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UNVEILING THE PROPERTIES OF FLS 1718+59: A GALAXY-GALAXY GRAVITATIONAL LENS SYSTEM

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ABSTRACT

We present the results of the analysis of FLS 1718+59, a galaxy-galaxy gravitational lens system in the *Spitzer* First Look Survey (FLS) field. A background galaxy ($z_s = 0.245$) is severely distorted by a nearby elliptical galaxy ($z_l = 0.08$), via gravitational lensing. The system is analysed by several methods, including surface brightness fitting, gravitational lens modeling, and spectral energy distribution fitting. From *Galfit* and *Ellipse* we measure basic parameters of the galaxy, such as the effective radius and the average surface brightness within it. *gravlens* yields the total mass inside the Einstein radius (R_{Ein}), and *MAGPHYS* gives us an estimate of the stellar mass inside R_{Ein}. By comparing these parameters, we confirm that the lens galaxy is an elliptical galaxy on the Fundamental Plane and calculate the stellar mass fraction inside R_{Ein}, and discuss the results with regards to the initial mass function.

Key words: gravitational lensing: strong – galaxies: elliptical and lenticular, cD – galaxies: mass function – dark matter

1. INTRODUCTION

The gravitational lens effect is one of the most fascinating predictions of Einstein's general theory of relativity. It occurs when the background source is sufficiently close to the foreground lensing object, in terms of angular distance. When the angular distance is less than the Einstein radius (R_{Ein}), which is a function of the mass of the lens, the source becomes significantly distorted, and we call this strong lensing. Since gravitational lensing depends solely on the mass distribution of the lensing object, it can be determined by detailed analysis, and offers a unique method for detecting dark matter in the lens.

The goals of this study are as follows. First, we analyze FLS 1718+59 using various methods, including surface brightness fitting, gravitational lens modeling, and spectral energy distribution (SED) fitting. Then, by estimating the velocity dispersion of the lens galaxy using the Fundamental Plane relation (Djorgovski & Davis 1987) and lens modeling, we confirm that it is an elliptical galaxy that lies on the Fundamental Plane. In addition, by comparing the stellar and lensing masses inside R_{Ein}, we calculate the stellar mass fraction at the galaxy core, and show that the Chabrier IMF explains the results of the analysis better than the Salpeter IMF.

A standard concordance cosmology with $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$, and $H_0 = 100h\ km/s$ is assumed, where $h = 0.7$. All magnitudes are in the AB magnitude system.

2. DATA

FLS 1718+59 is a newly discovered galaxy-galaxy gravitational lens system in the *Spitzer* First Look Survey (FLS) field, located at R.A. = 17h 18m 17.6s and Decl. = 59d 31m 46s. It was discovered from an image taken by the *Hubble Space Telescope* (HST) Advanced Camera for Surveys with the F814W filter, from the HST archives. The fact that the lens galaxy is one of the closest confirmed lenses that have been discovered so far enables us to delve into the details of the mass distribution of the lens galaxy. Photometric information from 15 broadbands, from the optical ($ugrRiz$) throughout the near infrared (JHK_s) and to the mid infrared (3.6, 4.5, 5.8, 8.0, 24, 70μm), taken from the NASA/IPAC Extragalactic Database (NED), comprise the rest of the data.

3. ANALYSIS

3.1. Surface Brightness Fitting

Galfit (Peng et al. 2002) and the *Ellipse* task of the Image Reduction and Analysis Facility (IRAF) were used as separate methods to measure basic parameters of the lens galaxy. In both cases, the lensed image was masked, then fitting procedures were conducted. The effective radius of the lens is measured to be 4.56 ± 0.007 kpc, a typical value for elliptical galaxies, and the Sèrsic index (Sèrsic 1968) is 4.09, also supporting the idea that the lens is an elliptical galaxy. The ellipticity and position angle, estimated from both methods, agree with each other within the errors.

