Gravitational Lensing

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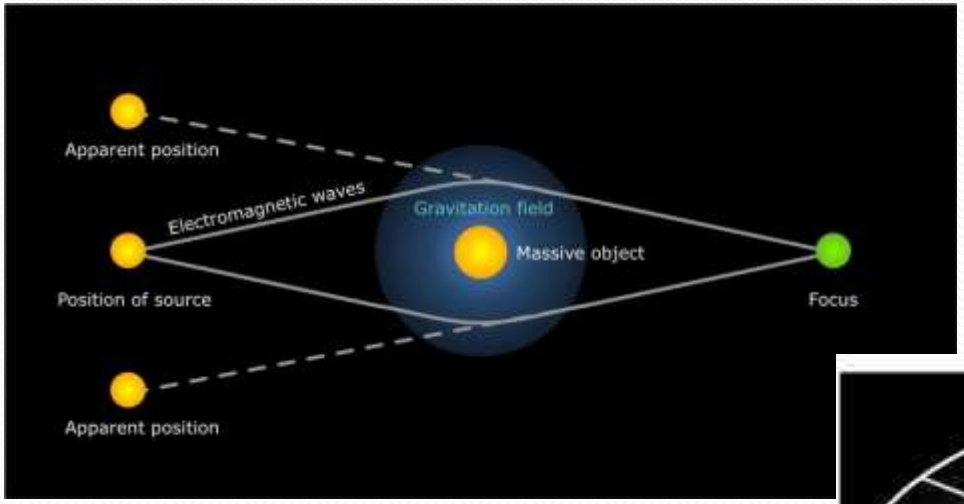
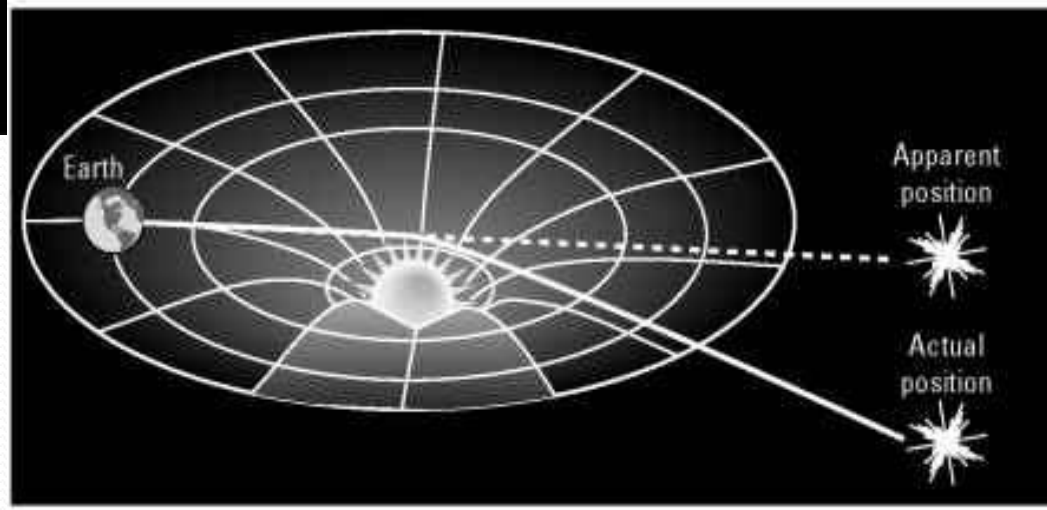
What is gravitational lensing?

Gravitational lensing is a visual effect caused by the distortion of space-time due to large masses. The paths that light follow no longer remain straight.





Understanding using GTR -

Bending of light ray near a spherically symmetric star

Schwarzschild Geometry (solution of vacuum Einstein equation)-

$$ds^2 = -\left(1 - \frac{2GM}{c^2 r}\right)(c\,dt)^2 + \left(1 - \frac{2GM}{c^2 r}\right)^{-1} dr^2 + r^2\left(d\theta^2 + \sin^2\theta\, d\phi^2\right)$$

Equation of motion of light ray :

$$\frac{1}{b^2} = \frac{1}{\ell^2}\left(\frac{dr}{d\lambda}\right)^2 + W_{\text{eff}}(r). \qquad b^2 \equiv \ell^2/e^2$$

