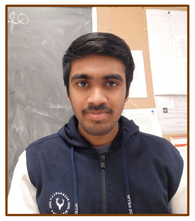
Testing ΛCDM: Faint end of satellite mass function with Vera Rubin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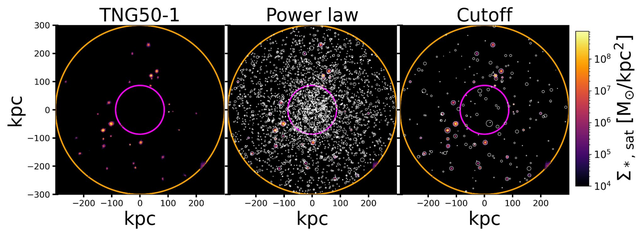

Within LCDM we expect 10k-100k dwarf satellites with at least 100 $L_\odot$ in Virgo-like clusters, which we should see with Vera Rubin. Cosmological simulations cannot resolve them.

ABSTRACT

Current cosmological simulations lack the resolution to make reliable predictions for faint and ultra-faint dwarf satellites, which will become crucial test of the LCDM model in the upcoming era of the Vera Rubin Observatory. To this end, we implement a semi-analytical model fitted to high-resolution controlled simulations to complement the predictions of the TNG50 cosmological numerical simulations. We focus on 3 clusters with virial masses ~1e14 Msun, comparable to Virgo and Fornax, and characterize their satellite population from ultrafaint dwarfs to massive elliptical galaxies. We find that under the assumption of cuspy dark matter halos such as NFW profiles, the majority of all satellite galaxies survive within cluster environments, expecting 10-100 thousand luminous satellites within the virial radius of such clusters. This is contrary to the results directly from the simulation where satellites get merged artificially due to poor numerical resolution. We characterize the radial distribution of satellites.

What did we do?

- **Worry!** We lose most of the low mass galaxies in cosmological simulations due to limited resolution. More than a million dark matter particles per subhalo are required to resolve their evolution.
- We address this issue using an empirical tidal evolution model for the evolution of stars and dark matter, fitted to controlled, high-resolution N-body simulations.
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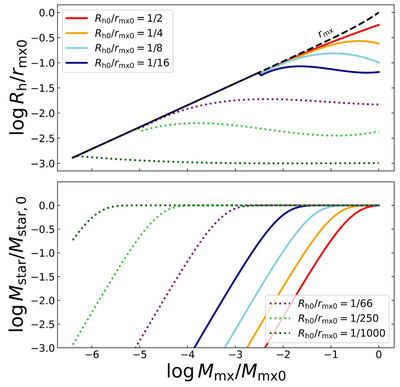
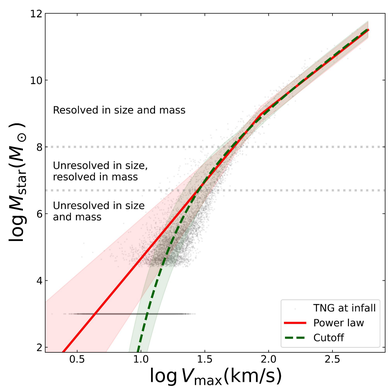


Figure 1: Tidal evolution of stellar half light radius (R_h) and bound stellar mass (M_{star}) against fraction of mass remaining within the radius of maximum circular velocity (M_{mx}).

- **From the three most massive FoF groups in TNG50, which have a virial mass of 10^{14} $M_\odot$, we take subhalos of at least 10^2 $M_\odot$ at infall and feed it to the tidal evolution model.**

Figure 2: Plot on the right shows TNG subhalos at infall. Different regions separated by dotted line indicate our trust of stellar mass and size within that region. To populate unresolved subhalos from TNG, we envisage the unresolved end of the galaxy luminosity function assuming either (1) a **power-law** extrapolation, or (2) a simple **cutoff**



- Finally, a stellar size is assigned to unresolved subhalos using a double power law fit to Virgo dwarfs and LG ultra faints.

