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

$$\theta_{+} = 5'' \tag{0.1}$$

$$\theta_{-} = -1'' \tag{0.2}$$

and from the quadratic equation for the angles:

$$\theta^{2}-\beta\theta-\theta_{E}^{2}=(\theta-\theta_{+})(\theta-\theta_{-}) \tag{0.3}$$

so

$$\theta_{E}^{2} = -\theta_{+}\theta_{-}=5 \tag{0.4}$$

$$\theta_{E} = \sqrt{5}'' \tag{0.5}$$

The unobstructed angle is given by

$$\beta=\theta_{+}+\theta_{-}=4'' \tag{0.6}$$

We can get the mass from

$$\theta_{E}\equiv\sqrt{D_{LS}\frac{4GM}{D_{L}D_{S}}} \tag{0.7}$$

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

$$\theta_E = \sqrt{5}" = \frac{\sqrt{5}}{3600}\frac{\pi}{180} = 1.084\times10^{-5} \text{ radians} \tag{0.8}$$

We therefore have

$$GM = \frac{D_L D_S}{4D_{LS}}\theta_E^2 = 0.189 \text{ ly} \tag{0.9}$$

Using 1 ly $= 9.46\times10^{12}$ km and $GM_{sun} = 1.477$ km, we get the mass of the galaxy as

$$GM = 1.211\times10^{12} \text{ solar masses} \tag{0.10}$$

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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