Effective potential for photon orbit:

$$W_{\text{eff}}(r) \equiv \frac{1}{r^2}\left(1 - \frac{2M}{r}\right)$$

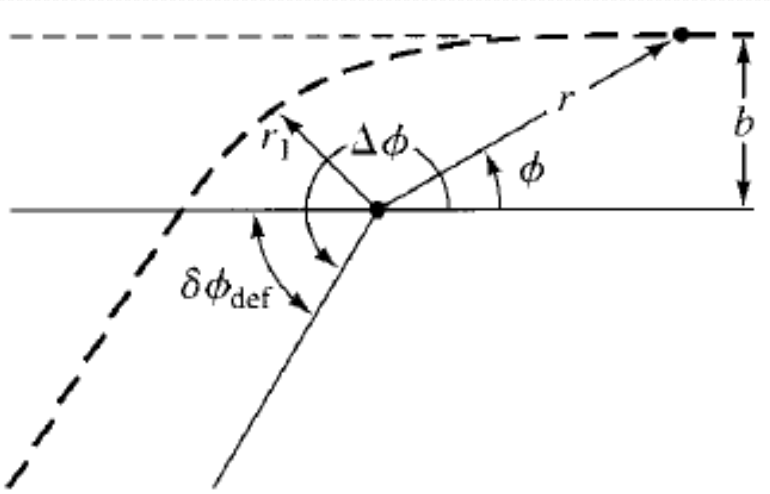
Calculating angle of deflection-

- Scattering orbit followed by light ray.
- Angle of deflection -

$$\delta\phi_{\text{def}} = \frac{4GM}{c^2 b}$$

Where
M= mass of object (lens)

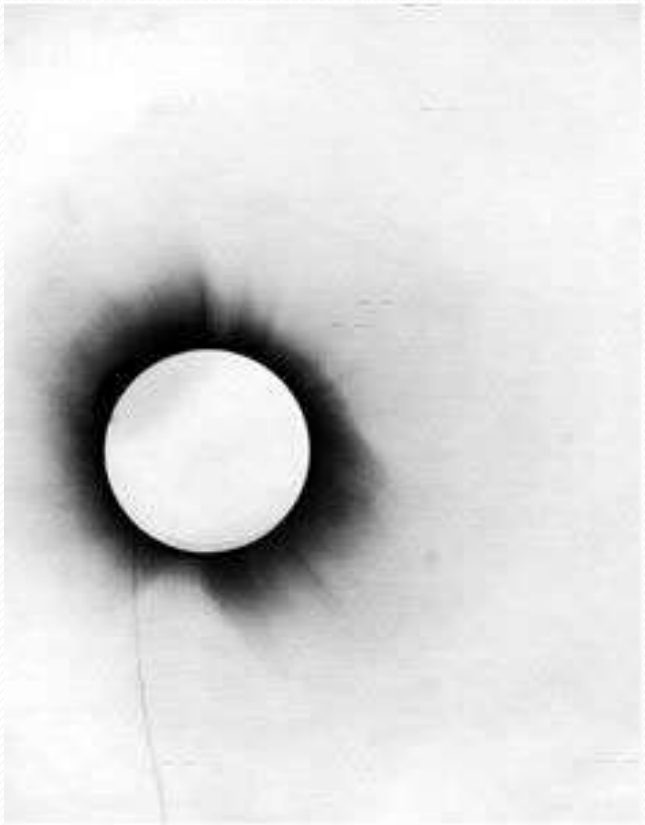
b= impact parameter (perpendicular distance between path of a projectile and center of potential)



Experimental test of GTR-

- Eddington observed the bending of light during the total solar eclipse of 1919
- Measured positions of stars before sunrise and during eclipse
- Possibilities-

✓ No deflection
✓ Deflection of .87 arc seconds (predicted by Newtonian theory)
✓ Deflection of 1.47 arc seconds (predicted by GTR)



Eddington photo of 1919 eclipse for testing general relativity
Credit: Philosophical Transactions of the Royal Society of London. (1920) (https://eclipse2017.nasa.gov/testing-general-relativity)

Lensing effect-

Gives information about source, lens and curvature of spacetime.
Using thin lens approximation the lens equation-

