GRAVITATIONAL LENSING

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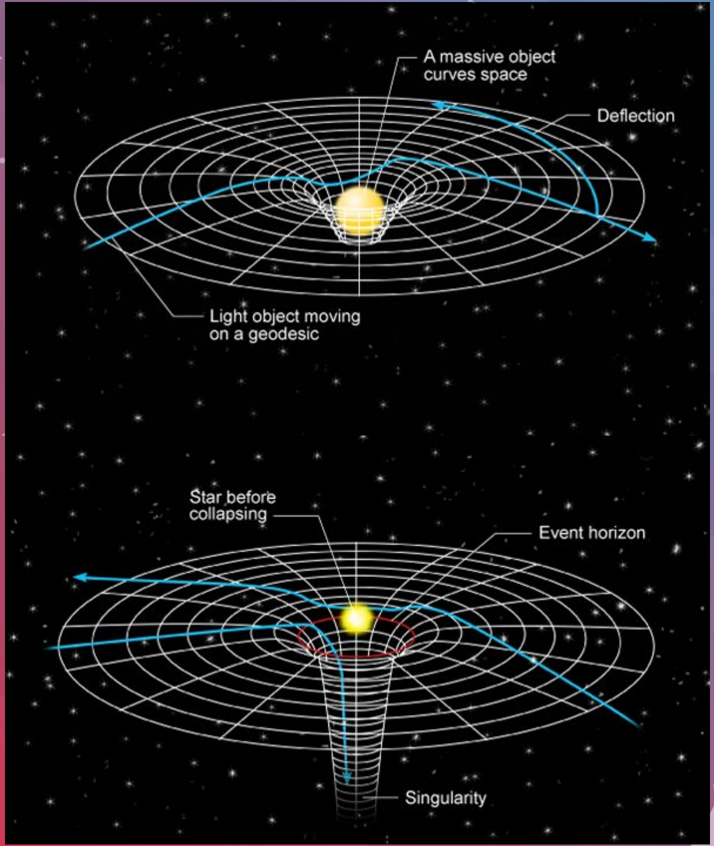
01

BACKGROUND INFO

BACKGROUND INFO

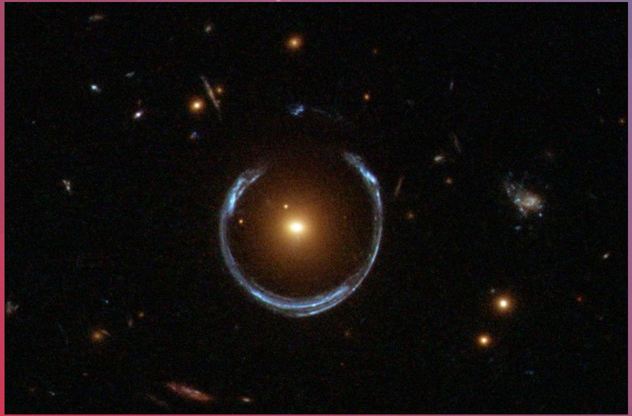
- General Relativity: mass warps space-time
  - Think of space-time as a 2D blanket
- When an object is placed on it, the blanket stretches out

MORE MASS = MORE STRETCHING!



WHAT IS GRAVITATIONAL LENSING?

- The effect of the massive object curves traveling light!
- This causes objects to appear in different places than they actually are
- Can also change object's appearance entirely with enough curvature!



02

Theory / Relevant Formulas

1 Gravitational Lensing Formula Special Case

The deflection is defined by $\tilde{\alpha}$ where M(ξ) is the mass within the distance of closest approach, ξ

$$\tilde{\alpha} = \frac{4GM(\xi)}{c^2}\frac{1}{\xi^2}$$

For the sun, $\tilde{\alpha} = \frac{4GM_{\odot}}{c^2}\frac{1}{R_{\odot}^2} = 1.74$ arcseconds
**1 arcsecond = 1/3600 degress

