Self-Similar Secondary Infall: A Physical Model of Galaxy Halo Formation

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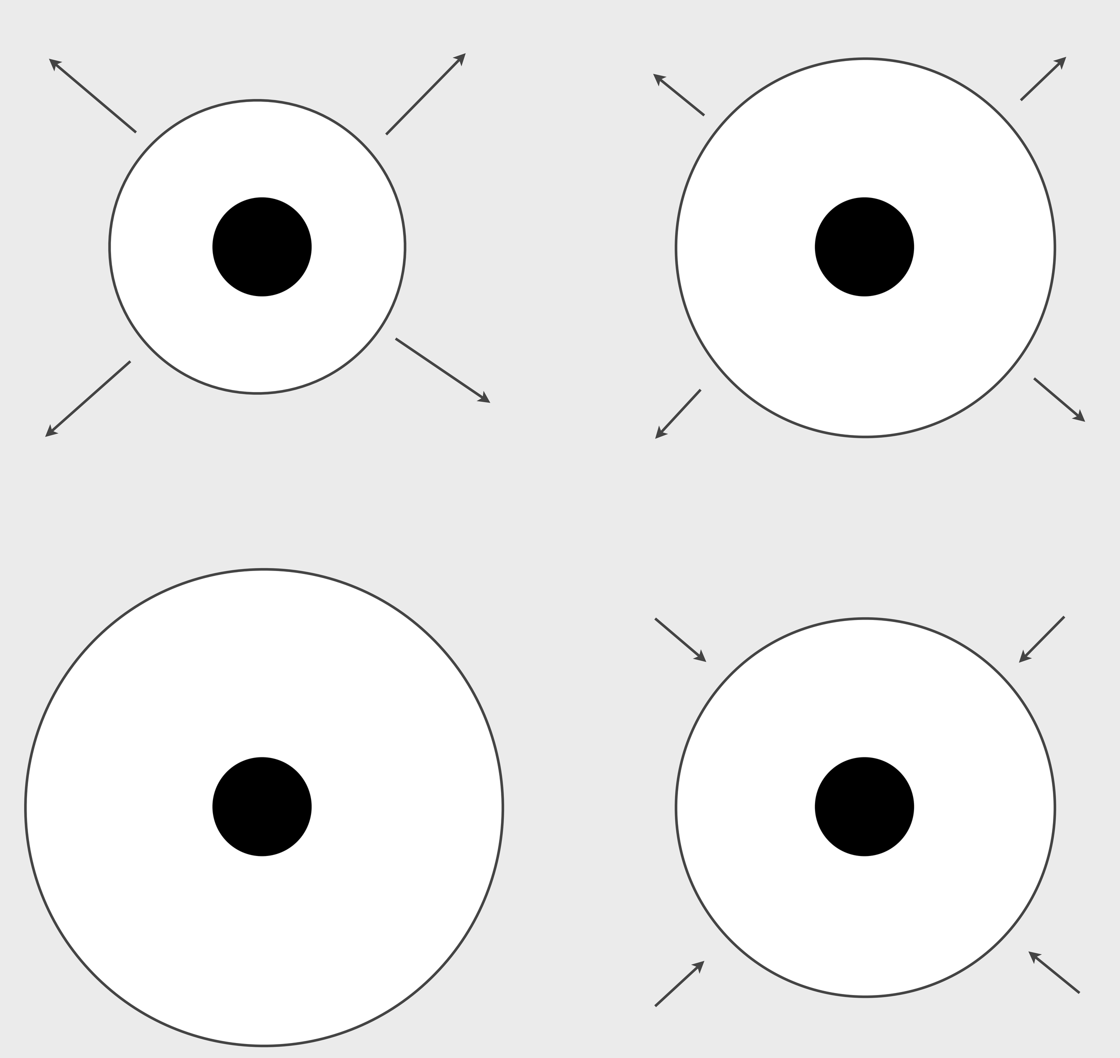
Questions

Why do dark matter halos have NFW (Einasto) density profiles?

