

Week 2 Notes Astro 2 (Discussion Section 101)

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Administrative Tasks

Crashing and Section Switching Those who attend section *and* are on the wait list will be given the first spots within a week or so. Those who are not on the wait list, but who have attended section will be given the next available spots. If you are trying to switch sections, don't come to me unless you have someone in the other section in particular with whom you want to switch. You are free to attend either section, so long as you turn in your homework and tests to the proper places. You will still be a member of whatever section appears in your GOLD account.

Homework Submission Reminder Homework is due Friday by 4:00. The stickers have been put on the submission boxes, so when you turn your homework in, look for the sticker with your section number on it (do you know your section number yet?!). Recall, the homework submission boxes are on the *left* entrance on the *right* wall. You submit to the *top* box and will get your homework *returned* to the lower slots. I will not hunt and peck for your assignments; you have been warned. Also, remember to use a staple if you have more than one page for your homework.

Review

Magnitudes and Measurements

The Magnitude System In the olden days, the Greek astronomer Hipparchus blessed the science of Astronomy with one of its worst attributes: the magnitude scales. He sought to classify the stars by their brightness with a number scale. The first group of stars to become visible at night were called magnitude one, the next group to become visible were the magnitude two stars, and so on up to magnitude 6. It's obvious here to note that stars with *lower* magnitude are actually the *brighter* stars.

Later, when astronomers modernized the science with mathematics and standardized units, the magnitude scale stuck around, but a mathematical meaning was tacked on to it to make it quantitative. Now each degree in magnitude corresponds to a brightness ratio of 2.512. That is, a magnitude 2.3 star is 2.512 times brighter than a magnitude 3.3 star. There's nothing special about the number 2.512— it's just what best preserved the original magnitude scale, though it is worthy of note that since $2.512^5 \approx 100$, a magnitude difference of 5 yields a brightness ratio of 100. What do we mean by “brightness,” anyway? It's exactly what we talked about in Astro 1: it's the flux that reaches our eyes here at earth.

Absolute and Apparent Magnitude Obviously how bright a star appears on earth is only somewhat related to how bright the star actually is, since varying distances can make a star appear brighter or dimmer. Astronomer then use the word **brightness** generically to talk about how bright a star *appears* from Earth, and **luminosity** to denote how much light the star is actually giving off. These two words have analogous magnitude scales. The magnitude scale that measures brightness is the one that Hipparchus thought up. We call it **Apparent Magnitude**, often denoted m . The scale corresponding to luminosity is called **Absolute Magnitude**, and it measures what the apparent magnitude of a star *would* be if it were at a distance of 10 pc. It is often denoted as M . (*Note: The distance of 10 pc was chosen since it was thought to be about the average distance away stars in the Milky Way are from Earth.*)

As an example, the sun has an apparent magnitude of $m = -26.7$. However, its absolute magnitude is only $M = +4.8$. That is, if the sun were moved to a distance of 10 pc, its apparent magnitude would be +4.8.

The apparent magnitude of an object is related by a well-defined formula to the brightness (flux we receive) of the object. Presented here with no proof, is the equation:

$$m_2 - m_1 = 2.5 \log \left(\frac{b_1}{b_2} \right)$$

where m_1, m_2 are the apparent magnitudes of two objects, and b_1, b_2 are their respective brightnesses. The logarithm is understood to be of base 10.

Magnitudes and the Distance Modulus Quite often magnitude measurements are only needed in order to calculate a distance. In this case, only the difference between the apparent and absolute magnitudes is needed. This difference, $m - M$ is often called the **Distance Modulus**, which is a rather cool name for something so mundane. The way this works is that the brightness relation,

$$b = \frac{L}{4\pi d^2}$$

is rephrased in terms of magnitudes. Qualitatively, we see that b is directly related to m since it measures the light we receive at Earth, and L is directly related to M since it measures how much light a star is emitting, regardless of how far away it is. This new equation, which is of great use, is

$$m - M = 5 \log d - 5$$

where here, d is the distance in parsecs and \log refers to the base 10 logarithm.