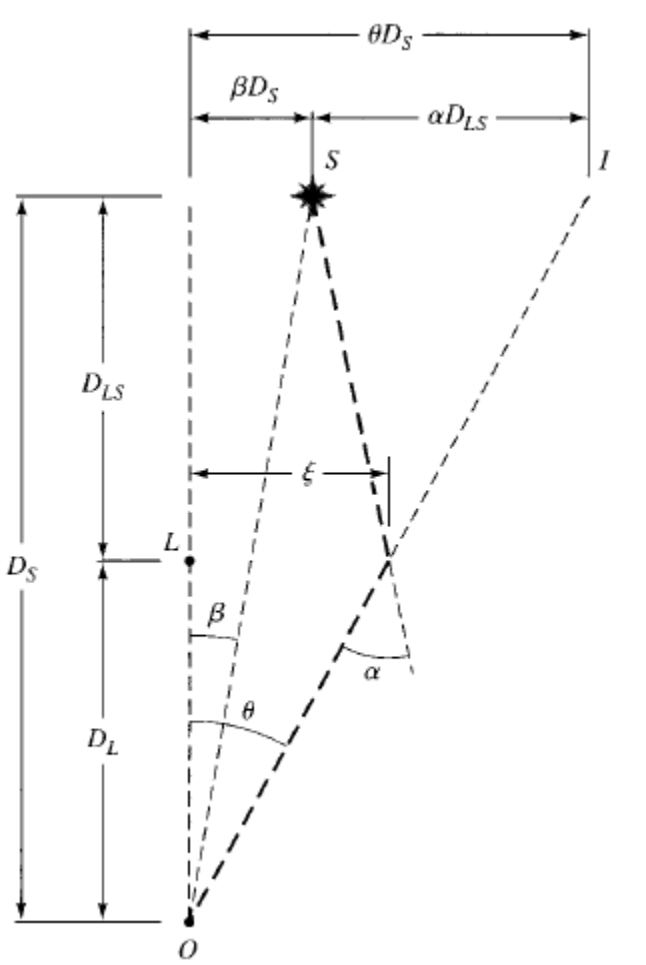
$$\theta D_S = \beta D_S + \alpha D_{LS}$$

Where α is the angle of deflection.

Under small angle approximation-

$$\theta = \beta + \frac{\theta_E^2}{\theta}.$$

$$\theta_E \equiv \left[2R_S\left(\frac{D_{LS}}{D_S D_L}\right)\right]^{1/2}$$ is Einstein angl



Micro and Macrolensing-

Lens can be star, cluster of galaxy or even a blackhole.
Typical case for solar mass star-

$$M \sim M_{\odot}, R_S \sim 1 \text{ km},$$

$$D_L \sim D_S \sim D_{LS} \sim 10 \text{ kpc} \sim 10^{17} \text{ km}.$$

$$\theta_E \sim 10^{-3}{}''.$$

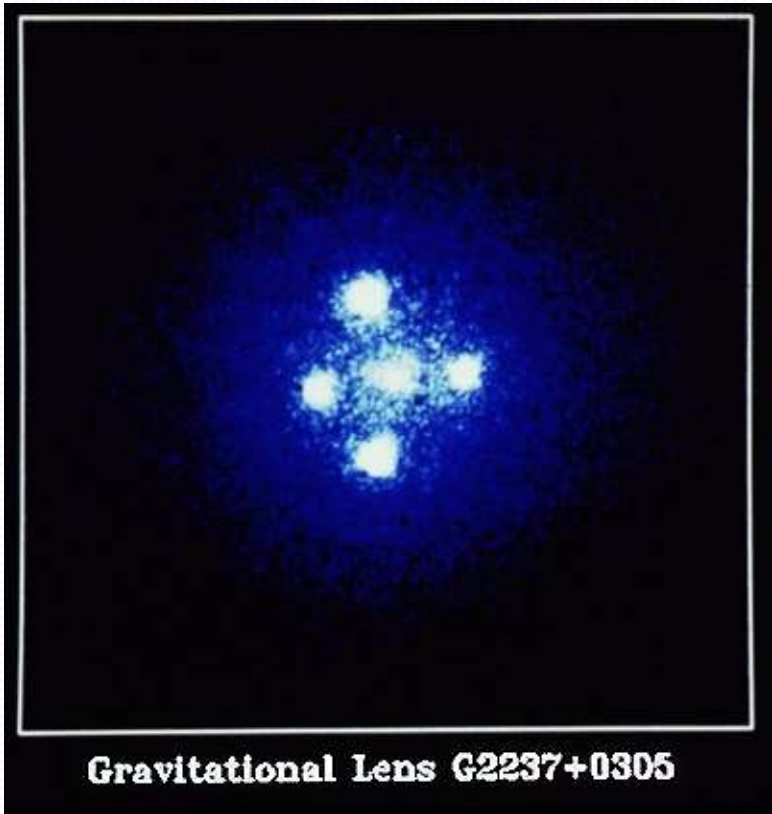
the angle involved is small – microlensing.