Why is the density profile roughly universal?

Why is the pseudo-phase-space density universal?

Secondary Infall



Model Parameters

n characterizes how quickly the initial density perturbation δ falls off with radius from the center of a density peak.

$$\delta \propto r^{-n}$$

Particles are torqued throughout evolution. We impose that the angular momentum L of a particle in a shell that turns around at t_* is given by:

$$L(r,t) = B\frac{r_{ta}^2}{t}\begin{cases}(r/r_{ta})^{-\gamma} & \text{if } t < t_* \\ (t/t_*)^{\varpi+1-2\beta} & \text{if } t > t_*,\end{cases}$$

where the turnaround radius satisfies: $r_{ta} \propto t^{\beta}$.

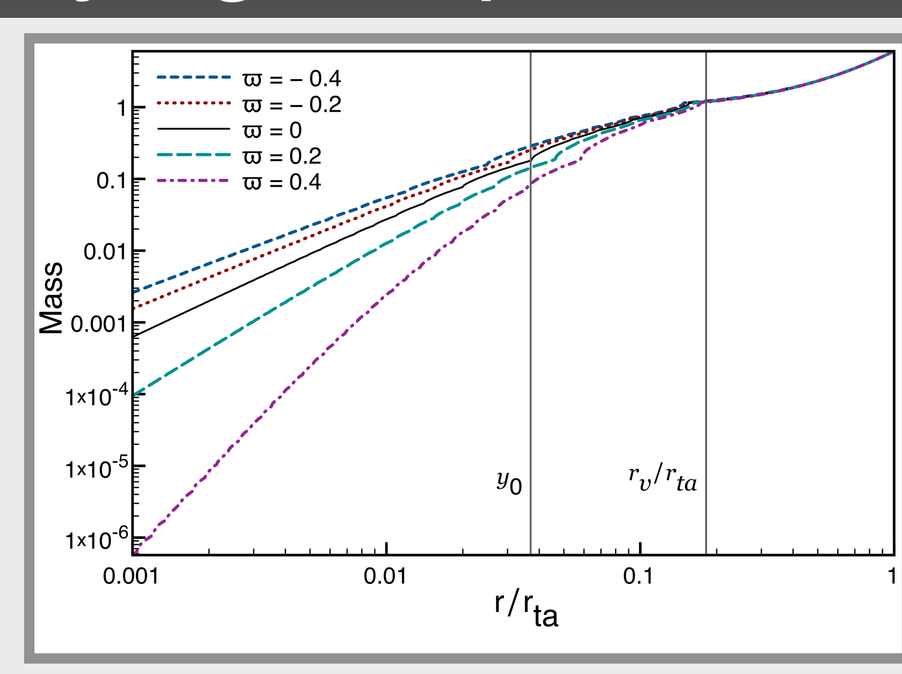
Using linear perturbation theory, we find that the parameters n, B, γ are set by the halo mass.

ϖ is difficult to constrain analytically since it depends on nonlinear dynamics within the halo. If no torque acts after turnaround, $\varpi = 0$.

