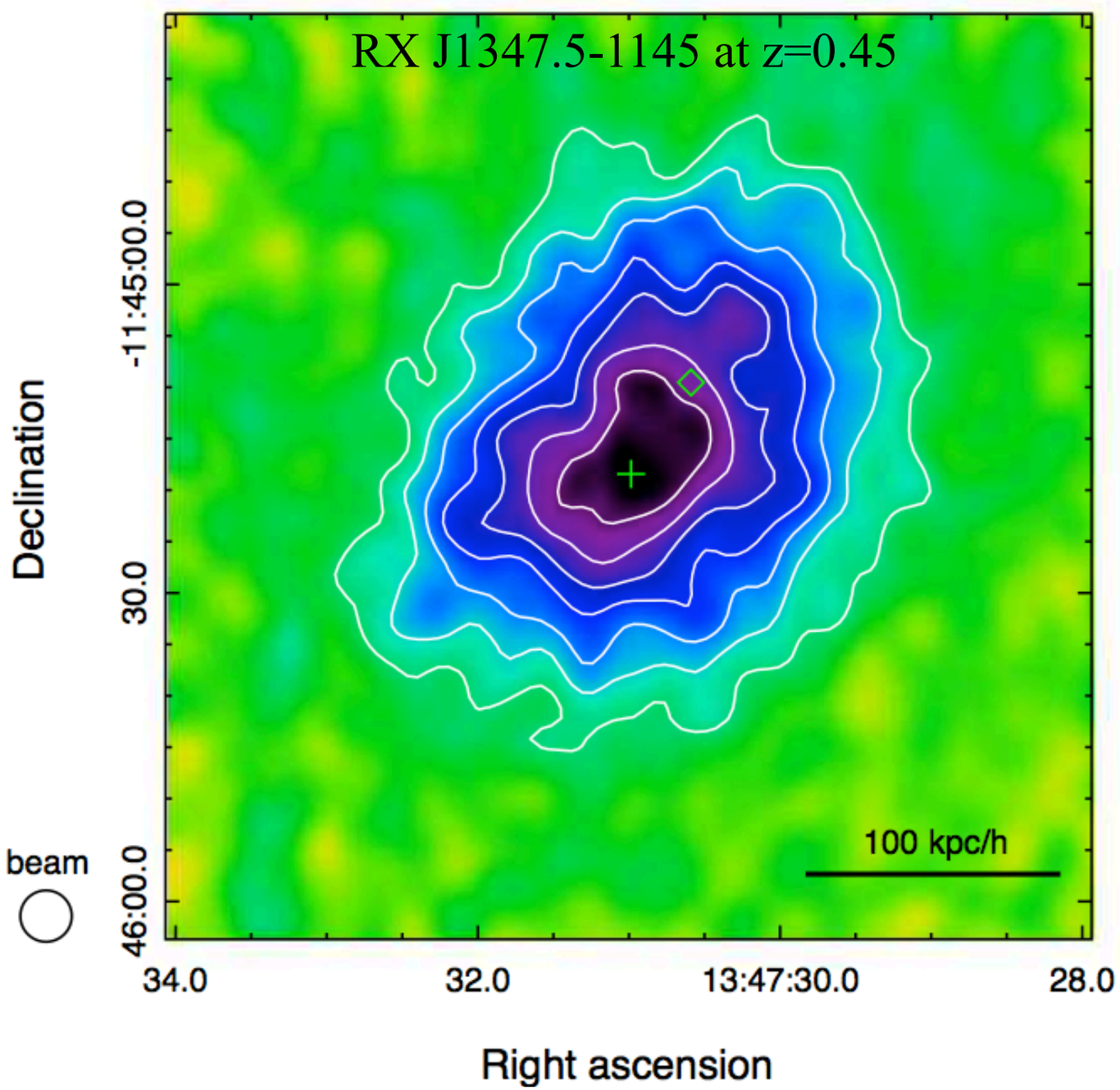
There are many SZ instruments



Towards SZ imaging at arcsec resolution with ALMA



First SZ detection with ALMA:

[Kitayama et al. (2016)]

- 90 GHz with 7m+12m array
- 5" FWHM (20 kpc) and up to 40"
- >15 sigma at the peak in ~8h

