The **LPSZ-CLASH galaxy cluster sample**: combining **lensing** and **hydrostatic mass estimates**

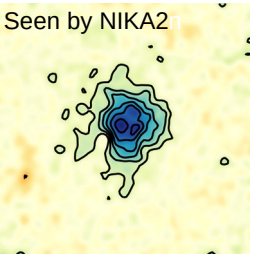
Miren Muñoz Echeverría, LPSC, Grenoble
on behalf of the NIKA2 collaboration

mm Universe @ NIKA2 – 30.06.2021

The mass of the galaxy clusters

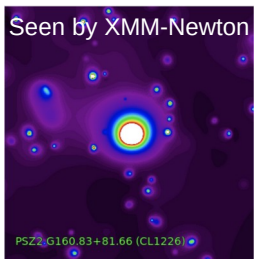
Context: cluster-based cosmology may be impacted by the lack of **knowledge on the cluster physics** and on how **reliable** are **mass estimates**

PSZ2G160



Different mass estimates affected by different systematic uncertainties:

- Hydrostatic equilibrium mass with SZ & X-ray:
  - Sensitive to baryonic physics, shocks, mergers, over-pressures
- Lensing mass:
  - Modelling effects, merging processes
- Others

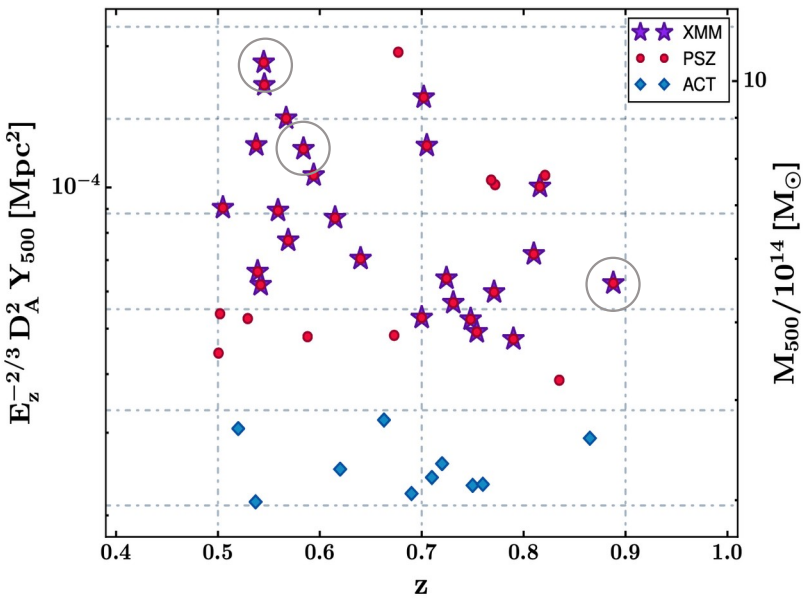


→ **Combining observables** may help building a consistent picture of the cluster physics to gain accuracy on the mass estimates

We will combine **hydrostatic equilibrium and lensing mass estimates**
Using the common **sample** between **LPSZ and CLASH**

NIKA2 Sunyaev-Zel'dovich Large Program (LPSZ)

Study of 45 high redshift galaxy clusters selected in SZ from Planck and ACT



Clusters selected in 5 bins in mass and 2 bins in redshift

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

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

Cluster Lensing And Supernova survey with Hubble (CLASH)

25 massive galaxy clusters

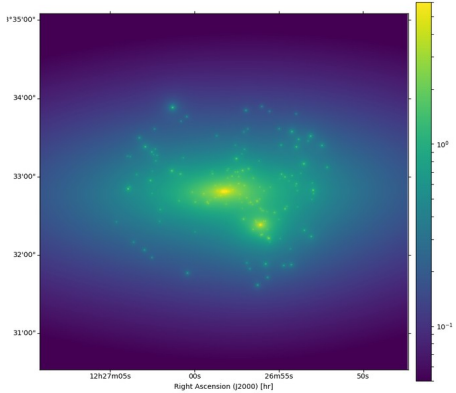
A distribution of matter with surface mass density κ deflects the light an angle α

The CLASH dataset provides **lensing convergence maps** or ***κ*-maps** (Zitrin et al., 2015)

PSZ2G160 seen by HST

$$\nabla \cdot \vec{\alpha} = 2\kappa$$

PSZ2G160's convergence map



For some clusters different convergence map models are available:

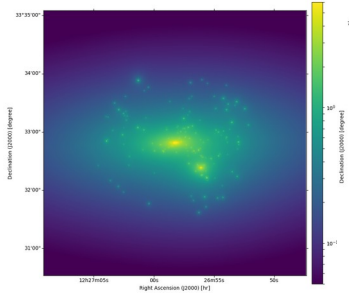
- LTM: Light-Traces-Mass (Zitrin et al., 2009)
- PIEMD+eNFW: Pseudo-Isothermal Elliptical Mass Distribution + elliptical NFW (Zitrin et al., 2013)

