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ON THE LOCAL DARK MATTER DENSITY

C. Moni Bidin[1], R. Smith[2], G. Carraro[3,4], R. A. Méndez[5], and M. Moyano[1]

RESUMEN

En 2012 propusimos una nueva formulación tridimensional y derivamos una densidad de materia oscura sorpresivamente baja en la posición solar. Bovy & Tremaine (2012) desafiaron este resultado, criticando una de las hipótesis y declarando que los datos son consistentes con lo esperado, si se adopta una ecuación unidimensional. Aquí demostramos que la validez de su formulación depende de la distribución de masa, y que su hipótesis es inconsistente con observaciones de la Vía Láctea y de galaxias externas. Concluimos que su crítica no es una explicación viable a la falta de materia oscura que detectamos en la posición solar.

ABSTRACT

In 2012, we proposed a new three-dimensional formulation, and we derived a surprisingly low dark matter density at the solar position. Bovy & Tremaine (2012) challanged this result, criticizing one of the assumptions and claiming that the data are consistent with the expectations, if a one-dimensional approach is adopted. We show here that the validity of their formulation depends on the mass distribution, and that their hypothesis is inconsistent with observations both in the Milky Way and in external galaxies. We conclude that their criticism is not a viable explanation for the lack of dark matter at the solar position detected by us.

Key Words: dark matter — Galaxy: kinematics and dynamics — Galaxy: structure

1. INTRODUCTION

Moni Bidin et al. (2010) and Moni Bidin et al. (2012b) (hereafter MB12b) have recently proposed a new three-dimentional approach to measure the dynamical mass in the Galactic disk up to large heights from the plane. Applying their method to the kinematical results of Moni Bidin et al. (2012a) (hereafter MB12a), MB12b found a surprising lack of dark matter at the solar position ($\rho_{\odot,\mathrm{DM}} = 0 \pm 1\,\mathrm{mM_\odot\,pc^{-3}}$). Bovy & Tremaine (2012) (hereafter BT12) argued that these results are flawed. Adopting a one-dimensional formulation, they recovered the expected DM density $\rho_{\odot,\mathrm{DM}}$ =8–10 $\mathrm{mM_\odot\,pc^{-3}}$, with a lower limit $\rho_{\odot,\mathrm{DM}} > 5\,\mathrm{mM_\odot\,pc^{-3}}$. Both MB12b and BT12 estimate the surface mass density $\Sigma(Z)$ within $\pm Z$ from the plane, from the integrated Poisson equation in cylindrical coordinates

$$2\pi G\Sigma(Z) = -\int_0^Z \frac{1}{R}\frac{\partial(RF_\mathrm{R})}{\partial R}dz - F_\mathrm{z}(Z), \quad (1)$$

where F_R and F_z are the radial and vertical components of the force per unit mass, respectively. We will indicate the integral term as $I_\mathrm{R}(Z)$ hereafter. MB12b assume a null radial gradient of the azimuthal velocity ($\partial_R\overline{V}$=$\partial\overline{V}/\partial R$=0) at any Z. BT12, arguing against this assumption, remove the whole integral I_R. While they claim that they only assume a flat rotation curve ($\partial_R V_\mathrm{c}$=0 at any Z), they actually implicitly assume $-F_\mathrm{R}R = V_\mathrm{c}^2$ up to Z=4 kpc, an equation strictly valid only on the plane. They also claim that $I_\mathrm{R}(Z) < 0$ and $I_\mathrm{R}/F_\mathrm{z} < 0.2$, hence their estimate is a lower limit, accurate within 20%. We are now performing new calculations and new studies. The results shown here are presented in more detail in Moni Bidin et al. (2015).

2. A LOWER LIMIT CORRECT WITHIN 20%?

It is easy to show that the BT12 claim ($I_\mathrm{R}(Z) < 0$, $I_\mathrm{R}/F_\mathrm{z} < 0.2$) is not general, but valid only under certain specific mass distributions. For example, $I_\mathrm{R}(Z) > 0$ for a Miyamoto-Nagai disk (Miyamoto & Nagai 1975) with a=4 and b =0.3 kpc, or a Flynn et al. (1996) disk with $R/h_\mathrm{R} > 2.3$, a condition most likely verified at the solar position (e.g., Jurić et al. 2008). A massive DM halo is required in this case to have a negative and small I_R. If I_R is positive and neglected, the *total* mass is overestimated, and the spurious excess of visible mass is ascribed to an even higher DM density. In conclusion, BT12 formulation implicitly assumes a specific mass density distibution. This is very unfortunate if the final aim

[1]Instituto de Astronomía, Universidad Católica del Norte, Av. Angamos 0610, Antofagasta, Chile (cmoni@ucn.cl).

