12.4: Weak Lensing

Learning Objectives

- You will understand the difference between strong and weak lensing.
- You will understand that weak lensing reveals the presence of dark matter throughout the Universe.

What Do You Think: What Kind of Matter Can Be a Lens?

All of the lensing we have discussed so far has been strong lensing. That occurs when the source of light is within or close to the Einstein radius of the lens. In strong lensing, obvious arcs and distortions are present. So are multiple images of the background lensed objects. In microlensing these distortions are blurred together so that a strong magnification is noticed, even if the individual images are too close together to be distinguished.

However, even when a source is far away from the Einstein radius, there can be small distortions. They can be so small that they are not noticeable in any individual source. Despite that, if many sources are present in the background, it is still possible to detect the effects of lenses by looking for correlated distortions in background objects. This technique, called **weak lensing**, has proven to be a very useful tool for cosmologists. They can use weak lensing to trace the distribution of totally unseen matter in regions of space far from galaxies. The effect is illustrated in Figures 12.15 and 12.16.

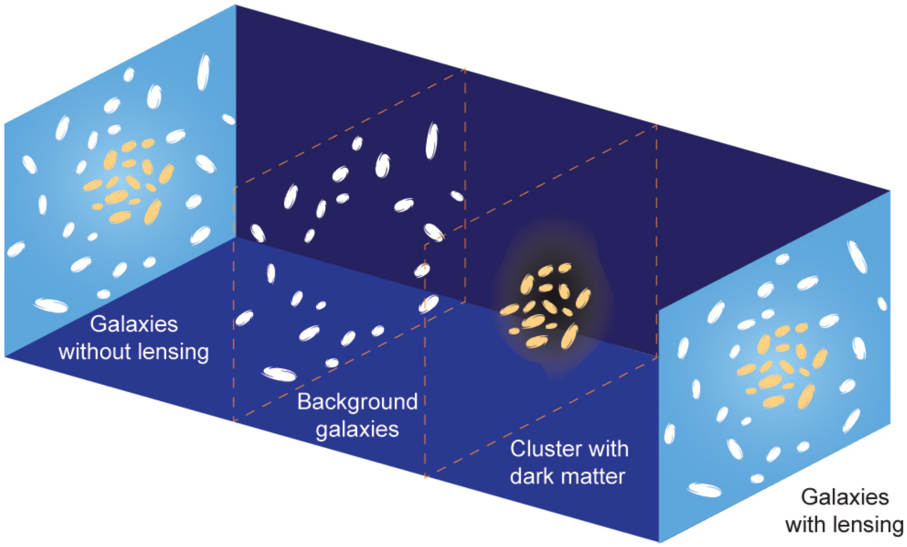

Figure 12.15 In weak gravitational lensing, a small distortion is introduced into the appearance of background objects as their light travels past foreground objects. The effect is generally too small to be seen in individual objects. However, the distortions of galaxies around a mass concentration are such that they will tend to align in circular arcs around the mass. The presence of correlated small distortions among many background objects can thus be used to detect otherwise unseen material between an observer and a source. Credit: NASA/SSU/Aurore Simonnet

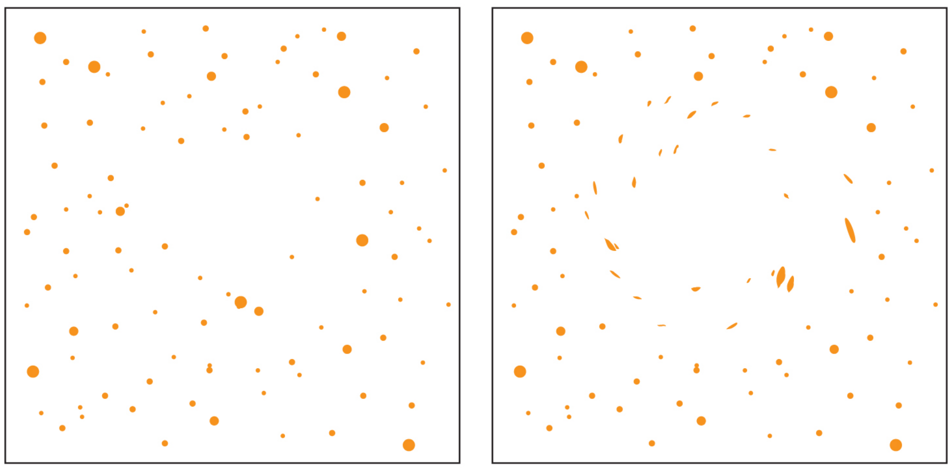

Figure 12.16 The panel on the left is an undistorted field. The panel on the right shows what is expected to happen if mass is concentrated along the line of sight: distortions are seen in the background field of galaxies. Here the distortions have been hugely exaggerated to make them more obvious. In general they are quite small and are not visible, but instead are revealed only with statistical image analysis. Credit: NASA/SSU/Aurore Simonnet

The Deep Lens Survey has been surveying the sky and has "reconstructed" the mass distribution (both seen and unseen) in their fields based on the weak lensing signal. One such reconstruction, of a 4 square degree field, is shown in Figure 12.17. Brightly colored areas in the figure represent regions with a higher lensing signal. They are therefore likely to have a greater density of matter. Notice the filamentary and clumpy structure. The team followed up with deeper imaging and found optical counterparts (e.g. visible galaxy clusters) for many of the peaks in this map.

