Strong Gravitational Lensing in the Era of Big Data
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Impact of Galaxy Dynamics on Modified Gravity Constraints from Strong Lensing Systems

Grasiele Romanzini-Bezerra[1], **Martin Makler**[2,1] **and Cristina Furlanetto**[3]

[1]Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil.
email: bezerragrasiele@gmail.com

[2]ICIFI, Universidad Nacional de San Martín, Provincia de Buenos Aires, Argentina

[3]Universidade Federal do Rio Grande Sul, Porto Alegre, Brazil

Abstract. Galaxy-galaxy strong lensing systems have been used in literature to test General Relativity by constraining the post-Newtonian parameter (γ_{PPN}). Nevertheless, these methods are prone to systematic errors, some of which arise from difficulties in modelling the dynamics of the lens galaxy. In this study, we address the systematic error related to the assumption of a constant anisotropy between the radial and tangential components of the velocity dispersion of stars within the lens galaxy, characterised by the parameter β. We considered two radial models for the anisotropy parameter, the Osipkov-Merritt and Mamon & Lokas, as well three Gaussian priors for constant β. Our analysis showed that the choice of β has a strong impact on the value of γ_{PPN}, with radial models leading to lower values of this parameter.

Keywords. Strong lensing, galaxies

A test of General Relativity (GR) can be carried out using galaxy-galaxy strong gravitational lensing (SL) systems. In the weak field approximation, it is possible to characterise the space-time metric with two potentials: a Newtonian, Φ, and a curvature one, Ψ. The ratio of these two potentials is the post-Newtonian parameter, γ_{PPN}. In GR the value for this post-Newtonian parameter is one.

It is possible to measure the post-Newtonian parameter at galactic scales by using SL systems in which the lens object is an early-type galaxy (ETG) (e.g., Cao *et al.* 2017). As gravitational lensing is sensitive to the sum of the potentials $(\Phi + \Psi)$, whereas the stellar kinematics exclusively relates to the Newtonian potential (Φ), combining these observables enables effective constraints on the parameter γ_{PPN}.

Despite the recent advancements in the measurement of γ_{PPN} through this method (Cao *et al.* 2017; Collett *et al.* 2018), there are still systematic uncertainties to be addressed. A specially concerning one is the systematic error caused by the incomplete knowledge on the dynamics of the lens galaxy. In particular, the anisotropy in the velocity dispersion of its stars, β, cannot be directly determined from observational data and is not accurately predicted from simulations. Addressing and understanding this systematic error is crucial for accurate measurements of γ_{PPN}.

In this work, we employ a methodology similar to that of Cao *et al.* (2017), where the velocity dispersion of the stars in the lens galaxy is determined by assuming power-law models for both the mass density and brightness profiles. The derived velocity dispersion is utilised to calculate $\overline{\sigma_*}(\theta_E)$, representing the observed line-of-sight velocity dispersion

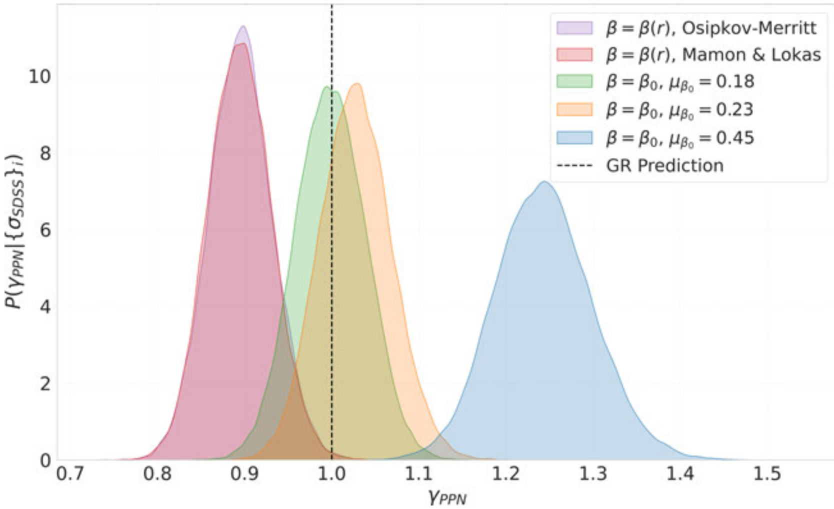

Figure 1. The posterior PDF of γ_{PPN} for the five models considered in this work: the two $\beta(r)$ models of OM and ML and the three Gaussian priors on β.

within the spectroscopic aperture. This computation takes into account the lens brightness and corrects for the point spread function. Furthermore, for this study we consider different priors on β and investigate their impact on the constraints on γ_{PPN}. First we derived the posterior probability density function (PDF) for γ_{PPN} for three Gaussian priors with the following parameters from the literature (written as: $\beta_0 = \mu_\beta \pm \sigma_\beta$): $\beta_0 = 0.18 \pm 0.13$, as in Cao *et al.* (2017); $\beta_0 = 0.45 \pm 0.25$, from Koopmans *et al.* (2009); and $\beta_0 = 0.23 \pm 0.19$, from Wang *et al.* (2019).

In addition to a constant velocity anisotropy, we consider two radial profiles for β: the Osipkov-Merritt (OM) model (Osipkov 1979; Merritt 1985) and the Mamon & Lokas (ML) one (Mamon *et al.* 2005). The OM is given by

$$\beta_{\rm OM}(r) = \frac{r^2}{r^2 + r_a^2}, \tag{1}$$

where $r_a = a\, r_{200}$, with r_{200} being the radius where the mean density of the galaxy is equal to 200 times the critical density of the universe. And the ML is given by

$$\beta_{\rm ML}(r) = \frac{1}{2}\frac{r}{r + r_a}. \tag{2}$$

We employed the aforementioned anisotropy profiles in the computation of $\overline{\sigma_*}(\theta_E)$. This quantity can be directly compared to the actual velocity dispersion σ_v obtained from the spectra of the lens galaxies of our sample. In addition to the Einstein radius, θ_E, measured from the SL modelling, $\overline{\sigma_*}$ depends on the density and brightness profiles, the cosmological distances involved, $\beta(r)$ and γ_{PPN}.

From the data set comprising 80 strong lensing systems used in Cao *et al.* (2017), containing measurements of θ_E and σ_v, we optimised the likelihood to obtain a PDF for γ_{PPN} for the different anisotropy models described above. The results are shown in Figure 1. The two superimposed curves on the left correspond to the OM and ML models for $\beta(r)$. The green curve following those reproduces the result of Cao *et al.* (2017), which used $\beta_0 = 0.18 \pm 0.13$. The two curves on the right (orange and blue), correspond, respectively, to the priors $\beta_0 = 0.23 \pm 0.19$ and $\beta_0 = 0.45 \pm 0.25$.

In summary, there is a clear correlation between β_0 adopted and γ_{PPN}. Furthermore, the models featuring radially dependent anisotropy profiles (OM and ML) yield lower

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values for the post-Newtonian parameter values than the constant β models considered. The pivotal inference drawn from this analysis underscores the pronounced influence of assumptions surrounding β on the resultant γ_{PPN} outcomes, thereby evoking considerations about potential biases in prior selections for β in preceding investigations. Despite the significance of contrasting lens stellar kinematics with the lensing phenomenon as a crucial experiment for GR and modified gravity theories at galactic scales, it becomes evident that achieving precise outcomes will require a deeper understanding of the anisotropy profiles.

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