Results

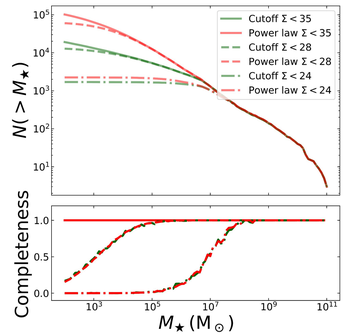


Figure 3: **Surveys with surface brightness limit of 32 mag/arcsec^2 should be complete to 100 $M_\odot$ being able to see 10k-100k satellites in Virgo like clusters.** *Top:* The satellite mass function (SMF) for the FoF0 in the simulation with different surface brightness cuts. *Bottom*: Completeness of sample against stellar mass

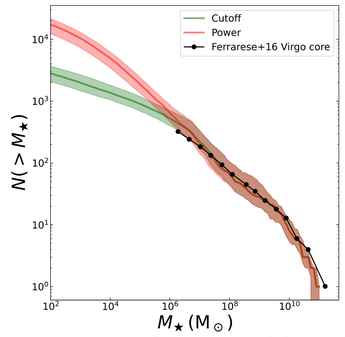


Figure 4: **Consistency with stellar mass function in the core of Virgo.** Plot shows SMF in the core of Virgo (300 kpc) on top of median of projected SMFs for three FoF groups that we studied. SMFs for different initial abundance matching relations deviate from each other below 10^6 $M_\odot$.
Side result:Using Fornax's SMF, we estimate its virial mass at 3.5 × 10^{13} $M_\odot$

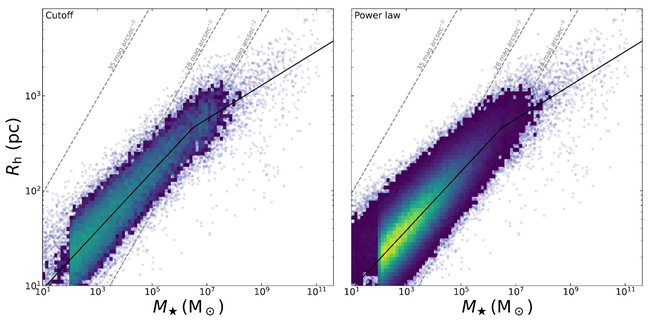


Figure 5: **Tidal evolution is mostly along the currently known size mass relation.** The half light radius vs stellar mass for satellites evolved using the model at z = 0. We don't expect a significant population of outliers tidally-formed

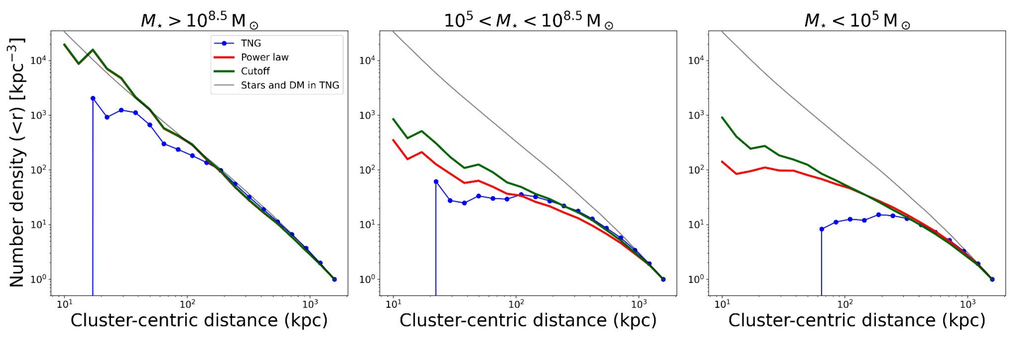


Figure 6: **Massive dwarfs follow the density distribution of matter**. The radial density distributions of satellites with assumed power law (red), cutoff (green) models and TNG50 (blue) in different mass bins. In central regions, lack of resolution results in artificial flattening of the blue curve.