$$\alpha(\theta) = \frac{D_{ls}}{D_{os}}\tilde{\alpha}(\theta)$$

$$\beta(\theta) = \theta - \alpha(\theta)$$

$$\beta(\theta) = \theta - \frac{D_{ls}}{D_{os}D_{ol}}\frac{4GM}{c^2\theta}$$

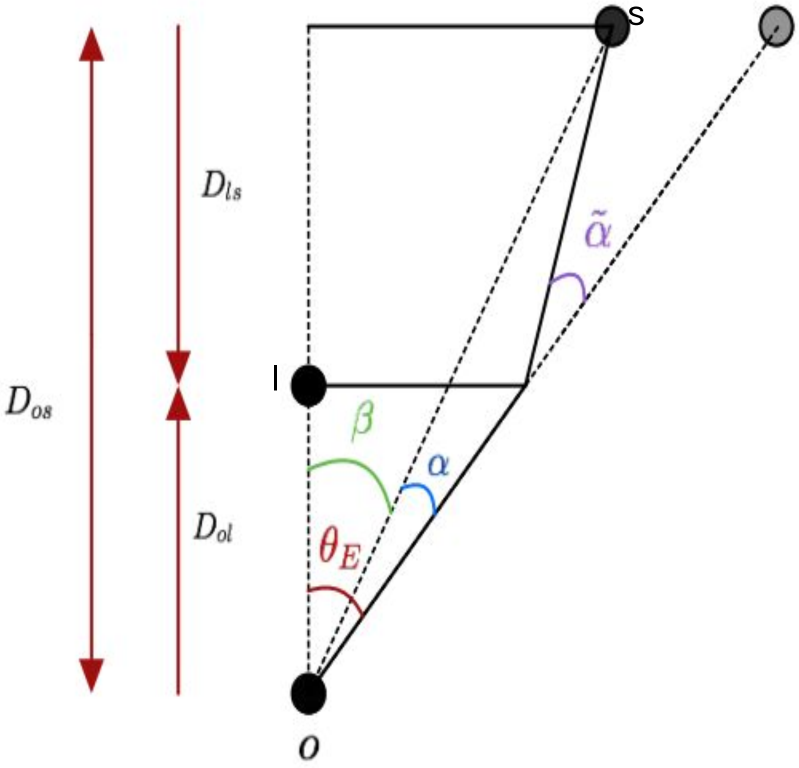
If we set $\beta(\theta) = 0$ such that the source is just behind the lense, then we get,

$$\theta = \theta_E = \sqrt{\frac{4GM}{c^2}\frac{D_{ls}}{D_{os}D_{ol}}}$$

D_{ij} = distance from plane i to plane j
l= lens
o=observber
s= source
assuming that $D_{ls} \approx D_{ol}$

$$\theta = \theta_E = \sqrt{\frac{4GM}{c^2 D_{os}}}$$

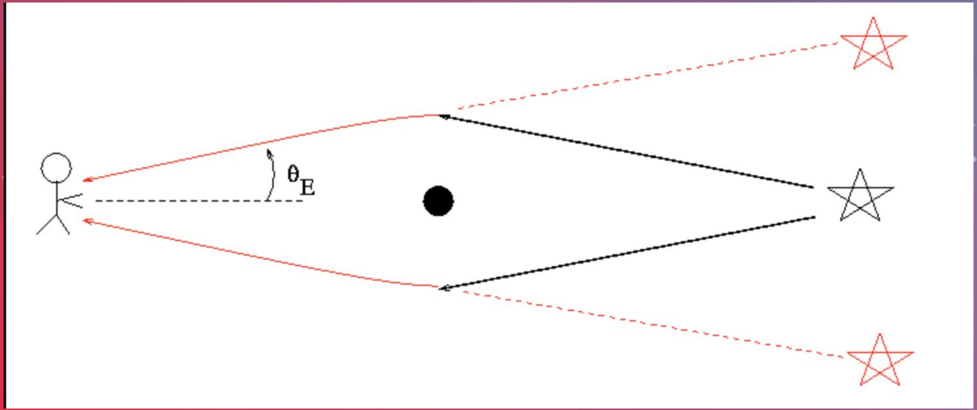
I will write a function that can give us the angle for the various parameters



