Scientific preparation of CATARSIS: Mass profiles of galaxy clusters using The300

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Supervisors:

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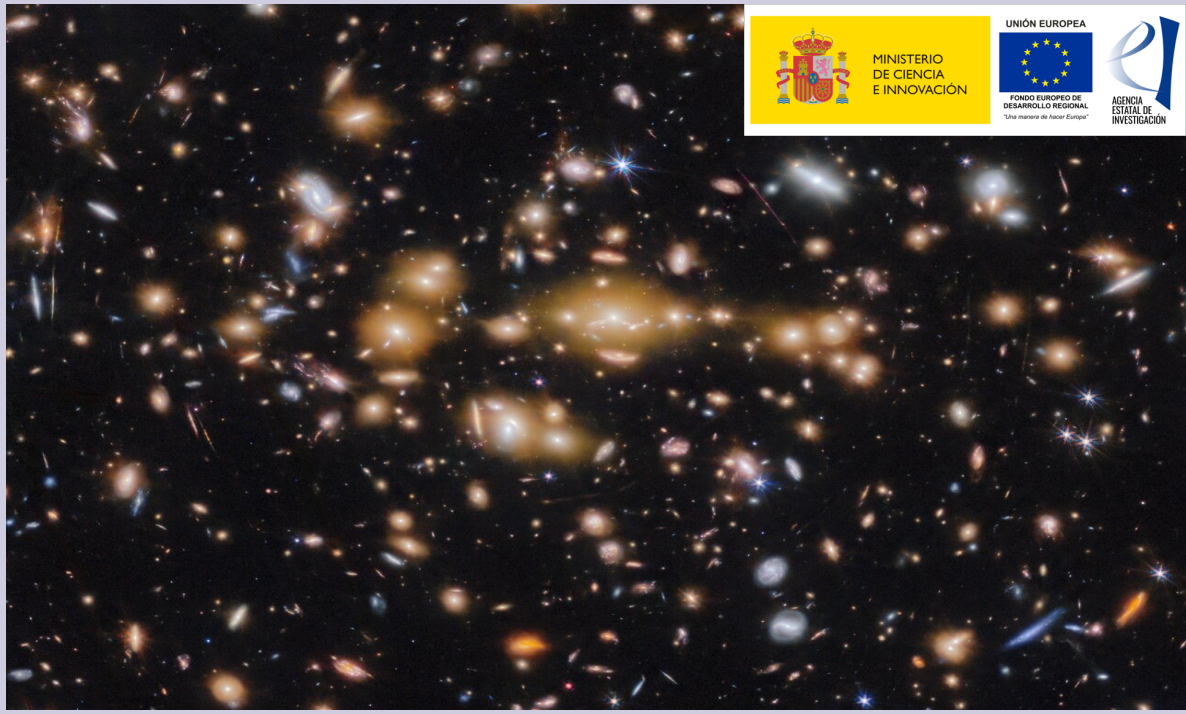
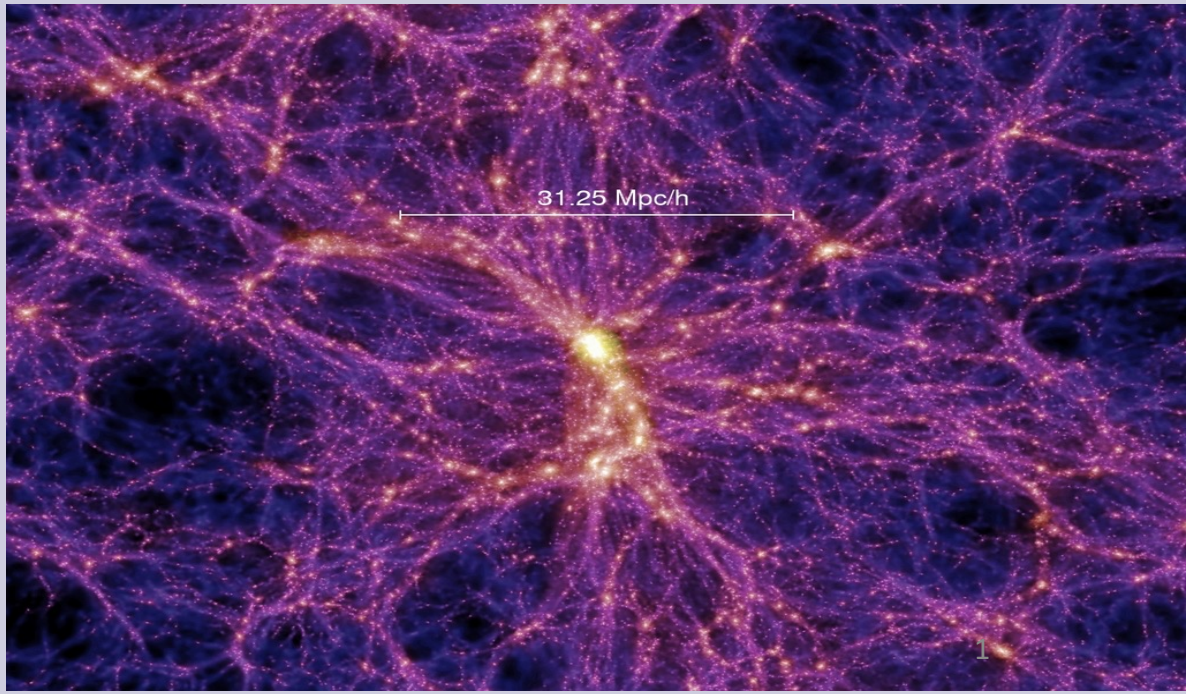
GUAIX meeting 17 - 12 - 2025





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PID2022-138621NB-I00 / PID2022-138855NB-C31, funded by MCIN/AEI/10.13039/501100011033/FEDER, EU

Main Objective

Estimate the **mass profile** of galaxy cluster to understand the **nature of dark matter and energy** in the **dynamical history formation of galaxy clusters.**

