Multi-probe analysis of the galaxy cluster **CLJ1227:** unveiling **systematics in mass estimation**

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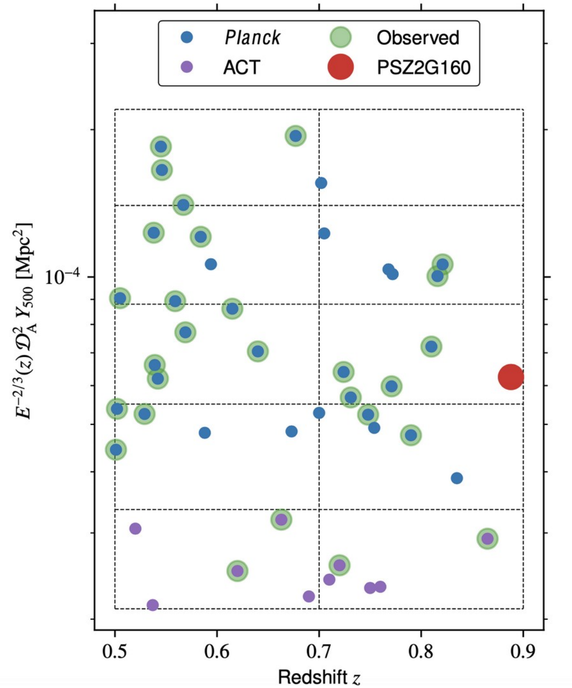
on behalf of the NIKA2 collaboration

mm Universe @ NIKA2 – 28.06.2021

NIKA2 Sunyaev-Zel’dovich Large Program

Study of 45 high redshift galaxy clusters



One of the **objectives**...

...**hydrostatic mass estimate** combining:

- Electron pressure from thermal SZ effect with NIKA2
- Electron density and temperature from X-rays with XMM-Newton

Which **systematic errors** can **affect the hydrostatic mass estimate**?
How is this mass **compared to other estimations**?

The cluster: **CLJ1227** or PSZ2G160

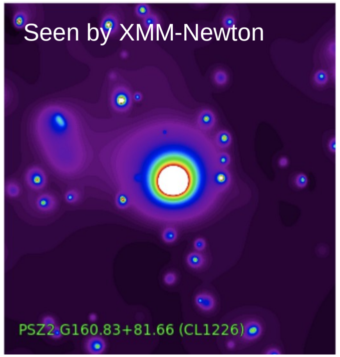
Prior knowledge of the cluster

(Planck SZ 2)

z	0.888
$Y_{500}[10^{-3}\mathrm{arcmin}^2]$	0.38
$\theta_{500}[']$	1.9
$M_{500}[10^{14}M_\odot]$	5.7

← Highest redshift cluster of the NIKA2-LPSZ

- The **main clump**:
  - centered on the BCG (Zitrin et al., 2009)
  - BCG, X-ray peak and the galaxy number density peak seem to match (M.Jee and J.Tyson, 2009)
- The **secondary clump**:
  - A hot substructure / overdensity at ~ 40 ″ to the southwest of the center (B. J. Maughan et al., 2007, M.Jee and J.Tyson, 2009)
  - Correlated to the cluster galaxy distribution (M.Jee and J.Tyson, 2009)



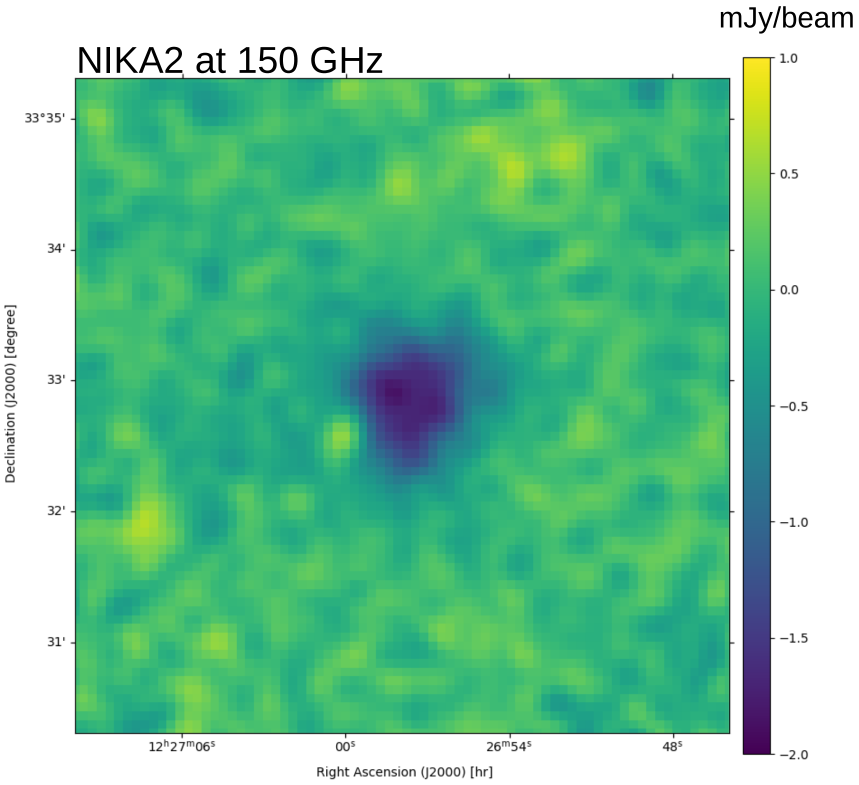
From raw data to mass estimation

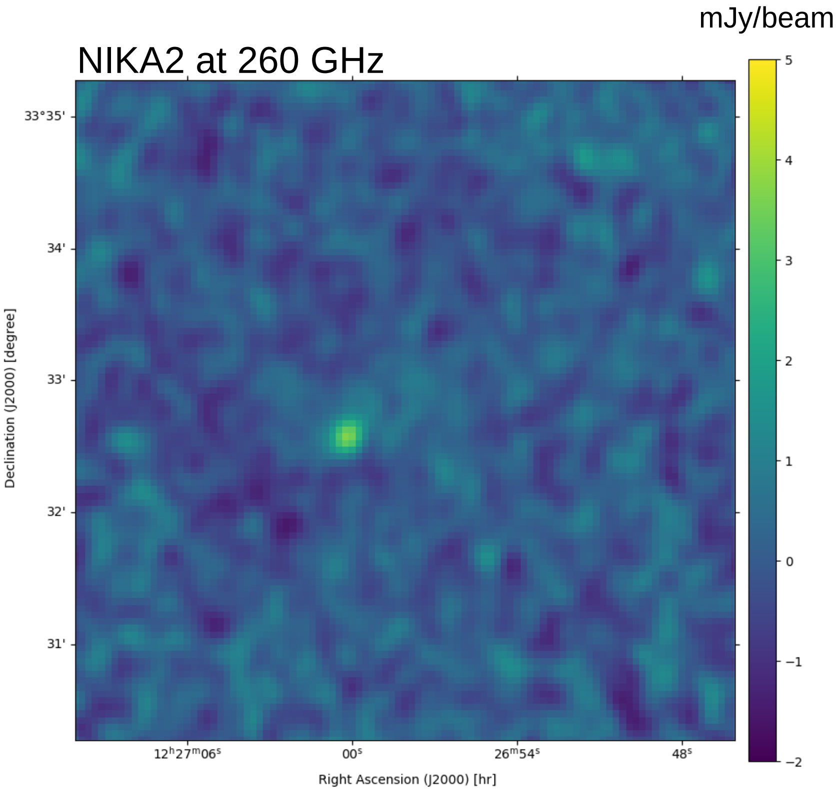
- **Data processing:**
  - **Map-making**
  - Quantifying data processing filtering (transfer function)
- From maps to pressure profiles:
  - Point sources contamination
  - Pressure profile reconstruction
- Hydrostatic mass estimation

