Testing TeVeS with Non-Spherical Lenses

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Introduction

TeVeS [Bekenstein (2004) relativistic MOND theory] has been under many observational tests lately. Zhao, Bacon, Taylor, Horne (2005) have modeled spherical lenses (point mass and Hernquist model) in TeVeS, and found many outliers when fitting observed CASTELS quasar lens sample. **OUR GAOLS** here are (i) to examine whether their findings are restricted to the spherical assumption by fitting quasar images using the analytica Kuzmin disk lens models, (ii) to constrain MOND interpolating functions by lensing fits.

Method

First, we set out some interpolating functions:

"standard model" $\mu(x) = \frac{x}{\sqrt{1+x^2}}$

"simple model" $\mu(x) = \frac{x}{1+x}$

"toy model" $\mu(x) = \frac{\sqrt{1+4x}-1}{\sqrt{1+4x}+1}$

"α–model" $\mu(x) = \frac{2x}{1+(2-\alpha x)+\sqrt{(1-\alpha x)^2+4x}}$

where, for the α–model, when $\alpha=1$, it is the simple model; and when $\alpha=0$, it is similar as toy model.

1. Kuzmin Disk

A Kuzmin disk's gravity can be treated as the gravity of two point masses M at opposite sides of the disk ($+r_k$ or $-r_k$). This means we can use the bending angle for one of the point-masses for a light path segment in the opposite side of the plane. The lens equation is,

$$\theta_s = \theta - \alpha$$
$$\alpha = \frac{D_{ls}}{D_s}\left(\int_{-\infty}^{-r_k}\frac{g_\perp(r)dz}{c^2} + \int_{r_k}^{\infty}\frac{g_\perp(r')dz}{c^2}\right)$$

where r_k is the Kuzmin length.

Here we will consider its two extreme situations: face-on and edge-on, because we consider that these two situations are the limits of a Kuzmin disk.

2. Methods to Fit Lens

Here we will examine lenses with almost co-linear double images.

Source position method:

$$\theta_{S1} = \theta_1 - \alpha_1, \quad \theta_{S2} = \theta_2 - \alpha_2, \quad \theta_{S1} = \theta_{S2}$$

where, θ_s is the source position, θ is the image position, α is the deflection angle. 1, 2 are the two images.

Flux ratio method:

$$A = \frac{\theta}{\theta_S}\frac{\partial\theta}{\partial\theta_S}$$
$$\frac{\partial\theta}{\partial\theta_S} = \left(1 - \frac{\partial\alpha}{\partial\theta}\right)^{-1}$$
$$R = \frac{A_1}{A_2}$$

where, A is amplification and R is flux ratio.

3. Flux ratio error as a measure of the goodness of lens model

With the source position method we can get the lens mass and predict the flux ratio F with two images. The difference between F and the observed flux ratio R can be used to measure systematic error of the lens model [assuming no microlensing etc.]. For a set of lenses ,we have