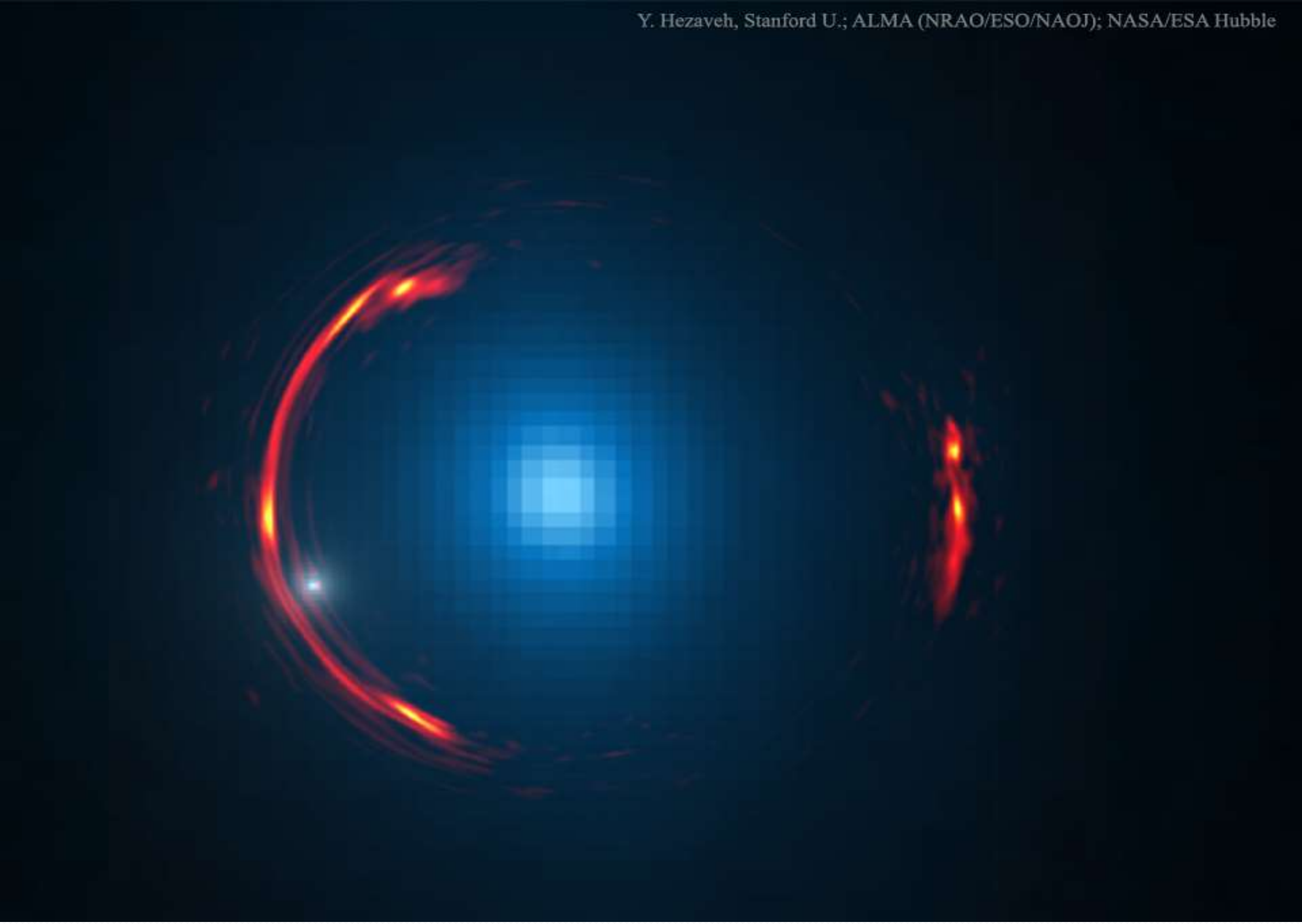
For galaxy clusters as lens

$\theta_E \sim 1''$. called macrolensing.

