How round is your halo? The shape of dark matter haloes from gravitational lensing

How round is your halo?

Probing the Shape of the Central Dark Matter Distribution with Gravitational Lensing

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Background

The shape of a gravitationally lensed image depends strongly on the shape of the overall matter distribution in the region of the images.

Since most lensed images are within ~1" of the galaxy centre, lensing has the potential to be a powerful probe of the dark matter in the central regions of lens galaxies.

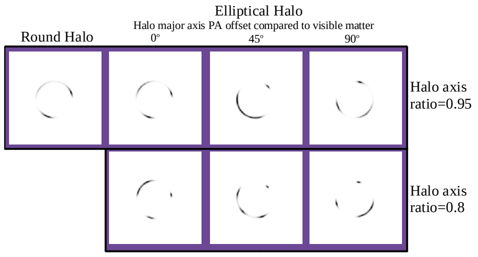
The effect of a non-spherical halo

As a qualitative example, we show the lensing effects of an elliptical galaxy using a Sersic brightness profile with a cored isothermal halo. The example is designed to simulate what might be seen for the 0047 system below. The scale length of the Sersic profile and halo core are both 0.5". The visible matter has an axis ratio of 0.5.There are roughly equal parts visible and dark matter inside the lensed image.

As figure 1 shows, even a small amount of ellipticity in the dark matter has an enormous impact on the shape of the image. Strong lensing provides powerful constraints on the shape and orientation of the halo.

Extended Image Analysis Software

We have developed sophisticated new software, “Lensview” [1], based on the LensMEM algorithm [2]. The software can analyse images of extended sources using a variety of mass models. It also reconstructs the unlensed source. The software will be publicly available soon. Please contact me (rwayth@physics.unimelb.edu.au) if you are interested in testing the software.



0047-2808

0047-2808 is a z=0.48 elliptical galaxy lensing a z=3.6 background starburst galaxy [3]. The image consists of four bright spots plus two arcs of extended emission. Figure 2 shows the HST F555 image. The light profile of the lens is modelled with a Sersic profile defined by
$$\Sigma = \Sigma_{1/2}\exp(-B(n)[(r/R_{1/2})^{1/n}-1])$$
The best fitting parameters are shown in table 1.

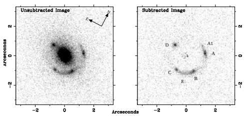


Figure 2. HST F555W image of 0047-2808 (left) and with lens galaxy subtracted (right).

Basic lens model

Parameter	Value
$R_{1/2}$ (arcsec)	1.09
$\Sigma_{1/2}$ (mag/arcsec^2)	24.11
ε	0.31
PA (deg E of N)	62.4
n	3.11

Table 1. Fitted parameters of the Sersic profile for the lensing galaxy.

The lensed image can be successfully modelled using a Pseudo-Isothermal Elliptic Potential (PIEP) defined by $\psi = b[r_c^2+(1-\epsilon)x^2+(1+\epsilon)y^2]^{1/2}$

The best fitting PIEP parameters are shown in table 2. The model image and reconstructed source are shown in figure 3.

Parameter	Value
b (arcsec)	1.17
ε	0.08
PA (deg E of N)	66
r_c	0

Table 2. Best fitting parameters of the PIEP lens model.

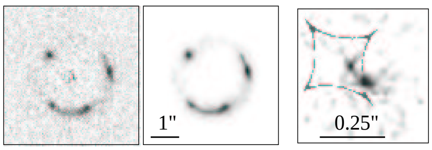


Figure 3. Data (left) and model image (centre) for the SIE model of 0047-2808. The reconstructed source is shown to to be a double, with small bight spot inside the caustic and a larger region which straddles a fold caustic.

Halo model

Next we separate the luminous and dark components of the mass model to find the shape of the halo. Assuming the visible/baryonic matter component follows the light profile with constant M/L, we model the halo as a PIEP with non-zero core. The Einstein radius of the image tightly constrains the total projected mass within the image. Thus for a fixed halo velocity dispersion far from the core, the core radius is completely specified by the M/L of the visible matter.

