Student name:

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```
#Start all notebooks with this line.  It sets a lot of variables to values we want to use,
#and reads in some important packages of routines, too.
%pylab inline
```

Question 1: Chapter 5, Exercise 8

Compute the frame width (in arcmin) and pixel scale, a.k.a., plate scale (in arcsec per pixel) for CCD observations with the following telescope and instrument: aperture 1.0 m, focal ratio f/6.0. CCD is 1024 x 1024 pixels; each pixel is 18 μm square.

```
R=6.0 #focal ratio
a=1.0 #aperture
f=a*R #Focal length
p=18*(10**-6)
print("The focal length is:",f)
sp=(206265/f)*a  #plate scale
fov=((1024*p)*sp) #Frame width (FOV)
fov_arcmin=fov/60  #Frame width in arcmin
print("The frame width in arcmin is:", fov_arcmin)
ps=fov/1024  #pixel scale (arcsec per pixel)
print("The Pixel scale is:", ps)
```

```
The focal length is: 6.0
The frame width in arcmin is: 10.560768
The Plate scale is: 0.618795
```

- Frame width: 10.561 arcmin
- Plate scale: 0.619 arcsec

- First I calculated the focal length which I used the equation
$$f = a * R$$
- Used f to compute the plate scale using the equation
$$\frac{206265}{f} * a$$
- Then I used sp to find the FOV by using the equation
$$1024 * p * sp$$
- Divided FOV by 60 to find the frame length in Arcmin
- To find plate scale, Divide the FOV by 1024 to get the pixel scale in arcsec per pixel

Comments from instructor: Good

Question 2: Chapter 5, Exercise 12, with supplement

(a) Compute the diffraction limit of the Hubble Space Telescope (2.4-m diameter) in the ultraviolet (300 nm) and near infrared (2.0 μm).

```
λ=300*(10**-3)  #Wavelength of Ultraviolet light in μ m
D=2.4 #meters
da=((0.252*λ)/D)
print("The diffraction limit in UV wavelength in arcsec is:", da)

λ=2  #Wavelength of Near infrared light in μ m
da=((0.252*λ)/D)
print("The diffraction limit in NIR wavelenth in arcsec is:", da)
```

```
The diffraction limit in UV wavelength in arcsec is: 0.0315
The diffraction limit in NIR wavelenth in arcsec is: 0.21000000000000002
```

- α_A UV Wavelength: 0.032 arcsec
- α_A NIR Wavelength: 0.210 arcsec

Longer wavelengths with the same diameter telescopes will cause a larger diffraction limit.

(b) Compare with the diffraction limit of the human eye at 0.5 μm

```
λ=0.5 #Wavelength of Visible in μ m
D=24.2*(10**-3)  #millmeters to meters
da=((0.252*λ)/D)
print("The diffraction limit of the human eye in visible wavelength in arcsec is:", da)
```

```
The diffraction limit of the human eye in visible wavelength in arcsec is: 5.206611570247934
```

- α_A Visible Wavelength in Human Eye: 5.207 arcsec

The human eye has a much higher diffraction limit than the Hubble Space telescope.

Source for human eye diameter: Inessa Bekerman,2014,Variations in Eyeball Diameters of the Healthy Adults,Pg.1

(c) Compare with the diffraction limit at 2.0 μm of a space telescope that has an 8-m diameter

```
λ=2.0 #Wavelength of Near Infrared in μ m
D=8 #meters
da=((0.252*λ)/D)
print("The diffraction limit of a space telescope at NIR wavelength in arcsec is:", da)
```

```
The diffraction limit of the human eye in visible wavelength in arcsec is: 0.063
```

- α_A NIR Wavelength: 0.063 arcsec

The larger the diameter of the telescope, the smaller the diffraction limit will be assuming wavelength remains constant.

(d) Compare with the diffraction limit of a 30-m ground-based telescope at 2.0 μm.

```
λ=2.0 #Wavelength of Near Infrared in μ m
D=30 #meters
da=((0.252*λ)/D)
print("The diffraction limit of a ground based telescope at NIR wavelength in arcsec is:", da)
```

```
The diffraction limit of a ground based telescope at NIR wavelength in arcsec is: 0.0168
```

- α_A NIR Wavelength: 0.017 arcsec

Large ground based telescopes have the smallest diffraction limits, so they are heavily seeing limited, and can use adaptive optics to correct that issue.

(e) Discuss what you learned

Diffraction limits are both wavelength, and diameter dependent. The longer the wavelength assuming diameter is fixed, causes a larger diffraction limit. The larger the diameter of the telescope assuming wavelength is fixed, causes a smaller diffraction limit. The largest telescopes on the ground have extremely small diffraction limits, and use adaptive optics to correct seeing limits.

*Comments from instructor: Good. (You forgot to change the text about the eye...) Note that for our eye, the relevant "aperture" is the pupil. *

Question 3:

Suppose you are trying to image a planet orbiting a star with the Hubble Space Telescope. The star (and planet) are at a distance from us of 100 parsec. What is the smallest separation between the planet and star (in Astronomical Units) that would allow you to separate the planet from the star in an image? Assume you are observing at a wavelength of 300 nm.

