Homework 1: astronomy basics

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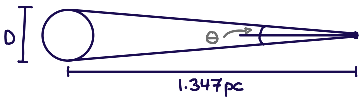
1. The star α Centauri, has a parallax of 0.742 arcsec. What is its distance in parsec? If it has same diameter as the Sun ($D \sim 1.4 \times 10^{11}$ cm) what is its angular diameter in radians and in arcseconds?

distance in parsec: $d = \frac{1}{p''} = \frac{1}{0.742''} = \boxed{1.347\text{pc}}$



$\tan\left(\frac{\theta}{2}\right) = \frac{D/2}{1.347\text{pc}} \Rightarrow \theta = 2 \cdot \tan^{-1}\left(\frac{1.4 \times 10^{11}\text{cm}/2}{1.347\text{pc}}\right) = 3.368 \times 10^{-8}\text{rad}$

so angular diameter = $\boxed{3.368 \times 10^{-8}\text{rad}}$ or $0.00694''$

* unit conversions done w/ wolfram alpha

2. What is the definition of *Absolute Magnitude*? Derive the distance modulus formula, $m\text{-}M = 5 \log d - 5$ from the inverse square law $f = L/4\pi d^2$ and the definition of a magnitude $\Delta m = 2.5 \log$ (flux ratio).
   - Use the notation: luminosity L, apparent flux f, distance d (in parsec), apparent magnitude m, and absolute magnitude M.
   - What is the distance modulus to the center of the Milky Way galaxy?
   - What will be the apparent magnitude of a star like the Sun at the distance of the galactic center?

absolute magnitude = apparent magnitude of a star if it were 10pc away, where apparent magnitude is <0 for brightest objects in the sky and increases for dimmer stars s.t. $\Delta m = 5 \Rightarrow 100\times$ brighter object

$$\Delta m = m - M = 2.5 \log\left(\frac{L/4\pi(10\cancel{pc})^2}{L/4\pi d^2}\right)$$

cancel w/ units from d so argument in log remains unitless

$$= 2.5 \log\left(\frac{d^2}{10^2}\right)$$

$$= 2.5 \cdot 2\left(\log(d) - \underbrace{\cancel{\log(10)}}_{=1,\ \text{base }10}\right) \Rightarrow \boxed{m - M = 5 \log d - 5}$$

The milky way is 8000 pc away → $m - M = 5 \log(8000) - 5 \approx \boxed{14.52}$

For a sun-like star @ galactic center, apparent magnitude is $m = 5\log 8000 - 5 + M_\odot$

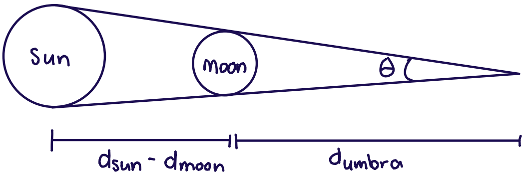
$M_\odot$ is ~ 4.83, so $m = 14.52 + 4.83 = \boxed{19.39}$

3. Many of us enjoyed the solar eclipse over North America this spring. Here are a few questions to get you thinking about eclipses more deeply:
   - During which phases of the moon can a Solar eclipse occur?
   - Why isn't there a Solar eclipse every Moon cycle?
   - Using trigonometry, estimate the "size of totality" of a Solar eclipse on Earth, i.e., the stretch of Earth in kilometers that experiences a total Solar eclipse. Start by making a drawing.

· for an eclipse to occur, the moon needs to be positioned between the earth and the sun, which is the new moon phase.

