

Evidence for Light-weight Local Group Dwarf Spheroidal Galaxies

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1. Introduction, and Discussion

A simple and natural explanation for the dynamics and morphology of the Local Group Dwarf Spheroidal galaxies, Draco (Dra) and Ursa Minor (UMi), is that they are weakly unbound stellar systems with no significant dark matter component. A gentle, but persistent, Milky Way (MW) tide has left them in their current kinematic and morphological state (the “parametric tidal excitation”). A new test of a dark matter dominated dS potential follows from a careful observation of the “clumpiness” of the dS stellar surface density.

Controversy over the dynamical masses of the MW dS centers around whether or not they are in equilibrium. At one extreme the equilibrium models account for elliptical morphology and dynamics with ad hoc multiparametric dark matter mass distributions. In contrast a variety of non-equilibrium dS models account for their properties through MW tidal interactions (Kuhn and Miller 1989; Kroupa 1997). Several years ago Kuhn and Miller (1989) argued that if only the dS luminous mass component is present (as is the case in globular clusters) then their dynamical timescales are comparable to their MW orbital times. This has important consequences since then even a relatively weak MW tidal force can dramatically affect the dS through its orbital time dependence. Recently it was shown using analytic and numeric models of a parametric tidal resonance that a gentle, but variable, tidal interaction can readily inflate the velocity dispersion of a dS stellar system (Fleck and Kuhn 2003). Examples of tails beyond a dS tidal radius and with a surface density far above what is expected from a massive equilibrium system have been discovered in Carina (Kuhn et al. 1996), Ursa Minor (Smith et al. 1997), and Sculptor (Walcher et al. 2003).

There exist equilibrium mass calculations for Dra which claim a M/L in excess of 500 solar units (Kleyna et al. 2002). If this were true the Dra potential must be dominated by its dark matter. If we assume the DM is collisionless and relaxed, and that it and the baryonic mass of the dS formed at the same epoch, then the dS stars are, effectively, massless test particles within a smooth DM-dominated potential. Such stellar “particles” must be uncorrelated, with a null two-particle correlation function (cf. Binney and Tremaine 1987). It follows that the stellar particle distribution function, $f(\vec{r}, \vec{v}, t)$, can be computed from the collisionless Boltzmann equation and the net dS gravitational potential (cf. Binney and Tremaine 1987).

For a smooth gravitational potential we also expect $f(\vec{r})$ to be smooth so that the projected star counts in a small spatial region (for example as derived from one pixel of a two-dimensional star count map) can yield a reasonable

estimate of the projected number density, $n(\vec{x})$. Here \vec{x} is a 2-d coordinate in the plane of the sky and a line-of-sight and velocity integration of $f(\vec{r}, \vec{v}, t)$ to obtain $n(\vec{x})$ is implicit. On scales small compared to the variation of the potential we also expect $n(\vec{x})$ to be smooth. In fact, since stars are uncorrelated, our estimate of $n(\vec{x})$ from the star counts per pixel should be Poisson distributed – like the photon count in a 2-dimensional image. Any spatial “clumpiness” in the number of stars per pixel which is in excess of Poisson distribution variations violates our assumption that Dra has a smooth DM dominated potential.

Using deep V and I colour-magnitude data obtained from the CFHT 12K CCD mosaic camera over a $2^\circ \times 1^\circ$ region centered on Dra (Kocevski et al. 2003) we estimate the circularly symmetric projected number density $n(R)$ when $R = \|\vec{x}\|$. The effect of non-dS background stars was minimized by counting stars in a colour-magnitude region that included the Dra giant branch, horizontal branch and main sequence down to $V=25$. Radial bins were scaled along the y axis to account for the ellipticity of Dra. The radial binwidth also increased with R in order to maintain a constant count per bin, and constant statistical significance, since the mean density $n(R)$ decreased with R . The fluctuations in $n(R)$ in groups of 5 bins were used to compute the normalized (reduced) chi-squared. At radial bin R_i we obtain (with the assumption of Poisson statistics)

$$\chi_5^2(R_i) = \frac{1}{5} \sum_{j=0}^4 \sigma^2(R_{i+j})/n(R_{i+j})$$

Here $\sigma^2(R_i)$ is the sample variance computed at each radius bin from it and 4 nearby bins. We find that χ^2 derived from the outer bins (with $R > 20'$) is consistent with the expected reduced χ^2 distribution. The inner Dra bins have a variance which is too large. Using a Kolmogorov-Smirnoff test we find that the inner region is not consistent with the expected χ_5^2 distribution at better than a 99% confidence level (while the outer region is). Thus, the stellar density in the inner region of Dra is “clumpier” and more variable with spatial position than it should be if the Dra mass were dominated by a smooth DM component.

References

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