Preliminary

The **LPSZ-CLASH galaxy cluster sample** and NIKA clusters

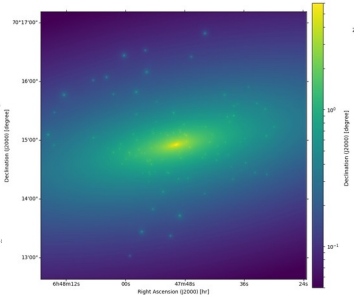
κ-maps and SZ maps

PSZ2G160



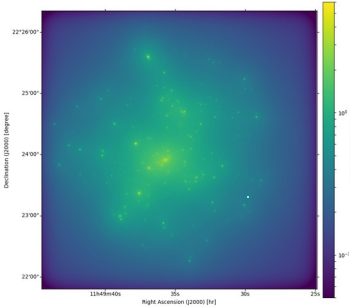
NFW

PSZ2G144



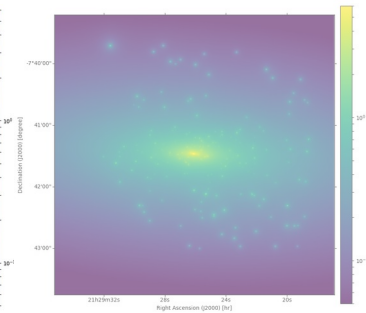
NFW

PSZ2G228



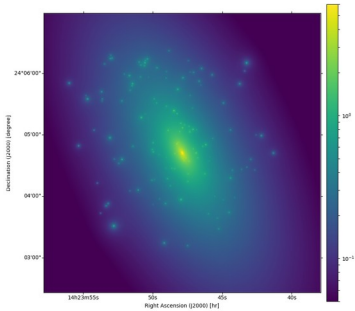
LTM-Gauss

PSZ2G045



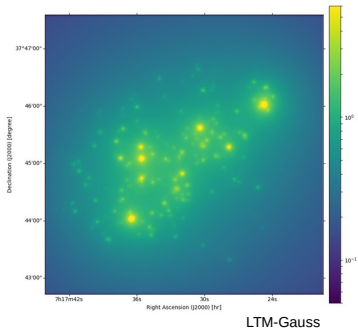
NFW

MACSJ1424

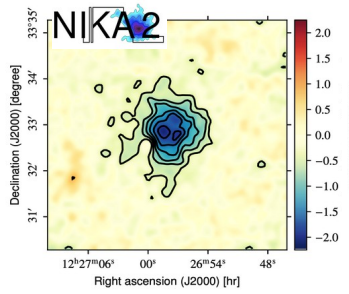


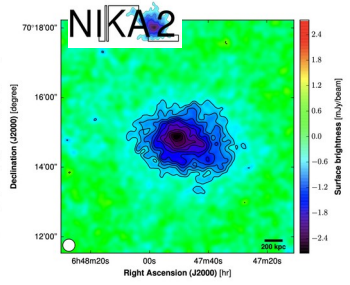
NFW

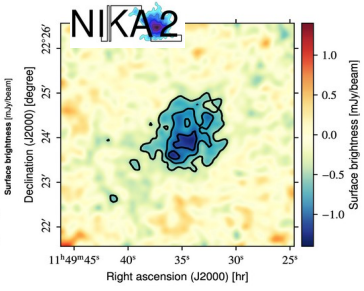
MACSJ0717

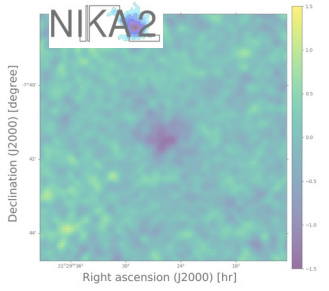


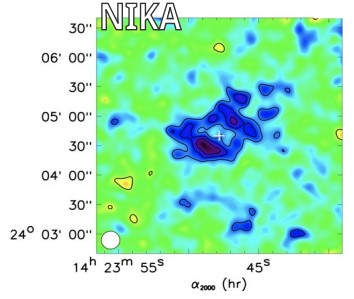
LTM-Gauss

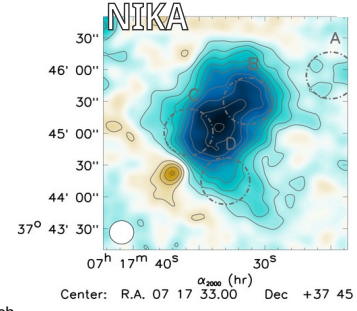












First Sunyaev-Zel'dovich mapping with the NIKA2 camera: Implication of cluster substructures for the pressure profile and mass estimate (Ruppin et al., 2018)

High angular resolution Sunyaev-Zel'dovich observations of MACS J1423.8+2404 with NIKA: Multiwavelength analysis (Adam et al., 2018)

Mapping the kinetic Sunyaev-Zel'dovich effect toward MACS J0717.5+3745 with NIKA (Adam et al., 2016)

