ASTRO 100/G – Experiment 2

Telescopes: Area & Resolution

Name:	**Grade**
ID:	
UPI/Username:	/5

IMPORTANT

IN THIS EXPERIMENT YOU DO NOT NEED TO DO ANY UNIT CONVERSION!

Collecting Area

In lectures, we learned that the amount of light that can be collected by a telescope depends on the surface area of the telescope. Because telescope mirrors are typically round/circular, the area is given by

$$\text{Area} = \pi \times (\text{radius})^2 = \pi \times \left(\frac{\text{diameter}}{2}\right)^2$$

Thus, if we double the radius of the telescope, we quadruple (as $2^2 = 4$) the area of the telescope. With more collecting area, we collect more light – so we can see fainter objects. This is also how the first image of a black hole was taken – by creating a telescope that's effectively the size of the Earth!

1. The Physics Department has a telescope which has a diameter of 300mm. If the diameter of the pupil of a dark adapted eye is about 6mm, what is the ratio of the amount of light collected by the telescope to the amount of light collected by the eye?

   (Hints: If something has a bigger area it collects more light. How much more area does the telescope with respect to the eye? Also, ratio = $\frac{\textit{Light collected by telescope}}{\textit{Light collected by eye}} = \frac{\textit{Area of telescope}}{\textit{Area of eye}}$*.)*

Resolution

There is another reason why we build big telescopes that is a bit more subtle. Light is a wave and whenever a wave tries to go through a hole or gap it spreads out. This is called *diffraction*. The spreading/blurring is greater the more similar the wavelength of light is to the size of the gap – or in this case the size of the mirror in the telescope.

For a circular aperture, that is our mirror, there is a relatively simple equation that can tell us how much the light spreads. This equation is *Rayleigh's Criterion*, it gives the limit of angular resolution θ (in arcseconds, symbol $''$) for a telescope under perfect conditions. It depends on the telescope diameter d (in millimetres), and the wavelength of light λ (in nanometres, symbol nm):

$$\theta = 0.252 \times \left(\frac{\lambda}{d}\right)$$

2. Using blue light (which has a wavelength of 300nm), calculate the angular resolution limit for the telescope in Q1 (300mm diameter) in arcseconds.

The distance (D), between the Earth and the Moon is approximately 4×10^8 metres. The angular resolution can be turned into a distance at which two objects, for example two mountains on the Moon, can be seen as separate (i.e. 'resolved') and not blurred into one. The "resolution" is given by:

$$R = \theta \times \left(\frac{D}{206265}\right)$$

The units of the resolution are the same as what the distance was measured in. The 206265 converts arcseconds to radians so the maths all works out nicely for you.

3. Use your value of θ (in arcseconds) from above to find the size of the smallest feature visible on the Moon (the resolution) with this telescope. Remember to include units!

   (Hint: Again, no number conversion required; just plug in the numbers).

4. The Hubble Space Telescope (HST) collects about 64 times more light than the telescope in front of you does. If the diameter of this telescope (present in room) is 300mm, what is the diameter of the HST?

   (Hint: Start by writing down the ratio: ratio = $\frac{\textit{area of the HST}}{\textit{area of the telescope in the room}} = 64$. *You'll need to do a tiny bit of rearranging the equation to figure out the diameter of the HST.)*

5. Calculate the angular resolution θ (in arcseconds) for the HST, if the wavelength of light it detects is 600nm, using $\theta = 0.252 \times \left(\frac{\lambda}{d}\right)$

   (Hint: You're repeating Q2 for a new telescope)

6. Now use $R = \theta \times \left(\frac{D}{206265}\right)$ to find the size of the smallest feature visible on the Moon with the Hubble Space Telescope (same D as in question 3). Remember to include units!

   (Hint: Assume that the HST is located on earth even though it is in orbit at a height of $\approx$ 550 km.)

7. Now consider a galaxy 1 million light-years away. What is the smallest distance (in light years) between two stars such that they can still be resolved as separate by the Hubble Space Telescope? Remember to include units!

   (Hint: this is a repeat of Q6 but now the HST is pointing at a galaxy. Also we have switched distance unit from metres to light-years.)

You are now finished. Please hand your sheet to the demonstrator for marking.