# High-resolution SZ observations for cluster cosmology with NIKA2

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Action Dark Energy 2020, 15/10/2020

financé par
IDEX Université Grenoble Alpes

# OUTLINE

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Action DE 2020
15/10/2020

## Cosmology with the SZ effect

The NIKA2 SZ Large Program

NIKA2/XMM-*Newton* analysis of a faint cluster

Summary, conclusion

# SZ CLUSTER COSMOLOGY

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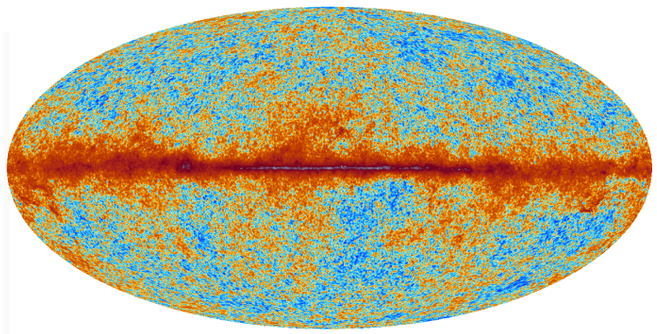
- Abundance of galaxy clusters with mass and redshift: **cosmology dependent**

  → Cosmology can be probed with **surveys** of clusters with **known masses**

- **Cosmology with the Sunyaev-Zeldovich (SZ) effect**
  - Compton scattering of CMB photons on hot electrons in the intracluster medium (ICM)
  - Can be used to detect large numbers of clusters in CMB experiments (*Planck*, SPT, ACT…)

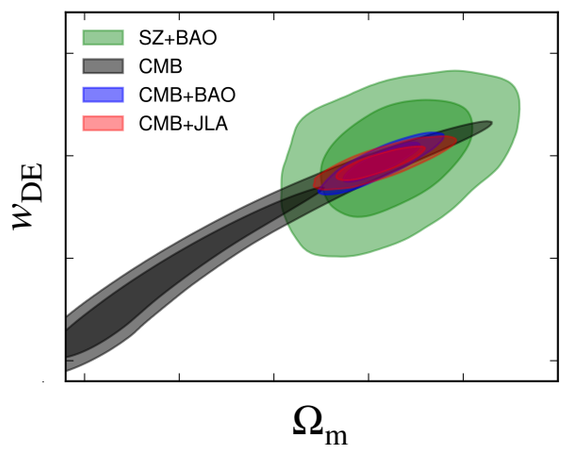
**Cluster detection** → *Requires: mean pressure profile* → **Mass calibration** → *Requires: scaling relation* → **Number counts** → *Requires: mass function*



*Planck* @ 143 GHz,
*Planck* collaboration 2018

| Cluster | Obs. $Y$ |
|---|---|
| #1 | $Y_1$ |
| #2 | $Y_2$ |
| #3 | $Y_3$ |
| #N | $Y_N$ |

| Cluster | Mass $M$ |
|---|---|
| #1 | $M_1$ |
| #2 | $M_2$ |
| #3 | $M_3$ |
| #N | $M_N$ |




*Planck* collaboration 2016

# TOOLS NEEDED FOR SZ COSMOLOGY

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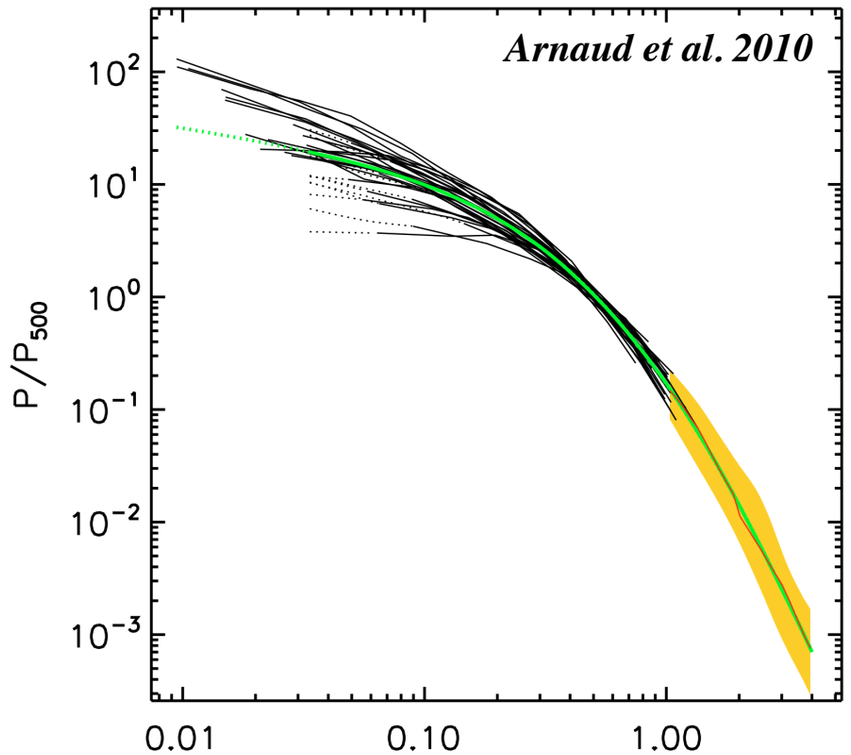
## ICM mean pressure profile $P(r)$

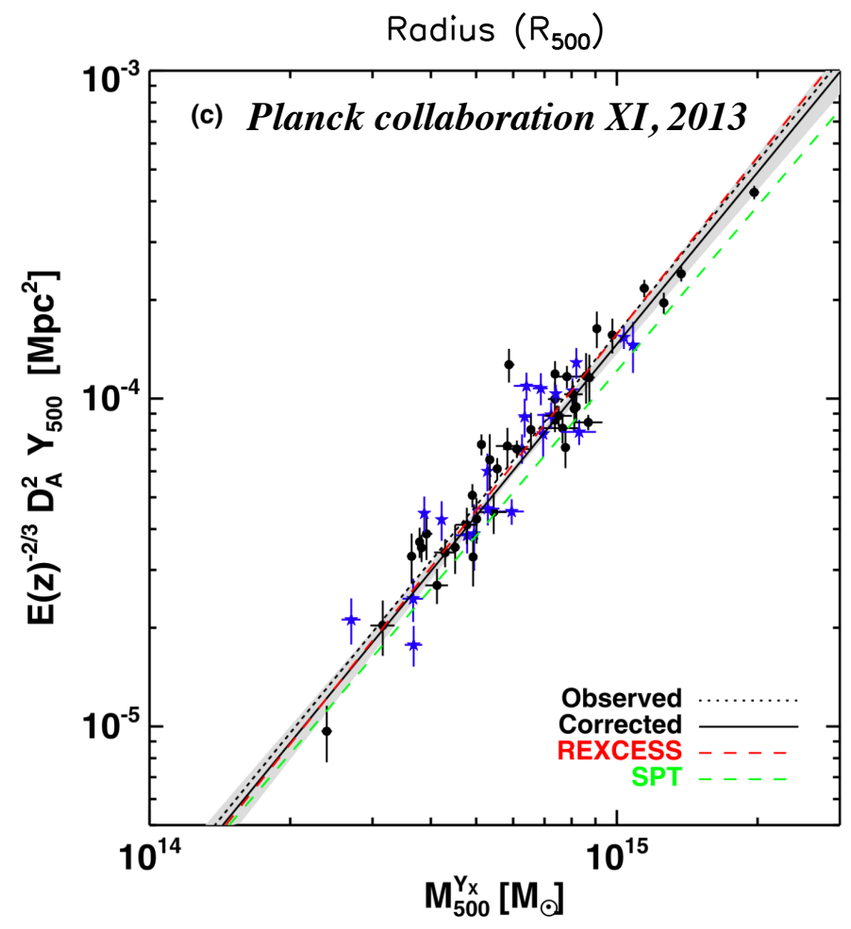
- Needed for SZ cluster detection: SZ amplitude $y \propto \int_{\mathrm{LoS}} P(r)\,\mathrm{d}l$
- So far, mostly measured at low-$z$ either:
  - With low-resolution SZ
  - In X-rays




## SZ—Mass scaling relation: $Y^{\mathrm{SZ}} = f(M)$

- Links the integrated SZ signal $Y^{\mathrm{SZ}}_{500}$ and the mass $M_{500}$ inside a characteristic radius $R_{500}$
- Usually calibrated with:
  - Weak lensing masses *(e.g. SPT, Bocquet et al. 2019)*
  - X-ray masses *(e.g. Planck, Planck collaboration 2016)*

