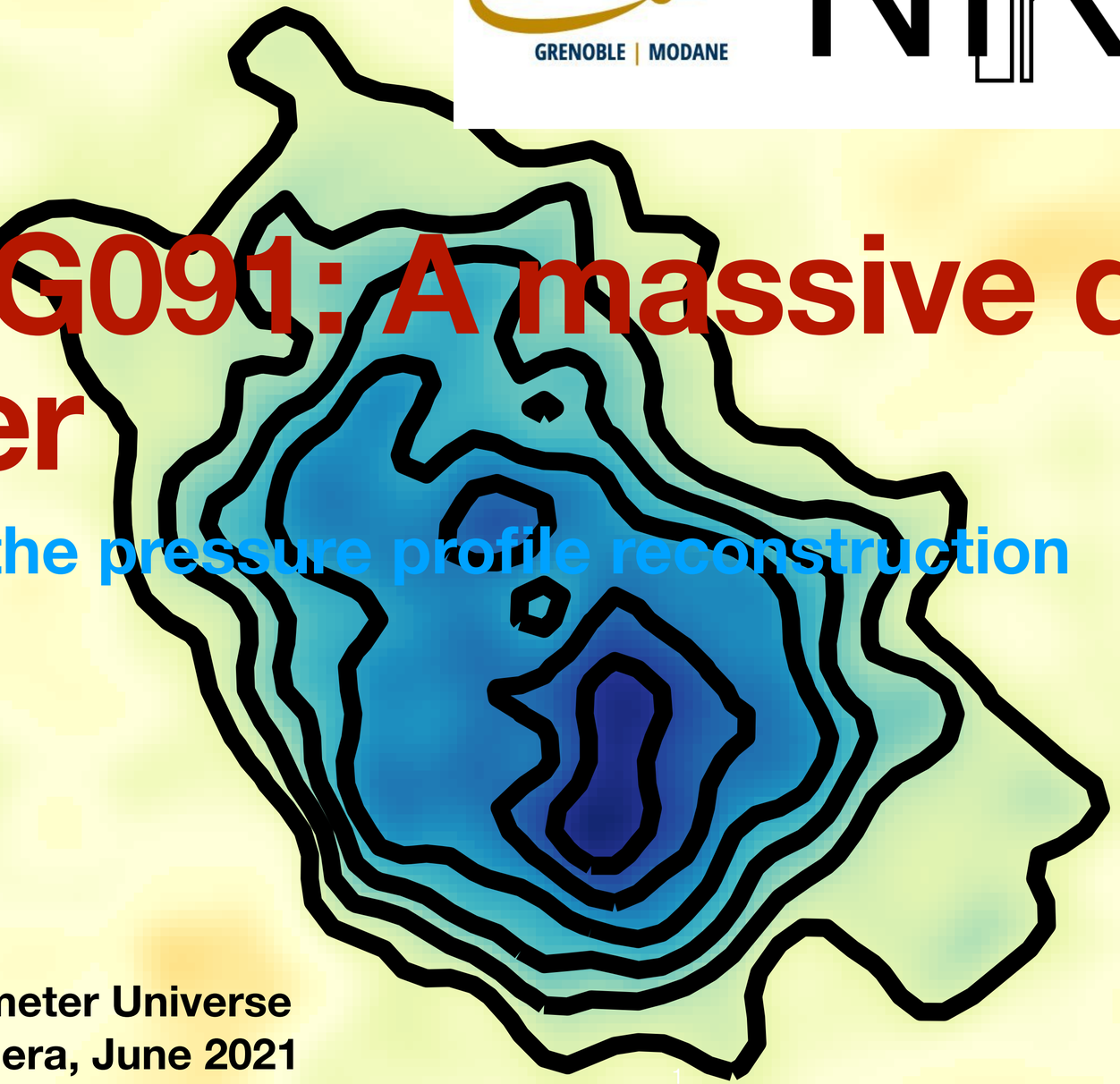
PSZ2G091: A massive double cluster

Impact on the pressure profile reconstruction



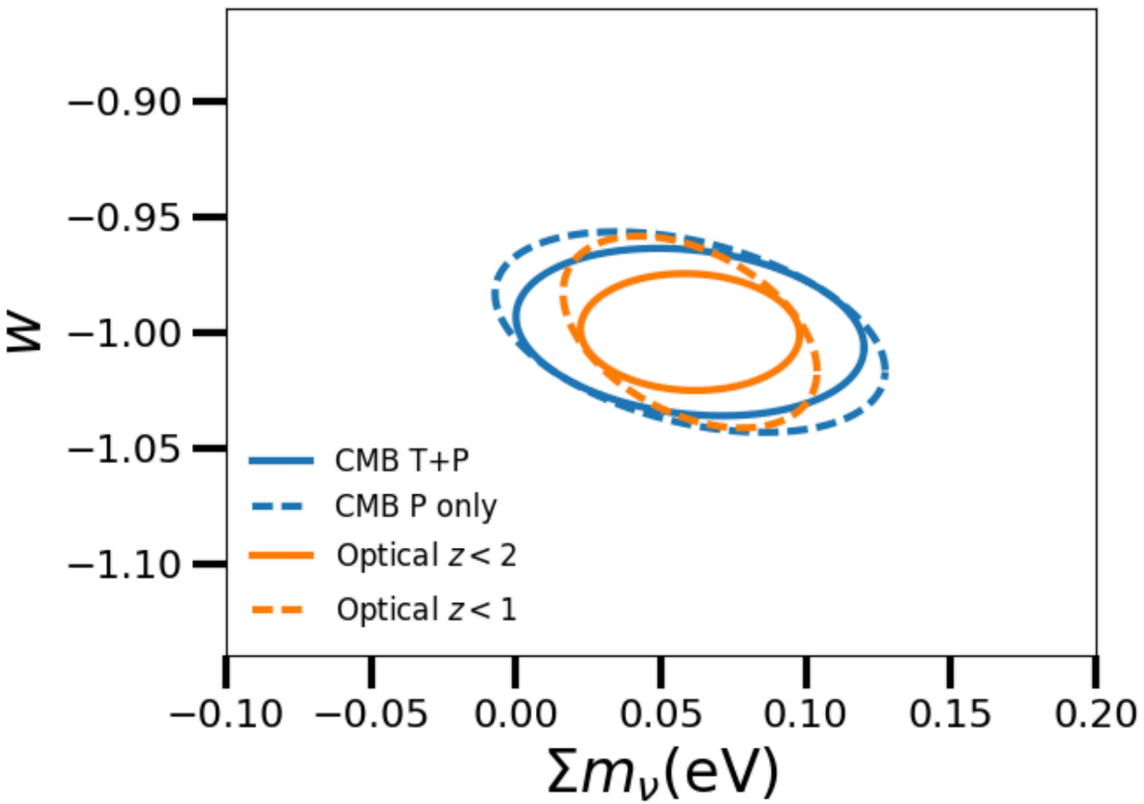
Observing the millimeter Universe
with the NIKA2 camera, June 2021

E. ARTIS (LPSC), on behalf of
the NIKA2 collaboration

Cluster number counts

A powerful probe for cosmological studies

Madhavacherii, Battaglia, Miyatake, 2017



Constraints obtained for a CMB-S4-like (70,000 clusters with $S/N > 5$)

Future cluster surveys shed light on:

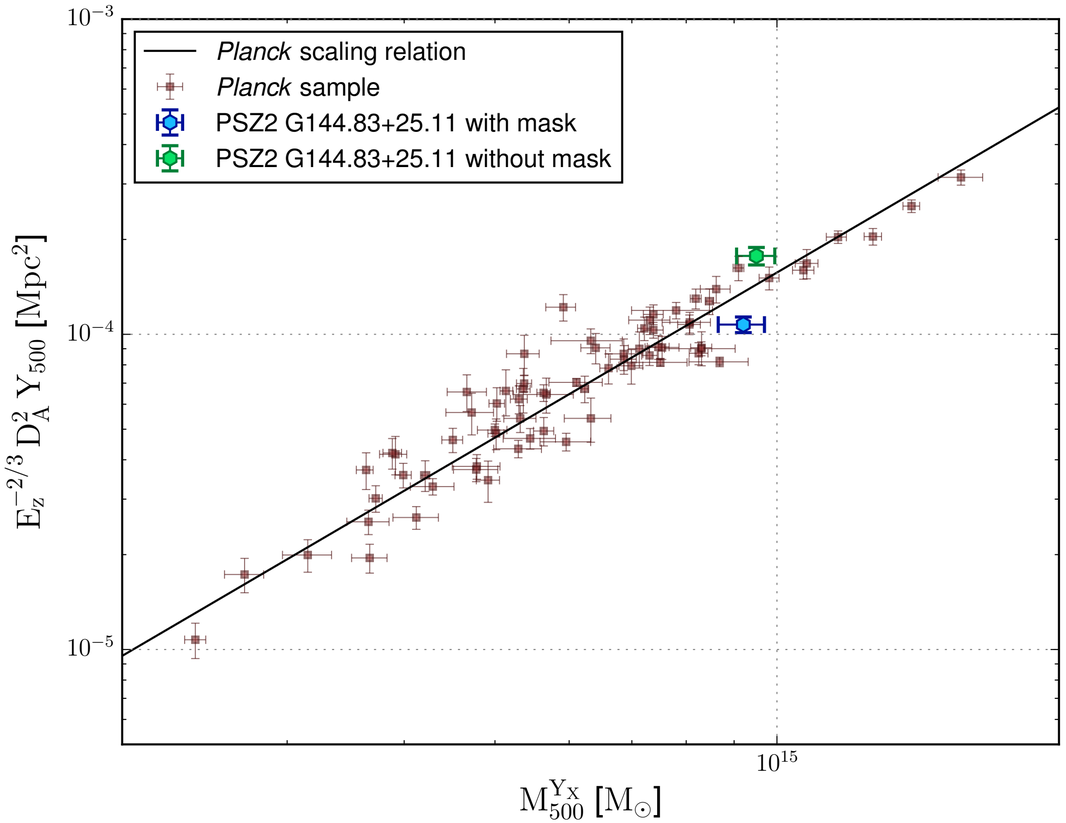
- the mass hierarchy of the neutrinos
- the dark energy equation of state
- the cosmological parameters (Ω_m, σ_8, …)
- …

Reaching this goal requires a precise understanding of the systematics, like the impact of cluster morphology

Cluster number counts

A powerful probe for cosmological studies

Ruppin et al., 2018



Planck's scaling relation re-analyzed: the green and the blue points are obtained with or without masking overpressured regions

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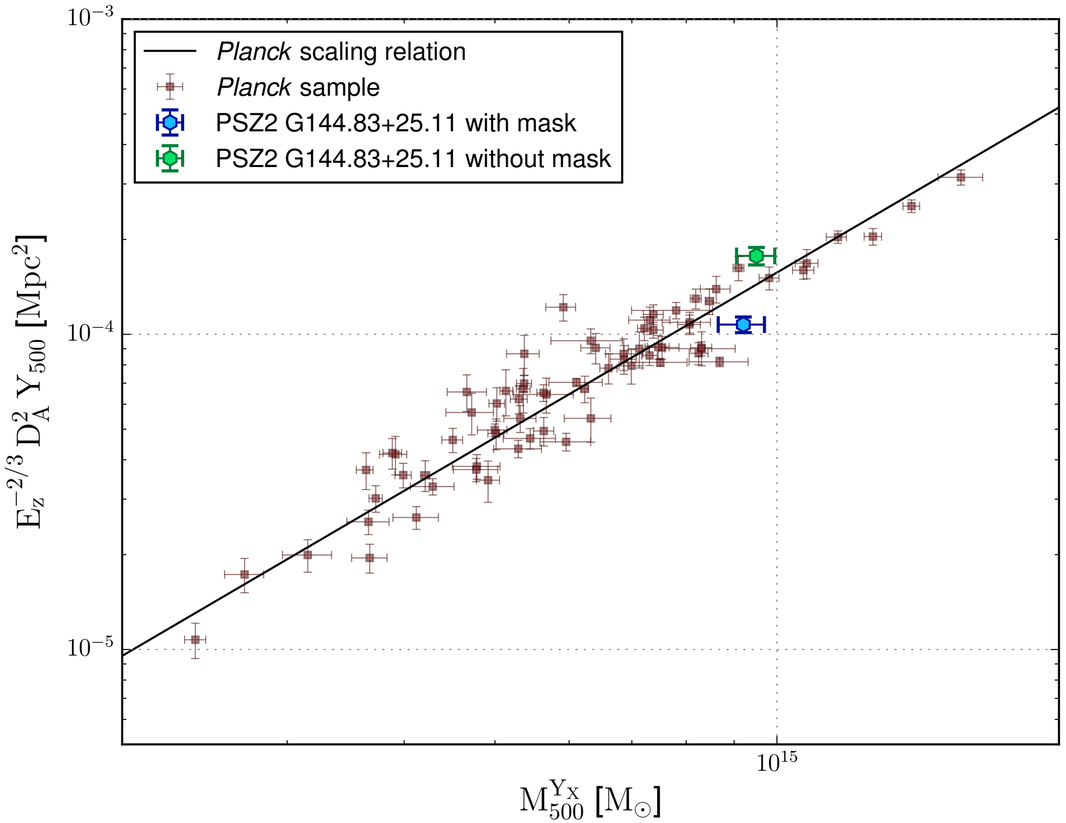
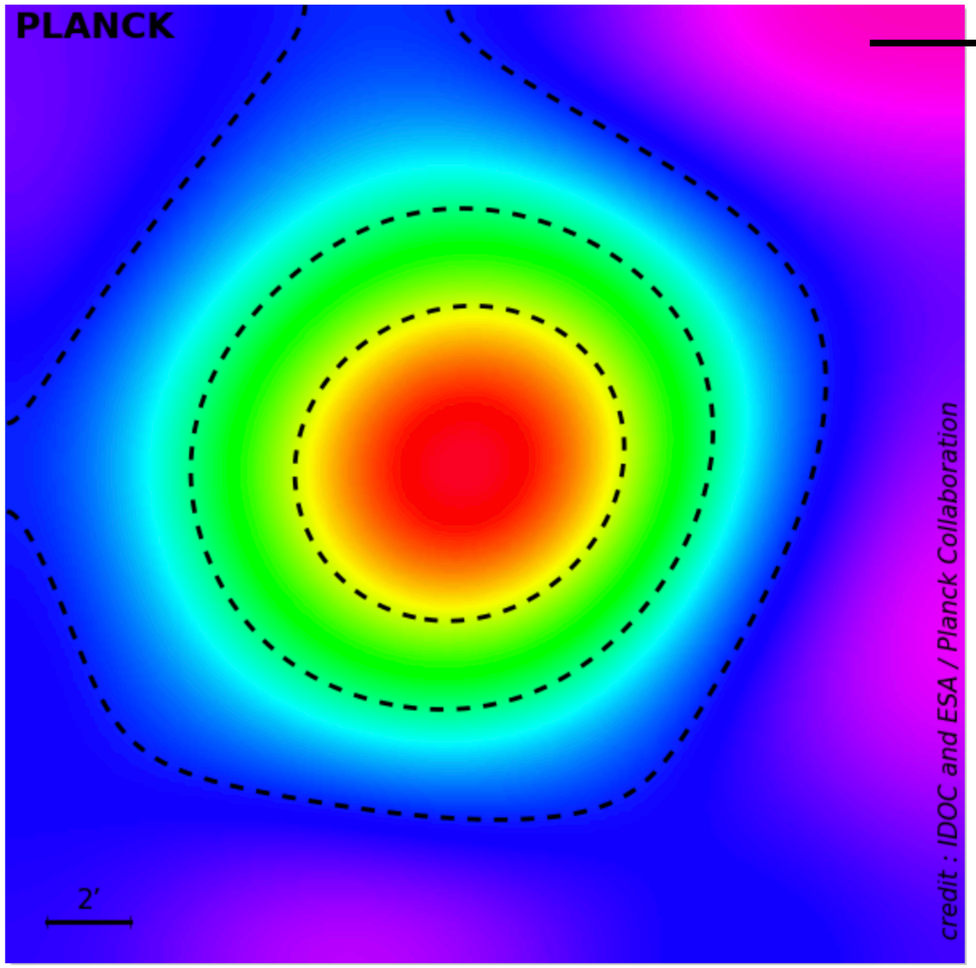


