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Vertical distribution of stars and flaring in the Milky Way

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Abstract. We study the vertical stellar distribution of the Milky Way thin disk treated as a gravitationally coupled system of stars, HI and H_2 gas in the field of dark matter halo, from R = 4 to 22 kpc. We show that the gas and halo gravity mainly constrain this vertical distribution toward the mid-plane in the inner and the outer Galaxy, respectively. The halo gravity reduces the disk thickness by a factor of 3-4 in the outer Galaxy. Despite this constraining effect the disk thickness increases steadily with radius, flaring steeply beyond 17 kpc, making a flaring disk a generic result.

Keywords. Galaxy: disk - Galaxy: halo - galaxies: kinematics & dynamics

1. Introduction

The vertical density distribution for a one-component isothermal self-gravitating stellar disk is given as $\rho(z) = \rho_0\,\mathrm{sech}^2(z/z_0)$. But a real galaxy disk is a gravitationally coupled multi-component system consisting of stars, HI, H_2 gas in the field of dark matter halo. The vertical structure of this disk was studied theoretically by Narayan & Jog (2002) for the Galaxy for $R < 12$ kpc which we extend to the outer disk, upto 22 kpc (Sarkar & Jog 2018).

1.1. *Equation and Numerical solution*

We solved the following joint hydrostatic balance and Poisson equation for this coupled system using 4^{th} order Runge-Kutta method as in Narayan & Jog (2002)

$$\frac{\mathrm{d}^2\rho_i}{\mathrm{d}z^2} = \frac{\rho_i}{\langle (V_z)_i^2 \rangle}\left[-4\pi G\left(\rho_\mathrm{s} + \rho_\mathrm{HI} + \rho_{\mathrm{H}_2}\right) + \frac{\mathrm{d}(K_z)_\mathrm{DM}}{\mathrm{d}z}\right] + \frac{1}{\rho_i}\left(\frac{\mathrm{d}\rho_i}{\mathrm{d}z}\right)^2, \tag{1.1}$$

where $i =$ stars, HI and H_2, and $|K_z|$ is the vertical force per unit mass. Here $\langle (V_z)_i^2 \rangle$ is the random velocity dispersion of each component.

2. Results

2.1. *Constraining effect of gas and dark matter halo*

The vertical stellar density distribution is found to be significantly constrained by gas gravity, in the inner disk, e.g, at R = 6 kpc (Fig. 1). The addition of gas increases stellar mid-plane density and reduces disk thickness, thus gives a steeper stellar density profile. In the outer Galaxy,e.g, at R = 18 kpc, the stars-alone case produces an extended, diffuse vertical distribution due to very low self-gravity. The halo gravity mainly strongly constrains this distribution making it less likely to get disturbed.

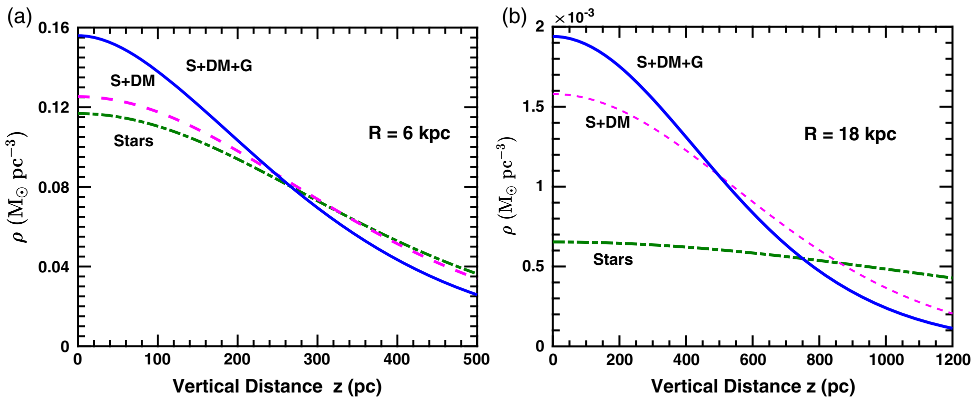

Figure 1. Vertical density distribution of stars in the gravitational field of stars-alone(Stars), stars & dark matter halo(S+DM), and stars, halo & gas (S+DM+G) cases. The mid-plane density is increased, disk thickness is reduced and the curves are steeper at R = 6 kpc (inner disk) & 18 kpc (outer disk), due to mainly the constraining effect of gas and halo, respectively.

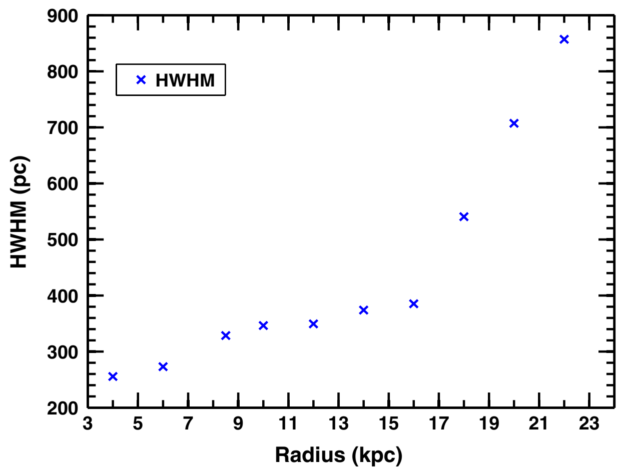

Figure 2. Stellar disk thickness (HWHM of $\rho(z)$) as a function of radius.

2.2. *Vertical disk thickness measurement*

We measure the stellar disk thickness in terms of the half-width at half-maximum(HWHM) of $\rho(z)$ (Fig. 2), which increases steadily with radius showing flaring beyond 17 kpc. The stars-alone disk would have flared by a factor of 14 and the halo gravity reduces the disk thickness almost by a factor of 4 in the outer Galaxy. Interestingly, various observations that find flaring in the outer Galaxy agree reasonably well with our results. A similar flaring trend was also noted for a LSB galaxy- UGC7321 (Sarkar & Jog 2019).

2.3. *Shape of the vertical density profile*

We fit our model results to a function of type sech$^{2/n}$ instead of sech^2 and found that, $n < 1$ for R>14 kpc, when constrained by halo gravity and $n > 1$ when constrained by gas gravity. Further, note that $n < 1$ is a new regime not studied previously in literature. However, the best-fit value of 2/n changes steadily with the vertical range used for the fit, implying that n is not a robust parameter.

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3. Conclusions

The vertical stellar distribution of the Galaxy disk is shown to be constrained toward mid-plane mainly by the gas and the halo gravity in the inner and the outer disk, respectively. The disk thickness increases steadily with radius flaring steeply beyond 17 kpc, despite a strong constraining effect of the halo, making flaring a generic result. The stellar density profile deviates from sech^2 giving $n > 1$ & $n < 1$ for gas and halo dominated region respectively, when fit to sech$^{2/n}$ function.

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