Boletim da Sociedade Astronômica Brasileira, **34**, no. 1, 124-125

The dynamical masses of galactic gravitational lenses

I. Beloto[1], E. Cypriano[1], & M. Makler[23]

[1] Instituto de Astronomia, Geofísica e Ciências Atmosféricas da USP, São Paulo, Brasil.
e-mail: ingridbeloto@usp.br, eduardo.cypriano@iag.usp.br
[2] Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brasil
[3] International Center for Advanced Studies, UNSAM, Buenos Aires, Argentina
e-mail: martinmakler@gmail.com

Abstract. One way to estimate the value of the post-Newtonian gravitational parameter γ on a galactic scale is to compare the dynamic mass of galactic gravitational lensing (which does not depend on γ) with the mass found through gravitational lensing modeling (which will depend on γ). The aims of this research is inserted in this context, with the purpose of measuring the velocity dispersion of lens galaxies through their spectra, to find the dynamical mass of the sample. These spectra were acquired through observations made with the SOAR telescope in the first and second half of 2022 using the long slit configuration with the Goodman spectrograph. Furthermore, with the aid of 5-band photometry of the sample, it is intended to determine properties of the stellar populations of these galaxies including the initial stellar mass function. Until the current period, it was possible to extract the spectra of the 10 galaxies observed in the first semester using *software* IRAF, and to infer the velocity dispersion of 5 of these with the pPXF code.

Resumo. Uma forma de estimar o valor do parâmetro gravitacional pós-newtoniano γ em escala galáctica é comparar a massa dinâmica de lentes gravitacionais galácticas (que não depende de γ) com a massa encontrada por meio da modelagem da lente gravitacional (que irá depender de γ). O objetivo desta pesquisa está inserido neste contexto, tendo como finalidade medir a dispersão de velocidades das galáxias lente através de seus espectros, para encontrar a massa dinâmica da amostra. Estes espectros foram adquiridos através de observações feitas com o telescópio SOAR no primeiro e segundo semestre de 2022 utilizando a configuração de fenda longa com o espectrógrafo Goodman. Além disso, com o auxílio da fotometria em 5 bandas da amostra, pretende-se determinar propriedades das populações estelares dessas galáxias incluindo a função de massa estelar inicial. Até o atual período, foi possível extrair os espectros das 10 galáxias observadas no primeiro semestre utilizando o *software* IRAF, e inferir a dispersão de velocidades de 5 destas com o código pPXF.

Keywords. Galaxies: stellar content – Galaxies: kinematics and dynamics – Galaxies: luminosity function, mass function – Gravitational lensing: strong – Techniques: spectroscopic – Methods: observational

1. Introduction

It is known that currently the cosmological model ΛCDM is based on the General Theory of Relativity (GR). Such a theory would have been successful in tests carried out on scales comparable to the Solar System, but for the cosmological model to be more substantiated, it is necessary to prove the theory also on cosmological scales. To this end, the post-Newtonian parameter γ is analyzed, which describes a curvature induced by a body with additional mass to the curvature predicted in the GR in the Schwarzchild metric (Eq. 1).

$$ds^2 = -\left(1 - \frac{2GM}{c^2 r}\right)c^2dt^2 + \left(1 + \gamma\frac{2GM}{c^2 r}\right)dr^2 + r^2 d\phi^2 \qquad (1)$$

In order to find the value of γ, the study of the effect of strong gravitational lensing between galaxies is used, measuring the mass of the lensing galaxy through its kinematics.

Equating the value of this measurement (which does not depend on γ), with the mass equation found via gravitational lenses (dependent on γ), one can infer values for the analyzed parameter.

2. Aims

The main objective of this project is to determine the velocity dispersion of galactic gravitational lenses with an accuracy of approximately 5% from the spectra obtained with the Goodman/SOAR long slit and, with these data, estimate the dynamical masses of galaxies to obtain γ. Additionally, with the help of photometry in 5 filters that we have, we will determine the mass-luminosity ratio and the stellar populations of these galaxies.

3. Methods

The first step was to obtain the spectra of 10 galaxies (Fig. 1) previously chosen, giving priority to systems where the redshift of the lens and the source had already been measured spectroscopically, in order to guarantee the measurement of the mass via gravitational lenses, and in addition to being systems with particularly favorable morphologies for modeling.

These galaxies were observed by Eduardo Cypriano (supervisor of this master's degree) and by Martin Markler (P.I. of the general project) in the SOAR telescope, using the Goodman spectrograph with a long slit and a diffraction grating of 600 lines/mm in the red configuration (6300Å to 8930Å). The exposure time varying from 1 to 3 hours according to the magnitude of each object. For data processing, the IRAF software[1] (Image Reduction and Analysis Facility) was used for flat field corrections, bias, exposure combinations, wavelength and flux calibrations, removal of sky background and telluric lines. For the removal of cosmic rays, the program LA-Cosmic[2] (*Laplacian*

[1] https://iraf-community.github.io/
[2] http://www.astro.yale.edu/dokkum/lacosmic/

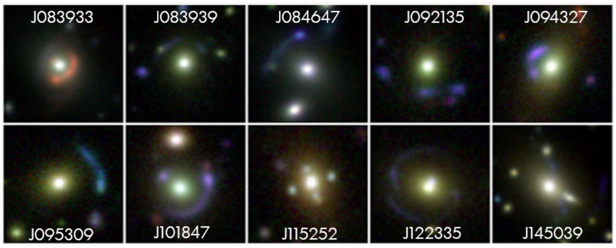


Figure 1. Sample of gravitational lensing observed with Goodman/SOAR.