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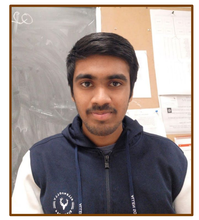

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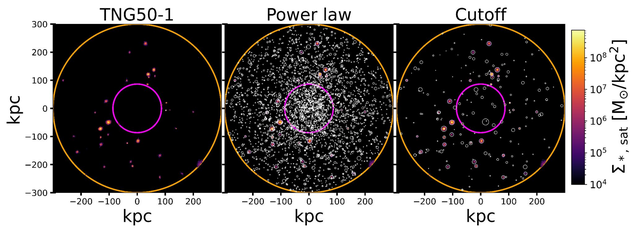

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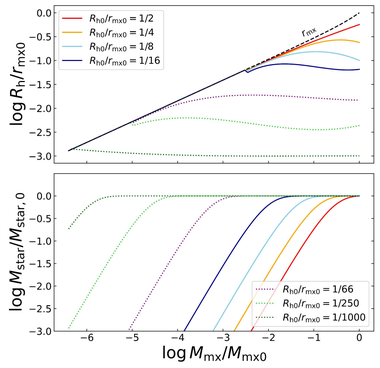

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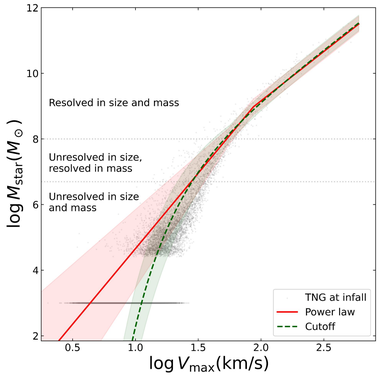

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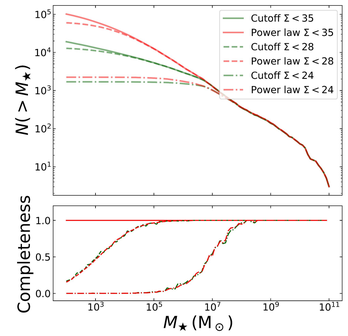

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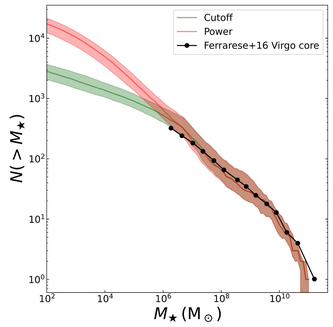

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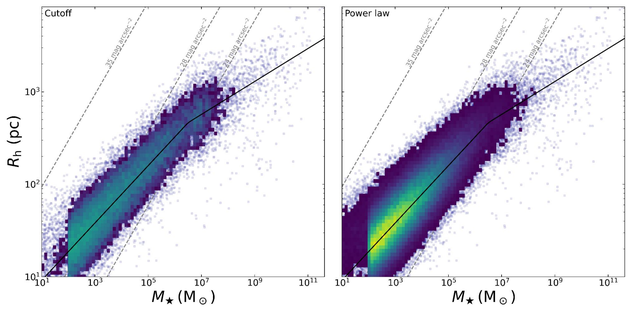

