Bending Light

New Mexico Supercomputing Challenge
Final Report
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Introduction

In 1704 Sir Isaac Newton thought,

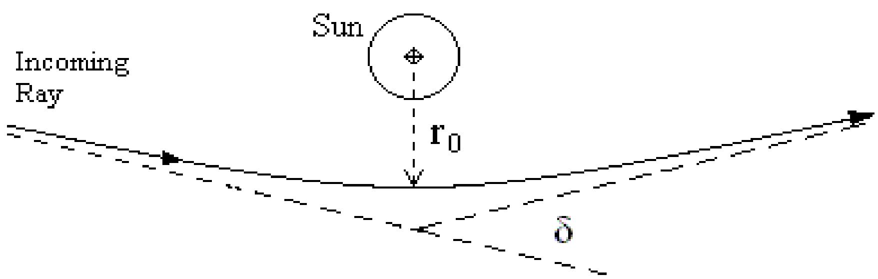
> *"Do not bodies act upon light at a distance, and by their action bend its rays, and is not this action strongest at the least distance."*

In the early 1900's Einstein also thought that the gravitation of a large body could bend light rays. Both Newton and Einstein, using the current particle theory of light, thought the earth's sun would deflect the light from a star in line with the earth and sun by about .875 arc seconds. However, once Einstein had worked out the General Theory of Relativity and thought about the possibility of light being waves, he realized the deflection would be about 1.75 arc seconds. (The difference has to do with the fact that light travels at a constant speed and does not accelerate in gravity.)

Back around September 2009, when everyone was starting to think of ideas on what to do for the Supercomputing Challenge, we came up with the idea of researching calculations for bending light. We set out to initially learn how to use C++ to perform simple calculations and then how to use the program to explore the application of the equations we found in our research.

Computational Solution

We were first successful in writing a C++ program to simply calculate the angle of deflection as proposed by Einstein:



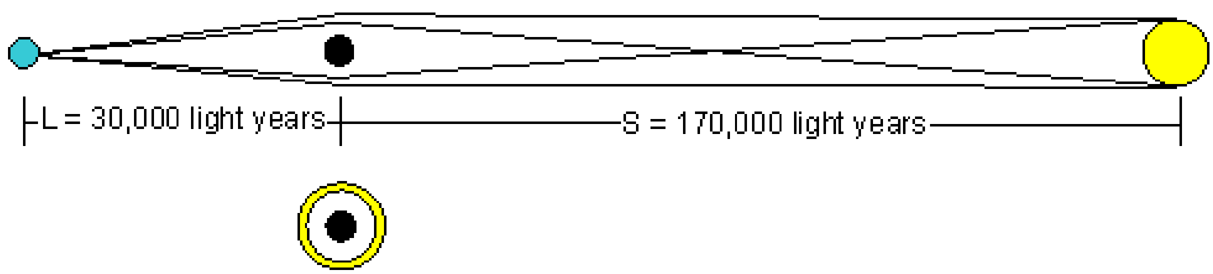
$$\text{deflection} = \frac{4\ G\ M}{r_0\ c^2}$$

Where for a star in line with the earth's sun and the earth:
G = Gravitational constant
M = Mass of the sun
r_0= radius, where light from the star is observable (not blocked by the sun)
c = speed of light

Historically, being able to observe and prove this equation would open possibilities for further research and application of the equations. As early as 1919, rough measurements made during solar eclipses with simple equipment resulted in 1.98 arc seconds (location: Sobral) and 1.16 arc seconds (location: Principe). In 2004 over 2 million Very Long Baseline Interferometry measurements has verified Einstein's deflection angle.

These results can be applied to other situations, such as gaining information about stars that are very far away but pass behind a "gravitational lens" such as a black hole, galaxy or galaxy cluster. When this happens the star appears as a ring around the lens. This ring is called an Einstein Ring.

So as an additional calculation, one can enter the distance the star is from the lens, and the distance the lens is from earth (always the observer location). The result will be the radius for the Einstein ring that will form and, thus, the distance the light is from the lens. As an alternate calculation, one can enter the distance the lens is from earth, and radius of the Einstein ring. The result will be the distance the star is from the lens.



Conclusion

We found that a large mass will bend light around the mass. We achieved our goal in learning how light bends. In fact, this phenomenon is called "gravitational lensing" as the star becomes more easily seen because the light becomes brighter.

Personal Achievements

We have initially gained an understanding of the early concepts of gravitational bending of light (and the fact that sometimes original hypotheses are wrong) We learned how to write a simple program for requesting variables, performing calculations and outputting results.

We learned that the initial concepts are very important. They have been applied to "see" black holes and further use them to analyze what we see in the night sky.

Acknowledgements

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