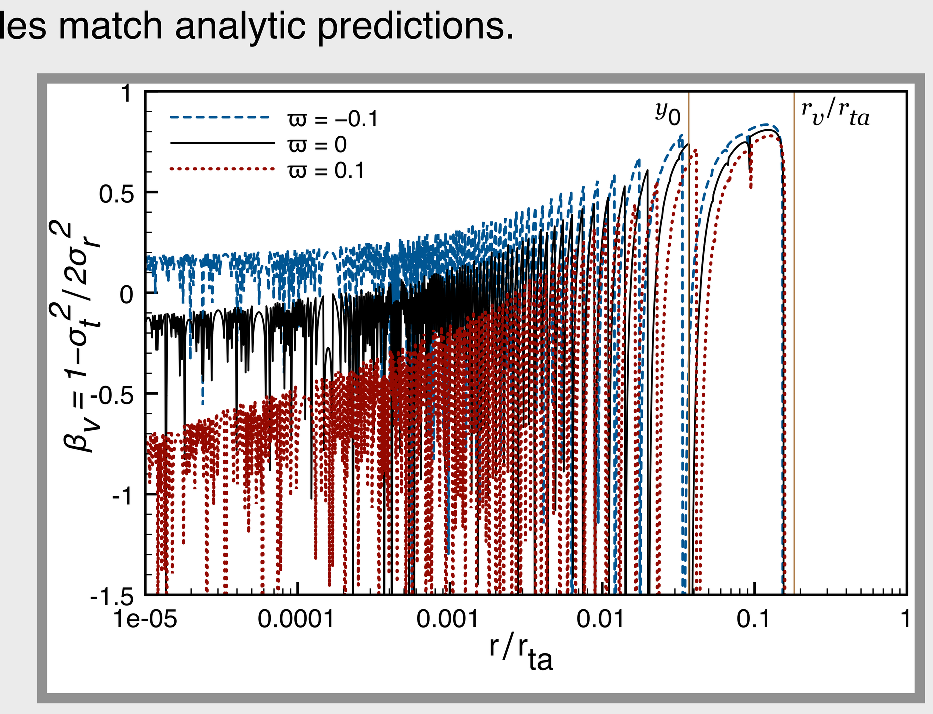
Summary

N-body simulations have revealed a wealth of information about dark matter halos, but their results are largely empirical. Using analytic means, we attempt to shed light on simulation results by generalizing the self-similar secondary infall model to include tidal torque. Imposing self-similarity allows us to analytically calculate the structure of the halo in different radial regimes *and* numerically compute the profiles of the halo without being limited by resolution effects inherent to N-body codes. We find good agreement with mass and velocity profiles from recent N-body simulations and show that angular momentum plays an important role in determining the structure of the halo at small radii.

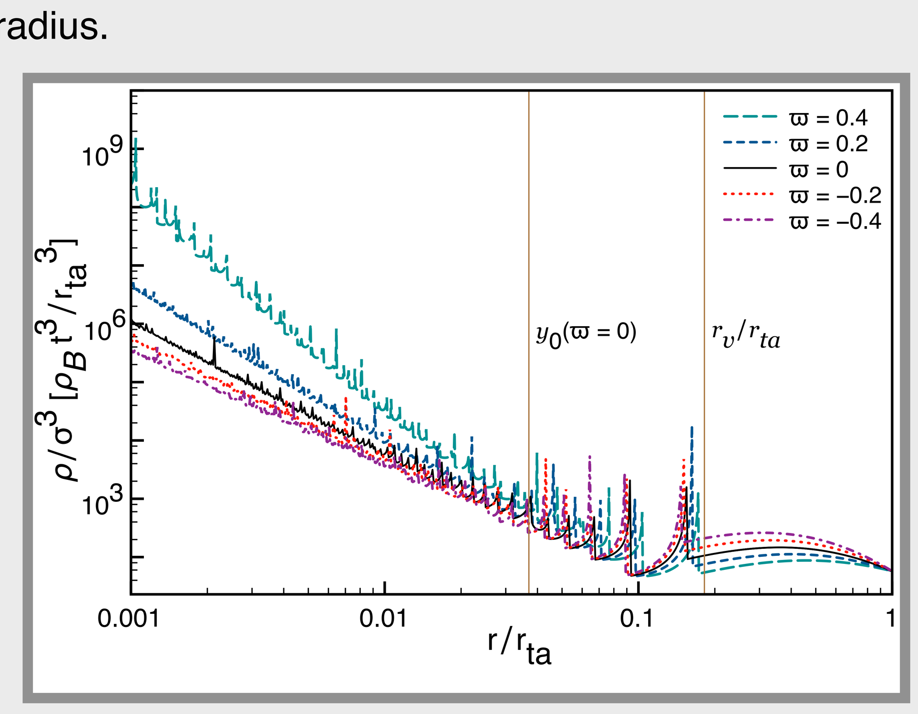
Varying Torque



The mass profile for a galactic size halo with a varying torque parameter. The amount of torque changes how pericenters evolve with time and thereby affects how many shells at a particular radius contribute to the internal mass. The numerically computed profiles match analytic predictions.

