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Planetarium Based Laboratory Activity
Star Magnitudes, Twilight and Surface Brightness

Background

This is a very brief introduction to important definitions and terminologies that astronomers use. It is hoped that you have already come across these in your astronomy class. Details can be found from a variety of online resources or any college level introductory astronomy text.

<u>Luminosity Brightness and Distance</u>

The **Luminosity** (*L*) of a star is the intrinsic energy it emits. It is measured in *Joules/second* or *watts*. When this energy is detected by us on earth via telescopes and instruments it is no longer the same. For one, the energy from the light source has traveled long distance (*D*) and its reduced. We therefore often also talk about **brightness** (*B*) of stars.
The stars are assumed point sources and the energy or radiation from them is spread out in form of a sphere of surface area $4\pi D^2$. The relationship between luminosity, brightness and distance is given by

$$B = \frac{L}{4\pi D^2}$$

Measured in *watts/cm*^{2}. Since we can only really talk about brightness of stars it makes sense to talk about comparing the brightness of the star at different distances. If we set B_1 to the be the brightness at D_1 and B_2 at distance D_2 then we can say that

$$\frac{B_2}{B_1} = \frac{D_1^2}{D_2^2}$$

For example, if a star is twice as far as before $D_2 = 2D_1$ then $B_2 = \frac{1}{4}B_1$. From this example we conclude that the brightness of the star decreases as the square of the distance and this observation is known as Inverse Square Law. For light.

<u>Brightness and Magnitude Scale</u>

How do we measure and quantify brightness of stars? The answer to this question was first attempted by the Greek astronomer Hipparchus around 200 BC. He invented the ***magnitude*** (*m*) scale in which the faintest star he could see was labelled magnitude 6 and brightest magnitude 1. Today we know that the eye's response to light in not linear, so in order to connect this new fact with Hipparchus magnitude scale, we say that the 5 difference in magnitude (6-1) corresponds to a ratio of 100 in brightness. The actual mathematical treatment was presented by Norman Pogson in 1856 and is written as

$$\frac{B_{Star\ 1}}{B_{Star\ 2}} = \left(100^{1/5}\right)^{m_2 - m_1}$$

Where *m* is termed as the apparent magnitude. The above formula allows one to calculate the ratio of brightness between two stars if their apparent magnitudes are known. Equally important is know the magnitude difference if the brightness ratio of the two stars are given. This is determined by using the equation:

$$m_1 - m_2 = -2.5 \log\left(\frac{B_{Star\ 1}}{B_{Star\ 2}}\right)$$

It should be noted that these relationships define relative magnitudes and thus compares only brightness between two stars however if we wanted to be more precise we would need a third star source which would be taken as a fixed reference and compare the brightness of both stars relative to the brightness of the reference. The star **Vega** is often used for this purpose and it is defined to be of magnitude 0.0. The modern magnitude scale now extends to negative numbers with Sirius whose apparent magnitude is -1.46 mag and to large positive numbers down to 30 which is the faintest stars Hubble Telescope can detect. The magnitude scale that Hipparchus presented was during the time when there was not light pollution. Today this is not the case and hence the limiting magnitude is often small (larger number) dictated by the amount of light pollution or the background light (like from the full moon). One final point one should remember is that the eyes response to different colors is different form color to color. Astronomers often take this into account when reporting magnitudes by attaching a subscript of the color wavelength like m_B would be the magnitude in blue wavelength and m_R would be in red wavelength. The cumulative magnitude in all wavelengths combined together is called **Bolometric** magnitude m_{bol}.

Surface Brightness

Not all celestial objects are point sources like stars in the sky. We have Planets, Comets, Milky Way, Galaxies and Nebulae that actually cover some area in the sky and are generally called extended objects. How do astronomers define brightness of extended objects? The term **surface brightness** is a measure of brightness per area on the sky. As we know the area on the sky is measured as an angle (degrees, minutes and seconds of arc). Therefore, the measurement units for surface brightness is $mag/arcsec^2$. Even the sky can be considered an extended object and can have a surface brightness defined. Detail discussion is beyond the scope of this activity and are not necessary and can be found however in order to complete part 2 and 3 of this activity we can estimate the sky glow based on the magnitude of the faintest star visible to the naked eye. Table 1 gives the approximate surface brightness of the sky for several of the Naked Eye Limiting Magnitude (NELM). In order to cross reference the NELM number with night sky we need special star charts. The Globe at Night Program (http://www.globeatnight.org/observe_practice.html) have the appropriate charts that are needed here for this activity. The chart is given below and the picture number corresponds roughly to the NELM. Keep in mind that any extended object that has a larger surface brightness than the sky will be completely washed out and will be not visible (remember the reverse magnitude number scale for brightness). In addition, color of the object is also important for example Betelgeuse is red and Rigel is blue in the Orion constellation, but if the sky color has orange tint due to street lights, then Betelgeuse will have less contract compared to Rigel and Rigel will appear brighter even though it is not. In this respect an 18 mg/arcsec2 nebula is brighter than the 20 mag/arcsec2 sky but may not be visible because of the sky color and contrast. Does surface brightness depend on distance of the source? Contrary to brightness of the sources which decreases as given by the inverse square law, the surface brightness of the sources remains the same. When the extended object is further away its angular distance covers more area in the sky as when the object is nearby. Infect, the factor by which the area increase is the same as the factor by which the brightness decreases so the two factors cancel each other out make the surface brightness independent on distance.

