HIGH RESOLUTION CLUSTER COSMOLOGY WITH THE NIKA2 CAMERA

LPSC-CNRS

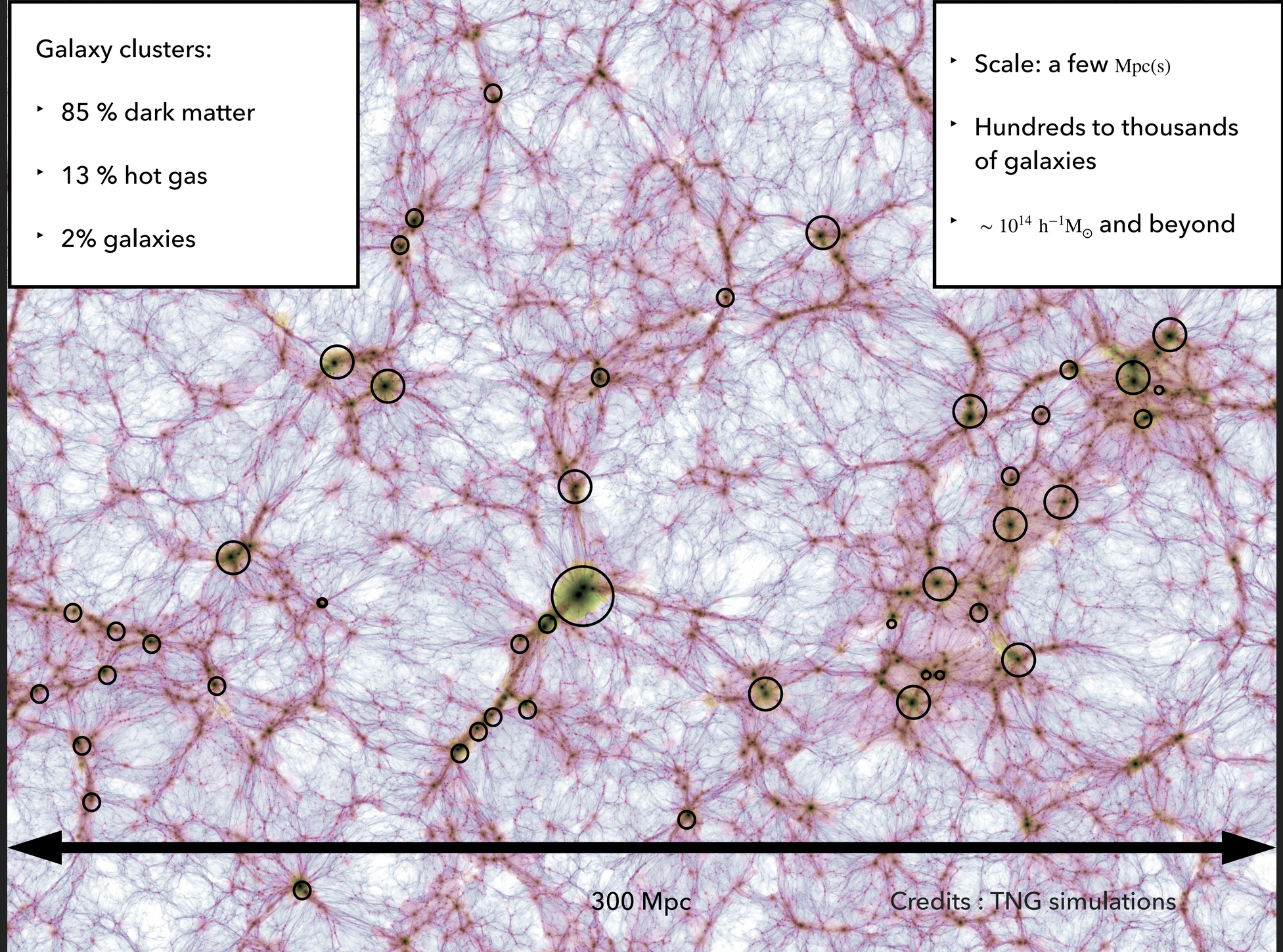
Emmanuel Artis (14/10/22)

ENIGMASS MEETING

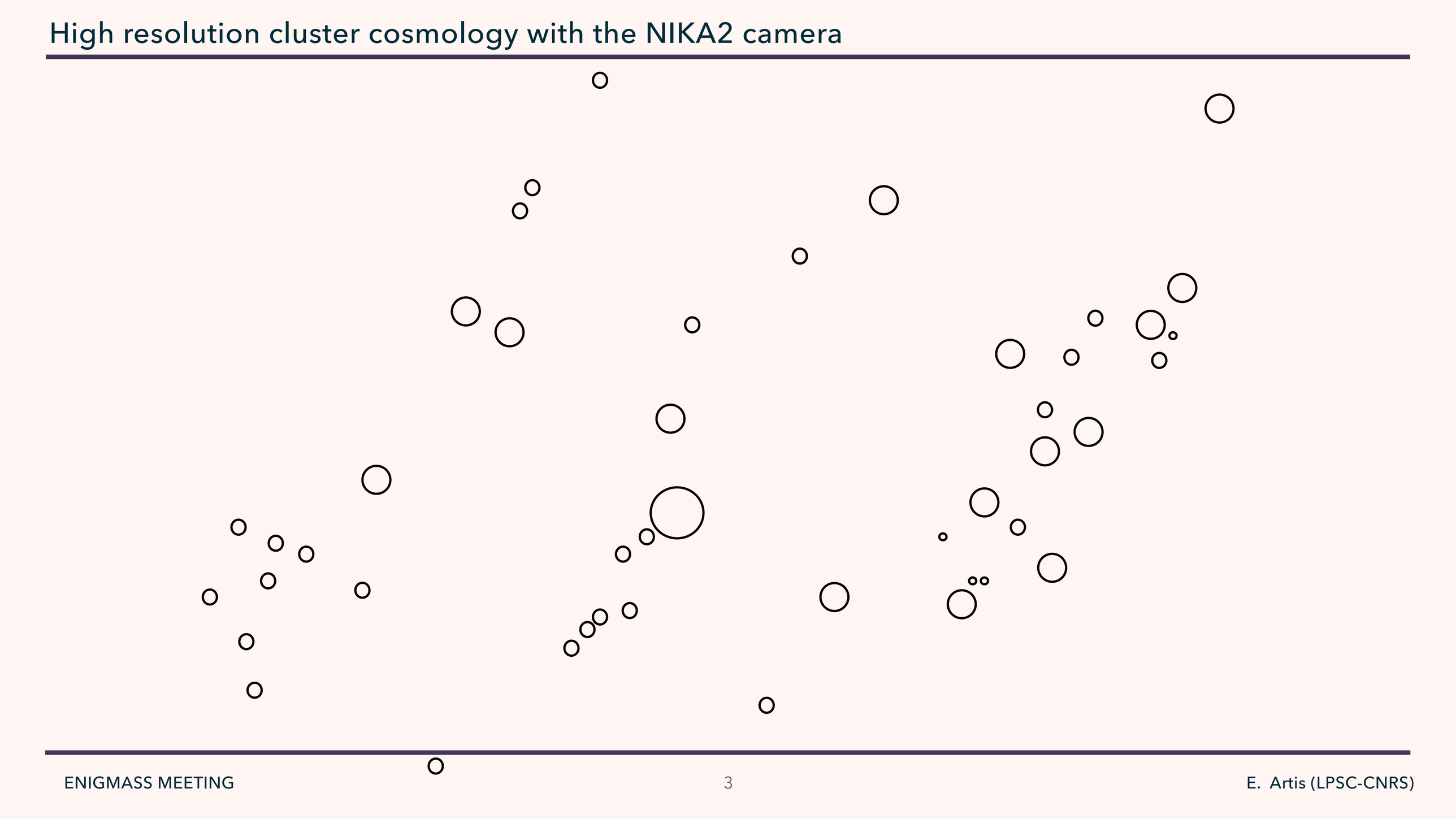
Galaxy clusters:

- 85 % dark matter
- 13 % hot gas
- 2% galaxies

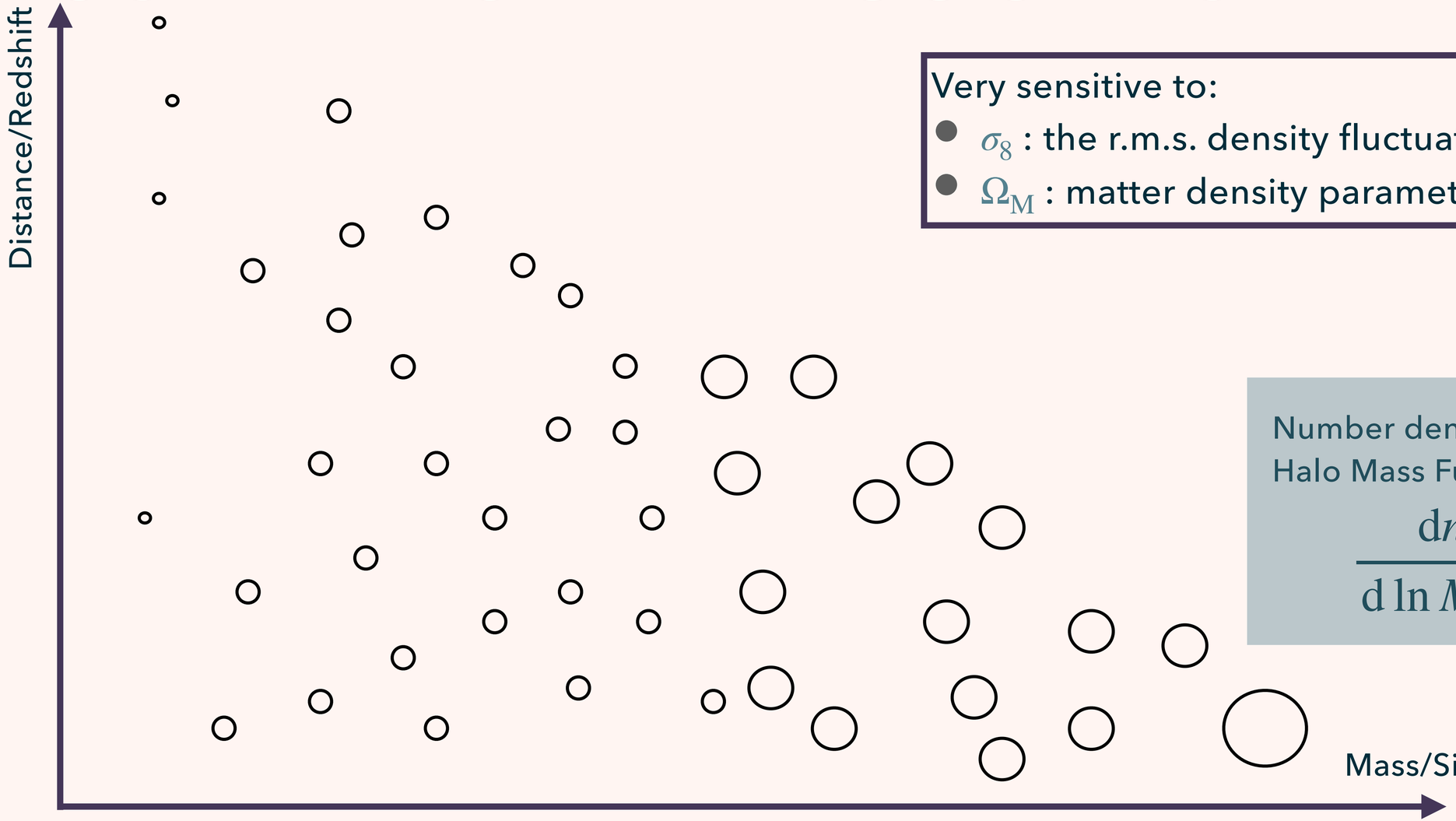
- Scale: a few Mpc(s)
- Hundreds to thousands of galaxies
- $\sim 10^{14}\ h^{-1}M_{\odot}$ and beyond



High resolution cluster cosmology with the NIKA2 camera



CLUSTER NUMBER COUNTS



Very sensitive to:

- σ_8 : the r.m.s. density fluctuation in $8\ \mathrm{h^{-1}Mpc}$
- Ω_M : matter density parameter

Number density of clusters / Halo Mass Function

$$\frac{\mathrm{d}n}{\mathrm{d}\ln M \mathrm{d}z}(M,z)$$

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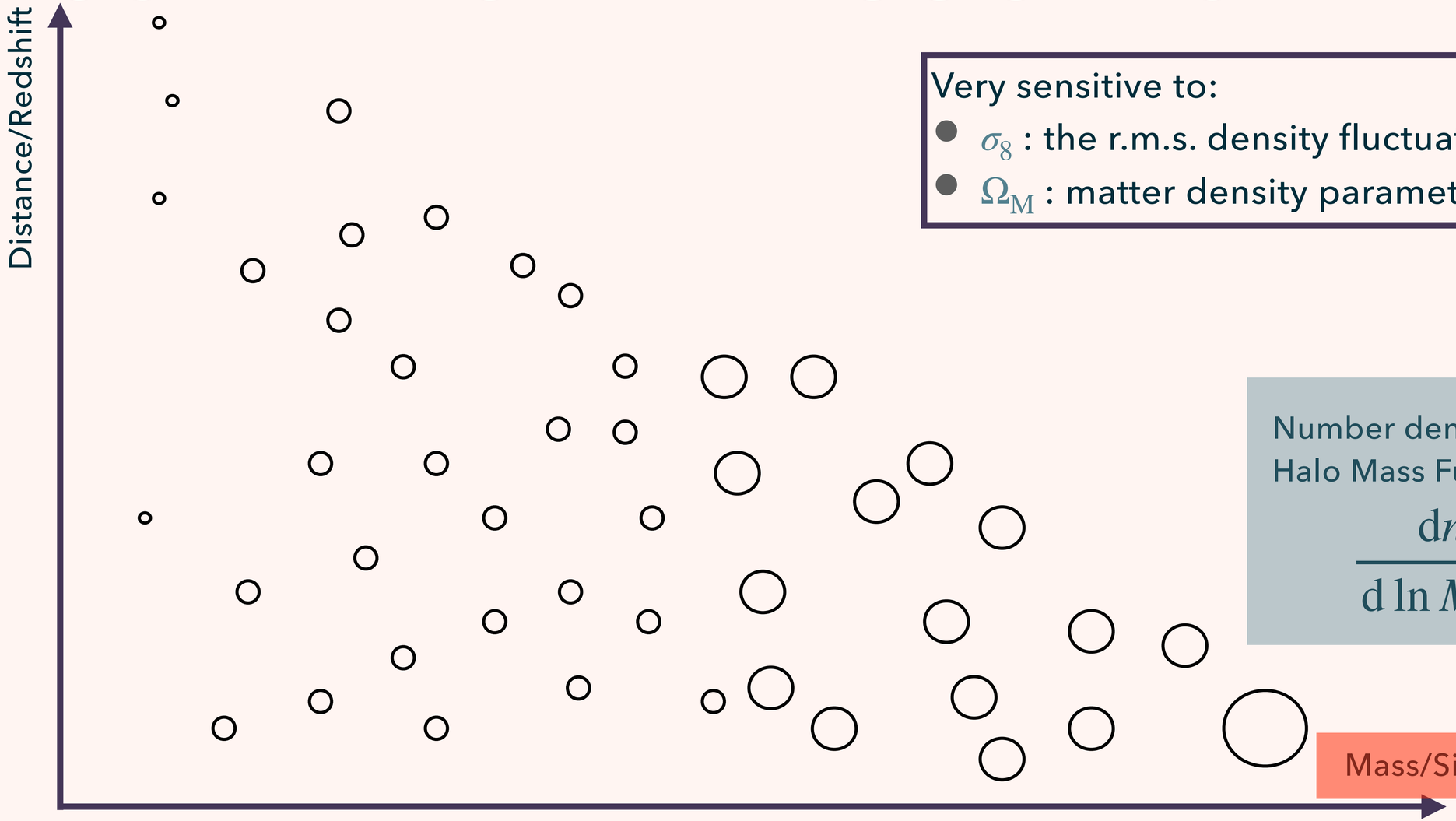

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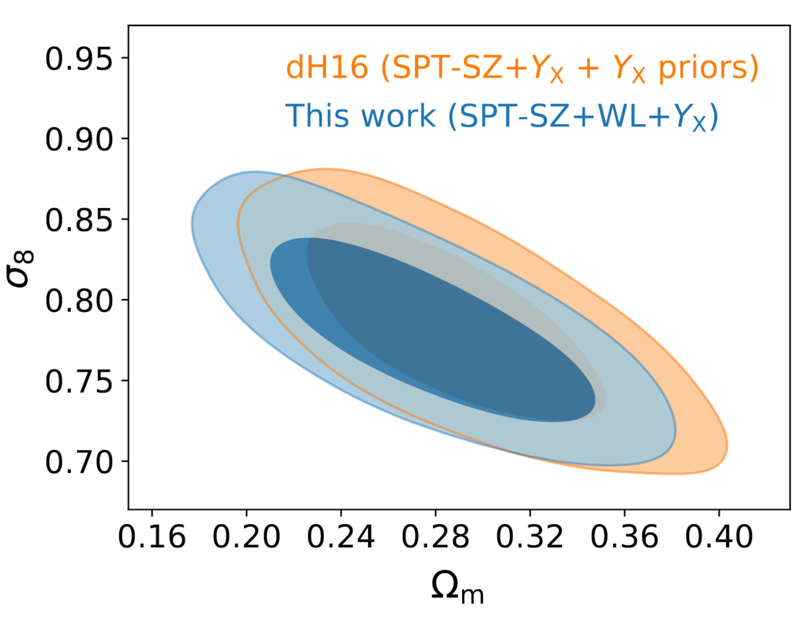
CLUSTER COUNTS COSMOLOGY