Planck's scaling relation re-analyzed: the green and the blue points are obtained with or without masking overpressured regions

Astrophysical uncertainties have a strong impact on the scaling relations

PSZ2G091: a massive cluster

As seen by Planck



Smoothed y-map of PSZ2-G091 observed by Planck

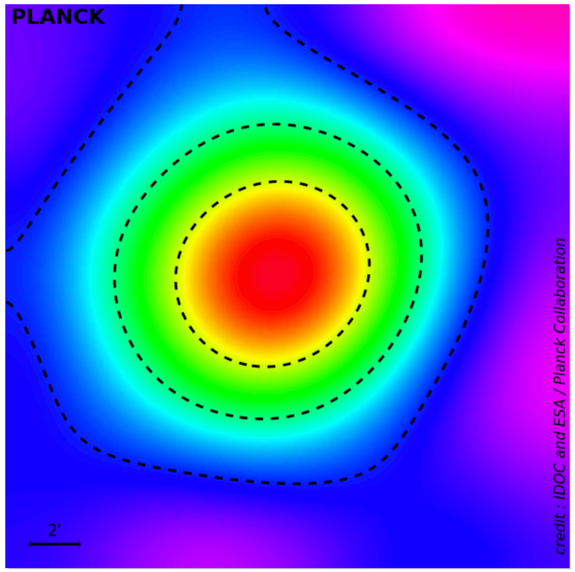
- Massive object detected by Planck
- $z \sim 0.822$
- $Y_{500} = 0.63 \times 10^{-3}$ arcmin^2
- $M_{500} = 7.43 \times 10^{14}$ M$_\odot$
- $\theta_{500} = 2.2'$

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

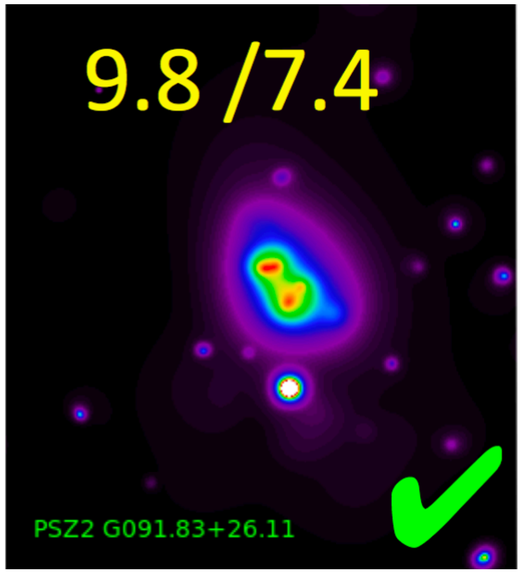
Credits: Planck collaboration

PSZ2G091: a massive bimodal cluster

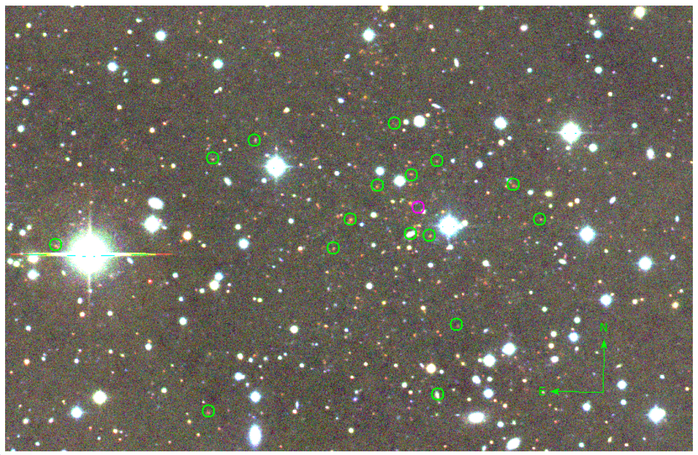
Planck (SZ)



XMM (X-rays)



GTC (Optical)



PSZ2G091: a massive bimodal cluster

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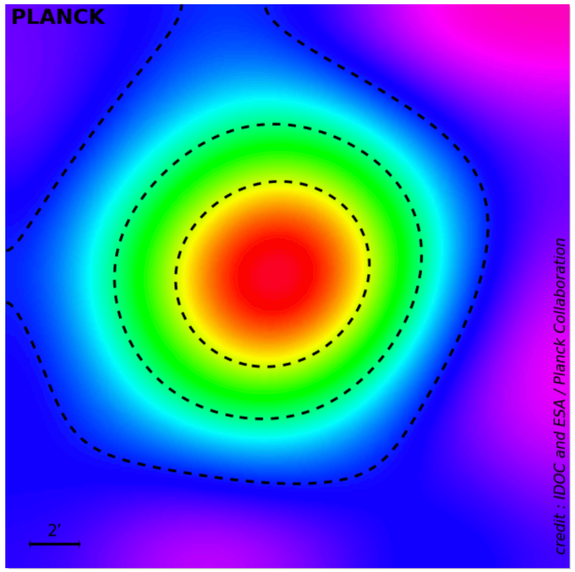

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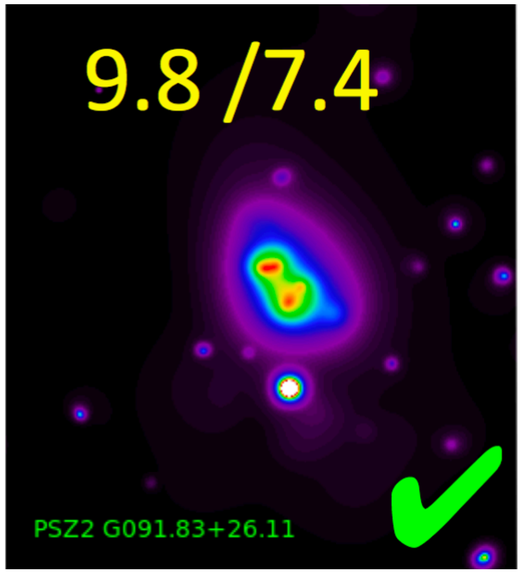

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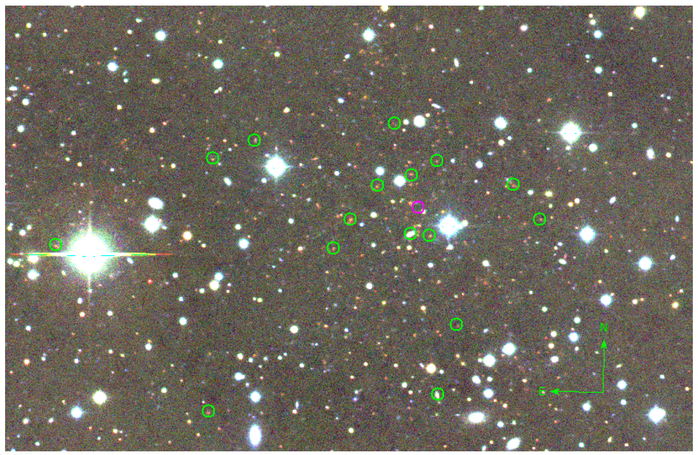

- Optical maps from the Canary Islands telescopes provide the spectroscopic redshifts from 16 confirmed cluster galaxies, and confirm the presence of two BCGs

PSZ2G091: a massive bimodal cluster

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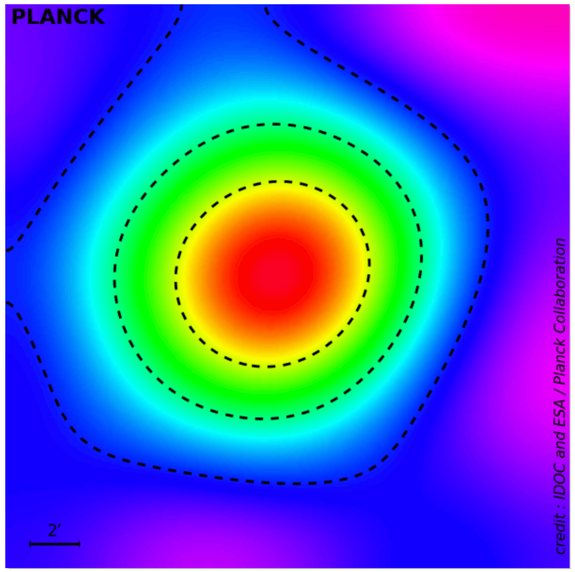

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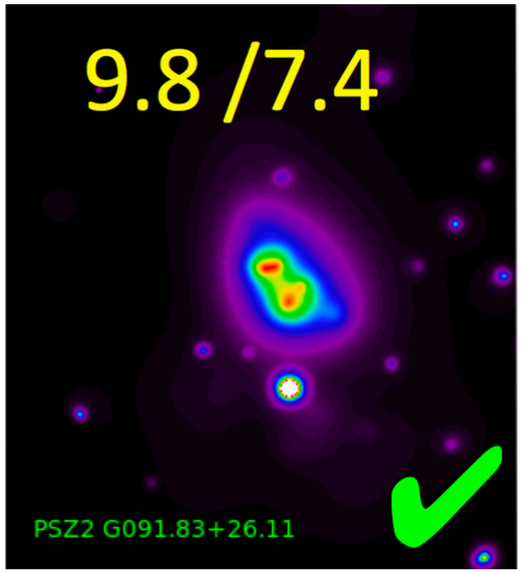

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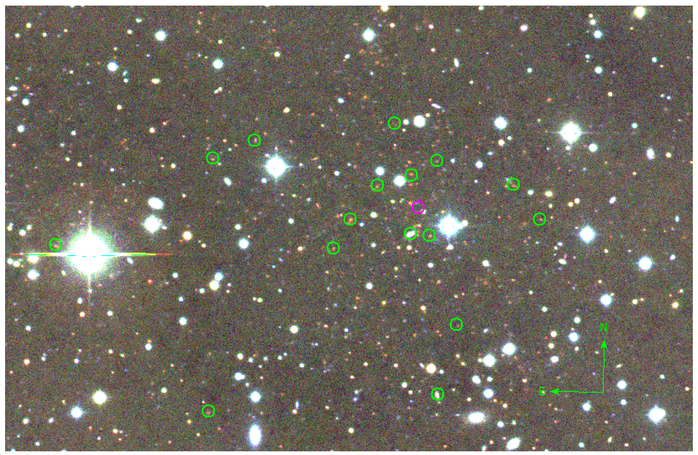

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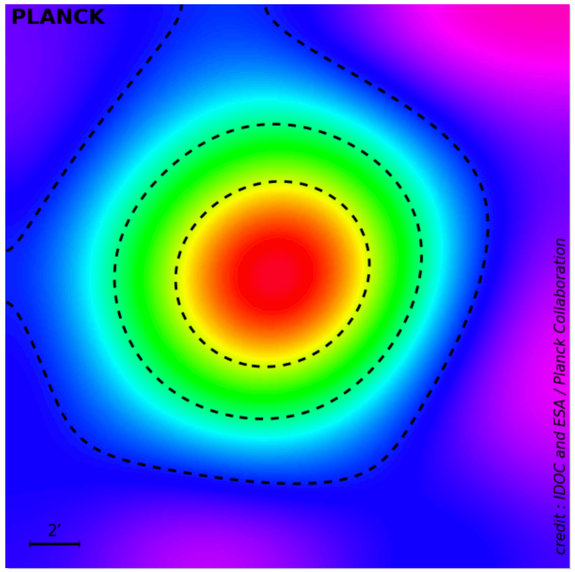

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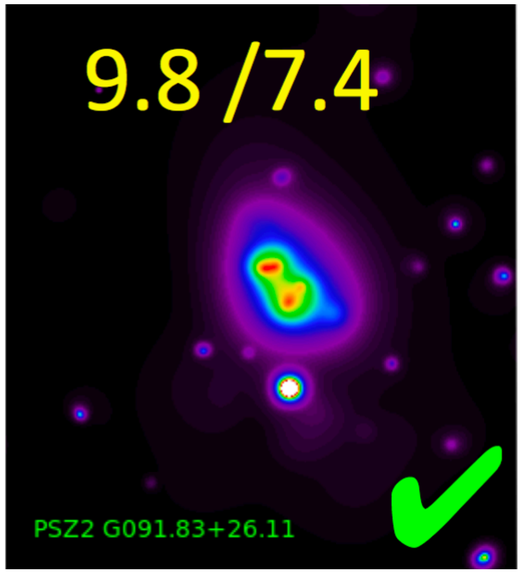

