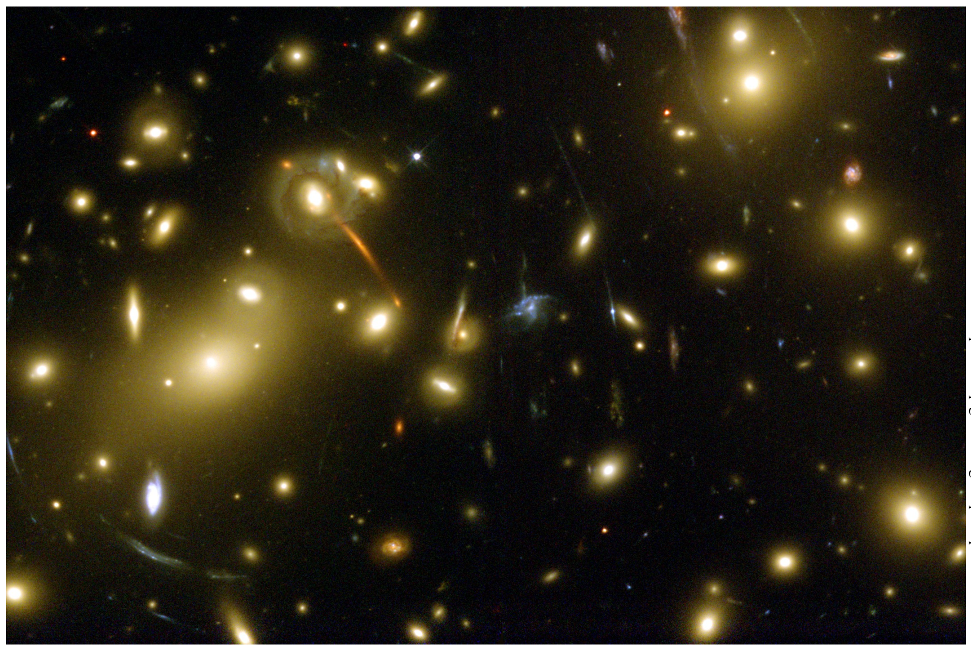
Our Amazing Universe

- By Jedidiah Orrison



This Hubble picture shows a galaxy cluster, located in the Draco constellation, lensing galaxies that are behind it. The galaxies being lensed appear as partial halos around the cluster. Pictures of natural gravitational telescopes like this one can give us some interesting insights.

The Most Amazing Phenomena Fill Our universe. All we need to do is look up into the night sky to observe meteors burning through the atmosphere as shooting stars, see distant galaxies hurtling away from us at velocities near the speed of light, or watch the calm and slow rise of our sun over the horizon.

Did you know that people have been able to look through telescopes that are millions of light-years in diameter? Gravitational lensing is a curious phenomenon that results when light strays too near a massive object and the light's path is bent. Through this natural phenomenon, gravitational telescopes are formed. These telescopes focus light from very distant sources down to earth using astronomical objects like galaxies as lenses. To explore how these telescopes work, we first should explore their discovery.

History

The first gravitational lensing event was found, as things in science history often are, by accident. In 1979, astronomers were cataloguing different quasars (the cores of distant galaxies) when they happened to find two blue quasars right next to each other. The quasars were so close that the separation looked like an equipment glitch. The researchers carefully examined the quasars and found them to be not only similar in color, but identical in the radiation they put out. The researchers also confirmed that the quasars were in different places. Theoreticians clamored to explain the apparent contradiction, but the theory that best explained the observations was that this phenomenon is an example of a gravitational telescope. The researchers were actually seeing a single quasar's light that had been bent around a galaxy. Gravitational telescopes are just one of the many unusual things that are allowed according to Einstein's theory of general relativity.

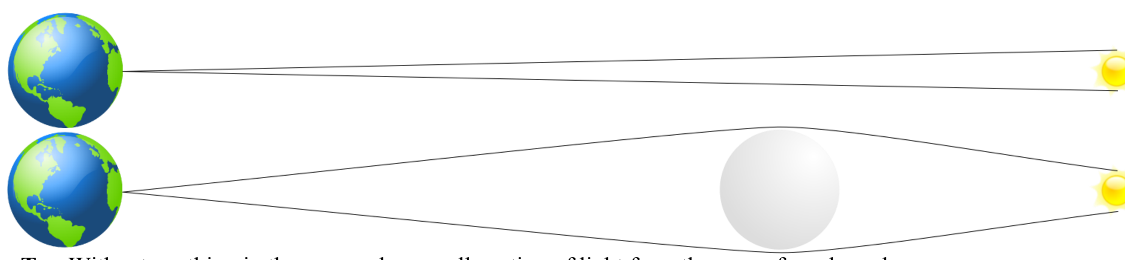
General Relativity

General relativity proposes that light will bend around an object if it is sufficiently massive (like a galaxy). The bending of light was confirmed in 1919 by Sir Arthur Eddington and others. During a solar eclipse they measured the position of one of the stars near the sun that they could see and found that the path of the light had indeed been changed because of the sun.

This confirmation gives us some very interesting insight into the nature of our universe. We know that light always follows the path of least time because of the nature of light. So for light to bend around the sun, both space and time have to be warped around the sun.

The classic example is that of a trampoline, a bowling ball, and a small rubber ball. Placing the bowling ball in the center of the trampoline warps the trampoline around the bowling ball.

