

GRAVITATIONAL LENSING - THE TWIN QUASAR

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Here's an example of using the gravitational lensing formulas to calculate the mass of the lensing object. The first observed example of a lensed object was in 1979, when a quasar showed up as a double image on either side of a galaxy. The galaxy was known to be at a distance of 3.7×10^9 light years and the quasar at 8.7×10^9 ly. One image of the quasar was observed at $5''$ from the centre of the galaxy and the other image was at $1''$ from the galaxy's centre. From this data, we know that

$$\theta_+ = 5'' \quad (1)$$

$$\theta_- = -1'' \quad (2)$$

and from the quadratic equation for the angles:

$$\theta^2 - \beta\theta - \theta_E^2 = (\theta - \theta_+)(\theta - \theta_-) \quad (3)$$

so

$$\theta_E^2 = -\theta_+\theta_- = 5 \quad (4)$$

$$\theta_E = \sqrt{5}'' \quad (5)$$

The unobstructed angle is given by

$$\beta = \theta_+ + \theta_- = 4'' \quad (6)$$

We can get the mass from

$$\theta_E \equiv \sqrt{D_{LS} \frac{4GM}{D_L D_S}} \quad (7)$$

We are given $D_L = 3.7 \times 10^9$ ly and $D_S = 8.7 \times 10^9$ ly so $D_{LS} = D_S - D_L = 5.0 \times 10^9$ ly. We need θ_E in radians, so we have

$$\theta_E = \sqrt{5}'' = \frac{\sqrt{5}}{3600} \frac{\pi}{180} = 1.084 \times 10^{-5} \text{ radians} \quad (8)$$

We therefore have

$$GM = \frac{D_L D_S}{4D_{LS}} \theta_E^2 = 0.189 \text{ ly} \quad (9)$$

Using $1 \text{ ly} = 9.46 \times 10^{12} \text{ km}$ and $GM_{sun} = 1.477 \text{ km}$, we get the mass of the galaxy as

$$GM = 1.211 \times 10^{12} \text{ solar masses} \quad (10)$$

This is about twice the mass of the Milky Way. The lensing galaxy is a giant elliptical galaxy. Further information on the twin quasar image can be found on Wikipedia.

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