Dynamics of disk and elliptical galaxies in Refracted Gravity

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Abstract

We test Refracted Gravity (RG) (Cesare et al., 2020b, Cesare & Diaferio in prep.) by investigating the dynamics of disk galaxies in the Disk Mass Survey (DMS) and elliptical galaxies in the SLUGGS survey without the aid of dark matter. RG reproduces the rotation curves, the vertical velocity dispersions and the observed Radial Acceleration Relation (RAR) of DMS galaxies and the root-mean-square (rms) velocity dispersions of stars and globular clusters in SLUGGS galaxies. Our results show that RG can compete with other theories of gravity to describe the gravitational dynamics on galactic scale.

1. INTRODUCTION

In Newtonian gravity, we can model the observed rotation curves in the external regions of disk galaxies by assuming the presence of dark matter. This mass discrepancy can be neatly quantified by the RAR (McGaugh et al. 2016), which shows that the observed radial acceleration traced by the rotation curves ($g_{\rm obs}$) is tightly correlated with the Newtonian acceleration due to the baryonic matter distribution ($g_{\rm bar}$). The observed RAR is fitted by this relation (McGaugh et al. 2016):

$$g_{\rm obs}(R) = \frac{g_{\rm bar}(R)}{1-\exp\left(-\sqrt{g_{\rm bar}(R)/a_0}\right)} \quad (1)$$

with $a_0 = 1.20 \times 10^{-10}\ \mathrm{m/s^2}$.

Newtonian gravity needs dark matter also to reproduce the velocity dispersions in the outermost regions of elliptical galaxies, probed by the detection of kinematic tracers, like globular clusters (GCs) or planetary nebulae. Specifically, the mass discrepancy in these systems might be positively correlated with their ellipticity (Deur 2014).

2. REFRACTED GRAVITY

RG (Matsakos & Diaferio 2016) is a classic theory of gravity whose field equations yield the modified Poisson equation

$$\nabla \cdot [\epsilon(\rho)\nabla\phi] = 4\pi G\rho, \quad (2)$$

where the permittivity $\epsilon(\rho)$ is an arbitrary monotonic function of the mass density ρ with the asymptotic limits $\epsilon(\rho) = 1$ for $\rho \gg \rho_c$ and $\epsilon(\rho) = \epsilon_0$ for $\rho \ll \rho_c$. As a test case, we adopt the function

$$\epsilon(\rho) = \epsilon_0 + (1-\epsilon_0)\frac{1}{2}\left\{\tanh\left[\ln\left(\frac{\rho}{\rho_c}\right)^{Q}\right]+1\right\}, \quad (3)$$

with $\boldsymbol{\epsilon_0}$, $\boldsymbol{Q}$ and $\boldsymbol{\rho_c}$ free universal parameters (Fig. 1). Fig. 2 compares the gravitational fields in Newtonian and Refracted gravities for flat and spherical systems. In RG the acceleration boost in flat systems is due to the focusing of force lines rather than to the presence of dark matter as in Newtonian gravity.