**→ High resolution SZ: new information**



# NIKA2: AN IDEAL INSTRUMENT FOR HIGH-RES SZ

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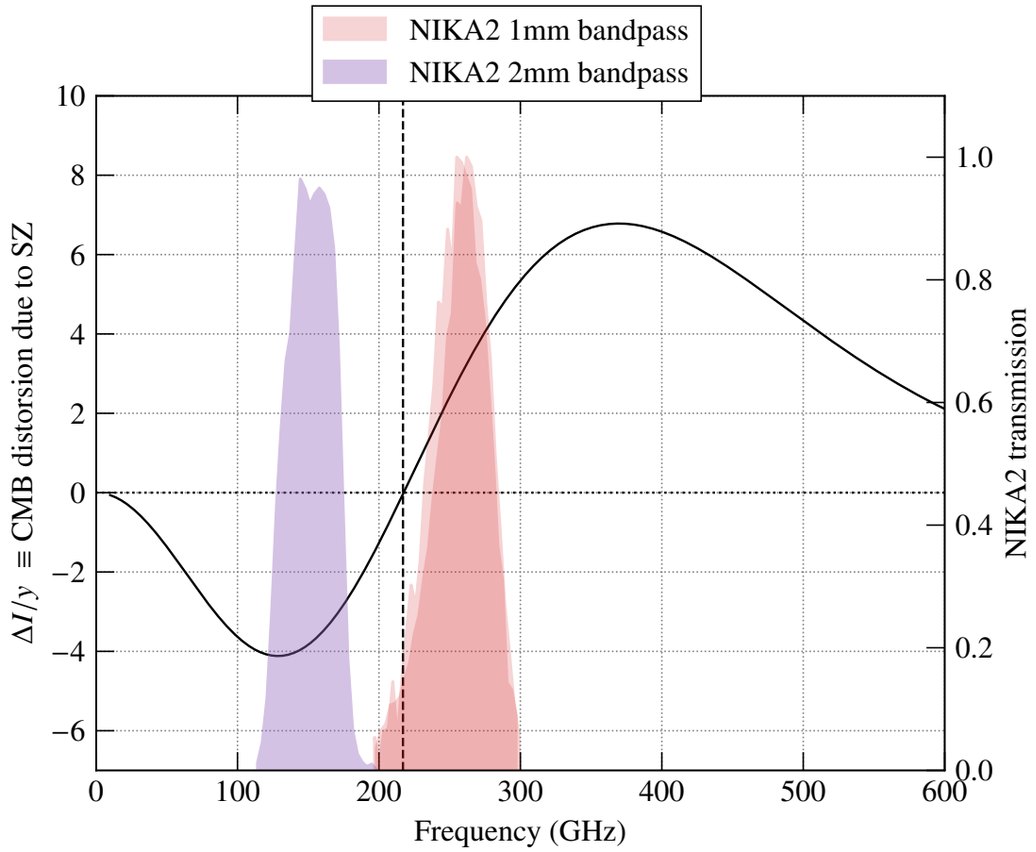
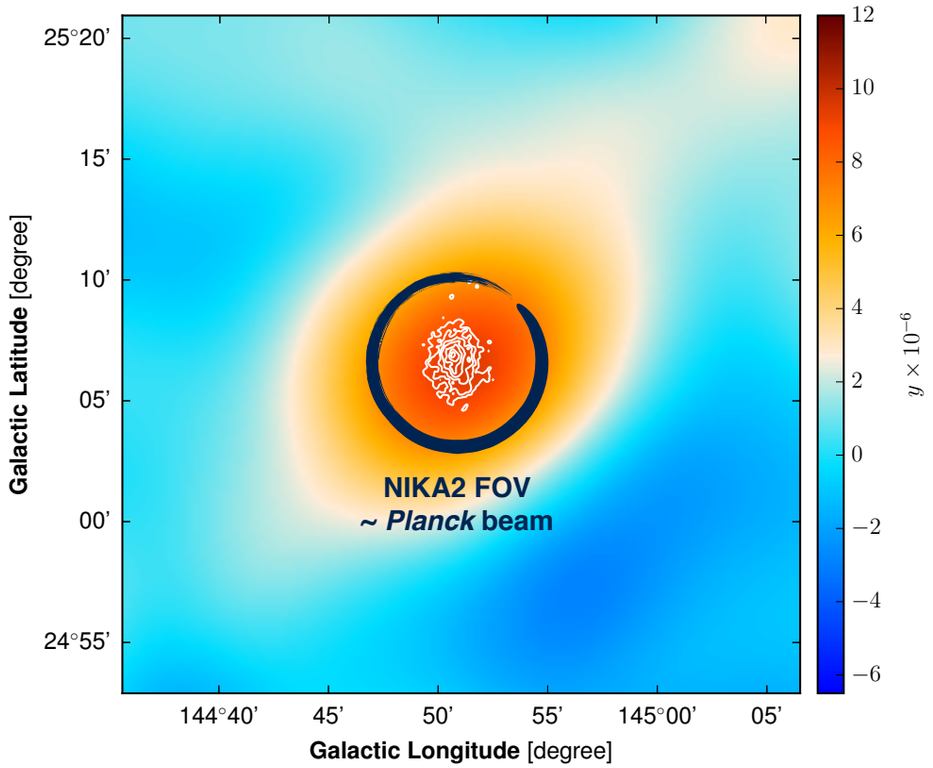
- Kinetic Inductance Detectors (KIDs) camera
- 30 meter telescope, Sierra Nevada, Spain
- Well-suited to SZ observations:
  - Dual band
    → *Enables the exploitation of the spectral dependence of SZ*
  - High angular resolution
    → *Provides detailed information about the structure of the ICM*
  - Large field of view
    → *Allows us to map extended regions*
  - High sensitivity
    → *Efficient at mapping faint signal*




| | 1.2 mm | 2 mm |
|---|---|---|
| FWHM [arcsec] | $11.1 \pm 0.2$ | $17.6 \pm 0.1$ |
| Field of view [arcmin] | 6.5 | |
| Sensitivity [mJy · s$^{1/2}$] | $30 \pm 3$ | $9 \pm 1$ |
| Mapping speed [arcmin$^2$ · mJy$^{-2}$ · h$^{-1}$ ] | $111 \pm 11$ | $1388 \pm 174$ |



# THE NIKA2 SZ LARGE PROGRAM (LPSZ)

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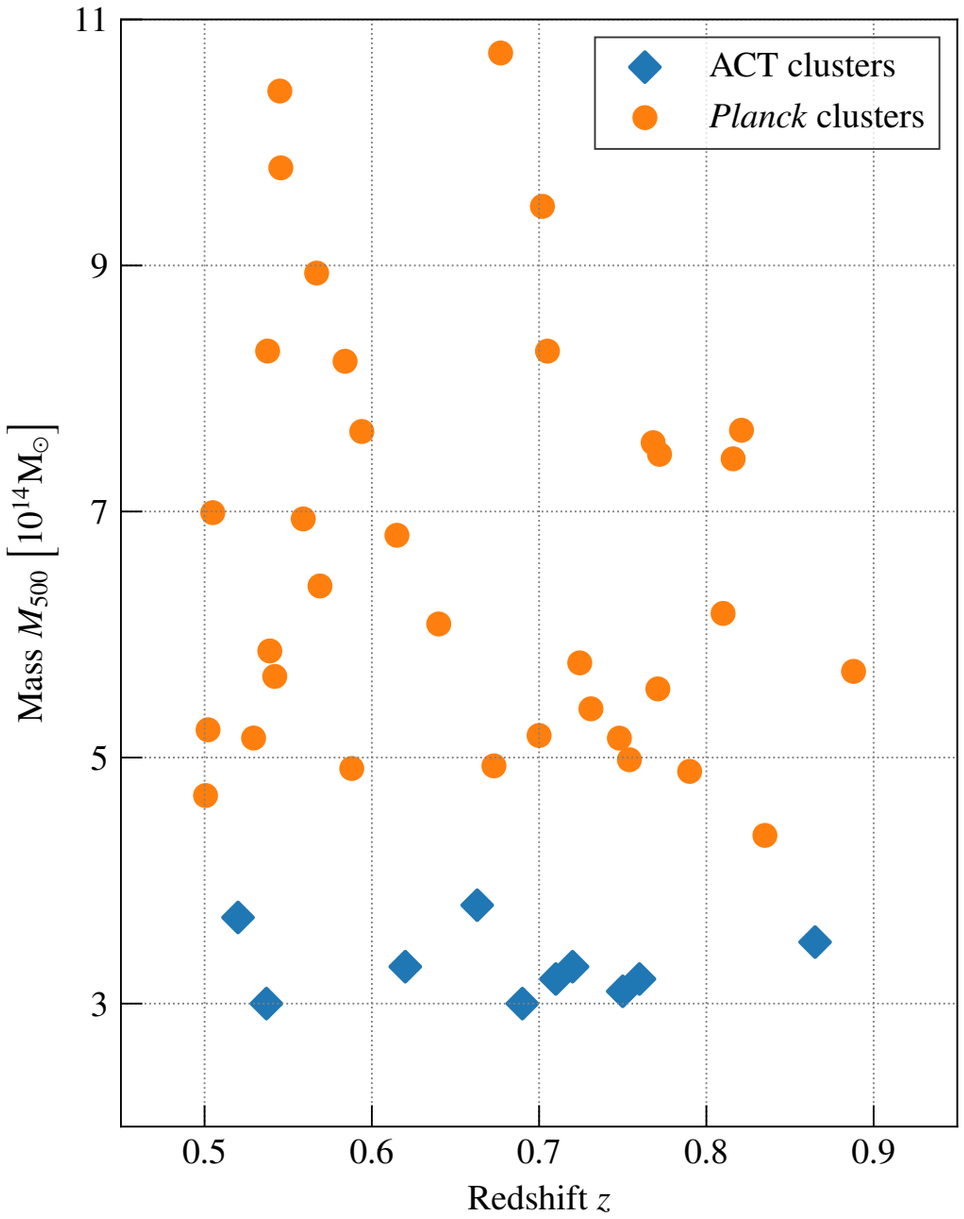
- Follow-up of ~50 SZ-detected clusters
- 300h NIKA2 guaranteed time
- Combination of high-resolution SZ & X-rays
- Measurement of the tools needed for cosmology:
  - The ICM mean pressure profile
  - The SZ — Mass scaling relation
- Improvement over previous measurements:
  - high angular resolution SZ observations
    *identification of substructures, contamination…*
  - at high redshift $(0.5 < z < 0.9)$
    *more accurate for more distant objects*