RELEVANT EQUATION

$$\theta_E = \sqrt{\frac{4GM}{Dc^2}}$$

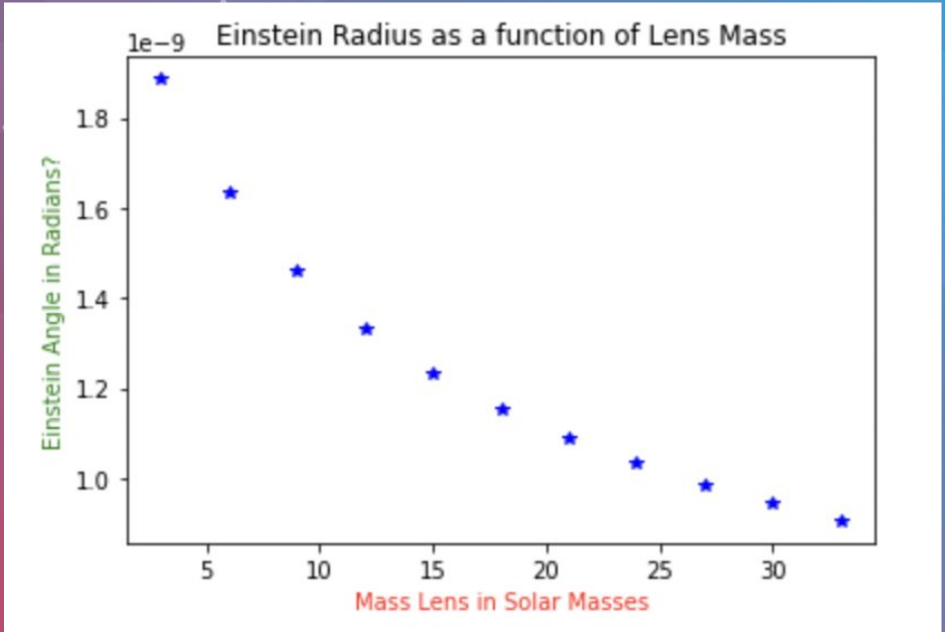
- As mass increases, the angle of deflection increases
- Larger distance creates a smaller angle