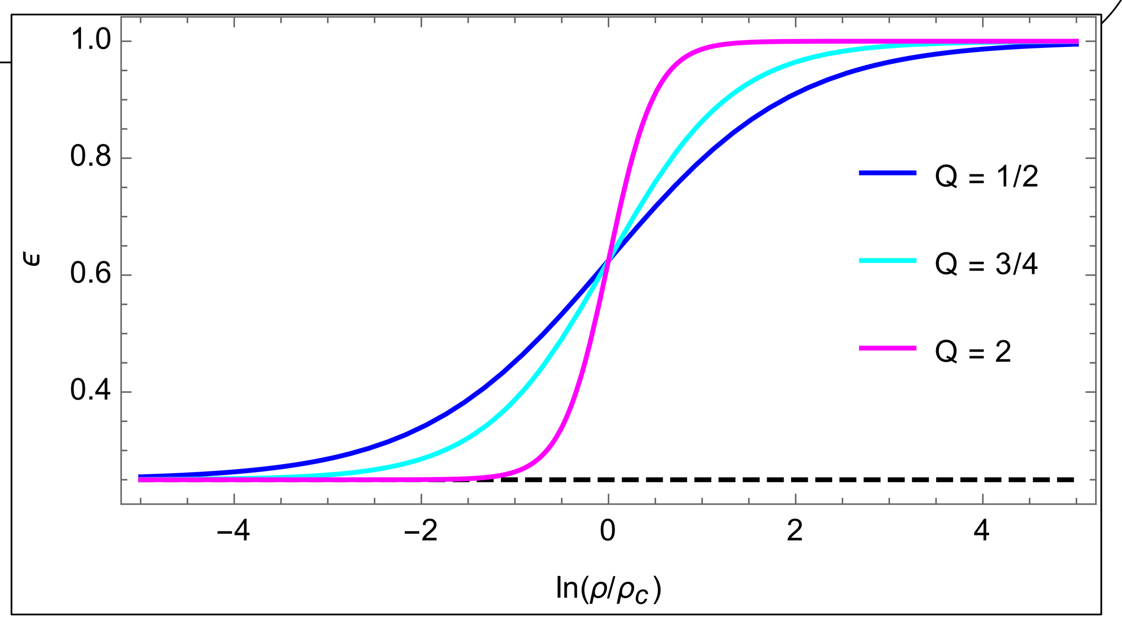

Figure 1

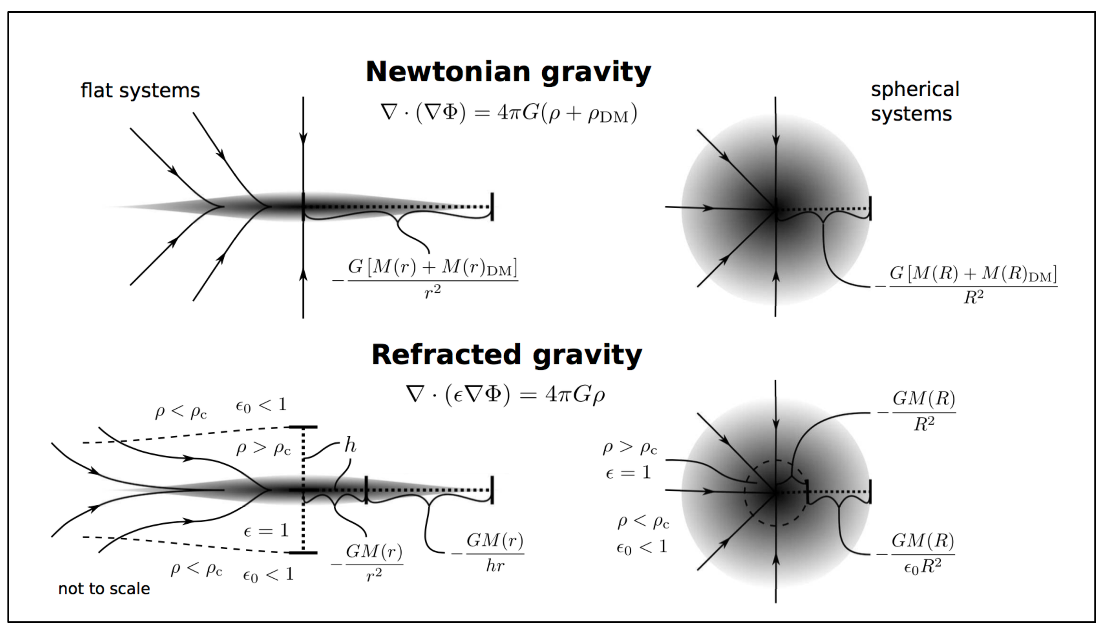

Figure 2

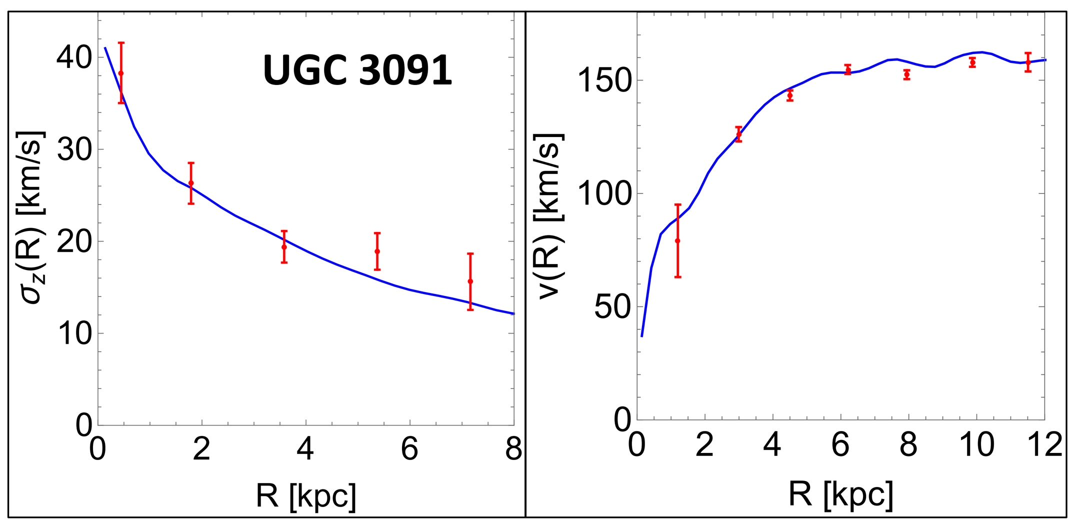

Figure 3

3. ROTATION CURVES AND VERTICAL VELOCITY DISPERSIONS IN DMS

We consider 30 disk galaxies from the DMS (Bershady et al. 2010a). We model the mass distribution with **(1) a stellar disk**, **(2) a spherical stellar bulge**, and **(3) an atomic and molecular gas components**.

We solve the RG Poisson equation (Eq. (2)) with a Successive Over Relaxation numerical method and use a MCMC algorithm to estimate the mass-to-light ratio, $\boldsymbol{\Upsilon}$, the disk scale height, $\boldsymbol{h_z}$, and the 3 RG parameters, $\boldsymbol{\epsilon_0}$, $\boldsymbol{Q}$ and $\boldsymbol{\rho_c}$, from the two kinematic profiles at the same time. Fig. 3 shows one example. Both profiles are well described and the flat trend in the outer region of the rotation curve is properly reproduced by RG.