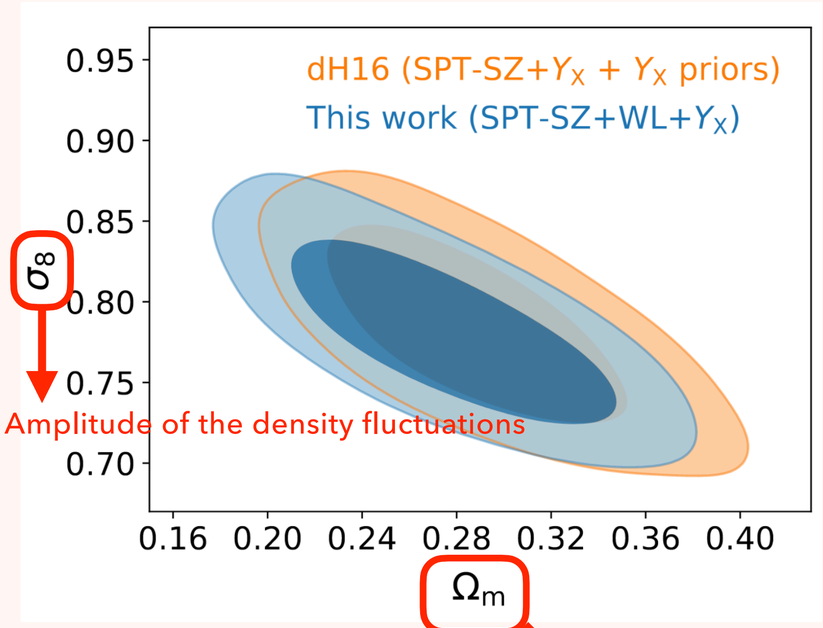


Bocquet al., 2019

- Cluster number density per unit of mass and redshift $\mathrm{d}N/\mathrm{d}M\mathrm{d}z$ provides information on the cosmological parameters (Ω_M, σ_8, etc.)
- Clusters surveys are at a turning point:
  Planck (10^3 objects) ⟶ Euclid(10^5 objects)
- However, their mass has to be inferred from physical observables

Inferring cluster mass is the key to get reliable contraints from cluster counts

CLUSTER COUNTS COSMOLOGY



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OUTLINE

AIM : Investigating the impact of the systematics affecting cluster counts cosmology

- **The NIKA2 Large Program SZ (LPSZ)**
- **The case of PSZ2G091**

IRAM 30 m telescope, Pico Veleta, Spain

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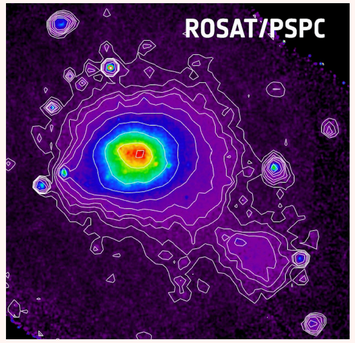
X-RAY/SZ SYNERGIES

X-ray



- X-ray surface brightness

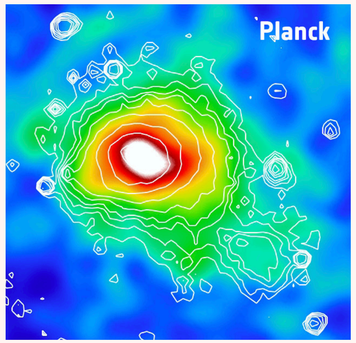
$$S_{\rm X} = \frac{1}{(1+z)^4}\int n_{\rm e}^2 {\rm d}l$$

Direct measurement of the ICM density

- X-ray spectroscopy

Measurement of the temperature profile

Millimetre domain



- Sunyaev-Zeldovich effect

Amplitude $y = \frac{\sigma_{\rm T}}{m_{\rm e}c^2}\int P_{\rm e}{\rm d}l$

Direct measurement of the ICM pressure integrated along the line of sight

- A common choice of observable is $Y_{500} = \int_{\Theta_{500}} y \, {\rm d}\Omega$ where Θ_{500} is the angular area covered up to R_{500}

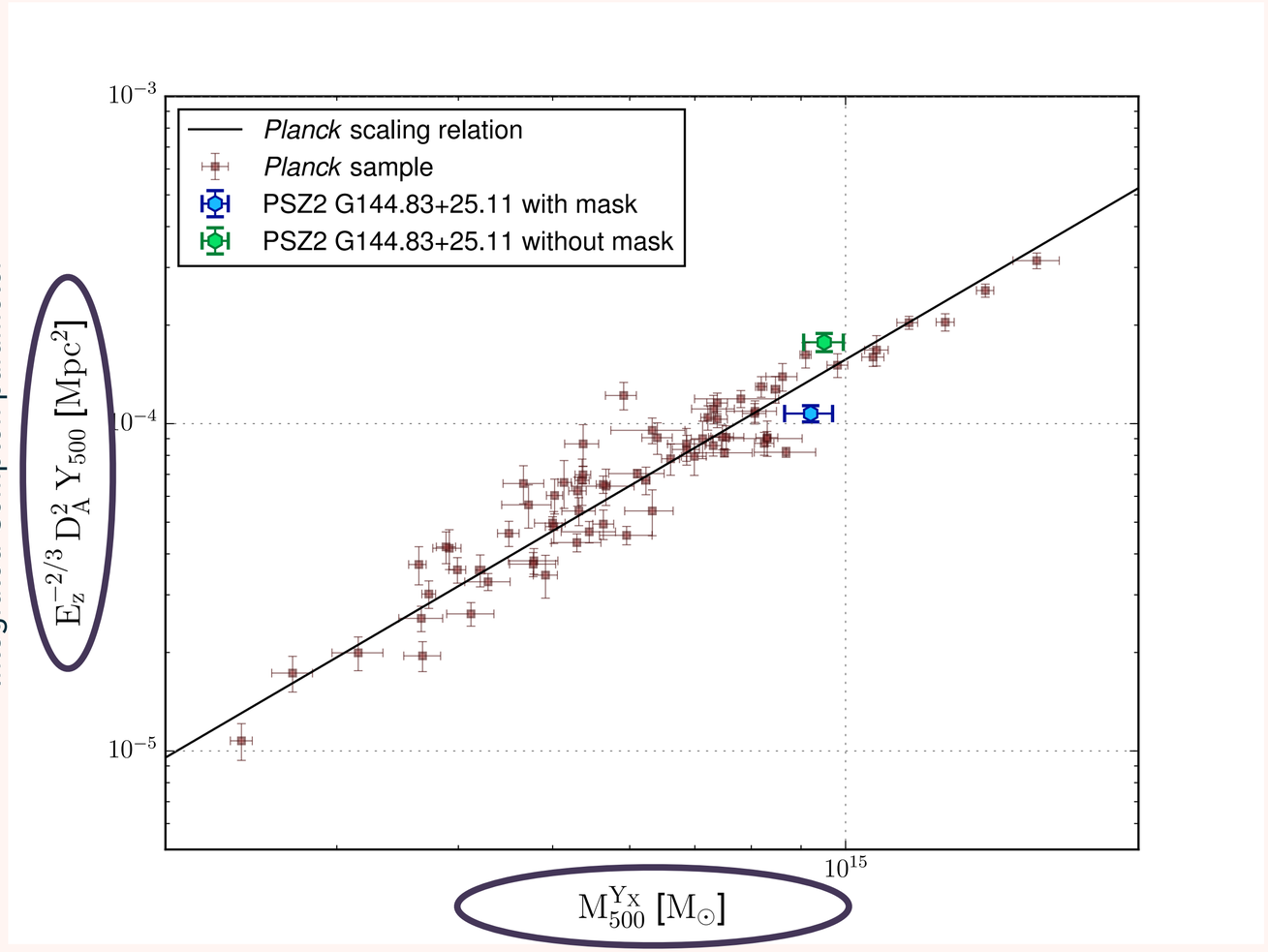
Assuming hydrostatic equilibrium

$$M_{\rm HSE}(r) \propto \frac{r^2}{n_{\rm e}(r)}\frac{{\rm d}P(r)}{{\rm d}r}$$

For SZ surveys, the pressure profile is one of the key ingredients

SCALING RELATIONS : LINKING THE MASS AND THE OBSERVABLE

Ruppin al., 2018



- Scaling relations link the observable and the underlying mass
- Cluster may have over-pressured regions
- With or without masking over-pressured regions in clusters, different results are obtained

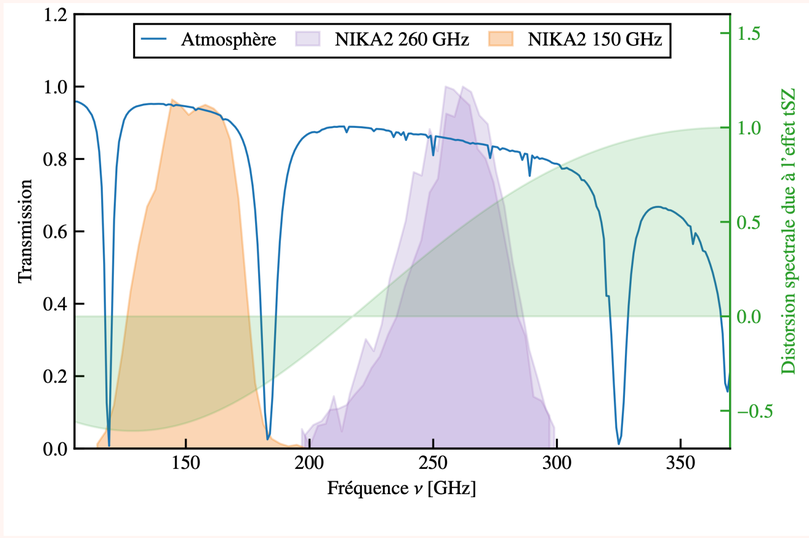
Astrophysical uncertainties are affecting the scaling relations (scatter or bias)

