Publications of the Korean Astronomical Society
30: 381 ∼ 383, 2015 September

pISSN: 1225-1534
eISSN: 2287-6936
http://dx.doi.org/10.5303/PKAS.2015.30.2.381

FINDING THE ACCELERATION PARAMETER IN MODIFIED NEWTONIAN DYNAMICS WITH ELLIPTICAL GALAXIES

Yong Tian[1] & Chung-Ming Ko[2]
[1]Institute of Astronomy, National Central University, Taiwan (R.O.C.)
[2]Institute of Astronomy, Department of Physics and Center for Complex Systems, National Central University, Taiwan (R.O.C.); cmko@astro.ncu.edu.tw
E-mail: yongtian@astro.ncu.edu.tw
(Received November 30, 2014; Reviced May 31, 2015; Aaccepted June 30, 2015)

ABSTRACT

MOdified Newtonian Dynamics (MOND) is an alternative to the dark matter paradigm. MOND asserts that when the magnitude of acceleration is smaller than the acceleration parameter a_0, the response of the system to gravity is stronger (larger acceleration) than the one given by Newtonian dynamics. The current value of a_0 is obtained mostly by observations of spiral galaxies (rotation curves and the Tully-Fisher relation). We attempt to estimate a_0 from the dynamics of elliptical galaxies. We seek elliptical galaxies that act as the lens of gravitational lensing systems and have velocity dispersion data available. We analysed 65 Einstein rings from the Sloan Len ACS survey (SLACS). The mass estimates from gravitation lensing and velocity dispersion agree well with each other, and are consistent with the estimates from population synthesis with a Salpeter IMF. The value of a_0 obtained from this analysis agrees with the current value.

Key words: Dark Matter - Elliptical Galaxies - MOND - SDSS - Strong Lensing - Einstein Ring

1. INTRODUCTION

MOdified Newtonian Dynamics (MOND) asserts that when the acceleration of a system is small Newton's law of motion or the law of gravity have to be modified (e.g., Milgrom, 1983; Bekenstein & Milgrom, 1984). In the form of modified gravity, MOND can be expressed as a nonlinear Poisson equation (Bekenstein & Milgrom, 1984),

$$\nabla \cdot [\tilde{\mu}(|\mathbf{g}|/a_0)\mathbf{g}] = \nabla \cdot \mathbf{g}_{\rm N} = -4\pi G\rho \,, \qquad (1)$$

where $\mathbf{g}$ is the gravitational acceleration in MOND and $\mathbf{g}_{\rm N}$ in Newtonian dynamics. a_0 is the acceleration scale of MOND. With $x = |\mathbf{g}|/a_0$, $\tilde{\mu}(x)$ is called the interpolation function, which has the asymptotic behaviour $\tilde{\mu}(x) \approx 1$ for $x \gg 1$ (Newtonian regime) and $\tilde{\mu}(x) \approx x$ for $x \ll 1$ (deep MOND regime).

MOND has been successfully employed as an alternative to dark matter to explain the flat rotational curves and Tully-Fisher relation of spiral galaxies (see review by Sanders & McGaugh, 2002). From studies of spiral galaxies, the acceleration scale a_0 is found to be around $10^{-10}\,{\rm m\,s^{-2}}$. However, only a handful of investigation have been devoted to elliptical galaxies in the framework of MOND. Milgrom & Sanders (2003) found that MOND could explain the dynamics of the elliptical galaxies reported by Romanowsky et al. (2003), who used planetary nebulae to probe dynamics up to 6 effective radii. Chiu et al. (2006) established the formulation for gravitational lensing in relativistic MOND. It was employed in quasar strong lensing (Zhao et al., 2006; Chiu et al., 2011), and in quasar time delays (Tian et al., 2013) where the lenses are elliptical galaxies. Recently, Sanders (2014) tested MOND in 65 suitable Einstein rings with elliptical lenses from the Sloan Lens ACS (SLACS) Survey (Auger et al., 2009). He found that the mass in MOND lensing is consistent with the result from population synthesis with a Salpeter IMF. It is time to work out the acceleration scale a_0 using elliptical galaxies, something which has not been done before.

2. DATA AND METHODS

In this work we adopt 65 Einstein rings from the SLACS survey (same as Sanders, 2014). All the lenses in this sample have velocity dispersion measurements and estimated stellar masses from population synthesis (with a Salpeter IMF).