30.06.2021

Miren Muñoz Echeverría

Combining SZ, X-ray and lensing

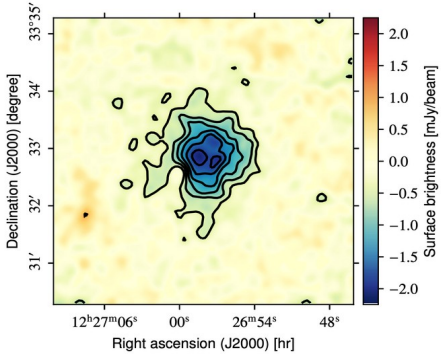
- **1D analysis:**
  - **Reconstruction of hydrostatic mass profiles**
  - Reconstruction of lensing mass profiles
  - Hydrostatic to lensing mass bias
- 2D analysis:
  - Identification of structures

Hydrostatic mass reconstruction

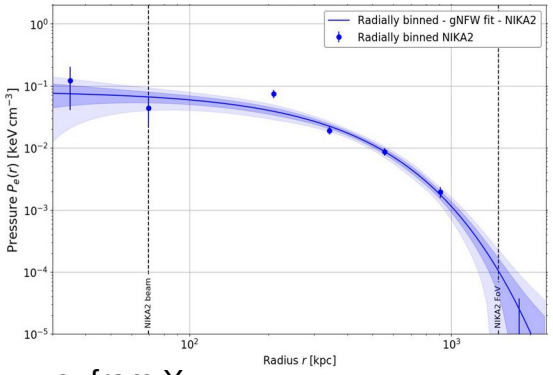
Combining SZ and X-ray data

+ Monday's talks

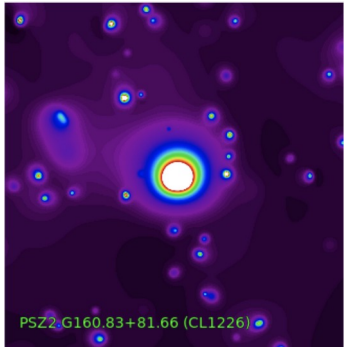
NIKA2: SZ



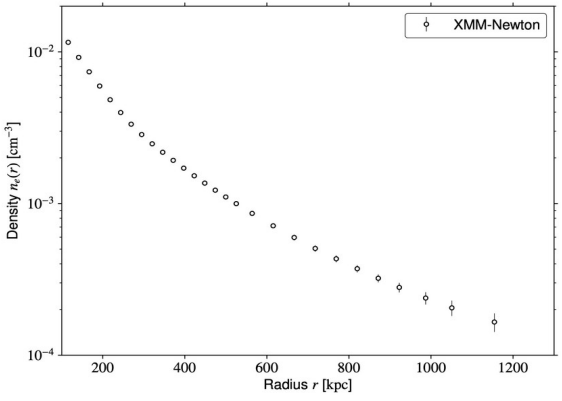
P_e from SZ



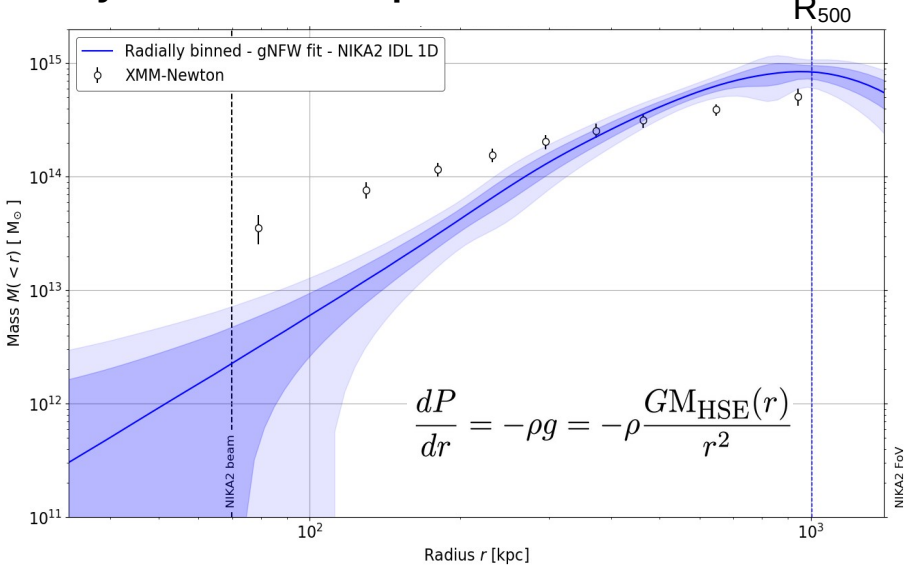
XMM-Newton: X-ray



n_e from X



Hydrostatic mass profile for PSZ2G160



From X-ray only and from SZ+X-ray combination

Combining SZ, X-ray and lensing

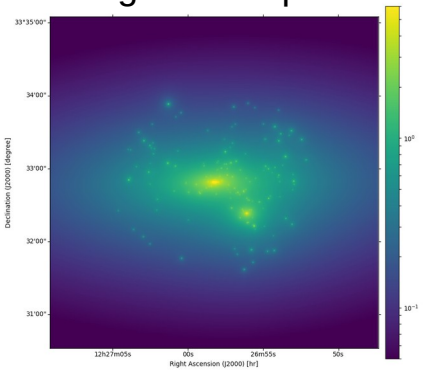
- **1D analysis:**
  - Reconstruction of hydrostatic mass profiles
  - **Reconstruction of lensing mass profiles**
  - Hydrostatic to lensing mass bias
- 2D analysis:
  - Identification of structures