**→ Detailed information on distant clusters**



# STATUS OF NIKA2 LPSZ ANALYSES

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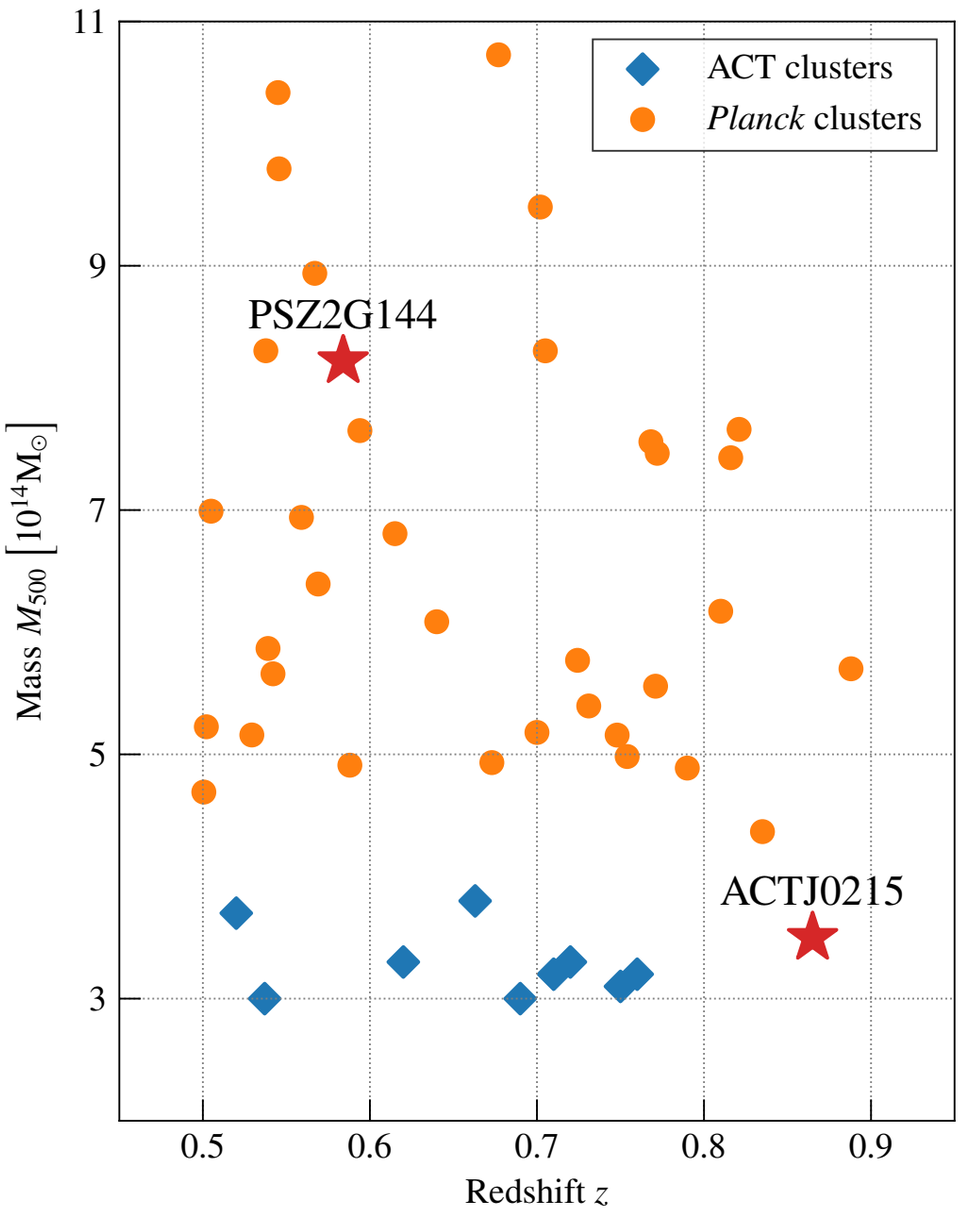
- **Setting up the tools** needed to measure the **physical properties** of clusters from NIKA2 maps
- **First cluster seen by NIKA2:** Science verification
  ***Ruppin et al. (2018)***
  - High mass, low redshift
  - High observation time → high SNR
- **Next target:** tackle different possible challenges
  - Low mass, high redshift
  - Not detected by *Planck*
  - Standard LPSZ observations

→ **Next target:** ACT-CL J0215.4+0030 (aka ACTJ0215)

***Kéruzoré et al. (2020, accepted in A&A)***



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# NIKA2 MAPS OF ACTJ0215

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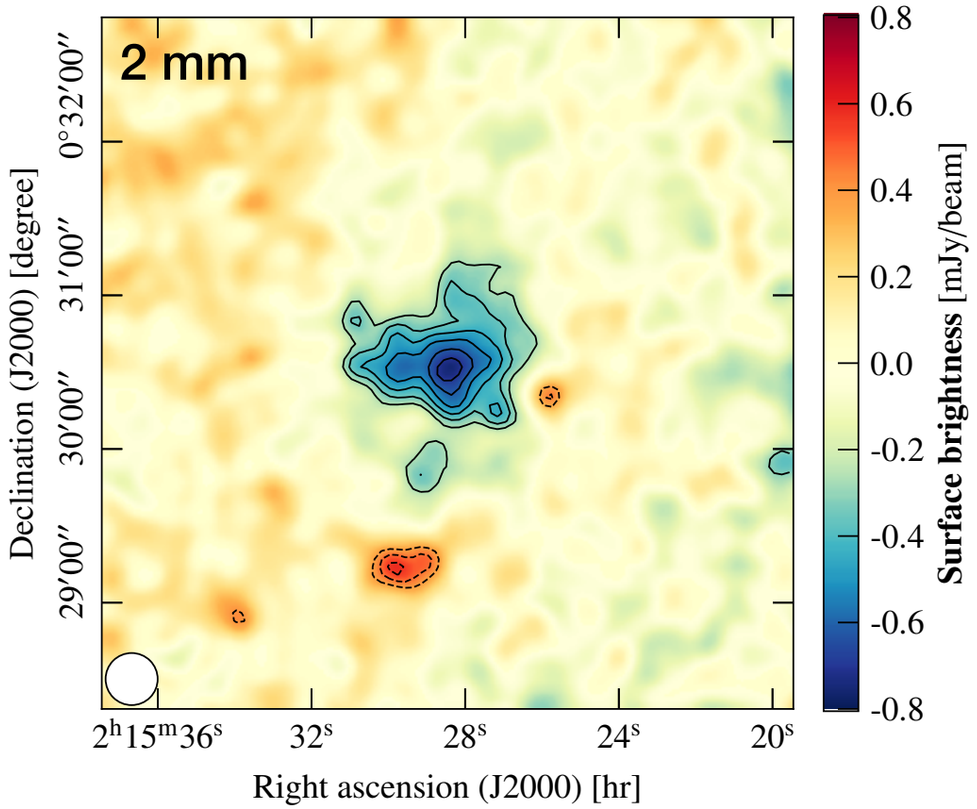