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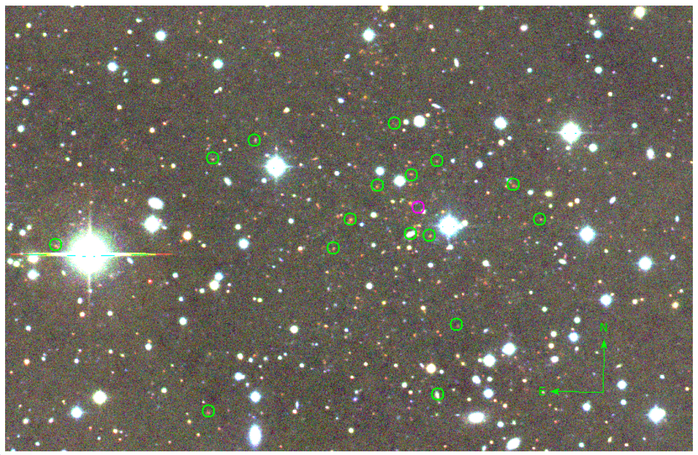
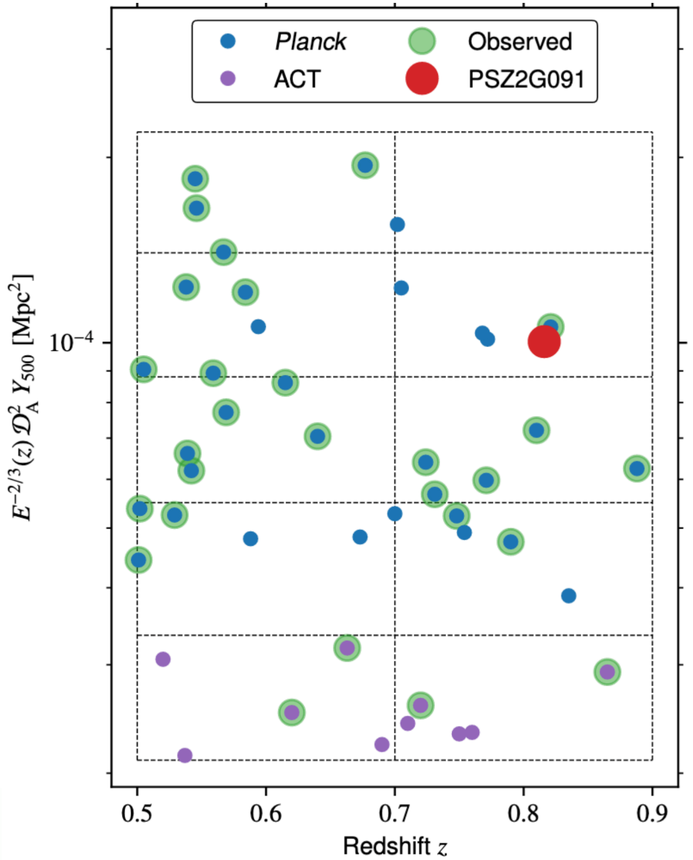


PSZ2 G091 appears as a bimodal object for which spherical assumptions does not hold

PSZ2G091: a massive bimodal cluster

Cluster part of the Large Program SZ (LPSZ) with high-quality data obtained in October 2017:

- 24/24 scans
- ~ 2.5 hours of observation



AIM: Investigating the impact of the bimodality on integrated quantities reconstruction

1. Context
2. Cluster analysis
3. Bimodal model and impact on mass reconstruction

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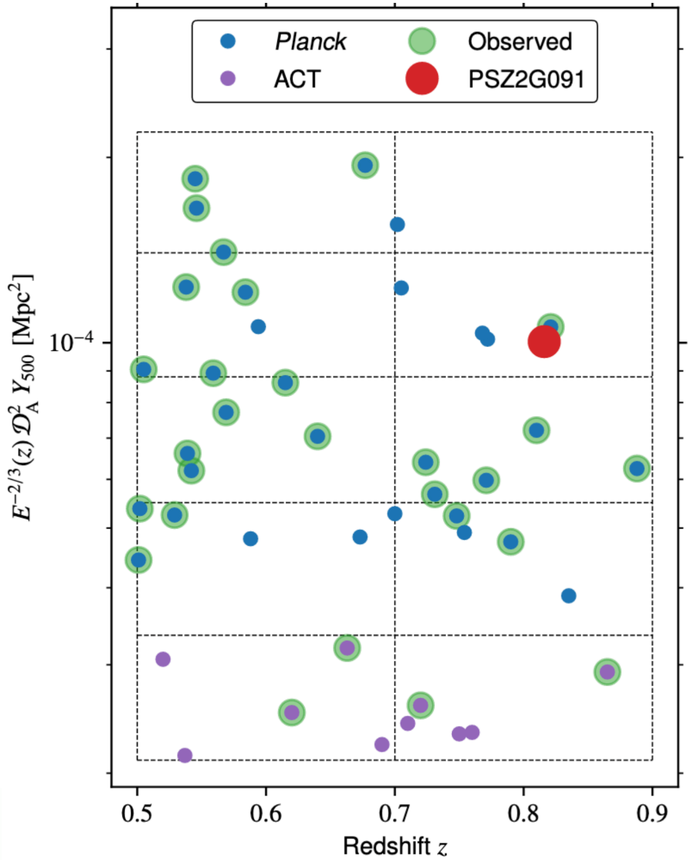

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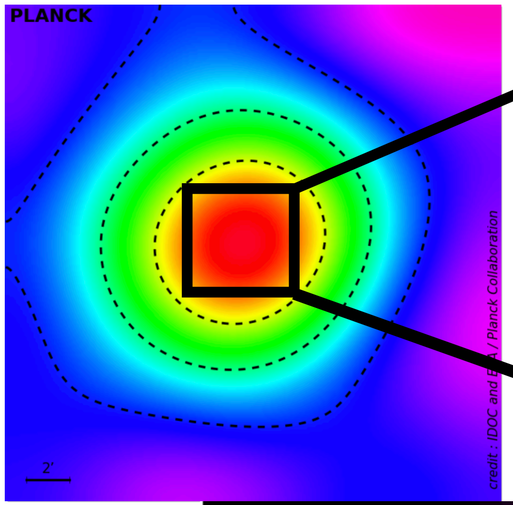
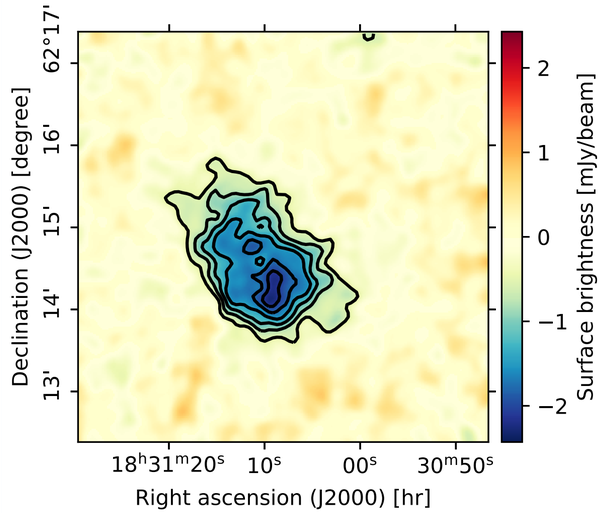
Analysis : PSZ2G091

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

Planck



NIKA2 2mm map



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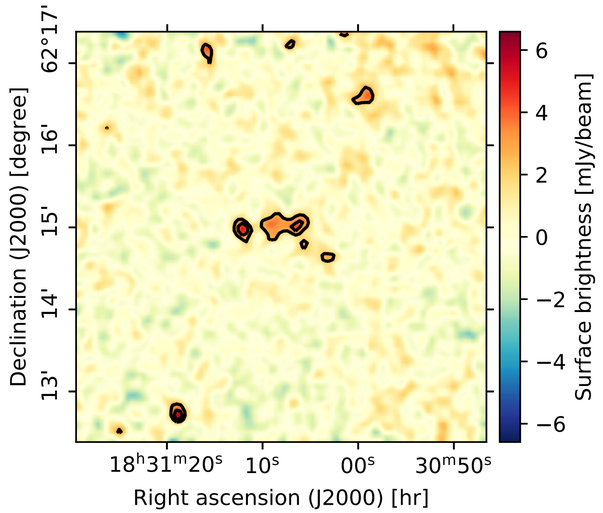
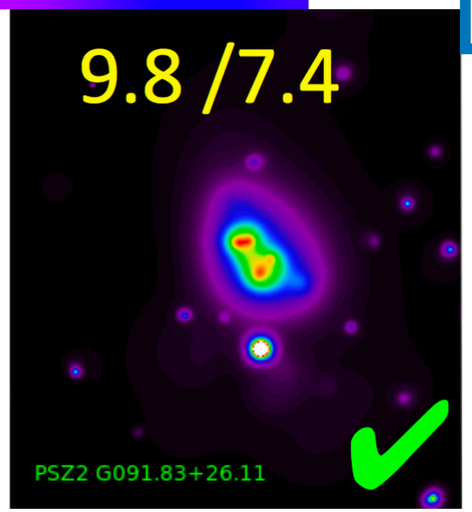


XMM-Newton



- The NIKA2 2mm map shows structures that are similar to the X-ray one
- The 1mm map shows point sources that are to be considered in the analysis, before moving on to the thermodynamical quantity software PANCO2 (see F. Kéruzoré's talk)

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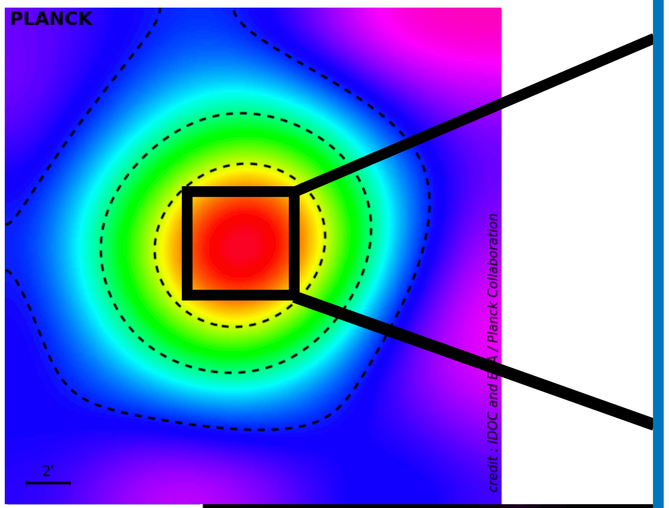
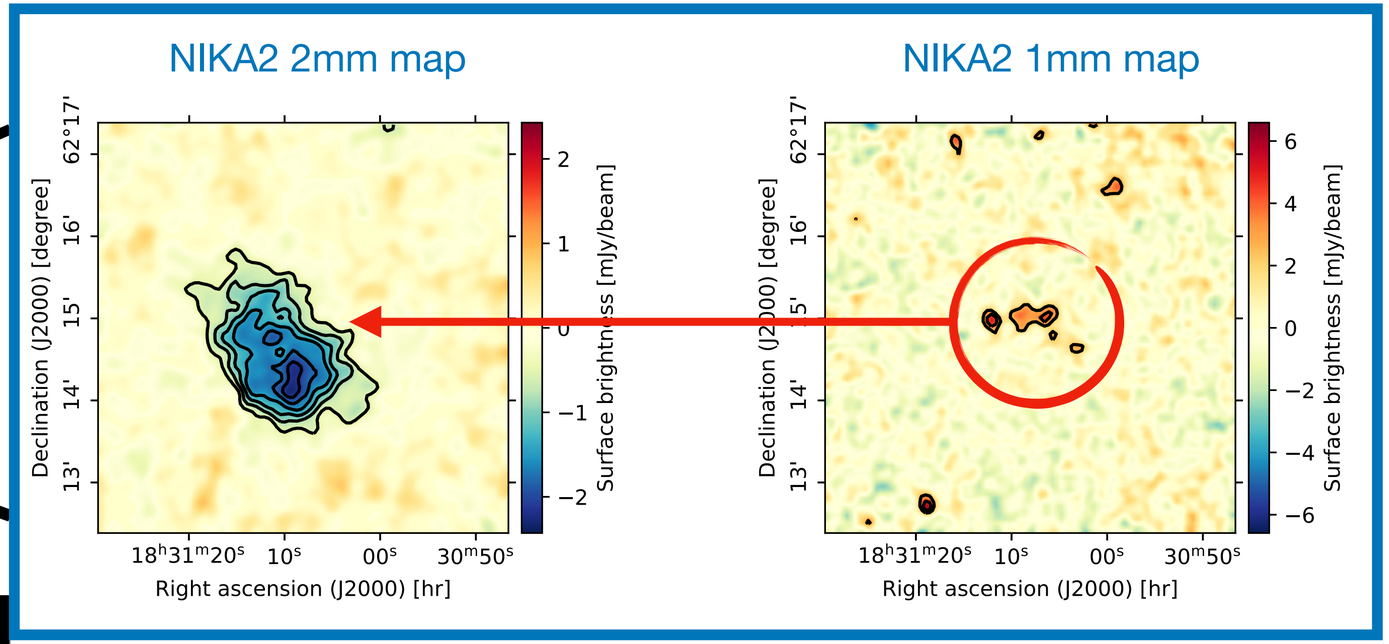
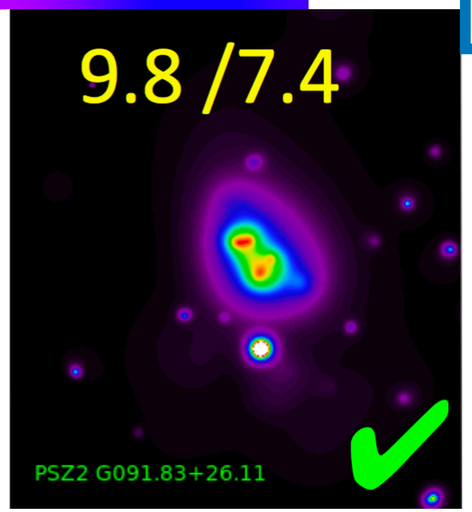




Infer the impact of these point sources on the SZ signal

XMM-Newton



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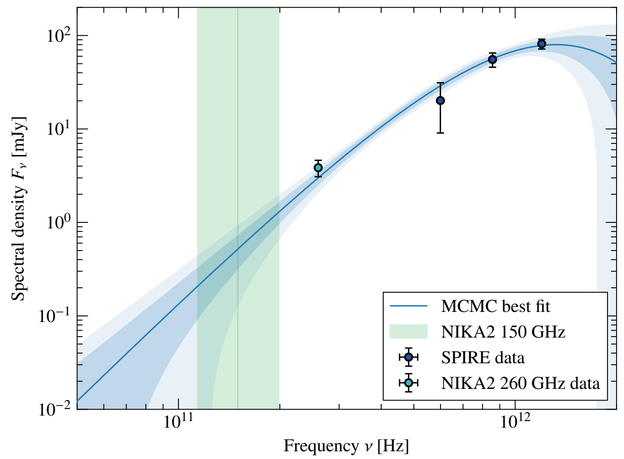
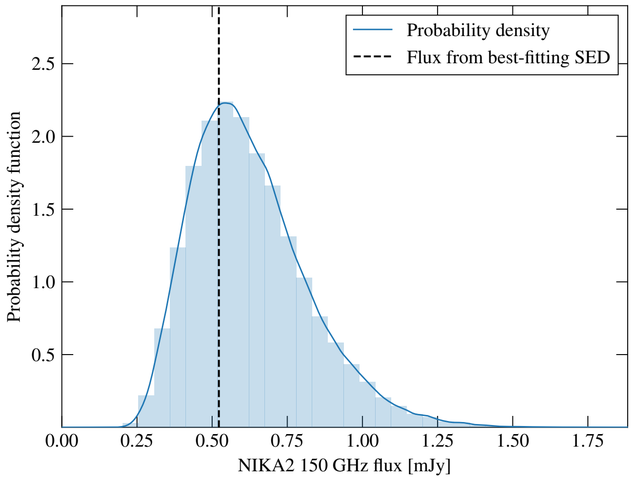
Analysis : PSZ2G091