Preliminary

Lensing mass reconstruction

From CLASH convergence maps

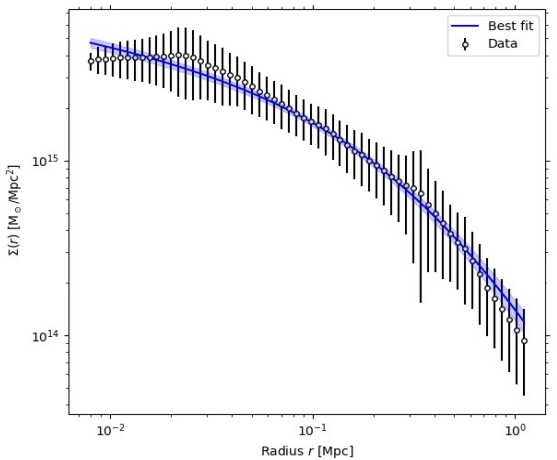
Convergence maps can be converted in **lensing estimates of the total mass** of the cluster:

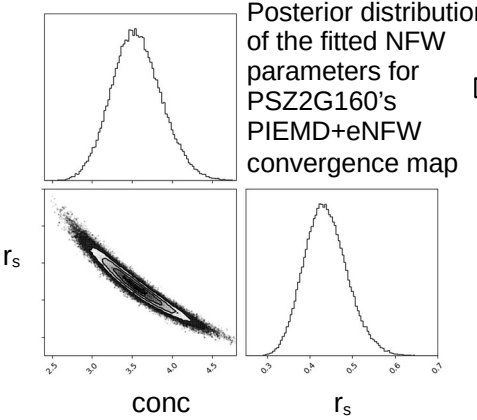


$$\kappa = \Sigma / \Sigma_{crit}$$

κ : Σ in critical density unities Σ_{crit}
Σ : surface mass density
Σ_{crit} : the density needed for strong lensing to occur

Fit Σ to a projected NFW density model using MCMC approach:

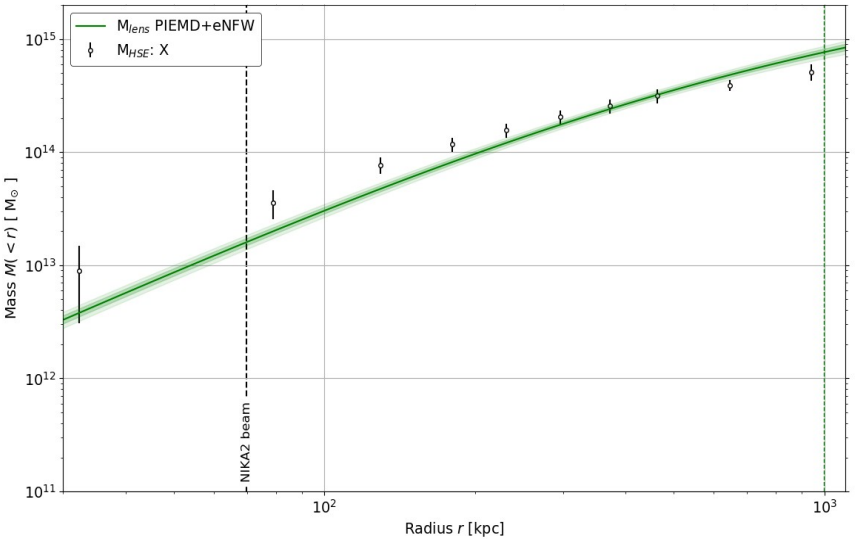




r_s

Posterior distributions of the fitted NFW parameters for PSZ2G160's PIEMD+eNFW convergence map