THE NIKA2 CAMERA AT THE IRAM 30M TELESCOPE

Characteristics of the instrument, Perotto et al., 2020

	150 GHz	260 GHz
FOV diameter	6.5′	6.5′
Angular resolution: FWHM	17.6″ ± 0.1″	11.1″ ± 0.2″
RMS calibration uncertainties	3%	6%
Absolute calibration uncertainties	5%	5%
Systematic uncertainties	<1%	<1%
Sensitivity: NEFD	9 ± 1 mJy.s$^{1/2}$	30 ± 3 mJy.s$^{1/2}$
Mapping speed arcmin^2 /mJy^2 / hours	1388 ± 174	111 ± 11

NIKA2 spectral bands



Credits : F. Kéruzoré's Ph.D. thesis

With such characteristics, the NIKA2 instrument has:

- A field of view large enough to probe the ICM at R_{500}
- A spatial resolution that allows us to analyse the substructures of the ICM

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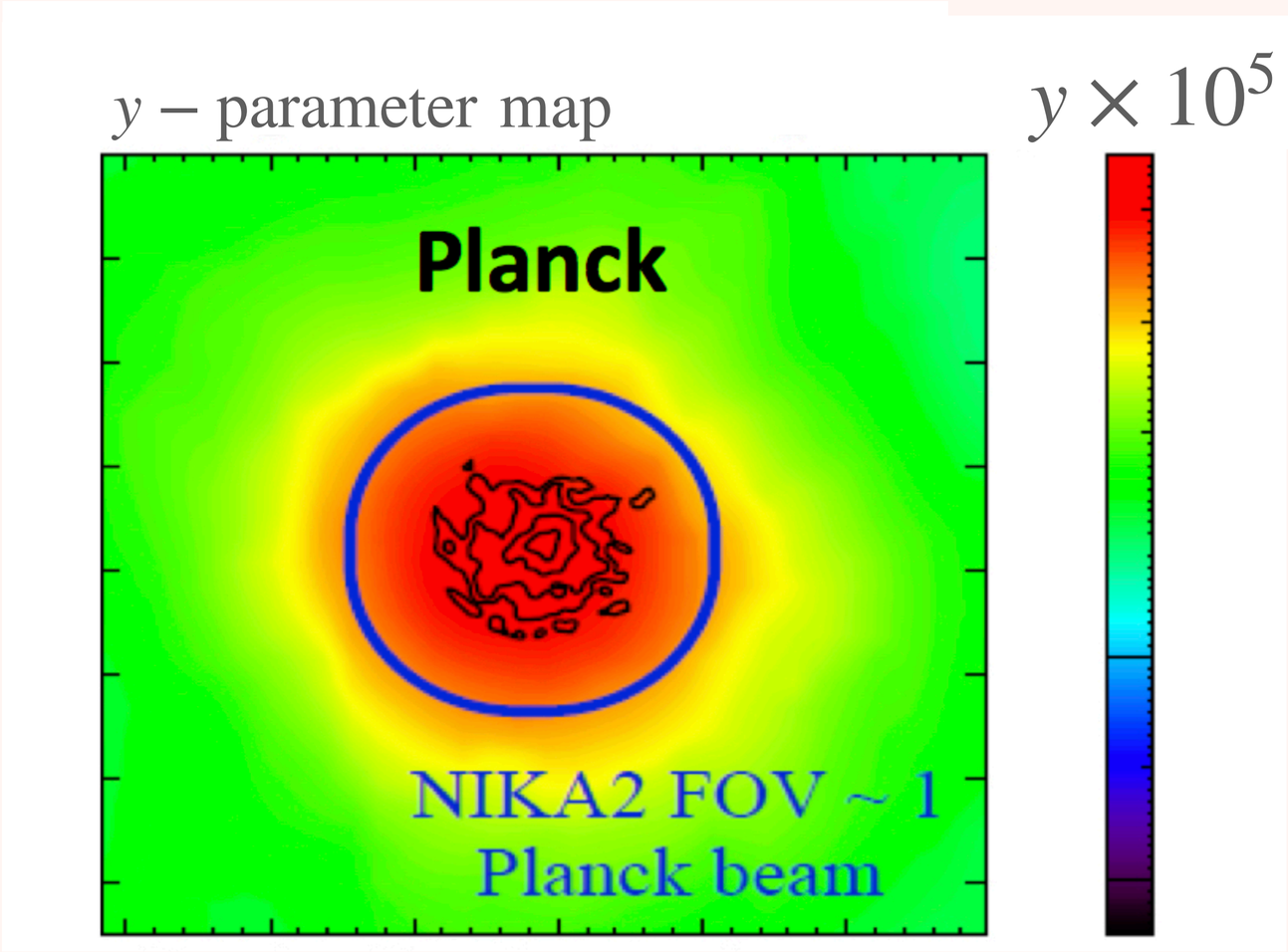
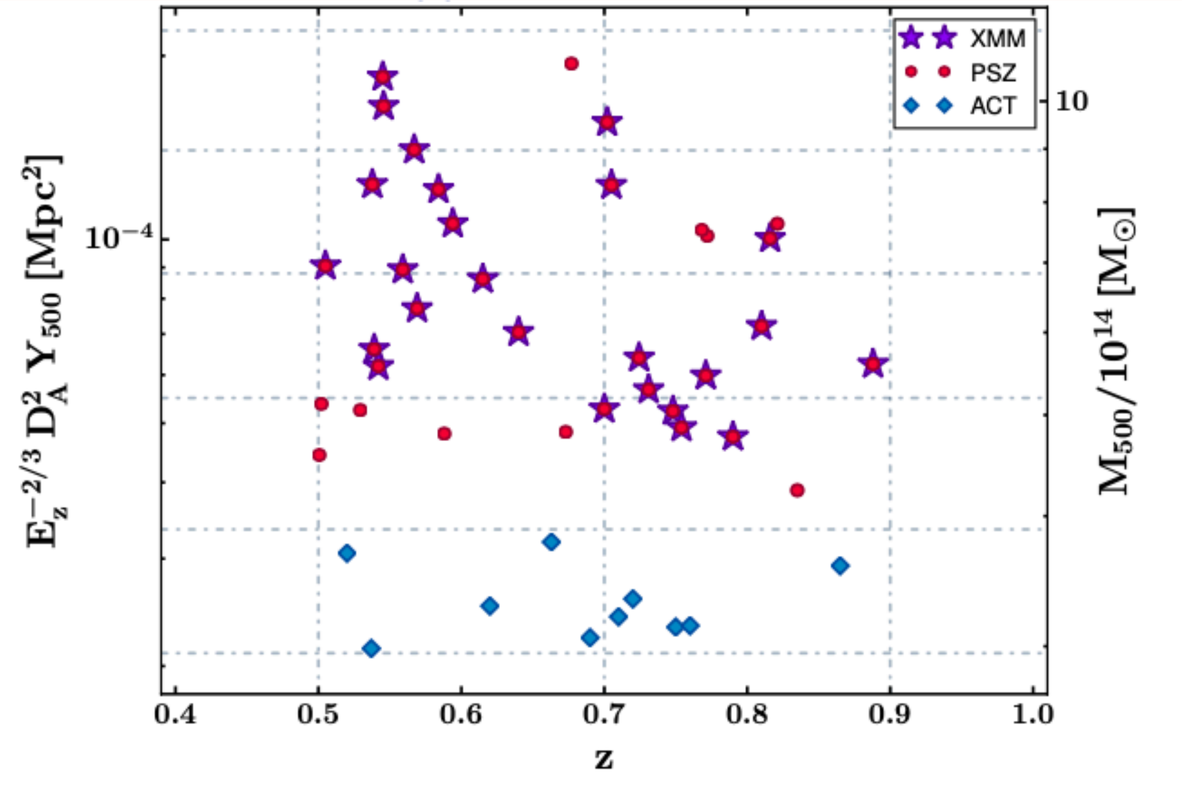
Resolution of the Planck satellite : 5′ at 217 GHz



LARGE PROGRAM SZ OF THE NIKA2 COLLABORATION

Distribution of the LPSZ clusters (credits : F. Ruppin)



The Large Program SZ (LPSZ) aims at observing a representative sample of galaxy clusters with high-resolution SZ observation from NIKA2