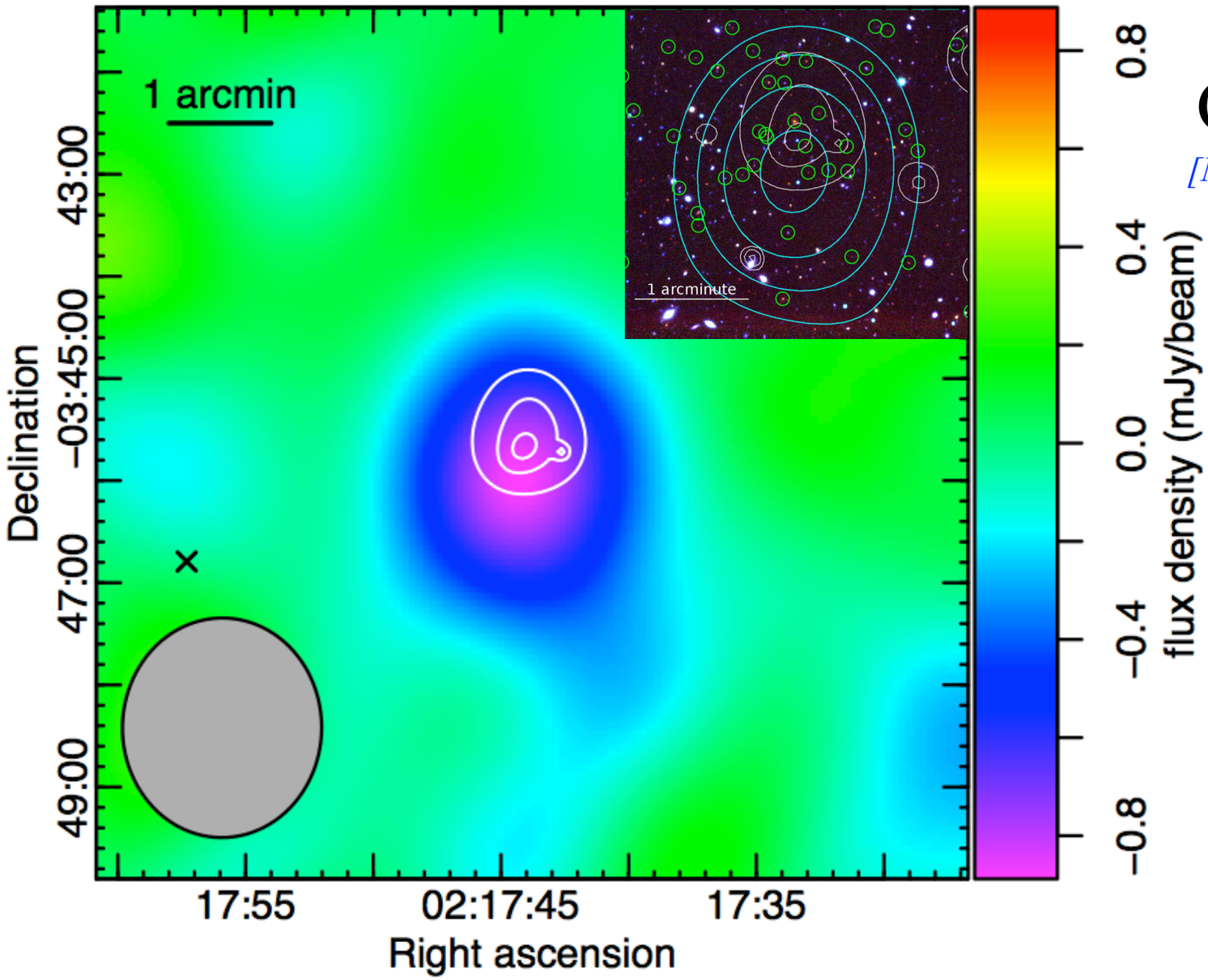
➡ SZ highest angular & physical resolution

See also the SZ detection of a shock in El Gordo (z ~ 0.9)

[Basu et al. (2016)]

➡ **Huge potential for ALMA SZ observations**

SZ detection at very high redshift with CARMA



CARMA follow-up at high z

[Mantz et al. (2014)]

- XXL cluster XLSSUJ021744
  [see also M. Ricci's poster for XXL]
- z = 1.9
- Good agreement with extrapolation of L_X - SZ flux scaling

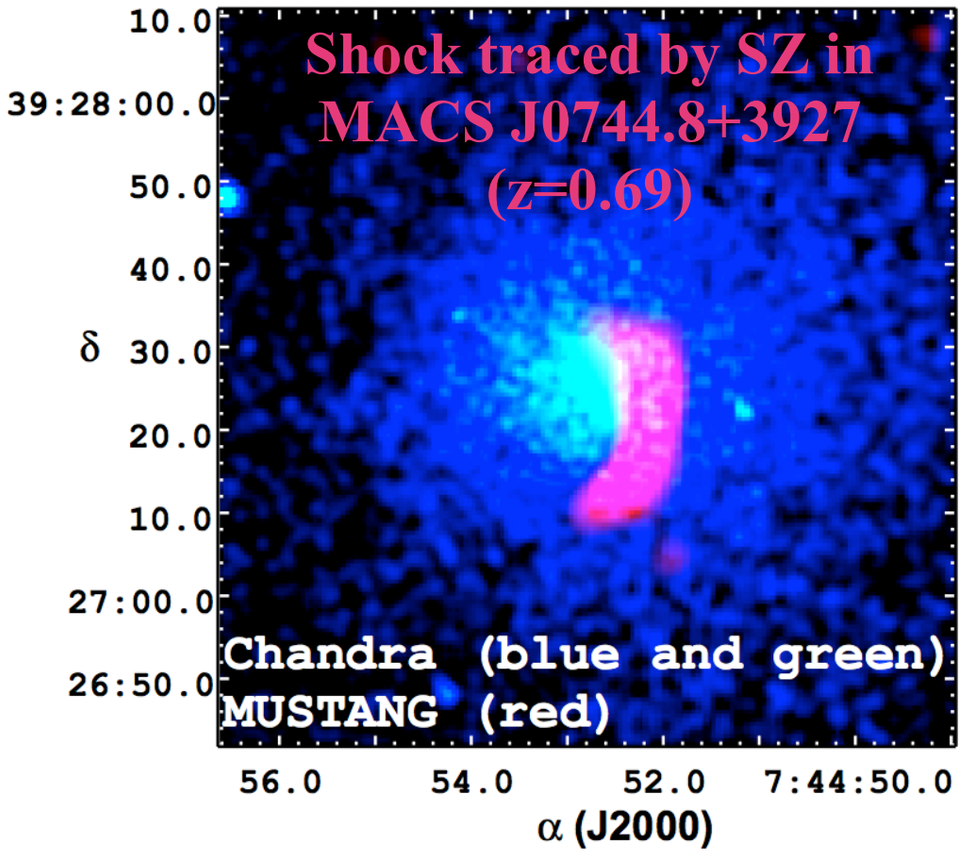
➡ No evolution anomaly with one high z cluster

