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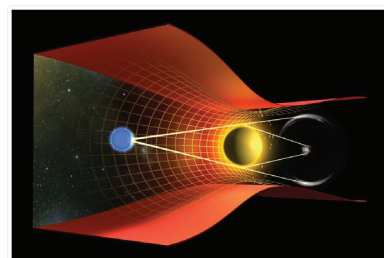
1 Feb 2009

Born on Israel's 28th Independence Day, Assaf's first love was aviation, but later he became interested in science and astronomy. He also loves to see the world, and travels whenever he has the chance. Assaf is a firm supporter of science outreach, believing that a broad education is the foundation of making a better society.

Imagine if you could bend light to create a cosmic magnifying glass, letting you peer out into space to see some of the most distant objects known to man. That's exactly what astronomers do, using a technique first predicted by Albert Einstein: gravitational lensing.

Gravitational Lensing: magnifying the cosmos

Looking through a telescope at the starry skies can be an amazing experience. Revealing a detailed view of the Moon's craters, taking a first glance at Saturn's rings, and watching stars unseen by the naked eye, gives you the opportunity to explore deeper and farther into the Universe. Now imagine that instead of peering through a telescope you are looking through a cluster of thousands of galaxies, and instead of seeing deeper into our own Milky Way Galaxy you can glance farther, watching the Universe when it was still young, observing the first galaxies ever formed. This is the strength and beauty of the phenomenon which we call "Gravitational Lensing", namely the bending of light rays by sheer mass.

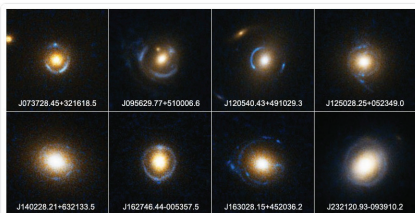


This image illustrates a gravitational lensing effect. Imagine the Earth (represented as a blue sphere on the left), a massive body (represented as a yellow sphere near the centre) and a spiral galaxy (represented as the yellow grid) are aligned. The massive body distorts the spacetime (represented as the yellow grid) and observers on Earth, instead of seeing the spiral galaxy as it is, see the galaxy distorted, as arcs of light. It is like having a "lens" in front of the galaxy.
Image credit: NASA, ESA, and Johan Richard (Caltech, USA).
Acknowledgement: Davide de Martin & James Long (ESA/Hubble).

A rich history

Discussions about the effect of gravity on light can be traced back hundreds of years into the past. In his book "Opticks", Sir Isaac Newton already raised the question in 1704 of whether the gravitational force of bodies acts on light rays, causing them to bend. This question intrigued many other scientists, like Mitchell and Laplace. The first explicit calculation of the bending of light rays by gravity was made by the German astronomer Johann von Soldner, in 1801. Soldner calculated the angle by which a light ray is deflected when passing at some distance from a gravitational mass. However, Soldner based his calculation on classical Newtonian mechanics leading to an incorrect expression of this so-called deflection angle.

The full description of the gravitational lensing phenomenon that is still used today was derived by Albert Einstein in 1915 using his theory of General Relativity. Einstein's prediction of the deflection induced by the Sun's mass on light rays was first confirmed by Eddington in 1919, who measured the positions of stars that appeared projected close to the Sun's limb during the 1919 solar eclipse. The light rays from these stars were bent by the Sun's gravitational field. Due to this deflection the stars appear to be at a different positions compared to a different time of the year when they are observed at night, and when their light rays are not deflected since they do not pass close to the Sun.



Einstein rings are magnified images, sometimes heavily distorted as seen from the Earth.
Image credit: NASA, ESA, A. Bolton (Harvard-Smithsonian CFA), and the SLACS Team.

Einstein ring

The gravitational lensing of light manifests itself in different forms. The most simple and striking form is that of an Einstein ring. Imagine a distant point source of light, like a quasar, situated far behind a massive galaxy. The galaxy acts as a gravitational lens, bending and focusing the light from the point source into a ring shaped image. This form of gravitational lensing is called strong lensing since the light from the point source is greatly magnified. This magnification can be explained by the simple fact that instead of seeing a point source of light we see a larger image of it in the shape of a ring, thus we see more light. This simple case of strong lensing exists in nature in more complicated forms as well. For example, if the mass of the gravitational lens is not distributed symmetrically, then the symmetry of the ring-like lensed image is also broken. Instead of a ring, we will see several images of the point source. Due to the strong lensing effect, these images are sometimes also distorted and appear in the form of beautiful colourful arcs.



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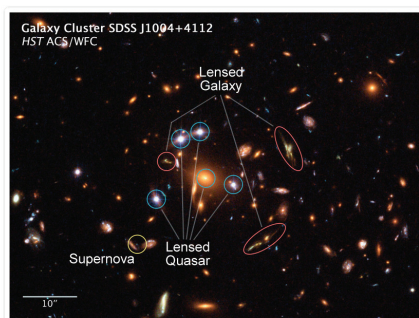
Microlensing

Another form of gravitational lensing is called microlensing, a special case of strong lensing. Microlensing applies when the Einstein ring or the multiply-lensed images are on scales too small to be resolved. Then we only observe a total increase in the amount of light reaching us from the lensed source compared to the light that would have reached us if it were not lensed.

Microlensing can be used as a tool for discovering new extra-solar planets. This is achieved by tracking the brightness of millions of stars in our Galaxy. When one of them is passing behind an extra-solar planet, an increase in its brightness is observed. The planet, in this case, is too faint to be observed directly, but its effect as a gravitational lens on the brightness of the star passing behind it serves as indirect evidence for its existence. Recently, an international team of scientists, including Israeli astronomers, were able to find a solar look-alike planetary system in which two planets, closely matching Jupiter and Saturn, orbit a star half the size of our Sun.



Strong lensing has made these galaxies appear like arcs, stretching over the vastness of space.
Image credit: NASA, A. Fruchter and the ERO Team (STScI).



When many distant objects are lensed, the result can look surrealistic!
Image credit: K. Sharon (Tel Aviv U.) and E. Ofek (Caltech), ESA, NASA.

Weak lensing

Gravitational lensing also appears in a less prominent form called weak lensing. In this case, the light from galaxies which lie behind a gravitational lens but not in its strong "focusing" area is only slightly deflected. Therefore, no Einstein ring, nor multiple images nor arcs of these galaxies will appear. Instead, the gravitational lens induces small distortions on the galaxy shapes, compared to their unlensed shapes. Although not as visually striking as strong lensing, weak lensing has turned out to be an important tool in studying the distribution of dark matter in the Universe.

Unveiling the Universe's secrets

On a more personal note, I find gravitational lensing to be a phenomenon that encompasses all the things that make astronomy such an exciting field of research. It provides both amazing visual images and important tools to unveil the secrets of the Universe.

This feature article was written as part of the Cosmic Diary Cornerstone project for the International Year of Astronomy 2009. To find out more, check out www.cosmicdiary.org and www.astronomy2009.org.