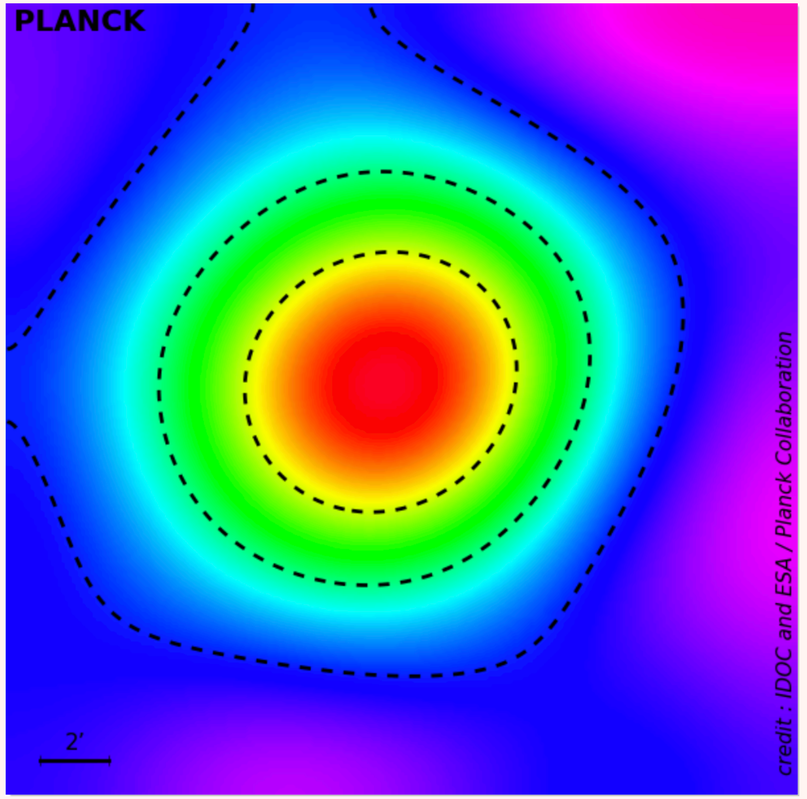
- **300 hours of guaranteed time at the IRAM 30 m telescope**
- **XMM data + follow-up**
- **P.I.: Frédéric Mayet and co. P.I.: Laurence Perotto**
- **45 clusters with $0.5 < z < 0.9$, ~35 already observed**

Investigate systematic effects related to cluster counts cosmology

- Departure from the universal pressure profile
- Scaling relations
- Properties of low-mass and high-z clusters

OUTLINE

- **The NIKA2 Large Program SZ (LPSZ)**
- **The case of PSZ2G091**



Smoothed y-map of PSZ2-G091 observed by Planck

Credits : Planck collaboration

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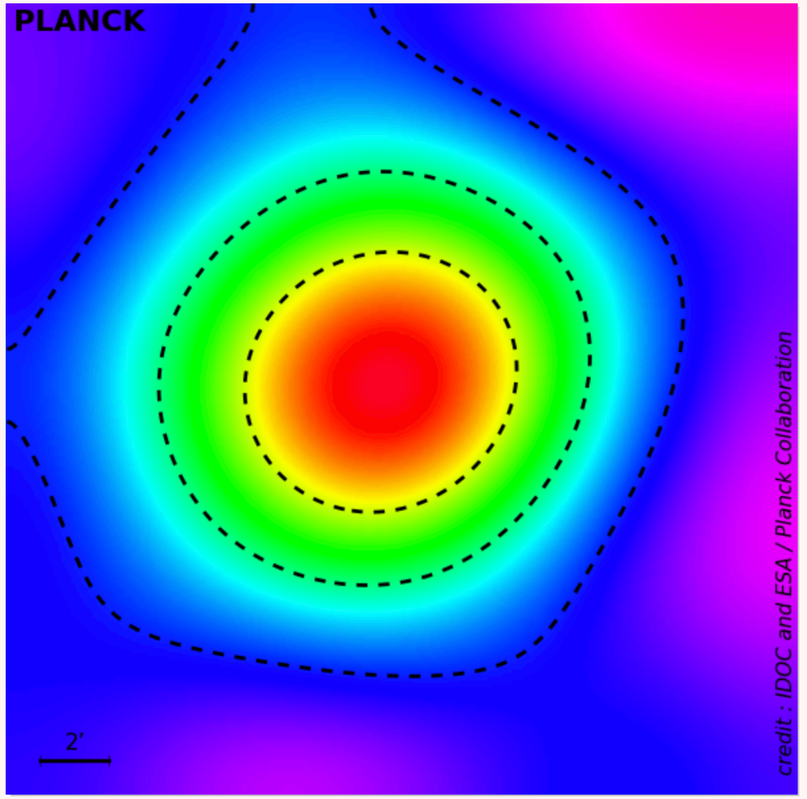

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PSZ2G091 : A MASSIVE CLUSTER

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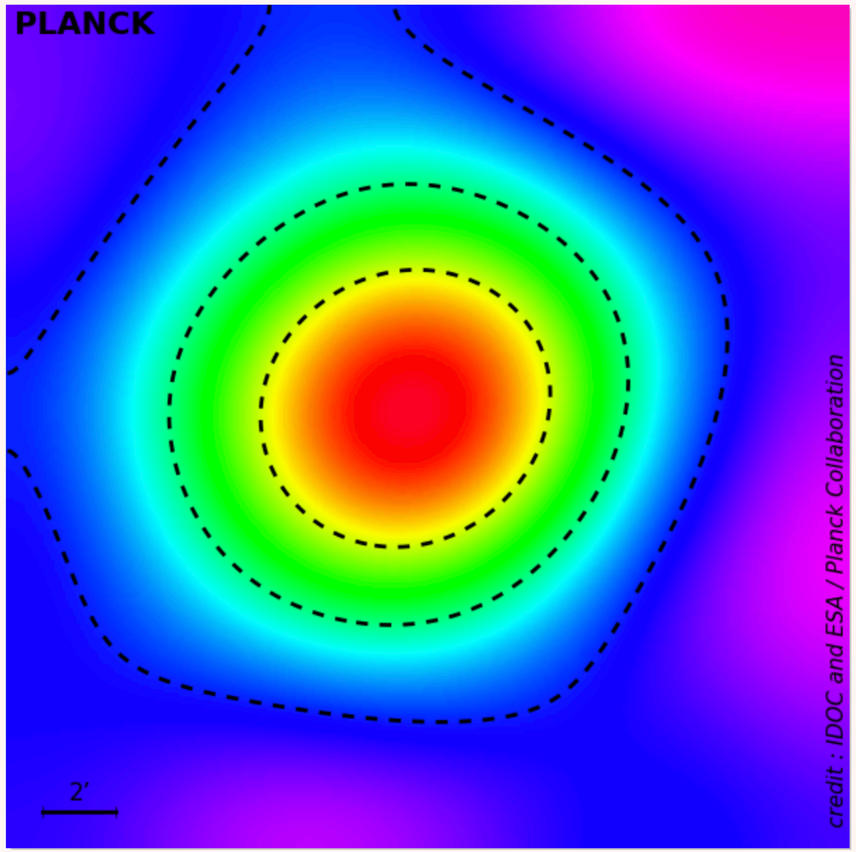


Credits : Planck collaboration

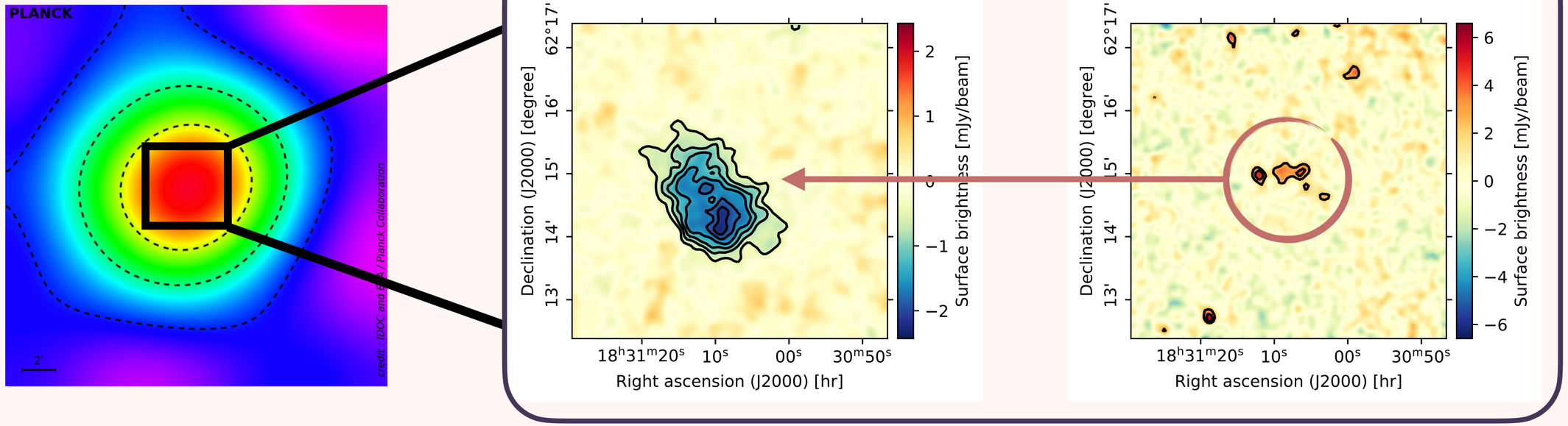
- **Massive object detected by Planck**
- **Redshift :** $z \sim 0.822$
- $Y_{500} = 0.63 \times 10^{-3}$ arcmin^2
- $M_{500} = 7.43 \times 10^{14}$ M$_\odot$
- $\theta_{500} = 2.2'$

Nothing can be said about the structure of the cluster from Planck's observations

