Necessity of Dark Matter in Modified Newtonian Dynamics within Galactic Scales? - Testing the Covariant MOND in Elliptical Lenses

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ABSTRACT
Modified Newtonian Dynamics (MOND) and its relativistic version — TeVeS offer us an alternative perspective to understand the universe without the demand of the elusive cold dark matter. This MONDian paradigm is not only competitive with the conventional CDM in a large range of scales, but also even more successful in the galactic scale. Recently, by studying 6 lensing systems, Ferreras et al. (2008) claimed that MOND still needs dark matter even in galactic scales. When we study the same systems, however, we yield an opposite conclusion. In this contribution, we report our result and conclude that MOND does not need dark matter in galactic lensing systems. Furthermore, we extend our study to 22 SLACS (Sloan Lens ACS Survey) lenses, and obtain the same conclusion as well, i.e., no dark matter is needed in elliptical galaxies.

Key words: Gravitational lensing - MOND - dark matter - gravitation - relativity

1 INTRODUCTION
Migrom’s MOdified Newtonian Dynamics (MOND) is an alternative to the conventional dark matter paradigm for the rotation curve of galaxies and similar phenomena (Milgrom 1983). TeVeS—a relativistic MOND theory (Bekenstein 2004) offered an opportunity to explain relativistic phenomena such as cosmology and gravitational lensing (Chiu et al. 2006).

Recently, Ferreras et al. (2008) studied 6 lensing systems and claimed that MOND still needs dark matter even in galactic scales. We revisit the problem and arrive at an opposite conclusion. Here we report our result on 10 lens from CASTLES (including the 6 lens studied by Ferreras et al.) and 22 lens from SLACS.

2 LENSING EQUATION
Since in the MONDian paradigm mass distribution only follows baryon, we adopt the Hernquist model, \(|\nabla \Phi_N| = GM/(r + r_h)^2\), to the lenses. We incorporate our lensing formalism in a νHDM cosmological background (Ωₐ = 0.05, Ω⁺ = 0.17, Ωₐ = 0.78, h = 0.7).

In general, for any double-images lensing systems:
\[ \theta_+ \theta_- = \theta_E^2 \frac{\theta_+ f_+ + \theta_- f_-}{\theta_+ + \theta_-}, \]

where \(\theta_\pm\) are positions of the two images, \(\theta_E^2 = 4GMD_L D_S/c^2 D_L D_S\), and \(f_\pm\) are dimensionless functions, which depend on the mass model of lenses and the forms of \(\tilde{\mu}(x)\) in MOND. We consider (i) the Bekenstein’s form \(\tilde{\mu} = (-1 + \sqrt{1 + 4x})/(1 + \sqrt{1 + 4x})\) (Bekenstein 2004), (ii) the simple form \(\tilde{\mu} = x/(1 + x)\) (Famaey & Binney 2005), and (iii) the standard form \(\tilde{\mu} = x/\sqrt{1 + x^2}\) (Sanders & McGaugh 2002). Here \(x = a/a_0\), the ratio of the actual acceleration to the acceleration parameter in MOND.

3 DATA AND RESULT
We apply 10 CASTLES lensing systems along with 22 SLACS lenses to study strong lensing in TeVeS.

CASTLES Catalogue has the most complete list of strong lensing systems. We examine 10 double-image lenses from this catalogue, of which the (aperture) stellar masses have been estimated from stellar population synthesis with two initial mass functions (IMF), Salpeter’s and Chabrier’s (Ferreras et al. 2005). In Table 2 we list the aperture mass and total mass computed from the three forms of \(\tilde{\mu}(x)\) (Bekenstein, simple and standard).

We also work out the masses for 22 SLACS lens. SLACS lens come from SDSS Luminous Red Galaxy and MAIN SDSS galaxy sample, in which the dispersion velocity can be estimated. We use the M-σ relation in (Sanders 2000) to create a M-σ-R_eff relation of V-band in MOND, and apply
Table 1. Aperture mass (total mass) of 10 lenses from CASTLES ($10^{10}M_\odot$) in $\nu$HDM

| Lens            | Bekenstein | Simple | Standard |
|-----------------|------------|--------|----------|
| Q0142 − 100     | 10.79 (18.36) | 13.66 (23.20) | 16.05 (27.31) |
| HS0818 + 1227   | 18.14 (28.30) | 23.39 (36.17) | 27.79 (43.35) |
| FBQ9091 + 2635  | 1.54 (2.16) | 1.91 (2.67) | 2.15 (3.01) |
| BRI0952 − 0115  | 2.01 (2.48) | 2.59 (3.21) | 3.19 (3.93) |
| Q1017 − 207     | 2.45 (3.89) | 3.22 (7.55) | 3.81 (9.15) |
| HEI1104 − 1805  | 45.17 (59.58) | 58.44 (77.08) | 71.78 (94.68) |
| LBQ1009 − 025   | 7.71 (10.79) | 9.76 (13.67) | 11.53 (16.15) |
| B1030 + 071     | 9.76 (16.61) | 12.06 (20.51) | 13.80 (23.47) |
| SBS1520 + 530   | 11.91 (16.67) | 15.20 (21.28) | 18.08 (25.31) |
| HE2149 − 274    | 7.04 (13.58) | 8.96 (17.28) | 10.67 (20.58) |

Figure 1. Comparison of mass from lensing and mass from dynamical measurement (i.e., velocity dispersion). Simple form gives the best correlation.

Table 2. Mass of 22 lenses from SLACS ($10^{10}M_\odot$) in $\nu$HDM

| Lens           | $M_{\text{bek}}$ | $M_{\text{apl}}$ | $M_{\text{std}}$ | $M_\sigma$ |
|----------------|------------------|------------------|------------------|------------|
| SDSS J092097.8 − 005550 | 15.22 | 19.68 | 23.45 | 36.82 |
| SDSS J015758.9 − 005626 | 29.68 | 38.12 | 45.13 | 77.94 |
| SDSS J021652.5 − 081345 | 119.91 | 151.50 | 172.79 | 262.12 |
| SDSS J025245.2 + 003958 | 25.84 | 33.44 | 40.27 | 64.49 |
| SDSS J033012.1 − 002052 | 27.26 | 35.43 | 42.76 | 50.07 |
| SDSS J072805.0 + 383526 | 25.72 | 32.95 | 38.35 | 58.20 |
| SDSS J080558.8 + 470639 | 26.01 | 33.88 | 39.57 | 49.75 |
| SDSS J090315.2 + 416109 | 41.75 | 54.77 | 65.92 | 87.36 |
| SDSS J102053.3 + 002328 | 18.00 | 23.12 | 28.76 | 35.49 |
| SDSS J230321.7 + 142218 | 16.67 | 21.95 | 27.23 | 33.32 |
| SDSS J234111.6 + 000019 | 18.03 | 23.12 | 28.76 | 35.49 |

Figure 2. Aperture mass ($M_\text{ap}$) for 10 lenses from CASTLES ($10^{10}M_\odot$) in $\nu$HDM.

4 SUMMARY

Our investigation supports that there is no need of dark matter in elliptical galaxies.

Among the three choices of $\tilde{\mu}(x)$ of MOND, simple form seems to yield the best fit with dynamical counterparts. This echoes the dynamical studies in spiral galaxies (Famaey & Binney 2005; Famaey et al. 2007).

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