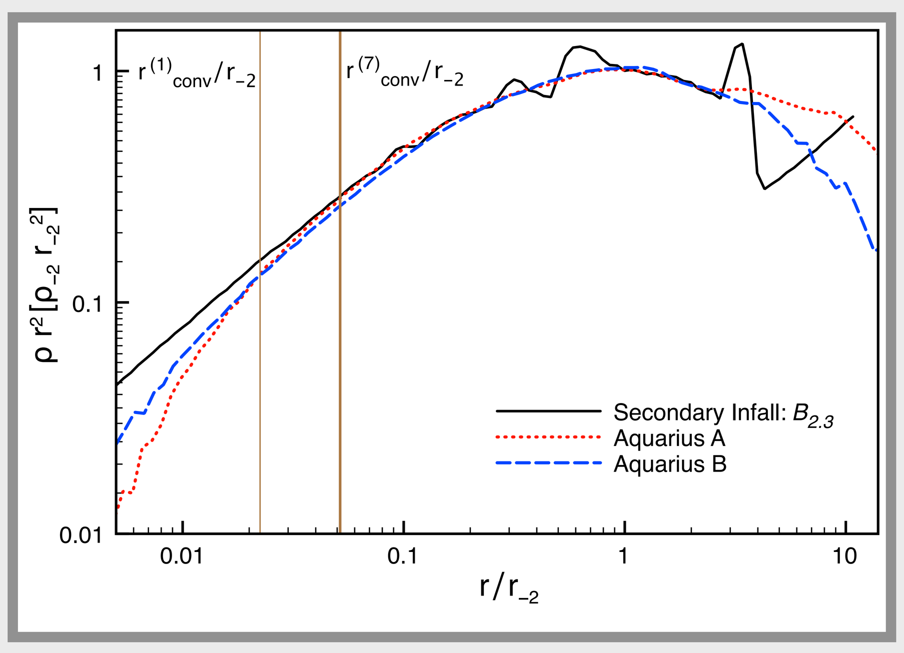


The velocity anisotropy profile for a galactic size halo with a varying torque parameter. A smaller amount of torque leads to halos with more radial orbits at a particular radius. We've analytically shown that the velocity anisotropy should asymptote at small radii, increase at intermediate radii, and fall off near the virial radius.

