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

$$\theta_+ = 5'' \tag{1}$$

$$\theta_- = -1'' \tag{2}$$

and from the quadratic equation for the angles:

$$\theta^2-\beta\theta-\theta_E^2=(\theta-\theta_+)(\theta-\theta_-) \tag{3}$$

so

$$\theta_E^2 = -\theta_+\theta_- = 5 \tag{4}$$

$$\theta_E = \sqrt{5}'' \tag{5}$$

The unobstructed angle is given by

$$\beta=\theta_++\theta_-=4'' \tag{6}$$

We can get the mass from

$$\theta_E \equiv \sqrt{D_{LS}\frac{4GM}{D_L D_S}} \tag{7}$$

We are given $D_L=3.7\times10^9$ ly and $D_S=8.7\times10^9$ ly so $D_{LS}=D_S-D_L=5.0\times10^9$ ly. We need θ_E in radians, so we have

$$\theta_E = \sqrt{5}\text{"} = \frac{\sqrt{5}}{3600}\frac{\pi}{180} = 1.084 \times 10^{-5} \text{ radians} \tag{8}$$

We therefore have

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

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

$$GM = 1.211 \times 10^{12} \text{ solar masses} \tag{10}$$

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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