Map-making: **CLJ1227** seen by **NIKA2**

Observed for 3.6h during the 15th NIKA2 run (N2R15, Feb. 13-20 2018, NIKA2 Guaranteed Time)

Maps obtained with the PIIC (*Pointing and Imaging In Continuum*) IRAM pipeline



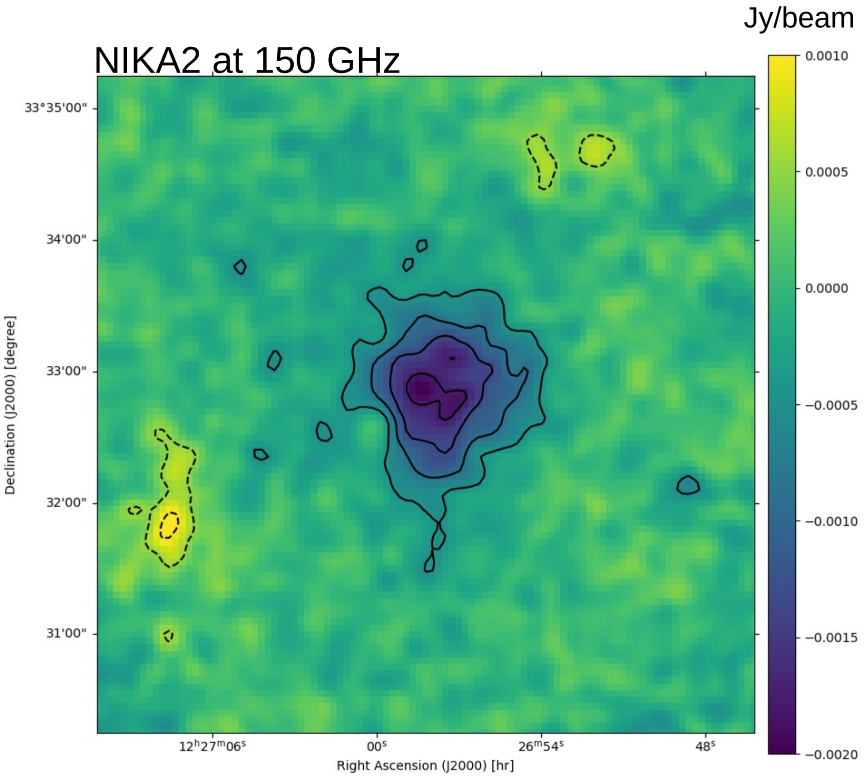


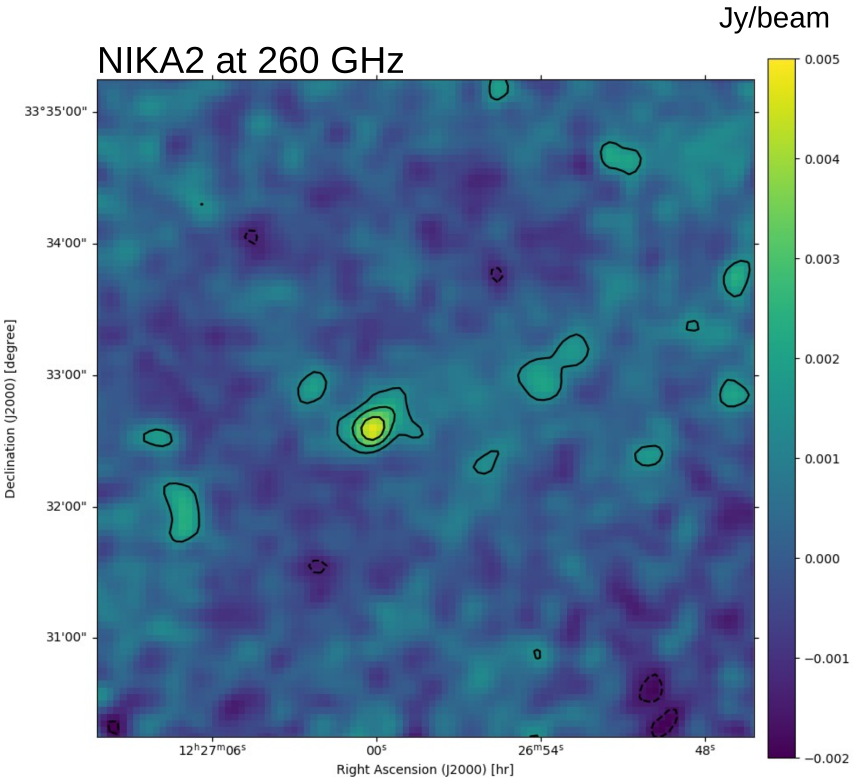
5’ maps, with a 10’’ FWHM smooth

Map-making: **CLJ1227** seen by **NIKA2**

Observed for 3.6h during the 15th NIKA2 run (N2R15, Feb. 13-20 2018, NIKA2 Guaranteed Time)

Maps obtained with the NIKA2 collaboration's IDL pipeline





5' maps, with a 10'' FWHM smooth. Contours are multiples of 3σ.

Maps used for the following analysis in this presentation

From raw data to mass estimation

- **Data processing:**
  - Map-making
  - **Quantifying data processing filtering (transfer function)**
- From maps to pressure profiles:
  - Point sources contamination
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- Hydrostatic mass estimation

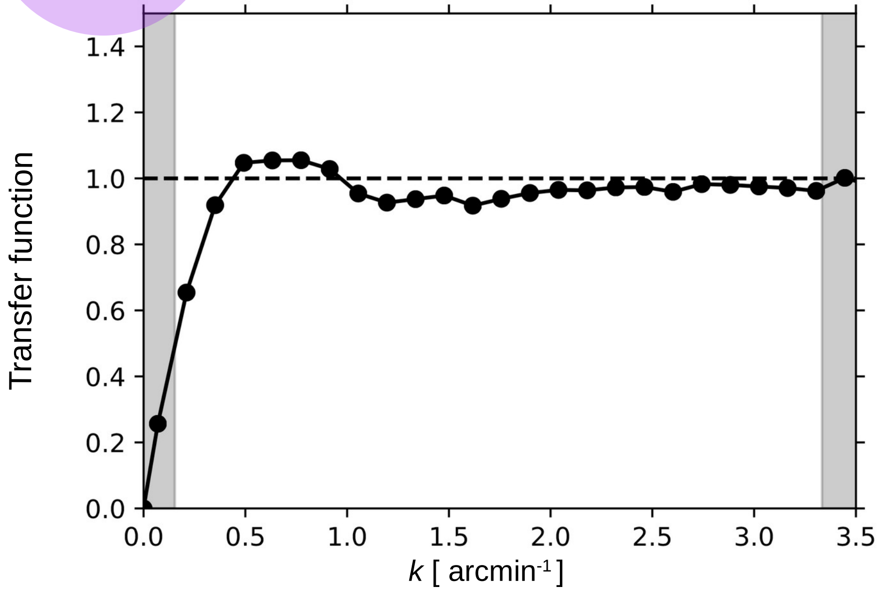
Quantifying **data processing filtering: transfer function**