Point sources : usual method for sub-millimetric sources

Kéruzoré et al., 2020



SED of a source in the cluster ACTJ0215



PDF of the flux inferred at 2mm

Each source in PSZ2G091 can be identified as a sub-millimetric source. Before trying to fit the thermodynamical quantities, we need to infer the counterparts of the fluxes measured at 1mm at 2mm

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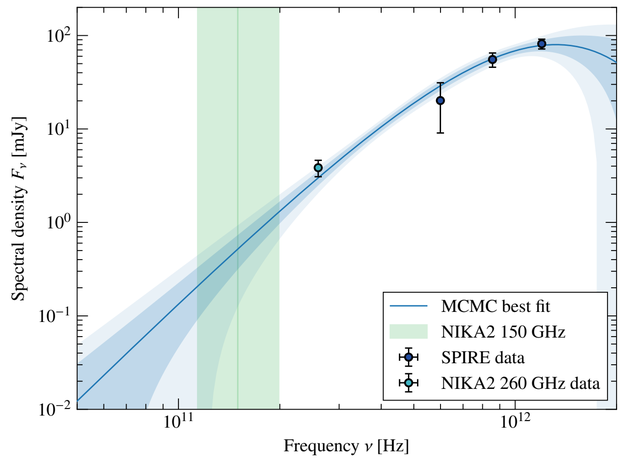

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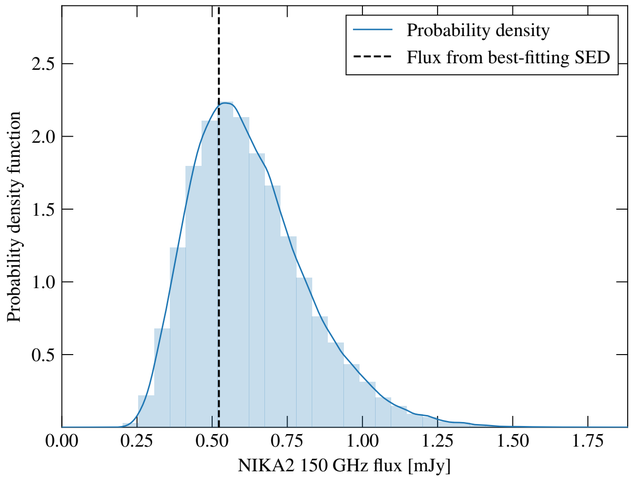

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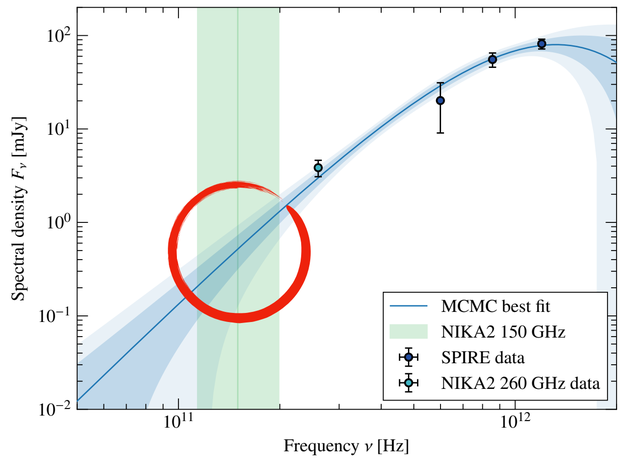

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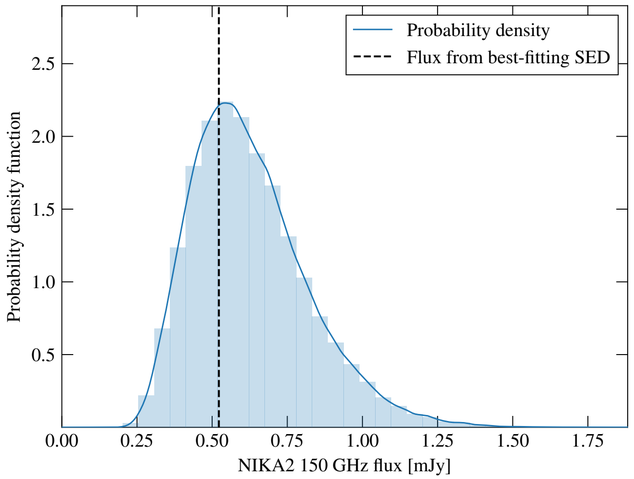

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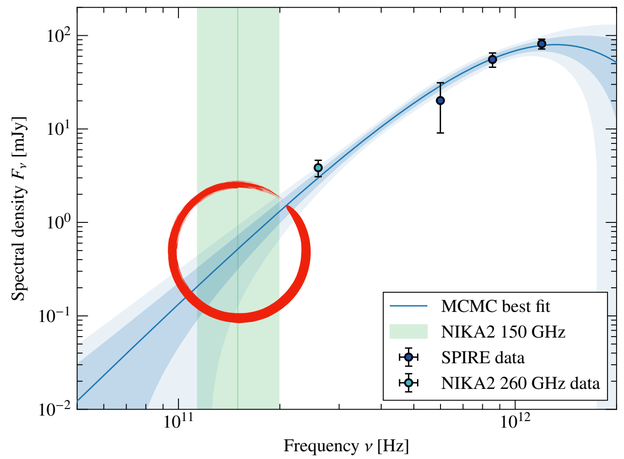

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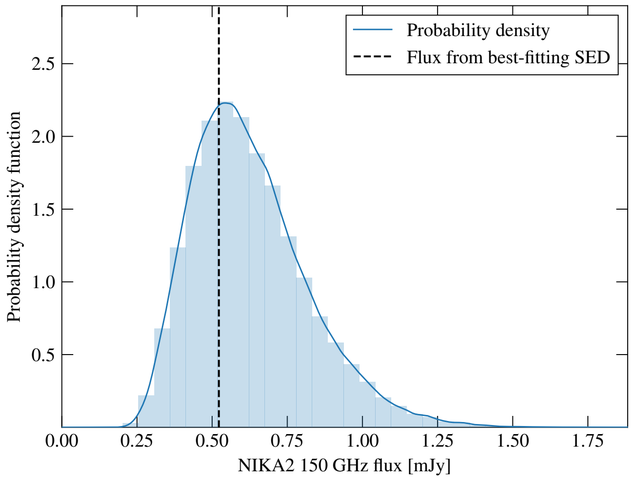

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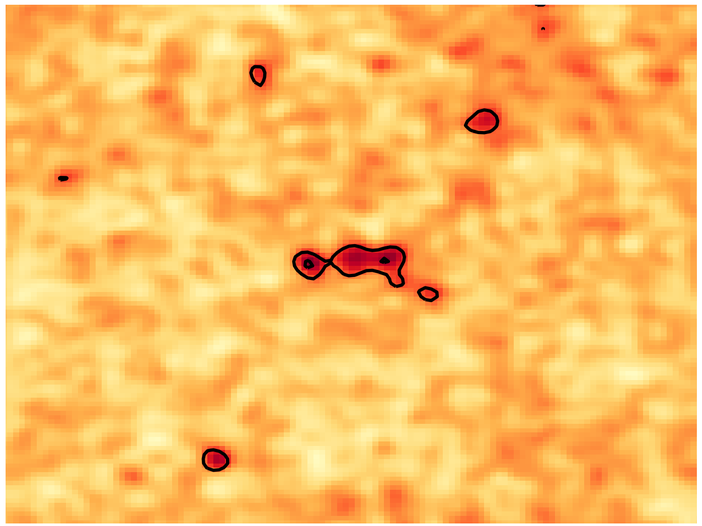
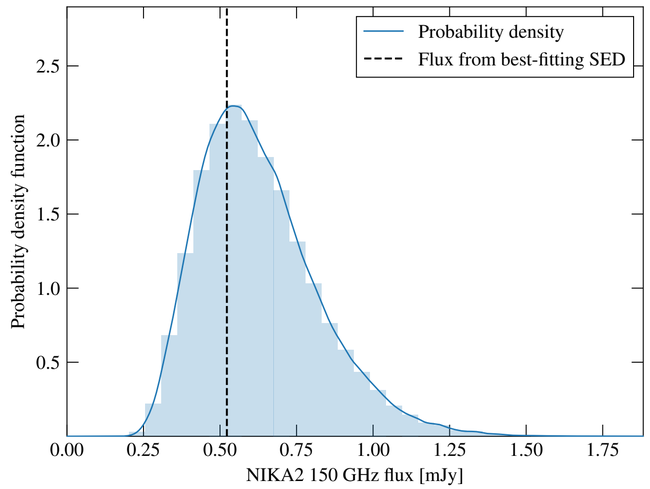
- However, in the case of PSZ2G091, no additional data were available

Analysis : PSZ2G091

Point sources : Treatment

NIKA2 1mm map





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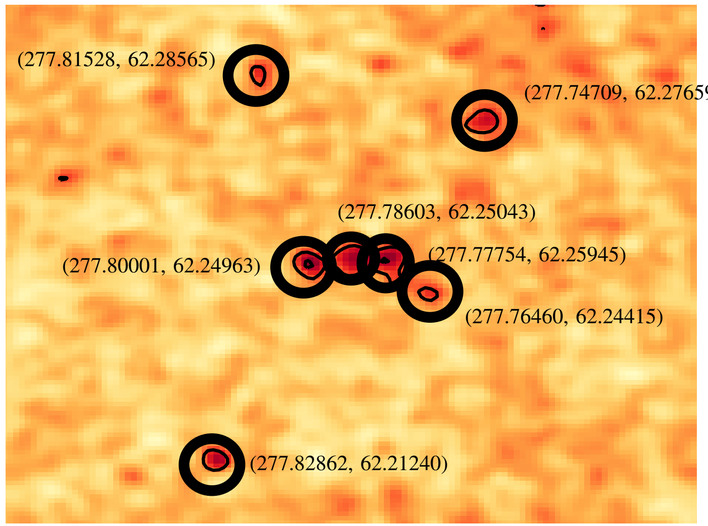

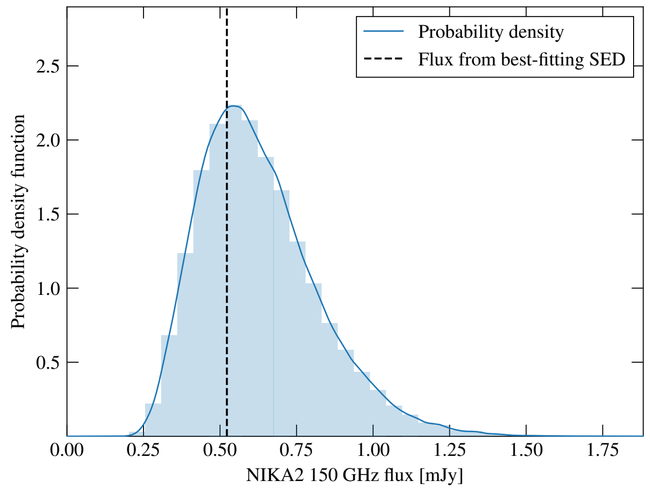

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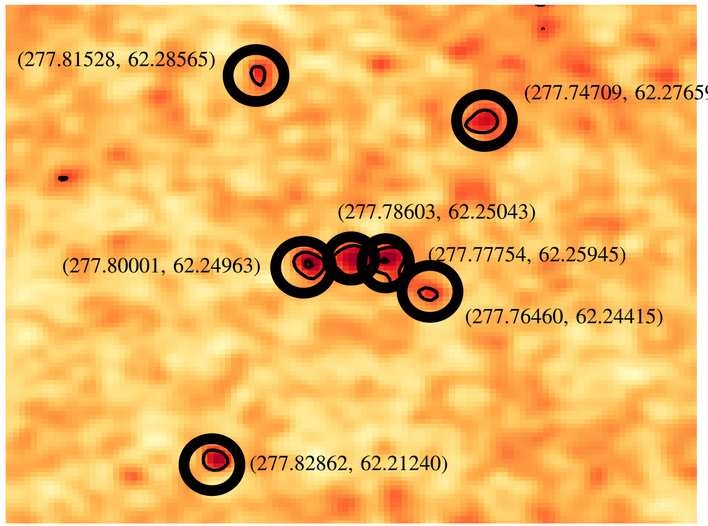

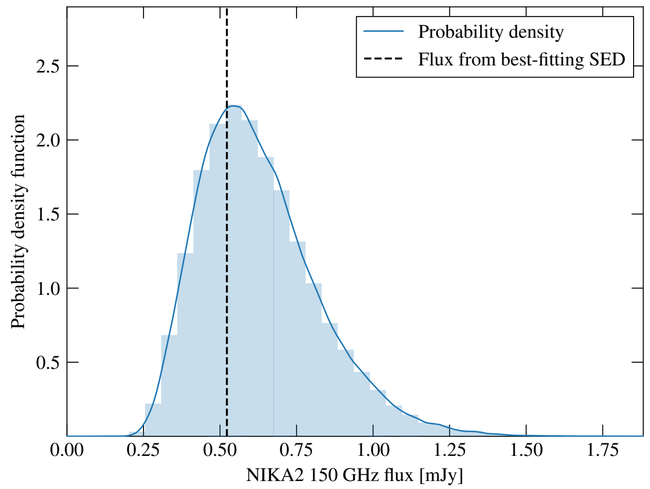

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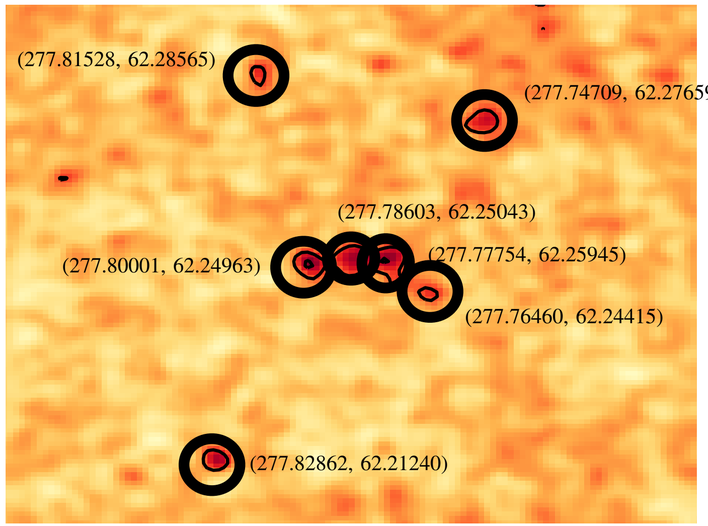