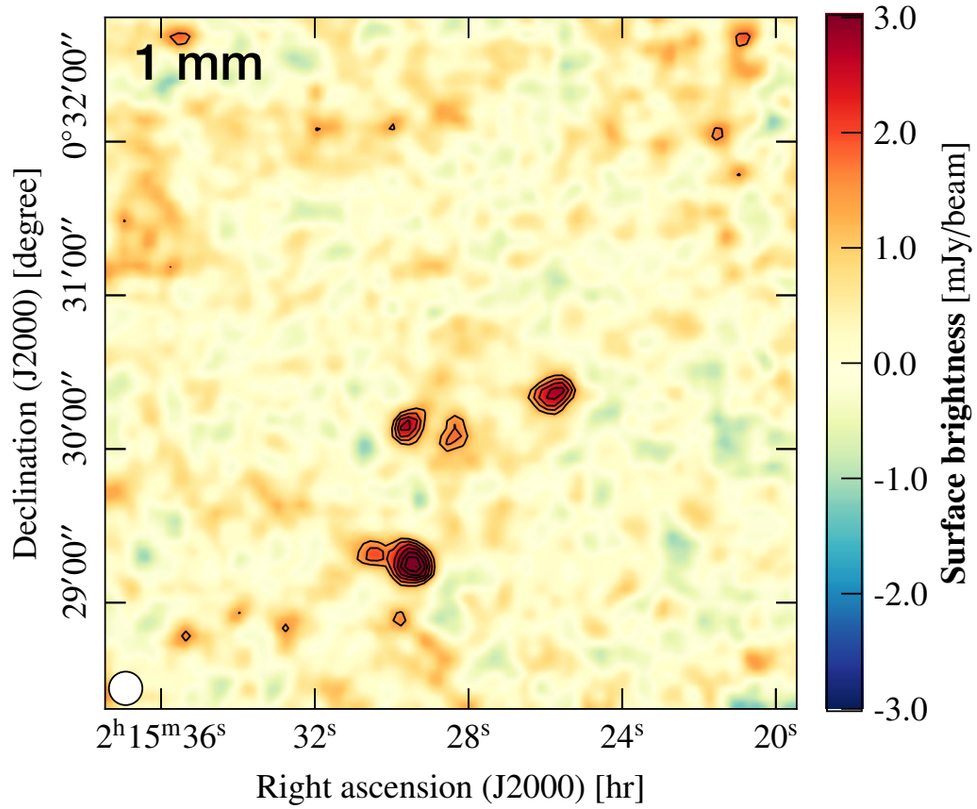


## At 150 GHz (2 mm):

- **SZ decrement detected at** $\lesssim 9\sigma$
  *Low: first NIKA2 cluster was* $\sim 14\sigma$
- **Faint** (<1 mJy peak),
  **small** (NIKA2 beam in bottom left corner)
- **Hints of point source contamination:**
  *Sources with positive fluxes compensate the SZ decrement*

## At 260 GHz (1.2 mm):

- **No SZ detected** (none expected given the noise level)
- **Point source contamination confirmed**
  *Sources close to the cluster*

Need to take contamination into account

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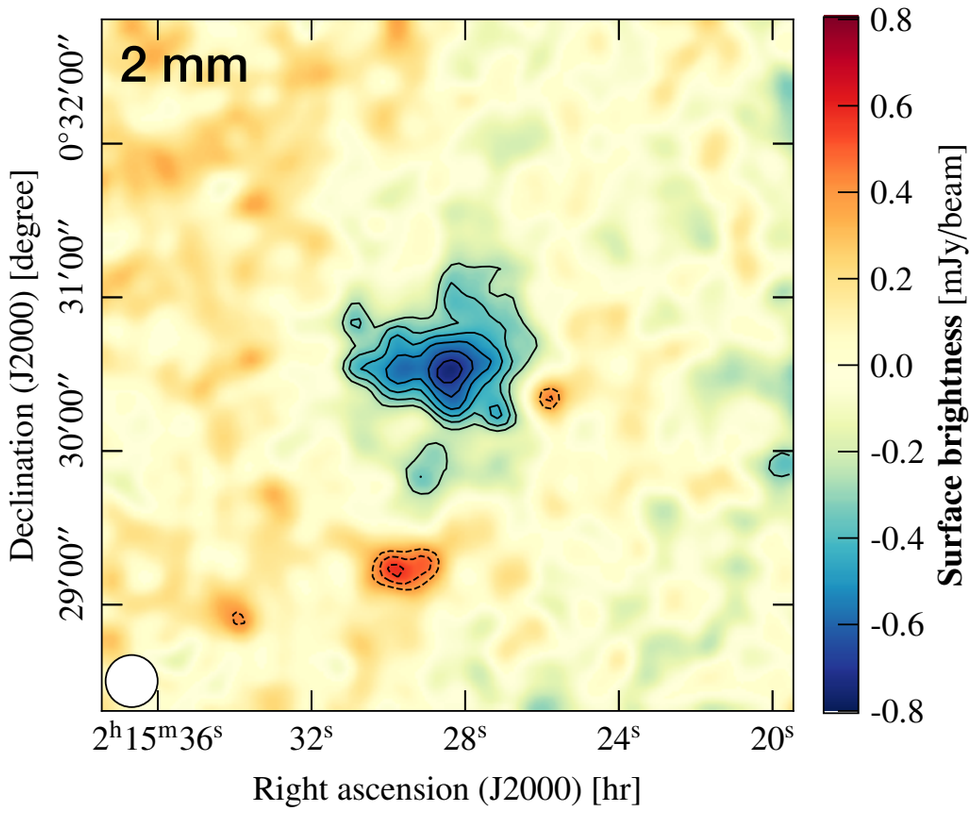


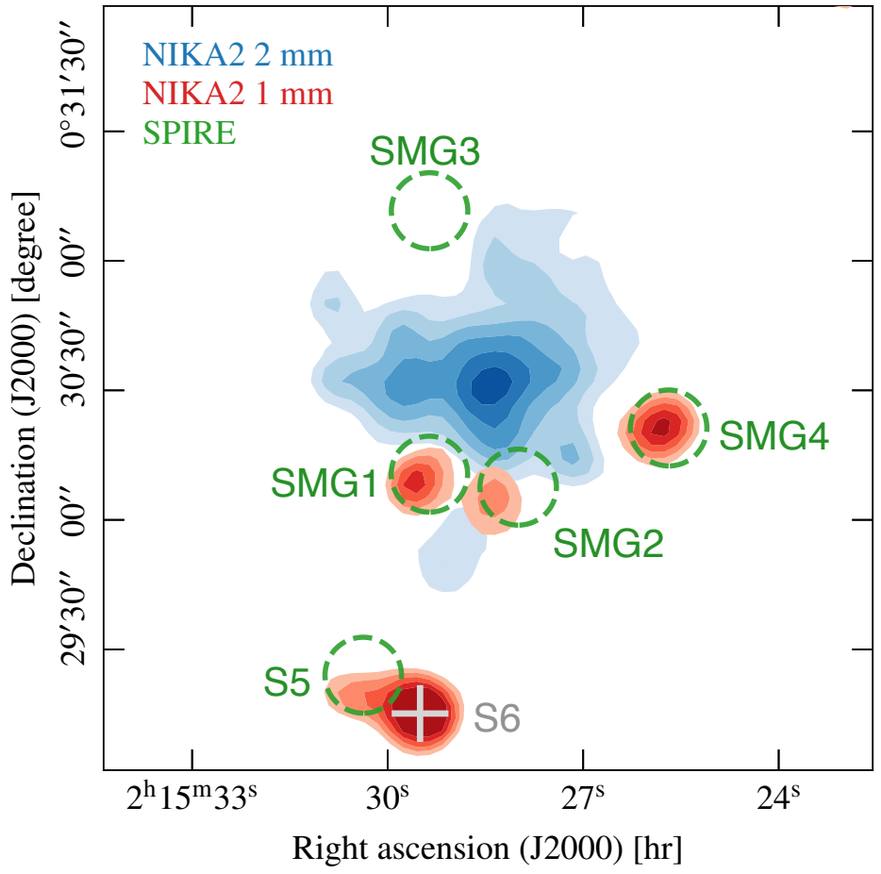


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# JOINT SZ-POINT SOURCES MODEL

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**NIKA2 150 GHz map** = **ICM SZ signal** + **point source contamination** (+ noise)

→ *Extension of the NIKA2 SZ pipeline to perform joint fits of SZ + point sources*

## 1) ICM SZ signal

- Spherical symmetry → ICM pressure profile

  gNFW model: $P_e(r) = P_0 \left(\frac{r}{r_p}\right)^{-c} \left[1 + \left(\frac{r}{r_p}\right)^{a}\right]^{(c-b)/a}$