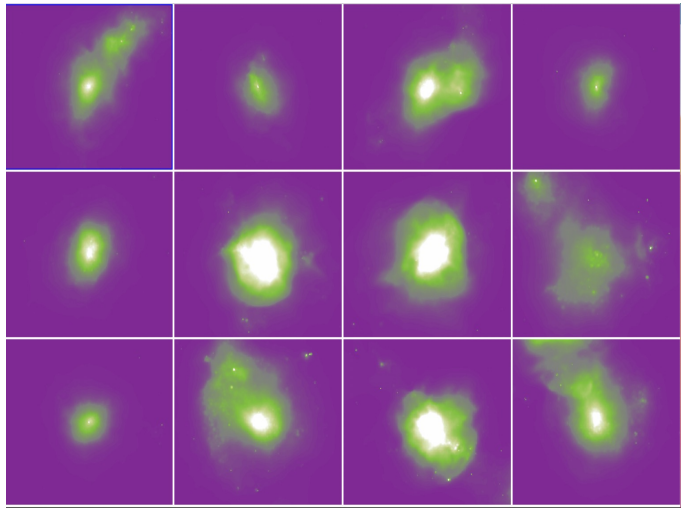
Hydrodinamical simulation

The Three Hundred

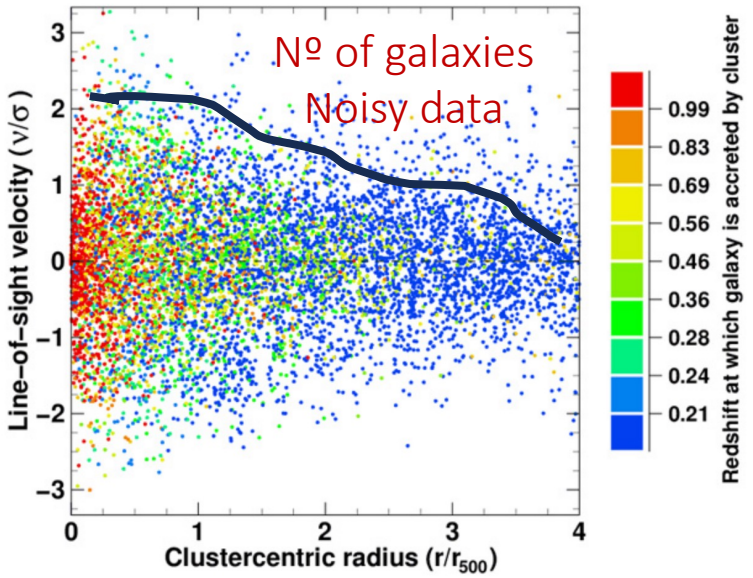
Cui et al 2018

Survey CATARSIS

0.15 < z < 0.27



Caustic method



Effects and Constraints Impacting the Caustic Method

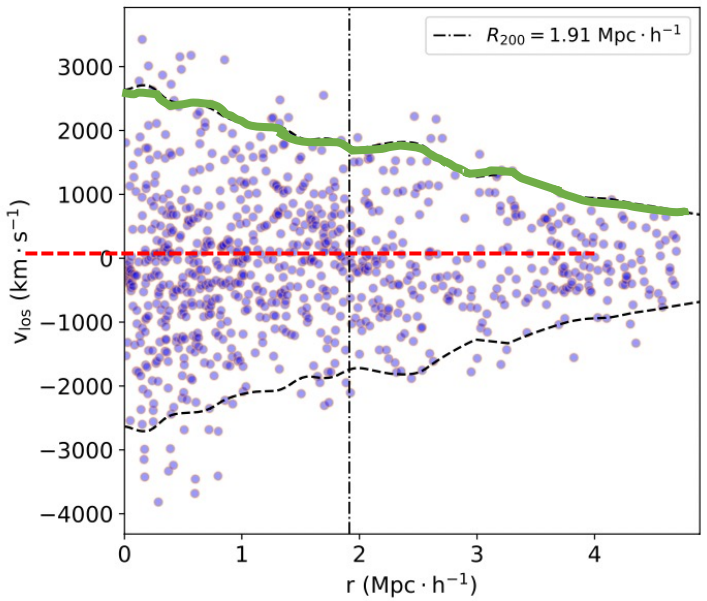
Caustic method

Method to estimate the galaxy **cluster mass distribution beyond virial radius**

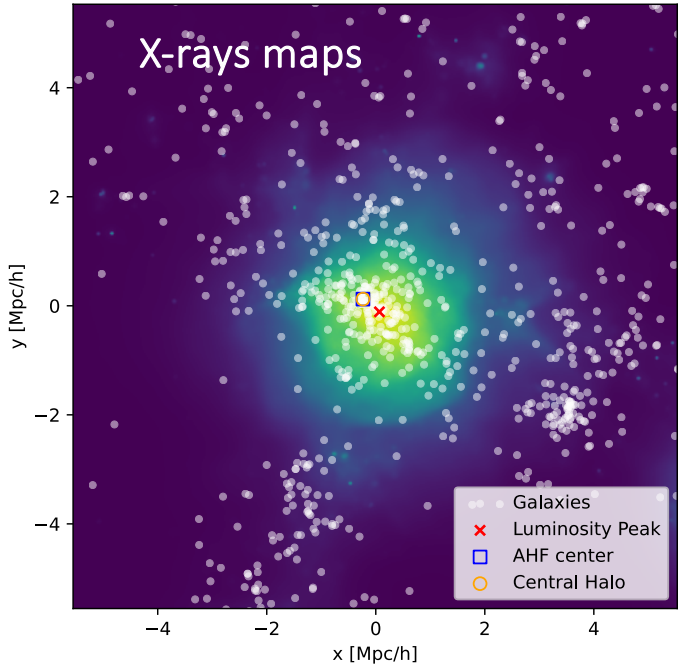
$$GM(<r) = \int_0^r A^2 \mathcal{F}_\beta(r)\mathrm{d}r \qquad \boldsymbol{A^2(r) = \langle v^2_{esc,los}(r)\rangle} \quad + \quad \boldsymbol{\mathcal{F}_\beta(r) = -2\pi G g(\beta(r)) \frac{\rho(r) r^2}{\Phi(r)}}$$