The inner structure of SZ clusters: sub-structures

MUSTANG on the GBT

[Mason (2010), Korngut (2011), Mroczkowski (2012), Romero (2015,2016), Young (2015)]

- 9” FWHM at 90 GHz
- 42” FOV filled with 64 TES

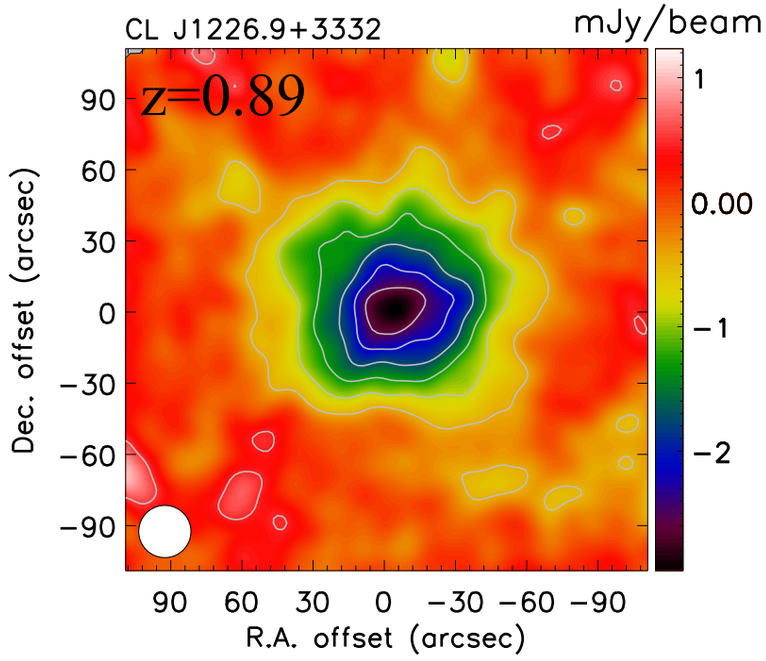


NIKA on the IRAM 30m

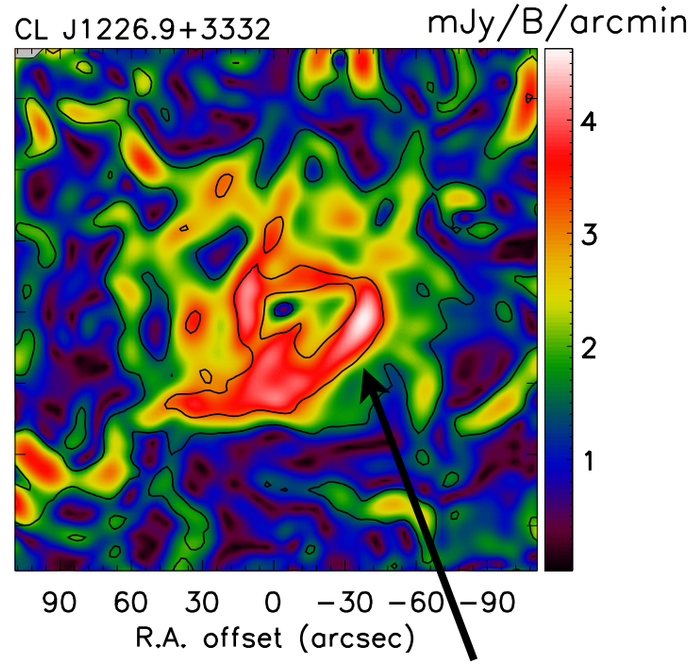
[Adam (2014,2015,2016a,2016b), Ruppin (2016)]

