Assignment 2: Telescope Optics

Due at Beginning of class Tuesday, March 29

This assignment is designed to get you a bit more familiarity with the key properties of telescope optics that we introduced on March 22nd:

- Degrees, arc-minutes, arc-seconds
- Focal Length, f
- The f/ Ratio
- Eyepiece focal length
- Magnification
- Apparent Field of View

Additionally, there is a property of eyepieces we didn't have time to get to:

- Exit Pupil

This subject is short and the two key things to know is that the Exit Pupil Diameter = focal length of eyepiece divided by the f/ ratio of the telescope and (2) When comparing exit pupil diameter to the human eye pupil, it is handy to have the typical dilated eye pupil value of 7mm.

Problem 1 — Degrees, Arc-Minutes, and Arc-Seconds

(a) The Andromeda Galaxy is 2.5 million light-years away. It is about 250,000 light-years across. Draw an excruciatingly simple picture of an object whose distance from the viewer is 10 times its width. It could be a billboard whose width is 15 feet and whose distance from the viewer is 150 feet. It doesn't matter as long as the ratio of distance to width is 10. Draw the picture to scale. Find a protractor and measure the angular width of the object in degrees as seen by the viewer.

(b) Use trigonometry to derive the angular width. HINT: the arctangent function is going to be important. THIS IS THE LAST TIME WE WILL USE TRIG FOR THESE COMPUTATIONS.

(c) Use the wonderful approximation we showed in class (that used that the arc length of a circle and the object width are about the same) to get the angular width of the object IN RADIANS.

(d) Convert what you got in (c) to degrees.

(e) If any of a, b, and d are in substantial disagreement with each other, search for errors. Small disagreements are expected. FROM HERE ON WE USE THE METHOD IN (c) AND CONVERT TO DEGREES.

Problem 2 — Focal Length, f

(a) Our Meade has a focal length of 2540mm and an aperture of 254mm. Knowing its focal length, how large would an object that is 1^{o} in size appear in mm on the focal plane. HINT: If you use the methods in 1(c) and first convert 1^{o} degree to radians, this calculation is simple.

(b) With compound optics, focal length is more complicated. It is not just the light travel path from the objective to the focal plane. However, manufacturers keep your life simple and quote an “effective focal length” so that you can do the same simple calculations by just putting the effective focal length of the compound optics in for focal length. Our Meade can accept a Celestron reducer/flattener that makes its effective focal length 1600mm. Repeat the calculation in Part 2(a) with this focal length.

Problem 3 — Focal Length and Camera Size

(a) You have the spec sheet for the ASI 2600 camera. What is the cameras image area width and height (in mm)?

(b) How many degrees does this correspond to (width and height) when placed on a telescope with 1600mm effective focal length?

(c) Convert your answer to (b) to arc-minutes.

(d) On the spec sheet you will find that the camera has 6248 x 4176 pixels. Take the product of these two numbers. Convert to Megapixels.

(e) Divide the width in (c) by 6248 and the height by 4176. The results should be about the same (because the pixels are square). This will be a tiny amount of arc-minutes. Convert your results to arc-seconds. You now have answers in arcseconds per pixel.

(f) Sadly, due to atmospheric turbulence, anything smaller than about 2 arc-seconds per pixel is wasted. You don't really get 26 Megapixels of resolution. Use the result of part (c) converted to arc-seconds to figure out what resolution our sensor area can actually achieve using the assumption that any resolution finer than 2 arc-seconds is wasted.

Problem 4 — Magnification and Apparent Field of View

(a) The magnification calculation we did in class was strikingly simple. A telescope’s magnification is its focal length divided by its eyepiece’s focal length. I think the eyepiece we are using is 40mm. Assuming that and a focal length of 2540mm for the telescope, what magnification are we working with?

(b) Just to double-check that you know what magnification is, how large would an object in the sky whose size is 1° appear to be in our eyepiece?

(c) The Apparent Field of View (AFOV) measures how much you can peer around in an eyepiece. If it is something huge like 105° you can look all over the place, almost like you are immersed in space. If it is small, like 40°, you feel constrained. Our eyepiece has an apparent field of view of 67°. What is the largest object in the sky (in degrees) that when magnified by the amount you found (a) will just fit within the AFOV?

Problem 5 — f/ Ratio and Exit Pupil

(a) Our Meade LX 200's telescope has an f/ ratio of? (You can look it up on the LX200 spec sheet or you can easily calculate it from the numbers in previous problems.)

(b) It turns out the exit pupil diameter of an eyepiece is the eyepiece focal length divided by the telescope's f/ ratio. What is the exit pupil diameter of our setup?

(c) Simple yes/no answers are all I am looking for on this last part.... The human eye has a dilated pupil size of 7mm. Will the shaft of light coming out of our eyepiece fit through a dilated pupil? Can you see why it is important to have your eye in the right position over the eyepiece and many people fail to see the image at all because they are not used to centering their eye over the eyepiece?

(d) There is one more eyepiece property that I haven't gotten into, called eye relief. It is how close your pupil has to be to the eyepiece. Take a look at a person wearing glasses. Estimate in mm how far from their eye their glasses lenses are. With glasses on, they can't get their pupil any closer to the eyepiece than whatever your estimate is. What is the minimum eye relief needed for glasses wearers? It is common to remove glasses to use eyepieces that don't have this amount of eye relief.