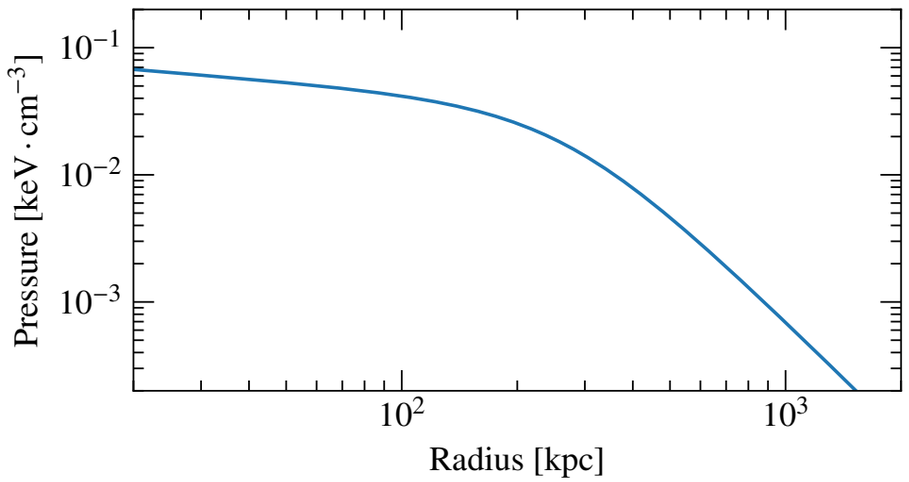
  → 5 parameters: $P_0$, global amplitude,

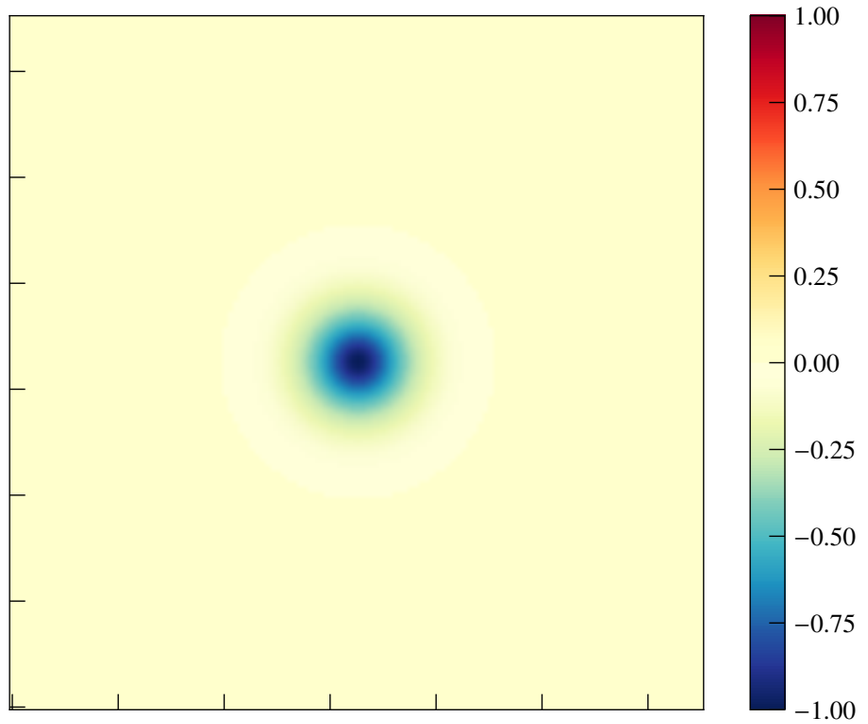
  $r_p, a$, transition radius/steepness

  $b, c$, external/internal slopes

- Integrated along the line of sight & calibrated
  Convolved by the NIKA2 instrumental response

  **→ SZ model map**



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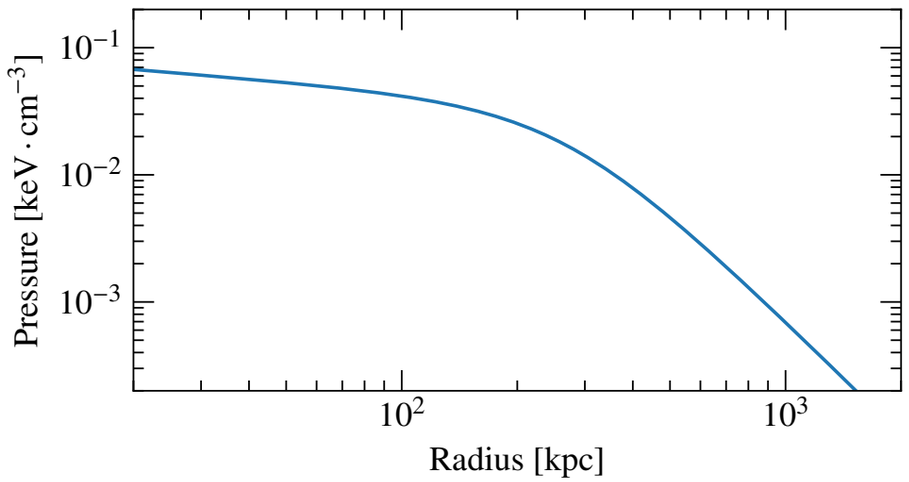


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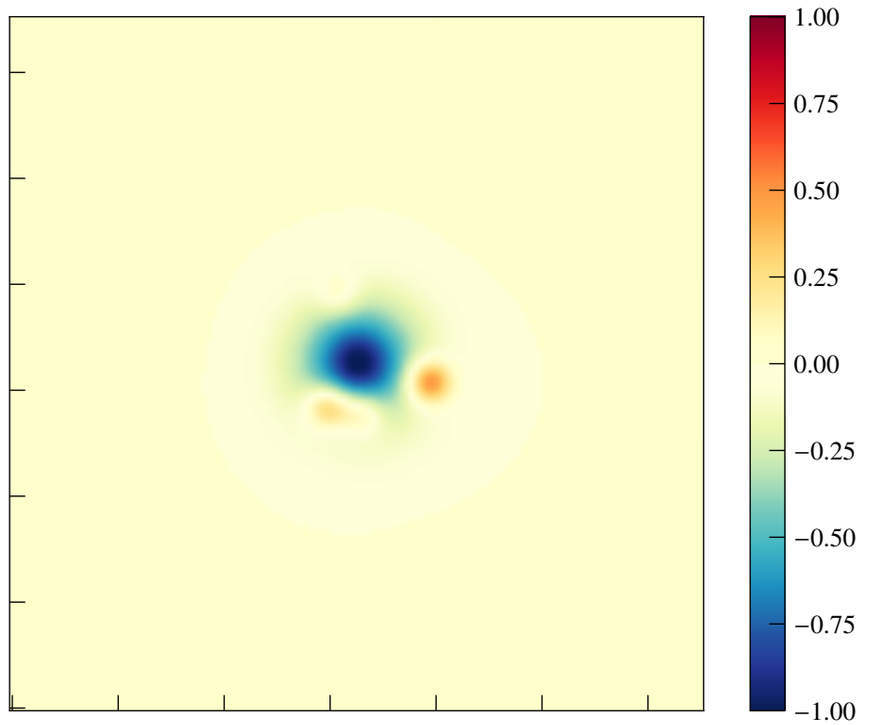
→ **SZ model map**




## 2) Point source contamination

- Model: NIKA2 PSF with variable amplitude
- Positions known from the NIKA2 260 GHz map
- Fluxes as free parameters with priors from SED extrapolation (NIKA2 + *Herschel*)

Parameters $\theta$ → model map $M(\theta)$

# JOINT MODEL FITTING

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Fit the joint model (SZ + point sources) on the NIKA2 150 GHz map using MCMC

$$\text{Likelihood: } -2\log\mathscr{L}(\theta) = \sum_{\text{pixels}} \left(D - M(\theta)\right)^{\mathrm{T}} C^{-1} \left(D - M(\theta)\right) + \left(\frac{Y_{500}^{\mathrm{ACT}} - Y_{500}(\theta)}{\Delta Y_{500}^{\mathrm{ACT}}}\right)^2$$