Filtering estimated for 150 GHz maps in Fourier space, computed using simulations

$$\text{signal}_{\text{processed}} = \text{TF} * \text{signal}_{\text{in}}$$

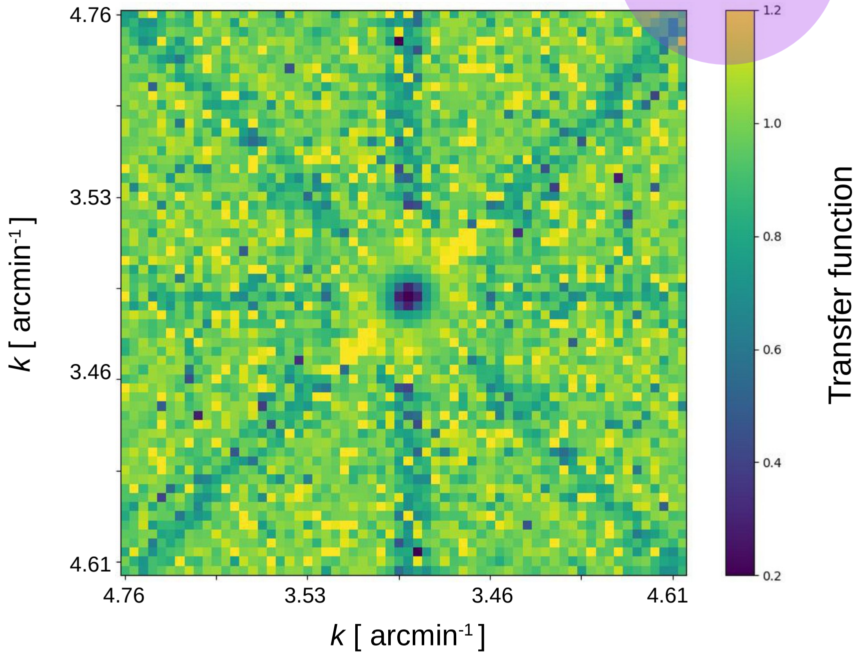
Standard LPSZ analysis

1D TF: circular symmetry



New approach

2D TF



2D transfer function allows us to deal with scanning angle effects

From raw data to mass estimation

- Data processing:
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- **From maps to pressure profiles:**
  - **Point sources contamination**
  - Pressure profile reconstruction
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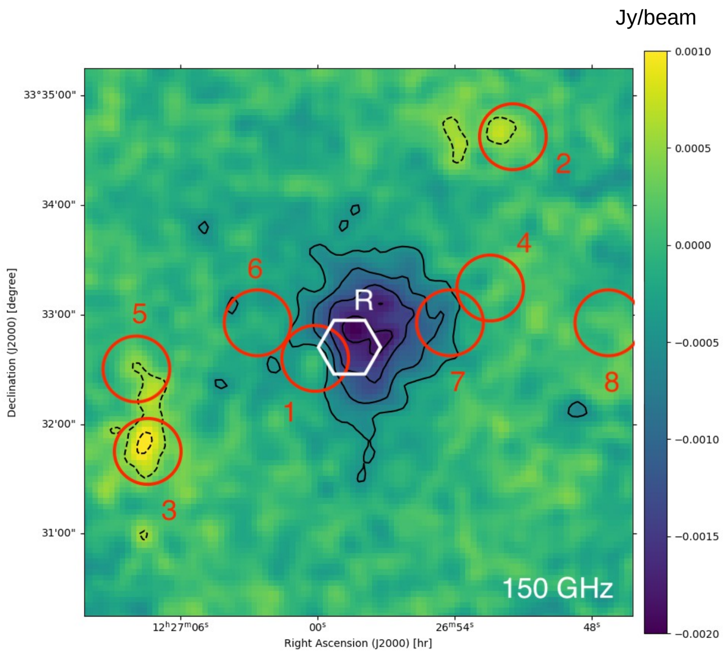
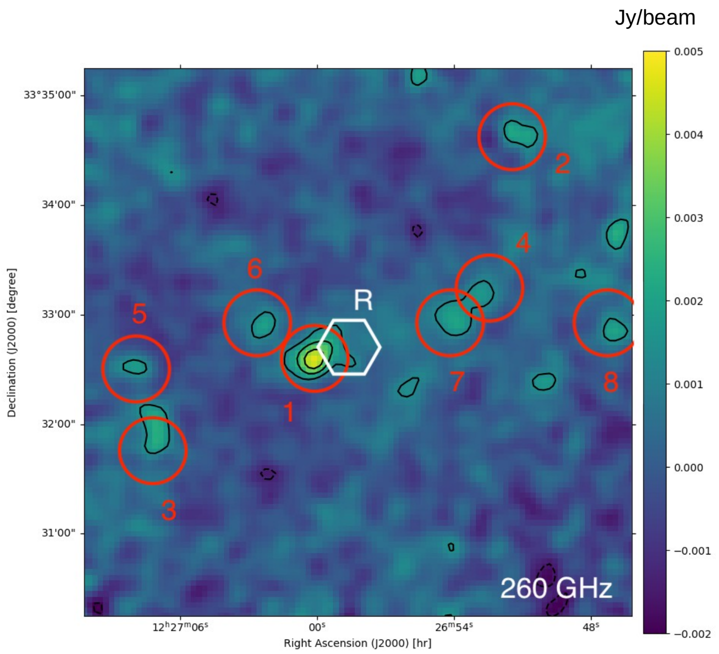
Preliminary

Point sources

Goal: to estimate their flux at 150 GHz

Identification





Submillimeter sources:

- NIKA2 maps (150 & 260 GHz)
- *Herschel* SPIRE (600, 860 & 1200 GHz) and PACS (1800 & 3000 GHz) catalogues

Radio source:

- VLA FIRST catalogue (1.4 GHz)

