**ASTR 503 Homework 3: Magnitudes, Small Angles and Distance**

Always use **scientific notation,** always **give units**, and **show your steps!**

1. (2 pt) Betelgeuse (the red star in Orion's armpit) has a resolvable disk with a diameter of 0.054 arc seconds, which is just barely discernable by Hubble Space Telescope.

Astronomers use both radians (a big unit of angle) and arc seconds (a small unit of angle).

You need to understand both of them.

**A radian** is a unit of angular measure, defined that a circle = 2pi radians, = 360 degrees, so that one radian = 180 / pi = 57.296… degrees (you can use 57.30).

An **Arc second** is 1/60th of an arc minute, which is 1/60th of a degree.

Given that, how many arc seconds are in a radian?

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So now calculate the actual diameter in km of Betelgeuse if it is at a distance of 643 LY (light years). Show your steps, and use the small-angle approximation: d/D = angle in radians if d/D is small. Here d is the diameter of Betelgeuse and D is the distance to it; both must be in the SAME units, so you need to know the number of km in a Light Year (the distance light travels in a year).
1 LY = (3.0 E5 km/sec) \* 365.25 days/Y \* 24(hr/day) \* 60(min/hr) \* 60(sec/min) = 9.47 E 12 km.

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2. (1 pt) The **"apparent magnitude"** (m) of a star is a logarithmic measure of how bright a star appears. Logarithmic means that the steps are not linear in the value of the brightness, but that each step is a fixed **multiple** of the previous step. The brightest stars have magnitudes of -1 to 0, and the dimmest naked-eye stars have magnitudes of 5 or 6. Each 5 steps in magnitude corresponds to a factor of 100 in brightness. Thus each step is a ratio of the fifth root of 100, or about 2.512 times the brightness of a star with that is one magnitude larger in apparent magnitude. Thus, if one star is a magnitude of 12 and the other is a magnitude of 4, then difference of magnitudes is 8, which means that the ratio of apparent brightness is greater than 100 (which would be 5 steps) and closer to 10000 (which would be 10 steps).

To do it exactly, the brightness of star 1 divided by the brightness of star 2 is given by

B1/B2 = (10\*\*((m2 - m1)/2.5)). Or, log (B1/B2) = ((m2 - m1)/2.5).

What is the exact brightness ratio for these two stars? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

(Note: some calculators allow 10\*\*y or 10^y where y is a non-integer. Other calculators may just use the "antilog" function.

Remember the definition of log (common log): if y = 10\*\*x, then log y = x .)

3. (1 pt) By using a large aperture, we collect more light from a star, allowing us to see much dimmer stars. If the Rice telescope is 16 inch diameter and your eye pupil is only .25 inch, what is the ratio of area of light collected of the telescope compared to your eye? Note you want the ratio of AREA not of DIAMETER.

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This then can allow us to see much fainter stars.

If with your naked eye you can see a 5th magnitude star, how dim a star can we see from the Rice observatory - that is, what is the magnitude of the dimmest star you can see from Rice?

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 (remember: the ratio in brightness is the ratio of the AREAs, not the diameters!)

4. (2 pt) We also can see dimmer stars by integrating the light over time, by having long-time exposures for CCD's (previously, astronomers used camera film). If you can have a 4-hour time exposure on an earth-based telescope, what is the ratio of time between that and your eye integrating time (assume that’s 1/30 sec)?

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How many magnitudes in brightness does that correspond to? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

5. (2 pt) The **"Absolute Magnitude" (M)** is the apparent magnitude of a star if you move it to a **standard distance** of 10 pc (1 pc = 3.262 ly = 3.09 E16 m). The **"Distance Modulus",** (m - M), is the apparent magnitude m minus the absolute magnitude M, and is a logarithmic measure of distance. m - M = ( 5 log (r/1pc) - 5 ) where r is measured in pc.

Check: for r = 10 pc, log r = 1, so m - M = 0. For r = 100 pc, log r = 2, so m - M = 5, so its true brightness M is smaller than its apparent brightness m by 5 magnitudes, or a difference of a factor of 100.

If the distance to Betelgeuse is 643 LY, what is that in parsecs? \_\_\_\_\_\_\_ pc.<br>

Then, what is its distance modulus? \_\_\_\_\_\_\_\_\_ <p>

6. (1 pt) If Betelgeuse has an apparent magnitude of 0.5, what would its absolute magnitude be? \_\_\_\_\_\_\_\_\_\_\_<br>

Does this agree with any textbooks or software you find? (list the source \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

And the value \_\_\_\_\_\_\_\_\_\_\_\_).

7. (2 pts) Estimates of the value of the Hubble constant H, are converging to about 71 km/s per Mpc (megaparsec) (for an interesting history see http://cfa-www.harvard.edu/~huchra/hubble/ )

This means, for a galaxy which is 1 Mpc away, its speed away from us is 71 km/s, and farther away galaxies are receding proportionately faster.

For this value of H, what is the age of the universe in years if the expansion has been

uniform in time? (1 / H, but watch your units!). \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

At that age, what is the knowable size of the universe (the Hubble time times the speed of light).

 (Give it in MPc \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ as well as km\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_).

Is that the same as the distance at which the recession speed equals the speed of light? \_\_\_\_\_

Please note: you \*can\* get a Doppler shift z =  / o (That is, the change in wavelength divided by the rest wavelength) for very distant galaxies greater than one!

In that case, the simple Doppler formula we did before has to be modified for high speeds (because v never gets bigger than c!).

In that case, z =  / o = -1 + SQRT ((1 - v/c)/(1 + v/c)).

This formula reduces to z = v/c for small v's.

Note: New ways of calculating H have arrived at 67 km/s/Mpc via the microwave background, or 74 km/s/Mpc using Cepheids.

https://www.nasa.gov/feature/goddard/2019/new-hubble-constant-measurement-adds-to-mystery-of-universe-s-expansion-rate

Stay tuned! See also: https://news.uchicago.edu/explainer/hubble-constant-explained

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