Dark Matter in Local Group Dwarf Elliptical Galaxies

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A. The Big Picture

❑ Dwarfs at the heart of Cosmological Physics

♦ The numbers, total masses, and internal kinematics and mass distributions of dwarf galaxies ("subhalos") within the influence of giant galaxies ("halos") provide key tests for cosmology in general, and for scenarios of structure formation in particular. The mysteries behind the nature of the dark matter that dominates the mass density of the universe may be approached by systematically studying the small.

❑ Dwarf Elliptical (dE) Galaxies

♦ dE's comprise one of the most numerous types of galaxies in the universe, but their origins and histories remain unclear. As a class, they may constitute the bright extension of the even more ubiquitous dwarf spheroidals, the most dark matter dominated objects known, and thus it is important to determine whether there are any connections.

♦ Kinematically speaking, dE's have not been studied in enough detail yet, and most of the current constraints on their internal dynamics and dark matter content come from distant environments, such as galaxy clusters. Moreover, all of these are restricted to mass-to-light (M/L) ratio measurements made at small galactocentric radii, thus being possibly more indicative of the characteristics of their stellar populations than their true dark matter halos, which are most effectively probed by discrete kinematic tracers at large radii.

C. Evidence for Extended Dark Halos from Simplified Models

❑ As an initial step to interpreting the data, we have constructed simplified models based on the solutions of the Jeans equations for an axisymmetric geometry. These models are very restrictive in the sense that they have a M/L ratio that is constant with radius (i.e., no dark halo, so mass follows light) and have isotropic velocity dispersions in the meridional plane.

Figure 2. Jeans-equations fits to the (folded) kinematics along the major axes of NGC 147 and NGC 185. While for the case of NGC 147 the fits to the rotation curve and the "pressure-like" $V_{rms} = (v^2+\sigma^2)^{1/2}$ are acceptable, for NGC 185 the data at large radii clearly exceed the predictions of the Jeans models with high significance. The natural interpretation of this result is the M/L of NGC 185 increasing towards large radii.

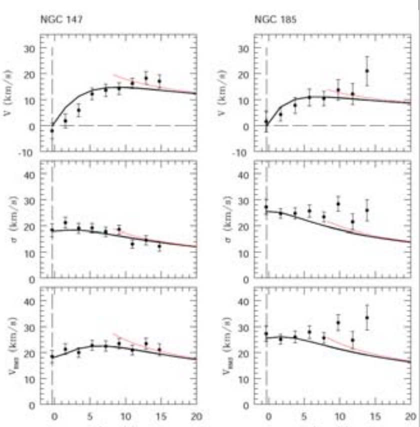
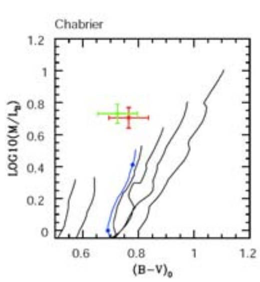


Figure 3. M/L ratios of the Local Group dE's from the Jeans analysis, compared to Bruzual & Charlot (2003) models of the M/L evolution of a simple stellar population for a range of metallicities. The high M/L ratios of NGC 147 (red) and NGC 185 (green) are hard to reconcile with the models, hinting at the presence of dark matter in the two dE's.



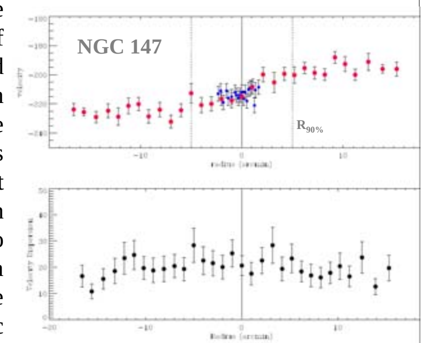
B. The Andromeda dE Satellites



NGC 205 **NGC 147** **NGC 185**

❑ Only three galaxies of the dE type exist in the Local Group, all satellites of M31. Due to their proximity, these constitute our best chance to learn about their mass distributions and dynamics. Of the three, only NGC 205 shows signs of tidal interaction with its giant host, making it inadequate for the equilibrium dynamical studies needed to safely map its underlying gravitational potential.

Figure 1. Using DEIMOS@Keck we mapped the kinematics of hundreds of individual red giants in NGC 147 and NGC 185 out to about 10 R_{eff} in both galaxies. Here we show in red the extent of our (binned) data, as compared with the integrated-light measurements available before, shown in blue (de Rijcke et al. 2006). Due to the low surface brightness, only data of a discrete nature are possible to be gathered at such large galactocentric radii.



D. Generalized Schwarzschild modeling

❑ While the Jeans and stellar population models already hint at the presence of dark matter in both dE's, mapping any variation of the M/L with radius requires more general models that avoid oversimplifying assumptions on the form of the stellar distribution function and the degree of (an)isotropy of the orbits.

❑ To construct such general models, we are using our recently developed axisymmetric 3-integral orbit-based code, the first of its kind designed to handle discrete datasets on a "star-by-star" basis, thus avoiding potentially important losses of information due to data binning (Chanamé, Kleyna, & van der Marel 2008). This is work in progress, and Figures 4 and 5 illustrate the capabilities of this new tool. The combination of our state-of-the-art models and data will soon provide the strongest constraints to date on the dark halos of dE's.

❑ Figure 4 shows the predictions of a computationally inexpensive Schwarzschild model with constant M/L at each location on the sky where there is a velocity measurement. Figure 5 shows the recovered orbital distribution as a function of energy and angular momentum corresponding to that model.

Figure 4

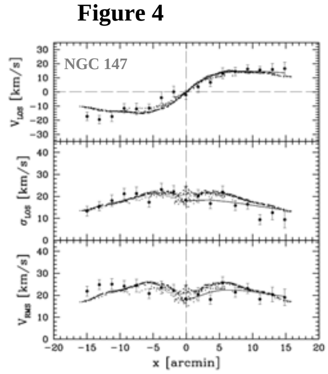


Figure 5