Diffraction by a Circular Aperture

We will begin with the classical case of diffraction by a circular aperture. This is the case that has long concerned astronomers, microscopists, photographers, and others who use light for technical or scientific purposes. The fundamental problem is the effect of such an aperture on the image of a point source, such as a star. While this may seem to be a very limited case, it must be remembered that any image is simply the sum of its myriad points!

The lens of a telescope or microscope is certainly not a “pinhole,” but such lenses are nevertheless circular apertures, and they produce diffraction just as a pinhole does. It is this diffraction of light, due to the wave nature of light, that limits the ability of telescopes and microscopes to see fine detail. Even photographers must exercise caution; if a camera (or enlarger) lens is “stopped down” to too small an aperture, the image will blur due to diffraction.

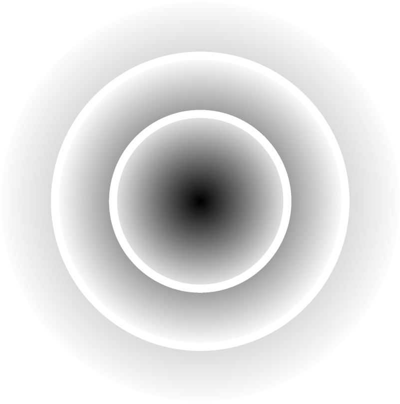

Figure 5.1: Airy Disk pattern (colors are inverted for clarity)

In the laboratory, you should see an image of the diffraction pattern of the pinhole similar to Figure 5.1. Notice that the image consists of a central disk surrounded by a series of circular ”diffraction fringes.” While it is not evident in the figure, the central disk will contain about 85% of the total energy of the image in a good optical system; i. e., it is far brighter than the surrounding fringes, as you will see during the experiment. The central disk is often referred to as the Airy disk in honor of the British Astronomer Royal, Sir George Airy, who called attention to its importance in star images.

Since most of the light is concentrated in the Airy disk, it is the size of this disk that determines the resolving power or ability to see detail in an image; the smaller the Airy disk, the finer the detail that can be seen. Optical theory predicts that the angular diameter θ of the Airy disk (as seen from the lens or the pinhole) will be

$$\theta = \frac{2.44\lambda}{D}$$

where λ is the wavelength of the light and D is the diameter of the lens or pinhole. Notice that the Airy disk shrinks as the lens (or pinhole) becomes larger (for a fixed wavelength). This means that, at the same wavelength, a larger (diameter mirror/lens) telescope produces smaller star images than a smaller telescope (down to an atmospheric limit unless in space)!

For example, the James Webb Space Telescope (6.5 meters) produces about three times crisper images than than the Hubble Space Telescope (2.4 meters) at the same wavelength. However, critically note that, because James Webb is designed to image further into the infrared (longer wavelengths) than Hubble, Hubble produces more detailed images when the difference in wavelength is different by more than about a factor of three. Also, this means that radio observations