ANALYSIS : PSZ2G091

From the LPSZ analysis pipeline, we get the 1 mm and 2 mm maps of PSZ2G091

E.A. et al.,2111.05082



Infer the impact of point sources

Observation summary Atmospheric opacity at 225 GHz

τ_{225}	$t_{\rm obs}/t_{\rm LPSZ}$	tSZ decrement peak
0.243	2.5h/2.5h	14.9σ

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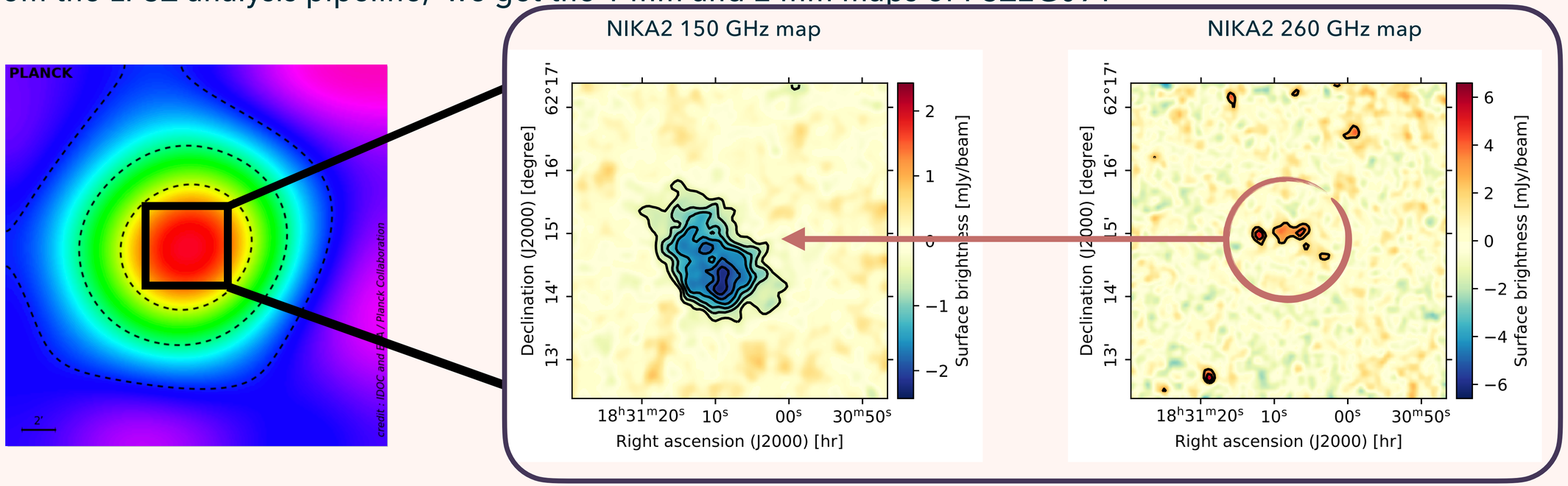
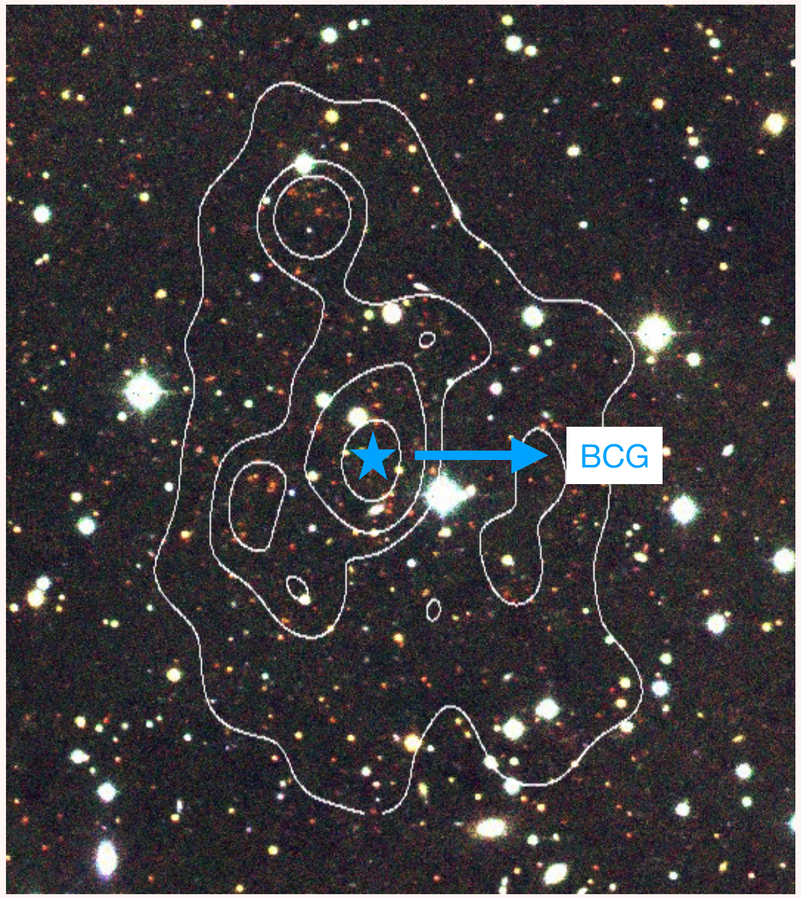


Infer the impact of point sources

- The NIKA2 150 GHz map shows structures that are hints of bimodality
- The 260 GHz map shows point sources that are to be considered in the analysis, before moving on to the thermodynamical quantity reconstruction software PANCO2 , Kéruzoré et al., 2021

PSZ2G091 : DYNAMICAL ANALYSIS

Courtesy: R. Barrena



Galaxy density contours (Canary Island telescopes)

- **Colour selected galaxies ($r - z > 2.1$)**
- **16 spectroscopic redshifts**
- **2D galaxy distribution from an adaptative kernel procedure (Pisani et al., 1993)**

PSZ2G091 : DYNAMICAL ANALYSIS

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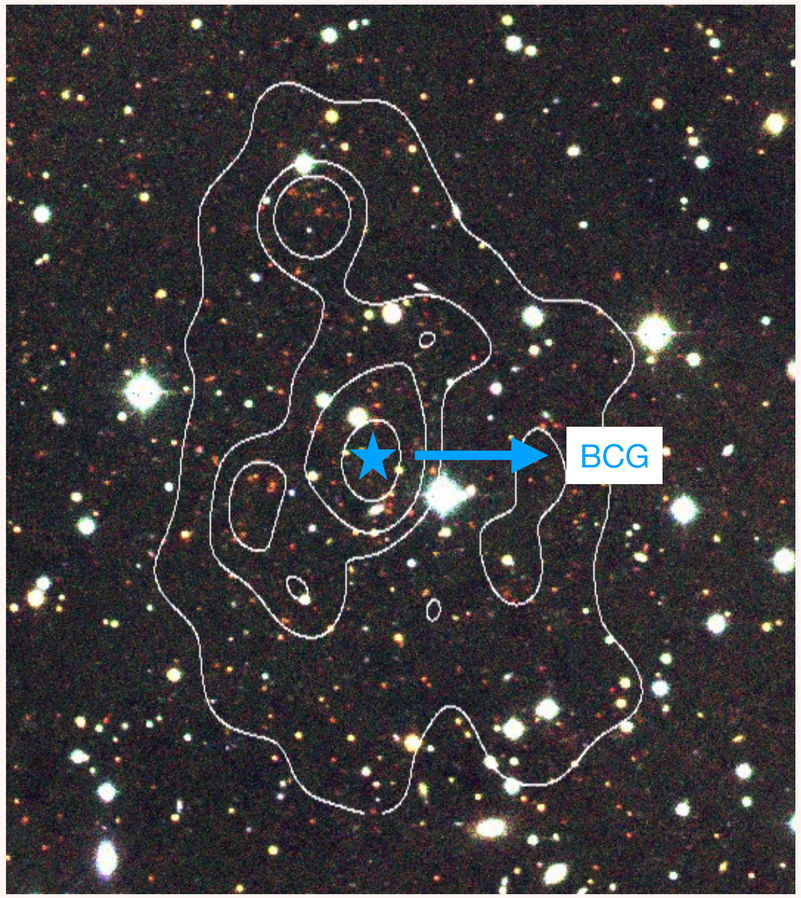
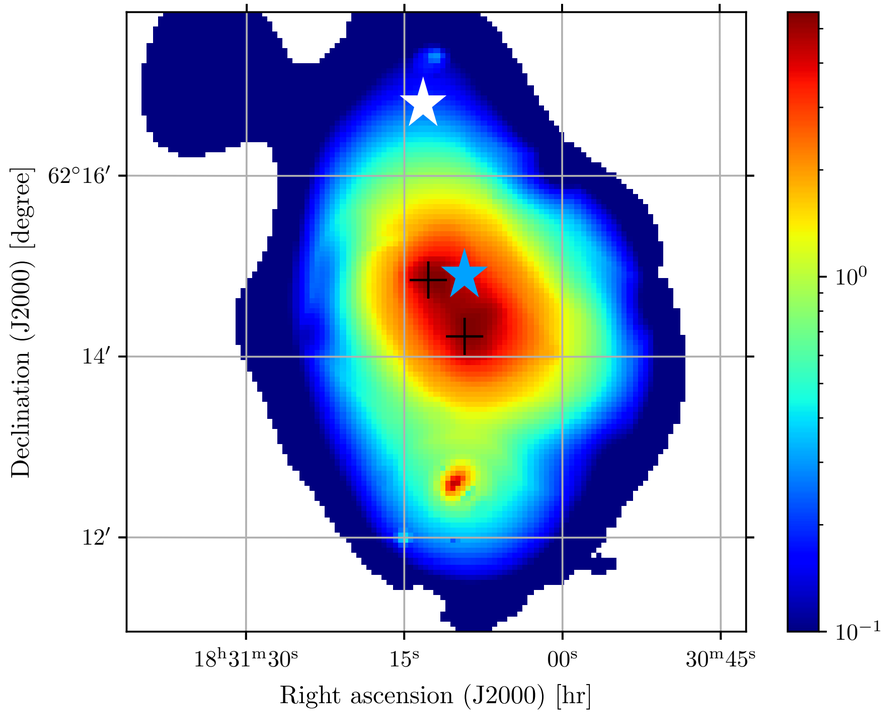