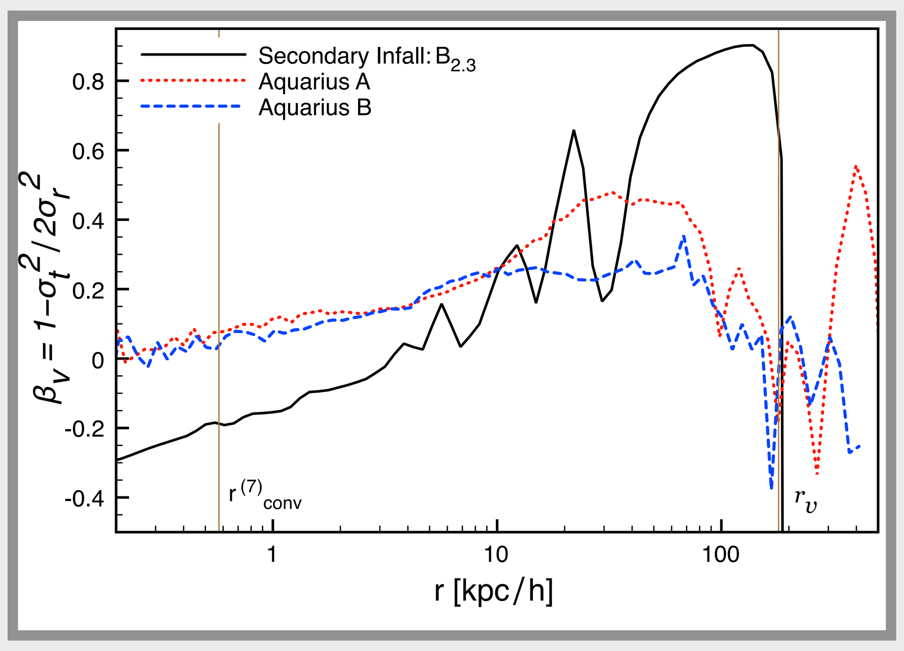


The pseudo-phase-space density for a galactic size halo with a varying torque parameter. The numerically computed profiles match analytic predictions.

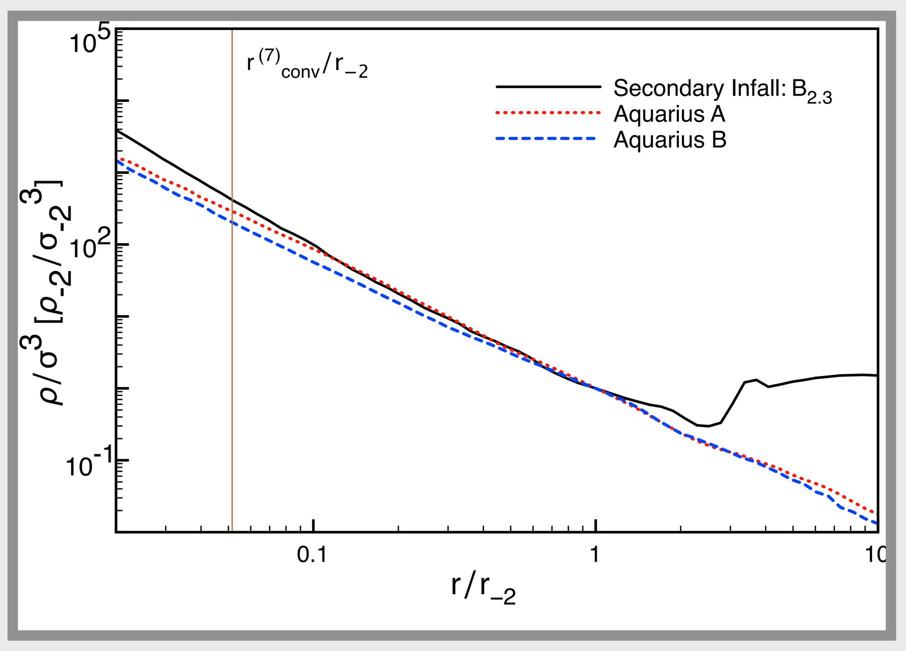
Comparing to N-body



A spherically averaged density profile for a self-similar galactic size halo compared to profiles from high resolution N-body simulations. We've chosen a torque parameter ($\varpi = 0.12$) that gives rise to NFW behavior at small radii.



A smoothed velocity anisotropy profile for a self-similar halo compared to profiles from high resolution N-body simulations. The profiles are qualitatively similar, but because it lacks substructure, the self-similar model produces orbits that are too radial at intermediate radii and too circular at small radii.



A smoothed pseudo-phase-space density profile for a self-similar halo compared to profiles from high resolution N-body simulations. We find good agreement with simulations at intermediate radii but predict deviations from the universal power law at small radii.

Implications of Model

Inner logarithmic slope of density and velocity profiles depend on mass (n) and angular momentum evolution after turnaround (ϖ).

Higher resolution simulations should see deviations from the universal pseudo-phase-space density relationship.

Substructure dominated by baryons torques halo particles more strongly than substructure dominated by dark matter since baryons can achieve higher densities and hence are not tidally disrupted as easily. Therefore, the presence of baryons should increase the amount of torque in the halo, and lead to less cuspy profiles.

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