Anisotropy

Building redshift diagram (RD) (v_{los} - R_{proj})



Identify the centre of cluster



FIRST WORK

Under review by the collaboration steering committee…

The Caustic Method Applied to The Three Hundred: Prospects for Upcoming CATARSIS and Other Surveys

B. Callejas-Córdoba[1,2], P. Sánchez-Blázquez[1,2], A. Gil de Paz[1,2], A. Knebe[3,4,5], W. Cui[3,4,6], and C. Catalán-Torrecilla[1,2]

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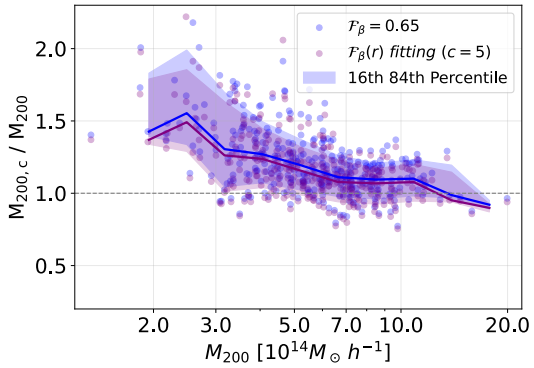
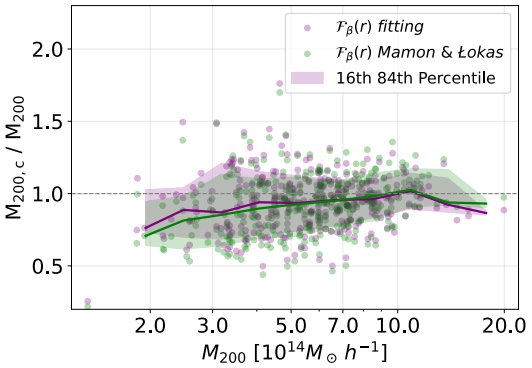
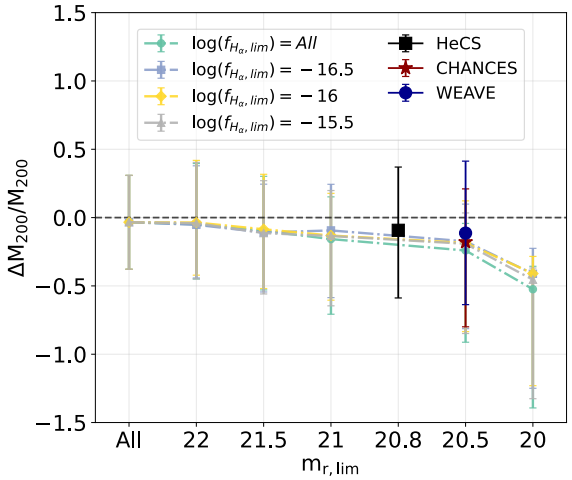
Implementation on caustic → Itherative method

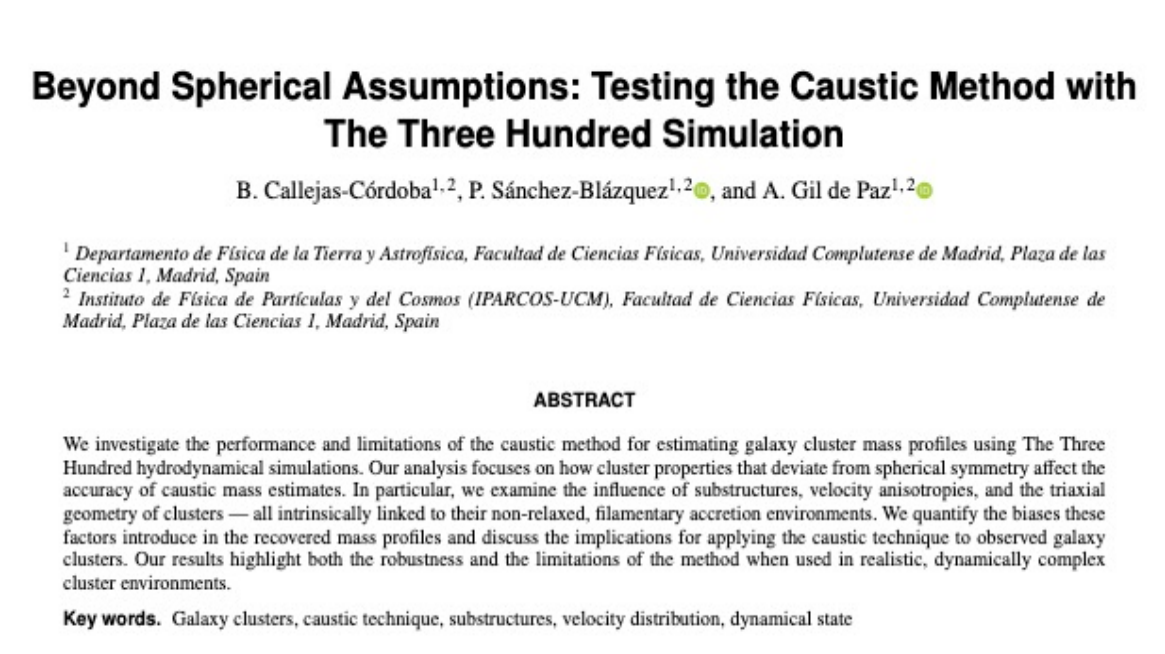






FOLLOWING WORK

Paper in prep…



Beyond Spherical Assumptions: Testing the Caustic Method with The Three Hundred Simulation

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ABSTRACT

We investigate the performance and limitations of the caustic method for estimating galaxy cluster mass profiles using The Three Hundred hydrodynamical simulations. Our analysis focuses on how cluster properties that deviate from spherical symmetry affect the accuracy of caustic mass estimates. In particular, we examine the influence of substructures, velocity anisotropies, and the triaxial geometry of clusters — all intrinsically linked to their non-relaxed, filamentary accretion environments. We quantify the biases these factors introduce in the recovered mass profiles and discuss the implications for applying the caustic technique to observed galaxy clusters. Our results highlight both the robustness and the limitations of the method when used in realistic, dynamically complex cluster environments.

