

GRAVITATIONAL LENSING: THE TWIN QUASAR

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Reference: Moore, Thomas A., *A General Relativity Workbook*, University Science Books (2013) - Chapter 13; Problem P13.3.

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

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

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

and from the quadratic equation for the angles:

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

so

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

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

The unobstructed angle is given by

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

We can get the mass from

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

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

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

We therefore have

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

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

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

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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