Cosmic Ray Identification; Pieter & van Dokkum 2001) was used. Finally, after extracting the spectrum, it was possible to obtain the velocity dispersion of some of the objects through the width of the absorption lines, using the pPXF code (*Penalized Pixel-Fitting*; Cappellari, 2017) which adjusts the model taking into account a χ^2 which penalizes bad pixels in the adjustment.

4. Results

In Fig. 2 we can see five examples of spectra fitted with the pPXF code (Cappellari, 2017).

Table 1 contains the values found for the velocity dispersions of the stars in the sample galaxies, as well as their uncertainty and the signal-to-noise ratio of the objects.

Galaxy	z	S/N	σ_v (km/s)
J083933	0.27	22	288±15
J084647	0.24	18	269±21
J083939	0.43	24	301±13
J101847	0.39	16	291±21
J115252	0.47	15	217±24

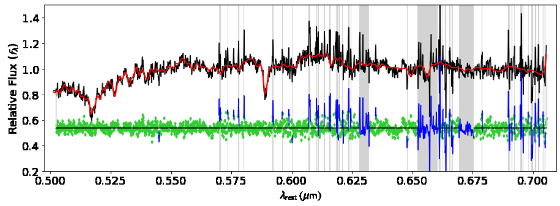
Table 1. Table containing the results of the fit given by pPXF, where z is the *redshift*, S/N the signal-to-noise ratio and σ_v the velocity dispersion found.

5. Conclusions

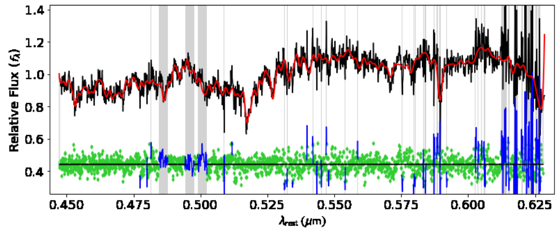
It was possible to notice that objects with a signal-to-noise ratio greater than 20 reached the measurement objective of σ_v with an error of 5%. The next step will be to observe other systems with an exposure time that may allow reaching an S/N>20, thus obtaining accurate σ_v values. After measuring the dispersion for all galaxies, the dynamical mass inference will be made through the MAMPOSSt code (*Modelling Anisotropy and Mass Profile of Spherical Observed Systems*; Mamon, Biviano & Boué 2013) using the Jeans equation. Finally, the determination of the M/L ratio and parameters of stellar populations with photometric data will be done.

Acknowledgements. This study was financed in part by the *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* - Brasil (CAPES) - Finance Code 001.

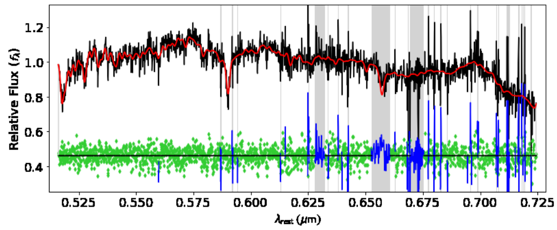
ESC acknowledges the support of the funding agencies CNPq (309850/2021-5) and FAPESP (2019/19687-2)



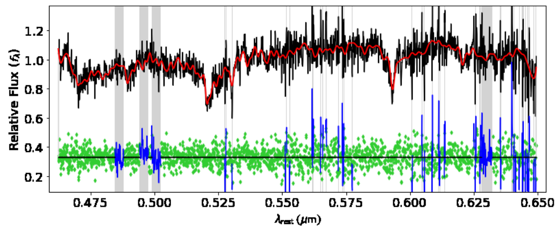
(a) J083933



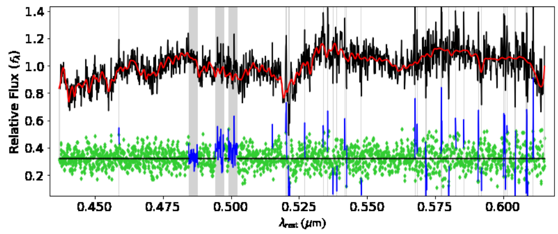
(b) J083939



(c) J084647



(d) J101847



(e) J115252

Figure 2. Fit (in red) made with pPXF in 5 spectra of the sampled galaxies. Green dots represent residuals and blue lines are noise in the spectrum that was discarded from the fit.

References

Cappellari M., 2017, MNRAS, 466, 798-811
Pieter G. van Dokkum 2001 PASP 113 1420
Mamon G., Biviano A., Boué G.,2013 MNRAS, 429, 4