· the reason is the moon's orbit is not aligned with the earth's orbit around the sun (there's ~5° difference between between the moon's orbital plane and the ecliptic). So, during the new moon phase the shadow is often cast such that it's not on the earth's surface.

estimating the size of totality

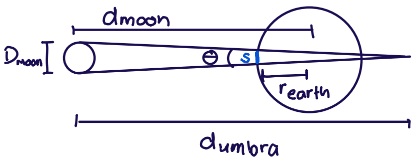


$$\tan\theta = \frac{D_{sun}}{1au} \longrightarrow \theta = \tan^{-1}\left(\frac{D_{sun}}{1au}\right)$$

$$\theta = 0.009\,\text{rad}$$

$$\sin(\theta/2) = \frac{r_{moon}}{d_{umbra}} \Rightarrow d_{umbra} = \frac{r_{moon}}{\sin(0.009\text{rad}/2)} \approx 3.74\times10^{8}\,\text{m}$$

now we can work out the size of the shadow; we'll neglect the curvature of the earth in the area of the shadow since it is quite small.



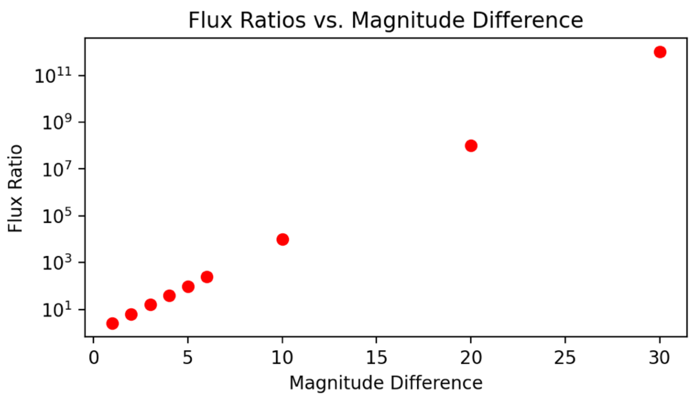
$$\tan(\theta/2) = \frac{S/2}{d_{umbra} - d_{moon} + r_{earth}}$$

$$s = \tan\left(\frac{\theta}{2}\right)\cdot(d_{umbra} - d_{moon} + r_{earth})\cdot 2 \approx 219\,\text{km}$$

4. a. Write a python script, *magnitude.py*, that calculates the *flux ratios* for stars with a *magnitude difference* Δm of 1, 2, 3, 4, 5, 6, 10, 20, 30 mags. Present the results graphically. (Check out section 3.3 of *Python for Astronomers* if you aren't sure where to start!)

   b. The faintest stars we can observe with our 16-inch telescope are about V=16, while for the recorded with the Hubble Space Telescope its about V= 30. What is the brightness ratio?

graphical results for a:



b. (from script) brightness ratio will be 3.98×10^{5}

5. The star Vega is the prime photometric standard in many astronomical filter systems. In the ***Johnson*** system, U B V R I J H K L M, Vega is (almost) zero magnitude at all wavelengths. The conversion from apparent magnitude in each filter to monochromatic flux density can be found at: https://irsa.ipac.caltech.edu/data/SPITZER/docs/dataanalysistools/tools/pet/magtojy/

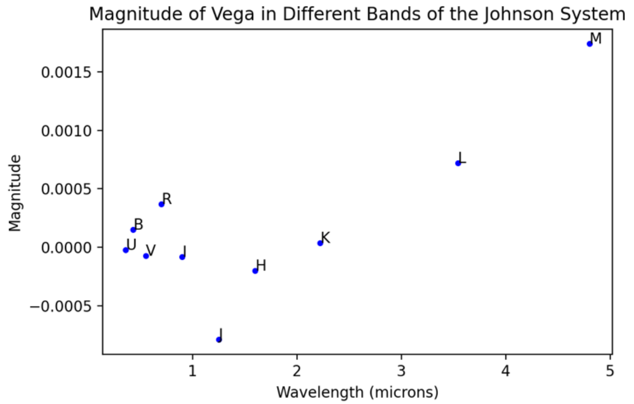
   a. Run the conversion routine for each of the 10 Johnson filters at magnitude = 0, and record
      - F_λ in in Wm^{-2} $micron^{-1}$
      - λ_c central (effective) wavelength in micron.

