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Constraining general relativity at z ∼ 0.299 MUSE Kinematics of SDP.81

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Abstract. General Relativity has been successfully tested on small scales. However, precise tests on galactic and larger scales have only recently begun. Moreover, the majority of these tests on large scales are based on the measurements of Hubble constant (H_0), which is currently under discussion. Collett *et al.* (2018) implemented a novel test combining lensing and dynamical mass measurements of a galaxy, which are connected by a γ parameter, and found $\gamma = 0.97 \pm 0.09$, which is consistent with unity, as predicted by GR. We are carrying out this same technique with a second galaxy, SDP.81 at $z = 0.299$, and present here our preliminary results.

Keywords. gravitational lensing, stellar dynamics, gravitation

1. Introduction

General relativity (GR) has been tested in many ways. Precise tests in the Solar System and the Milky Way show that GR is currently the most successful theory of gravity (Will 2014; Ferreira 2019). However, on larger scales, there are few tests of this theory. Although GR is the most successful theory of gravity, some unresolved tensions remain, for example, inconsistent values for the Hubble constant (H_0) (Riess 2020) and the discovery of dark energy. For these reasons, modified theories of gravity have been proposed to address these tensions (Ishak 2019). One such approach is the Parameterized Post-Newtonian (PPN) formalism (Bertschinger 2011).

The PPN formalism has two important potentials: the classical Newtonian potential Φ, which acts on massive and non-relativistic particles; and Ψ, that can be interpreted as a curvature potential, more important for the motion of relativistic and massless particles. In the weak gravitational field approximation, GR predicts that these two potentials must be the same, $\Phi = \Psi$. Usually, the PPN approach is characterized by the parameter $\gamma = \Psi/\Phi$, that clearly is equal to one for GR.

One way of constraining this parameter is to measure the mass of a galaxy by different methods, such as gravitational lensing and dynamical modeling. The measurement of mass performed by gravitational lensing (M_{lens}) is sensitive to both potentials, while the dynamic mass measurement (M_{dyn}) is affected only by the classical Newtonian potential. In the PPN approach, these measurements are related by the simple relation $M_{dyn} = \frac{1+\gamma}{2} M_{lens}$.

2. SDP.81 data and MUSE Kinematics

To perform the test mentioned above, we use observations of SDP.81 obtained with three different instruments: Multi-Unit Spectroscopic Explorer (MUSE), Hubble Space Telescope (HST) and Atacama Large Millimeter/submillimeter Array (ALMA). SDP.81 (H-ATLAS J090311.6 + 003906) consists of an elliptical lens galaxy at $z_l = 0.299$, which

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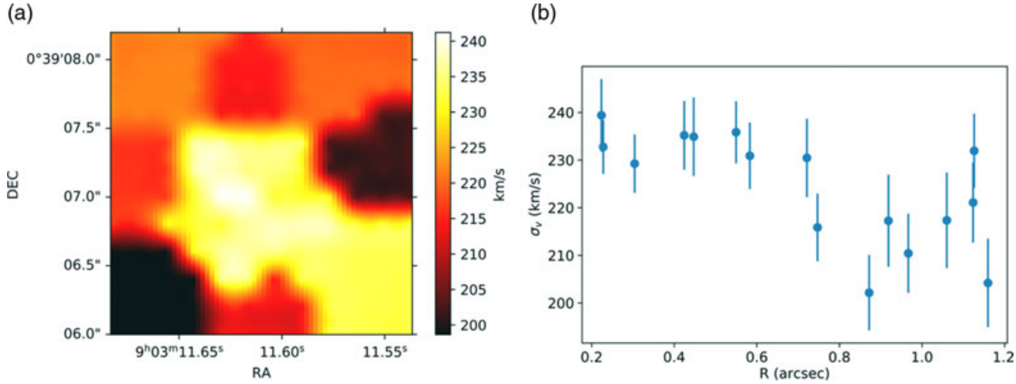

Figure 1. (a) velocity dispersion map of SDP.81. (b) radial profile of SDP.81 assuming the highest dispersion as the center of the galaxy. The error bar is the 1-σ deviation calculated through pPXF output. Note that from $R \approx 0.9''$ the velocity dispersion increases again.

is gravitationally lensing a submillimeter galaxy at $z_s = 3.04$. This system was observed with MUSE, covering the spectral range of 460−935 nm with 0.2″ spatial pixels. For the extraction of stellar kinematics, we use the Voronoi binning method (Cappellari & Copin 2003) in the central 2.5″. We use the pPXF method (Cappellari 2017) to determine the velocity dispersion in each bin in SDP.81 and the Medium-resolution Isaac Newton Telescope library of empirical spectra (MILES) (Sanchez-Blazquez *et al.* 2006) for modeling each binned spectrum in a wavelength range of 480−800nm, masking regions of emission and telluric lines. Finally, for each spectrum we derive a velocity V, velocity dispersion σ_V and 2 other moments (h_3,h_4). For the velocity dispersion, we construct a bi-dimensional map and a radial profile (Figure 1).

3. Discussion

As expected, the dispersion decreases from the galaxy center to the outskirts, but an unexpected result is the higher dispersion in the bottom right side of Figure 1a. This becomes clearer when we look at the radial profile in Figure 1b. Usually, these higher dispersions at the borders are caused by perturbations. However, in the SDP.81, there is no evidence for such perturbations. On the other hand, tests using higher S/N and different regions of the spectrum reproduce this same result, indicating that a problem with the fitting is unlikely. The next step is to construct a dynamical model based on HST images using the JAM code (Cappellari 2008), that could confirm or refute these previous results. Hereafter, we aim to combine these measurements obtained from kinematics with measurements obtained from the modeling of the gravitational lens to infer γ and test GR.

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