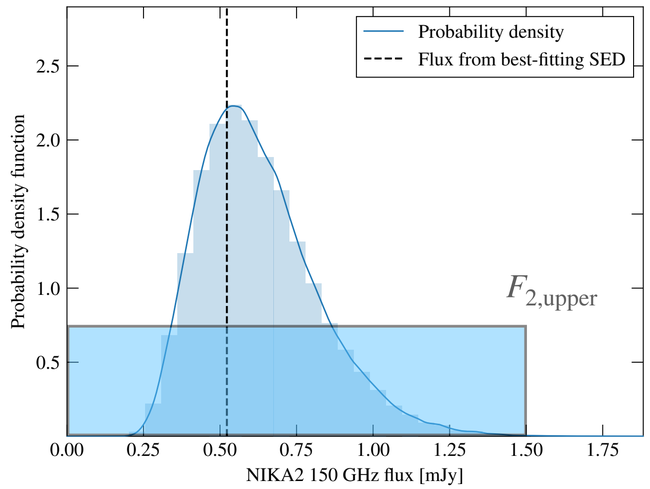

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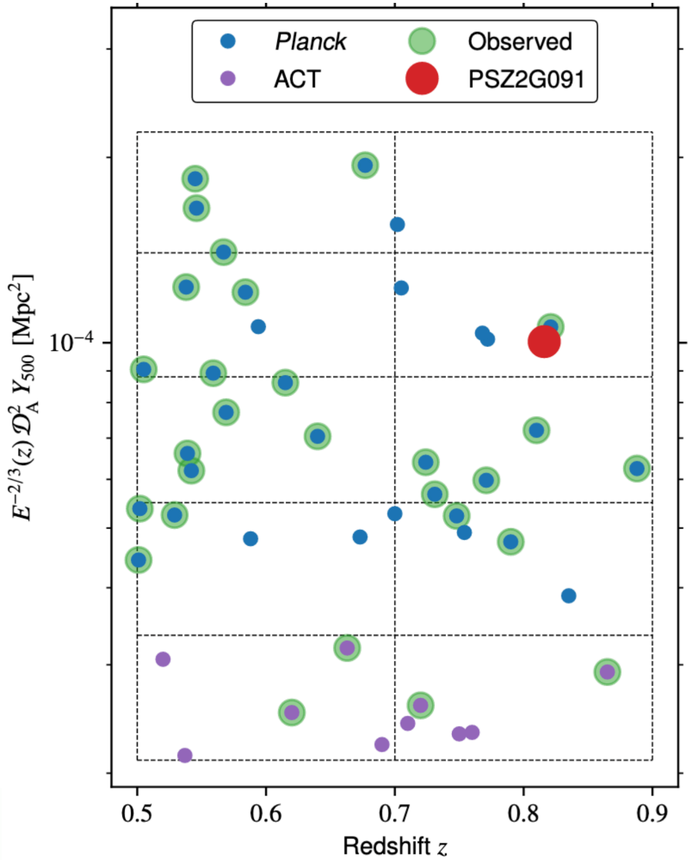
- We replace the PDF of the flux at 2mm with flat priors, with the an upper limit equal to $F_{2,\mathrm{upper}}$

PSZ2G091: a massive bimodal cluster

Cluster with high-quality data obtained in October 2017:

- 24/24 scans
- ~ 2.5 hours of observation



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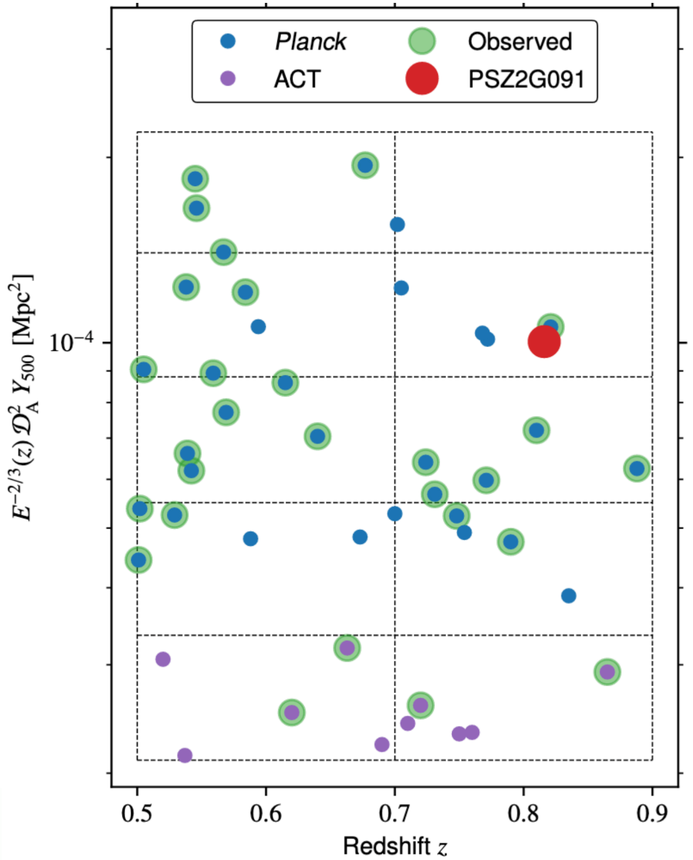

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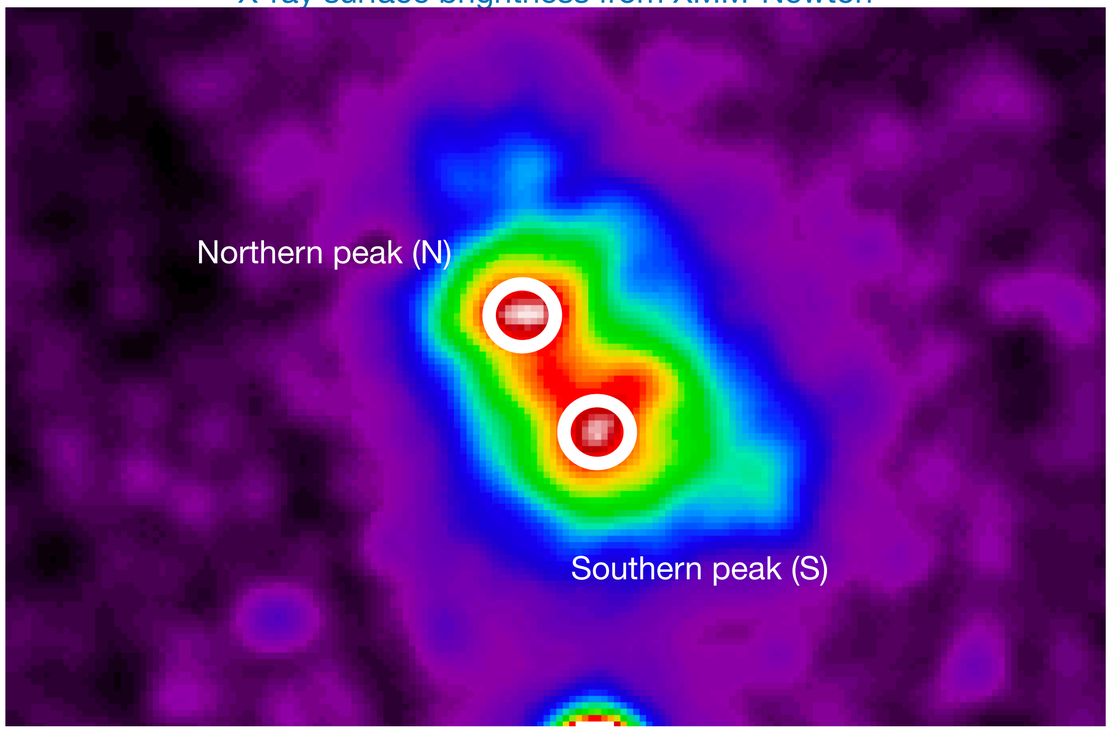
PSZ2G091

As seen by XMM-newton

X-ray surface brightness from XMM-Newton



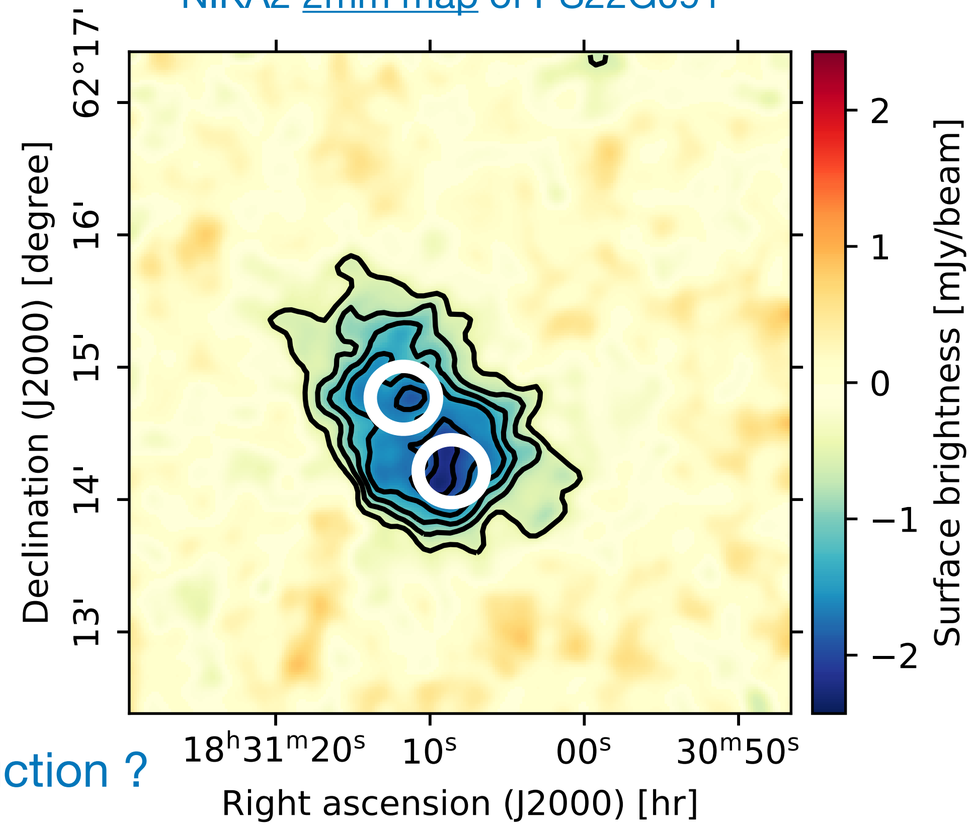
Done by G. Pratt et al.

The object clearly exhibits two centers in X-rays

$$(\alpha_N, \delta_N) = (277.80,\ 62.247)$$

$$(\alpha_S, \delta_S) = (277.79,\ 62.237)$$

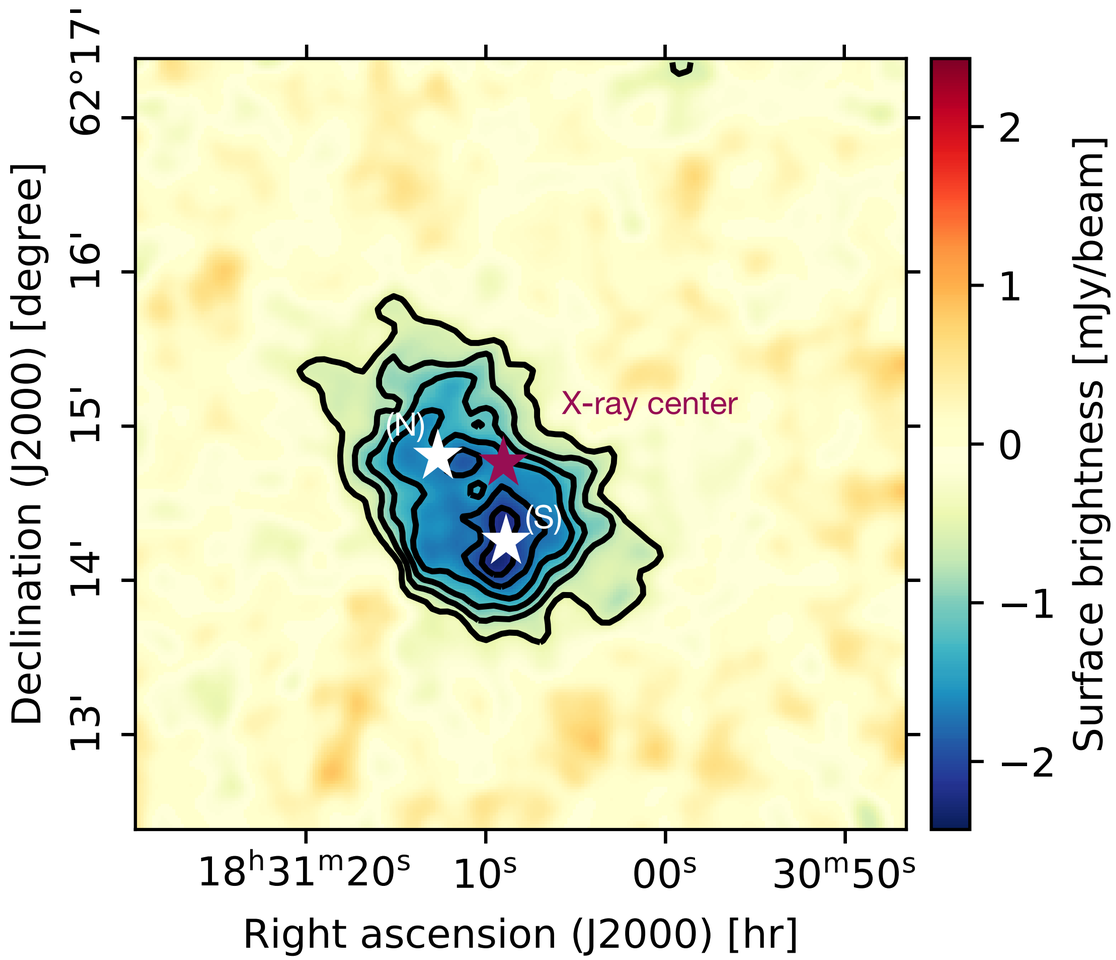
NIKA2 2mm map of PS22G091



- How refining the model of the cluster affect mass reconstruction ?