Galaxy density contours (Canary Island telescopes)

Courtesy: I. Bartalucci

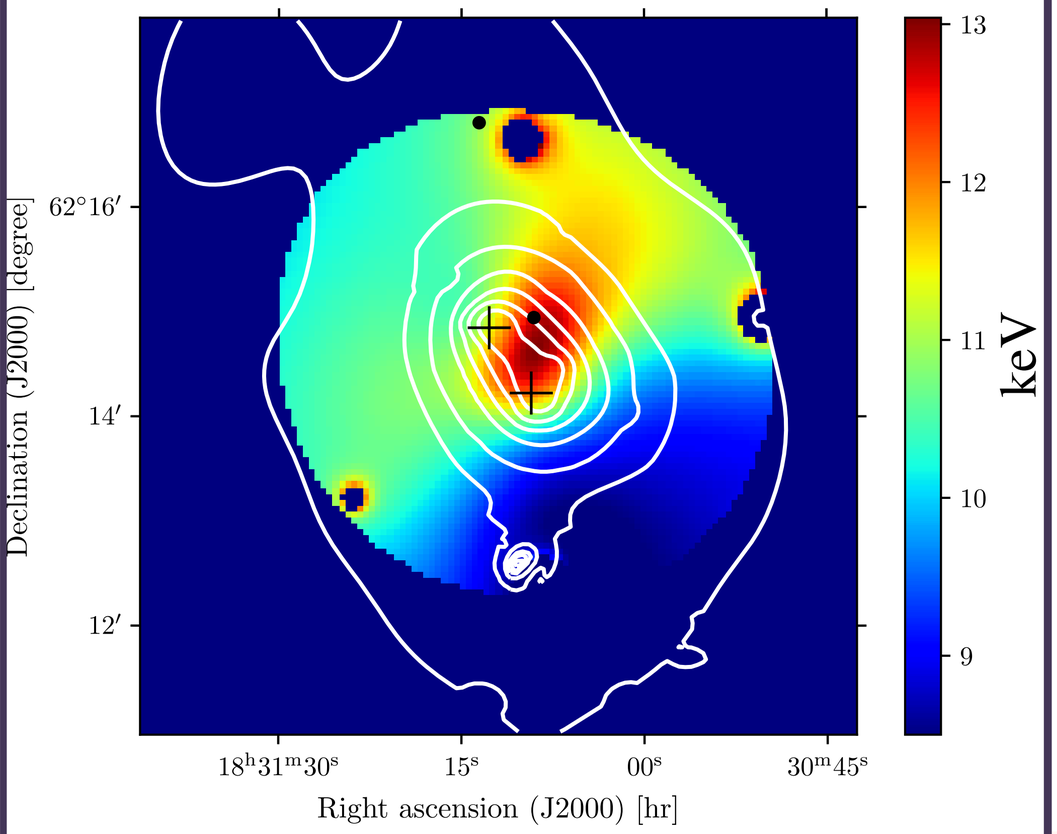


X-ray surface brightness (XMM-Newton), Bourdin & Mazzotta, 2008

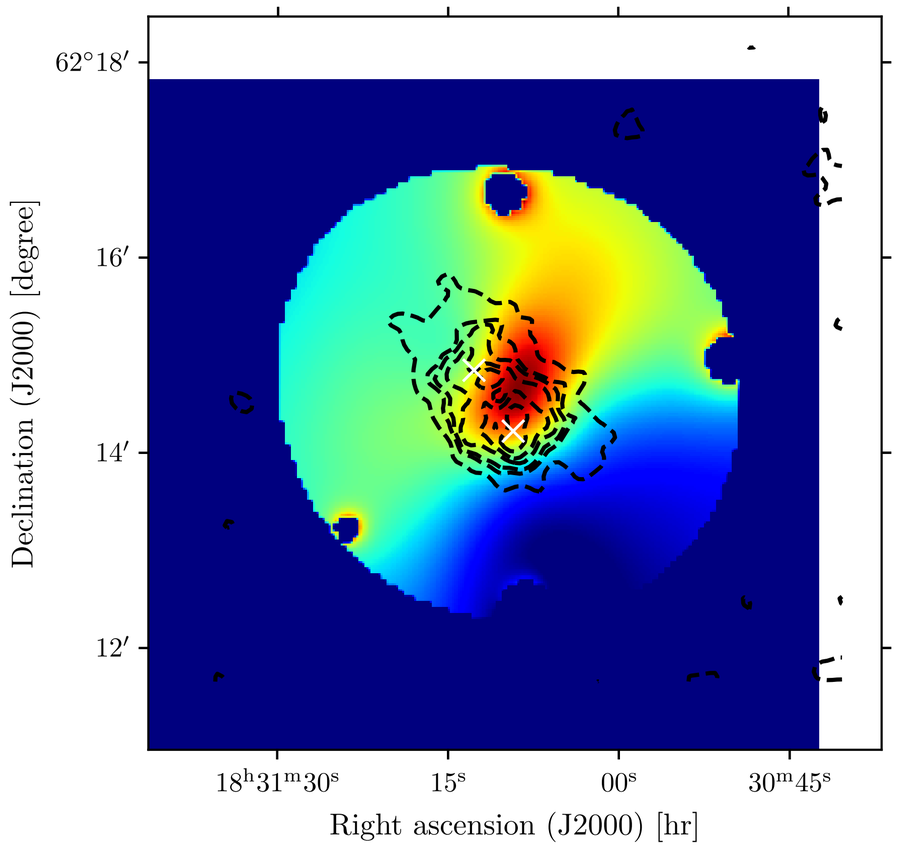
Disturbed structure

- Optictical BCG (blue star) and X-ray peak compatible (black crosses)
- White star : center of the galaxy distribution of the northern shallower clump
- The bimodal structure is outlined even better in the X-ray data

PSZ2G091 : DYNAMICAL ANALYSIS



Temperature map (XMM-Newton) + Surface brightness S/R contours in white (XMM-Newton)



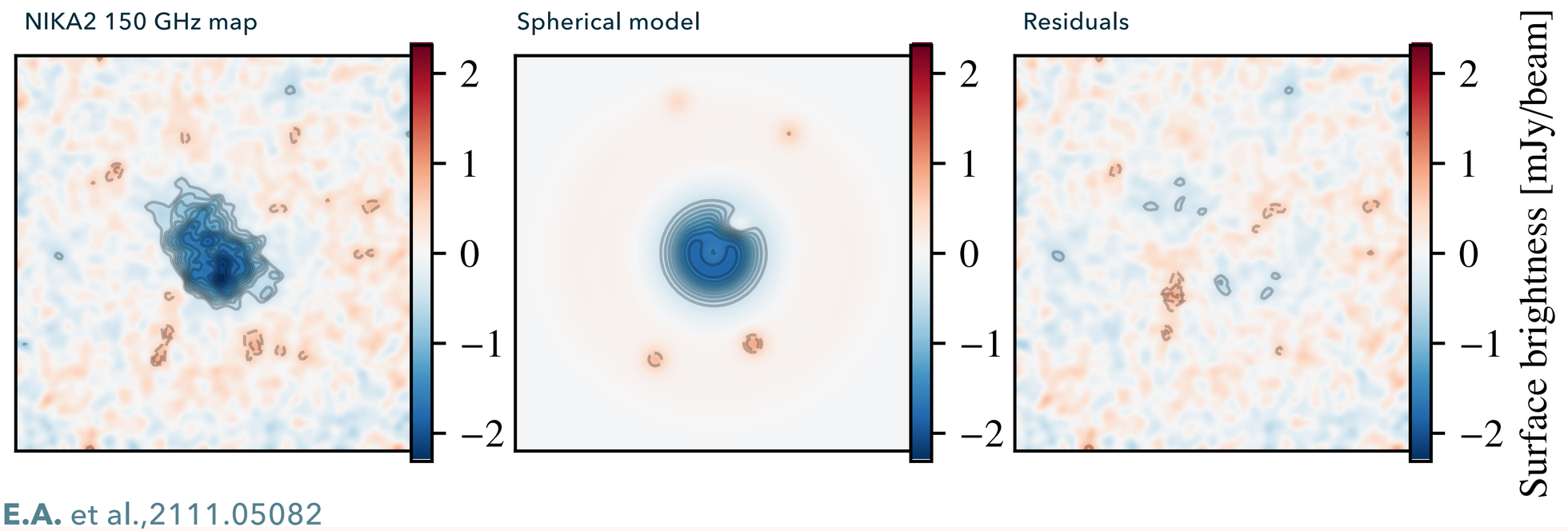
Temperature map (XMM-Newton) + 150 GHz flux density S/R (NIKA2)