$$\Delta F = \sqrt{\Sigma\frac{F^2 - R^2}{N}}$$

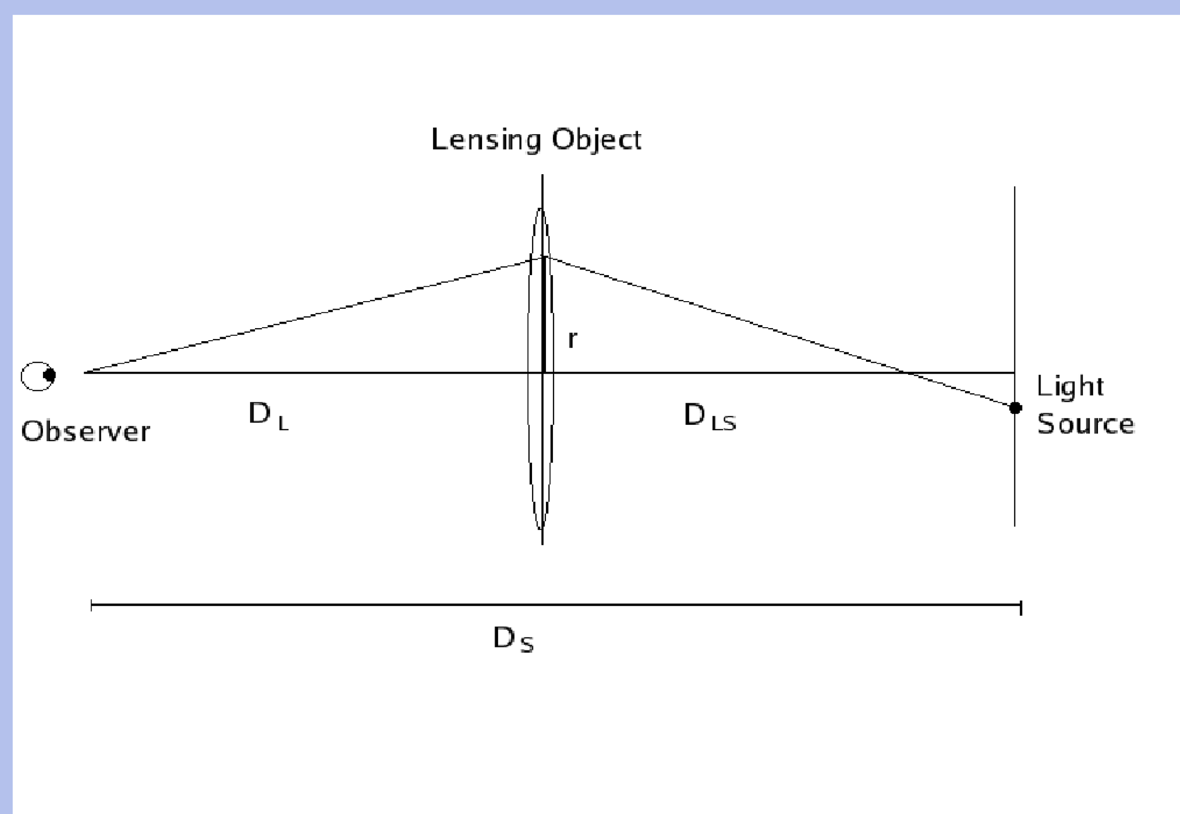

Fig. 1. Schematics of a kuzmin disk lens geometry. the angular distance from observer to lens, D_l, from lens to source, D_{ls}, and from observer to source, D_s. The light trace the dashed line.

Conclusion

Applying non-spherical Kuzmin disk lenses to test TeVeS, we find that,

1. Kuzmin disk TeVeS lensing can yield similar fits to observations [Fig. 2].

2. Different interpolating functions on many variation of the lens models yield very similar fits, too [Fig. 3] (we just choose a situation as an example here).

3. Considering a set of lens systems, we find that **TeVeS provides an acceptable explanation for the lensing data with reasonable correlations of lens mass with stellar mass and luminosity [Fig. 4, 5]. But outliers remain unexplained even for non-spherical lenses.**

4. The predicted image flux ratio from the image positions is generally at a variance with observed value. One reason may be that **the models are too simple to fit lens system [Fig. 6].**