We assume the local mass-to-light ratio of the galaxies is constant and take a spherical Hernquist model for the stellar mass distribution (the gas content is negligible in elliptical galaxies)

$$\rho = \frac{M r_{\rm h}}{2\pi r(r+r_{\rm h})^3}\,, \quad \mathbf{g}_{\rm N} = -g_{\rm N}\,\hat{r} = -\frac{GM\,\hat{r}}{(r+r_{\rm h})^2}\,, \quad (2)$$

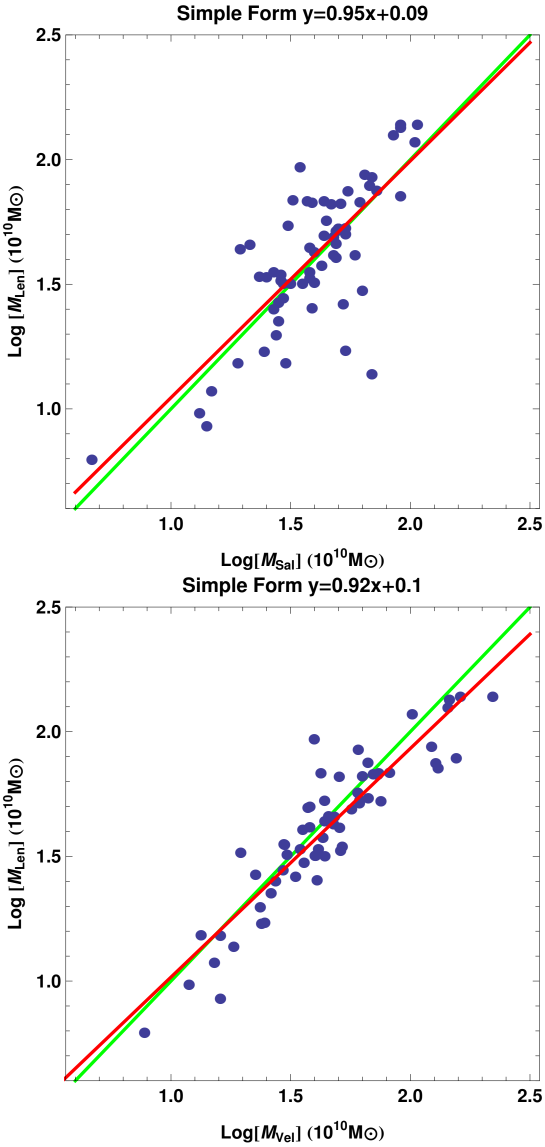

Figure 1. Relations between masses. *Top Panel*: Lensing mass versus dynamical mass. *Bottom Panel*: Lensing mass versus stellar mass. Red solid line is the best linear fit to the data, and green solid line denotes identical mass.

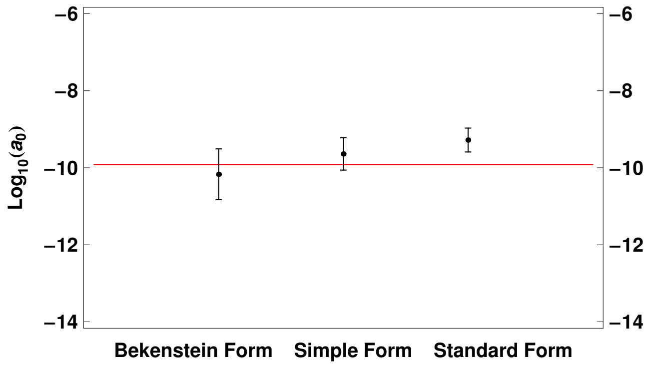

Figure 2. a_0 from different forms, red line is its value obtained from studies on spiral galaxies, i.e., $1.2 \times 10^{-10}\,\mathrm{m\,s^{-2}}$.

Table 1
THE MOND ACCELERATION SCALE a_0 (IN M S^{-2}).

	Bekenstein	Simple	Standard
Mean	6.81×10^{-11}	2.31×10^{-10}	5.28×10^{-10}

where M is the total stellar mass of the galaxy, $r_{\rm h} \approx 0.55\,r_{\rm eff}$ ($r_{\rm eff}$ is the effective radius or the half light radius). For an isotropic system, the velocity dispersion σ_r is given by $\rho\sigma_r^2 = \int_r^\infty \rho\, g\, {\rm d}r'$, in which $g = -|\mathbf{g}|$ and g_N is related by the interpolation function $\tilde{\mu}$. We use three forms of the interpolation function in the following analysis: the Bekenstein form, simple form and standard form (Chiu et al., 2011).