Comprehension Question: Without performing any calculation, what would the distance be to a star whose distance modulus is 0?

Answer: It would be 10, since $m = M$, and M is just what m would be if $d = 10$.

Challenge Problem: How far away would the sun have to be to shed only one ten thousandth as much light on us as possible? In other words, how far away would it have to be for its brightness (not apparent magnitude) to decrease ten thousand fold? Also, what would its new apparent magnitude be? Its absolute magnitude? Check these answers by using the distance modulus.

Solution: The first part of this question is just an application of the brightness formula. Originally,

$$b_{\odot} = \frac{L_{\odot}}{4\pi(1 \text{ AU})^2}$$

so now,

$$b = \frac{b_{\odot}}{10000} = \frac{b_{\odot}}{100^2} = \frac{1}{100^2} \frac{L_{\odot}}{4\pi(1 \text{ AU})^2} = \frac{L_{\odot}}{4\pi(100 \text{ AU})^2}$$

So evidently the sun must be moved to a distance of

$$\boxed{d = 100 \text{ AU}}$$

Earlier we mentioned that a difference in apparent magnitude of 5 resulted in a brightness difference of 100. Fortunately, $100^2 = 10000$, so it appears that the sun as it stands now would have to have its apparent magnitude *increased* by 10. The increase is needed since the sun would necessarily need to appear dimmer. Thus, since the original apparent magnitude (given earlier) is $m_{\odot} = -26.7$, the new one is just

$$\boxed{m = -16.7}$$

Alternatively, one could have simply plugged $b_1/b_2 = 1/10000$ into

$$m_2 - m_1 = 2.5 \log \left(\frac{b_1}{b_2} \right)$$

to obtain the same result, given the initial apparent magnitude.

Absolute magnitude is only a function of the luminosity of the star, so it remains unchanged at $M = +4.8$.

$$\boxed{M = 4.8}$$

Finally, we use the distance modulus equation to verify our results:

$$-16.7 - 4.8 = 5 \log(100 \text{ AU}) - 5$$

$$-21.5 = 5 \log(.000485) - 5$$

$$-21.5 = -21.5$$

So the equation checks out, and we're happy with our results.

Hubble's Law

Redshift We define the **redshift** of an object by

$$z = \frac{\lambda - \lambda_0}{\lambda_0}$$

Hubble's Law After many measurements were made in the early years of this century, it was found that distant galaxies are *all* moving away from us. This was found from looking at spectra of distant galaxies. Surprisingly, all the spectra were redshifted rather than blueshifted. In fact, they were redshifted in such a way that a plot of their receding velocity against their distance from us formed a linear graph. The slope of this graph is often called Hubble's constant, in honor of Edwin Hubble's contribution to the study, and **Hubble's Law** is often stated by the equation

$$v = H_0 d$$

where v is the recessional velocity of a galaxy and d is the distance to the galaxy. The units on H_0 define the units of d and v . Often we'll use $H_0 = 73 \text{ km/s/Mpc}$. This behooves d being measured in Mpc and v being measured in km/s.

Example Suppose a galaxy has redshift of $z = .5$. What is the apparent magnitude of a star in this galaxy if its absolute magnitude is +4?

We'd like to use the distance modulus to find M . Thus, our first task is to find the distance to the galaxy. If $z = .5$, then $v = .5c = 150,000 \text{ km/s}$. If we assume $H_0 = 73 \text{ km/s/Mpc}$, then the distance is

$$d = \frac{v}{H_0} = \frac{150,000 \text{ km/s}}{73 \text{ km/s/Mpc}} \approx 2,000 \text{ Mpc}$$

Then using the distance modulus, we have

$$m = M + 5 \log d - 5 = 4 + 5 \log (2 \times 10^6) - 5 = +30.5$$