

Intracluster light as a dark matter tracer

*How their spatial and kinematic relationship
is shaped by satellite demographics*

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ICL as a dark matter tracer?

Intracluster light (ICL) — diffuse stars originate primarily from infalling satellites — traces the cluster potential and accretion history.

ICL morphology broadly follows the DM distribution (Montes & Trujillo 2019; Ellien et al. 2025), making it a candidate mass probe with Euclid and LSST.

However, the ICL is systematically more centrally concentrated than the DM (e.g. Diego et al. 2023; Contreras-Santos et al. 2024). Stars occupy lower orbital energies and angular momenta than the DM (Butler et al. 2025).

Key question: What governs the magnitude of this ICL-DM offset, and can we predict it well enough to use ICL as a quantitative DM tracer?

Controlled N-body experiments

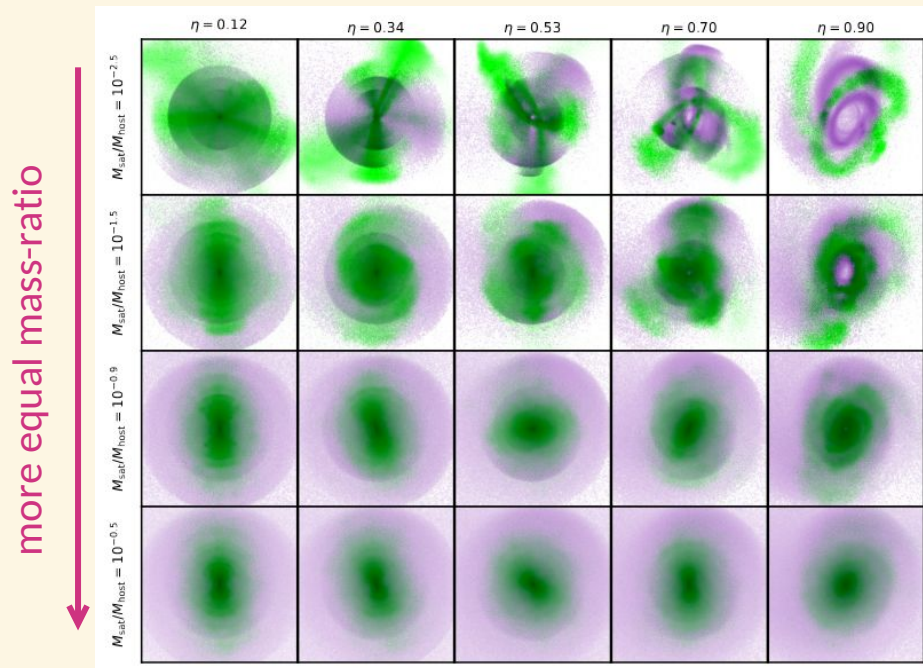
DM
Stars

We inject model satellites (DM + stars) into a live $10^{14.5}$ M_{\odot} cluster halo (Gadget-4), systematically varying satellite-to-host mass ratio and orbital circularity.

This isolates how differential stripping and orbital decay shape the phase-space distributions of stripped stars and DM.

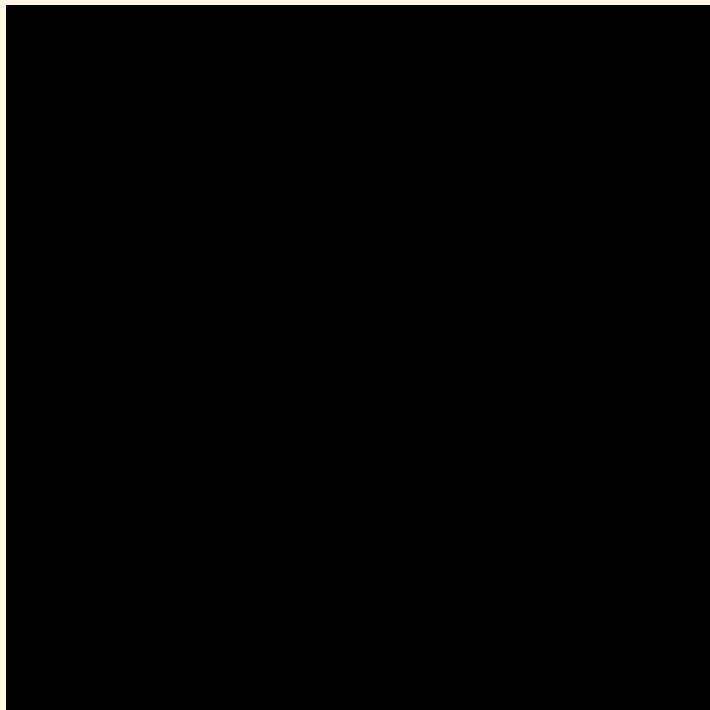
Two coupled mechanisms:

1. DM is stripped early; stars survive to later, more bound orbits
2. Dynamical friction decays massive satellite orbits before stars are stripped



Stars (green) and DM (purple) stripped from satellites across a grid of mass ratios (rows) and orbital circularities (columns)

Phase-space offset driven by mass ratio



The stellar-to-DM orbital energy and angular momentum ratios depend strongly on satellite mass:

Low-mass satellites (mass ratio $\lesssim 1:10$) produce negligible offsets — stars and DM are stripped at similar energies.