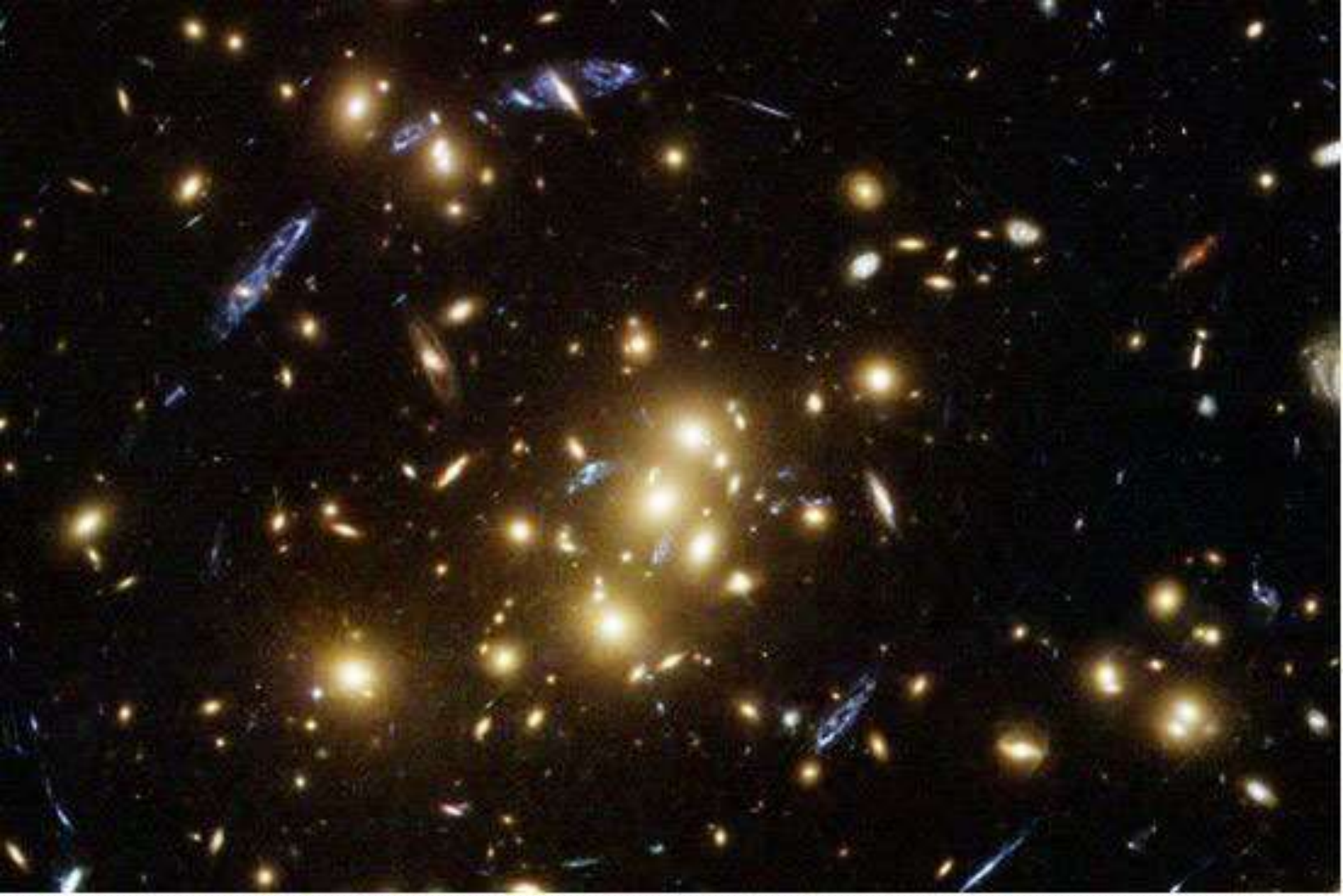
Einstein Cross-

- Extreme case of lensing of a quasar due to massive galaxy
- Four images are formed
- Generally Einstein ring is formed
- Lens, source and observer aligned

