General Astronomy (29:61)
Fall 2012
Lecture 19 Notes, October 15, 2012

1 Telescopes: Image Formation and Astronomical Detection of Light

Last time we ended up with the definition of the *image scale* or *plate scale* s,

$$s = \frac{\phi('')}{d(mm)} = \frac{206,265}{F(mm)} \tag{1}$$

Note from this equation that the image scale is entirely determined by the focal length, not the diameter or area of the lens. The diameter *is* very important in that determines how many photons fall on a given area in the focal plane (determined by collecting area).

Let's use this equation to come up with some interesting conclusions about astronomical observations.

1.1 The size of the image of Jupiter

Jupiter is a large angular diameter object. It has a diameter at the present time of 44", so $\phi = 22$ ". A superb view of Jupiter is had with an 8 inch Celestron telescope, like we used to observe the Moon at the beginning of the semester. An 8 inch Celestron has $F = 2032$ mm. We can plug this into our above formula to get the size of the image of Jupiter formed by the Celestron telescope,

$$2d(mm) = \frac{F(mm)2\phi('')}{206265} \tag{2}$$

$$2d = \frac{2032(44)}{206265} = 0.43 \text{ !} \tag{3}$$

The image is tiny!

1.2 Use of eyepieces in telescopes

If we are going to see anything interesting in a telescope, we need a magnifying glass to magnify the tiny image and examine it. These magnifying glasses are called eyepieces.

$\longrightarrow$ Online diagram on how eyepieces work, produce magnification.

Let's image we look at the image, of diameter $2d$, with a magnifying glass of focal length F_2. The rays of the image going through the center of the lens will emerge from it with an opening angle $\pm\Phi$

$$\tan\Phi = \frac{d}{F_2} = \Phi, \text{ if}\Phi \ll 1 \tag{4}$$

We can rely on what we learned above to know that all rays striking the lens from the same point on the image will end up going off at the same angle (Φ in the case of the points coming from the ends of the image.)

The *magnification* of the telescope is pretty obviously

$$M = \frac{\Phi}{\phi} = \frac{d}{\phi F_2} \tag{5}$$

But from above, $d = F\phi$, so The *magnification* of the telescope is pretty obviously

$$M = \frac{\Phi}{\phi} = \frac{F}{F_2} \tag{6}$$

The magnification depends only on the ratio of the focal lengths of the main lens to that of the eyepiece. Let's work out an example for the Celestron C8. A standard eyepiece that gives moderate, but not high magnification has $F_2 = 25$ mm. So, $M = \frac{F}{F_2} = \frac{2032}{25} = 81.3$. This telescope and eyepiece combination makes an astronomical object appear 81 times closer than it really is.

2 Diffraction Limitation

Based on above, you might think that you could see as much detail as you would like, depending on how small F_2 is. This is not true. There are fundamental limitations to the angular resolution a telescope can achieve, based on the wavelength of observation, and the diameter of the lens.

The calculations above have assumed *ray optics.* This means that the wavelength is much smaller than the size of the lens that the light goes through. The light can then be considered like a stream of bee bees, or rays of infinitely small extent. However, light is also a wave, and this characteristic is always present if you look closely enough.

A set of parallel light rays going through a lens of diameter D don't form a point on the focal plane. They form a ripple pattern called an *Airy Disk.* A picture of an Airy Disk is shown in Figure 6.5.

The smallest angle you can distinguish is the angle between the peak of the Airy disk, and the first minimum in the pattern, or the angular width of the central "fringe". This angle is given by

$$\theta_A = 1.22\frac{\lambda}{D} \tag{7}$$

where λ is the wavelength of observation, and D is the diameter of the aperture. If you can discern angles that small with a telescope, it is called *diffraction limited*.

At optical wavelengths, blurring of astronomical objects by turbulence in the atmosphere limits the angular resolution to much larger angles. A typical night here in Iowa might have a "seeing disk" of about 1 arcsecond. The best sites would have about 0.25". In observatory field trips, we will see how you can estimate these angular sizes by observations at the eyepiece.

3 Refractors and Reflectors

So far, we have talked about refractors, which are telescopes that use a lens to focus light rays. All large research telescopes nowadays are reflectors, in which parabolic mirrors are used to focus the light.
$\longrightarrow$ See slides in online presentation. See also demos with blackboard optics.