- 12” & 18” FWHM at 260 & 150 GHz
- 2’ FOV filled with ~300 KIDs

NIKA map



Gradient filtered map



Pressure jump caused by merger

➡ **Detailed characterization of the pressure sub-structures**

The inner structure of SZ clusters: pressure profile

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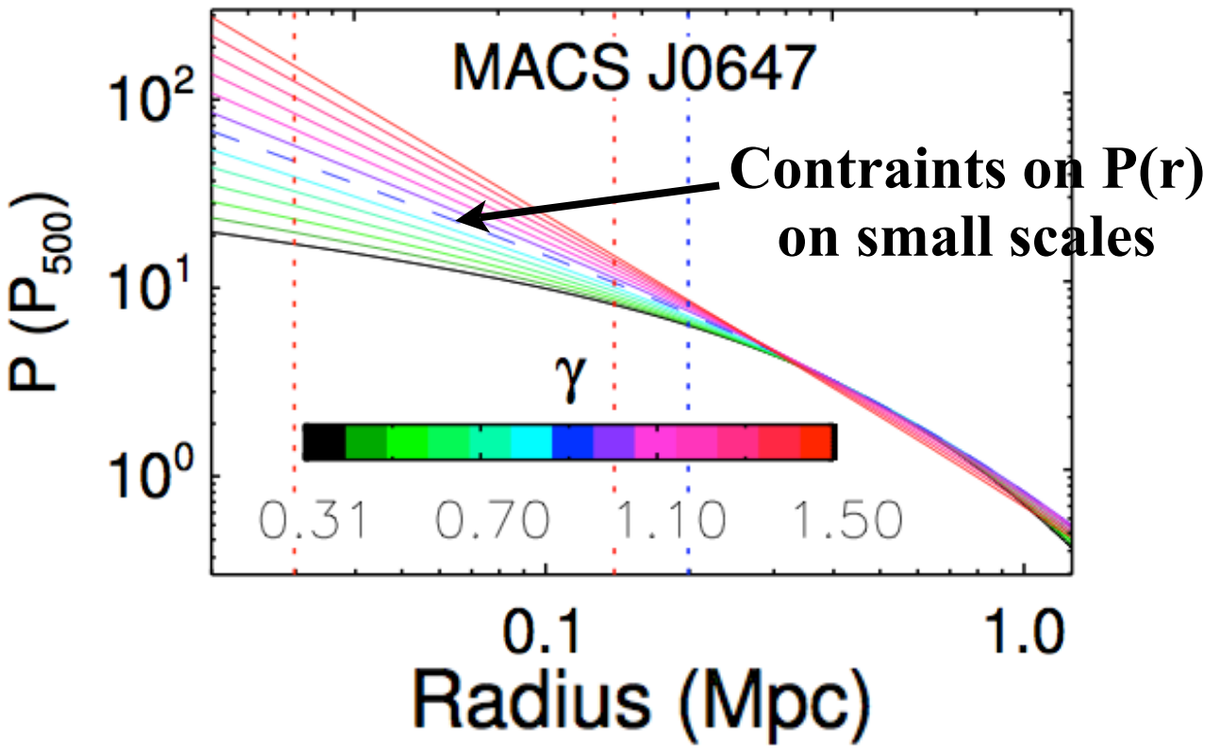

➡ **CC/NCC dichotomy**

NIKA on the IRAM 30m

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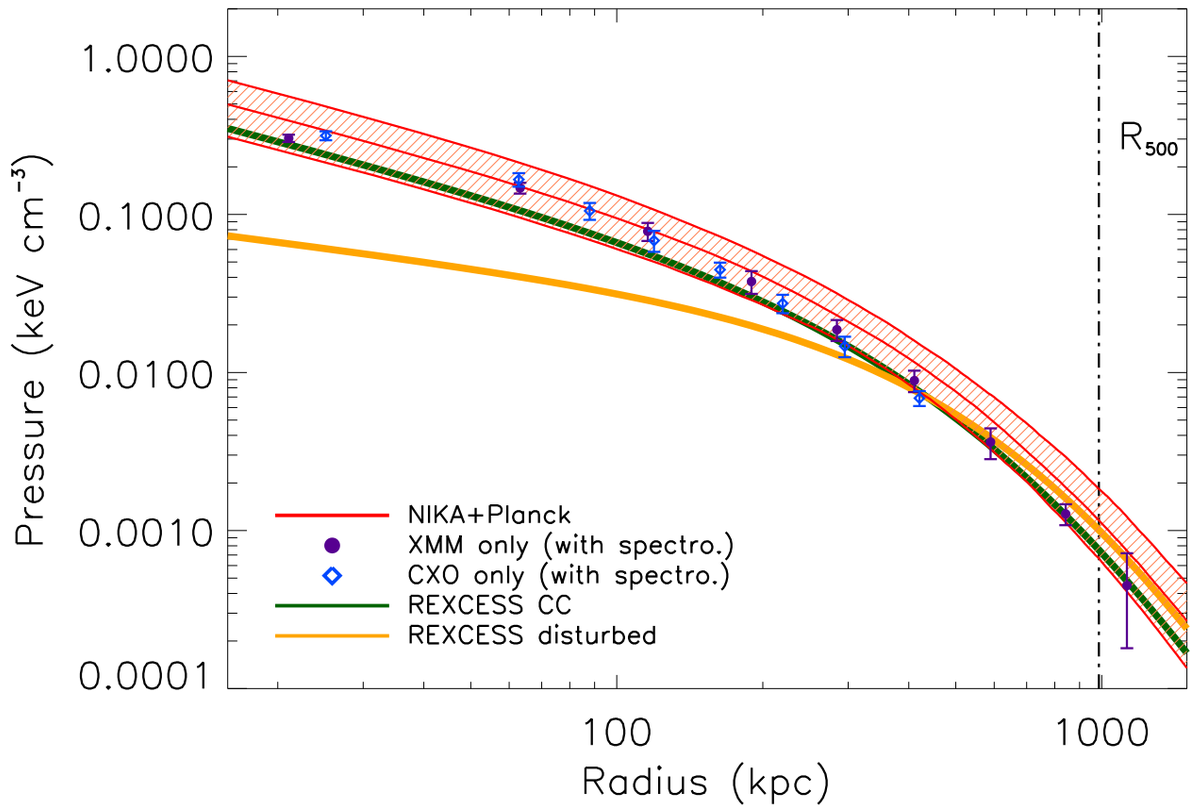