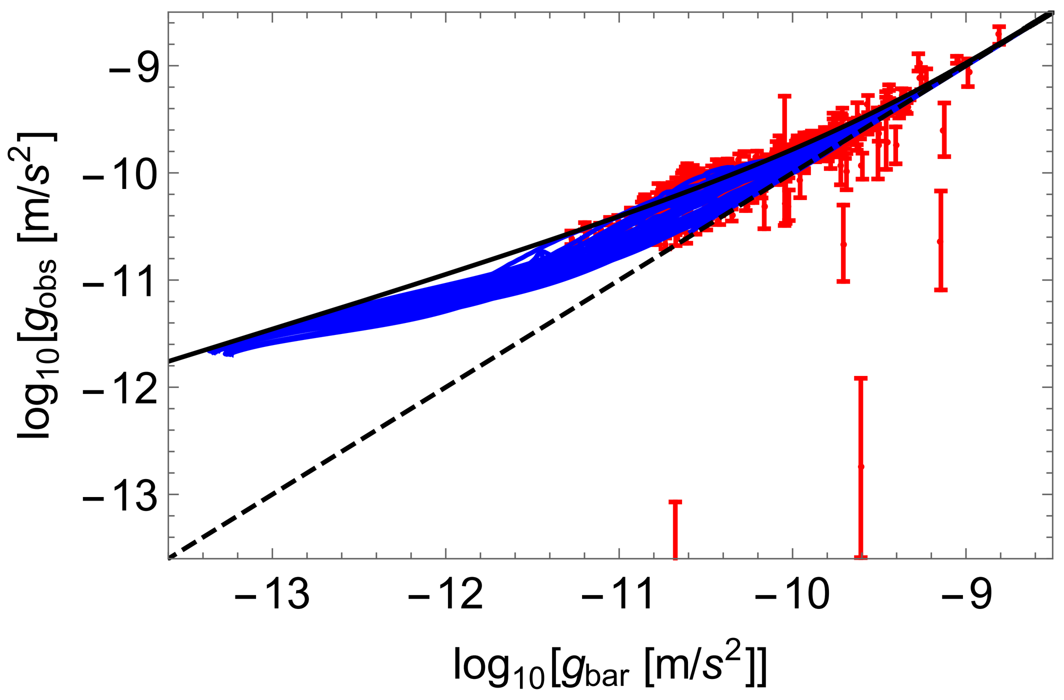

Figure 4

4. RAR IN DMS

Fig. 4 shows the RAR for DMS galaxies. The points with error bars show the data of the DMS sample, the black curve is Eq. (1), and the blue lines are the RG models. $g_{\rm obs}$ is the centripetal acceleration $\frac{v_{\rm obs}^2}{R}$ implied by the observed rotation curve $v_{\rm obs}(R)$ and $g_{\rm bar}$ is the baryonic radial acceleration, $\frac{\partial\phi}{\partial R}$, obtained by solving the Newtonian Poisson equation, $\nabla^2\phi = 4\pi G\rho$, where ρ is the sum of the contributions **(1)**, **(2)** and **(3)**. The two asymptotic limits for large and small $g_{\rm bar}$ of Eq. (1) are properly reproduced by RG.

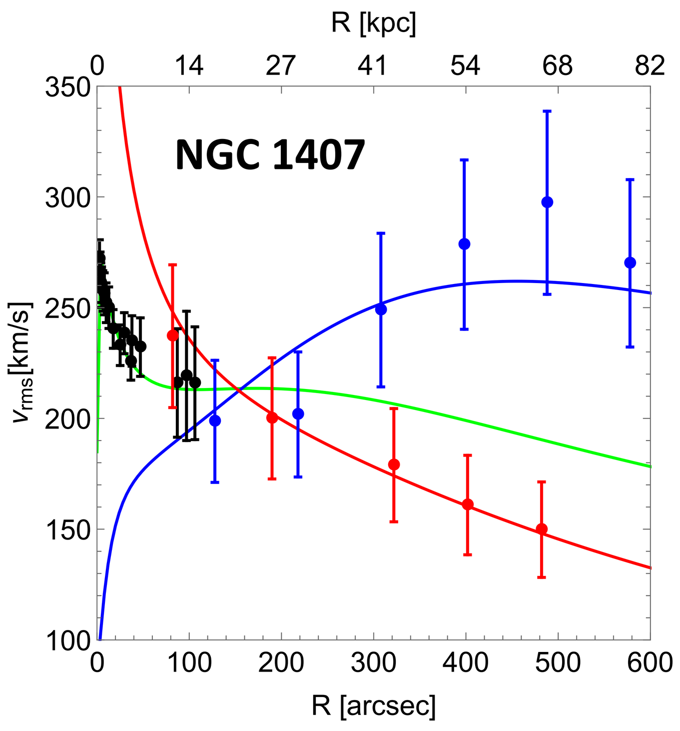

Figure 5

5. RMS VELOCITY DISPERSIONS IN SLUGGS

We consider 3 E0 galaxies from the SLUGGS survey (Pota et al. 2013). We model, at the same time, the rms velocity dispersions of the 3 kinematic tracers, **stars**, **blue GCs**, and **red GCs**, with spherical Jeans analysis:

$$V_{\rm rms,t}^2(R) = \frac{2G}{I_{\rm t}(R)}\int_R^{+\infty} K\left(\beta_{\rm t},\frac{r}{R}\right)\nu_{\rm t}(r)\frac{M(r)}{\epsilon(\rho)}\frac{\mathrm{d}r}{r}, \quad (4)$$

where $M(r)$ is the mass profile and $I_{\rm t}(R)$, $\nu_{\rm t}(r)$, and $\beta_{\rm t}$ are the surface brightness, the 3D luminosity density, and the anisotropy parameter of each tracer t. We estimate the mass-to-light ratio, $\boldsymbol{\Upsilon}$, the 3 RG parameters and the 3 $\beta_{\rm t}$ from the data with a MCMC. Fig. 5 shows one example: RG properly describes the dynamics of the three populations with a unique set of RG parameters.

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