8 sub-mm and 1 radio sources identified

Point sources

Goal: to estimate their flux at 150 GHz

Estimation of the flux at 150 GHz

Submillimeter sources:
Using PSTools by F. Kéruzoré

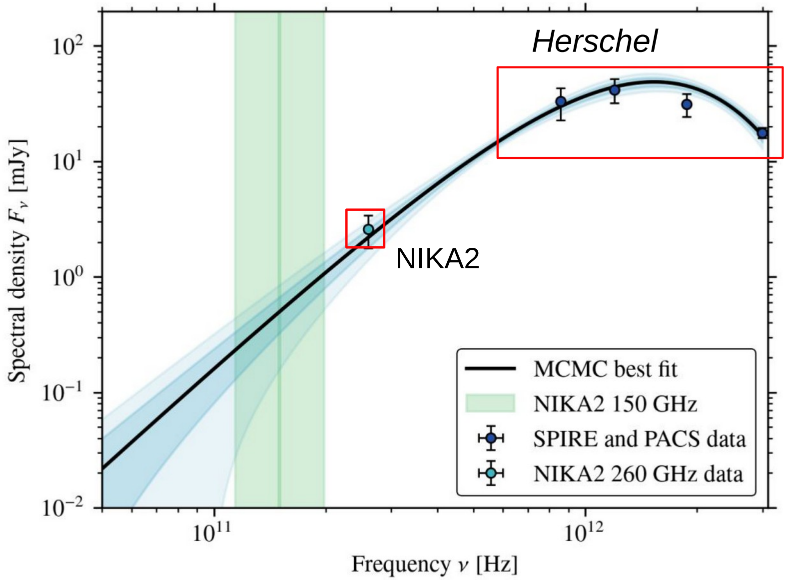
1. Measurement of the flux in the 260 GHz NIKA2 map
2. Fit of a modified blackbody spectrum

$$F_\nu(F_0, \beta, T) = F_0 \left(\frac{\nu}{\nu_0}\right)^\beta B_\nu(T)$$

3. Extrapolation to 150 GHz

→ used as prior in the official LPSZ code panco2

Spectral density distribution for PS4



Radio source:

1. Supposing a $F(\nu) = F(\nu_0) \times (\nu/\nu_0)^\alpha$ spectrum with α = - 0.7 ± 0.2 and 3.60 ± 0.13 mJy at 1.4 GHz: at 150 GHz ~ 0.1 mJy

→ not considered

From raw data to mass estimation

- Data processing:
    - Map-making
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- **From maps to pressure profiles:**
    - Point sources contamination
    - **Pressure profile reconstruction**
- Hydrostatic mass estimation

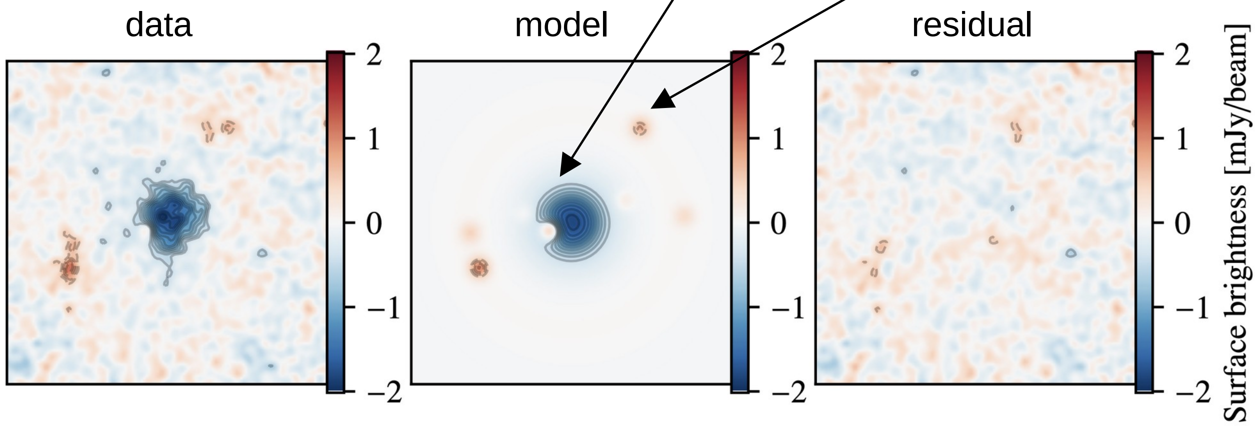
Pressure profile determination

MCMC fit of electronic pressure profile and point sources to the NIKA2 150 GHz map using panco2

+ in F. Kéruzoré's talk

$$\mathrm{MODEL}^{(x,y)}_{150GHz} = C^{(x,y)}_{150GHz} \left(\frac{\sigma_T}{m_e c^2} \int P_e \, dl \right)_{cluster} + \sum_{Sources} g_{2D}\left(F_{150GHz},\ 17{,}7''\right) + \mathrm{Zero}$$

- Calibration
- **TF**
- beam



Two pressure models:

gNFW

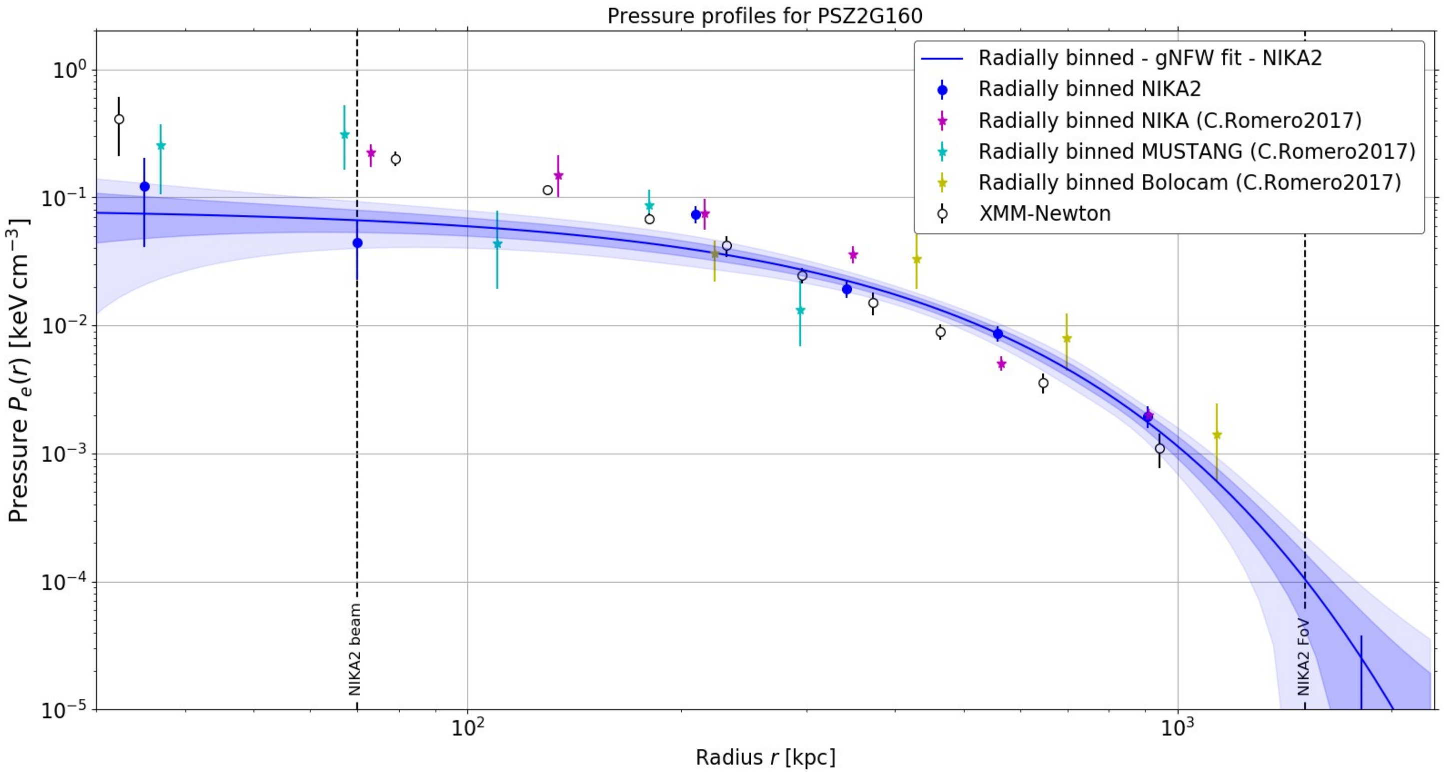
$$P_e(r) = \frac{P_0}{\left(\frac{r}{r_p}\right)^c \left(1 + \left(\frac{r}{r_p}\right)^a\right)^{\frac{b-c}{a}}}$$

