KINEMATICAL PROPERTIES OF ELLIPTICAL GALAXIES IN YUKAWA-LIKE GRAVITY

Vesna Borka Jovanović[1], Duško Borka[1] and Predrag Jovanović[2]

[1]Department of Theoretical Physics and Condensed Matter Physics (020), Vinča Institute of Nuclear Sciences - National Institute of the Republic of Serbia, University of Belgrade, P.O. Box 522, 11001 Belgrade, Serbia
[2]Astronomical Observatory, Volgina 7, P.O. Box 74, 11060 Belgrade, Serbia

***e-mail*: vborka@vinca.rs, dusborka@vinca.rs, pjovanovic@aob.rs**

ASTRONOMICAL OBSERVATORY BELGRADE

VINČA INSTITUTE OF NUCLEAR SCIENCES

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Motivation

Fundamental plane (FP) of elliptical galaxies can be used to constrain theories of gravity, i.e. to obtain observational constraints on the parameters of the theories of modified gravity [1,2,3]. The fundamental plane is connected to global properties of ellipticals and also can be connected with the parameters of extended theories of gravity. On the other hand several extended gravitation potentials in the weak field limit have Yukawa-like form. That is why in this paper we first analyze the velocity distribution of elliptical galaxies comparing theoretical results in case of Yukawa-like gravity with astronomical data for elliptical galaxies. In that way we constrain the Yukawa parameters α and λ, and analyze the properties of elliptical galaxies in Yukawa-like gravity where 1/λ is the range of Yukawa interaction (scale length) and α is a universal constant which gives the strength of the correction.

Yukawa-like gravity potential: $\Phi(r) = -\frac{GM(r)}{r}\left[1 + \alpha e^{-\lambda r}\right]$

Stelar kinematics in Yukawa-like gravity

Empirical relation: $\log(r_e) = a \times log(\sigma_0) + b \times log(I_e) + c$

The important empirical relation [4,5,6] gives us the possibility to obtain unique observational constraints on the structure, formation, and evolution of early-type galaxies, as well as on the parameters of the theories of modified gravity.

In order to model the mass distribution in elliptical galaxies, we took the singular isothermal sphere (SIS) model:

$$\mathrm{M}_{SIS}(r) = \frac{2\sigma_{SIS}^2}{G} \cdot r.$$

We obtain circular velocity:

$$v_c^2(r) = 2\sigma_{SIS}^2 \left(1 + \alpha\left(1 + \lambda r\right) e^{-\lambda r}\right)$$

If we introduce the new variable: $w = \lambda r_e$

the squared circular velocity at the effective radius (for $r = r_e$) is :

