Dwarf Galaxies and Dark Matter

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Abstract

The nearby dwarf spheroidal galaxies help us to probe the nature and extent of dark matter in at least two ways. First, if they are regarded as test particles orbiting our Galaxy, their Galactocentric radial velocities and distances can be used to constrain the distribution of dark matter in the Galactic halo. Although this problem has been investigated several times in the past [1,2,3,4], there are at least two motivations for another look: (i) A number of accurate new radial velocities for dwarf spheroidals and distant globular clusters have become available in the past few years; the present study [5] is based on 10 galaxies and globular clusters—all those with distances between 50 and 200 kpc and velocity errors of less than $25\,\mathrm{km\,s^{-1}}$; (ii) We have devised a new method of statistical analysis based on Bayes' theorem, which directly yields confidence intervals for the mass of the Galaxy once the eccentricity distribution of the orbits is specified. Assuming an isotropic velocity ellipsoid, we find that the mass of the Galaxy is $\lesssim 5 \times 10^{11}\,\mathrm{M}_\odot$ at the 95% confidence level. If we assume that the Galaxy has a flat rotation curve out to several hundred kpc, then for isotropic orbits, the circular speed is $\lesssim 160\,\mathrm{km\,s^{-1}}$ at the 95% confidence level. These results suggest that the Galaxy's massive dark halo extends to $\lesssim 50\,\mathrm{kpc}$; a more massive halo is only consistent with the data if the orbital velocities of the satellites are mostly tangential. We have investigated the suggestion of LYNDEN-BELL et al. [2] that predominantly tangential velocities might arise because satellites on elongated orbits have been tidally disrupted, and find that tidal disruption in an initially isotropic satellite population with a power-law density distribution is unlikely to have an important effect on our results.

The internal dynamics of dwarf spheroidal galaxies also provide evidence for dark matter. The line-of-sight velocity dispersions of $\approx 10\,\mathrm{km\,s^{-1}}$ in Draco and Ursa Minor suggest that most of the mass in these systems is in some invisible form [6,7,8]. One alternative possibility is that the dispersions reflect the orbital motion of binary stars rather than the motion of the stars through the galaxy. We have investigated this hypothesis using Monte Carlo simulations of a population of binary stars, similar to the simulations described by AARONSON and OLSZEWSKI [6]. Although neither the fraction of binary stars nor their semi-major axis distribution is known, it turns out that these parameters are not needed: there is a strong, largely model-independent, correlation between the velocity dispersion due to orbital motion and the fraction of stars which show velocity variations over a fixed interval of time. A crude rule of thumb is that for plausible stellar masses, the dispersion is roughly $10f\,\mathrm{km\,s^{-1}}$, where f is the fraction of stars showing velocity changes $\geq 4\,\mathrm{km\,s^{-1}}$ in a one year interval. AARONSON and OLSZEWSKI [6] find that $f \lesssim 40\%$ in Draco and Ursa Minor; this result implies that binaries contribute at most $4\,\mathrm{km\,s^{-1}}$ to the observed dispersion of $10\,\mathrm{km\,s^{-1}}$. Thus it appears that binarism is not a viable alternative to dark matter in these galaxies.

A related possibility is that the stars in these galaxies may be clumped into "hard" subsystems or clumps whose internal dispersion is much larger than the orbital velocity dispersion. However, it is straightforward to show that these clumps would either evaporate

(through star-star encounters) or merge on a timescale much shorter than the Hubble time. Thus, so far I have been unable to find an acceptable dynamical explanation for the large velocity dispersions in Draco and Ursa Minor which does not imply that large quantities of dark matter are present.

References

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