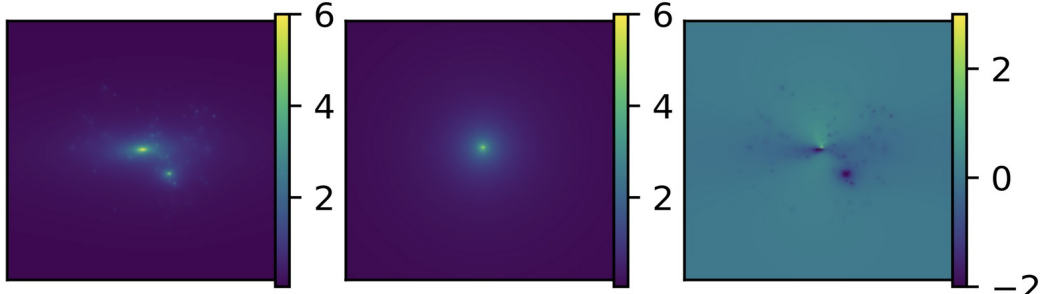
Lensing mass profile for PSZ2G160



Fit of ***κ*-maps** to **density models**

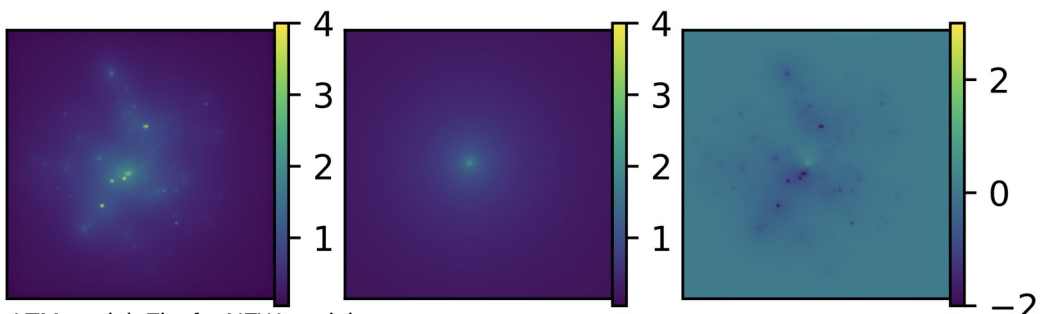
Consistency of the NFW profiles with *κ*-maps

PSZ2G160



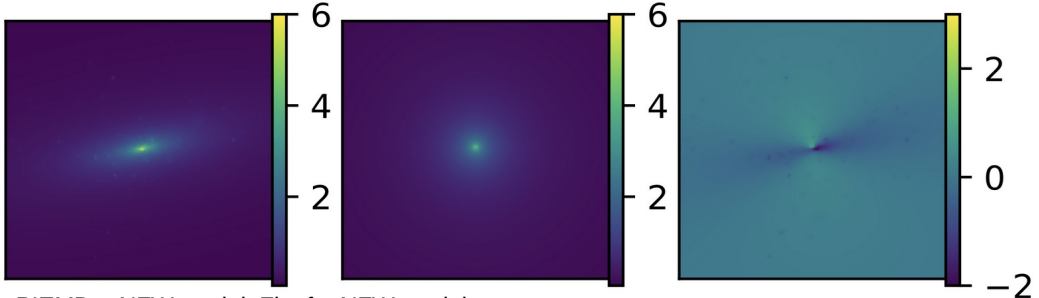
PIEMD+eNFW model. Fit of a NFW model.
Second clump present in projected density map.

PSZ2G228



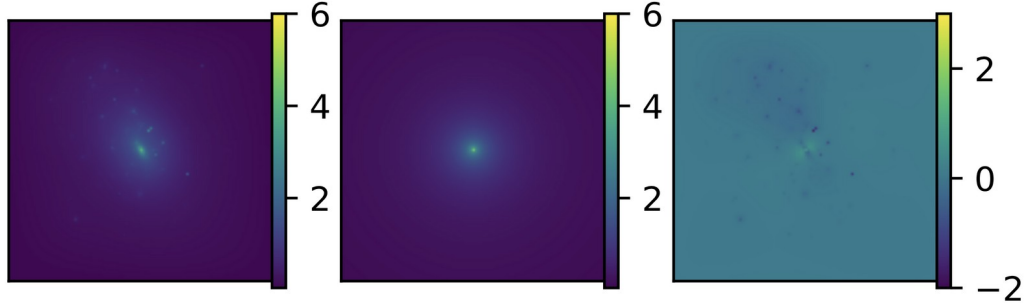
LTM model. Fit of a NFW model.
Complex morphology and diffuse signal, color scale adapted.

PSZ2G144



PIEMD+eNFW model. Fit of a NFW model.
No hints of over-density in the south-west.