03

METHODS/TECHNIQUES

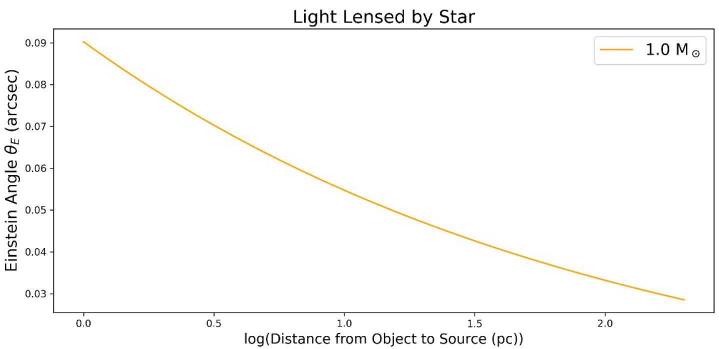
INITIAL PLOT OF ANGLE VS. MASS

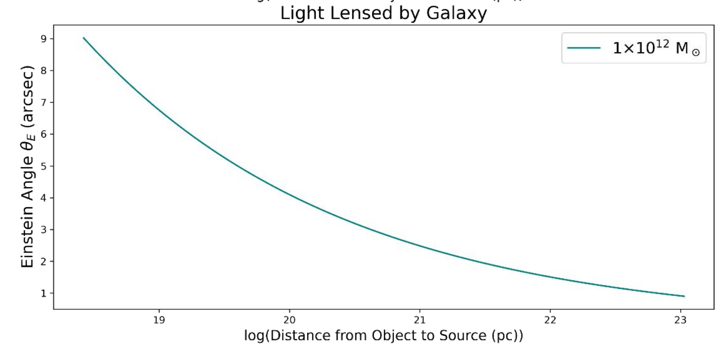


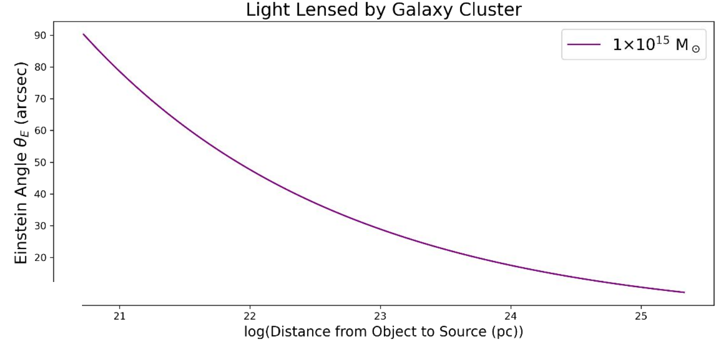
Einstein Angle Python Function

```python
# Eistein Angle Function theta_E
constant = 4 * con.G / con.c**2

Mass = input('Mass in Solar Masses = ') * u.solMass
D_ol = input('D_ol in parsec = ') * u.parsec

def theta_e(Mass, D_ol):

    E = np.sqrt(constant * Mass  /  D_ol) * u.rad

    return E.to(u.arcsec)
#E is in radians and 1 rad is 206265 arcseconds
print('\nthe Einstein Angle of Sagittarious A* (black hole at the center of the milky way galaxy)')
print('\ntheta_e =',theta_e(Mass, D_ol))
```

```
Mass in Solar Masses = 4.154e6
D_ol in parsec = 26673

the Einstein Angle of Sagittarious A* (black hole at the center of the milky way galaxy)

theta_e = 1.1261916005486818 arcsec
```

