Visualizing gravitational lensing with varying mass distance and position

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Abstract

In this paper, we explore how we can implement a strong gravitational lensing visualizer. We use Python to create a program that uses Einstein's general relativity. We compare results with other simulators and photographs observed in real life and conclude that the simulations do correspond to the references. However, rendering speed depends on the source image's size with inaccuracies due to approximations from the equation.

Keywords: gravitational lens, visualization, Python

Introduction

Gravitational lensing is a phenomenon predicted by Albert Einstein's general relativity. Instead of light travelling in a straight line, gravity pulls the light to travel in a bent path like a convex lens [1]. Astronomers use it to observe distant celestial objects, from stars to exoplanets [2]. However, understanding the effect can be challenging due to its complexity. Thus, we created a gravitational lensing visualizer.

Methodology

We decided to use Python due to its flexibility and stability. We also chose to replicate strong lensing, as its effects can be calculated using an approximation of Einstein's general theory of relativity. The angle of deflection can then be determined using $\hat{a} = \frac{4GM}{c^2 b}$. Here, $\hat{a}$ is the deflection angle, G is the gravitational constant, M is the object's mass, c is the velocity of light, and b is the impact parameter. We assume the image is a light source behind the celestial body and created variables for distance, mass, position, and field of view to use in the program. We read the input image via Pillow and converted into an array with NumPy then calculate the reflection with the equation above for mapping by Matplotlib. As some pixels may originate out of bounds, we resolve by sampling colors from the opposite side, similarly to a skybox. Finally, we display the rendered image to the user.

Results

After using the program, we obtained the following images from the output. The results are shown in Fig 1. and 2.

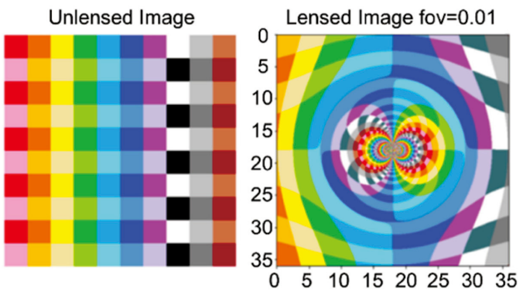

Fig 1. Comparison between unlensed (left) and lensed (right) image from the program. Parameters: mass=1×10^{38} kg (5.029×10^{7} M⊙) dL= 1×10^{20} m, FOV=0.01°, image size 500×500px, lens position (250,250) render time 6s

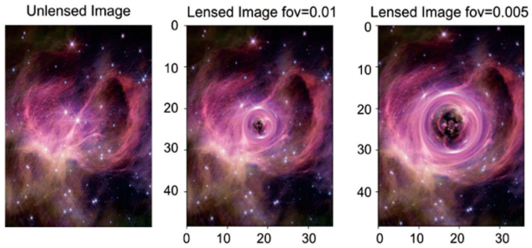

Fig 2. Comparison between unlensed (left) and lensed (middle and right) image from the program. Parameters: mass=1×10^{40} kg (5.029×10^{9} M⊙), dL= 1×10^{43} m, FOV=0.01°, 0.005°, image size 298×400 px, lens position (149,200) render time 3s for both images. Source picture by NASA's Webb Identifies Tiniest Free-Floating Brown Dwarf (NIRCam Image) by NASA, ESA, CSA, STScl, Kevin Luhman (PSU), Catarina Alves de Oliveira (ESA)

Discussion

Our method to visualize gravitational lensing focuses on usability, and low computation. The key factors are the distance between the observer and viewer, field of view, and mass which agrees with Einstein's gravitational lensing formalism. The program also successfully replicated Einstein cross with multiple masses with an off-centered source. Additionally, we compared effects from Alison Hume and Jacek Guzik's gravitational lensing simulator and concluded that it is similar to ours. The results are shown in Fig 3.

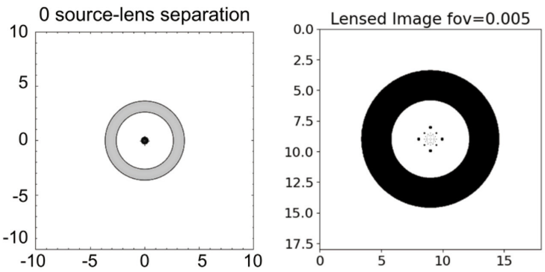

Fig 3. Comparison between Alison Hume and Jacek Guzik's gravitational lensing simulator (left) with ours (middle and right). Parameters: mass= 1.988×10^{42} kg (1×10^{12} M⊙), dL= 1.419×10^{25} m, or 1.5×10^{9} lightyears, FOV=0.005° or ≈ 18 arcsec, image size 500×500px, lens position (250,250) render time 5s. Left image from http://demonstrations.wolfram.com/GravitationalLensingByAPointMass/, License: Creative Commons Attribution-NonCommercial-ShareAlike 3.0 Unported, accessed on May 18th, 2024

However, since we base the calculations on point mass lenses, it can only calculate strong lensing. Moreover, using an approximation of Einstein's theory of relativity may cause inaccuracies near the lens' center.

Reference

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