Two different scenarios

Preliminary



We will be considering three different scenarios:

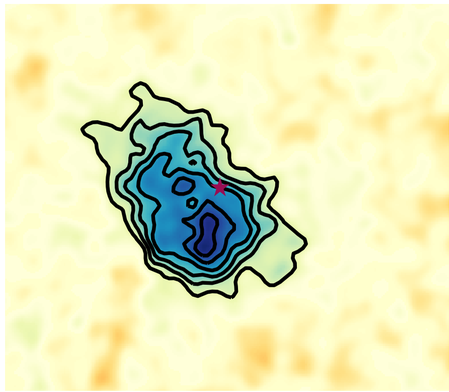
- Case 1: A test case with an analysis centered at the X-ray centroid coordinates, and a spherical model
- Case 2: A double halo model which takes into account the morphology of the cluster

We will compare the value of integrated quantities at a fixed radius R_S

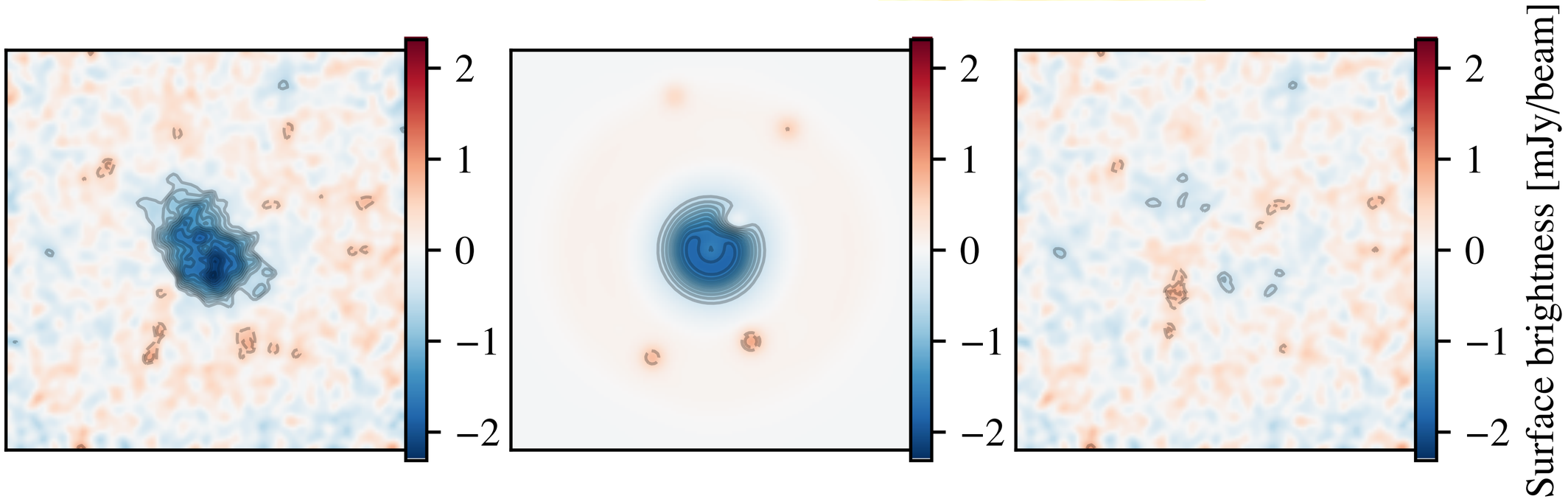
Case 1: One spherical halo model centered on X-rays coordinates

Using PANCO2 (See F. Kéruzoré's talk)

Respectively, data, model, and residuals as an output



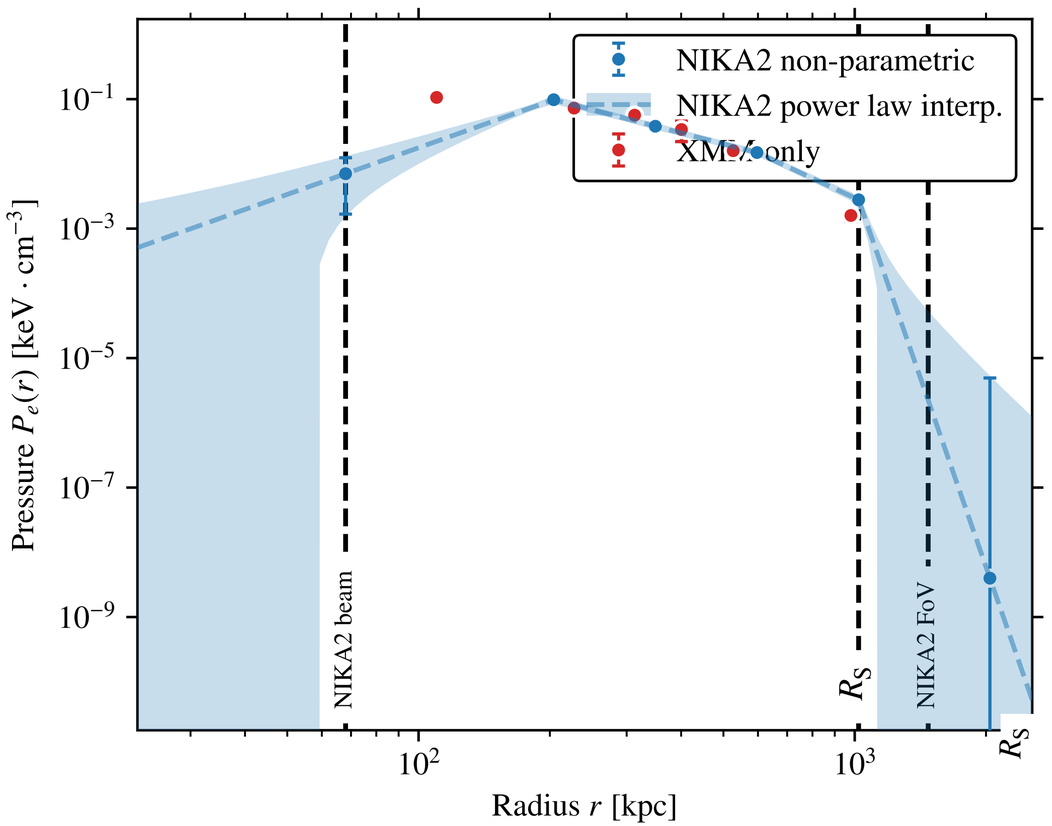
Preliminary



Case 1: One spherical halo model centered on X-rays coordinates

Pressure profile obtained for the spherical model centered at the X-ray centroid

Preliminary



Distance from the X – ray center coordinates

Non parametric pressure profile

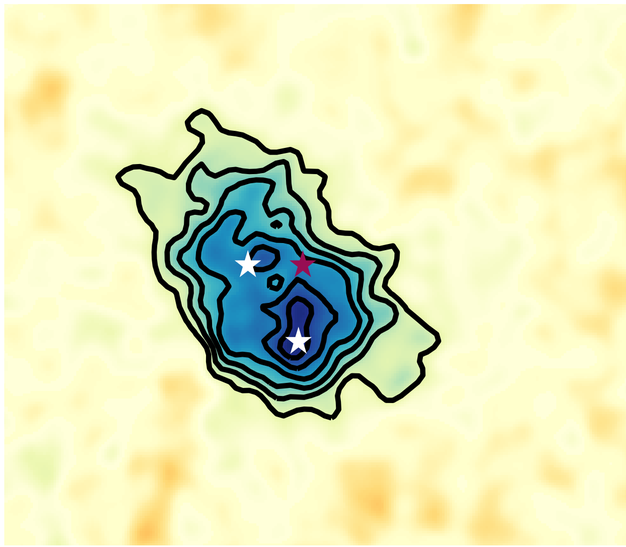
$$P(r) = P_i(r/r_i)^{-\alpha_i}$$

- The pressure profile decreases at low radius because of the impact of mis-centering (impact on the mass reconstruction).
- Using the hydrostatic equilibrium equation, we compute the mass inside the radius R_S (here strictly equal to R_{500})
- Using this profile combined with X-ray data from XMM, we find a total mass of

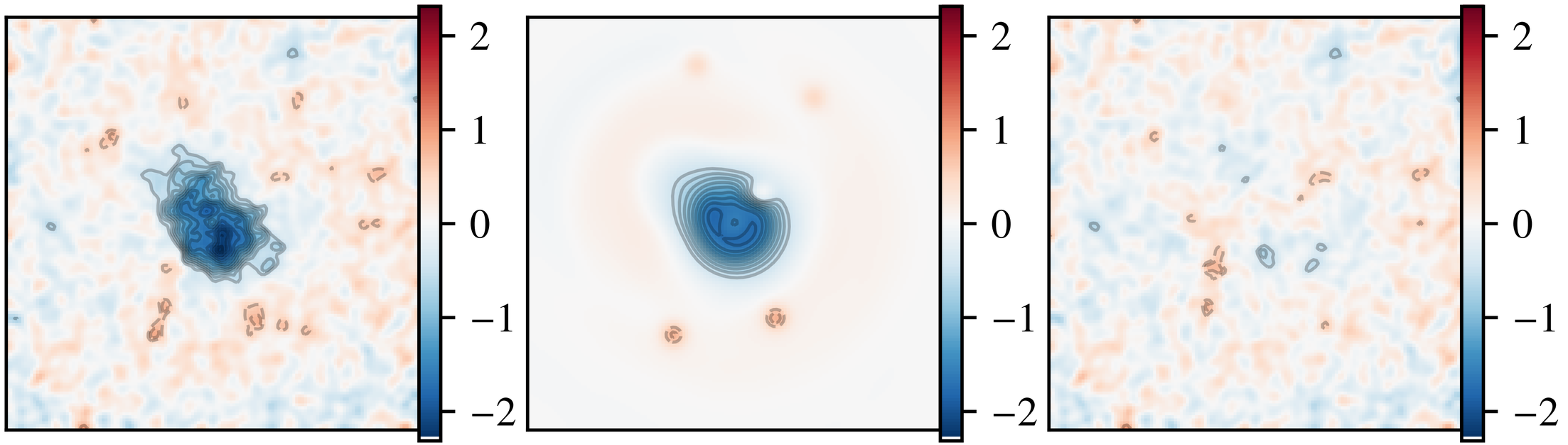
$$M_s = 9.1^{+0.6}_{-0.11} \times 10^{14} M_\odot$$

Case 2: Two halo model

We jointly fit two pressure profiles at the positions of the X-ray peaks



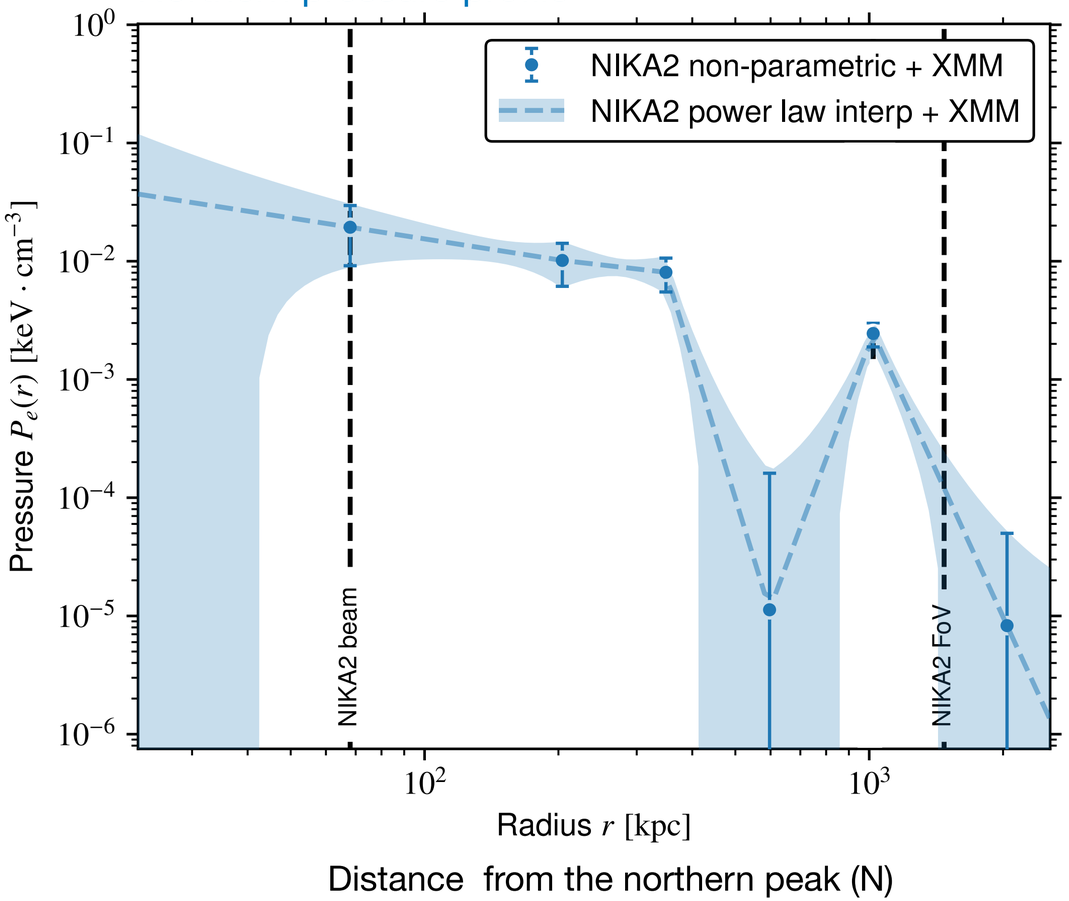
Respectively, data, model, and residuals