➡ **See Florian Ruppin’s poster/talk**

➡ **Direct measurement of P(r): universality as a matter tracer?**

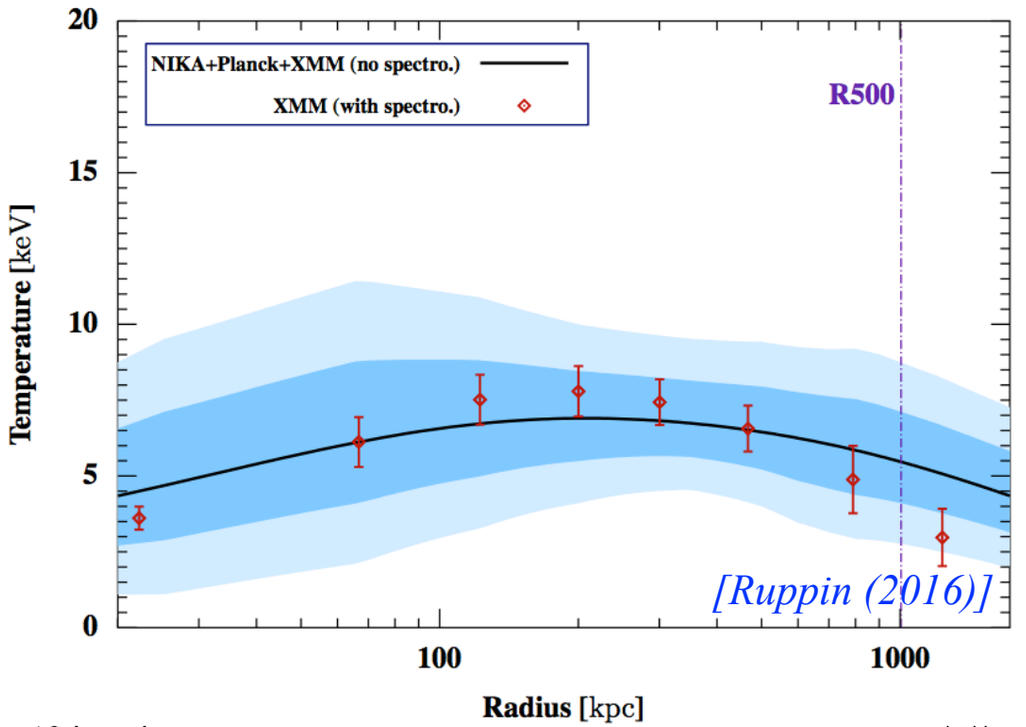
Gas temperature from SZ+X-ray imaging

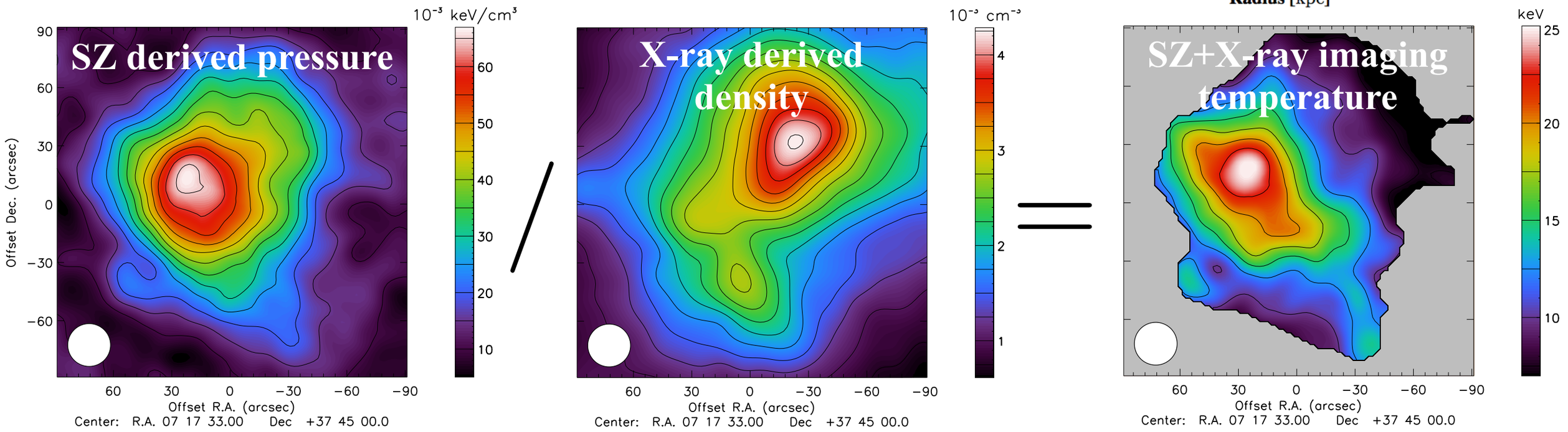
- Temperature fundamental for astro & cosmo
- Several systematics in X-ray spectroscopic T

$$\Rightarrow k_{\rm B}T = P_{\rm SZ}/n_{\rm X}$$

- Independent cross-check of X-ray spectro.

➡ Done in 1D *[e.g., Basu (2012), Adam (2015), Ruppin (2016)]*
➡ And now in 2D *[NIKA+XMM]*