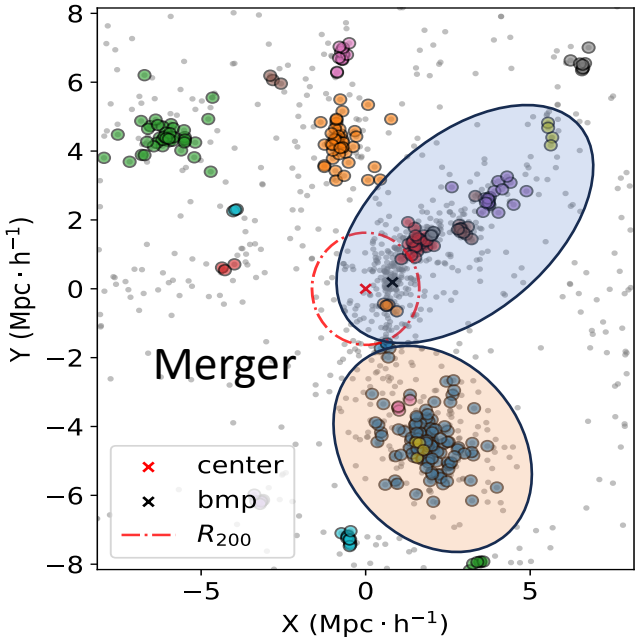
Key words. Galaxy clusters, caustic technique, substructures, velocity distribution, dynamical state

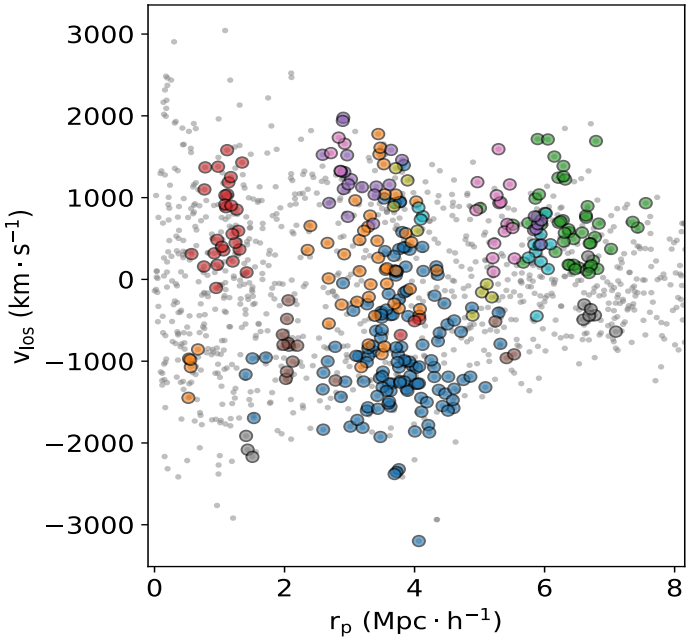
- **Substructures:** The presence of mergers and smaller groups can affect the velocity dispersion and distort the caustic profile.
- **Anisotropy:** Differences in profiles, assumptions, and dynamical behaviors between galaxies and dark matter halos.
- **Triaxiality:** The asphericity of clusters arises from their dynamical state and the influence of surrounding filaments.

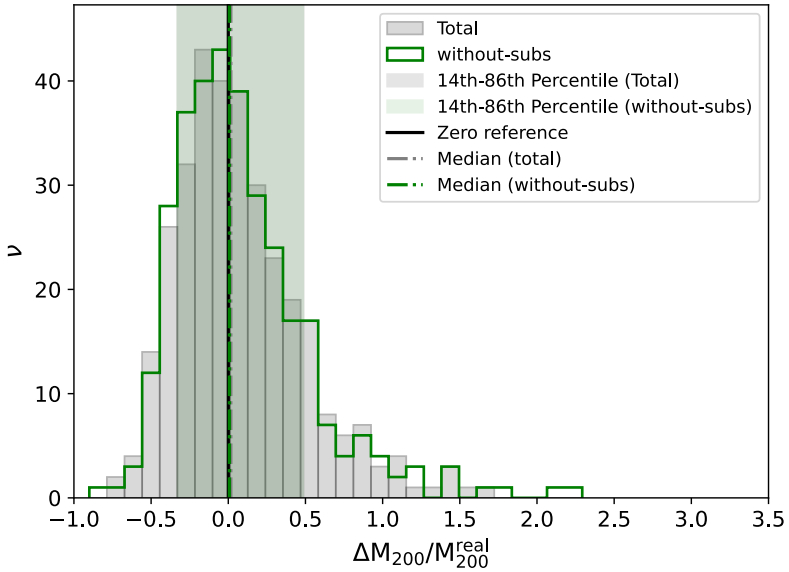
Effects and Constraints Impacting the Caustic Method