Case 2: Two halo model

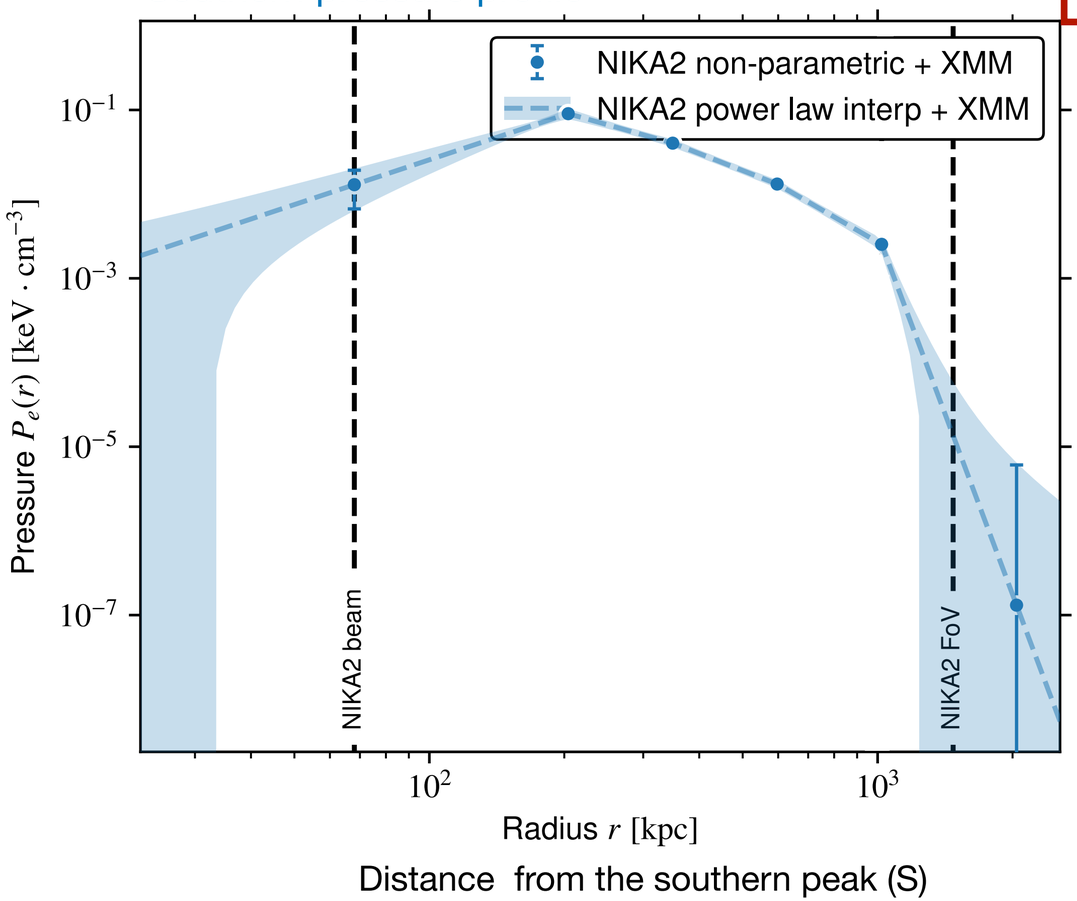
Preliminary

Northern pressure profile



Distance from the northern peak (N)

Southern pressure profile



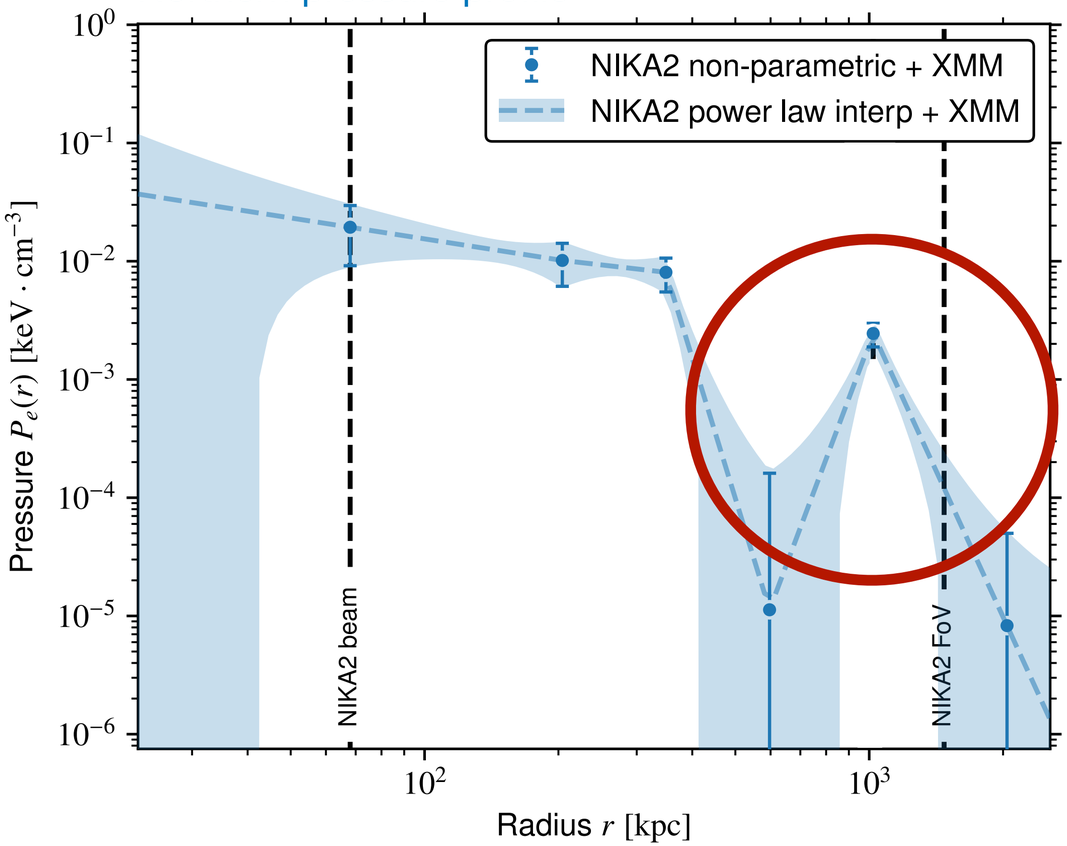
Distance from the southern peak (S)

The behavior at the ends of the profile is related to the bimodality of the cluster

Case 2: Two halo model

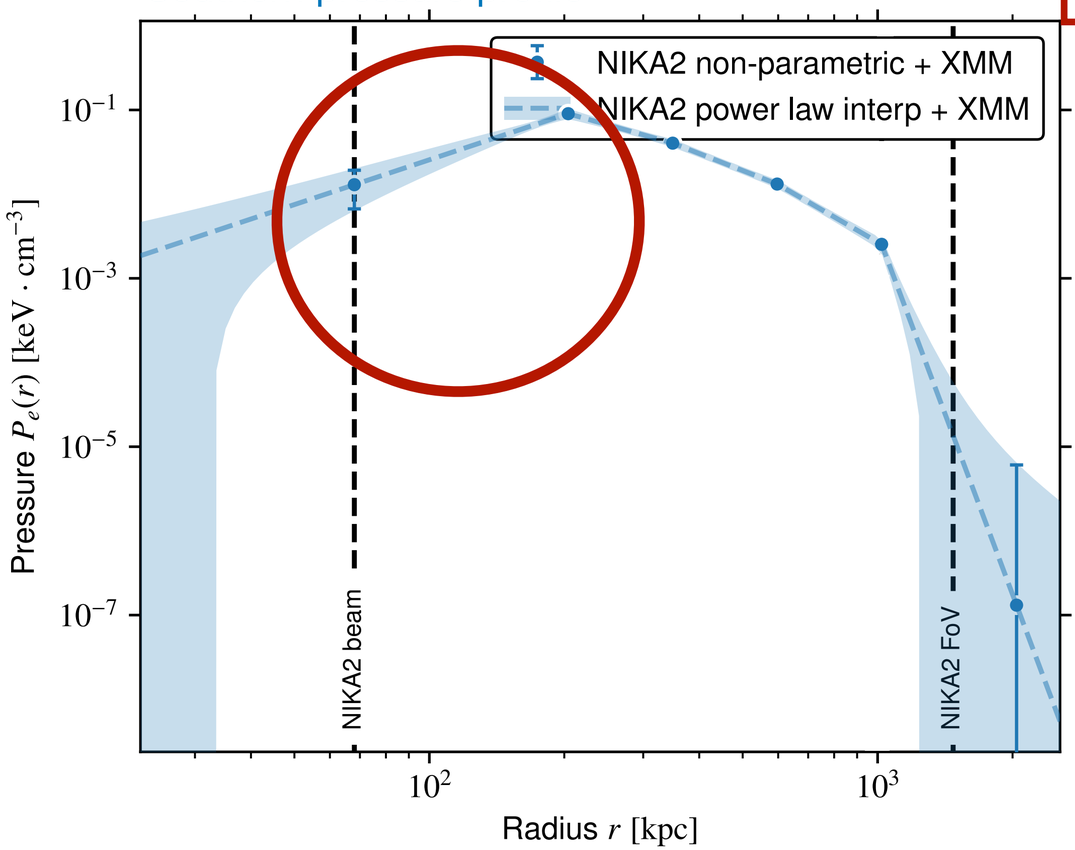
Preliminary

Northern pressure profile



Distance from the northern peak (N)

Southern pressure profile



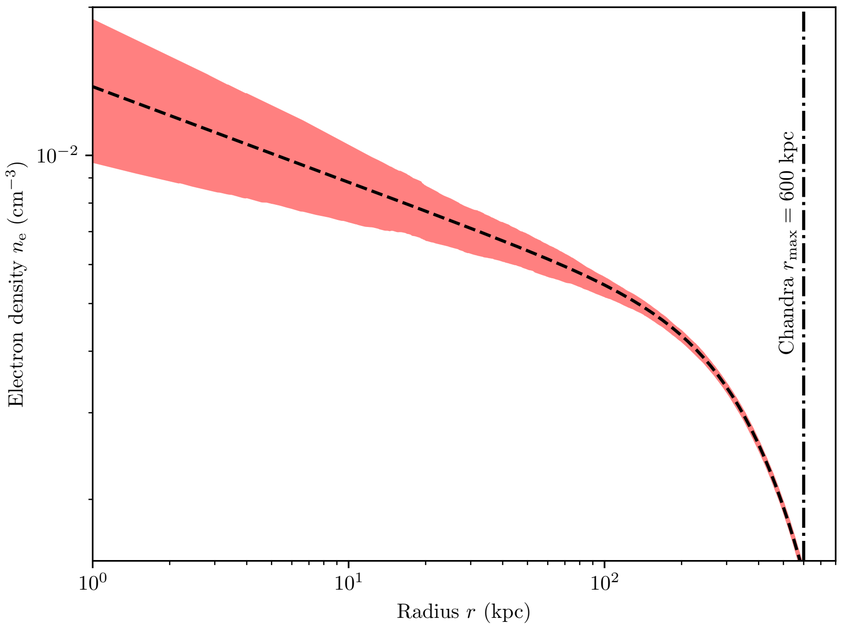
Distance from the southern peak (S)

The behavior at the ends of the profile is related to the bimodality of the cluster

Case 2: Two halo model

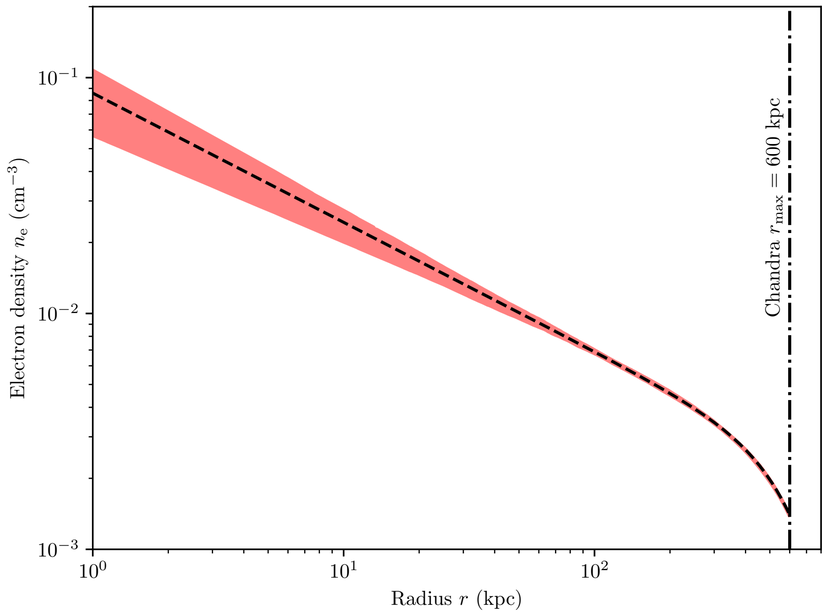
Electron density profiles, from Chandra data (from F. Ruppin)

Northern electron density



Distance from the northern peak (N)

Southern electron density



Distance from the southern peak (S)

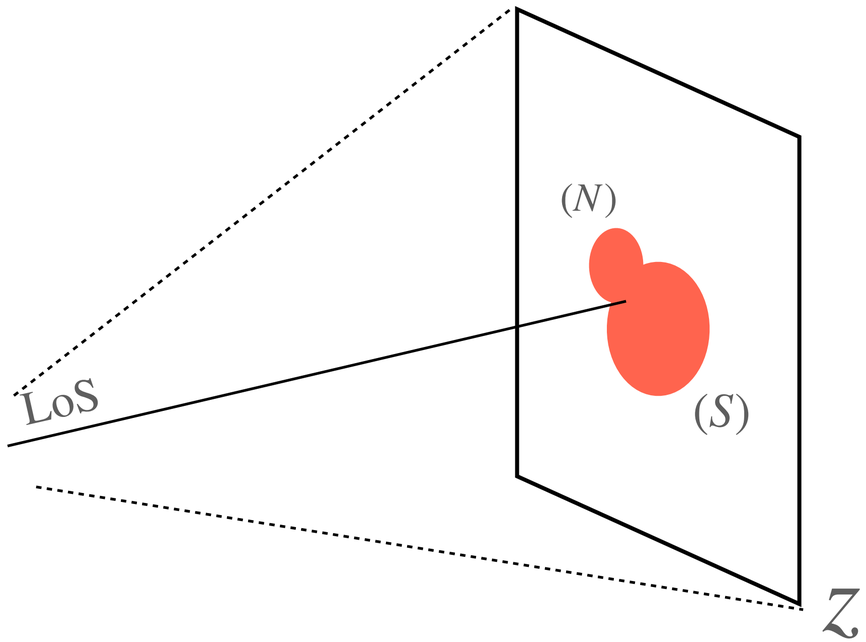
- In a first attempt to provide a mass estimation, we use electron densities from Chandra centered at (N) and (S)
- We extrapolate the value of the density outside of $r_{\mathrm{max}} = 600\ \mathrm{kpc}$ using the outside slope of XMM

Case 2: Two halo model

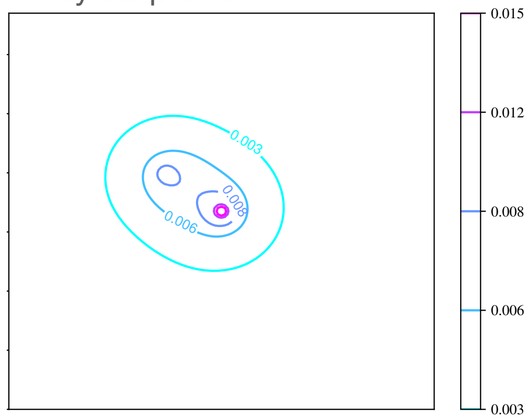
Best- fit double halo-profile model

Sum of the two spherical profiles obtained respectively in X-rays and SZ.