[2]Departamento de Astronomía, Universidad de Concepción, Casilla 160-C Concepción, Chile.

[3]European Southern Observatory, 3107 Alonso de Cordova, Vitacura, Santiago, Chile.

[4]Dipartimento di Fisica e Astronomia, Universitá di Padova, Vicolo Osservatorio 3, 35122 Padova, Italy.

[5]Universidad de Chile, Departamento de Astronomía, Casilla 36-D Santiago, Chile.

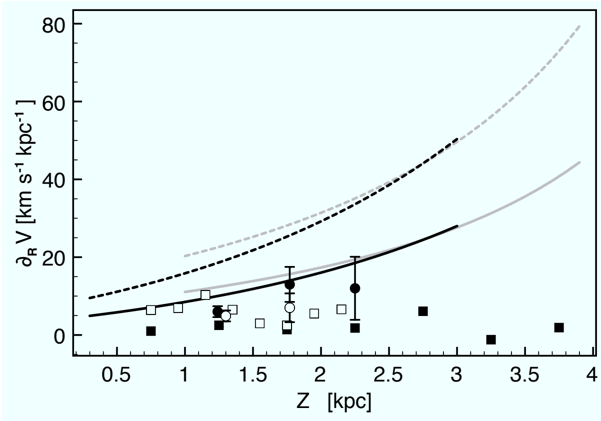

Fig. 1. $\partial_R \overline{V}(Z)$ predicted by the BT12 assumption, with the kinematics of MB12a (in black) and CD11 (in grey), and thick disk parameters of MB12b (solid curves) and BT12 (dashed curves). The solutions are compared with the results of CD11 (solid dots), our revision of CD11 results (open dots, see text), a symulated sample (solid squares), and SDSS data (open squares).

is to estimate the mass density itself. If the mass distribution is different from the expectations, the results are neither a lower limit, nor accurate witin 20%.

3. TEST TO THE BT12 ASSUMPTION

The BT12 assumption requires $\partial(RF_{\rm R})/\partial R = 0$ at any Z. We can express $F_{\rm R}$ by means of the radial Jeans equation, to study the predictions on $\partial_R \overline{V}(Z)$ cast by the BT12 assumption. Adopting the kinematical results of MB12a or Casetti-Dinescu et al. (2011) (herafter CD11), and the thick disk geometrical parameters of BT12 or Jurić et al. (2008), we obtain the curves shown in Fig. 1. We note that:

- The expected thick disk kinematics is exotic: $\partial_R \overline{V}(Z)$ increases so steeply with R, that the well-known vertical shear observed at the solar position (e.g., Girard et al. 2006) disappears within 3 kpc farther out, and stars at Z=4 kpc co-rotate with those on the plane.

- Such kinematics has never been observed in external galaxies. In fact, $\partial_R \overline{V}(Z)$ is rather flat outside the central regions at any height (Kregel et al. 2004), and no appreciable variation of $\partial_R \overline{V}$ with Z is found (Yoachim & Dalcanton 2005, 2008).

- The observational data of CD11 indicate that $\partial_R \overline{V}(Z)$ is much lower than the predictions of BT12. Moreover, CD11 likely overestimate $\partial_R \overline{V}(Z)$ at the solar position, because they use stars in a large range of R. A revision of their results considering only the stars with R=7–9 kpc returns even lower values (see Fig. 1).

- SDSS data fully confirm that, while $\partial_R \overline{V}(Z)$ is not zero, it is small and nearly constant with Z.

- While BT12 claim that $\partial_R \overline{V}(Z)$ must steeply increase with Z, orbit integration simulations relax to a very small $\partial_R \overline{V}(Z)$ in the Flynn et al. (1996) Galactic model.

The BT12 assumption is therefore ruled out by all observational evidences, both in the Milky Way and in external galaxies.

4. MB12B REVISED

Figure 1 shows that the MB12b assumption $\partial_R \overline{V}(Z) = 0$ is only a rough approximation. If it is dropped, an additonal term is added to the formulation (see Equation (21) of MB12b). Assuming $\overline{V}(Z)$ from MB12a and $\partial_R \overline{V}(Z)$ from CD11, we obtain $\rho_{\odot,{\rm DM}}$ in the range 2–3 $\pm 3\,{\rm mM}_\odot\,{\rm pc}^{-3}$, depending on the adopted thick disk parameters. These should be considered only upper limits, due to the likely overestimate of $\partial_R \overline{V}(Z)$ by CD11. The resulting local DM density is compatible with the previous results of MB12b. In conclusion, dropping the questioned assumption and estimating the new term from the data available in the literature, barely changes the results. Hence, this assumption is not the cause of a major bias, and the BT12 criticism is not an explanation of the lack of DM found by MB12b.

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