THE BRIGHT AND DARK SIDES OF ELLIPTICAL GALAXIES

Gravitational lensing search for dark matter haloes around early-type galaxies

Why bother ?

Unlike spiral galaxies, ellipticals offer few dynamical proxies to study their mass distributions. They lack a group rotation and strong hydrogen emission lines, as they have much less gas than spirals. Nonetheless, some authors have obtained dynamical data for early-type galaxies, based for example on the motion of planetary nebulae (1) or X-ray emission (2). The study of their kinematics has also become feasible for low-redshift galaxies : the SLUGGS survey team directly mapped star velocities in 14 early-type galaxies using the DEIMOS spectrograph at the Keck Observatory (3), but their respective results seem discrepant.

Because it does not depend on the galaxy type, gravitational lensing provides a solution to that problem. We aim to model the mass profiles of early-type gravitational lenses observed with the Hubble Space Telescope in the frame of the CASTLES survey (4), as well as their luminosity profiles, using custom image processing methods best-suited for gravitational lensing. By comparing the luminosity profiles to the mass profiles, the distribution of dark (DM) and luminous matter can be revealed.

The sample

This research is based on work by P. Magain, V. Chantry and D. Sluse (5, 6), so we are focusing on their 15 galaxies sample. More specifically, we are choosing quadruply imaged sources where the lens redshift is securely known, and systems with multiple lenses of similar luminosity are excluded. Our subsample currently has six systems. (CASTLES database, NIC2 camera of the NICMOS instrument onboard the HST. Angular scale : 0.075 arcseconds per pixel.)

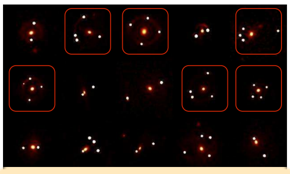

Fig. 1 - The subsample from (5, 6)

Light profile

Strong gravitational lensing galaxies appear surrounded by point-like and diffuse lensed components (Fig 2). The study of their luminosity profile is thus restricted to small, inner areas. In those conditions, usual fitting methods perform poorly; previous studies measuring their half-light radii (r_{eff}) using software such as GALFIT or IMFITFITS and various PSF-determining methods have resulted in somewhat discrepant results (7, 8). We designed a subtraction of the lensed signal, as well as an innovative scheme for computing isophotes to independently measures each shape parameter, namely, the position angle (PA), ellipticity, and r_{eff} of the galaxy (8).

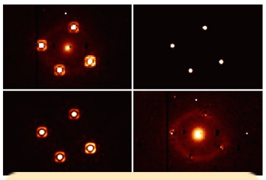

Fig. 2 - Point sources subtraction on HE0435-1223. (1) original image, (2) synthesised image of the deconvolved sources, (3) of the reconvolved sources (4) result of (1) - (3).

Subtracting the point-like source images

Previous processing of these data in (5, 6) includes a thorough determination of the PSF for each data frame, using the MCS (9, 10) algorithm. It finds the best PSF by iteratively subtracting any non-point-like object until convergence to an image of the point sources. It makes it possible to distinguish the deflected images from the galaxy, and to subtract their signal from the original image, as shown in Fig 2.

Subtracting the diffuse source images (arc)

As it is an image of a background galaxy, the radial light distribution of the arc should be roughly symmetrical around its maximum of intensity (I_{max}). We locate I_{max} , with respect to the center of the lens, for each angular coordinate. Then the arc is divided into sectors of roughly equal radii for I_{max}, and each sector collapses into a radial profile. We fit a de Vaucouleurs model on the profile, using as a validity criterion that it has to maximize the symmetry of the arc (Fig. 3) in a given region of interest. The residue acts as a numerical radial profile of the arc. Such a profile is obtained for each sector, then re-scaled for each angular coordinate, giving an image of the arc that we can subtract to the original observation.

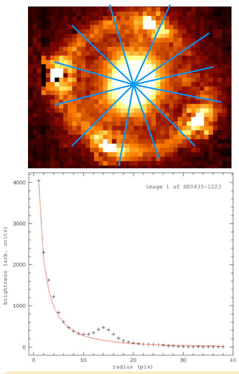

Fig. 3 - Top: sketch of the arc being divided into sectors on HE0435-1223. Bottom: radial profile of a sector (crosses) and best fitting de Vaucouleurs model (red).

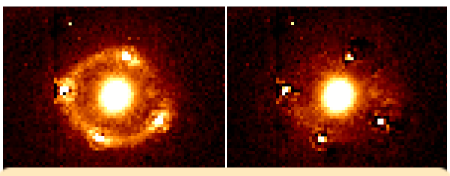

Fig. 4 - HE0435 -1223 before (left) and after (right) subtraction of the arc.