*Constraints from NIKA2 150 GHz map*

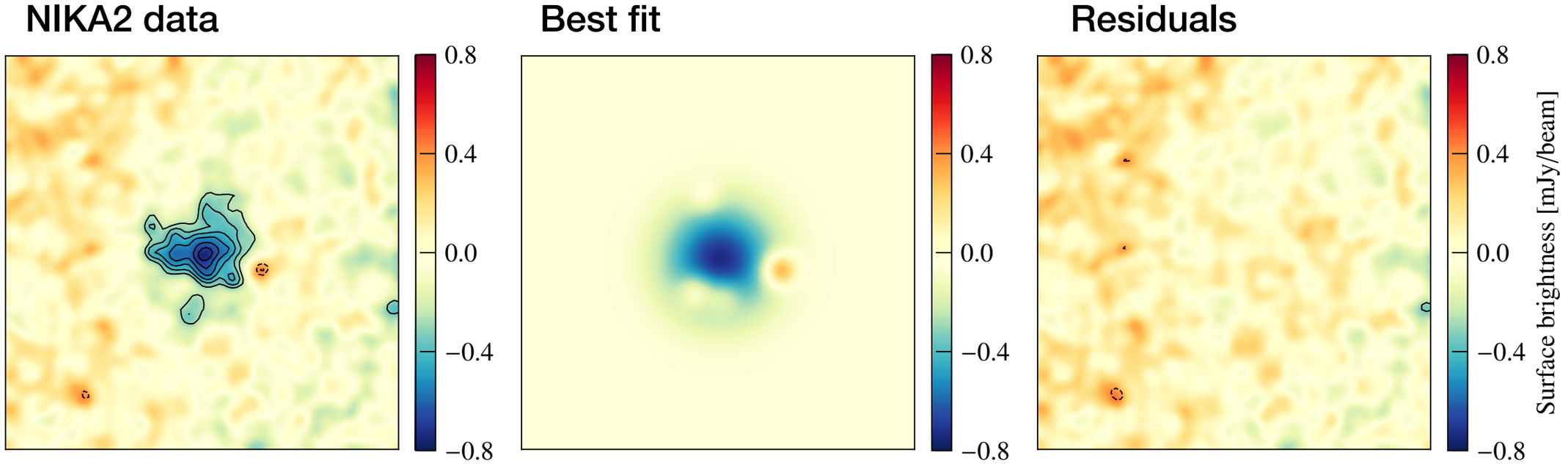
*Constraints from ACT integrated signal*

$\theta$ : parameters

$M$ : model map

$D$ : NIKA2 150 GHz map

$C$ : Noise covariance




NB: SMG5&6 were subtracted

Residuals compatible with noise

→ The NIKA2 data are well-described by a gNFW pressure profile + point sources

# FIT RESULTS: PRESSURE PROFILE OF ACTJ0215

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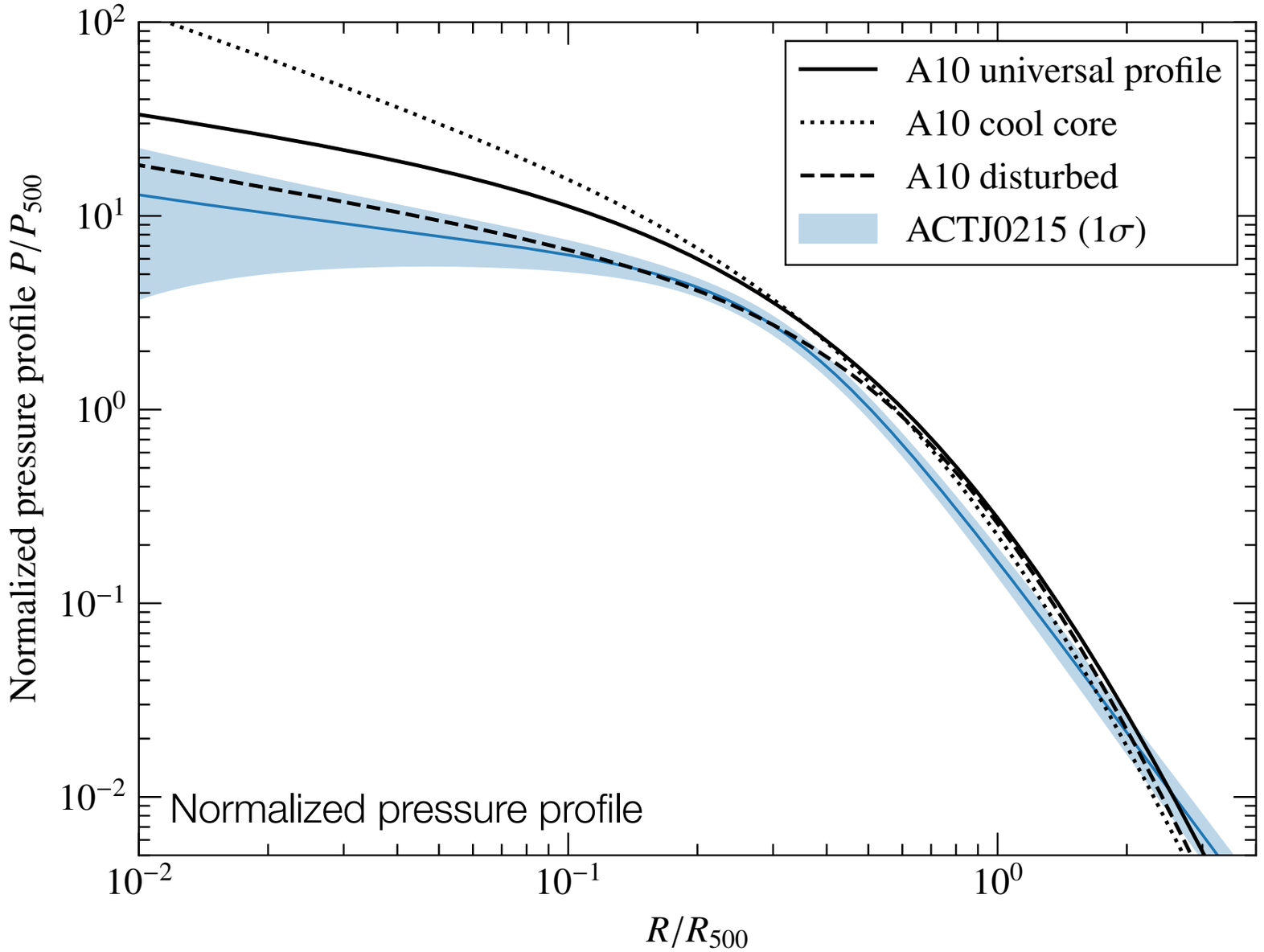


Pressure profile from NIKA2+ACT:
Incompatible with universal pressure profile

# X-RAY DATA

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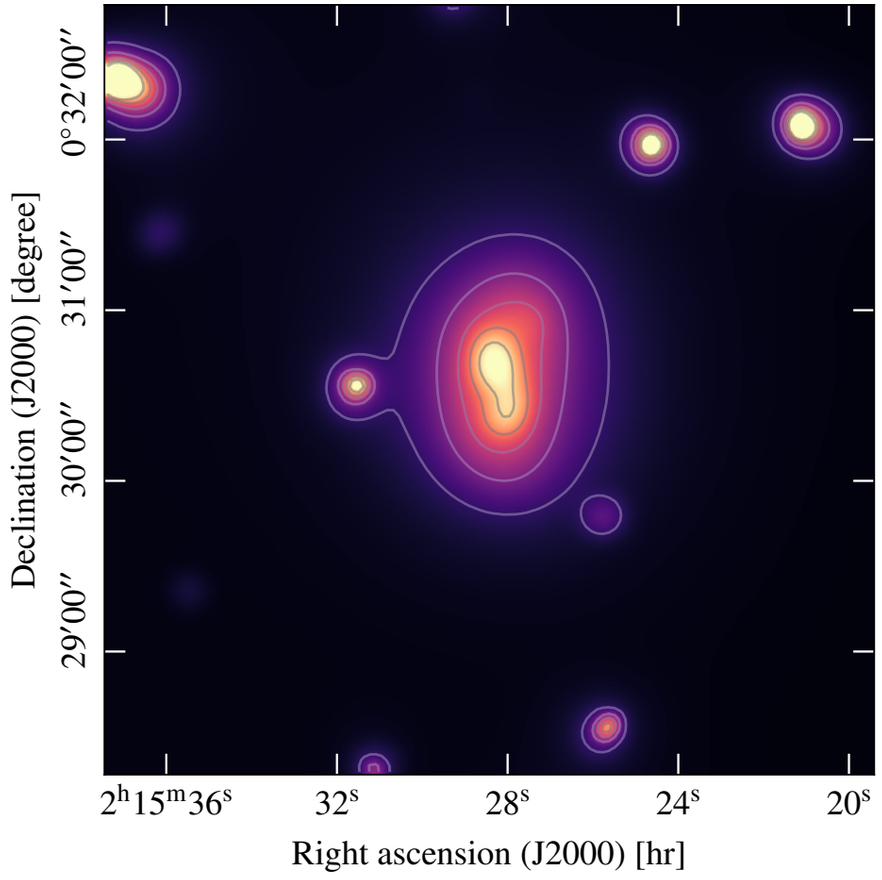
## XMM-*Newton* observations of the cluster:

