Does the cosmological constant affect gravitational lensing?

You are surely aware of normal lensing, such as the ones in a pair of spectacles or a magnifying glass. Light rays coming from a light source pass through a lens, are bent by refraction, and focused somewhere else.

In a similar way, mass also bends light. This is known as gravitational lensing and is one of the most important experimental tests of Einstein's theory of General Relativity. General Relativity predicts that the mass of an object will cause spacetime to curve around it, and subsequently light rays passing close to that object will appear to be bent. The more massive the object, the more spacetime curves, and the greater the bending of light rays. The most prominent effect is the existence of Einstein rings (shown below) where a galaxy (the lens) bends the light coming from the galaxy (the light source) directly behind it, focusing the light into a visible ring.

Normal gravitational lensing in an expanding universe is well understood. But we also know that the universe is expanding at an accelerating rate, from various complementary observations. In the standard cosmological model, this expansion is powered by a cosmological constant Λ.

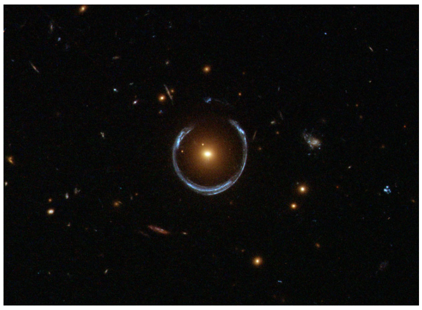

Figure 1: A horseshoe Einstein ring taken by the Hubble Space Telescope

In a universe with zero cosmological constant, the formula for light deflection is well known. However, it is not so clear for the case when the cosmological constant is non-zero. The question we aim to answer in this project is simple: **Does the cosmological constant affect the bending of light? If so, how?**

There has been quite some disagreement in the literature about this problem over the last decade or so. It may not seem difficult at first glance, since the propagation of light rays can be determined simply by solving the Einstein Field Equations, which is similar to solving the equations of motion for a particle in Newtonian gravity. The problem is that the Einstein Field Equations are a set of 10 interdependent partial differential equations and they can only be solved exactly under very specific simplifying assumptions. Multiple attempts have been made to settle the debate analytically using various analytic approximations, but some of these approximations and their interpretations are disputed.

In this project, we attempt to give an answer to this debate numerically instead of analytically, that is, solving the equations approximately with a computer rather than exactly. We propagate the light rays through a spacetime with a non-zero cosmological constant by numerically integrating the differential equations, and compare the result to predictions from theoretical models. Currently, even if the cosmological constant has an effect on gravitational bending, the effect may be too small for current cosmological measurements to pick up. However, this will be important for future generations as measurements become more precise. Moreover, given the success of General Relativity and the importance of the cosmological constant in our current model of the universe, the question of how light deflection is affected by Λ is an important one that this project hopes to settle.

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