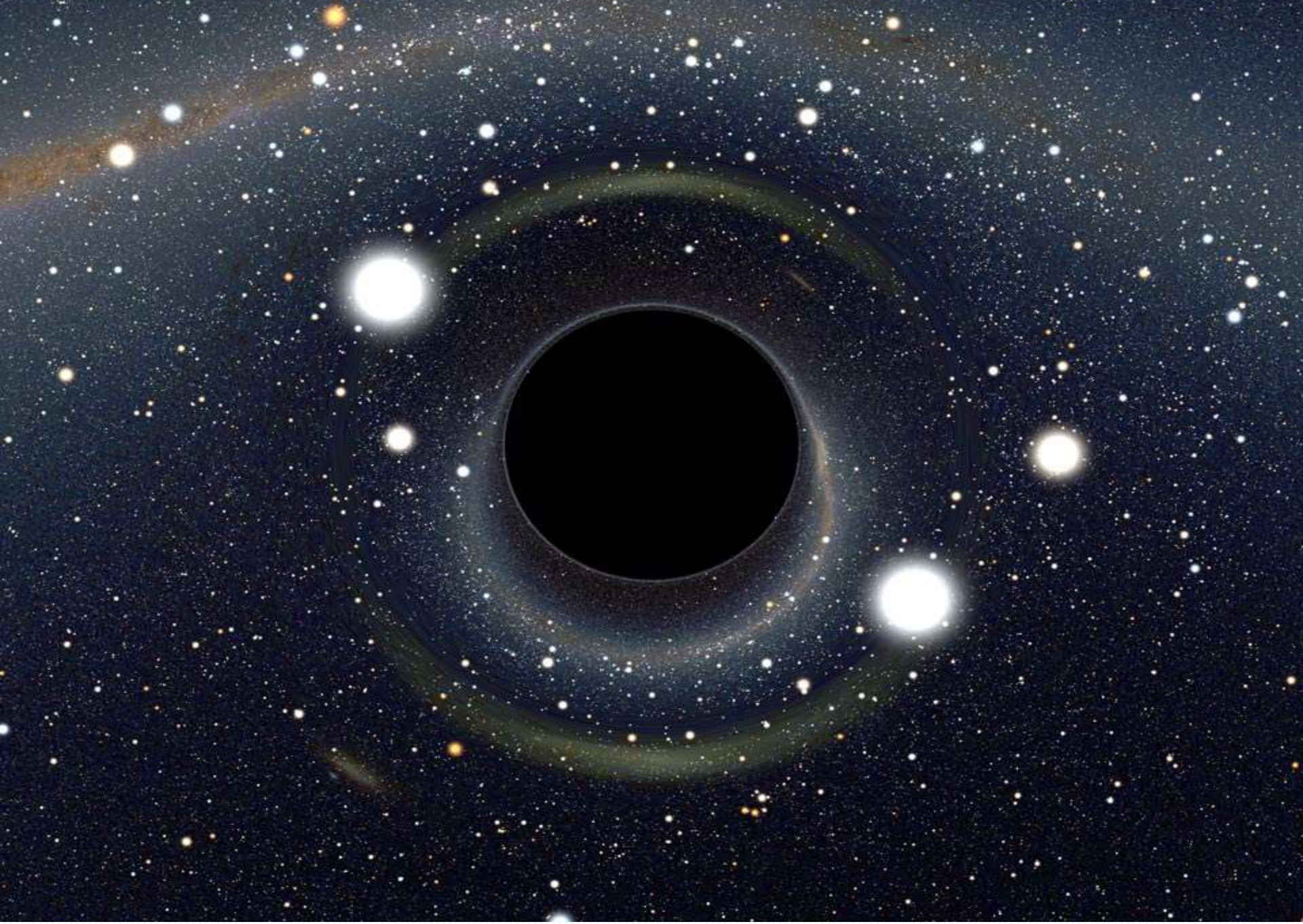




Einstein Ring- Astronomy Picture of the Day – 20 April 2016



Multiple images of a single distant spiral galaxy



Bending of light around black hole- Astronomy picture of the day- 26 October 2014

Conclusion

- Important for proving GR
- Makes distant objects visible
- Can help in spotting positions of black holes
- Angle of deflection will depend on the mass and hence gravity of the object acting as lens

Bibliography

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Thank you!