The temperature map obtained from X-ray spectroscopy shows a region with a high temperature, perpendicular to the axis of the merger

Overall, this dynamical structure will affect how the thermodynamical quantities are recovered

STANDARD ANALYSIS : PRESSURE PROFILE WITH A SPHERICAL MODEL

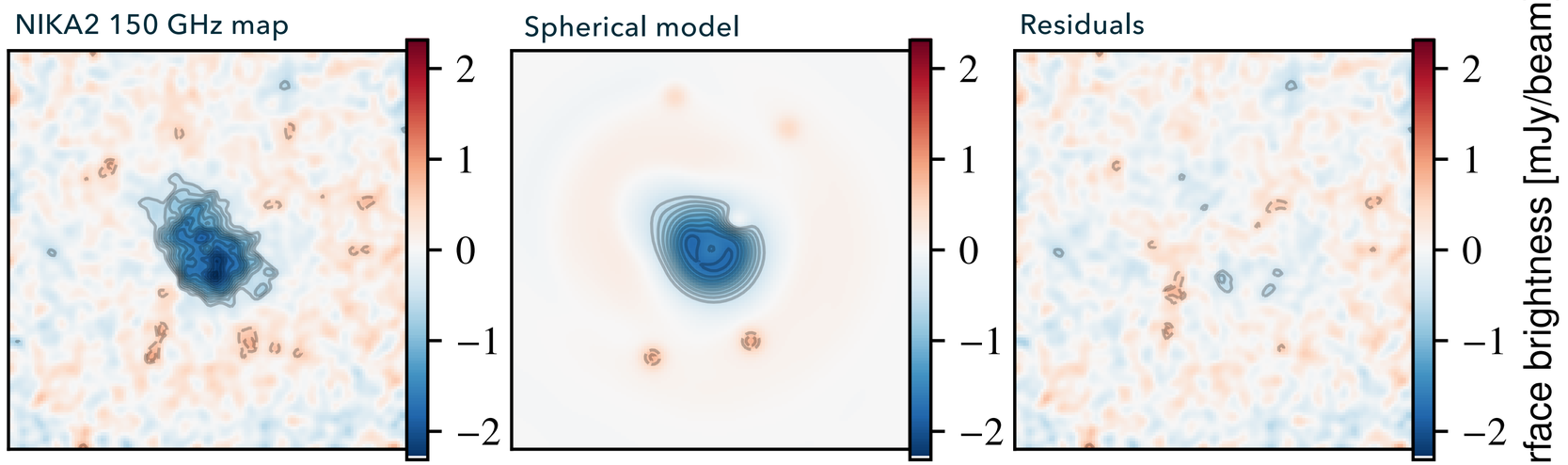
As a first test case, we first fit a single spherical model to the NIKA2 150 GHz map. The numerous point sources are fitted jointly in the analysis



E.A. et al.,2111.05082

ANALYSIS : BIMODAL CLUSTER MODEL

- **Instead of fitting the single spherical model, we fit a 2 sub-halo model which is taking into account the morphology of the cluster**
- **Is the spherical assumption impacting the shape of the profile ?**
- **The pressure obtained considering the 2-halo model is compared to the single spherical one**



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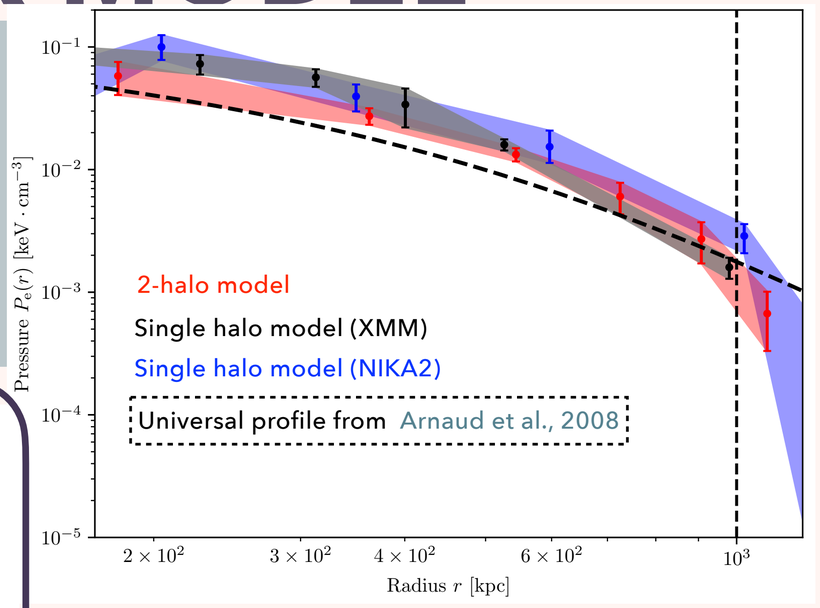
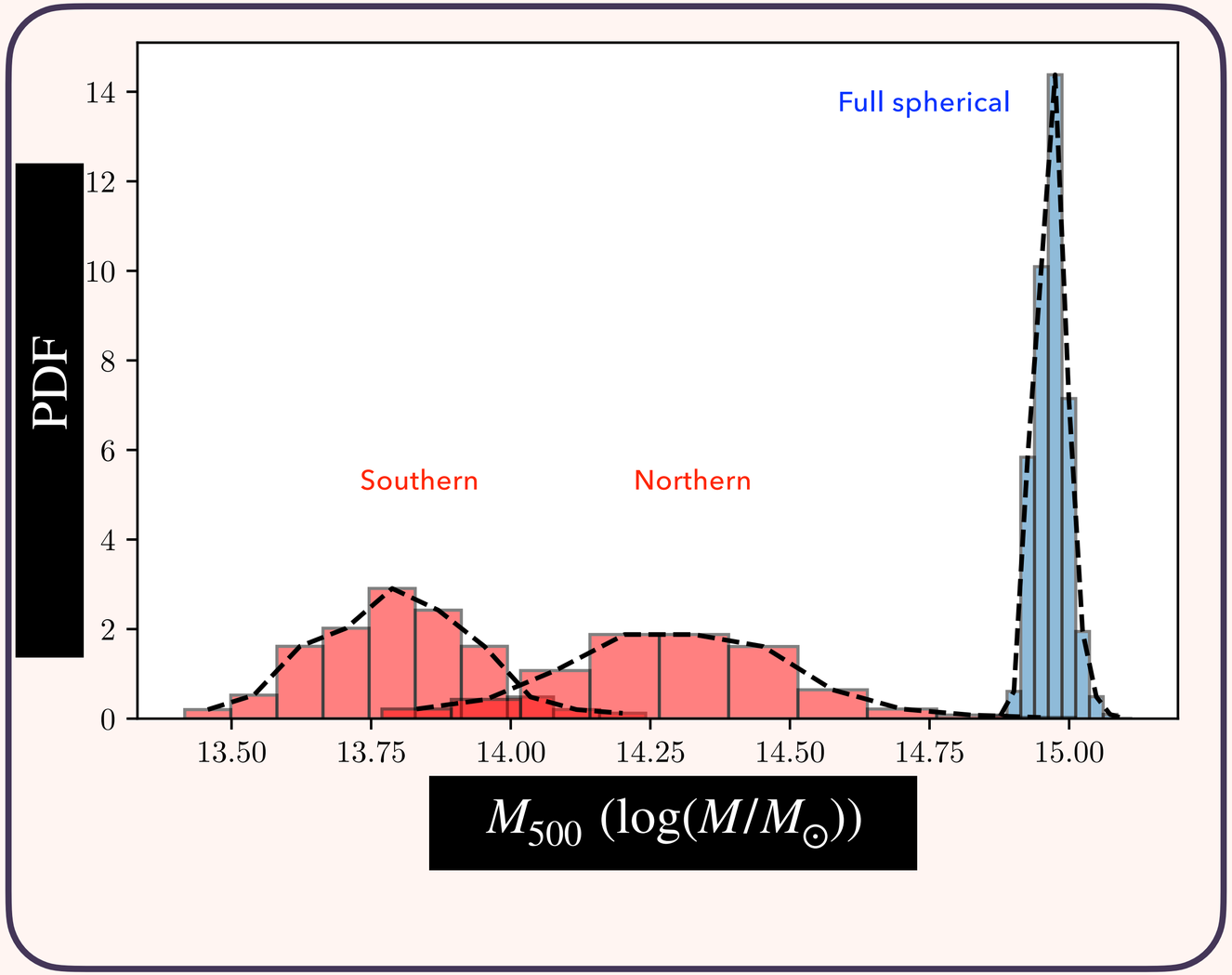


E.A. et al., in prep.

The 2-halo model differs significantly from the other profiles

ANALYSIS : BIMODAL CLUSTER MODEL



- **Using this model, we can reconstruct the hydrostatic mass as accurately as possible**
- **The effect of this modelling should be investigated in future cosmological studies**

CONCLUSION

- **Cluster counts cosmology is at a cross-road with upcoming large surveys**

  With a large field of view and a high angular resolution, the NIKA2 camera is the perfect instrument to study cluster structures in detail

- **High-resolution SZ observations (combined with X-ray and optical follow-up) fondamental to probe the systematics related to cluster counts**

  Cluster morphology has to be taken into account in future cluster surveys, as it strongly impact cluster related quantities

Thank you for your attention !