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# Simulator of light bending with Gravitational Lenses

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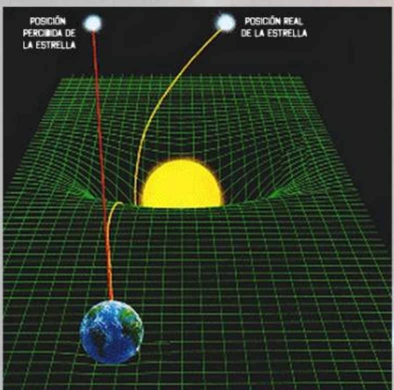
## 1- Introduction

Eddington's 1919 expedition confirmed Einstein's theory of general relativity by observing light bending around the Sun. This phenomenon, gravitational lensing, distorts spacetime and bends light paths. Our created lens simulation allows to change Sun size and it is available online.

In this project, we tried to replicate his experiment and calculate the light speed by ourselves.

## 2- Gravitational lenses

A gravitational lens is an astronomical phenomenon that occurs when the trajectory of a photon of light curves thanks to the gravity of a celestial body. This happens because gravity is a manifestation of spacetime curvature.




## 3- Mercury and gravitational lensing.

The relationship between gravitational lensing and perihelion precession of Mercury is a fascinating phenomenon in physics. Einstein's theory of general relativity predicts that the Sun's mass distorts spacetime around it, acting as a gravitational lens that deflects the path of light from nearby stars. This gravitational distortion affects Mercury's orbit, causing a slight precession at its perihelion, the point closest to the Sun's orbit. This precession was one of the first successes of the theory of relativity and remains a key example of its predictive power in the study of celestial objects.

## 4- Calculations (Mercury)

These calculations show the determination of a planet's orbit using both classical mechanics and general relativity. They begin with the calculation of the classical orbital radius, followed by the determination of the relativistic correction factor for perihelion precession. The relativistic orbit is then calculated taking this correction into account. Finally, this precession is converted into units of arc seconds per century. The results show how small relativistic corrections affect planetary orbits, in particular perihelion precession.

Perihelion precession is the phenomenon whereby the point of a planet's orbit closest to the Sun (called perihelion) moves slowly over time. This means that the planet's orbit is not a fixed ellipse, but gradually rotates on itself. This effect is due to several influences, including gravitational interactions with other planets and the effects of general relativity, which predicts a small additional correction to the Newtonian gravitational force. The precession of Mercury's perihelion was one of the first observational pieces of evidence that confirmed Einstein's theory of general relativity.

### 3.1- Classical orbit

$a = 0.387$ AU

$e = 0.2056$

$\theta = 0$

$G = 6.67430 \times 10^{-11}$ N·m²/kg²

$M_{\mathrm{sol}} = 1.989 \times 10^{30}$ kg

$c = 2.998 \times 10^{8}$ m/s

$$r = \frac{a \cdot (1 - e^2)}{1 + e \cdot \cos(\theta)}$$

$$r \approx 0.459 \text{ AU}$$

$$\Delta\phi = \frac{6 \cdot \pi \cdot G \cdot M_{\mathrm{sol}}}{a \cdot c^2 \cdot (1 - e^2)}$$

$$\Delta\phi \approx 5.018 \times 10^{-7} \text{ rad/órbita}$$

### 3.2- Relativistic orbit

$\phi = 0$

$t = 0$

$\text{period} = 87.9691$ days

$$\phi_{\mathrm{rel}} = \phi + \Delta\phi \cdot \frac{t}{\text{period}}$$

$$\phi_{\mathrm{rel}} \approx 0$$

$$\Delta\phi_{\mathrm{arcsec}} = \Delta\phi \cdot \frac{180}{\pi} \cdot 3600$$

$$\Delta\phi_{\mathrm{arcsec}} \approx 5.018 \times 10^{-7} \text{ rad/orbit} \cdot \frac{180}{\pi} \cdot 3600$$

$$\Delta\phi_{\mathrm{arcsec}} \approx 43.63 \text{ arcsec/century}$$

$$r = \frac{a \cdot (1 - e^2)}{1 + e \cdot \cos(\phi_{\mathrm{rel}})}$$

$$r \approx 0.459 \text{ AU}$$

## 4- Calculations (Einstein's ring)

$\theta_E$ is the angular radius of the Einstein ring.

$G$ is the universal gravitational constant.

$M$ is the mass of the massive object acting as a lens.

$c$ is the speed of light in a vacuum.

$D_{LS}$ is the distance between the lens and the source.

$D_L$ is the distance between the observer and the lens.

$D_S$ is the distance between the observer and the source.

Einstein's Ring angular radius Formula:

$$\theta_E = \frac{D_{LS}}{D_S}\alpha$$

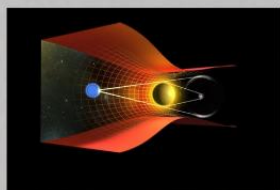
Photon deviation by Gravitational lensing:

$$\alpha = \frac{4GM}{c^2 b}$$

**Einstein's Ring Formula:**

$$\theta_E = \sqrt{\frac{4GM}{c^2} \cdot \frac{D_{LS}}{D_L D_S}}$$

An Einstein ring forms when a distant light source is perfectly aligned with a gravitational lens (a massive object) and the observer. The light from the source is deflected by the gravity of the lens, forming a complete circle of light.



## 5- Conclusion

In summary, our project offers an in-depth examination of gravitational lensing phenomena, from historical validations of general relativity to modern applications in astrophysics, highlighting the significance of Einstein rings in understanding cosmic structures.

## Extra: Important QR link codes:

Teacher's website

Teacher's Github page about fotonics