Radially binned model

$$P_e(r) = P_i \left(\frac{r}{r_i}\right)^{-\alpha_i}$$

Pressure profile for **reference** model

Radially binned model with 1D transfer function



Consistent at large radii with other measurements. Discrepancy in the core with NIKA and XMM-Newton, but consistent with MUSTANG.

From raw data to mass estimation

- Data processing:
    - Map-making
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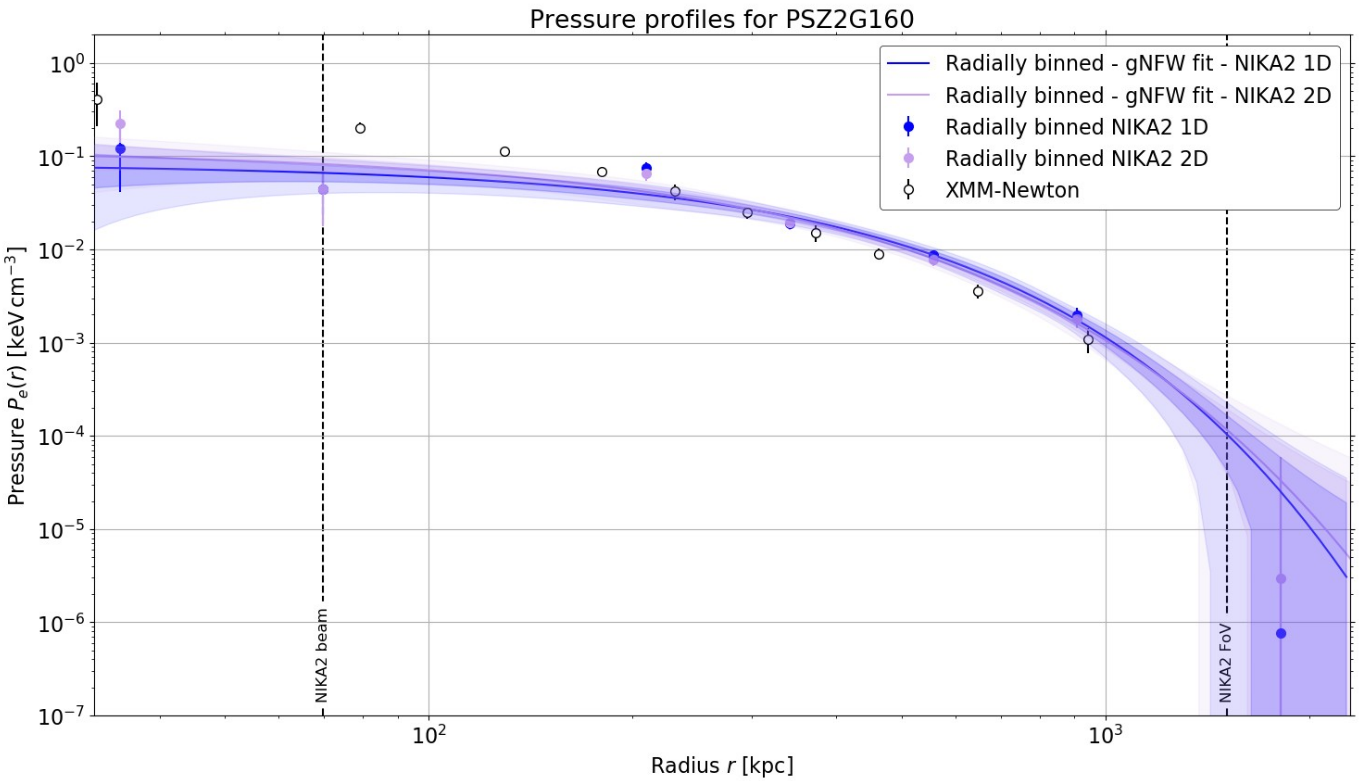
- **From maps to pressure profiles:**
    - Point sources contamination
    - **Pressure profile reconstruction: ROBUSTNESS TESTS**
- Hydrostatic mass estimation

Pressure profile reconstruction: filtering effects
1D & **2D transfer function**

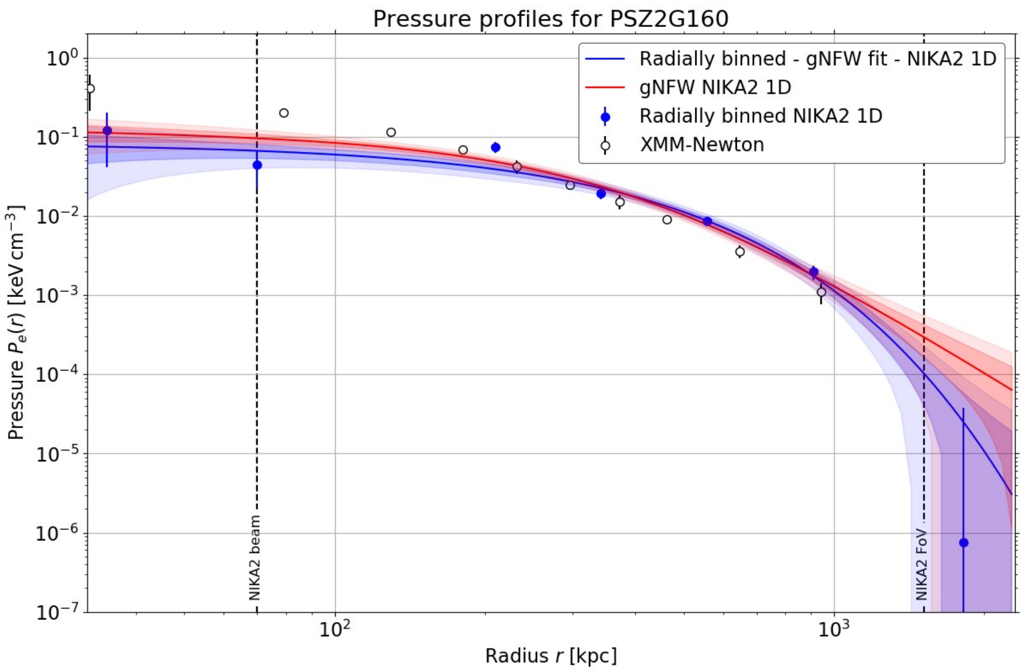


Scan direction filtering effects do not affect the reconstructed pressure profile

