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Triaxiality can explain the alleged dark matter deficiency in some dwarf galaxies

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CONTEXT

Dark Matter (DM) is an ingredient essential to the current cosmological concordance model (ΛCDM). It provides the gravitational pull needed for the baryons to form galaxies. Therefore, the existence of galaxies without DM is both disquieting and extremely interesting.[1] Thus, the finding of galaxies lacking DM prompted much discussion in the technical literature (e.g., van Dokkum et al. 2018; Trujillo et al. 2019).

Recently, Guo et al. (2019) presented *further evidence for a population of dark-matter-deficient dwarf galaxies.* They found 19 dwarfs that may consist only of baryons. They were selected from a sample of 324 galaxies in the ALFALFA HI survey (Haynes et al. 2011) that have optical counterparts and so their baryon mass (stars plus gas; M_{bar}) can be measured. The total mass of the galaxies (i.e., DM plus baryons) was inferred from the HI line width after correcting for the line-of-sight inclination (i) of the assumed HI disk. The unknown i was estimated from the axial ratio b/a measured on the optical images, leading to

$$M_{dyn} = M^i_{dyn}\,\sin^2 i\,\frac{1-(b/a)_0^2}{1-(b/a)^2}, \tag{1}$$

where M^i_{dyn} is the true dynamical mass, and M_{dyn} represents the dynamical mass estimated from the minor (b) and major (a) axes of the galaxies projected in the plane of the sky. The thickness of the disk, $(b/a)_0$, was set to 0.2. Guo et al. (2019) consider and discard various systematic effects associated with the misalignment between the HI and optical disks that may cause $M_{dyn} \neq M^i_{dyn}$. However, they bypass the triaxiality of the dwarf galaxies, i.e., the fact that dwarfs are 3D objects with different sizes in the three axes, while for $M_{dyn} \simeq M^i_{dyn}$ in Eq. (1) galaxies have to be axisymmetric structures. Such oversimplification may cause $M_{dyn} \ll M^i_{dyn}$ thus weakening their case for the existence of DM-deficient dwarfs.

EFFECT OF TRIAXIALITY ON THE DYNAMICAL MASS ESTIMATE

The galaxies are assumed to be disk-like so that when viewed almost face-on ($\sin i \to 0$) then $b/a \to 1$ and Eq. (1) gives $M_{dyn} \simeq M^i_{dyn}$. However, if the real galaxies are triaxial then $b/a \neq 1$ even when $\sin i \to 0$, leading to $M_{dyn} \ll M^i_{dyn}$ for small i. This effect was not considered by Guo et al. (2019) in their analysis, despite triaxiality being the rule among dwarf galaxies (e.g., Roychowdhury et al. 2013; Putko et al. 2019). The issue is whether triaxiality explains the apparent deficit of DM shown by some of their galaxies.

A Monte Carlo simulation was designed to address the impact of this triaxiality-induced bias on M_{dyn}. Specifically, we model the distribution of M_{dyn} provided by Eq. (1) from a non-DM-deficient distribution of M^i_{dyn}. All model galaxies have the same 3D ellipsoidal shape set by the three semi-axes A, B, and C.[2] The projection in the plane of the sky depends on the inclination and azimuth of the galaxy and can be computed analytically to get b/a (e.g.,

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[1] Although their existence can be accommodated without twisting the ΛCDM paradigm; e.g., Haslbauer et al. (2019).

[2] $A \geq B \geq C$, $A = B \gg C$ for disks, and $A \neq B \neq C$ for triaxial objects.