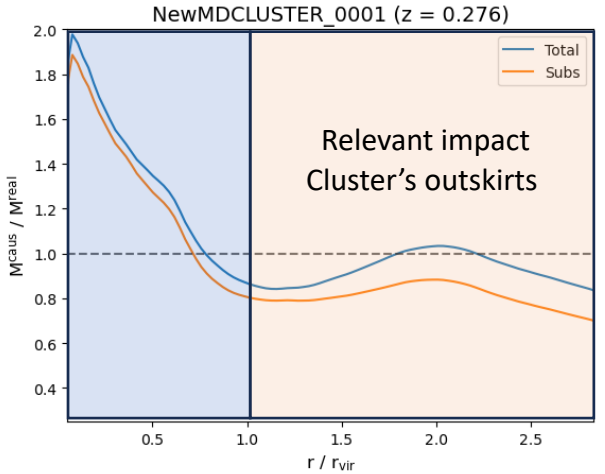
Substructures

The substructures do not significantly affect the caustic method







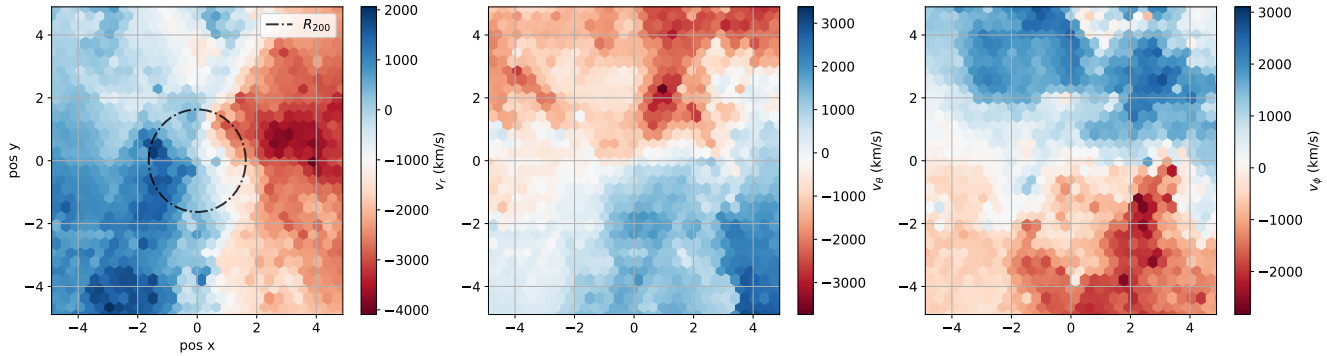


Effects and Constraints Impacting the Caustic Method

Anisotropy

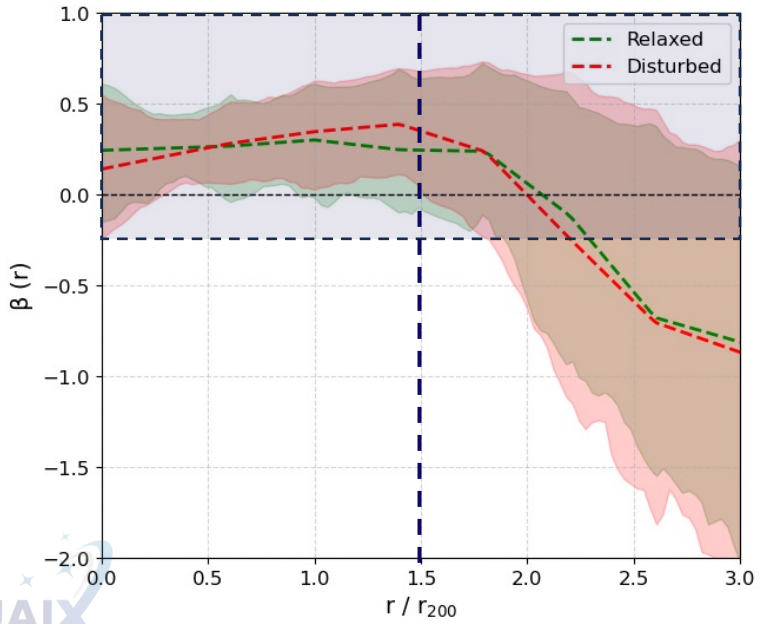
Rotation/galaxies in fall

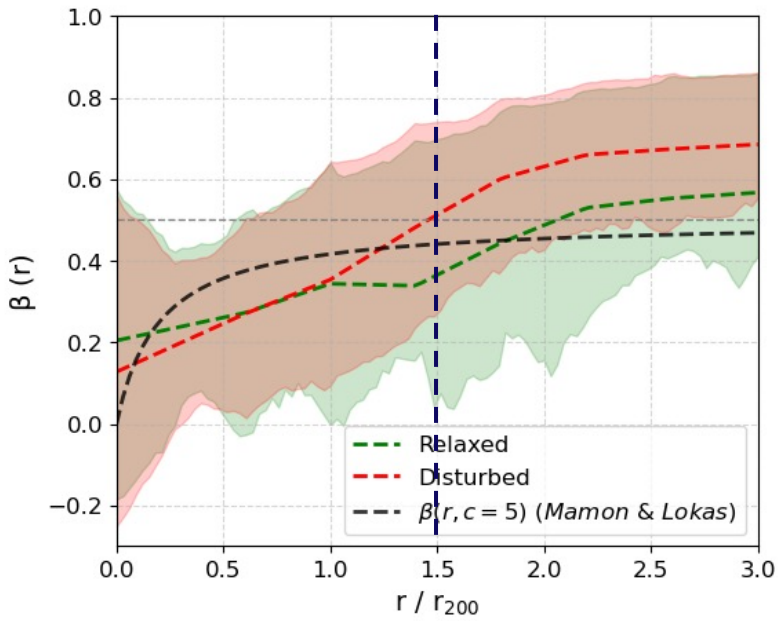
$$\sigma^2 = \langle v^2 \rangle - \langle v \rangle^2$$

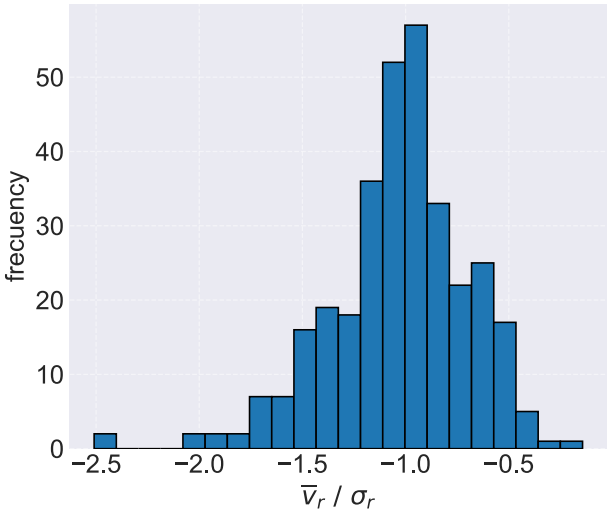


$$\beta(r) = 1 - \frac{\sigma_\theta^2 + \sigma_\phi^2}{2\sigma_r^2}$$

$$\beta(r) = 1 - \frac{\langle v_\theta^2 \rangle + \langle v_\phi^2 \rangle}{2\langle v_r^2 \rangle}$$