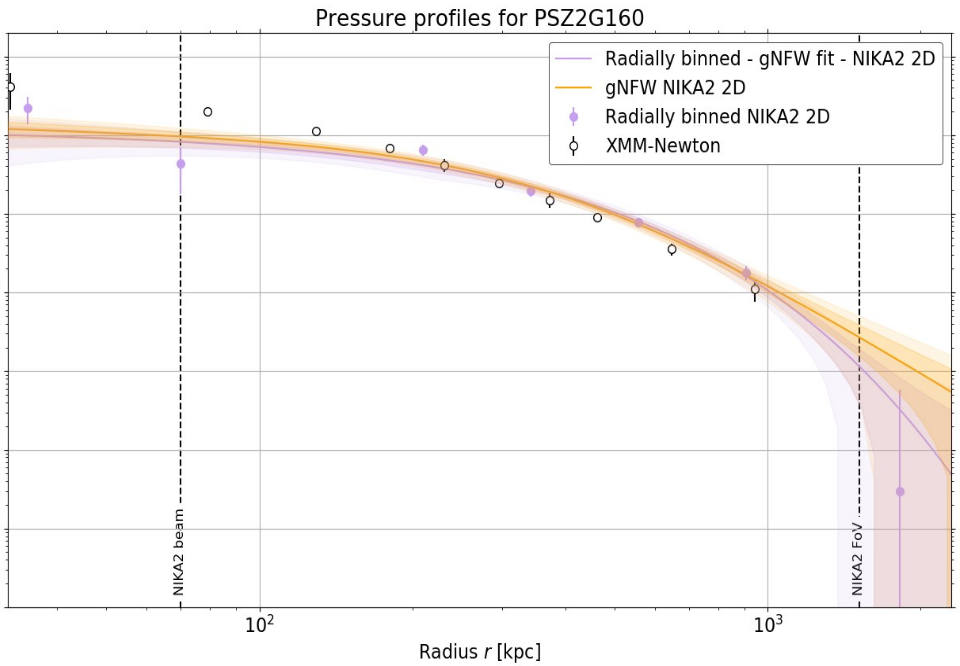
Pressure profile reconstruction: modelling effects

Radially binned & gNFW

1D TF



2D TF



Reconstructed pressure profiles are consistent within 1-σ. No significant effects from modelling.

From raw data to mass estimation

- Data processing:
    - Map-making
    - Quantifying data processing filtering (transfer function)
- From maps to pressure profiles:
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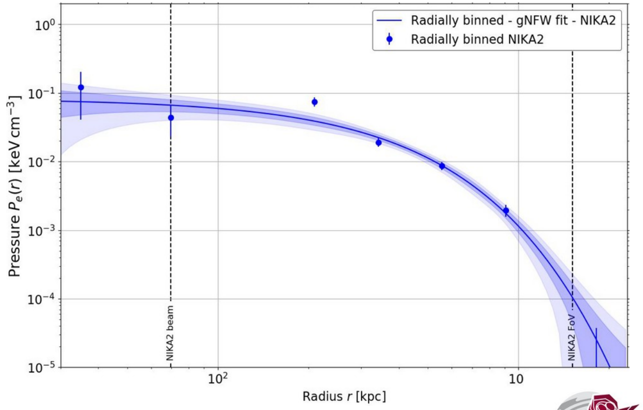
- **Hydrostatic mass estimation**

Hydrostatic mass profile

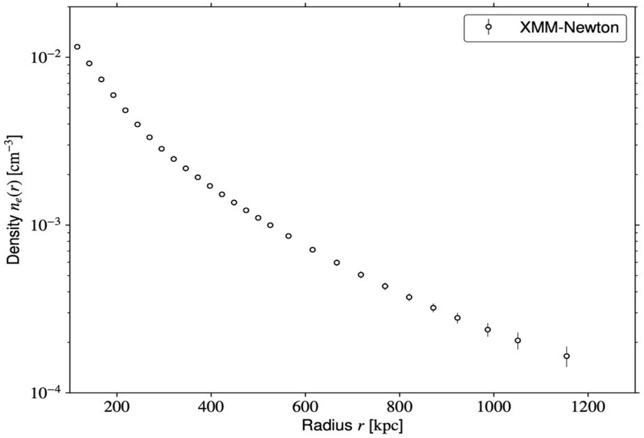
Applying the hydrostatic equilibrium hypothesis