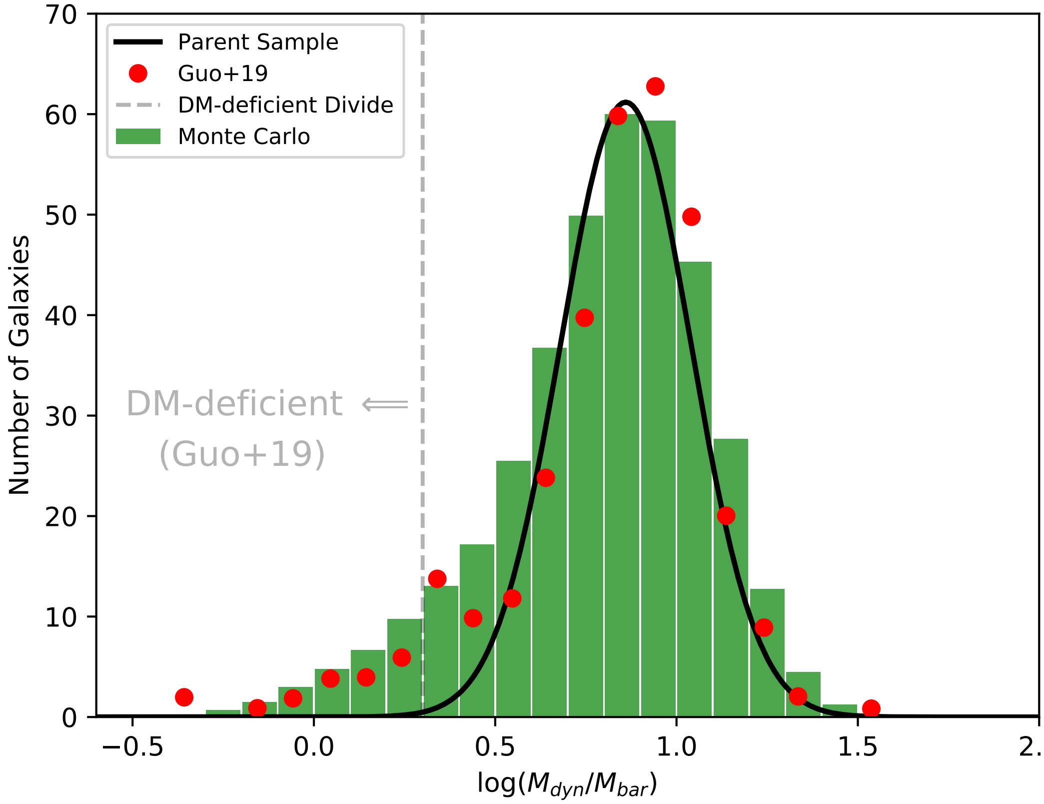

Figure 1. Monte Carlo simulated distribution of $\log(M_{dyn}/M_{bar})$ resulting from the triaxiality-induced bias. From a parent distribution with $M^i_{dyn} >> M_{bar}$ (black line; Gaussian with mean and standard deviation taken from the parent sample of Guo et al. 2019), the bias creates a long tail toward $M_{dyn} \simeq M_{bar}$ (green bars). The simulated distribution closely resembles the distribution inferred by Guo et al. (2019, red symbols). Almost face-on triaxial galaxies are never recognized as such in optical images, which systematically underestimate M_{dyn} (Eq. [1] with $b/a \neq 1$ even when $i \to 0$). All model galaxies have the same baryon mass and 3D axial ratio ($A : B : C = 1 : 0.62 : 0.3$), with random orientations independently of their true dynamical mass. Following Guo et al. (2019), only galaxies with $0.3 \leq b/a \leq 0.6$ are included in the simulated histogram, which is scaled to match the number of observed galaxies.

Simonneau et al. 1998). Thus, M_{dyn} is set given M^i_{dyn} and the 3D shape and orientation of the model galaxy (see Putko et al. 2019). Assuming the orientation of the model galaxies to be random and independent of M^i_{dyn}, one recovers a histogram for $\log(M_{dyn}/M_{bar})$ with an artificial tail toward $\log(M_{dyn}/M_{bar}) \sim 0$ (Fig. 1, green bars), which is absent in the distribution of the true $\log(M^i_{dyn}/M_{bar})$ (Fig. 1, black line). The model distribution closely resembles the distribution inferred by Guo et al. (2019, red symbols). The tail in the model is almost exclusively determined by B/A, set to 0.62, a value consistent with the range found in literature (e.g., Roychowdhury et al. 2013; Putko et al. 2019).

Another independent argument also suggests bias. If unbiased, galaxies should have random orientations and, therefore, a uniform distribution of b/a provided they are disks. If biased, the alleged DM-deficient galaxies should preferentially have large b/a since they are almost face-on. The latter trend is present in the b/a observed by Guo et al. (2019). A Kolmogorov-Smirnoff test shows with 92 % confidence that their b/a are inconsistent with a uniform distribution, invalidating the use of b/a to determine i.

CONCLUSIONS

Our simulation shows how the triaxiality of dwarf galaxies must be considered to measure dynamical masses, calling into question that Guo et al. (2019) found further evidence for a population of DM-deficient dwarf galaxies. Such a population may consist of normal almost face-on HI disks with their inclination overestimated.

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