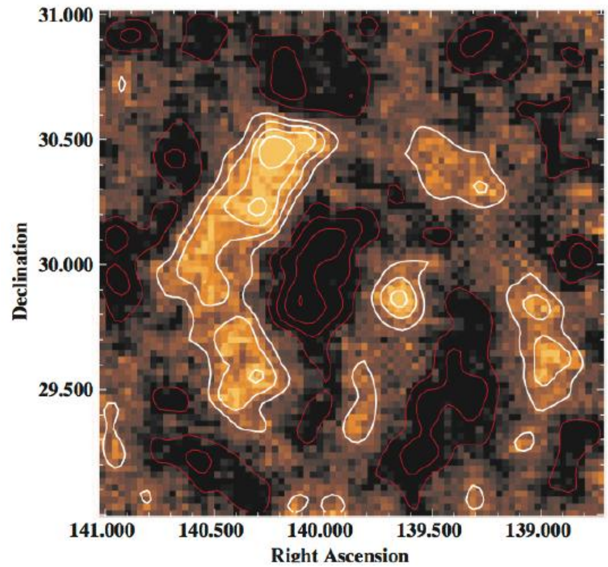

Figure 12.17 This map of a 4 square degree region of the sky was reconstructed from the weak lensing signal in the Deep Lens Survey. The brightly colored areas and white contours represent areas with a greater lensing signal, where there is more likely to be matter, whether dark matter or visible matter. The dark areas and red contours represent areas where there is less likely to be matter. Credit: NASA/SSU/Aurore Simonnet. Adapted from Kubo et al. (2009) *Astrophysical Journal*, 702, 980. For the team's first such reconstruction, see Wittman et al. (2006) *Astrophysical Journal*, 643, 128.

Figure 12.18 shows the results of a weak lensing analysis of Hubble Space Telescope (HST) data. In this study, the distortions caused by weak lensing reveal the presence of dark matter throughout the space along the sightline. Furthermore, the data show that the dark matter is more clumped together the closer it is to us. Recall the concept of lookback time; light that we are seeing now left closer objects more recently and farther objects longer ago. Thus these HST data suggest that the dark matter has become more concentrated over time. This observation is important for our understanding of the Universe and its origin. We will learn why in later chapters.

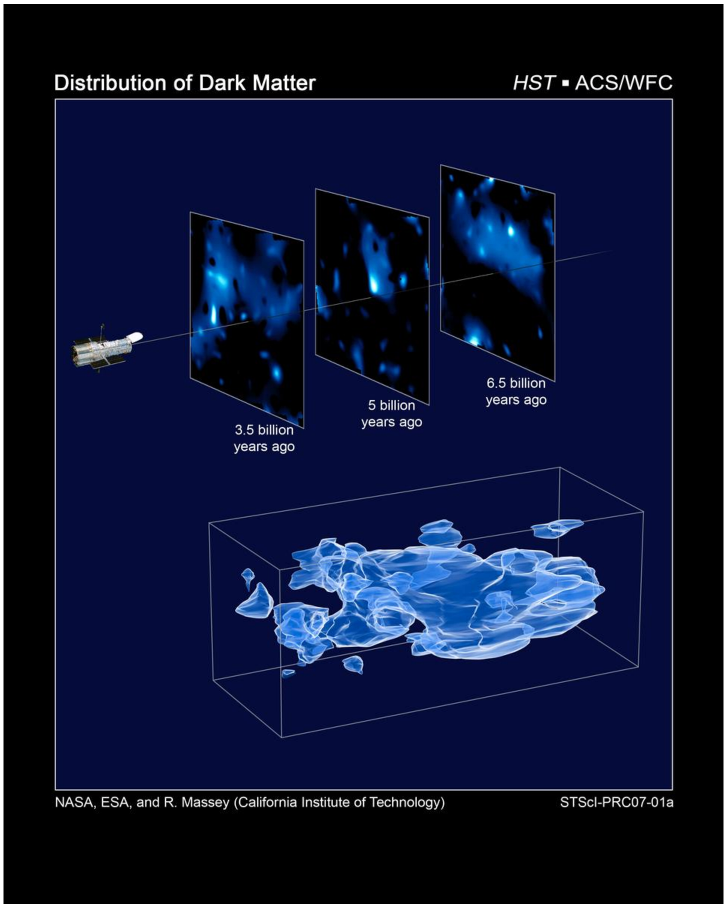

Figure 12.18 By studying the weak-lensing signature along this line of sight, astronomers have been able to determine that the matter causing the lensing, mostly unseen, is more concentrated for the closer galaxies than for the more distant ones. This implies that the dark matter is becoming denser in certain places with the passage of time. The top panel of this figure shows three slices of the dark matter distribution at three different epochs in the history of the Universe. The bottom panel shows the entire distribution vs. time. More recent times are on the left. For more information, see the press release. Credit: NASA/ESA/CalTech/Richard Massey

Since weak lensing is a statistical method, it requires the analysis of a large number of background galaxies. As a result, it has become an important method to use with large surveys of galaxies. The surveys use specially designed telescopes with very wide fields of view, allowing them to image many galaxies at once. By studying galaxies at different distances and noting their weak lensing distortions, astronomers can discern the distribution of dark matter in space. They these methods we are able to measure material that would otherwise be undetectable.

Several such surveys are planned for the coming decade. The Dark Energy Survey and Large Synoptic Survey Telescopes are two examples that will be studying weak lensing, among other things. A current survey called Pan-STARRS will study weak gravitational lensing as one of its science goals. It will be an important tool for astronomers in their investigations of galaxies, clusters, and larger structures.