X-ray observations: $S_X \propto \int_{\mathrm{LoS}} n_e^2 \, \Lambda(T) \, \mathrm{d}l$ → density measurement (all LPSZ clusters)

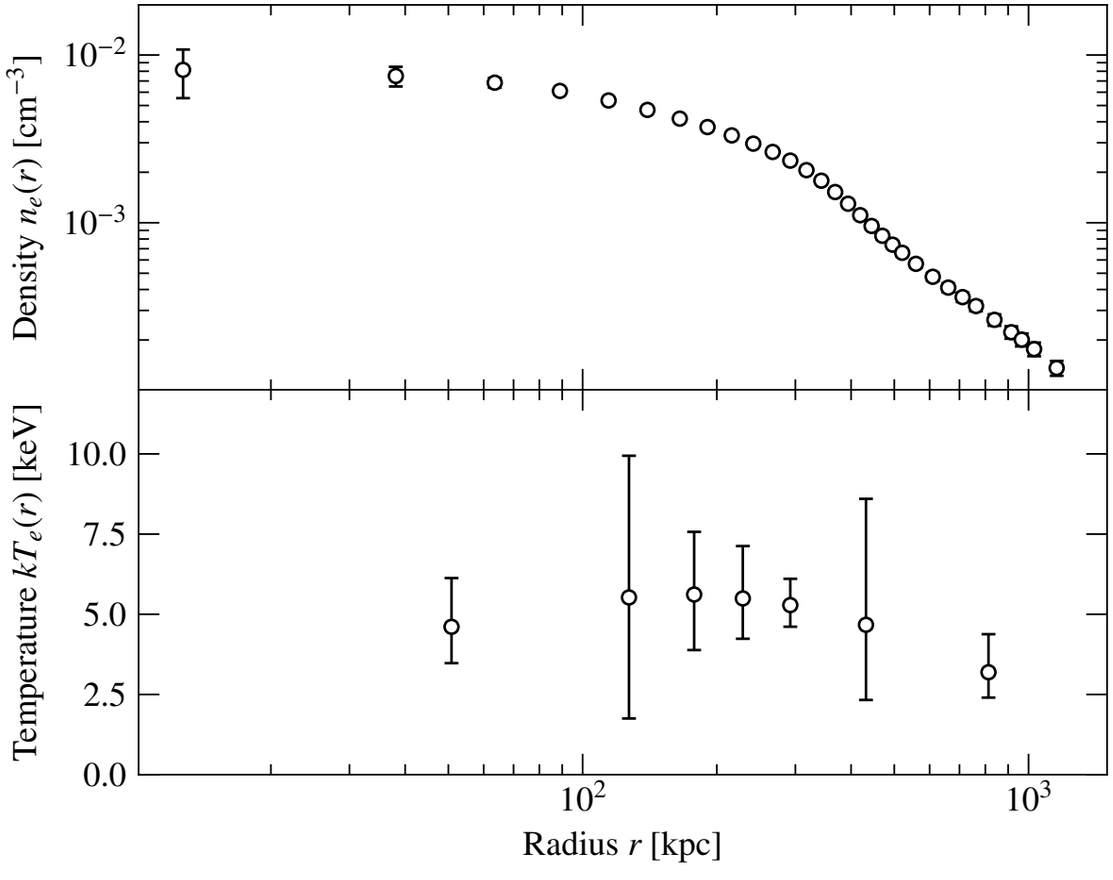
Deep: $t_{\mathrm{obs}} = 37$ ks → deep enough to measure the **temperature** of the ICM through **X-ray spectroscopy**

→ **Rare** at this mass and redshift: X-rays usually only give access to the density

**XMM-*Newton* map**




**Thermodynamic profiles**



# FIT RESULTS: PRESSURE PROFILE OF ACTJ0215

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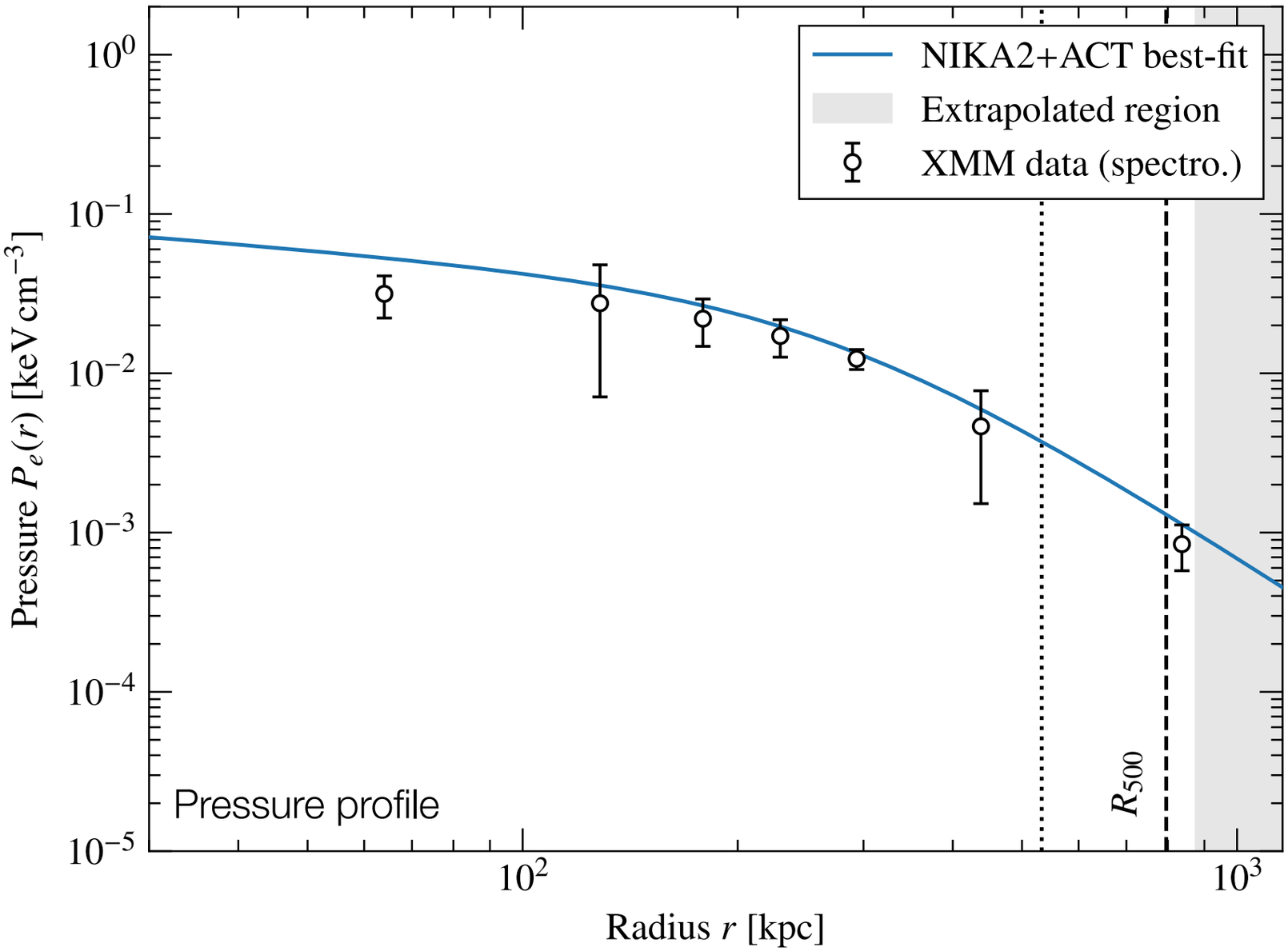
$P = nk_{\mathrm{B}}T \rightarrow$ X-rays can give a pressure profile too