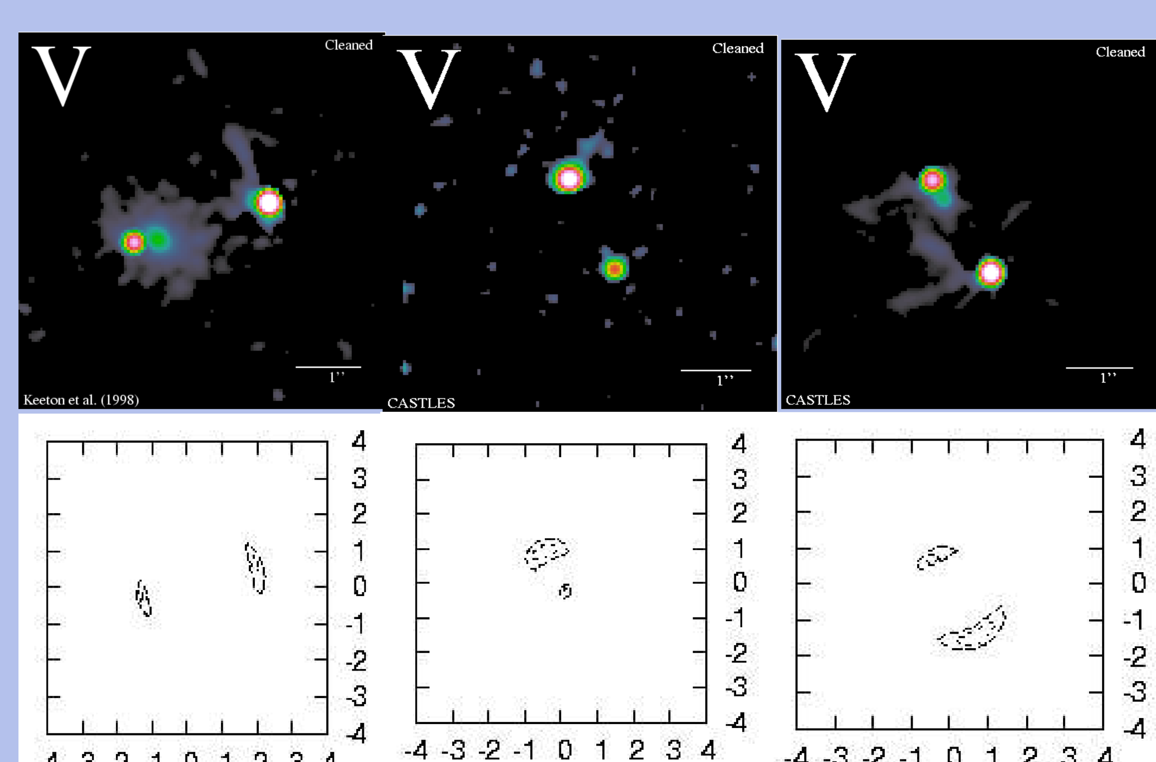

Fig. 2. Top: The observed nearly co-linear images of lens Q0142-100, LBQS1009-0252 and HE2149-2745 (from left to right). Bottom: The simulations of image positions for the three lens systems as a Kuzmin disk.