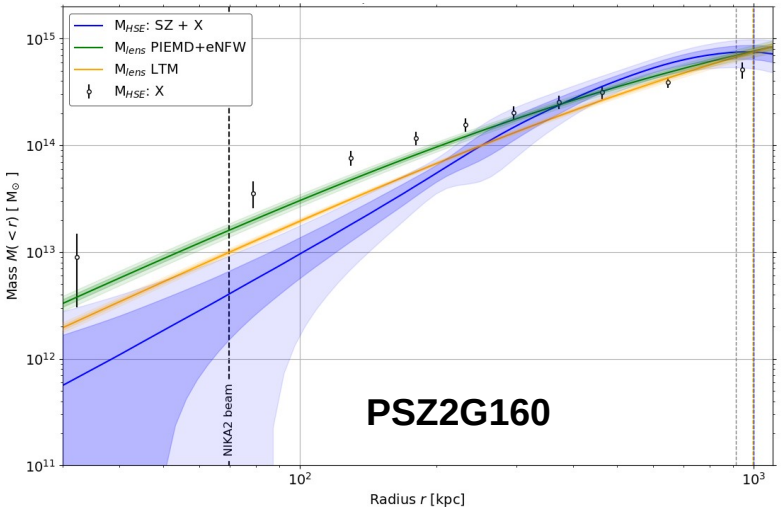
MACSJ1424

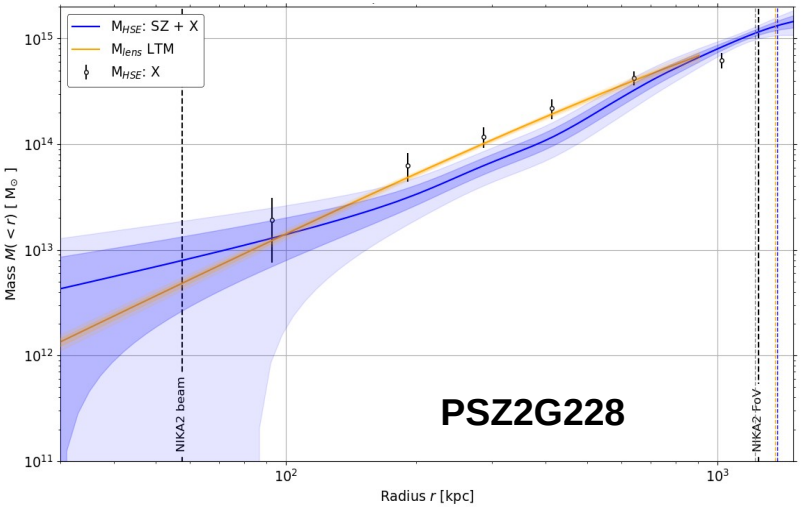


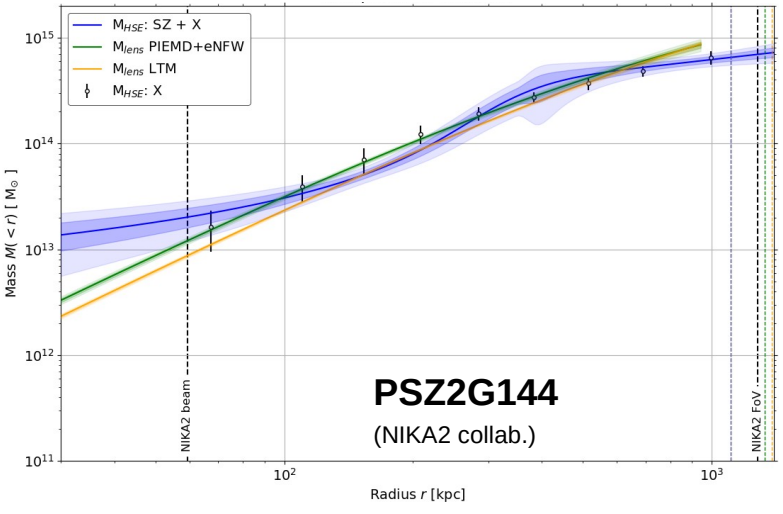
LTM model. Fit of a NFW model.