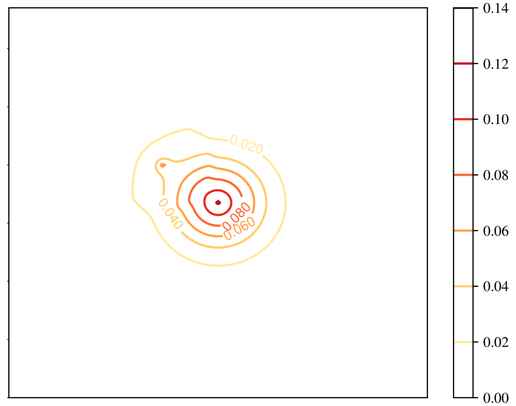
Preliminary



X-ray 2D profile



SZ 2D profile

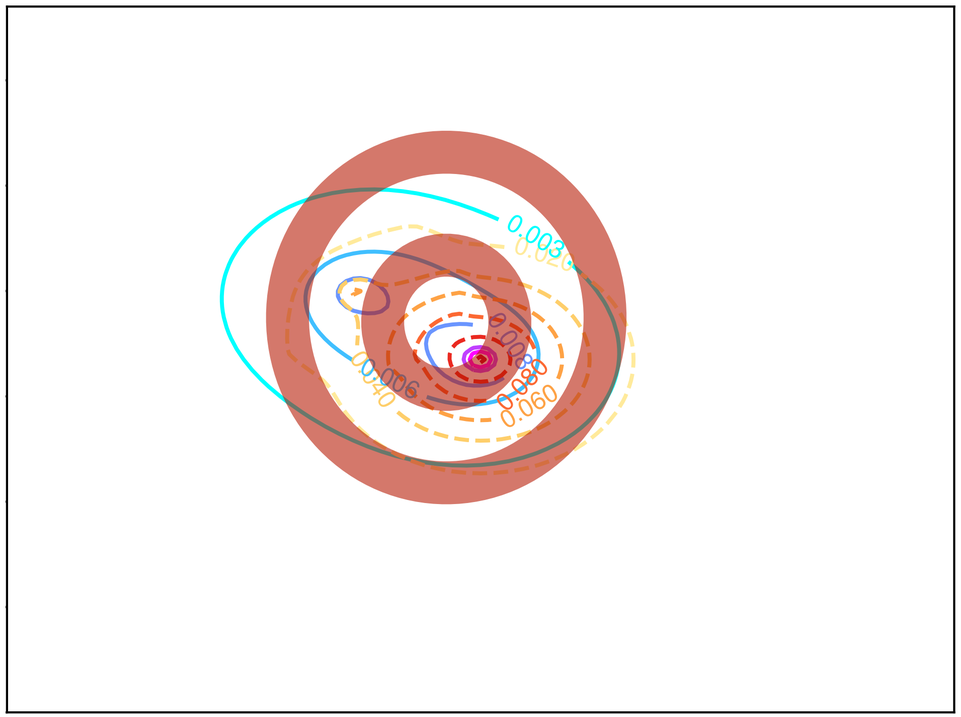


- Under the hypothesis that both sub-halos lie in a plane perpendicular to the LoS, we can reconstruct a 2D profile by summing the two spherical models that were shown before
- Then we can use these 2D profile to reconstruct 2 average profiles

Case 2: Two halo model

Best- fit double halo-profile model

Integration of the profiles in spherical annuli



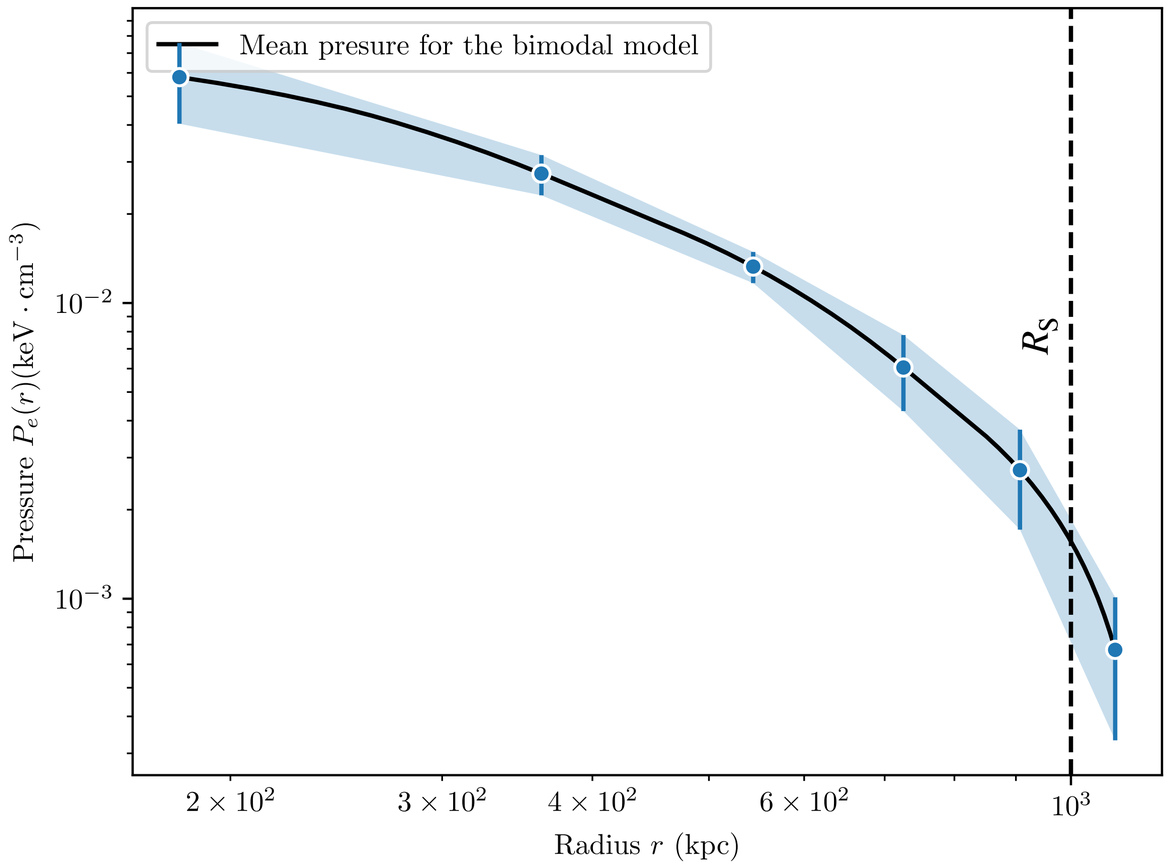
$$P_i = \left(\int_{r_i}^{r_{i+1}} (P_{\rm N}(r) + P_{\rm S}(r)) 2\pi r {\rm d}r \right) / \pi (r_{i+1}^2 - r_i^2)$$

In order to get a radial profile, we integrate both the SZ and X-ray in spherical annuli around the X-ray centroid position

Case 2: Two halo model

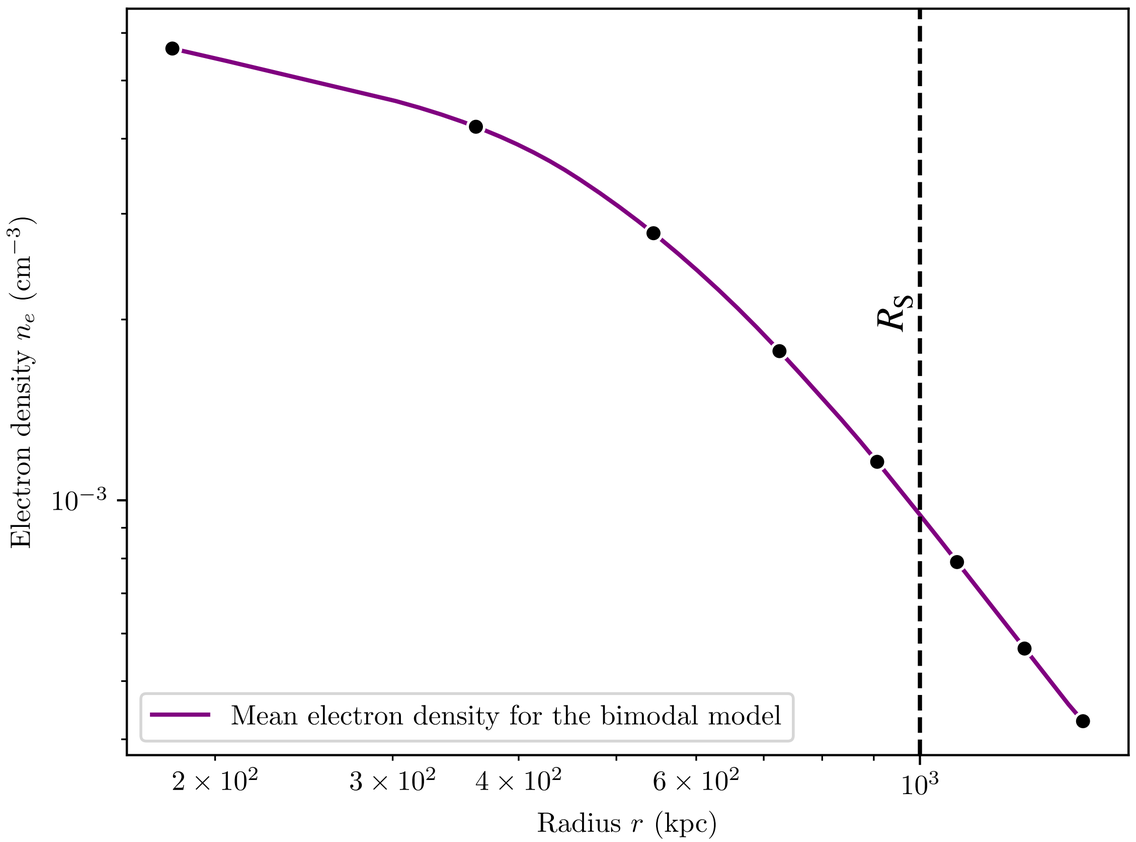
Preliminary

Mean pressure profile



Distance from the X – ray center coordinates

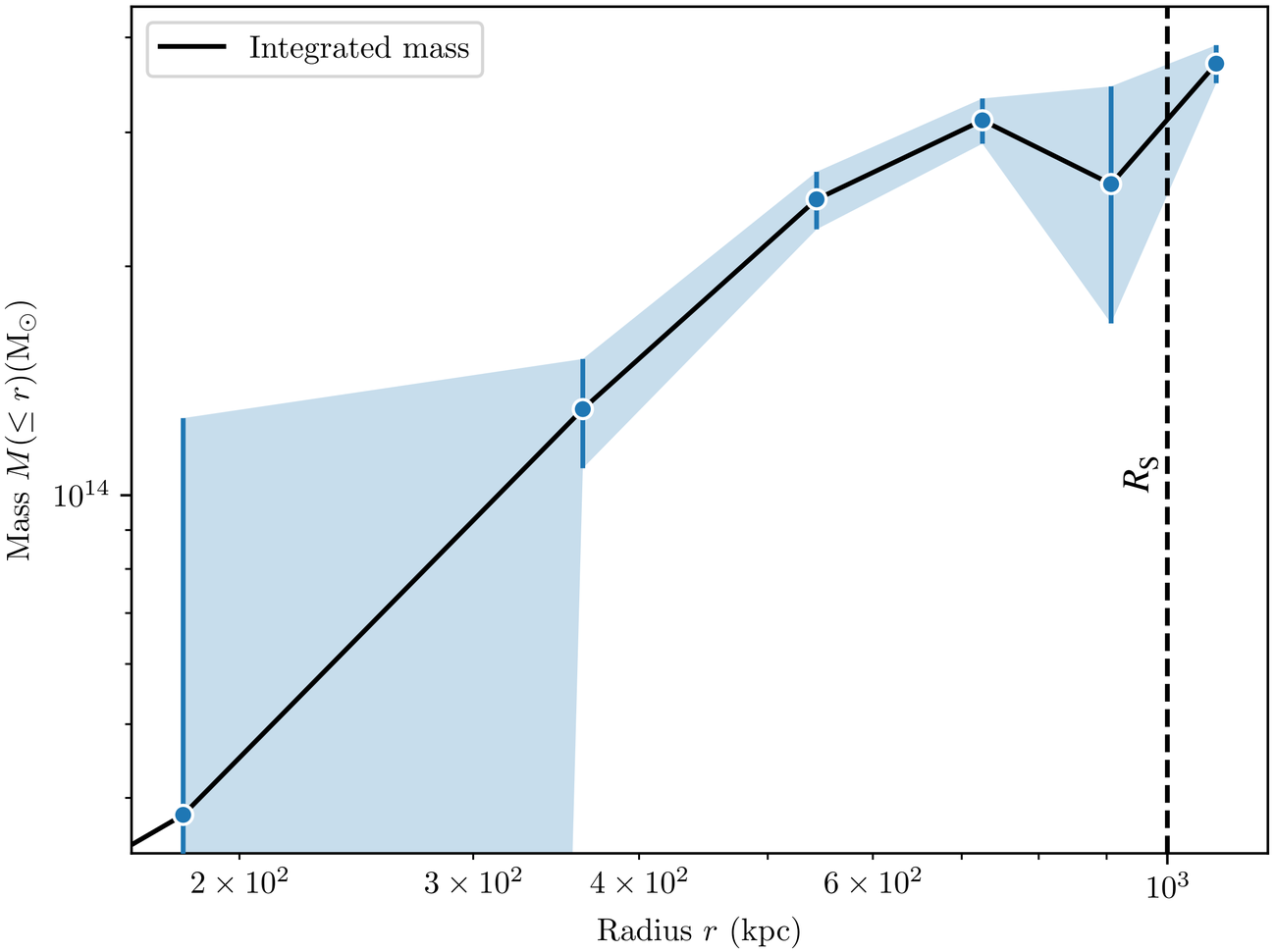
Mean density profile



Distance from the X – ray center coordinates

Case 2: Two halo model

Preliminary



Reconstructed $M_{\mathrm{bim}} = 2.9^{+0.7}_{-0.9} \times 10^{14} M_\odot$

In this case, M_{bim} is the mass computed with the bimodal model, and enclosed within R_S (which is equal to R_{500} computed for a spherical cluster)

This value has to be compared with the mass obtained with a single spherical profile:

$$M_S = 9.1^{+0.6}_{-0.11} \times 10^{14} \mathrm{M}_\odot$$

Case 2: Two halo model

Consequence:

- Mass estimated with the bimodal model three times smaller than the spherical l one
- This would strongly impact the Planck selection function, as the halo mass function decrease exponentially

Conclusion

- $\sim 25\,\%$ of the 45 clusters in the LPSZ exhibit a complex morphology
- This study shows that this could have a strong impact on the mass reconstruction
- Taking into account bimodal clusters in the scaling relation will be an issue in the upcoming years (should they be considered as single objects etc.)
- It is necessary to quantify the impact of the population of complex object on cosmological parameter estimation
- There are a lot of interesting perspectives on this cluster for 2D analysis (2D pressure, relaxation estimators etc.)