The Shape of the Milky Way's Dark Halo

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We determine the flattening of the Milky Way's dark halo based on a combination of two techniques: 1) the manner in which the gas layer in the Galaxy flares with radius, and 2) by comparing the inferred halo flattening to that obtained from a stellar-kinematic analysis, which can only be applied to the Milky Way. We find that the shape of the Milky Way's dark halo has a shortest-to-longest axis ratio of $q = 0.75 \pm 0.25$, and that $\Theta_0 \lesssim 190$ km s^{-1} if it is demanded that the dark halo is oblate. A disk-like dark matter (DM) distribution is only allowed if $\Theta_0 \lesssim 160\,\mathrm{km\,s^{-1}}$ (Olling & Merrifield 1999a,b, hereafter OM99a,b).

Beyond the optical disk, where the dark matter dominates the potential, the width of a galactic gas layer [$\mathrm{W}_{gas}(R)$] constrains the halo's shape (Olling 1996, and references therein). Since W_{gas} is dictated by the hydrostatic balance between the random motions of the gas and the pull of gravity W_{gas} measures the local dark matter density. Thin gas layers imply a large amount of dark matter, which implies that its distribution must be highly flattened (q small).

To apply this method, we need to know the Galactic rotation curve [$\Theta(R)$] and $\mathrm{W}_{gas}(R)$. However, these two quantities are intimately entwined. It is well known (e.g. Olling & Merrifield 1998) that the shape of the rotation curve depends on the adopted values for the Galactic constants (Θ_0, and R_0, the Sun's distance to the Galactic center). Thus, the impediment to our analysis is that the amount of dark matter in the plane depends on both the shape of the dark halo and the shape and amplitude of $\Theta(R)$, and that the linear thickness of the gas layer scales with R_0 (Merrifield 1992).

With only W_{gas} observed, it is not be possible to determine Θ_0, R_0 and the halo shape. Fortunately, we can also use local stellar kinematics as a constraint. Kuijken & Gilmore (1991) determined the total mass within 1.1 kpc of the Galactic plane in the Solar neighborhood: $\Sigma_{1.1} = 71 \pm 6\, M_\odot\,\mathrm{pc}^{-2}$. Part of this column comes from luminous matter, we assume 14.5 $M_\odot\,\mathrm{pc}^{-2}$ for the ISM, and $\Sigma_* = 35 \pm 5\, M_\odot\,\mathrm{pc}^{-2}$ for the stellar component, leaving $\Sigma_h \sim 22 \pm 8\, M_\odot\,\mathrm{pc}^{-2}$ for the dark halo. Large values for Σ_* require small values for Σ_h and vice versa. The Σ_h-constraint thus depends on three unknowns: the adopted values for the Galactic constants and Σ_*. Combining the two constraints, we see that there are two observables and four unknowns, which does not allow for a unique determination of either R_0, Θ_0, q, or Σ_*. However, when adopting a model for the DM distribution, these four unknowns are strongly inter-related, and their values can not be chosen independently.

We estimate R_0, Θ_0, q, and Σ_* as follows (see OM99a,b for details): 1) Pick values for R_0 and Θ_0; 2) Determine $\mathrm{W_{gas}}(R)$ and $\Theta(R)$; 3) Calculate mass models consistent with $\Theta(R)$ for a series of q's; 4) Calculate $\mathrm{W_{gas}}(R)$ and compare with the observations to determine q_{HI}; 5) Use the $\Sigma_{1.1}$-constraint to determine the

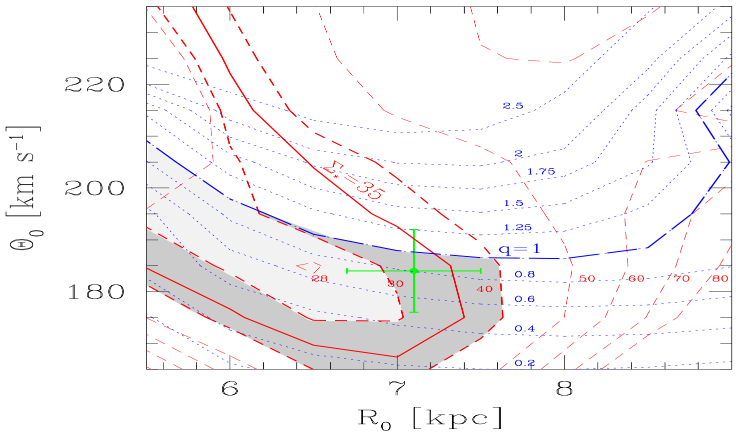

Figure 1. Here we present the values of DM halo shape (dotted lines) and Σ_* (long dashed lines) which lead to a *consistent* (i.e. $q_{HI} = q_{1.1}(\Sigma_*)$) Galactic mass model as a function of the Galactic constants. The oblate-prolate boundary is indicated by the heavy dash-dotted line. The heavy full line and the heavy dashed line delimit the $35 \pm 5 M_\odot\,\mathrm{pc}^{-2}$ area (dark shade). The light shading corresponds to $26 \pm 4 M_\odot\,\mathrm{pc}^{-2}$. The fat cross located at (R_0, Θ_0)= (7.1 kpc, 184 km s^{-1}) represents our independent determination based on the Oort constants (OM98).

halo flattening as a function of Σ_* [$q_{1.1}(\Sigma_*)$]; 6) The *mutually consistent* values for q and Σ_* are such that that q_{HI} equals $q_{1.1}(\Sigma_*)$; 7) GOTO step 1.

We contour the results in Figure 1, which shows that highly flattened dark halos are allowed if $\Theta_0 \lesssim 160$ km s^{-1}, and that $\Theta_0 \lesssim 190$ km s^{-1} if the dark halo is oblate. Further, because the parameters must be mutually consistent, one cannot arbitrarily choose R_0, Θ_0, q and Σ_*. Fixing one or more of these parameters severely restricts the others.

These results indicate that the Milky Way is smaller than hitherto assumed ($R_0 \sim 8, \Theta_0 \sim 200$). However, such a leaner Galaxy is fully consistent with all observational kinematical and geometric determination of R_0, the reflex motion of the Galactic centre, the Oort constants, radial and proper motions of Cepheids, the the local mass density, the Galactic escape velocity, the velocity of M31, and the orbits of the satellite galaxies.

References

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