High-mass satellites (mass ratio $\gtrsim 1:10$) undergo rapid orbital decay via dynamical friction before their stars are stripped, producing large phase-space offsets.

Orbital circularity plays only a secondary role.

→ **The ICL-DM offset is set by the most massive accreted satellites.**

*Stars stripped from the satellite only. Stars (green) and DM (purple), current satellite position (+).
Bottom: Evolution of average energy and AM.*

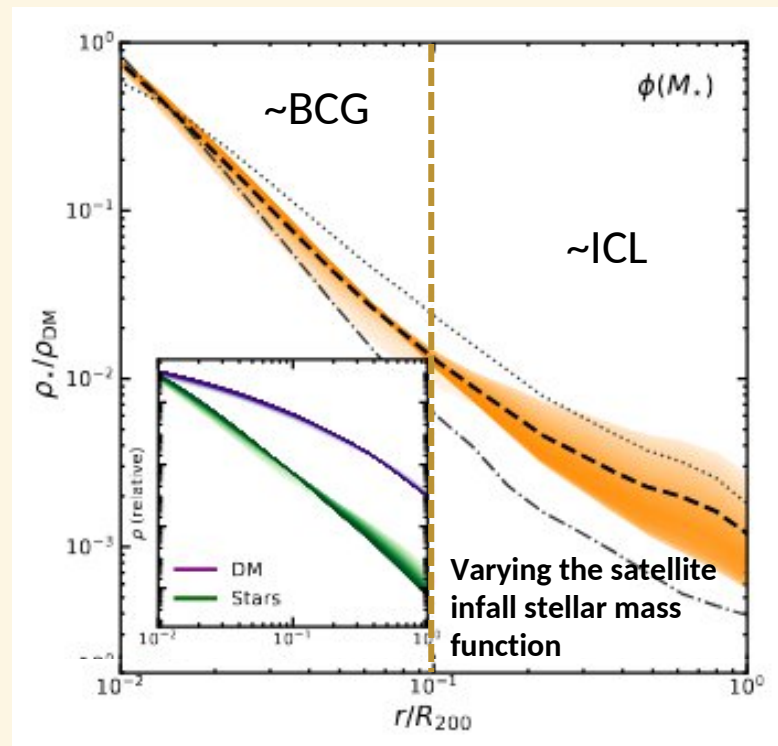
Satellite demographics shape the radial profile

We convolve our results over plausible infalling satellite populations, parameterised by a Schechter stellar mass function and an orbital circularity distribution.

The characteristic mass M^* of the infalling satellite stellar mass function is the dominant parameter controlling the radial stellar-to-DM density ratio.

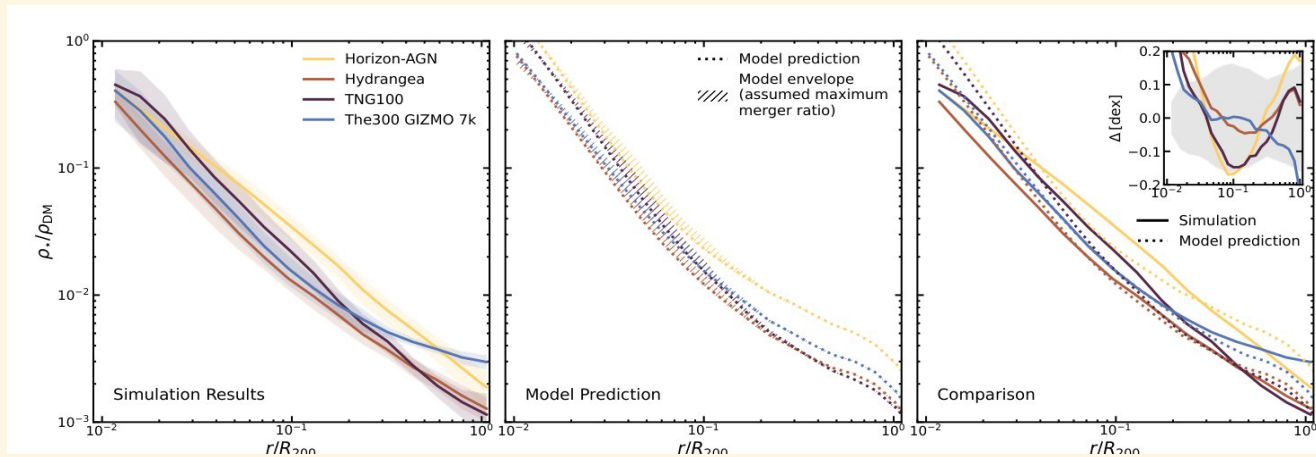
Varying the orbital circularity distribution has a comparatively weak effect.

ICL is always more centrally concentrated than the DM. No plausible satellite population produces a one-to-one ICL-DM mapping.



ρ_\star/ρ_{DM} vs. r/R_{200} — orange envelope from varying the satellite stellar mass function

Model reproduces cosmological simulations



Left: simulations. Middle: model predictions. Right: comparison (solid = sims, dotted = model). Inset: residuals < 0.2 dex.

Conclusions:

The ICL-DM phase-space offset arises naturally from differential stripping and orbital decay of satellites.

The characteristic mass M^* of infalling satellites is the key parameter, not orbital distributions or low-mass satellites.

Constraining the intermediate- and high-mass satellite population is sufficient for the ICL to serve as a quantitative DM tracer.