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Structural Evolution of Substructure

Eric Hayashi & Julio F. Navarro

Department of Physics and Astronomy, University of Victoria, Victoria, BC V8P 1A1, Canada

Abstract. The evolution of substructure in dark matter halos is investigated in a series of simulations of $N = 10^5$ satellite halos on elliptical orbits in the gravitational potential of a much larger host system. The bound mass of the satellite decreases with each pericentric passage and most of the mass is lost from the outer region of the satellite halo. We parameterize the change in its density profile by modifying the initial profile by a factor proportional to $(1 + r^{-3})$, which results in reasonable fits to the mass profiles of tidally stripped subhalos.

1. Introduction

The latest generation of cosmological N-body simulations has achieved sufficient numerical resolution to resolve a wealth of substructure in the dark matter halos of galaxies and galaxy clusters (Ghigna et al. 1998, Klypin et al. 1999). These substructure halos are typically comprised of $\lesssim 10^3$ particles and are therefore subject to numerical effects due to short two-body relaxation timescales. In order to investigate the evolution of the internal structure of subhalos in detail, we perform a series of high resolution simulations of a single satellite in a bound orbit within the gravitational potential of a much larger host system.

2. Simulations

The structure of the satellite halo is initially characterized by the universal density profile proposed by Navarro, Frenk & White (NFW, 1996, 1997):

$$\rho_{\rm NFW}(r) \propto \frac{1}{r/r_s(1 + r/r_s)^2} \qquad (1)$$

where r_s is the characteristic scale radius of the satellite. In order to reduce computational expense, the host potential is modelled as a static NFW potential within a scale radius, R_s, 10 times that of the satellite and a mass with 10 R_s of 300 times the initial mass of the satellite. The softening length of the $N = 10^5$ particle satellite halo was set to 0.06 r_s. The satellite halo was evolved in isolation for about 10 crossing times in order to ensure that it was in equilibrium before being placed in orbit in the host potential. All simulations were performed using Stadel & Quinn's (Stadel, 2001) parallel tree code PKDGRAV. A typical $N = 10^5$ particle simulation requires about 10 hours (wall clock) per orbit on 16 processors of an IBM RS/6000 SP machine.

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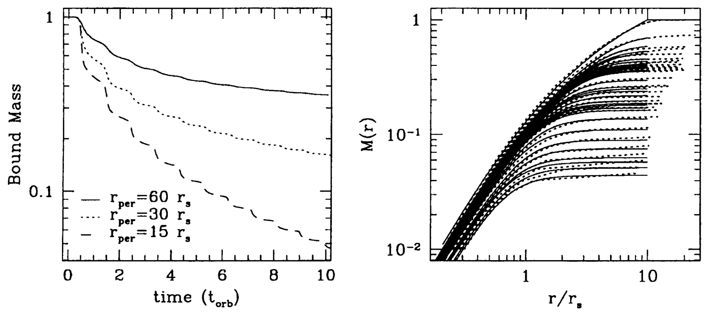

Figure 1. Left: Bound mass of the satellite halo as a function of time for three different elliptical orbits with apocentric radius, $r_{apo} = 100\, r_s$, and pericentric radius, r_{per}, as shown. Right: Modified NFW profile fits (solid) to the mass profiles of tidally stripped satellites at orbital apocentre (dashed). Fitting formula is given in equation (2).

3. Results

The bound mass of the satellite is shown as a function of time for three different orbits in Figure 1. Satellites appear to lose mass continuously as they orbit in the host potential, with most of the mass loss occurring near pericentre, especially in the more radial orbits. The evolution of the mass profiles of the bound satellite mass is also shown in Figure 1. We find that most of the mass is preferentially lost from the outer regions of the halo, resulting in a steepening of the outer slope of the density profile. The change in the density profile is reasonably well described by the following modification to the NFW profile:

$$\rho(r) = \rho_{\rm NFW}(r)\frac{f}{1+(r/r_0)^3} \qquad (2)$$

where the factor f corresponds to the reduction in the central density of the satellite due to tidal heating, and r_0 is a scale radius which sets the cutoff in the density profile. Since the fitting parameters f and r_0 appear to be well-behaved functions of the mass lost by the satellite, in principle we can use our modified NFW profile to predict the structure of a satellite given its mass loss.

References

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