If you then roll a rubber ball across the trampoline you see the effect that the bowling ball has. If rolled too close, the rubber ball will start to orbit the bowling ball and then eventually fall into it. If rolled far enough away, the rubber ball isn't affected. If you roll it just right, the rubber ball will turn because of the bowling ball, but continue on afterwards. This is the effect that we are seeing when light is bent around the sun.



Top: Without anything in the way, only a small portion of light from the core of a galaxy, known as a quasar, reaches the Earth.
Bottom: With an intervening mass of some kind, more of the light that would otherwise be emitted into an expanding cone gets focused down to Earth.

Sir Eddington and his team had to measure very precisely to see that the path of light was bent by the sun. When we look at something much larger and farther away, like a galaxy or a cluster of galaxies, the effect is much more pronounced. As we can see in the diagram, light that travels just the right path near the galaxy will be bent back and focused toward the earth. The result will be a cone of light that is redirected towards the earth.

A refracting lens works in much the same way (see diagram at the bottom of the page). The light from an object hits the lens and that light is focused down to an image that we can see. In principle, the bigger the lens you have, the better the image is because the lens captures more light. The telescope has the effect of making the object have more resolution and brightness.

Gravitational telescopes are similar to refracting telescopes, but the only light that they can focus is the light that passes in just the right area around the edge of the mass. Any light that strays too close to the mass will hit it and never reach Earth. Because the gravitational lens isn't capturing all of the light like an optical lens, the resolution gained by gravitational lensing is much less than a refracting telescope.

There are, however, many interesting things we can see and learn from gravitational telescopes. If a galaxy and a quasar are lined up just right for Earth viewing, the quasar will spread out in a halo around the galaxy. If the galaxy isn't quite lined up perfectly straight, there are many different patterns we could see and one of them is a double image.

This double image is what those astronomers were seeing. It appeared to be two identical quasars separated by a small distance to an earth observer, but originally the light came from one source. The "Twin Quasars" phenomenon was the first discovered gravitational telescope.

What can we learn?

The information that we can get from gravitational telescopes isn't limited to the image. An optical lens has to be clear for us to see through it. A star or a galaxy has to emit light for us to see it. But a gravitational lens doesn't have to be clear, and it doesn't have to emit light for us to learn about it.

One of the most impressive discoveries made with gravitational telescopes is that researchers were able to measure the mass of a galaxy based on how the light bent around it. They then looked very carefully at the galaxy itself and added up all the mass from the stars they could see. What they found was that there was not nearly enough mass from the stars to account for the mass of the galaxy. There had to be another source of matter, a source that didn't emit any light: dark matter.

Dark Matter

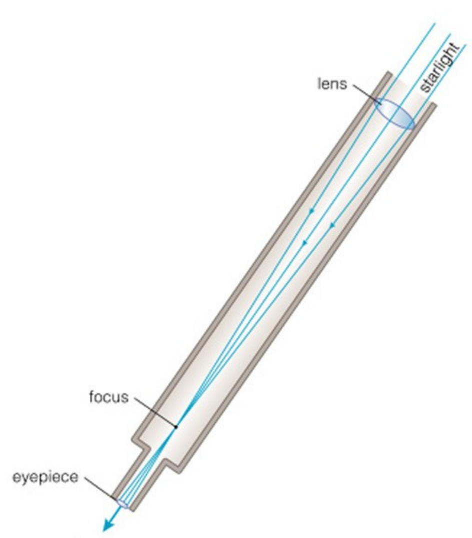
The mass that bends light doesn't have to be as big as a galaxy. Smaller lenses have a different effect called microlensing. Objects like small black holes can be observed by the microlensing they produce. Microlensing doesn't spread the star out into a halo, but does produce enough of a warping that scientists can find the object and learn things about it.

Conclusion

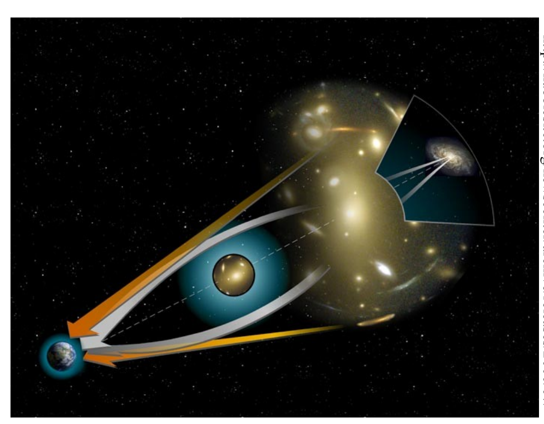
Before the discovery of gravitational lenses, there was no way to actually observe these objects that didn't emit any light. They just blended into the darkness of space. Now we have a new tool. Gravitational lensing allows us to get a glimpse into what scientists think makes up the majority of the universe, the mysterious dark matter.

The theory surrounding dark matter is constantly changing, but gravitational telescopes are giving us an important window into these dark objects. The universe is filled with things for us to explore and enjoy and gravitational telescopes are one more that we can add to the list.

An Einstein Ring The gravity of the yellow galaxy is lensing the blue galaxy behind it.



A Refracting Telescope The light goes through the lens and is focused down to the eyepiece.



A Gravitational Telescope Similar to the refracting telescope, the gravity of the cluster of galaxies focuses the background galaxy down to Earth.

An Einstein Cross This Galaxy is being lensed so that it appears as four different images. The central light is that of the galaxy that is acting as a lens