➡ **First temperature map from SZ imaging**

Individual detection of the kinetic SZ effect
MACS J0717.5+3745 at z=0.54

High sensitivity + high angular resolution + systematics removal required

➡ **Very challenging to measure**

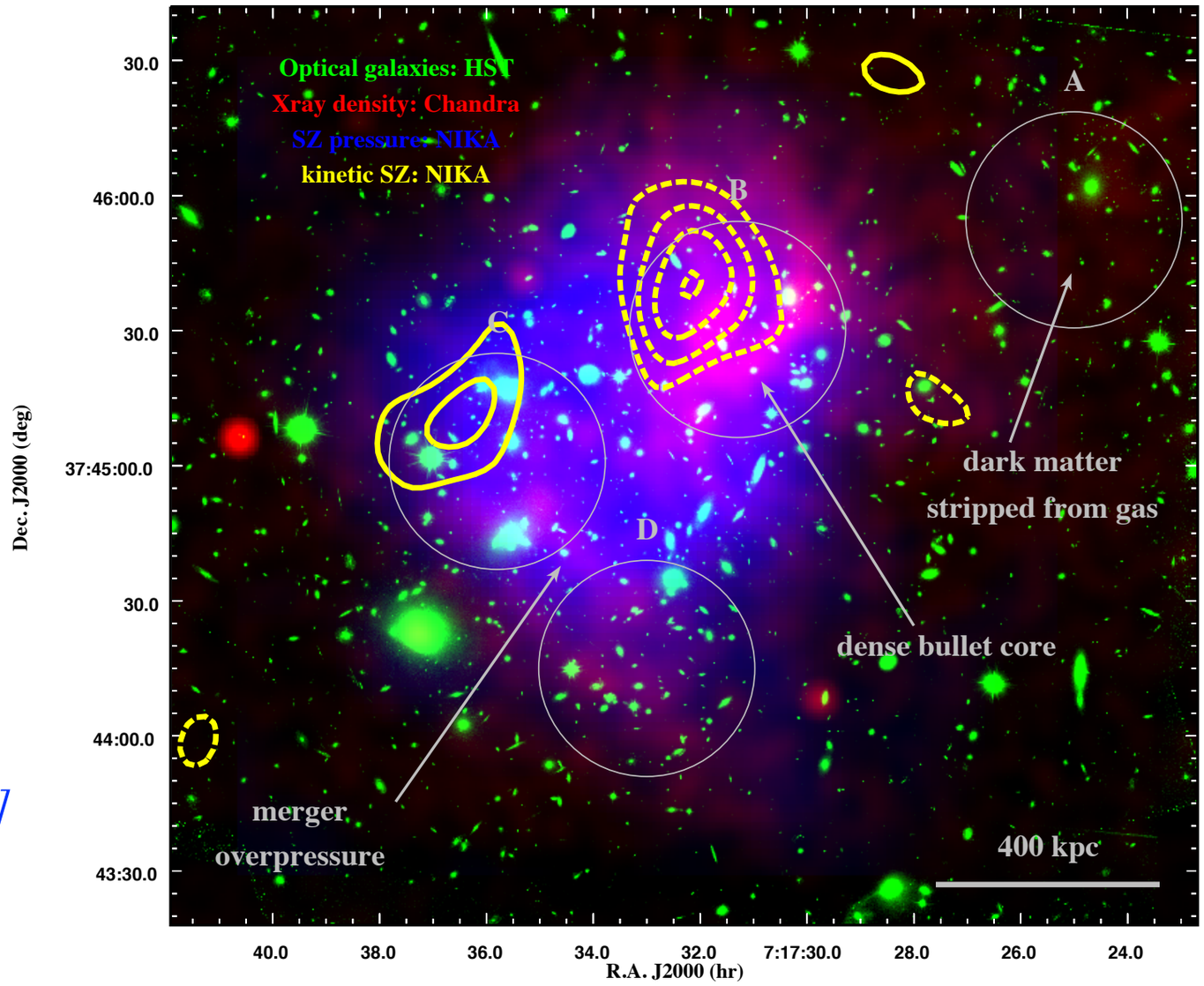
spectral dependencies

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

gas pressure — *gas velocity and density*

➡ Separate kSZ and tSZ with 2 bands

- First detection by Bolocam *[Sayers et al. 2013]*
- First imaging by NIKA *[Adam et al. 2016]*



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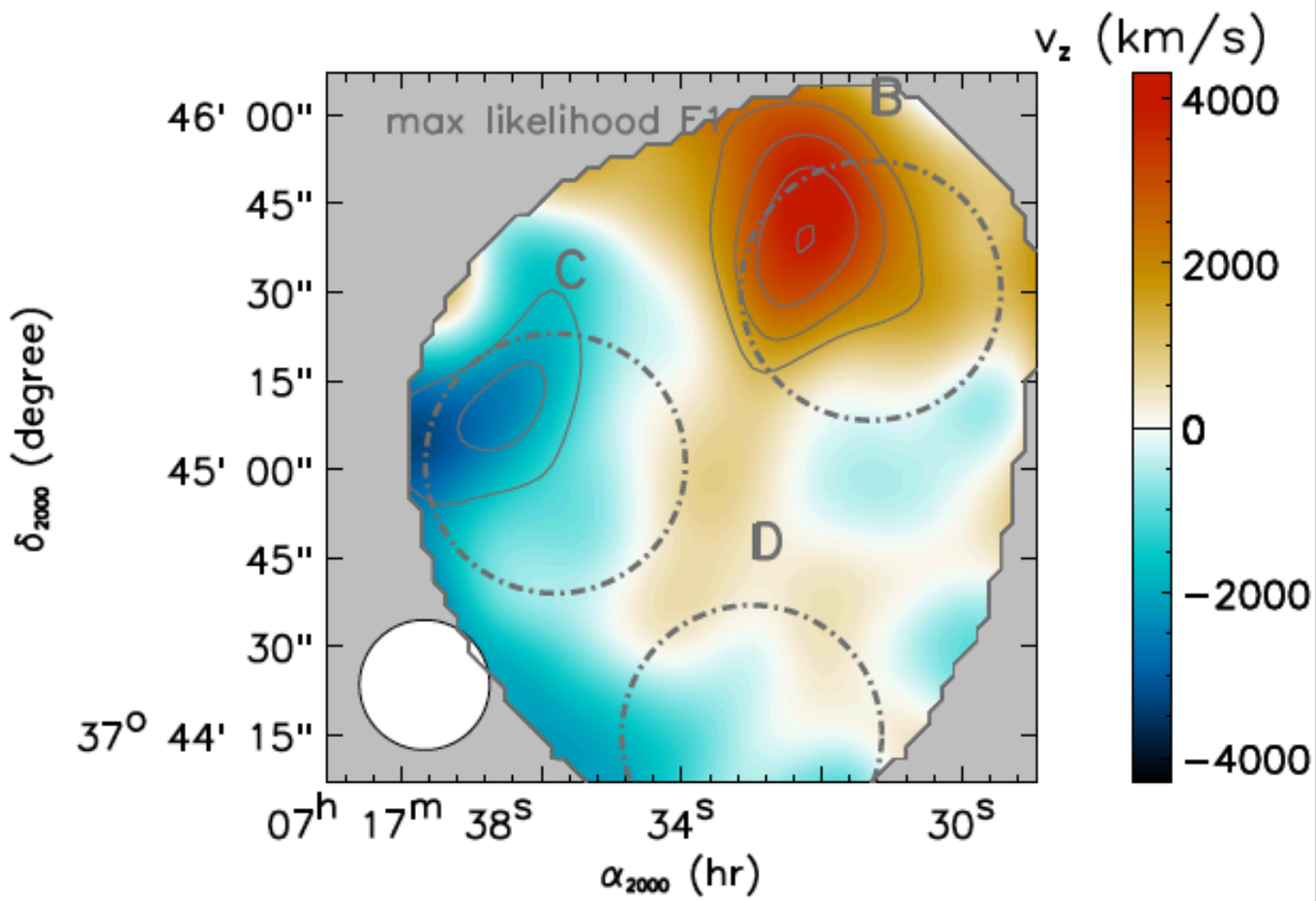