Effects and Constraints Impacting the Caustic Method

Anisotropy

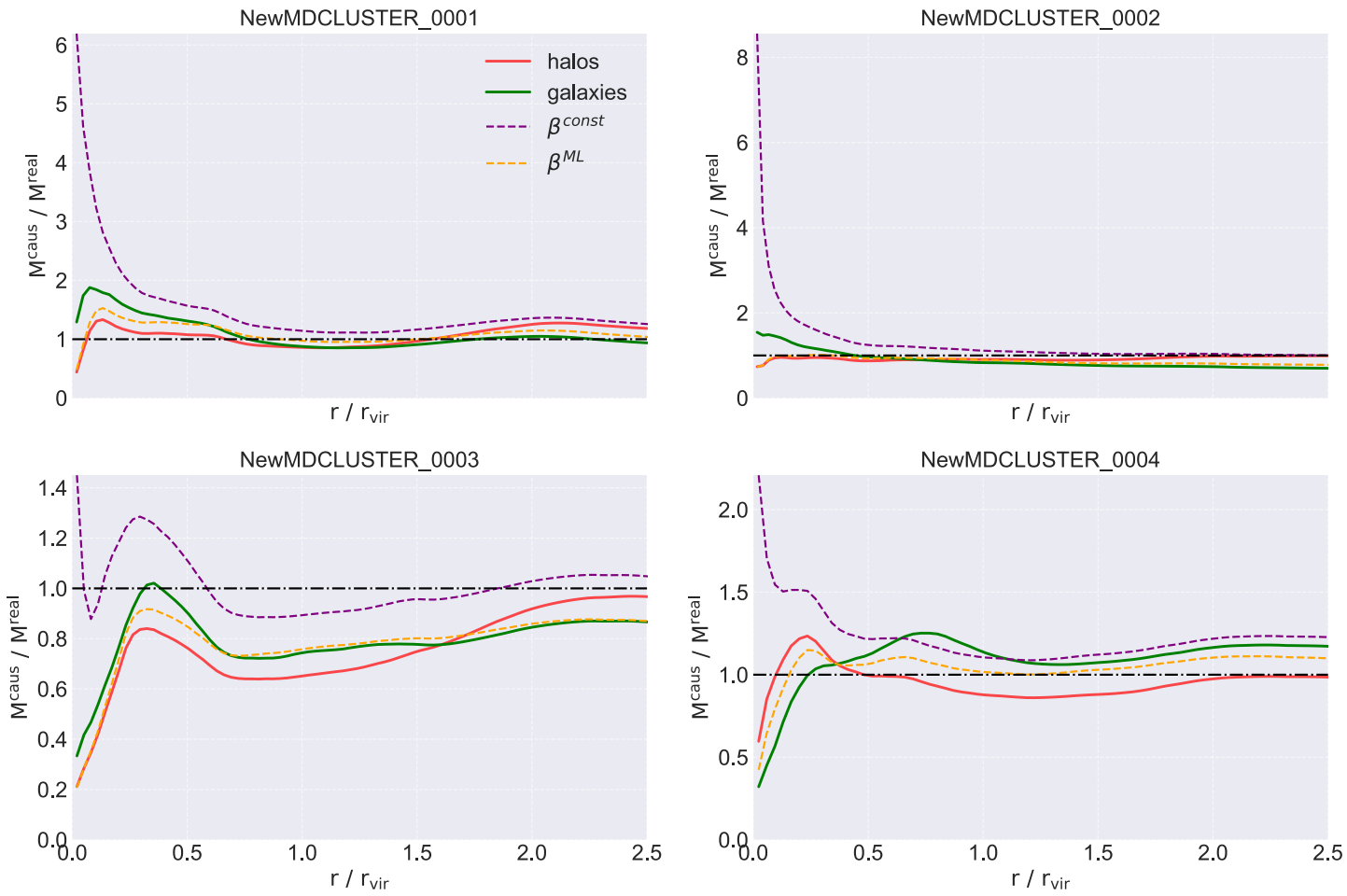
Global definition:

$$\beta(r) = 1 - \frac{\langle v_\theta^2 \rangle + \langle v_\phi^2 \rangle}{2\langle v_r^2 \rangle}$$

