Ay 7B – Spring 2010
Section Worksheet 5
Magnitudes and Coordinates on the Sky

1. **Exposure times**
   While at Lick Observatory on top of Mount Hamilton just outside of San Jose, you take a 10 second exposure of an 8th magnitude star and get about 10,000 counts. How long would you have to expose on an 11th magnitude star to get the same number of counts?

   `By construction, 5 magnitudes is equivalent to a factor of 100 in brightness. Then 1 magnitude corresponds to a factor of` $100^{1/5} \approx 2.5$ `in brightness (a good rule of thumb for any observers out there). An 11th magnitude star is then` $2.5^3 \approx 15.625$ `times dimmer than an 8th magnitude star. So, every 10 seconds, we get 15.625 times fewer photons from 11th magnitude star than from 8th magnitude star. To get the same number of accounts, we would have to integrate for` $10 \times 15.625 = 156.25$ `seconds or about 2.5 minutes.`

2. **Supernovae vs. Asteroid**
   The asteroid belt is a collection of small rocks and boulders in between Mars and Jupiter which never coalesced to form a planet. Like the planets, they orbit the Sun in the plane of the ecliptic. When searching for transient objects such as gamma ray bursts or supernovae, it is useful to have a plot of where asteroids are located in the sky as not to confuse an asteroid for a more interesting object. On a plot with right ascension on the x-axis and declination on the y-axis, sketch the position of the asteroid belt. Could a supernova candidate found at a RA=18:00 Dec=+00:01 actually be an asteroid?

   `We are told that the asteroid belt occupies the plane of the ecliptic. Let's first think about what part of the asteroid belt we would see at night on the vernal equinox. The Sun would be at an RA=00:00 and Dec=+00:00. The asteroid belt visible at night would be at RA=12:00 (that is on the exact opposite side of the Earth) and Dec=+00:00. You can easily convince yourself that at the autumnal equinox the positions of the the Sun and the asteroid belt are simply switched in comparison to the vernal equinox. Now consider the summer solstice. The Sun will be at an RA=06:00 and Dec=23.5. If you draw out a picture of the positions of the asteroid belt, the Earth, and the Sun, you will see that the part of the asteroid belt that is visible at night will lie below the celestial equator at about -23.5. The asteroid belt would be at RA=18:00 and a Dec=-23.5. Similarly, at the winter solstice the asteroid belt would be RA=6:00 and Dec=+23.5. When you flesh out the curve it ends up being a sine curve. So the SN candidate found at RA=18:00 Dec=00:01 is most likely not an asteroid.`

3. **Into the belly of the beast**
   If you wanted to study the galactic center of the Milky Way, would you be better off using radio wavelengths or optical wavelengths? Why? For reference, a typical dust grain size would be about 1 micron.

   `Recall from class; if the size of the dust particle was much greater than the wavelength then the dust particle would act like a brick wall. Thus we would not be able to see any optical light from the center of the galaxy. We would be able to see much more in radio waves since the wavelength of radio waves is much larger than the size of dust grains.`

4. **Dusty Skies**
   Looking out into the sky one night you find a hole with no stars! But after a bit of research you find

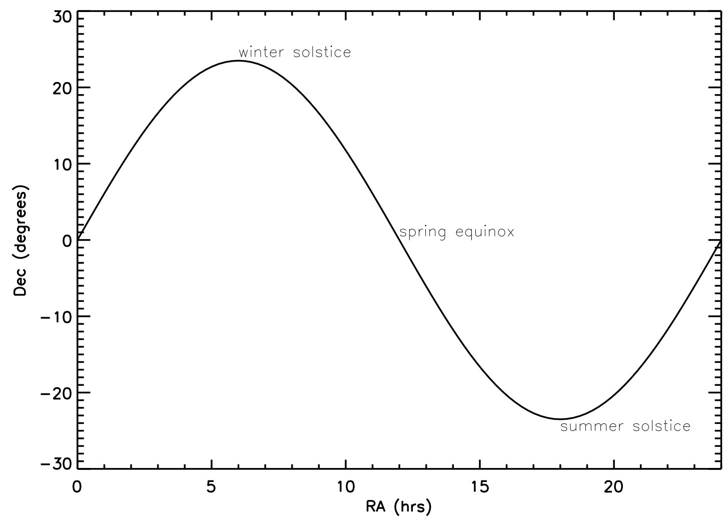

Figure 1: The position of the asteroid belt

that its just a cloud of dust and gas known as Barnard 68 (see gure 12.7 in your book). It only looks like a hole because it is blocking the light from the many many stars behind it. But youre still curious about it and so make a bunch of observations to see what you can learn. For the purposes of this problem, assume that the cloud is a uniform density sphere and there is no other source of extinction along the line of sight except for that cloud.

(a) Thinking more about the Sun-like star behind the cloud, if you measure the apparent magnitude of the star to be 18.1, what is the extinction, A, along the line of sight to that star? By measuring the parallax angles, you determined the star is 143pc away from us. What is the optical depth? (Hint: The absolute magnitude of the Sun is +4.74.)

`From the distance modulus formula,` $m - M = 5\log(d/10\text{pc})A$`, we have`

$$A = m - M - 5\log(d/10\text{pc}) = 18.1 - 4.74 - 5\log(14.3) = \boxed{7.6}.$$

`This corresponds to an optical depth of` $\boxed{\tau = A/1.08574 = 7.0}$.

(b) If you measure the cloud to be $\theta = 260$ arcseconds in diameter, what is its radius in pc? The cloud is 130pc away from us.

`This time were looking for angular size. Some quick trigonometry and small angle approximation can show that` $\theta = D/d$ `where D is the physical diameter and d is the distance to the cloud, and` θ `needs to be in radians,` $\theta = 260 \text{ arcseconds} = 0.00126 \text{ radians}$`. Thus` $D = \theta d = 0.18 \text{ pc}$`. The radius is thus half this,` $\boxed{R = 0.09 \text{ pc}}$.

(c) The line of sight to the star does not pass through the center of the cloud, but is displaced from the center by about half a radius. How long is the distance, L through the cloud along this line of sight? (Hint: It will likely help to draw a picture.)

From the picture above we can see that we have a right triangle with a hypotenuse of R and a leg of R/2. The distance we are looking for is just twice the other leg. A quick use of the Pythagorean theorem gives $L = 2\sqrt{R^2 - (R/2)^2} = R\sqrt{3} = 0.16$ pc.

(d) Now let's think about the dust in the cloud that is causing the extinction. At visual wavelengths, the cross section for the extinction by dust in clouds like this is typically about 1.5 times their geometric cross section. If the dust grains are spheres with radii of about $a = 0.5\mu m$, then $\sigma \approx 1.5\pi a^2 = 1.2 \times 10^{-12}\mathrm{m}^2$. What must the number density of dust particles be in the cloud in order to produced the observed amount of extinction?

$\tau = n\sigma L$, thus $n = \tau/(\sigma L) = 1.2 \times 10^{-3} m^{-3}$. This is an extremely low density. Note that it is also much lower than we said the ISM typically is. But how can that be? The answer is that this is just the density of dust particles. There are actually many orders of magnitude more gas particles in this cloud, but these few bits of dust are the primary source of the extinction.