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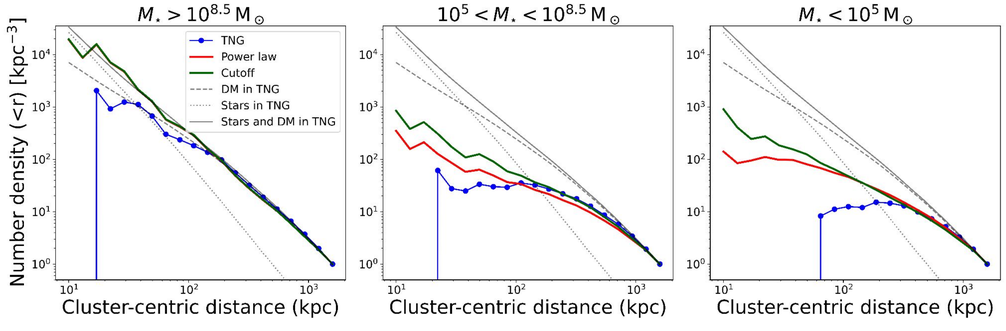

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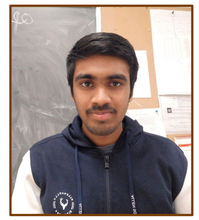

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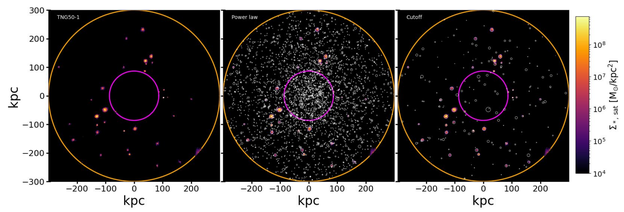

There should at least be 10k to 100k dwarfs in a Virgo like cluster when we see it with Vera Rubin

ABSTRACT

Current cosmological simulations lack the resolution to make reliable predictions for faint and ultra-faint dwarf satellites, which will become crucial test of the LCDM model in the upcoming era of the Vera Rubin Observatory. To this end, we implement a semi-analytical model based on higher-resolution simulations to complement the predictions of the TNG50 cosmological numerical simulations. We focus on 3 clusters with virial masses ~1e14 Msun, comparable to Virgo and Fornax, and characterize their satellite population from ultrafaint dwarfs to massive elliptical galaxies. We find that under the assumption of cuspy dark matter halos such as NFW profiles, the majority of all satellite galaxies survive within cluster environments, expecting 10-100 thousand luminous satellites within the virial radius of such clusters. This is contrary to the results directly from the simulation where satellites get merged artificially due to poor numerical resolution. We characterize the radial distribution of satellites.

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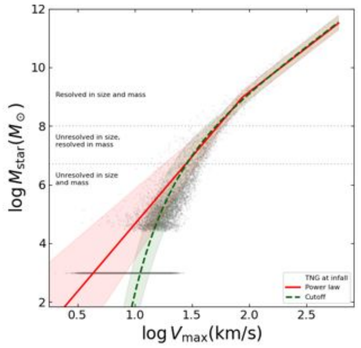
- **Worry!** We lose so many tiny cute galaxies (dwarfs) in cosmological simulations because we cannot yet computationally afford to follow it throughout.
- Plot on the right shows TNG subhalos at infall.
- Two abundance matching relations are used to populate the unresolved subhalos with stars.



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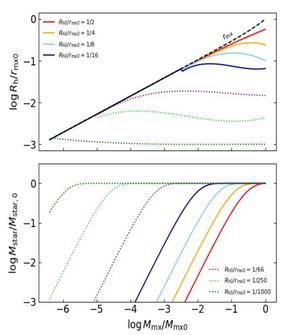
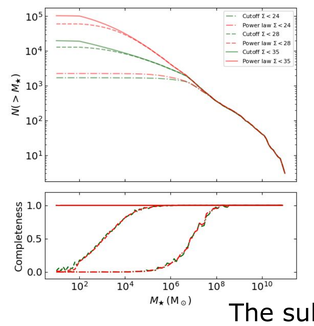
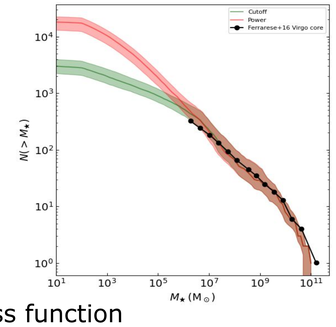