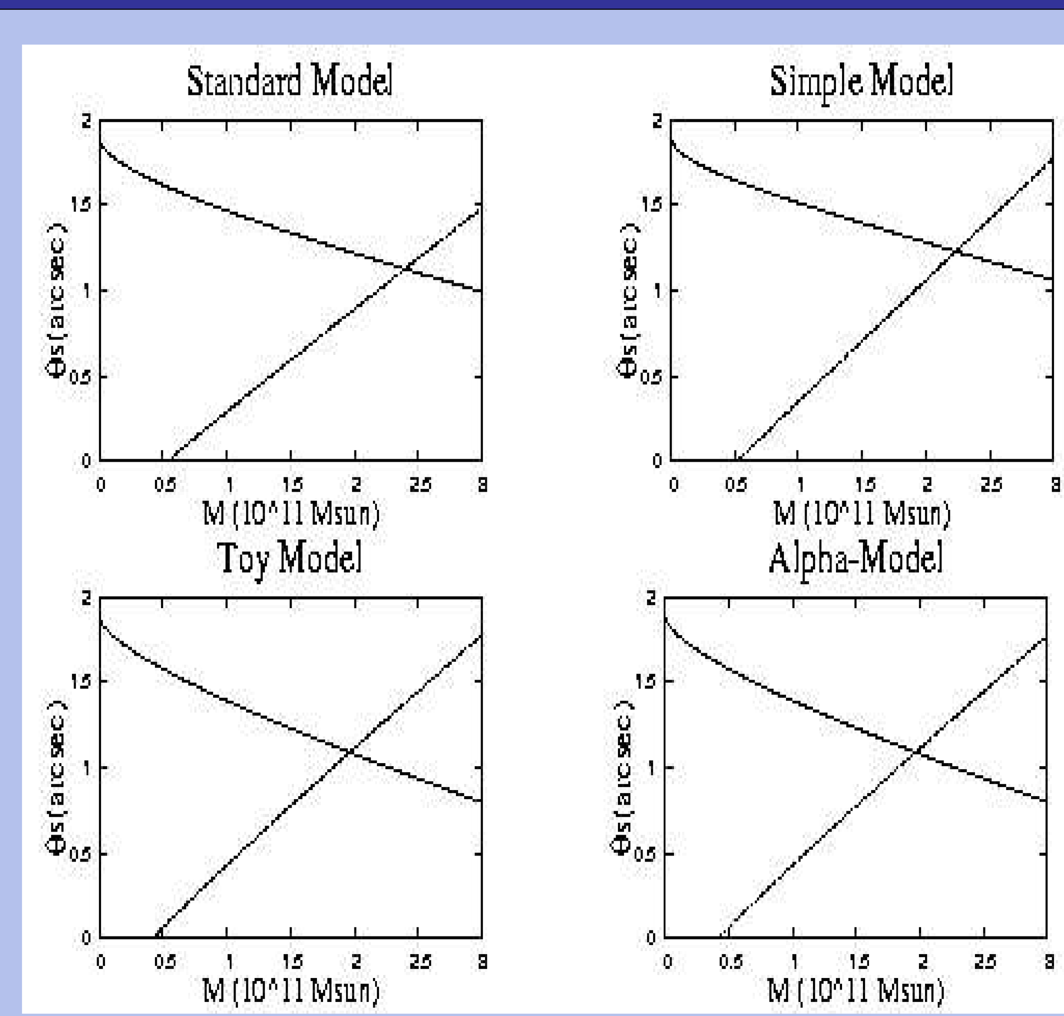

Fig. 3. Fit lens Q0142-100 as a face-on Kuzmin disk with different interpolating functions using source position method, where we choose $\alpha=0$ in α–model here.