3. RESULTS

We calculate the total mass of the elliptical lens galaxies from the lensing equation of relativistic MOND (Chiu et al., 2006). The lensing mass in MOND is consistent with the result from population synthesis with Salpeter IMF, as shown in the upper panel of Figure 1. The slope of the best fit line of lensing mass and Salpeter IMF mass is close to 1; the green solid line in Figure 1 represents identical masses. We also calculate the dynamical mass (i.e., stellar mass in MOND) from the velocity dispersion of the lens galaxies. The dynamical mass and lensing mass are also consistent with each other (and with less scatter), as shown in the lower panel of Figure 1.

Since the masses are consistent with each other, we turn the problem around and attempt to solve for a_0 by adopting the mass from population synthesis (with Salpeter IMF) as the stellar mass of the elliptical galaxies. Together with the Hernquist model we have the mass distribution of the galaxies. The estimated acceleration at the effective radius of these galaxies is within the range $1 \sim 20\,a_0$. Thus, unlike the case of flat rotational curves and the Tully-Fisher relation in spiral galaxies which are in the deep MOND regime, the systems we are dealing with may be sensitive to different interpolation functions. We study three common interpolation functions, the Bekenstein form, the simple form and the standard form. We compute a_0 from the lensing equation. The result is shown in Table 1 and Figure 2. We conclude that the simple form is preferred, as the value of a_0 from the study of gravitational lens of elliptical galaxies agrees with the value ($a_0 = 1.2 \times 10^{-10}\,\mathrm{m\,s^{-2}}$) obtained from spiral galaxy studies.

ACKNOWLEDGMENTS

This work is supported by the Taiwan Ministry of Science and Technology grant MOST 102-2112-M-008-019-MY3.

REFERENCES

Auger, M. W., Treu, T., & Bolton, A. S., et al., 2009, The Sloan Lens ACS Survey. IX. Colors, Lensing, and Stellar

Masses of Early-Type Galaxies, ApJ, 705, 1099

Bekenstein, J. & Milgrom, M., 1984, Does the Missing Mass Problem Signal the Breakdown of Newtonian Gravity?, ApJ, 286, 7

Binney, J. & Tremaine, S., 2008, Galactic Dynamics: Second Edition, Chapter 4, Princeton University Press

Chiu, M. C., Ko, C. M. & Tian, Y., 2006, Theoretical Aspects of Gravitational Lensing in TeVeS, ApJ, 636, 565

Chiu, M. C., Ko, C. M., & Tian, Y., et al., 2011, Mass of Galaxy Lenses in Modified Gravity: Any Need for Dark Mass?, PhRvD, 83, 3523

Hernquist, L., 1990, An Analytical Model for Spherical Galaxies and Bulges, ApJ, 356, 359

Milgrom, M., 1983, A Modification of the Newtonian Dynamics as a Possible Alternative to the Hidden Mass Hypothesis, APJ, 270, 365

Milgrom, M. & Sanders, R. H., 2003, Modified Newtonian Dynamics and the "Dearth of Dark Matter in Ordinary Elliptical Galaxies", ApJ, 599, L25

Romanosky, A. J., Douglas, N. G., & Arnaboldi, M., et al., 2003, A Dearth of Dark Matter in Ordinary Elliptical Galaxies, Science, 301, 1696

Sanders, R. H., 2014, MNRAS, A Dearth of Dark Matter in Strong Gravitational Lenses, 439, 1781

Sanders, R. H. & McGaugh, S. S., 2002, Modified Newtonian Dynamics as an Alternative to Dark Matter, ARA&A, 40, 263

Tian, Y., Ko, C. M., & Chiu, M. C., 2013, Hubble Constant, Lensing, and Time Delay in Relativistic Modified Newtonian Dynamics, ApJ, 770, 154

Zhao, H. S., Bacon, D. J., & Taylor, A. N., et al., 2006, Testing Bekenstein's Relativistic Modified Newtonian Dynamics with Lensing Data, MNRAS, 368, 171