3.2. Lens Modeling

We used *gravlens* (Keeton 2001) software for gravitational lens analysis, to estimate the total mass inside R_{Ein}. We use a singular isothermal ellipsoid as the lens mass profile, and use the ellipticity and position angle obtained from *Galfit* and *Ellipse* to constrain the parameters of the lens galaxy. We also assumed a two-component model for the source (bulge + disc). First, we inverse-map the brightest point of the lens image from the image plane to the source plane, to determine the position of the source. Then, we create models with various lens and source parameters, with the lens ellipticity and position angle fixed as above, and the source centered at the predetermined position. After that, we use *gravlens* to map these sources from the source plane back to the image plane, and convolve these images with the point spread function created with *Tiny Tim* (Krist et al. 2011). Finally, we compare these convolved images with the lens-subtracted residual image from *Ellipse*, and determine which set of lens and source parameters gives the best fit, by χ^2 minimization.

The most important parameter among the numerous parameters is the Einstein radius of the lens galaxy; the best fit comes out to be $0.5^{+0.02}_{-0.15}$ arcseconds, which corresponds to the mass inside R_{Ein} to be $log(M_{lens}/M_{\odot}) = 10.16^{+0.04}_{-0.31}$.

3.3. Spectral Energy Distribution Fitting

Multi-wavelength Analysis of Galaxy Physical Properties (MAGPHYS, da Cunha et al. 2008) is a program used for SED fitting, and gives the stellar mass (M_*) of the object. To estimate M_* inside R_{Ein}, we need to calibrate the magnitude data from NED to the same radius. We use the flux ratio of the luminosity inside R_{Ein} to the total luminosity in the *HST* F814W image for this calibration, which was calculated using SExtractor (Bertin & Arnouts 1996). The best fit SED gives $M_*(< R_{Ein}) = 10^{10.28} M_{\odot}$, when assuming a Chabrier initial mass function (IMF) (Chabrier 2003), which is the default IMF for *MAGPHYS*. Using the relation between the stellar masses assuming Chabrier and Salpeter IMFs (Salpeter 1955; Longhetti & Sarraco 2009), we get $M_{*,Salpeter}(< R_{Ein}) = M_{*,Chabrier}(< R_{Ein})/0.55 = 10^{10.54} M_{\odot}$.

4. DISCUSSION & SUMMARY

Using the Fundamental Plane relation coefficients from Hyde & Bernardi (2009), which is for the i filter, which is similar to the F814W filter, and inserting the effective radius and the average surface brightness inside it, obtained from *Galfit* results, we calculate $\sigma_{FP} = 203^{+75}_{-55} km/s$. The lens analysis also gives a velocity dispersion from $R_{Ein} = 4\pi(\sigma/c)^2(D_{ls}/D_{os})$, where $D_{ls/os}$ are the angular diameter distances from the lens or observer redshifts to the source redshift, respectively (Schneider et al. 1992). The result is $\sigma_{GL} = 162^{+3}_{-26} km/s$, so we can say that the lens galaxy is located close to the Fundamental Plane.

We can also compute the dark matter fraction within the Einstein radius ($f_{DM}(< R_{Ein})$), which is simply $1 - M_*/M_{lens}$, for masses within R_{Ein}. Treu & Koopsman (2002) demonstrate that for their lens galaxy at $z = 1.0$, $f_{DM}(< R_{Ein}) > 0.5$, while Auger et al. (2009), with their lenses from the Sloan Lens ACS survey, show that $f_{DM}(< R_{Ein}) = 0.6$ for a Chabrier IMF, and 0.3 for a Salpeter IMF. The results of this study are as follows; for a Chabrier IMF, $f_{DM}(< R_{Ein}) = -0.32^{+0.32}_{-1.77}$, and for a Salpeter IMF, $f_{DM}(< R_{Ein}) = -1.40^{+0.58}_{-3.22}$. We can see that the Chabrier IMF gives a marginally physically possible value, while the Salpeter IMF does not. Therefore, we conclude that the top-heavy Chabrier IMF is more likely than the bottom-heavy Salpeter IMF, and that the dark matter fraction must be dominant at the galaxy center. This is in line with previous studies; Treu et al. (2010) give evidence that the Chabrier IMF is more likely for $\sigma \sim 200km/s$, and Oguri et al. (2014) suggest that the Chabrier IMF is possible within 2σ.

To summarize, we have analysed the newly discovered lens system FLS 1718+59 using several methods, and obtain parameters of the lens galaxy. Comparing these parameters, we demonstrate that the lens galaxy is an elliptical galaxy located along the Fundamental Plane relation, and it is more likely that the galaxy follows a Chabrier IMF, with a high dark matter fraction at the galaxy center. A paper will be published with final results in the near future.

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