Mamon & Lokas et al 2005

$$\beta(r) = \frac{1}{2}\frac{r}{r + r_s}, r_s = \frac{r_{200}}{c}$$

$\beta = 0.2$ *Gifford et al 2013*

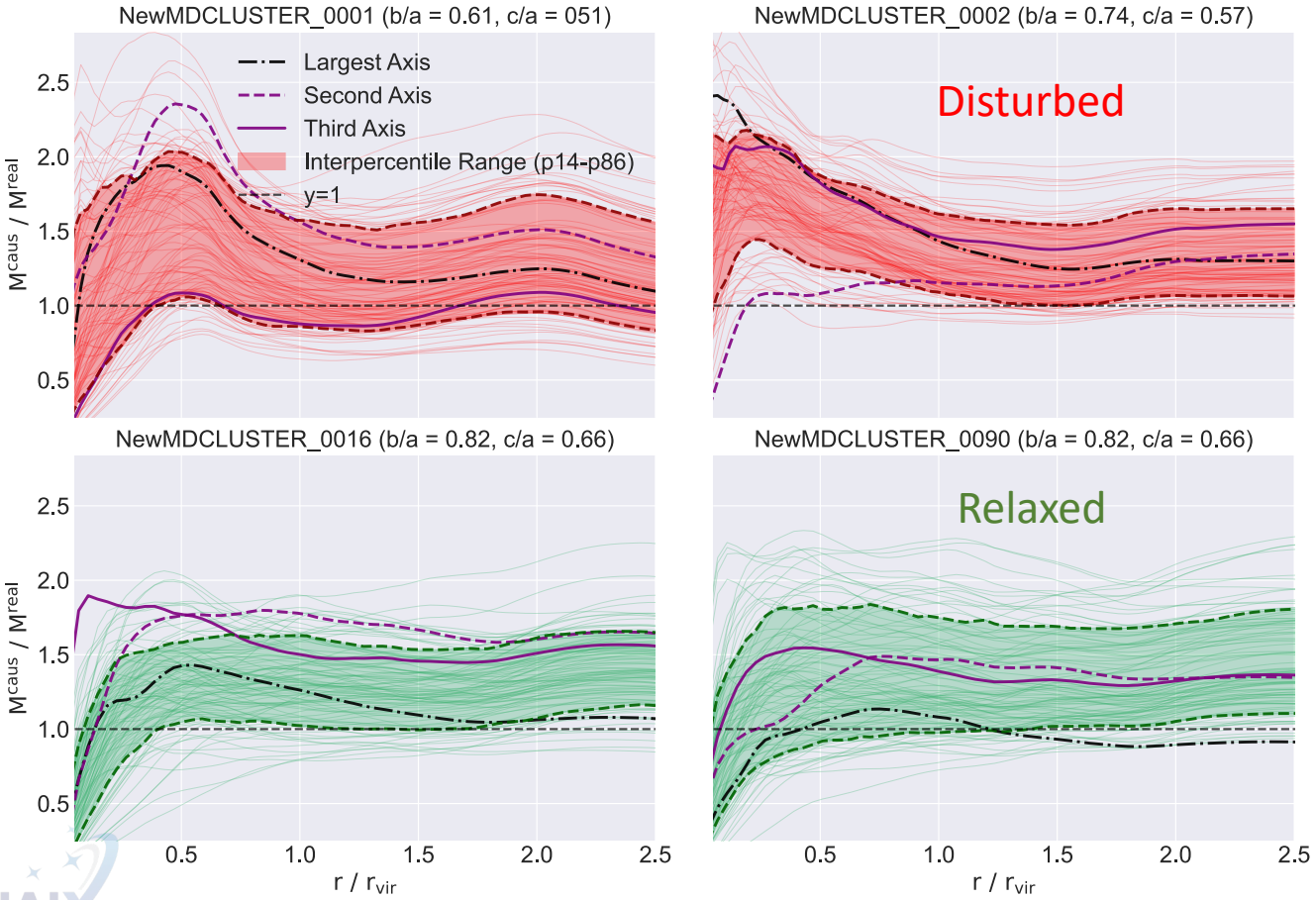


Effects and Constraints Impacting the Caustic Method

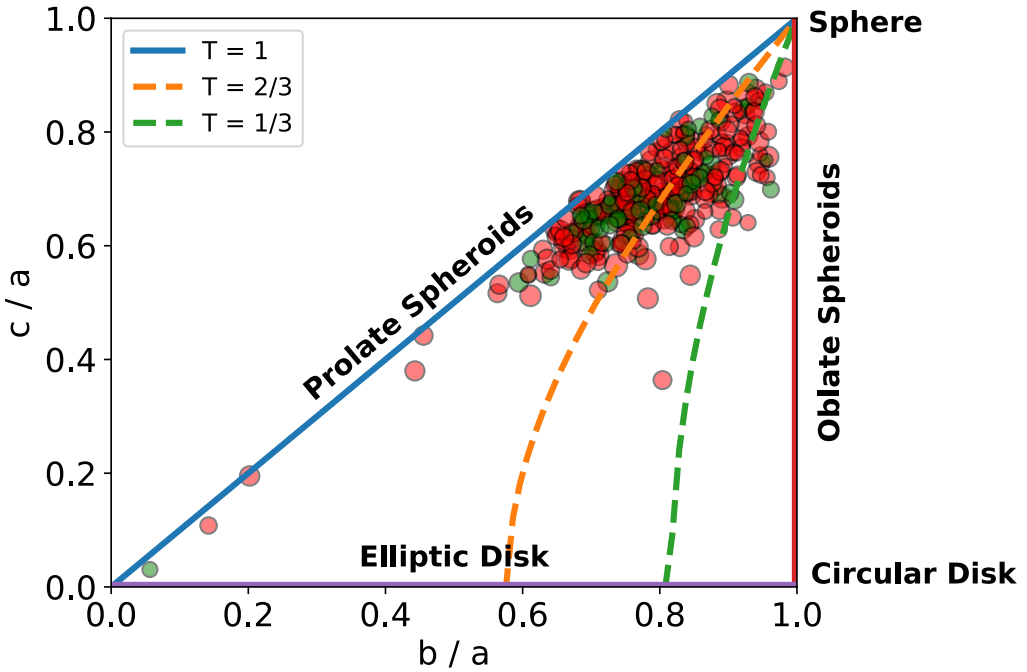
Triaxiality

Projection effects are the main source error in the caustic method!