$$v_c^2(r_e) = \sigma_0^2 \left(1 + \alpha\left(1 + w\right) e^{-w}\right)$$

$$v_c/\sigma = \sqrt{1 + \alpha\left(1 + w\right) e^{-w}}$$

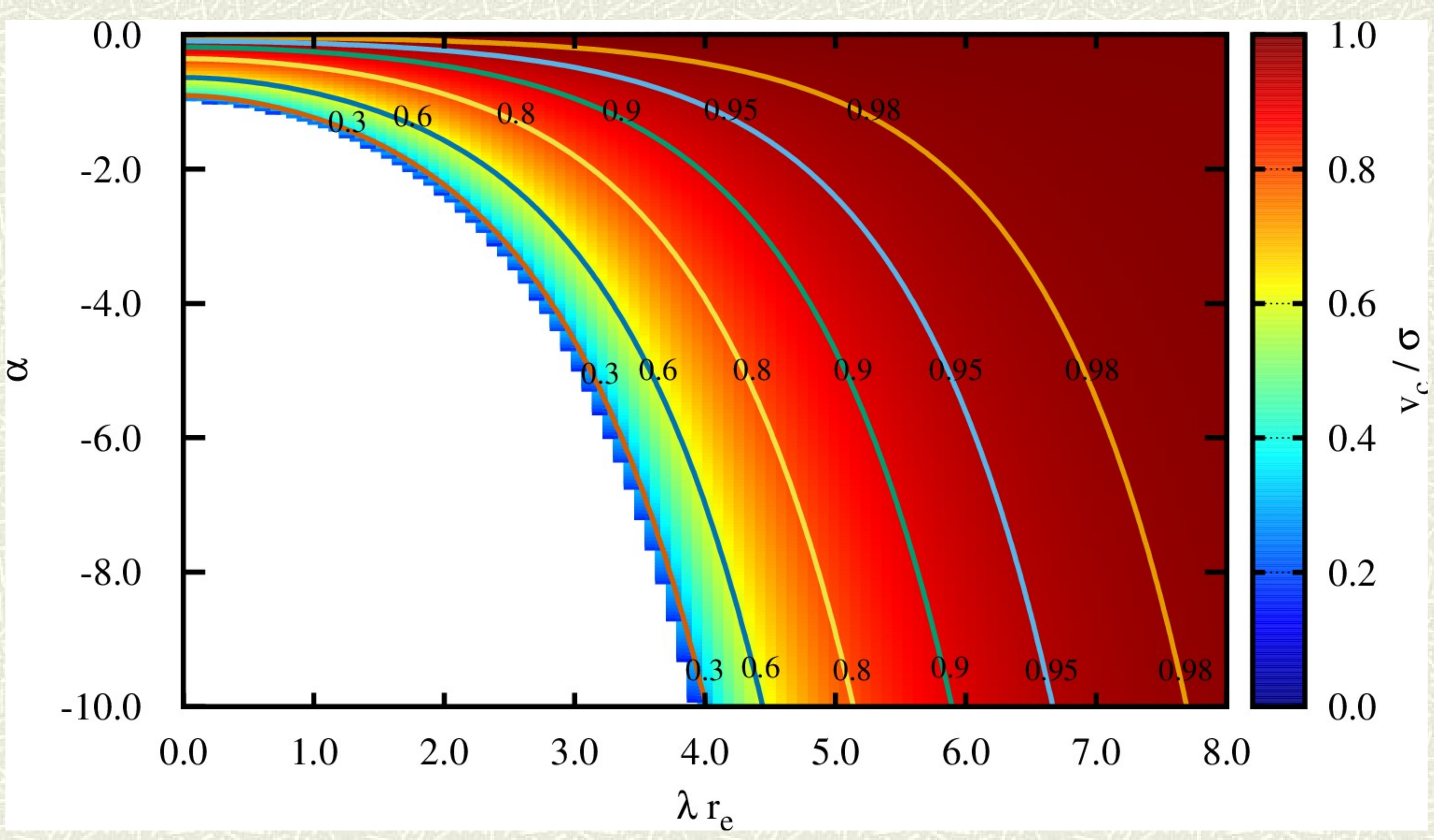

Figure 1. The vc/σ relation for the elliptical galaxies in the Yukawa-like gravity and represented by different color shades, as well as its dependence on the (λ, α) parameter space of the Yukawa-like gravitational potential.