We find that the ellipticity of the halo potential is quite small. Koopmans & Treu [6] found roughly 50% dark matter fraction inside the ring. This corresponds to a core radius between (approx) 1.5" and 2.5". Our results show that the dark matter is aligned with the visible matter but is substantially less elliptical.

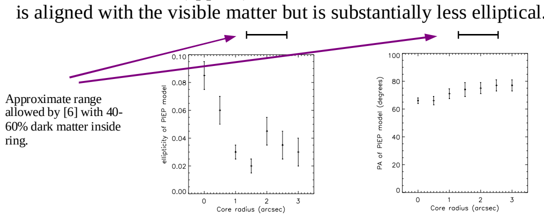


Figure 4. Left: The axis ratio of the projected 2-D potential of the halo using a cored PIEP model. As the core radius increases, the M/L of the visible matter must increase to maintain the Einstein Radius. Right: The position angle of the halo.

MG1549+3047

MG1549+3047 is a z=0.11 SB0 galaxy lensing a z=1.17 radio lobe [4,5]. It is one of 5 rare lensed lobes which form a complete (or almost complete) ring of emission. The image consists of two bright regions of emission (a multiply imaged section of the lobe near the hot-spot), and a fainter ring circling the centre of the galaxy as shown in Figure 5.

Very little work has been done on this object since 1993. The original analysis proceeded by identifying (assumed) multiply imaged points in the data then fitting in a similar manner to how QSO lenses are analysed. Lehar et al. used a cored isothermal model (similar to a PIEP) and found the best solution with parameters b=1.15", core = 0.22", ellipticity=0.073" and PA=-48º.

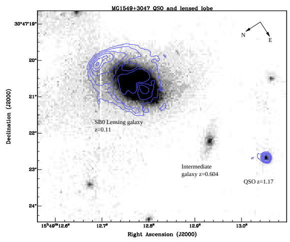


Figure 5. VLA 3cm radio contours overlaid on the HST NICMOS F160W image. Contours double from 0.2mJy. The other (unlensed) radio lobe is to the SE and not shown.

Here we present a preliminary analysis of MG1549 using Lensview and a PIEP mass model. The results differ significantly from [4] both in Einstein Radius and core radius. Table 3 shows the best fitting parameters. The data, model image and model source are shown in figure 6. The fit to the data from the PIEP model is remarkably good considering the prominent bar in the lens galaxy. There are no residuals between model and data above the lowest contour level in figure 6. We have not yet performed an analysis with a decomposed visible + dark matter model.

The relatively low ellipticity of the best-fit PIEP model and obvious ellipticity of the visible matter suggest that either there is very little dark matter in the image or that the halo is extremely round.

Parameter	Value
b (arcsec)	1.10
ε	0.04
PA (deg E of N)	-47
r_c (arcsec)	0.12

Table 3. Best fitting parameters of the PIEP lens model for MG1549.

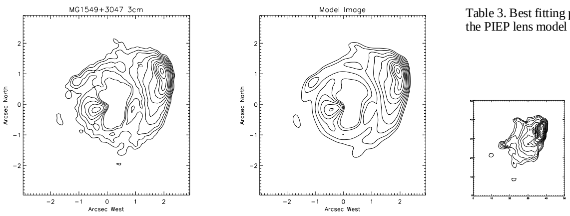


Figure 6. Data (left) and model image (centre) for the lensed radio lobe in MG1549+3047. The contours increase by $\sqrt{2}$ from 0.2 mJy. The reconstructed source (not convolved with the radio beam) is shown on the right. There are no residuals between model image and data above 0.2mJy.

References

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4- Lehar, J., Langston, G. I., Silber, A., Lawrence, C. R. 1993, AJ, 105, 107
5- Treu, T & Koopmans, L. V. E. 2003 astro-ph/0306045
6- Koopmans, L. V. E. & Treu, T. 2003, ApJ, 583, 606