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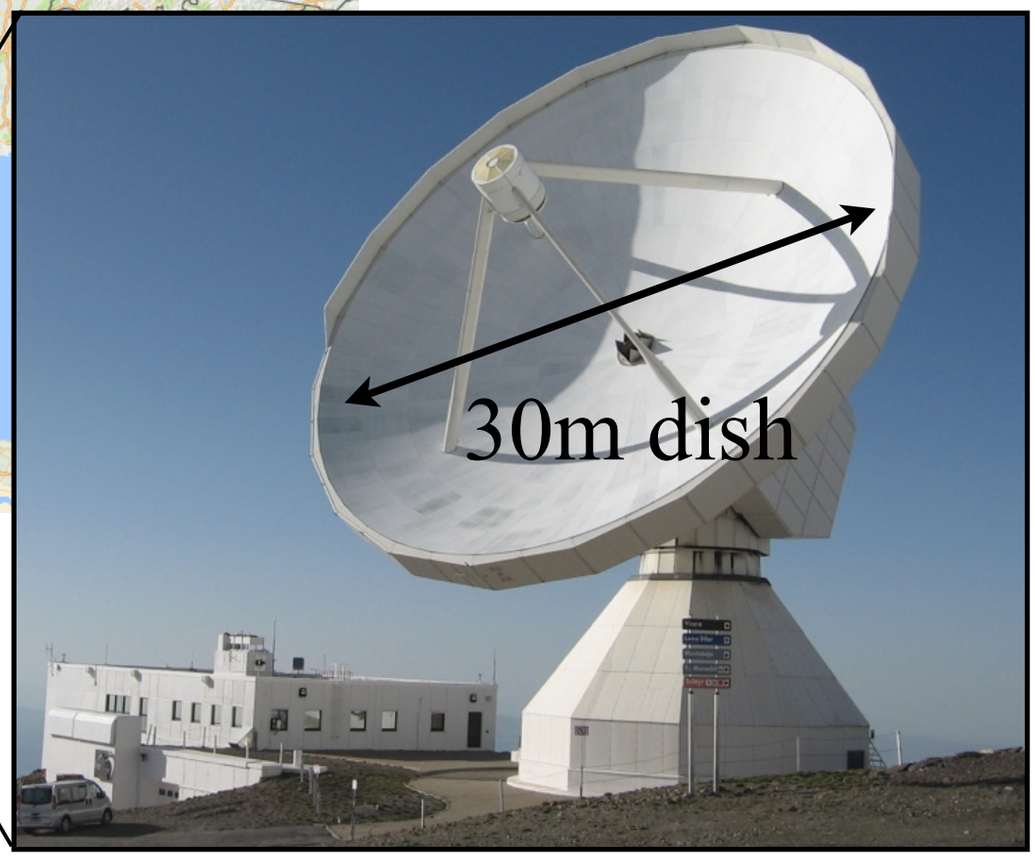
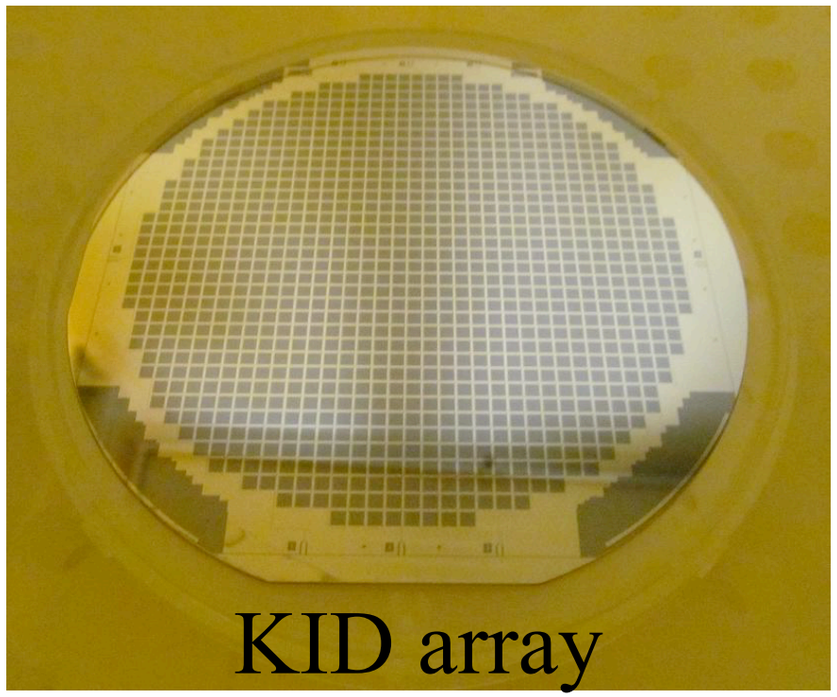
NIKA2 at the IRAM 30m telescope