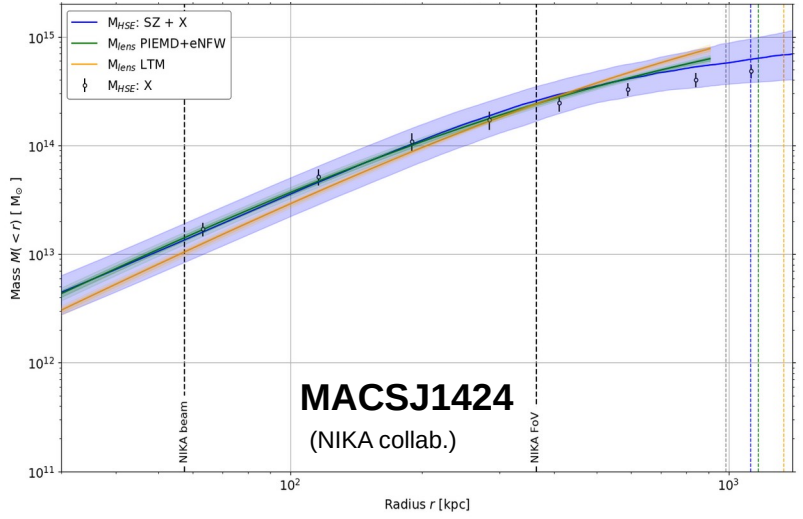
Preliminary

Reconstructed **hydrostatic** and **lensing mass profiles**



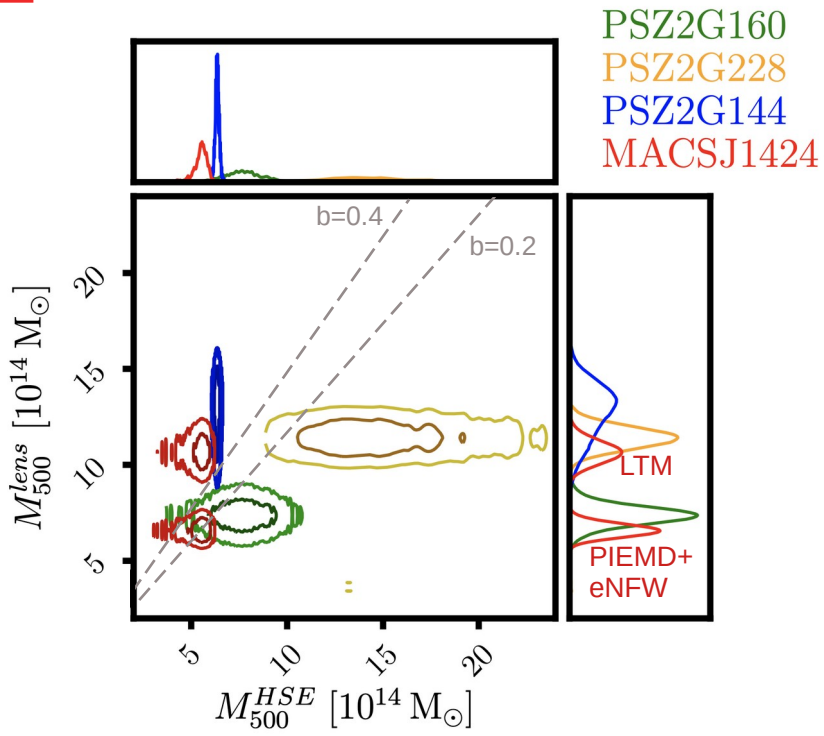






Hydrostatic and **lensing masses** at R_{500}

For each cluster the marginalized M_{500} distributions for hydrostatic and lensing estimates



With this sample, we don't get a linear M_{500}^{HSE} - M_{500}^{LENS} relation

- PSZ2G228 has a very complex morphology to be fit with spherical models

- For MACSJ1424, big impact of the κ-map model

- For equivalent M_{500}^{HSE} results the reconstructed lensing masses are different

Essential to compare the lensing mass to the hydrostatic mass estimate for the LPSZ clusters

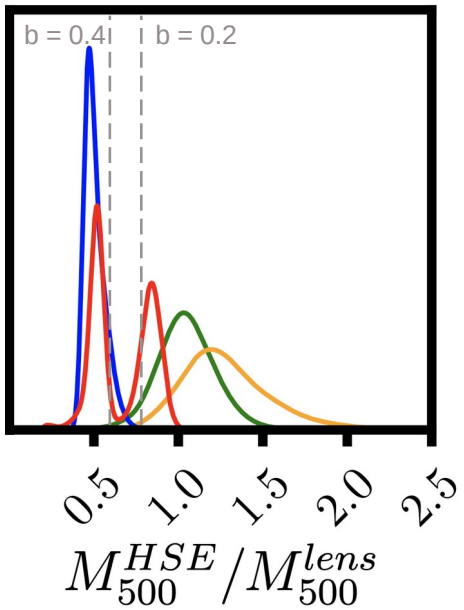
Combining SZ, X-ray and lensing

- **1D analysis:**
    - Reconstruction of hydrostatic mass profiles
    - Reconstruction of lensing mass profiles
    - **Hydrostatic to lensing mass bias**
- 2D analysis:
    - Identification of structures

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

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

We combine for each cluster the marginalized M_{500} distributions for hydrostatic and lensing estimates.



PSZ2G160
PSZ2G228
PSZ2G144
MACSJ1424

We observe a very different bias for each cluster

In a 1D analysis we lose information by mixing different effects: the dynamical state of the cluster, its morphology...

+ talk by E. Artis

A better way to do it is studying the properties in two dimensions

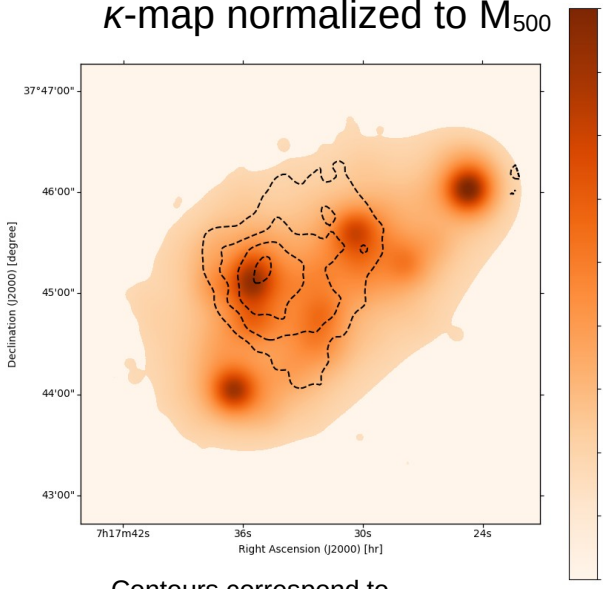
Combining SZ, X-ray and lensing

- 1D analysis:
    - Reconstruction of hydrostatic mass profiles
    - Reconstruction of lensing mass profiles
    - Hydrostatic to lensing mass bias
- **2D analysis:**
    - **Identification of structures**