Pressure profile compatible with XMM-only data

# NIKA2+XMM THERMODYNAMICS

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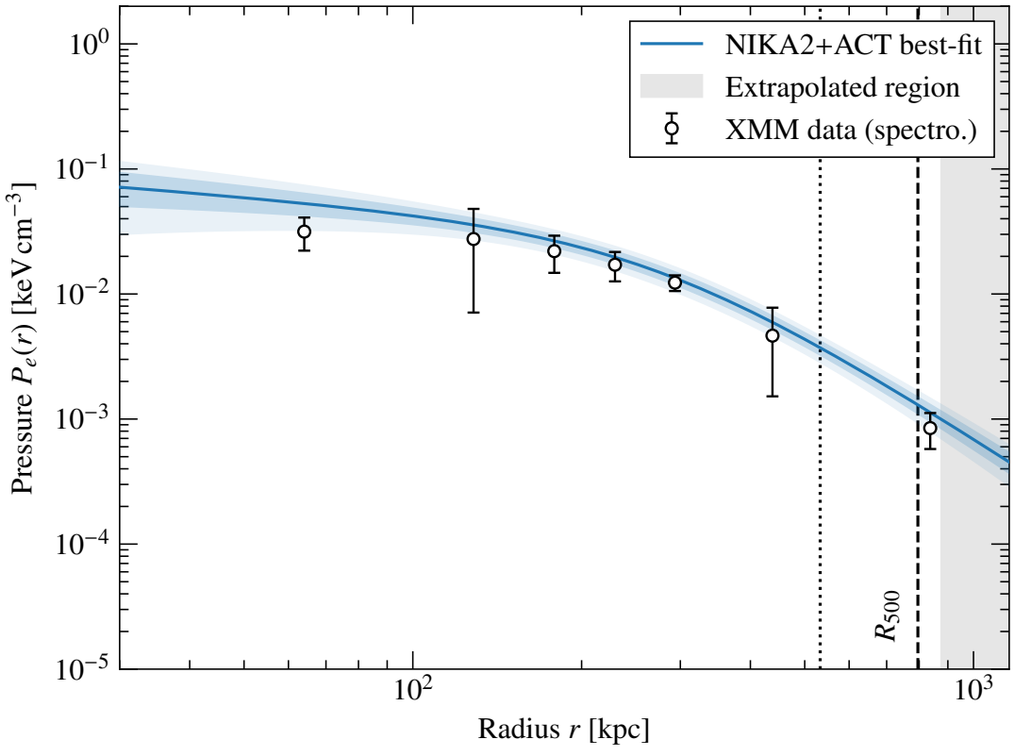
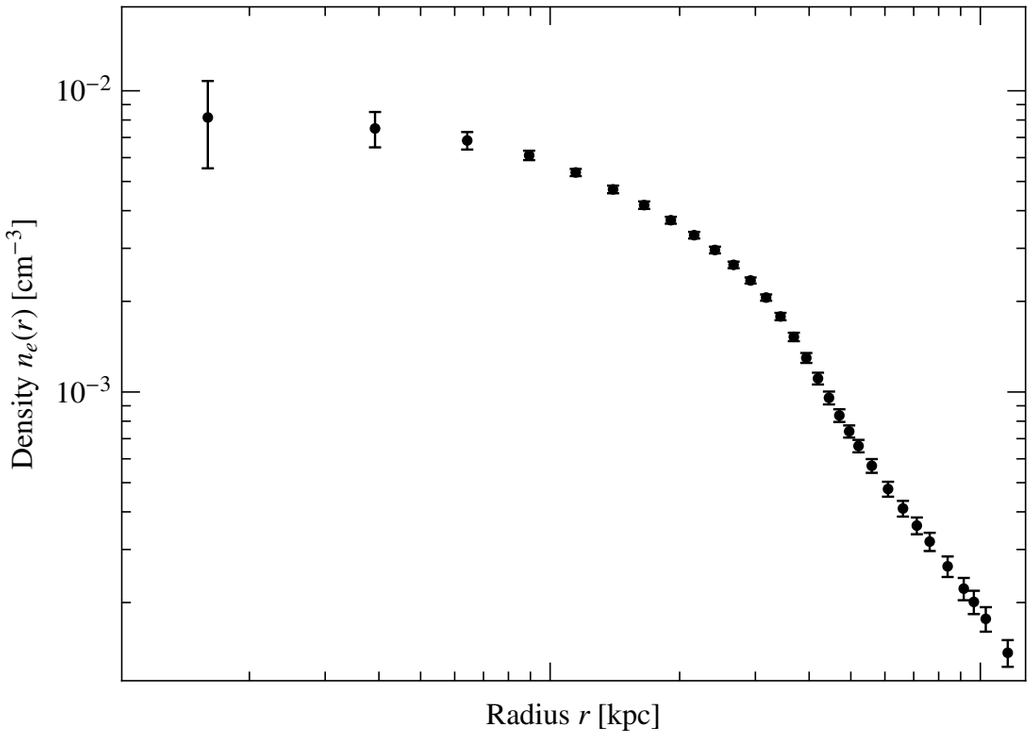
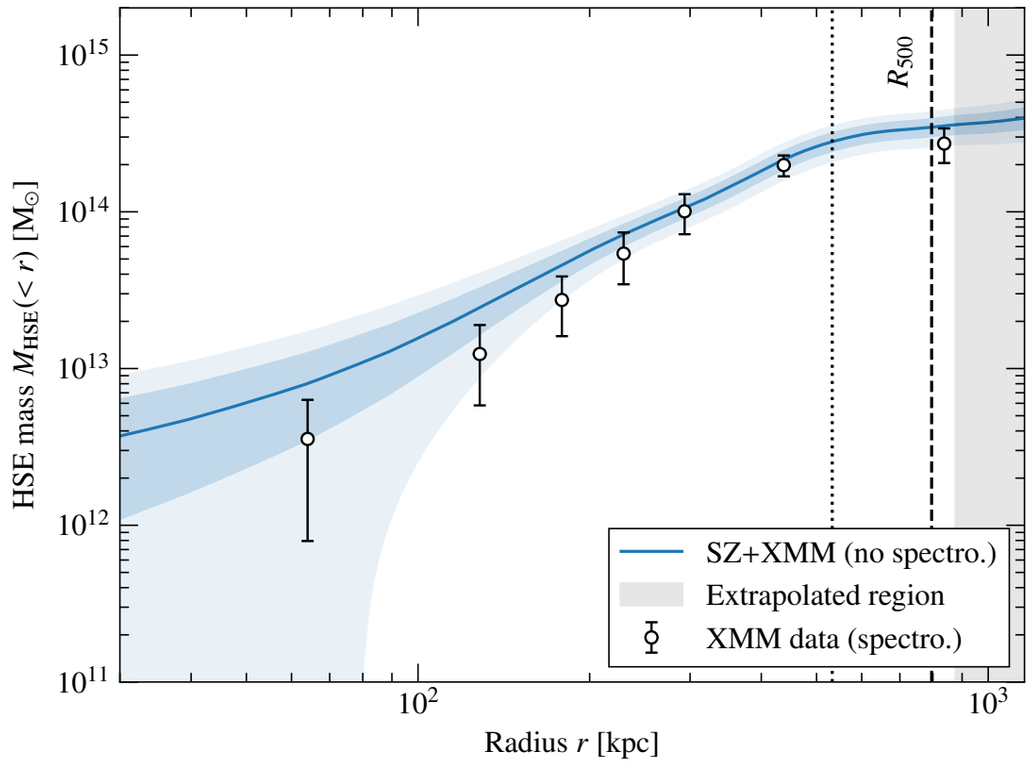
## NIKA2 pressure




## XMM density




## HSE Mass $M^{\mathrm{HSE}}(r) \propto \frac{r^2}{n_e}\frac{\mathrm{d}P_e}{\mathrm{d}r}$




→ Good agreement between NIKA2+XMM and XMM-spectro

# INTEGRATED QUANTITIES

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| | ACT | XMM-*Newton* | NIKA2+XMM |
|---|---|---|---|
| $R_{500}$ [kpc] | $877.8 \pm 46.2$ | $780.9 \pm 19.8$ | $810.1 \pm 41.9$ |
| $\mathcal{D}_A^2\ Y_{500}$ [$10^{-5}$ Mpc$^2$] | $4.07 \pm 1.13$ | – | $3.76 \pm 0.39$ |
| $M_{500}$ [$10^{14}$ $M_\odot$] | $3.5 \pm 0.8$ | $2.48 \pm 0.70$ | $3.79 \pm 0.58$ |
| | *From ACT & $Y_{500} - M_{500}$ scal. rel.* | *Hydrostatic mass* | *Hydrostatic mass* |

- Our measurements agree with previous results
- Improved precision on $Y_{500}$ thanks to high angular resolution
- Improved precision on $M_{500}$

  → Important: masses computed from scaling relations usually have smaller error bars than hydrostatic mass measurements

Improved precision on:

The integrated quantities

The scaling relation itself

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# CONCLUSIONS

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- Need to understand systematic effects in cluster cosmology
- High-resolution SZ at high redshift can bring valuable new inputs

  → **NIKA2 SZ Large Program**
- Promising results on an individual target:
  - **"Worst case scenario"** for the NIKA2 LPSZ:
    - A **faint** cluster (low mass, high z),
    - Strongly contaminated by **point sources**
  - Nonetheless: precise measurements of ICM thermodynamical properties

**Very promising for the future of the NIKA2 LPSZ and its impact on cluster cosmology**

- LPSZ observations progressing
  → Ongoing developments towards first cosmological results (half sample)