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

Different mass estimates affected by different systematic uncertainties:

- Hydrostatic equilibrium mass with SZ & X-ray:
  - Sensitive to baryonic physics, shocks, mergers, over-presures
- 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

One of the objectives...

...hydrostatic mass estimate combining:
- Electron pressure from thermal SZ effect with \( \text{NIKA2} \)
- Electron density and temperature from X-rays with \( \text{XMM-Newton} \)

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

\[
\frac{dP}{dr} = -\rho g = -\rho \frac{GM_{\text{HSE}}(r)}{r^2}
\]
Cluster Lensing And Supernova survey with Hubble (CLASH)

25 massive galaxy clusters

A distribution of matter with surface mass density $\kappa$ deflects the light an angle $\alpha$

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

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)
The LPSZ-CLASH galaxy cluster sample and NIKA clusters

κ-maps and SZ maps

PSZ2G160  PSZ2G144  PSZ2G228  PSZ2G045  MACSJ1424  MACSJ0717

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)

Preliminary
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

NIKA2: SZ

XMM-Newton: X-ray

P$_e$ from SZ

$n_e$ from X

Hydrostatic mass profile for PSZ2G160

$R_{500}$

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

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

Monday’s talks

30.06.2021

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Combining SZ, X-ray and lensing

- **1D analysis:**
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  - **Reconstruction of lensing mass profiles**
  - Hydrostatic to lensing mass bias
- **2D analysis:**
  - Identification of structures
Lensing mass reconstruction
From CLASH convergence maps

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

\[ \kappa = \frac{\Sigma}{\Sigma_{\text{crit}}} \]

- \( \kappa : \Sigma \) in critical density unities \( \Sigma_{\text{crit}} \)
- \( \Sigma : \) surface mass density
- \( \Sigma_{\text{crit}} : \) the density needed for strong lensing to occur

Fit \( \Sigma \) to a projected NFW density model using MCMC approach:

**Lensing mass profile** for PSZ2G160

Posterior distributions of the fitted NFW parameters for PSZ2G160’s PIEMD+eNFW convergence map
Fit of $\kappa$-maps to density models

Consistency of the NFW profiles with $\kappa$-maps

PSZ2G160

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

PSZ2G144

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

PSZ2G228

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

MACSJ1424

LTM model. Fit of a NFW model.

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

PSZ2G160

PSZ2G228

PSZ2G144

MACSJ1424

(NIKA2 collab.)

(NIKA collab.)
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 $\kappa$-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: $b_{\text{HSE/LENS}}$

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

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

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...

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

+ talk by E. Artis
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 $\kappa$-map ratio

$\kappa$-map normalized to $M_{500}$

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

Pixels in positions with $\kappa$ less than 0.5 are fixed to 0. All maps have a 18" smooth.

SZ-map normalized to $Y_{500}$

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

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

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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