MACSJ0717: cluster in merger scenario

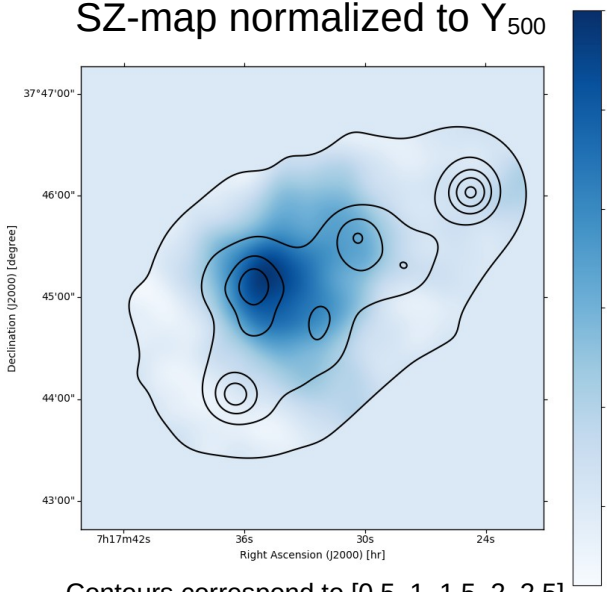
SZ-map to κ-map ratio

κ-map normalized to M_{500}



Contours correspond to
[-2.5, -2, -1.5, -1, -0.5] mJy/beam levels

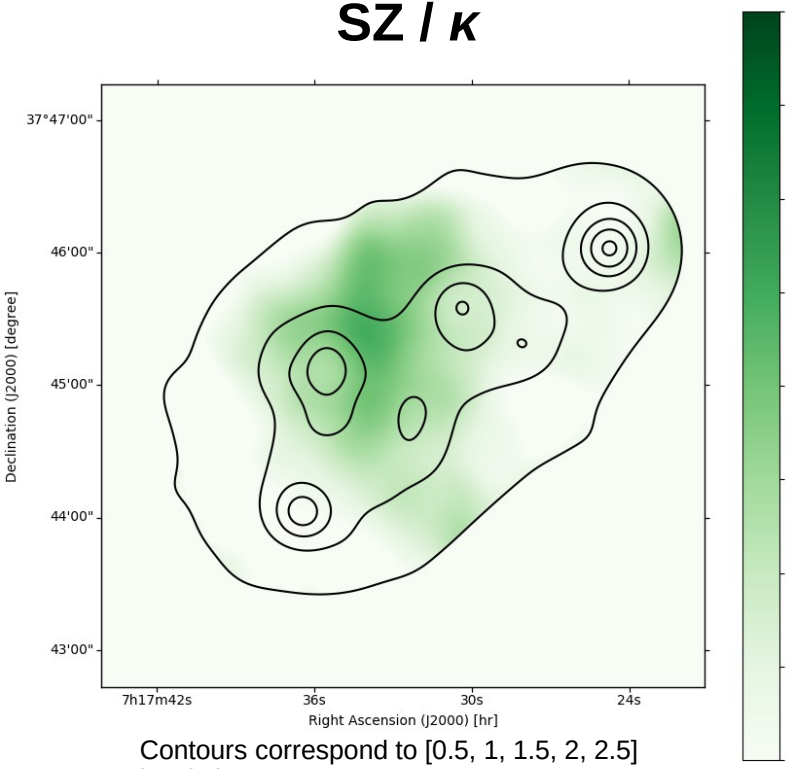
SZ-map normalized to Y_{500}



Contours correspond to [0.5, 1, 1.5, 2, 2.5] levels in κ-map. kSZ corrected.

Pixels in positions with κ less than 0.5 are fixed to 0. All maps have a 18'' smooth.

SZ / κ



Contours correspond to [0.5, 1, 1.5, 2, 2.5] levels in κ-map

The **SZ / κ map** shows the hot region between the two central density clumps from north-east to south-west

Conclusions

- We have constructed a **LPSZ-NIKA-CLASH** common **cluster sample**
- We have estimated **hydrostatic and lensing mass estimates** for each cluster which show evidence of the impact of **cluster physics**

  With the 1D analysis

  - For each cluster we get a **different bias**, being affected by the **systematics of the estimations**
  - In average the results are not inconsistent with the expected bias values from literature
  - Morphologically complex clusters are not suited for such an analysis

  With the 2D analysis

  - We have illustrated the **potential of map to map SZ and lensing comparison** for revealing cluster physics