A Fundamental Curve for Hot Stellar Systems in Dark Matter Halos

Erik J. Tollerud, James S. Bullock, Joe Wolf, Manoj Kaplinghat, Elizabeth J. Barton

University of California, Irvine

We consider how dark matter-dominated ultra-faint Milky Way dwarf spheroidal galaxies fit on galactic scaling relations. In the process, we introduce an alternative to fundamental plane space that relies on the half-light mass in place of velocity dispersion. This space clearly reveals a plane of observables that separates globular clusters from ultrafaint dwarf galaxies. It also reveals a fundamental curve (or "tube") upon which all spheroidal galaxies lie, including the Galactic satellites, dwarf ellipticals, giant ellipticals, and intra-cluster light distributions. This fundamental curve allows us to place dwarf spheroidals in a unified empirical framework that directly connects to all other pressure-supported stellar systems embedded in dark matter halos. We further show that this framework provides a new method for connecting galaxies of all types to their host dark matter halo properties. This approach is consistent with abundance matching, but also complimentary, as it allows probing of dark matter halos over a much wider dynamic range in both mass and luminosity.

Data Sets

Due to the large dynamic range investigated, a variety of different data sets are necessary. All photometric data is done corrected to V-band, and plotted in fundamental plane parameter space of surface brightness, effective radius, and velocity dispersion.

Miki Way dwarf spheroidal data is from the compilation of Wolf et al. 2009, based primarily on Mateo 1998 and Simon & Geha 2007. These include ultra-faint satellites down to M_B^* = -10, a regime poorly understood with scaling relations. All this due to the large numbers likely to be detected in ongoing surveys (Tollerud et al. 2008, Bullock et al. 2009).

Elliptical data are from Geha et al. 2003 (dE), and Graves et al. 2009. The Graves data is binned data of a large number of SDSS galaxies, and point size on the plot indicates number of galaxies in each bin. Clusters are included using the Intra-Cluster Light (ICL) data set of Zaritsky et al. 2008. The ICL is used rather than the cluster galaxy light, as it is a more direct comparison to the integrated galaxy light for the non-cluster samples.

Redshifts, a Globular Cluster (GC) sample is also included using kinematics from Pryor & Meylan 1993 and photometric properties from Harris 2003.

MLR Space

As shown above, in fundamental plane space, these data sets are difficult to interpret — the etch, dEs, and ICL data sets lift away from the fundamental plane (e.g. Joyce & Bernardi 2009), but in a complex fashion. Hence, we introduce the "MLR Space" to act as an intermediate parameter space between observables and N-body simulations, using the transforms below. The primary change is the use of M_T*, which, as described in Wolf et al. 2009, is dependent on anisotropy and hence unambiguously represents the dynamical radius within the 3D half-light radius r_200.

In this space, the data sets cleanly separate into a sequence of galaxies (the "Fundamental Curve"), and a separate locus for Globular Clusters. This allows us to define a separation plane (figure on right) in this space that cleanly separates GCs from dEs, but still requires the full 3D parameter space — typical 2D projections such as Luminosity/Effective Radius space will incorrectly classify some objects, particularly in the presence of large photometric errors.

References

- Harris 2003, ASPC, 35, 35
- Pryor & Meylan, O. 1993, ASPC, 50, 357

Conclusions

- For the scaling relations of ultra-faint dwarf spheroidals to larger galaxies using the MLR space provides a number of interesting results:
  - Galaxies separate from GCs in the MLR Space, and follow a definite one-dimensional sequence instead of a two-dimensional plane.
  - This sequence can be used to correct the globally-averaged properties of galaxies to the globally-averaged properties of their dark matter halos over 10 orders of magnitude in luminosity.
  - These results are consistent with and complimentary to abundance matching (e.g. Conroy & Wechsler 2009, Moster et al. 2009), providing better results in the regime where abundance matching is ineffective.
  - The faintest galaxies show hints of a change in scaling relations, but not enough ultra-faints are yet available with small enough error bars to determine this (or test the assumption of monotonocity in the M_T* relation).

The possibility of finding new dSphs in upcoming surveys like Pan-STARRS and LSST (Tollerud et al. 2009), or characterizing the faintest companions of M31 (e.g. Gough et al. 2009) will likely increase the size of this data set, providing an excellent opportunity for future application of this technique to better understand the faint end of galaxy formation.

Fundamental Curve

In MLR space, the galaxies and ICL all fall along a one-dimensional sequence — the "Fundamental Curve." This sequence is well-parameterized by a power law in M_T* vs. r_200 and a two-power relation in L* vs. r_200. This curve is valid over ~10 orders of magnitude in luminosity from the faintest dSphs in the MLR space. As described below, it can further be used to connect the luminous properties of galaxies to their dark matter halos.

Profile Matching

The fundamental curve above is the result of a fit to the observed scaling relations of hot stellar systems, which is a function of their dark matter halo properties. As described above, this curve can be used to determine the properties of a galaxy's dark matter halo, including its mass and concentration. This allows us to connect the observed properties of galaxies to their dark matter halos, providing a powerful tool for understanding the nature of dark matter.