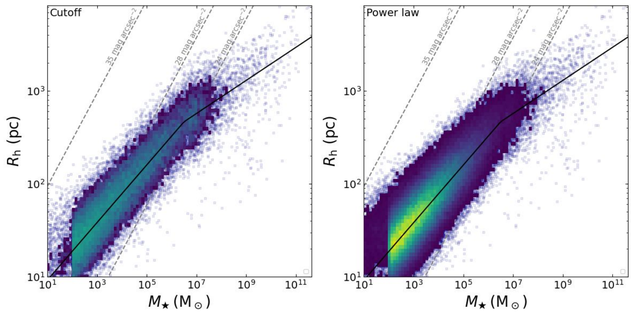
To our rescue, we have a tidal evolution model which can help us evolve dark matter dominated subhalos in constant isothermal halo potentials, thanks to Rapha!

What we found!

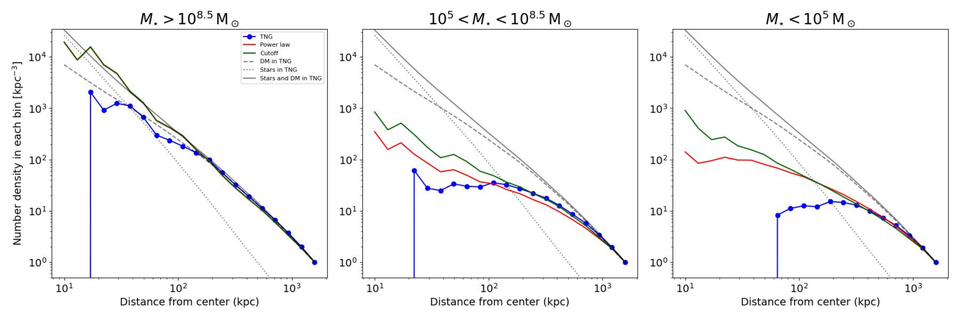




The subhalo mass function for the



The size - mass plot for the satellites shows that tidal evolution is mostly along the currently known size mass relation from observations of Local Groups and other clusters.



CONCLUSIONS

There should at least be

References :
Errani et al 2021, Errani et al 2022

Dwarf Galaxies, Star Clusters, and Streams in the LSST Era, University of Chicago, July 8 - 11, 2024

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2. McWilliams Center for Cosmology, Department of Physics, Carnegie Mellon University, Pittsburgh
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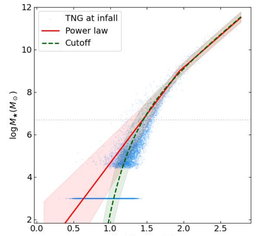

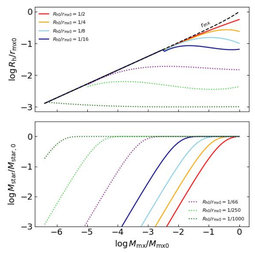

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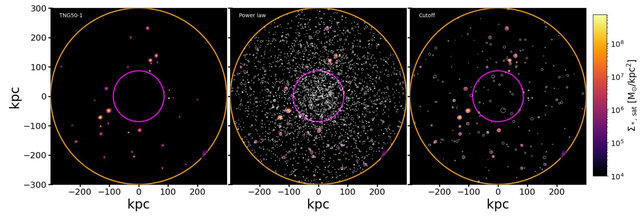
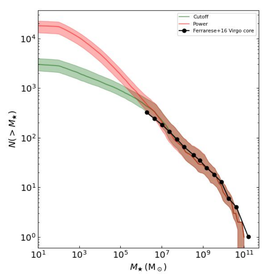


TA-DAA! We find that there must at least be 10,000 - 100,000 dwarf galaxies in a Virgo like cluster.



Conclusions and Implications

Grant

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