Measuring the shape parameters

Having cleared the lensed signal, we can conduct a secure measurement of the lens light profile shape parameters. We have chosen to compute them individually to avoid the existence of local minima in the parameters space. Our techniques, based on the computation of the lens isophotes, are all detailed in (8) and have proven to be much more stable than usual fitting methods, like GALFIT for example, regarding major aspects of image processing.

Scan the QR codes to access a poster (left) and a paper (right) about these light profiles !

Mass profile

We are using the GRAVLENS software package to solve the lens equation and fit a mass model on each lens. We are considering two cases of gravitational potentials.

- A singular isothermal ellipsoid model (includes a DM halo similar to spirals)
- A Sérsic model (constant mass-to-light ratio (M/L), no DM halo).

For four out of six systems, we have a secondary deflector that appears close in projection to the main deflector; we add a singular isothermal sphere to the potential to model it*.

We observe that :
- adding the secondary deflector to the potential gives better results.
- considering the chi-squared criterion, the constant M/L models render the observation with equal accuracy compared to the SIE models. This means that this particular set of observation ***does not rule out elliptical galaxies without dark matter haloes.***

Although they give very similar results, we use the best fitting model, whichever it is, to compute the Einstein radius (r_E) of each system.

Mass-to-light ratio

We compute the total brightness (in the H band) and integrated mass of each lens within the r_E to evaluate its M/L. The results are shown as a function of the r_E in r_{eff} units. These results are preliminary.

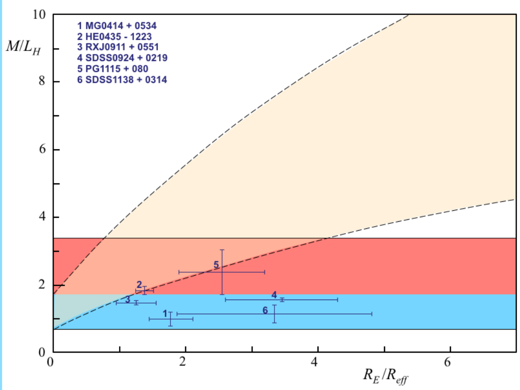

Fig. 5 - *M/L* as a function of r_E/ r_{eff}. The higher this ratio, the further out from the galaxy center we can probe.

Blue: theoretical *M/L* for elliptical galaxies without any dark matter, only stellar populations.

Red: theoretical *M/L* for elliptical galaxies with baryonic DM, distributed similarly to the light profile (= twice the blue area).

Beige: theoretical *M/L* for elliptical galaxies with a DM halo like the ones we find in spirals. (calibrated using NGC3198 (11))

Four systems seem to favor the "no DM" values, and two lie in the "baryonic DM but no halo" zone.

➡**Preliminary results show that elliptical galaxies do not seem to have dark matter haloes, in contrast with spirals.**

However, we observe that forcing the mass distribution to follow *exactly* the light distribution worsens the chi-squared. This may indicate a scaling factor between those two, favouring the hypothesis of baryonic dark matter distributed in a different way than a halo.

What is next ?

This result is only preliminary. Indeed, a complete error calculation on *L* as well as a more detailed study of the mass profiles are currently being conducted. The sample should also be expanded to doubly imaged quasars, and the time-delay constraints should be considered.

Nonetheless, it raises questions regarding generalities of extragalactic astrophysics. If ellipticals are the product of fusion of spirals, what happened to their haloes ? Could all the dark matter we detect around spirals only be cool hydrogen gas, as suggested by (12) ? It also could have major consequences for cosmology, where cold dark matter is a pillar, and serve as a basis for a discussion on alternative cosmologies.

*Ref. for position of secondary deflector : MG0414+0534 - Ros et al, 2000 / HE0435-1223 - Courbin et al, 2011 / RXJ0911+0551 - Sluse et al, 2012 / PG1115+080 - Sluse et al, 2012 & Momcheva et al, 2006

References and acknowledgements

(1) Romanowsky et al. 2003 (2) Memola et al. 2011 (3) Cappellari et al. 2013, 2015 (4) Muñoz et al. 1998b (5) Chantry et al. 2010 (6) Sluse et al. 2012 (7) Schechter et al. 2014 (8) Biernaux et al. 2016 (9) Magain et al. 1998 (10) Chantry & Magain, 2007 (11) T.S. van Albada et al. 1985 (12) Pfenniger et al. 1994, I and II

J. Biernaux acknowledges the support of the F.R.I.A. fund of the F.N.R.S.

Contact
Judith Biernaux
FRIA PhD Student
STAR-OrCA
University of Liège
jbiernaux@ulg.ac.be

Scan the QR code to access my webpage !