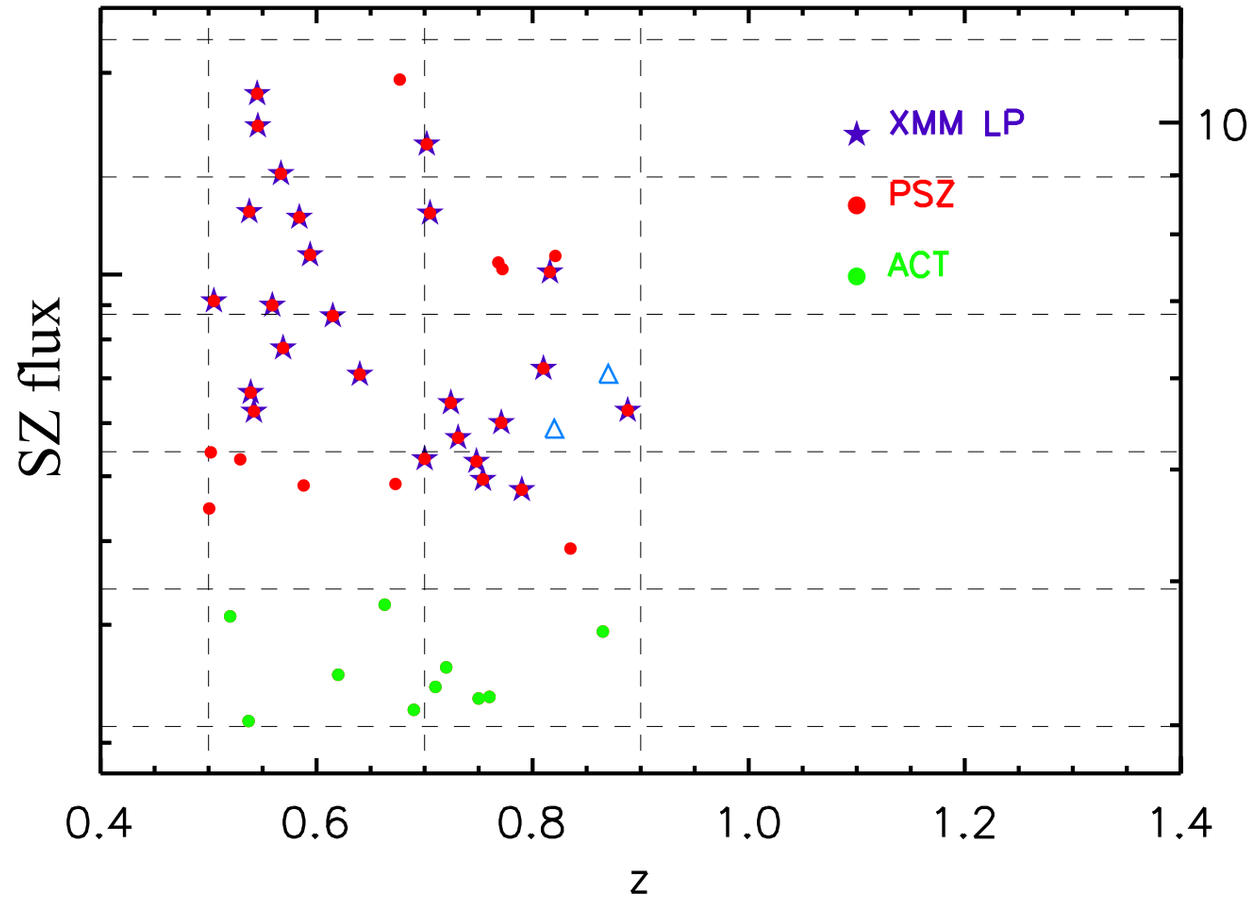
- ~3000 KIDs
- 6’.5 FOV
- 260 & 150 GHz
- 12” & 18” FWHM

➡ **Well suited SZ instrument under commissioning**

The NIKA2 SZ large program

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

➡ **NIKA2 capabilities demonstrated, observations will start soon**

Conclusions

The SZ effect in the Planck era

- The SZ effect is an excellent astro. & cosmo. probe
- Planck/SPT/ACT have pushed the field to a new era
- Need high angular resolution follow-up: substructure, high z

Status of SZ imaging

- Several pathfinder experiments: established capabilities
- SZ imaging: test case demonstration and outstanding results

Next steps

- Pathfinders studies to be applied on cosmological samples
- Mutli-wavelength synergies being developed

Thanks!