

Letter to the Editor

Comment on the dispersion-velocity of galactic dark matter particles

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Abstract. In a recent Letter, Cowsik, Ratnam and Bhattacharjee (1996a) have built a dynamically self-consistent spatial distribution of particles of galactic dark matter. They have come up with the rather unorthodox conclusion that the mean velocity dispersion of dark matter particles “should be 600 km s⁻¹ or larger”. Their letter triggered immediate comments (Evans 1996, Gates et al. 1996). Here we find, as did Cowsik et al. (1996a), that models of the dark matter halo can be made consistent with velocity dispersion much larger than that expected from a simple application of the virial theorem in the solar neighbourhood. But in contrast to their conclusions, we show that using their model, we also obtain solutions with smaller velocity dispersion down to ~ 270 km s⁻¹. These more orthodox dispersions arise because of less constraining boundary conditions for the central density but do not rely on indirect or model dependent measurements of the large scale distance behaviour of the rotation curve.

Key words: Galaxy: halo – Galaxy: kinematics and dynamics – dark matter –

We developed a numerical algorithm following the prescription presented by Cowsik et al. (1996a) and we obtain a rotation curve with the same general features. This result provides an independent validation of Cowsik et al.'s numerical work. The distribution of the baryonic matter in our Galactic model corresponds to a double-exponential disk (with a scale length of 3.5 kpc, a scale height of 300 pc and a surface density, Σ_0 , of 80 $M_\odot \text{pc}^{-3}$ at the solar radius $R_0 = 8.5$ kpc). The bulge's model is a Hubble profile with a core radius $a = 103$ pc and a central density $\rho_c = 343 M_\odot \text{pc}^{-3}$.

We check that the velocity curves of these models do tend asymptotically to $(2/3)^{1/2} \langle v^2 \rangle_{\text{DM}}^{1/2} = \Theta_\infty$. We determine veloc-

ity curves for three models with different $\langle v^2 \rangle_{\text{DM}}^{1/2} = 350, 450$ and 600 km s⁻¹ (Fig. 1) (the fixed size of our rectangular grid does not allow us to resolve simultaneously with sufficient accuracy both the velocity curve to galactic radius of 40 kpc and close to the galactic center below 2 kpc which we have therefore omitted).

For each dispersion we estimate values of $\rho_{\text{DM}}(R_0 = 8.5 \text{ kpc}, 0)$ in order to obtain a flat rotation curve in the range $R = 10 - 30$ kpc. We note a dip at about 20 – 25 kpc, which increases with the velocity dispersion (too high a velocity dispersion prevents a nearly flat rotation curve). The velocity curve maximum near $R = 7$ kpc is produced by the exponential disk of visible matter. At much larger galactic radius $R > 40$ kpc the dark matter contribution dominates the velocity curve which tends towards Θ_∞ . For instance in Fig. 1, the lowest curve (3) that corresponds to the largest $\langle v^2 \rangle_{\text{DM}}^{1/2}$ reaches 490 km s⁻¹ at large R while curves (2) and (1) only reach 367 and 286 km s⁻¹. Increasing $\rho_{\text{DM}}(R_0, 0)$ increases the mass contribution of the dark halo in the central region and convergence towards Θ_∞ is reached more rapidly. Yet, in this instance, the velocity curve does not remain flat below 40 kpc.

The most unusual feature of the models proposed by Cowsik et al. is that the central dark matter density is so low that the visible matter dominates the velocity curve at small galactic radius and allows for a galactic population with an extension stopping at 30 – 40 kpc while its velocity dispersion is $(2/3)^{1/2} 220 = 180$ km s⁻¹ (very similar to that of the Globular Cluster population for instance). The dark matter population having a larger $\langle v^2 \rangle_{\text{DM}}^{1/2}$ dominates fully after 30 kpc and as shown in Cowsik's reply (1996bc) this dark matter component may stop at 100 kpc without significant effect at small galactic radius.

Cowsik's results are in conflict with available data only in the range 20 – 40 kpc. In this range, constraints arise from the dynamics of distant objects such as globular clusters. These give access to the galactic mass inside $R \sim 40$ kpc, and suggest

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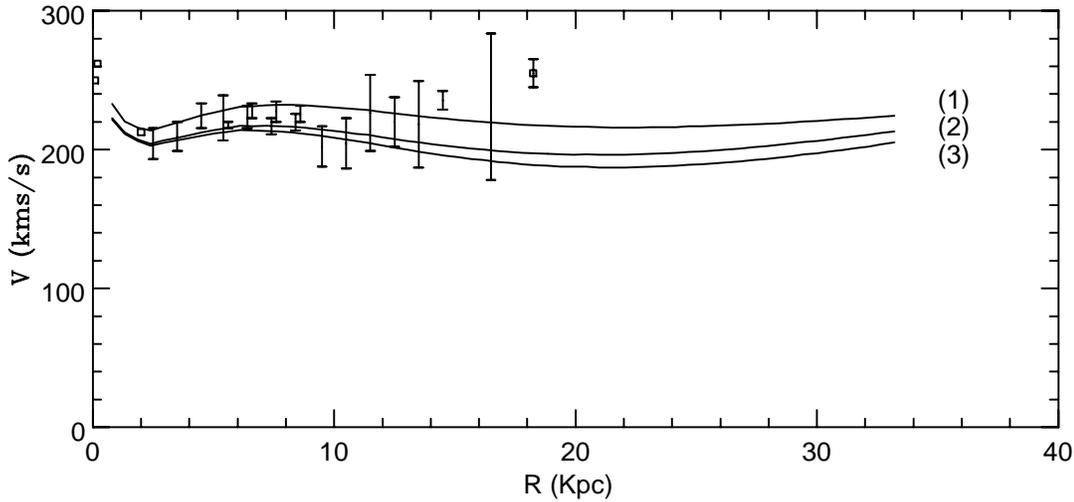