$$\frac{dP}{dr} = -\rho g = -\rho \frac{GM_{\mathrm{HSE}}(r)}{r^2}$$

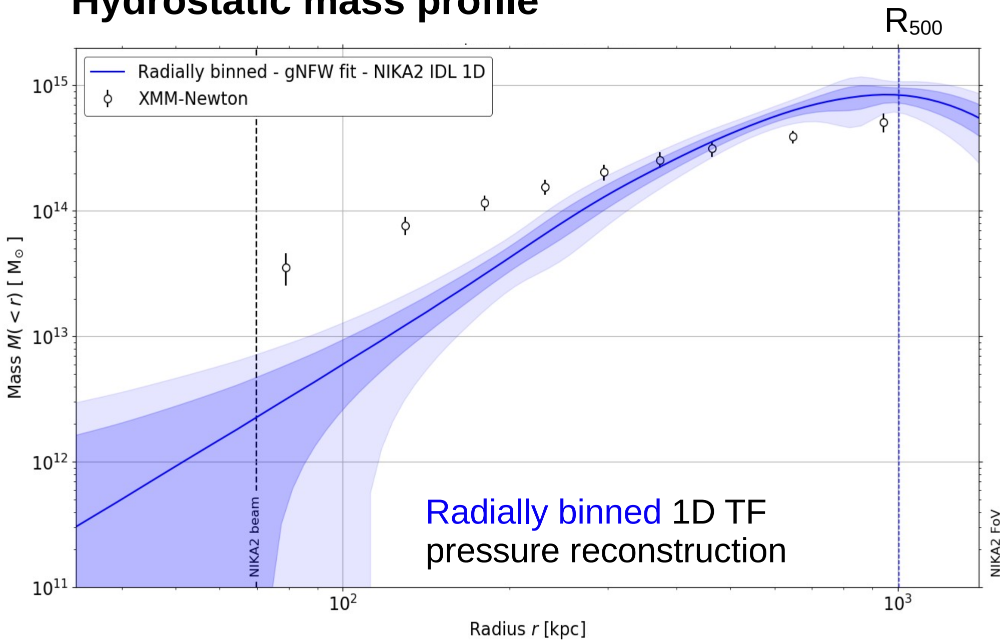
With: P_e from SZ with NIKA2



n_e from X with XMM-Newton

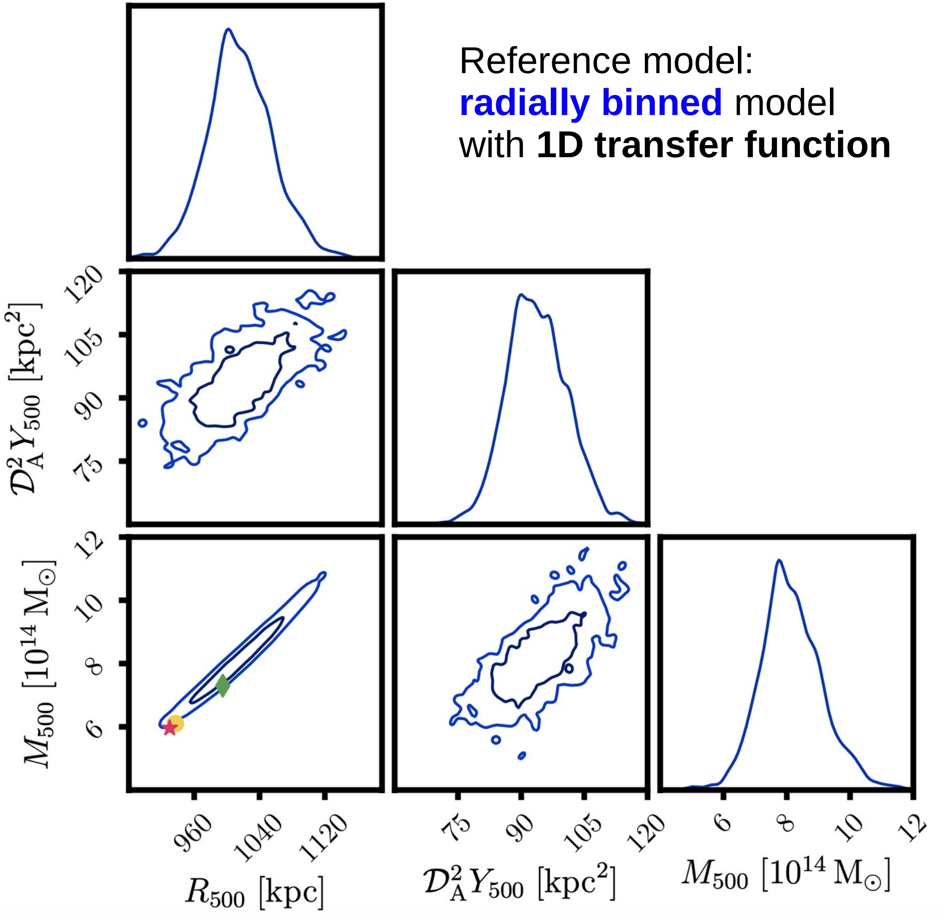


Hydrostatic mass profile



M_{500}^{HSE} is calculated in the extrapolated region
Very sensitive to the estimate of the pressure slope

Integrated values: R_{500} - Y_{500} - M_{500}^{HSE}



Reference model:
radially binned model
with **1D transfer function**

Other M_{500}^{HSE} estimations

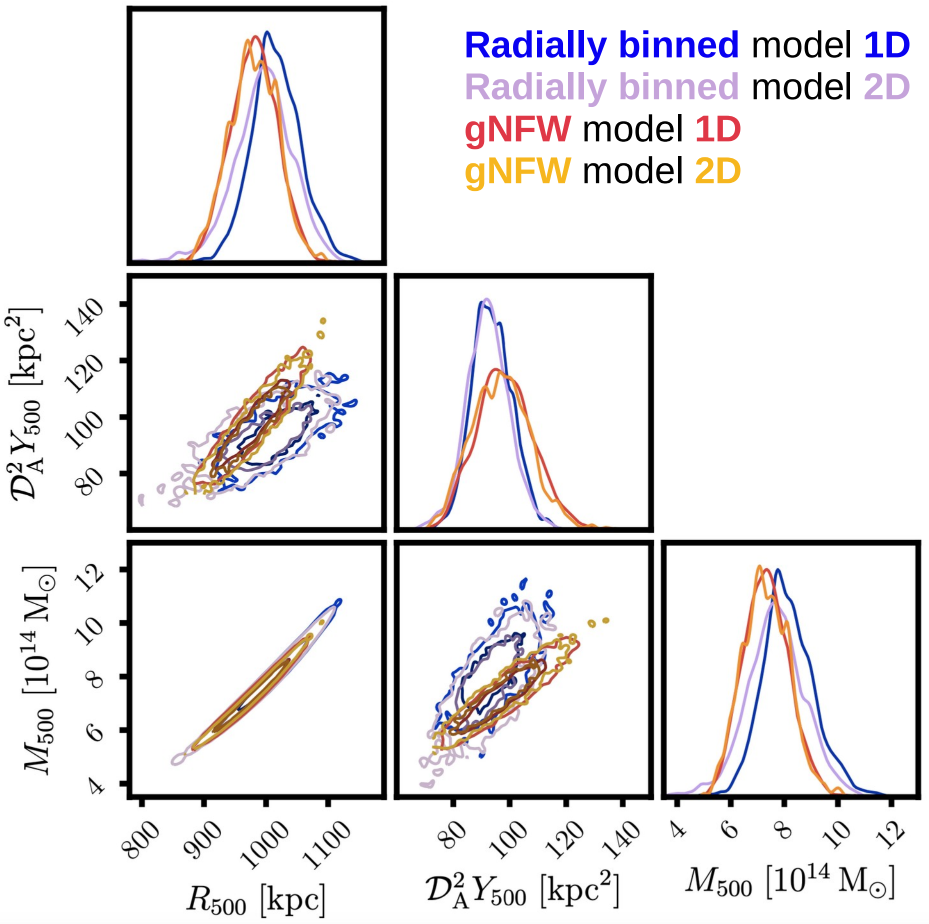
Data	M_{500} [10^{14} M☼]	R_{500} [kpc]
★ NIKA PPC (R.Adam et al., 2015)	$5.96^{+1.02}_{-0.79}$	930^{+50}_{-43}
● NIKA FPC (R.Adam et al., 2015)	$6.10^{+1.52}_{-1.06}$	937^{+72}_{-58}
◆ NIKA NNN (R.Adam et al., 2015)	$7.30^{+1.52}_{-1.34}$	995^{+65}_{-65}
XMM-Newton (this data)	$5.95^{+0.23}_{-0.22}$	915^{+11}_{-11}
XMM-Newton + Chandra (Maughan et al., 2007)	$5.2^{+1.0}_{-0.8}$	880 ± 50

M_{500} and R_{500} are very correlated
Only comparing the marginalized estimates may be misleading

⟶ we need to compare the posterior distributions

Robustness tests on integrated values: R_{500} - Y_{500} - M_{500}^{HSE}

Preliminary



Using 2D transfer function gives slightly lower R_{500} and M_{500} distributions for radially binned

The mass seems a bit tighter constrained using gNFW

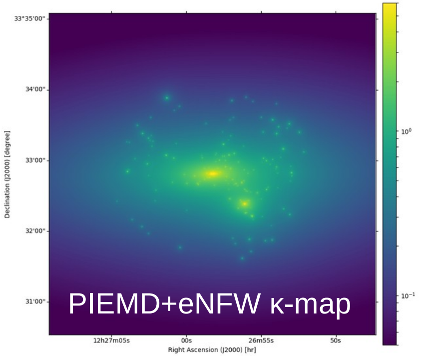
No big impact from pressure modelling if pressure derivative computed in a consistent way