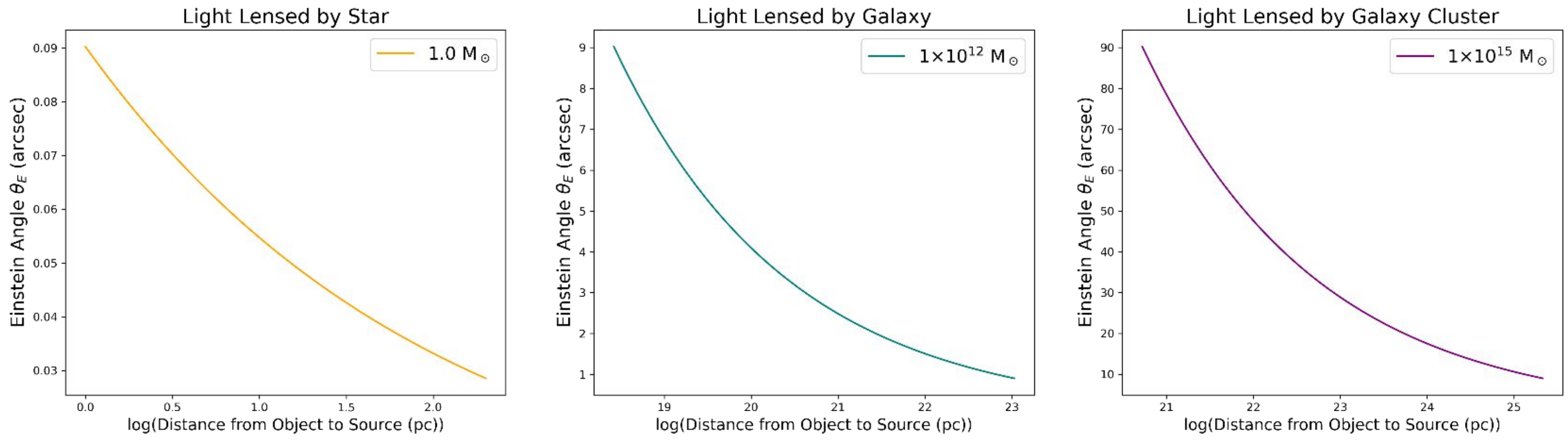






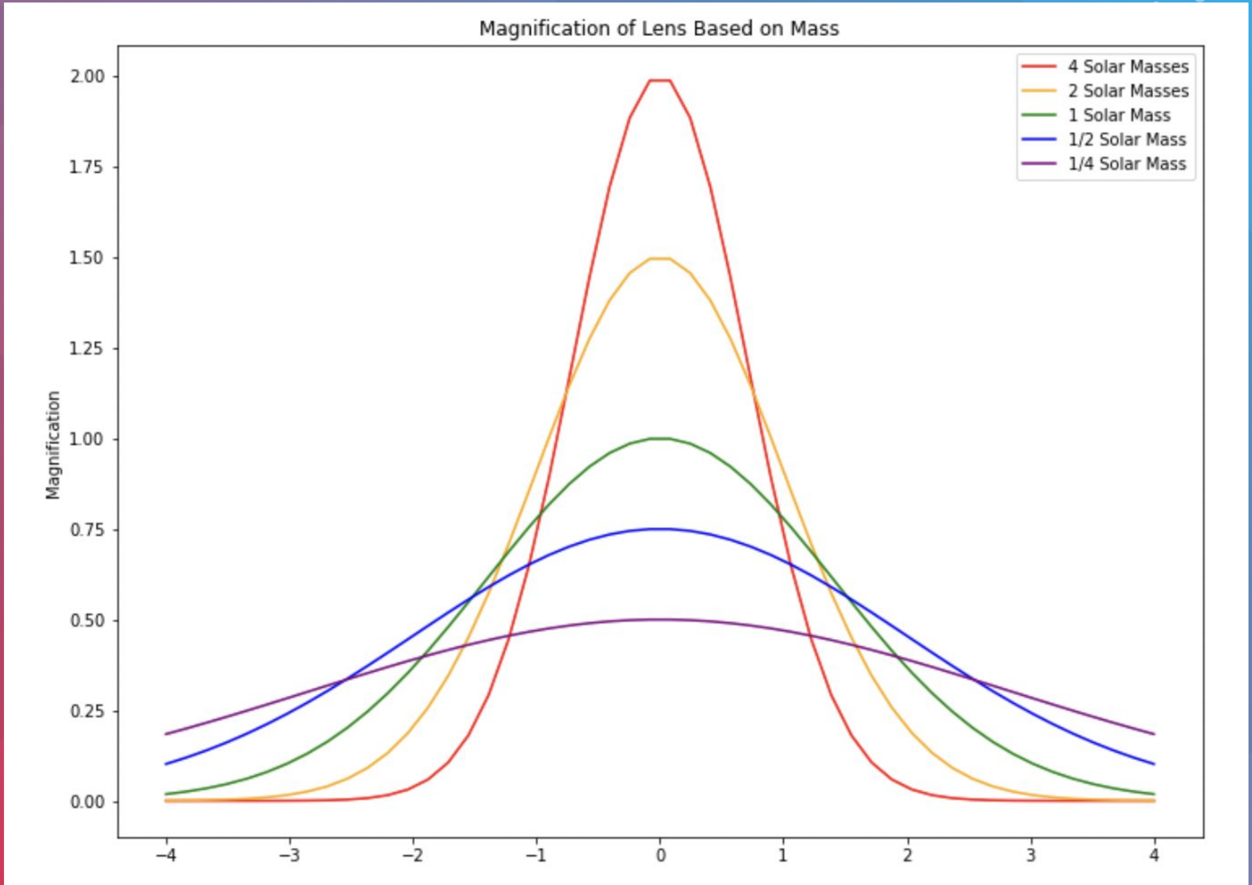
Need a Massive Object, some stars just do not deflect light enough, but blackholes, galaxies, galaxy clusters do!

Lens Mass $M_\odot$	D_{os}	θ_E
solMass	pc	arcsec
float64	float64	float64
1.0	100.0	0.009024330045344293
1.0	1000.0	0.0028537437300378554
1.0	10000.0	0.0009024330045344293
4154000.0	26673.0	1.1261916005486818
1000000000000.0	100000000.0	9.024330045344295
1000000000000.0	1000000000.0	2.8537437300378556
1000000000000.0	10000000000.0	0.9024330045344293
1000000000000000.0	1000000000.0	90.24330045344293
1000000000000000.0	10000000000.0	28.537437300378553
1000000000000000.0	100000000000.0	9.024330045344295



If the black hole/star is more massive, the magnification increases!

$$\mu = \frac{u^2 + 2}{u\sqrt{u^2 + 2}}$$



RESOURCES

LECTURES

- Astro 7B Lecture 25 (Spring 2020)

Academic Papers

Abdo, A. "Department of Physics and Astronomy Michigan State University East Lansing, Michigan 48823."