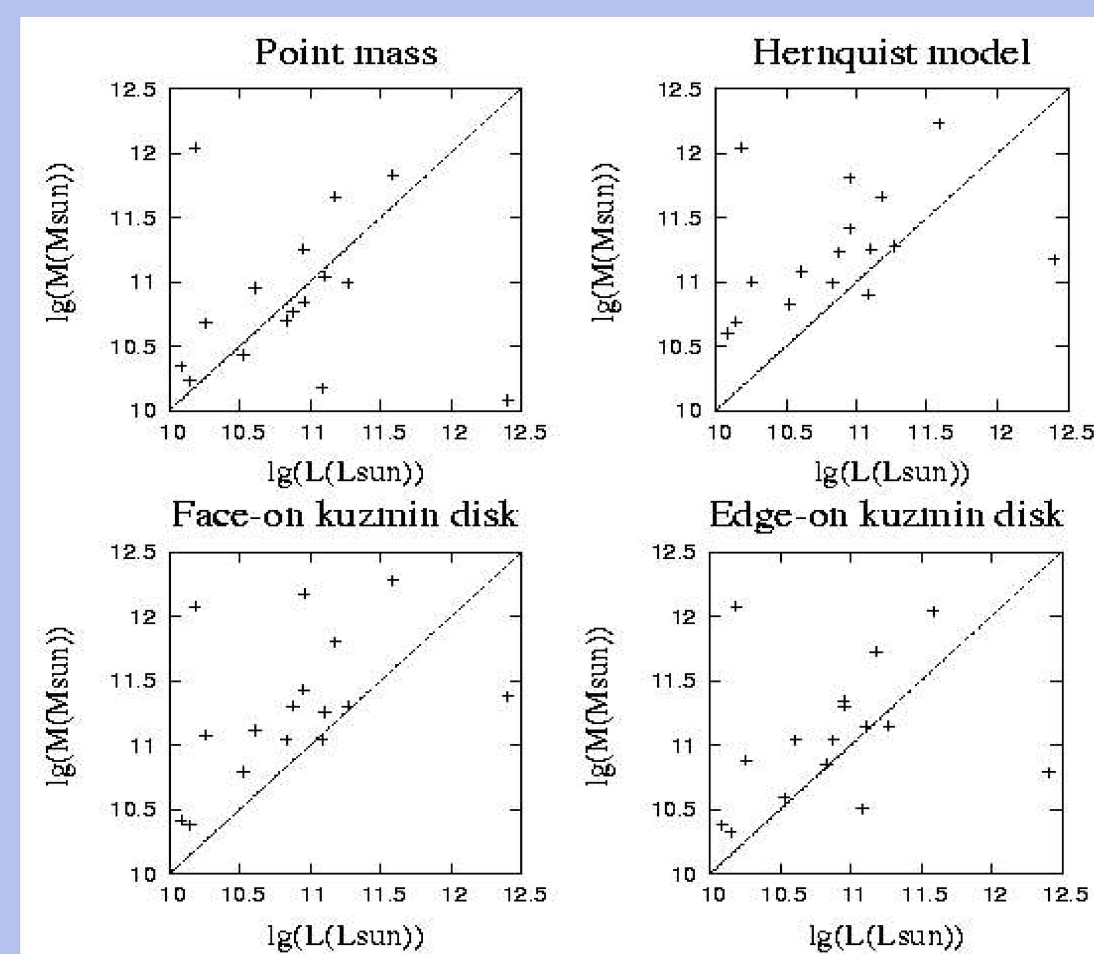

Fig. 4. The relation between TeVeS lens mass for 2-image lenses vs. F814 band absolute luminosity using source position method. Diagonal lines indicate M/L=1

