12.0: Gravitational Lensing Introduction

Video Transcript

Just as a wanderer in a desert sees a mirage when light from remote objects is bent by the warm air hovering just above the sand, we may also see mirages in the universe. The mirages we see with a modern telescope such as the Hubble Space Telescope do not arise from warm air, but instead from remote clusters of galaxies; huge concentrations of matter.

Long ago, some people thought the Earth was flat. This is not surprising, since, in our everyday lives, we're not aware of the curvature of our planet. Space is actually curved, although we can't see that for ourselves on a starry night. The curvature of space does, however, produce phenomena that astronomers can see.
One of Albert Einstein's predictions is that gravity warps space and therefore distorts rays of light in the same way that ripples on a pond create a warped honeycomb pattern of light on the sandy bottom. Light from distant galaxies is distorted and magnified by the gravitational field of massive galaxy clusters on its path to Earth. The effect is like looking through a giant magnifying glass and the result is called gravitational lensing.

The weird patterns that rays of light create when they encounter a weighty object depend on the nature of the lensing body; thus the background object can appear in several guises. Einstein rings, where the whole image is boosted and squeezed in a circle of light; multiple images, ghostly clones of the original distant galaxies; or distorted into banana-like arcs, then arclets.

Though Einstein realized in 1915 that this effect would happen in space, he thought that it could never be observed from the Earth. However, in 1919 his calculations were indeed proved to be correct. During a solar eclipse expedition to Principa Island near the west coast of Africa led by the renowned British astronomer Arthur Eddington, the positions of stars near the obscured solar disc were observed. It was found that the stars had moved a small but measurable distance outwards on the sky compared with when the sun was not in the vicinity.

Nowadays, faint gravitational images of objects in the distant universe are observed with the best telescopes on Earth and, of course, with the sharp-sighted Hubble.
Hubble was the first telescope to resolve details within the multiple arcs, revealing the form and internal structure of the lensed background objects directly.
In 2003, astronomers deduced that a mysterious arc of light on one of Hubble's images was the biggest, brightest, and hottest star-forming region ever seen in space.
I takes fairly massive objects, for example, clusters of galaxies, to make space curve so much that the effect becomes visible in deep images of the distant universe – even with Hubble's astonishing resolution. And so far, gravitational lenses have been observed mainly around clusters of galaxies, which are collections of hundreds or thousands of galaxies and are thought to be

the largest gravitationally bound structures in the universe.

Astronomers know that the matter we see in the universe is just a tiny percentage of the mass that must be there, for matter exerts a gravitational force and the visible stuff is simply not enough to hold galaxies and clusters of galaxies together. Since the amount of warping of the banana-shaped images depends on the total mass of the lens, gravitational lensing can be used to weigh clusters and to understand the distribution of the hidden dark matter.
On clear images from Hubble, one can usually associate the different arcs coming from the same background galaxy by eye. This process allow astronomer to study the details of galaxies in the young Universe and too far away to be seen normally with the present technology and telescopes.
A gravitational lens can even act as a kind of natural telescope. In 2004 Hubble was able to detect the most distant galaxy in the known Universe, using the magnification form just such a gravitational lens in space.

The measurement of the bending of starlight around the Sun during the total solar eclipse of 1919 is what made Albert Einstein a world celebrity. In this chapter we will explore gravitational lenses and the phenomenon of the bending of light by gravity. Some lenses are point-like masses such as stars. Others are extended mass distributions such as galaxies and galaxy clusters. We will discover that the lens phenomenon is an important tool for astrophysics. Beyond being an interesting consequence of general relativity in its own right, the presence of lenses can provide information about mass that is otherwise unseen, but that still affects the path of light through space.
