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A PRECISE MILKY WAY ROTATION CURVE MODEL FOR AN ACCURATE GALACTOCENTRIC DISTANCE

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INTRODUCTION

Many problems in Galactic structure benefit from accurate knowledge of the distance to the Galactic center, R_0. This crucial value has recently been measured to unprecedented accuracy — $R_0 = 8.122 \pm 0.031$ kpc — thanks to relativistic effects observed during the pericenter passage of a star orbiting the central supermassive black hole (Gravity Collaboration et al. 2018). Combined with the observed proper motion of Sgr A* (Reid & Brunthaler 2004), this Galactocentric distance implies a transverse speed of the sun of 245.58 ± 1.32 km s^{-1}. Adopting $V_\odot = 12.24 \pm 0.47$ km s^{-1} (Schönrich et al. 2010) for the solar motion leads to a circular speed of $\Theta_0 = 233.34 \pm 1.40$ km s^{-1} for the Local Standard of Rest.

In light of this development, I provide here an update to the Milky Way model of McGaugh (2016). In addition to the new Galactocentric distance, new measurements of the terminal velocities in the first quadrant are also available (McClure-Griffiths & Dickey 2016). Combining these with fourth quadrant terminal velocities (McClure-Griffiths & Dickey 2007) and the Galactic constants (R_0, Θ_0) = (8.122 kpc, 233.3 km s^{-1}) provides a remarkably detailed picture of the Galactic rotation curve.

The method of McGaugh (2016) applies the Radial Acceleration Relation (RAR: McGaugh et al. 2016) to derive the azimuthally averaged baryonic surface density profile $\Sigma(R)$ from the Galactic rotation curve. Features in $V(R)$ have corresponding features in $\Sigma(R)$ that map well to independently known features like the Centaurus spiral arm. The resulting $\Sigma(R)$ departs from a pure exponential profile in a way that is typical of other spiral galaxies.

The model Q4MB of McGaugh (2016) provides the starting point here as its bulge model provides an excellent match to the inner rotation curve obtained from the detailed modeling of Portail et al. (2015) when both are scaled to the same R_0. The pattern of bumps and wiggles at larger radii — presumably the signature of massive spiral arms like Centaurus — is a good match to the terminal velocity data in both quadrants. The new, slightly larger R_0 makes the Milky Way more massive, a net increase of 9% over the Q4MB model, with correspondingly higher surface densities.

RESULTS

The updated model is shown in Fig. 1. In addition to fitting the terminal velocities, it also fits the highly accurate Θ_0. This implies a slight dip in the rotation curve (Sofue et al. 2009), as expected from the sun's location interior to the Perseus arm. The rotation curve outside the solar circle is not constrained by the terminal velocities, but the model extrapolates well to known constraints (McGaugh 2016), including that from the recent analysis of the GD-1 stellar stream (Malhan & Ibata 2018).

The total stellar and gas mass of the model is $M_* = 6.16 \times 10^{10}$ M$_\odot$ and $M_g = 1.22 \times 10^{10}$ M$_\odot$. Treating the asymmetry between quadrants as an uncertainty, M_* is known to $\sim$5%. This is a map of the gravitational potential of each mass component, including the bumps and wiggles due to spiral structure in the disk.

The Milky Way is strongly baryon dominated interior to the sun, satisfying any definition of maximum disk (Sackett 1997; Starkman et al. 2018). The implied dark matter halo is also well constrained. The numerical results can be approximated by a pseudo-isothermal halo with core radius $R_C = 3.05$ kpc and asymptotic velocity $V_\infty = 185.8$ km s^{-1}. The nearest NFW approximation has $c_{200} = 8.07$ and $V_{200} = 161.5$ km s^{-1}.

The local density of dark matter is $\rho_{DM}(R_0) = 6.76^{+0.08}_{-0.14} \times 10^{-3}$ M$_\odot$ pc^{-3} = $0.257^{+0.003}_{-0.005}$ GeV cm^{-3}. The stated uncertainty is for a 5% uncertainty in M_*. This estimate from the *radial* force is about half that found by studies of the *vertical* force (e.g., Bienaymé et al. 2014). This may be a hint about the flattening of the halo or other effects (e.g., Necib et al. 2018).

It will be interesting to compare these results with Gaia, as the information utilized here is entirely independent.

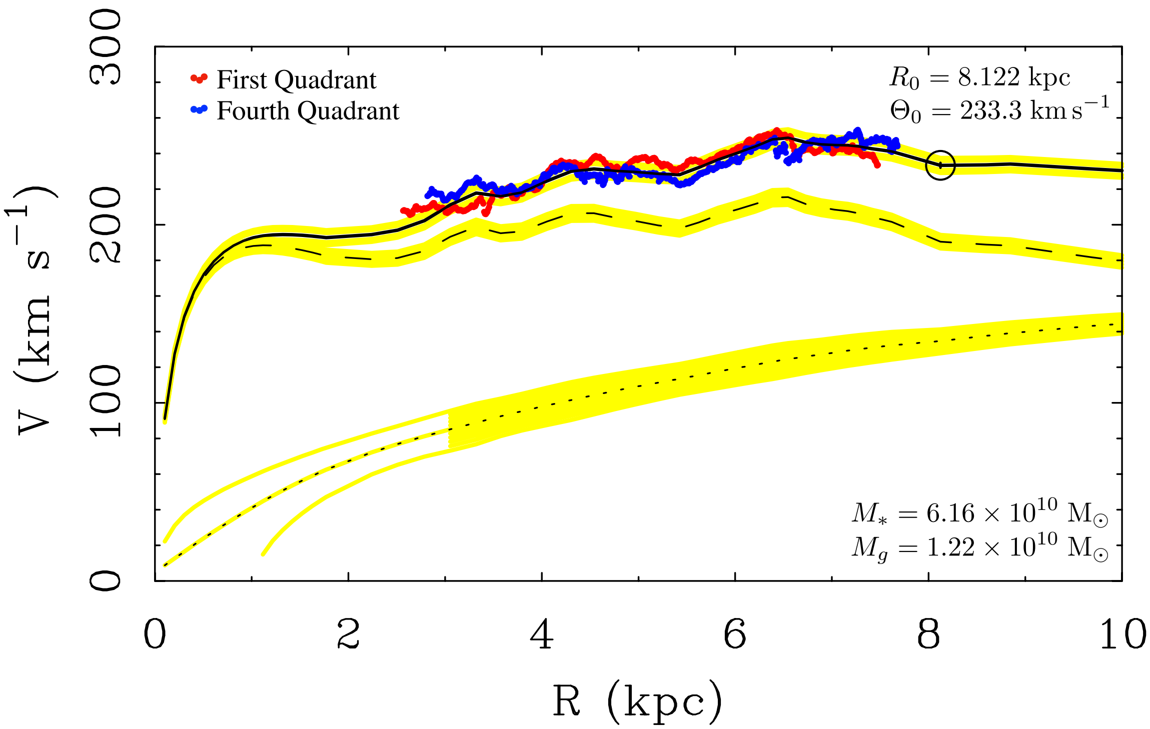

Figure 1. Model rotation curve for the Milky Way (solid line) matched to the first (red points; McClure-Griffiths & Dickey 2016) and fourth (blue points; McClure-Griffiths & Dickey 2007) quadrant terminal velocities following McGaugh (2016). The dashed line shows the rotation curve of the baryonic component and the dotted line is the implied dark matter. Yellow bands illustrate the range of variation for ±5% in stellar mass.

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