Fig. 1. Flat rotation curve of the Galaxy $\langle v^2 \rangle_{\text{DM}}^{1/2} = 350$ (1), 450 (2) and 600 km s⁻¹ (3). The observational data and their error bars are those given by Cowisk et al.: from Fich et al (1989), below 2 kpc from Burton & Gordon (1978) and for $R > 17$ kpc from Fich & Tremaine (1991). The corresponding χ^2 take respectively the values of 14, 18 and 22 km s⁻¹ for models (1), (2) and (3)

that its distribution is consistent with a flat rotation curve up to that distance (Dauphole & Colin 1996). In this reference, input data are 6D (r, v) positions and velocities for a critical subset of globular clusters, giving for the first time strong constraints on the rotation curve in the analysed range of distances. Their most probable fit corresponds to a flat rotation curve, but no upper limits to a rising rotation curve are given. Of course, such results remain model dependent and do not exclude a rising (or decreasing) rotation curve beyond 40 kpc.

We remark that the data used by Cowisk et al. (1996a) correspond to a rotation curve determined with the assumption that the solar galactic radius is $R_0 = 8.5$ kpc (a value recommended by the IAU - see Kerr & Lynden-Bell 1986), used to “facilitate intercomparison of the work of the different authors” (Fich & Tremaine 1991). Smaller values (Reid 1993) are now generally accepted and lead to a flat or locally decreasing rotation curve (Fich & Tremaine 1991).

Our models do not take as data input the mass determination from 17 satellites of the Galaxy more distant than 50 kpc (Kochanek, 1996). Only 3 have complete (r, v) data and mass estimate depends on complementary hypotheses like velocity isotropy or radial gradient of the density. Similarly we do not incorporate the timing argument as means to estimate the total mass of the Galaxy since as argued by Kochanek (1996) “The classical Local Group timing model of Kahn and Woltjer 1959 assumes that the orbits are radial and provides lower bounds on the mass.”

Within the framework of our isothermal model, we find that an upper limit of 600 km s⁻¹ is consistent with a flat rotation curve in the range $R = 10 - 40$ kpc. A range of possible galactic dark matter velocity dispersions from 270 to 600 km s⁻¹ are shown to be also consistent. We remark that the velocity dispersion can be much larger beyond 40 kpc without significant measurable effects on the rotation curve below this radius. If

the velocity curve of the Galaxy is only well defined over such a small distance interval, it is difficult to model it with a unique isothermal model. One should therefore be careful in estimating velocity dispersions from a crude application of the virial theorem, as mentioned by Cowisk et al. (1996a).

We find a large range of possible $\langle v^2 \rangle_{\text{DM}}^{1/2}$ with dispersion as low as 270 km s⁻¹ if we consider the rotation curve used by Cowisk et al., and from 270 to 600 km s⁻¹ if we consider a flat rotation curve up to 40 kpc. The discrepancies between Cowisk’s et al. conclusion and ours arises from the fact that we did not fix the dark matter density at the origin $\rho_{D.M.}(0, 0)$. Cowisk et al. set $\rho_{D.M.}(0, 0) = 1 \text{ Gev}/\text{cm}^3$ constant, arguing that the dynamical measure of the mass density in the solar neighbourhood is $\sim 0.3 \text{ Gev}/\text{cm}^3$. This value of $\rho_{D.M.}(R_0, 0) \sim 0.3 \text{ Gev}/\text{cm}^3 = 0.008 M_{\odot}/\text{pc}^3$ is very different from the values (0.05 – 0.1 M_{\odot}/pc^3) obtained in references (Oort 1960, Bahcall 1984) cited by Cowisk et al. (1996a). The exact estimate of the local dynamical mass density $\rho_{Dyn.}(R_0, 0)$ remains a very controversial subject, though it is now determined with smaller errors (see review by Cr ez e 1991 & Kuijken 1995). Models plotted in Fig. 1 have small $\rho_{D.M.}(R_0, 0)$ compatible with this last determinations of $\rho_{Dyn.}(R_0, 0)$; these models are in rough agreement with the data used by Cowisk in the range $R < 20$ kpc and have much smaller $\langle v^2 \rangle_{\text{DM}}^{1/2}$ values than those obtained by Cowisk et al. (1996a).

Cowisk et al. have pointed out the important fact that models of dark matter halo can be made consistent with velocity dispersion much larger than that expected from a simple application of the virial theorem in the solar neighbourhood. Their model should be applied to existing 6D data from globular clusters in order to obtain a realistic upper limit on $\langle v^2 \rangle_{\text{DM}}^{1/2}$. Here we have shown that, in contrast to Cowisk et al. assertion, models

with small orthodox $\langle v^2 \rangle_{\text{DM}}^{1/2} \sim 270 \text{ km s}^{-1}$ are also in agreement with their own observational constraints. Our conclusions suggest that the efforts on the part of experimentalists should not be directed towards the search for very hypothetical high velocity dispersion dark matter particles. These effort should on the contrary be directed towards better astrometric observations in order to reach valuable absolute proper motions for the most distant galactic satellites and globular clusters that may be achieved for instance with high resolution observations with HST or adaptative optics.

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