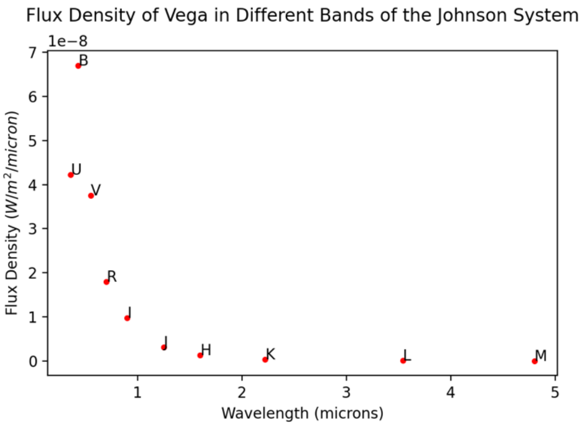
   b. Write a plotting script in python with an array for magnitude, F_λ and λ_c. Make two plots on one page. (You can stay in these units or convert to nm with 1000 nm = 1 micron).
      - The magnitude of each filter UBVRIJHK versus wavelength
      - Monochromatic Flux density at each filter versus wavelength

a)

Filter	F_λ ($Wm^{-2}micron^{-1}$)	λ_c (micron)	apparent magnitude
U	4.22E-8	0.36	-2.38E-5
B	6.7E-8	0.43	1.49E-4
V	3.75E-8	0.55	-7.18E-5
R	1.8E-8	0.7	3.69E-4
I	9.76E-9	0.9	-8.24E-5
J	3.08E-9	1.25	-7.9E-4
H	1.26E-9	1.6	-2.02E-4
K	4.06E-10	2.22	3.78E-5
L	6.89E-11	3.54	7.2E-4
M	2.21E-11	4.8	1.74E-3

b)



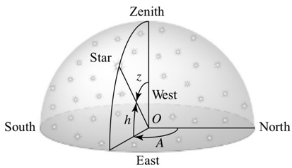


6. When planning an observing session you have to think of when the object you want to study will be visible from the site of the observatory you are using.
   a. To get you thinking about celestial coordinates: imagine you are the navigator on a ship without modern technology and you happen to know that the declination of Rigel (one of the stars is Orion) is -8.2 degrees. How do you figure out the latitude you are sailing on?

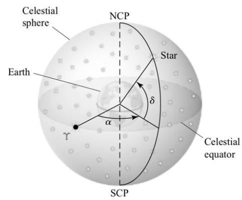
   b. Catalogs of astronomical objects typically list their right ascension and declination. Using the astropy library, write a function that takes the right ascension and declination of an object as input and plots the visibility of that object as a function of time (think of what coordinate determines the visibility of an object at any given time), for a given place on Earth (see http://docs.astropy.org/en/stable/coordinates/index.html to learn how you can use astropy to convert coordinates). Use the function to plot the visibility of the Triangulum Galaxy (M33) from Montréal on the night of September 13, 2024. You'll receive full marks for a correct plot of altitude vs. time.

a. We know the declination $\delta = -8.2^\circ$, so its 8.2° south of the celestial equator to go from this to our latitude, we would need to observe the altitude of Rigel, and see how high it rises in the sky. Let's call the max angle it forms w/ the horizon to be α, and the latitude were sailing at to be φ.

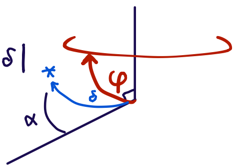
1.8 in C÷O:



1.13 in C÷O:



From these two diagrams: $\alpha = 90^\circ - |\varphi - \delta|$



Since Rigel is in the south hemisphere (negative declination), we could find our latitude as $\varphi = \alpha - \delta$

ex: via in-the-sky.org, Rigel can reach an altitude of $\alpha \approx 32^\circ$, so our latitude would be $\varphi \approx 32^\circ - (-8.2^\circ)$
$\varphi \approx 40.2^\circ$

b.