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The Role of the Radial Orbit Instability in Dark Matter Halo Formation and Structure

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Abstract. For nearly a decade, N-body simulations have revealed a nearly universal dark matter density profile. This density profile appears to be robust to changes in the overall density of the universe and the underlying power spectrum. Despite its universality, however, the physical origin of this profile has not yet been well understood. Semi-analytic models have suggested that scale lengths in dark matter halos may be determined by the onset of the radial orbit instability. We have tested this theory using N-body simulations of collapsing dark matter halos. The resulting halo structures are prolate in shape, due to the mild aspect of the instability. We find that the radial orbit instability sets a scale length at which the velocity dispersion changes rapidly from isotropic to radially anisotropic. Preliminary analysis suggests that this scale length is proportional to the radius at which the density profile changes shape, as is the case in the semi-analytic models; however, the coefficient of proportionality is different by a factor of ∼2. We conclude that the radial orbit instability may be a key physical mechanism responsible for the nearly universal profiles of simulated dark matter halos.

Keywords. methods: n-body simulations, cosmology: dark matter, galaxies: formation

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Simulations were done using PKDGRAV (Stadel 2001), a parallel KD Tree gravity solver. The initial system of over 570,000 particles is spherical with a Gaussian density distribution. It starts at a redshift of 15 with only Hubble flow velocities. During the collapse, the radial orbit instability (ROI) sets in and creates a prolate structure.

The resulting anisotropy profile, demonstrated by $\beta = 1 - \sigma_t^2/2\sigma_r^2$, exhibits isotropic orbits in the core of the halo, which may prevent a central buildup of mass, resulting in a shallower density profile. The density profile is well fit by Navarro *et al.* (2004) and less well by NFW (1996). The final shape is prolate within the anisotropy radius and becomes triaxial with increasing radius.

The semi-analytic model described in Barnes *et al.* (2005) shows a direct correlation between the anisotropy radius (r_a), defined as the radius where $\beta = 0.5$, and the density scale length (r_s, here defined as the radius where the slope $= -2$). While our N-body simulations do not confirm this exact result, the two scale lengths are clearly proportional to each other. We suggest a relation of $r_a \sim 2.5 r_s$ rather than equality, and conclude that the ROI may be a critical factor in the determination of the universal profiles of dark matter halos.

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