Conference Poster

Mass distribution in a dark matter halo

Author(s):
Trott, Cathryn

Publication Date:
2003

Permanent Link:
https://doi.org/10.3929/ethz-a-004582291

Rights / License:
In Copyright - Non-Commercial Use Permitted
Determining the Shape of a Dark Matter Halo Using Lensing

Cathryn Trott, Rachel Webster
The University of Melbourne

Introduction

2237+0305 is an extended Sab galaxy at z=0.0394 which displays four gravitationally lensed quasar images straddling its centre. Being at such low redshift compared with other lens galaxies, its light profile and kinematics can be well measured and the galactic mass distribution well constrained. In addition, the images lie sufficiently close to the galactic centre as to make this system excellent for studying the shape of the dark matter halo.

Lensing Basics

The location and magnification of gravitationally lensed images depends on the mass distribution of the lensing galaxy as well as the angular diameter distances to the lens and the source. The deflection of a light ray as it passes a massive object is given by:

\[ \alpha \left( \vec{x} \right) = \frac{4G}{c^2} \int \frac{\left( \vec{x} - \vec{x}' \right) \Sigma \left( \vec{x}' \right)}{\left| \vec{x} - \vec{x}' \right|^2} d^2x \]

and the lens equation describing the location of the images is:

\[ \vec{\beta} = \vec{\theta} - \alpha \left( \vec{\theta} \right) \]

where \( \Sigma \left( \vec{x} \right) \) is the surface mass distribution and the integral is performed over the mass surface, and \( \vec{\beta} \) is the source position and \( \vec{\theta} \) is the location of the images. Hence, the ellipticity of the mass distribution affects the orientation of the images.

Galaxy Mass Models

There are four major mass components in the galaxy which we will model in order to fit the measured image positions. These are the disk, bulge, bar and dark matter halo. The density profiles assumed are taken from previous imaging of the galaxy (luminous components) and commonly used profiles for the dark matter. The profiles and their origin are:
- Disk: exponential surface profile (Schmidt 1996),
- Bulge: de Vaucouleurs surface profile (Schmidt 1996),
- Bar: Ferrers ellipse (Schmidt 1996),
- DM Halo: elliptical NFW, Softened Isothermal Sphere.

As we are interested in the shape of the dark matter halo, we have used two different models. The forms for these models are:

\[ \rho \left( \vec{x} \right) = \frac{\rho_0 \epsilon r_c}{\xi \left( 1 + \frac{\xi}{r_c} \right)^2} \]

\[ \xi = r^2 \left( \cos \left( \epsilon \right)^2 + \sin \left( \epsilon \right)^2 \right) \]

\[ \rho \left( r \right) = \frac{\rho_0 \epsilon r_c^2}{r^2 + r_c^2} \]

Constraints

Schmidt (1996) used HST archival data to measure the scale lengths of the bulge and disk components, and to model the bar. In addition, Barnes et al. (1999) observed the galaxy in HI at the VLA. From this data we derived two rotation points in the outer galaxy, beyond the edge of the optical disk. With this information, there are 8(7) unknown parameters - four M/L values, the halo scale length and ellipticity (eNFW) or core radius (SIS) and two components of the source position. With the significant work undertaken on this system, we have 10 constraints - two components each of four image positions and two points on the rotation curve.

Results

Acceptable fits were found for both halo profiles. It is not surprising to see their best-fitting profiles contribute the same mass within the images and support the same rotation in the outer parts. As such, the softened isothermal sphere contains a small core radius:

Soft. I.S.: \( r_c = 1.03 \pm 0.02 \) kpc

\[ M/L_{bulge} = 1.9 \pm 0.1 \text{ (l-band)} \]

\[ e_{NFW} = 12.0 \pm 0.6 \text{ kpc, e=0.01} \]

\[ M/L_{bulge} = 1.8 \pm 0.1 \text{ (l-band)} \]

Best-fitting SIS Rotation Curve

Discussion

Although the results are very good, not all of the available information is contained in the fits. The flux ratios of the images can be calculated for the best-fitting profiles and compared with those measured in the mid-IR (Agol et al. 2000). Both mass distributions produce inconsistent ratios. In addition, the mass-to-light ratios calculated for the bulge component are much lower than one would expect for l-band values (a typical expected value would be ~5, Fukugita, Hogan & Peebles, 1998). If the bulge M/L is increased to reflect this, mass needs to be removed from another component in order for the convergence to produce the correct image radius. However, the bulge is quite elliptical and being a major component of the convergence it also contributes most of the shear required for the image locations.

A solution to this is to have an elliptical, cored dark matter halo whereby the halo’s shear counteracts that of the bulge. In order to determine the solution to this problem an optical rotation curve is required. Figure 2 shows a comparison rotation curve for an NFW and a Softened I.S. halo. In the inner regions it is clear a high-resolution rotation curve can break this degeneracy. Future observations are planned.

References


Schmidt, 1996, MSc Thesis

Fig. 2: comparison rotation curves