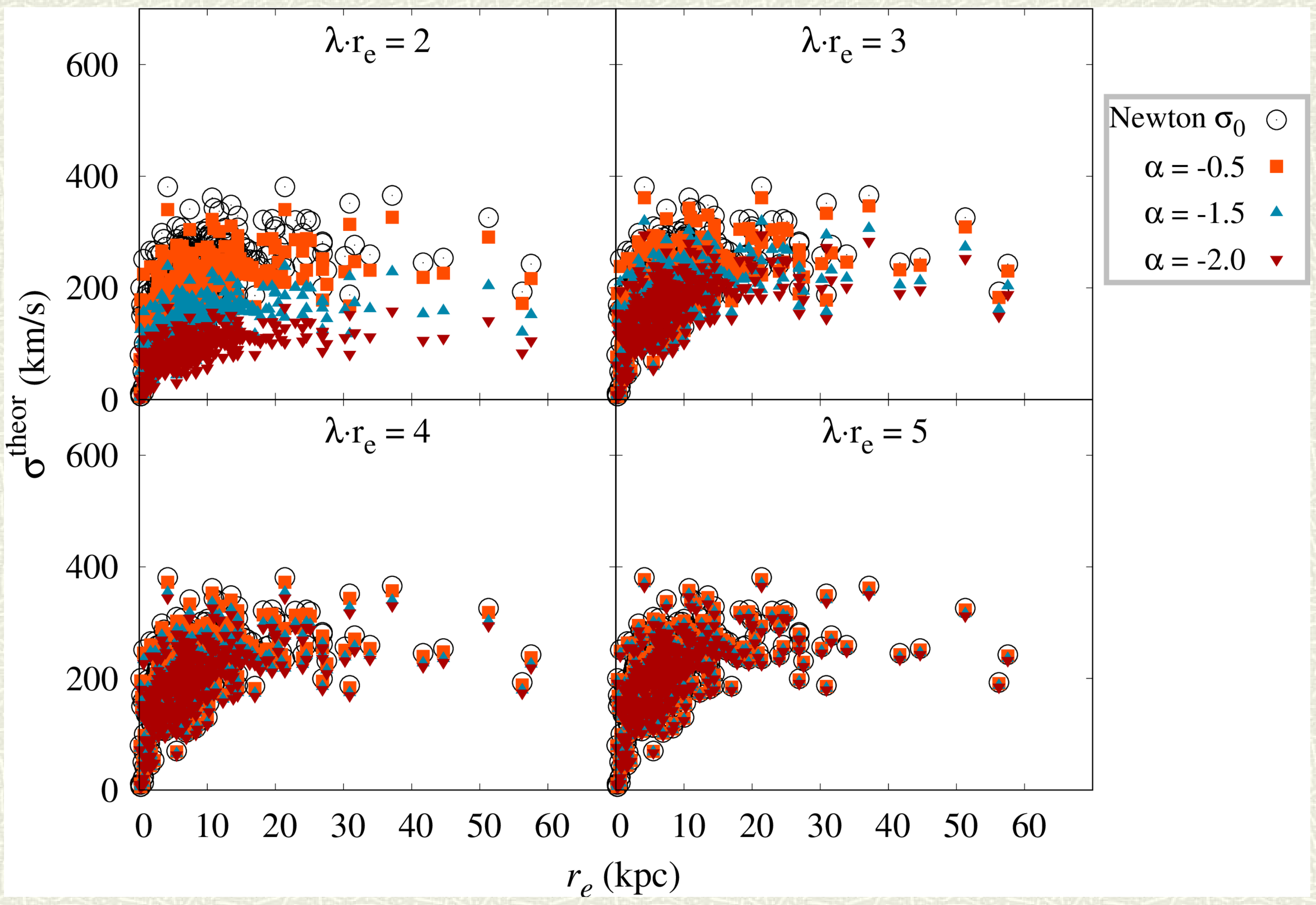

Figure 2. Velocity dispersion σ^{theor} as a function of the effective radius r_e for eliptical galaxies, for four different values of the $\lambda \cdot r_e$ product: 2, 3, 4 and 5. The Newtonian velocity dispersion at the effective radius σ_0 is taken from [7]. Theoretical values of velocity dispersion σ^{theor} are calculated for the three values of Yukawa parameter α: -0.5, -1.5 and -2.0.

α \ λr_e	2	3	4	5
-0.5	0.89	0.95	0.98	0.99
-1.5	0.63	0.84	0.93	0.97
-2.0	0.43	0.78	0.90	0.96

Table 1. The values of v_c/σ ratio for different combinations of (α, $\lambda \cdot r_e$) parameters of Yukawa-like gravity, presented in Fig. 2.

The obtained results show that the Yukawa-like gravity is able to explain elliptical galaxies with different stellar kinematics described by v_c/σ relations shown in Fig. 1 and Table 1, without introducing the dark matter hypothesis. Besides, we can notice from Fig. 2 that the Yukawa-like correction has strong influence on the FP of the elliptical galaxies, and that better agreement with observations is obtained for those gravity parameters α and λ which give a larger v_c/σ relation closer to 1 (i.e. for kinematically less hot systems). Therefore, the v_c/σ relation and the FP can be used as standard tools to probe the Yukawa-like gravity in the weak field limit, as well as to constrain its parameters α and λ.

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