100 Lines of sight



$$T = \frac{a^2 - b^2}{a^2 - c^2}$$

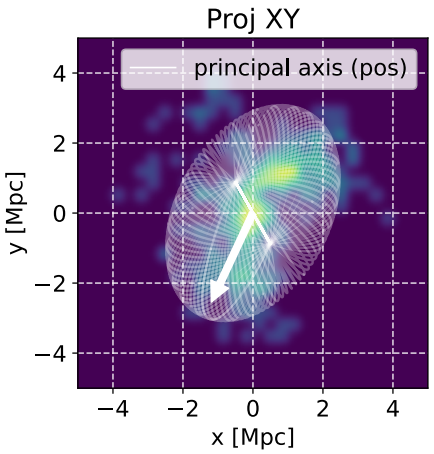


Asphericity of galaxy clusters

Clusters are prolate in average

Effects and Constraints Impacting the Caustic Method

ML aplications | Estimate the 3D shape of galaxy clusters

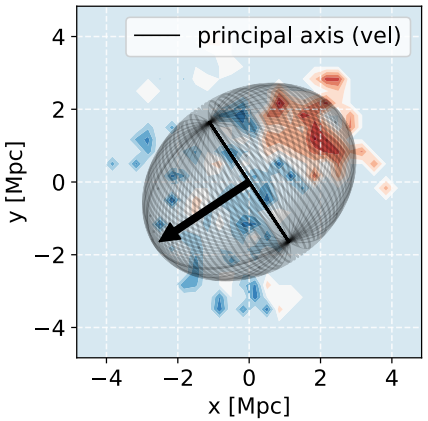


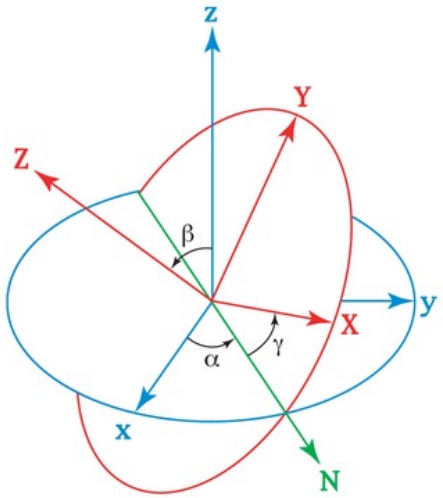
input

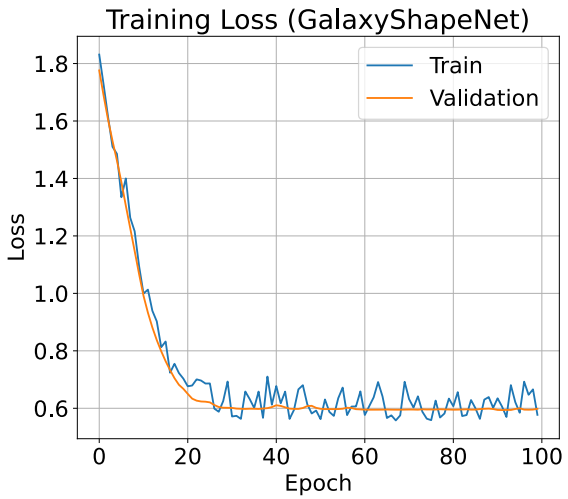
2D information
$v_{los} - R_{proj}$

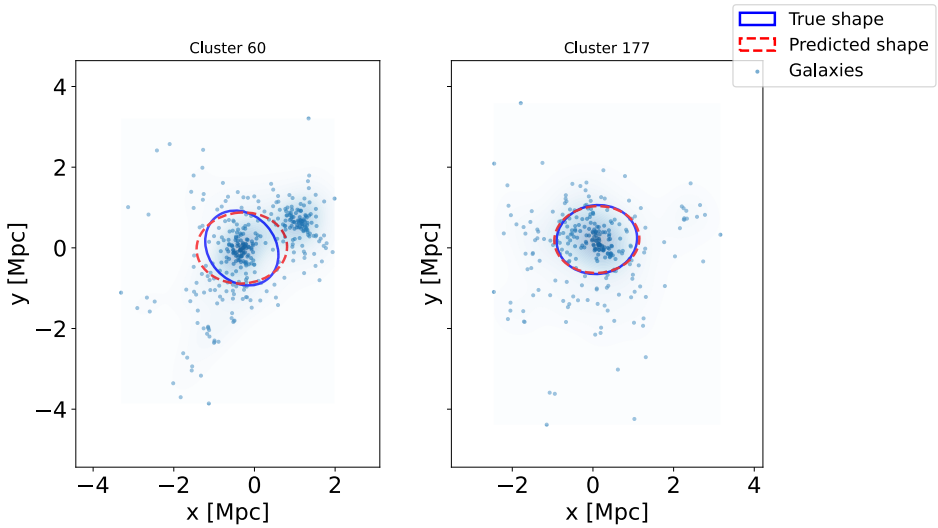
CNN

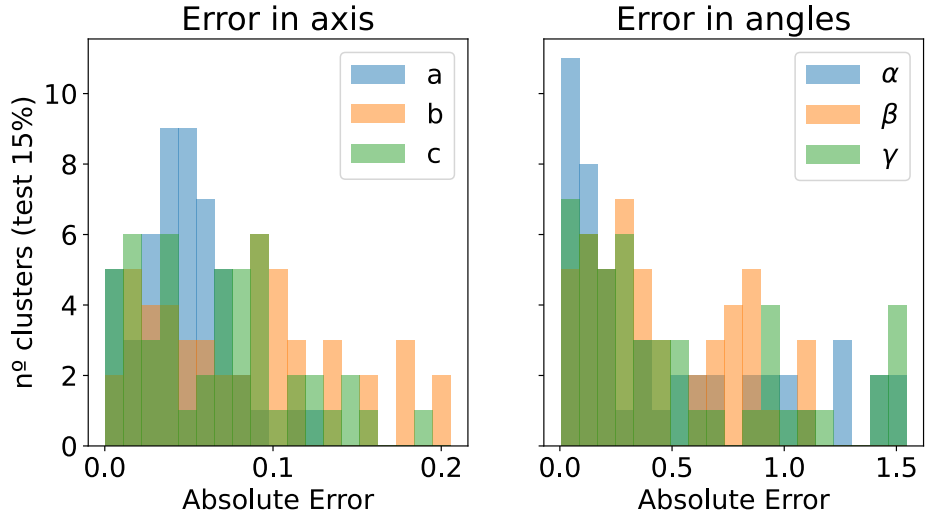
a, b, c & Euler angles











CONCLUSIONS

- ✓ **Substructures** do **not significantly affect** the mass estimation with **caustic method**.
- ✓ We investigated the role of the **anisotropy profile** and found that its influence is **less significant than projection effects**.
- ✓ The **ML aplications** perform well in estimating the shape of galaxy clusters using only 2D information.

Future work:

- We aim to further explore how the **triaxial shape of galaxy clusters** affects **mass estimation**, with the goal of developing more accurate correction methods.

  - Introduce another density profile in the method – considering a triaxial potential.
  - ML aplications with more information – 3D shape from 2D data.