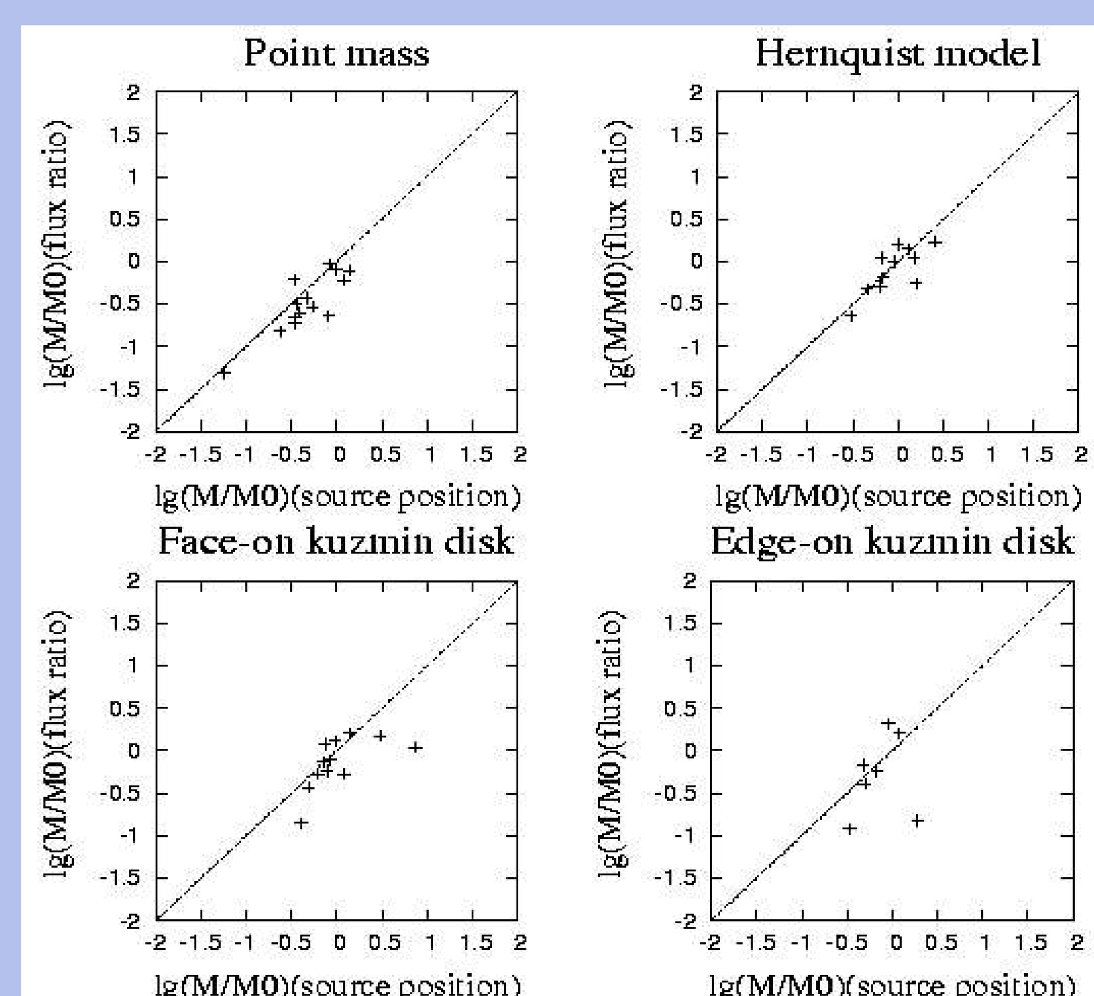

Fig. 5. The TeVeS lens mass to observed lens stellar mass ratio from two methods for different lens models, where M0 is the observation lens mass. Deviations from the diagonal lines indicate the mass ratio from two methods are not equal.

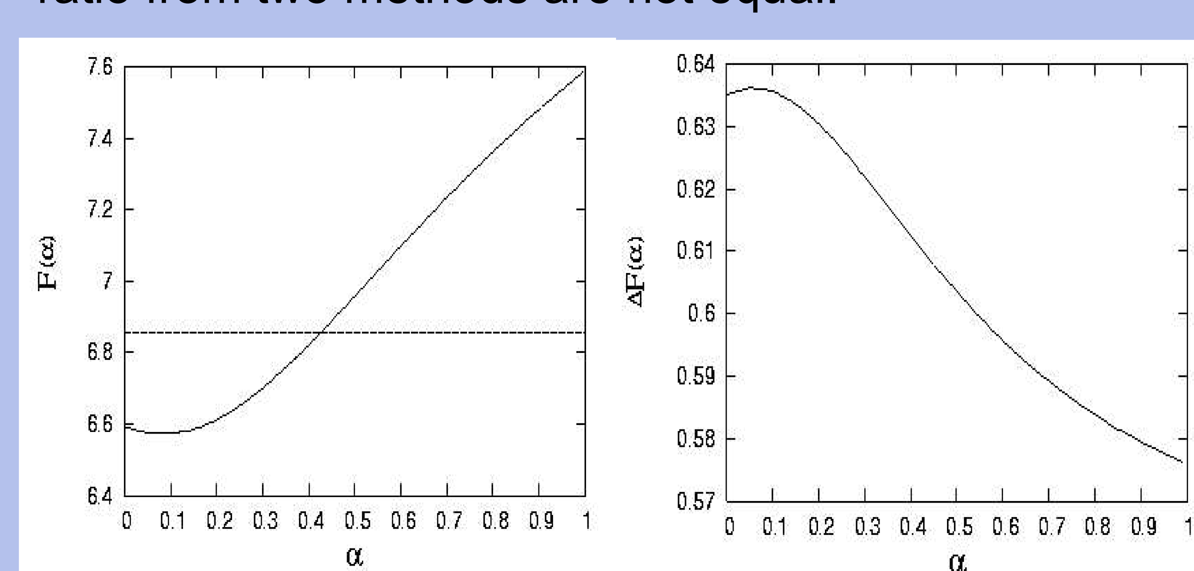

Fig. 6. Left: Lens Q0142-100's flux ratio $F(\alpha)$ from image position predictions (solid, as function of α) compared with the obs. flux ratio (about 6.857 as dashed). Right: Residue $\Delta F(\alpha)$ for 16 two-image lens galaxies. And we choose the Hernquist model as the lens model.