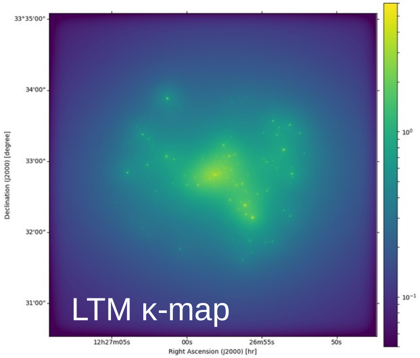
Mass estimation seems robust against tested systematics, we measure $M_{500}^{HSE} = (7.65 \pm 1.03) \times 10^{14} M_{\odot}$

Similar results obtained with PIIC (IRAM's pipeline) maps

Lensing integrated values: M_{500}^{LENS} – R_{500}

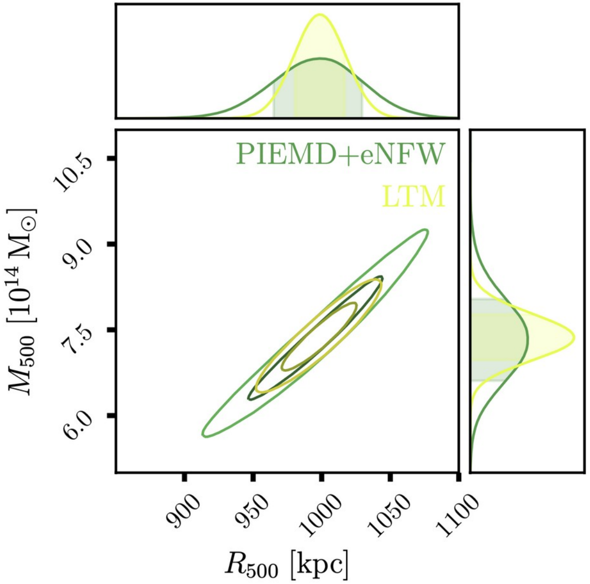
Using **convergence maps** from **CLASH (Hubble)** and based on A. Ferragamo's work





(Zitrin et al., 2015)

+ in Wednesday's talk



We measure $M_{500}^{LENS} = (7.35 \pm 0.65) \times 10^{14}\ M_\odot$

Robust lensing mass estimate, consistent with previous results

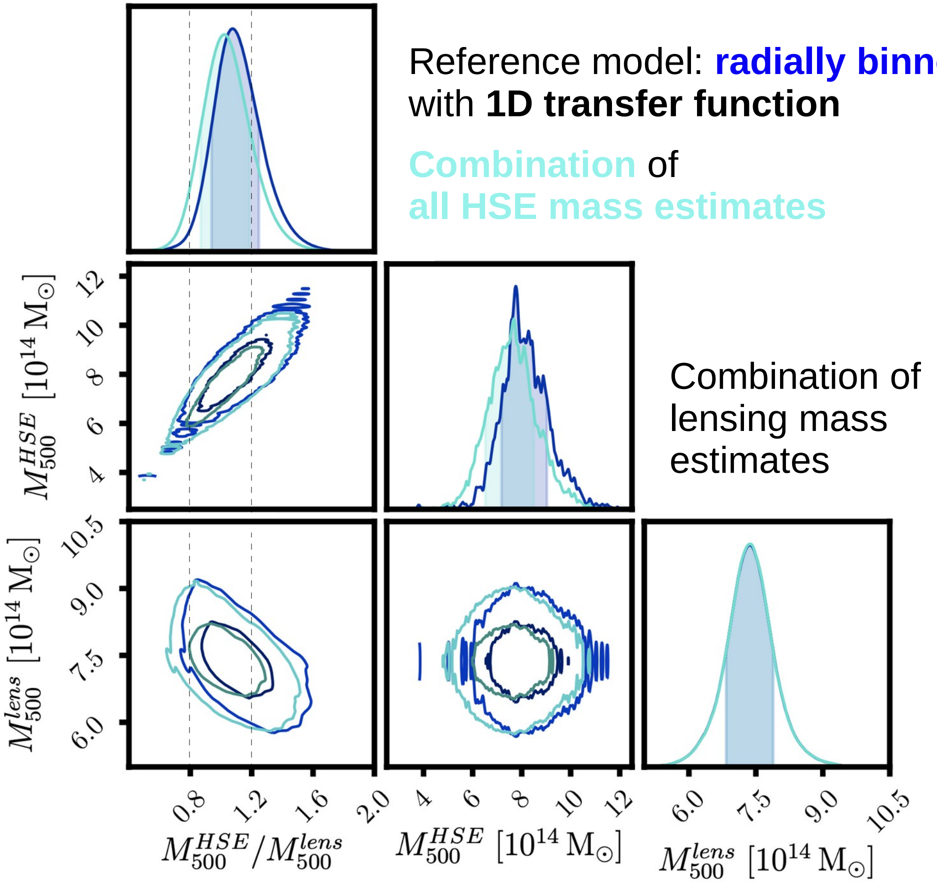
~ 10 % statistical uncertainties + less than 1 % systematics

Other M_{500}^{LENS} estimations

Data	**M_{500} [10^{14} $M_\odot$]**	**R_{500} [kpc]**
Hubble ST (M.Jee and J.Tyson, 2009)	7.34 ± 0.71*	*Calculated at the R_{500} by Maughan et al., 2007

Hydrostatic to lensing mass bias: $b_{HSE/LENS}$

$M_{500}^{HSE}/M_{500}^{LENS} = (1 - b_{HSE/LENS})$



Reference model: **radially binned model** with **1D transfer function**

Combination of **all HSE mass estimates**

Combination of lensing mass estimates

We combine the posterior distributions for all the considered cases to account for data processing and modelling systematic effects

Reference model gives a bias w.r.t. lensing centered in $b_{HSE/LENS} < 0$; $M_{500}^{HSE} > M_{500}^{LENS}$

When accounting for systematics small change towards $b_{HSE/LENS} = 0$

Conclusions

- Combining **SZ and X-ray data** we have obtained **hydrostatic mass estimates for CLJ1227,** which is a **high redshift** cluster

  For its the determination of **pressure profile derivatives is key**: in this work always deriving a gNFW

  We have demonstrated that our hydrostatic mass estimates are robust against **filtering** and **pressure modelling**

- We find **no hydrostatic to lensing mass bias** for CLJ1227. We have measured $M_{500}^{HSE} = (7.65 \pm 1.03) \times 10^{14}\ M_{\odot}$ and $M_{500}^{LENS} = (7.35 \pm 0.65) \times 10^{14}\ M_{\odot}$

- This analysis allowed us to develop a standard pipeline to compare and combine hydrostatic and lensing mass estimates

  + see Wednesday's talk

- To go beyond the current knowledge on CLJ1227: interferometer data from NOEMA to study the core and radio data to learn about non-thermal pressure