```
λ=300 #Wavelength in micrometers
pc=100 #distance in parsec
D=2.4
r=1.22*λ/D #Angular radius of airy separation
print("The angular radius of airy separation is: ", r)
arcsec=(152.5*(10**-9))*206265  #nanoradians to radians to arcsec
print("The angular separation between the planet and the star",arcsec)
sep_au=arcsec*pc #physical separation between planet and star
print("The smallest separation between the planet and star is:", sep_au)
```

```
The angular radius of airy separation is:  152.5
0.0314554125
The smallest separation between the planet and star is: 3.14554125
```

Smallest separation between the panet and the star: $3.14AU$

- To get the angular radius of airy separation I used the equation
$$r = \frac{1.22 * \lambda}{D}$$
- Then to find the physical separation, take the result which is in nanoradians and convert it onces to radians by multiplying by 10^{-9}, then converting it to arcsec by using the conversion 1 radian=206265 arcsec.
- The converted result is the parallax of the star and using the distance in PC given, I solved for the physical separation in AU.
- Used the equation
$$AU = arcsec * pc$$
which yields a result in Astronomical units
- The result 3.14 AU makes sense due to it being a reasonable location for a hypothethical planet in a solar system like our own.

Comments from instructor: Good

Question 4:

(a) In question 2 (Chapter 5, Exercise 12), you found the diffraction limit at 300 nm of the Hubble Space Telescope, which has a primary mirror with diameter 2.4 meters. The Atacama Large Millimeter Array (ALMA) is a millimeter-wave interferometer, which combines the light from multiple small telescopes. For interferometers, the diffraction limit is set by the longest distance between any two telescopes. This distance is called a baseline length, which we'll call B. Calculate B required for ALMA to have the same diffraction limit as the Hubble Space Telescope, if ALMA observes at a wavelength of 1 mm. Read about the baseline lengths on the ALMA Wikipedia page to check that your answer makes sense.

```
λ=1*(10**3)
da=0.032 #Diffraction limit of Hubble at UV Wavelength
B=(0.252*λ)/da  #Baseline length using diffraction limit equation
print("The baseline length in meters is", B)
```

```
The baseline length in meters is 7875.0
```

Baseline length: 7875 meters

- I used the diffraction limit for the Hubble Space Telescope at 300 nm which was 0.032 arcsec.
- I solve for B which is the equivalent to the diameter of the telescope using the following equation:
$$B = \frac{0.252 * \lambda}{da}$$
derived from the Diffraction limit equation

(b) Comment on your answer. Would it have been feasible to build a solid telescope with a diameter equal to this baseline length?

A mirror of 7875 meters would not be feasible for several reasons. A mirror that large would cost a ton of money and resources that we currently don't have on earth. A large amount of space would have to be reserved for the mirror which that much space would destroy habitats of wildlife in the area.

Comments from instructor: Good. It is also hard to even imagine how to support a dish that large

Question 5:

(a) Compute the diffraction limit (in arcsec) for the Vassar Class of 1951 observatory telescope, which has a 32" (inch) primary mirror. Assume you are observing at visible wavelengths, $\lambda \approx 0.6\,\mu$m.

```
λ=0.6  #Wavelength of visble light
D=32*0.0254  #Conversion from inches to meters
da=((0.252*λ)/D)
print("The diffraction limit in arcsec is:", da)
```

```
The diffraction limit in arcsec is: 0.1860236220472441
```

The telescope has a $\alpha_A = 0.186$ arcsec

- First I converted inches to meters to match the units of wavelength
- Then I used the diffraction limited equation

$$\alpha = \frac{0.252\lambda}{D}$$

  to find the diffraction limit of the Vassar Class of 1951 observatory telescope.

(b) Compare your answer to (a) to the typical size of a seeing-limited image at the observatory, which is about 2" (arcsec). Is the Class of 1951 observatory "seeing-limited" or "diffraction-limited"?

Seeing-limited due to the telescope being less than 2 arcsec. Telescopes are larger as the diffraction limit gets smaller. Telescopes with a diffraction limit larger than 2 arcsec are generally smaller than observatory telescopes and would be considered diffraction limited.

Comments from instructor: Good

Grade

Calculations:4 Great work

Concepts: 4 You showed good conceptual understanding

Communication: 4 Your work was very clear. You did a very comprehensive job with annotation.

Total grade: 12