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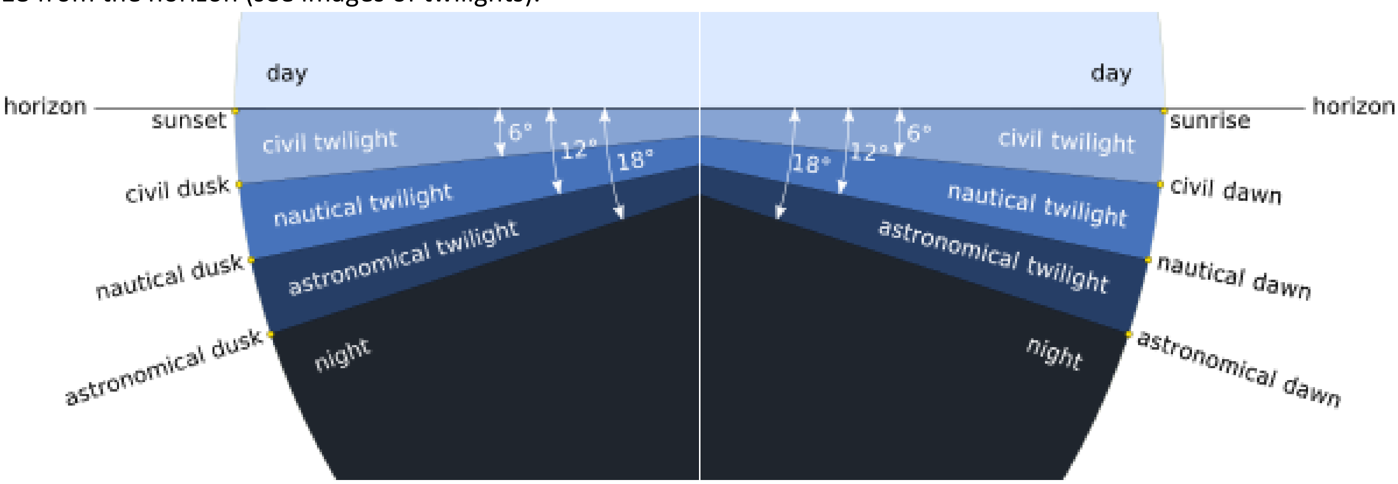
Table 1

NELM	SB (mag/arcsec^2)
0	13
1	15
2	16
3	17
4	18
5	19
6	21
7	23

Part 1: Twilights

Twilights is the time between sunset and night or before night turns into day at sunrise, where the sky is still lit up by the rays form the Sun even though the Sun is below the horizon. There are three different types of twilights, Civil, Nautical and Astronomical. Civil twilight is defined as the time between sunset/sunrise and when the center of the Sun is 6 degrees from the horizon. Nautical twilight is the time between sunset/sunrise and when the center of the Sun is 12 degrees from the horizon. Astronomical twilight is the time between sunset/sunrise and when the center of the Sun is 18 from the horizon (see images of twilights).



Evening Morning

Source: Wikipedia [CC BY-SA 4.0]

Your SI will setup the planetarium to simulate the beginning and end of each twilight for this evening. Use the sky charts to identify the NELM for each twilight as it begins and ends. Tabulate the data in table 2.

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Table 2

Constellation	Orion			
Twilight	**Start Time**	**Chart Number**	**End Time**	**Chart Number**
Civil				
Nautical				
Astronomical				

Part 2: Surface Brightness

Your instructor will set up the planetarium with Orion up and the lighting set to about the same level as the light pollution at the Tarleton Observatory.

1. When the planetarium is ready, compare what you see in the planetarium to the magnitude charts (included with the worksheet) to determine which chart matches best with what you see. Record the chart number in Table 3.
2. Your SI will adjust the sky brightness to simulate the other locations in Table 3. For dark sites, it is helpful to pay attention to the area around Orion's belt, pick which magnitude chart best matches on a goodnight.
3. Your SI will point out the Orion Nebula, which is a glowing cloud of gas with new-born stars. Label it on one of your sky charts.
4. Use the sky charts and Table 1 to determine the sky surface brightness in mag/arcsec^2 for these observations, and enter the values in Table 3.

Table 3

Location	Chart Number/NELM	Sky Surface Brightness (mag/arcsec2)	Limiting Magnitude (mag)	Orion Nebula Visible
Tarleton Observatory				
Stephenville, TX				
Dallas TX				

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Part 3: Limiting Magnitude

1. Your SI will point out a star and tell you its name. Compare it to the stars in Orion and determine its magnitude from the sky charts. The number of the sky chart shows the magnitude of the faintest stars shown. Record the star's name and magnitude here:

2. Use your sky chart to determine the limiting magnitude above which stars are invisible for the observations in Table 3, and enter the values here:

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Concluding Questions:

1. From Table 1 determine the duration of each Twilight. Are they all the same in duration or different? How can you explain this from the definition of each twilight given above?

2. Estimate the surface brightness of the Orion nebula at astronomical twilight. Explain how you obtained it.

3. Most of the Andromeda galaxy has a surface brightness of 22.3 mag/arcsec^2. Could you see this from Tarleton Observatory? From Dallas? Explain your answers.

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4. Explain why the surface brightness of the Milky Way is roughly the same as the surface brightness of the Andromeda galaxy (22.3mag/arcsec^2), even though the latter is 1000 times farther away than most of the Milky Way.

5. The star Betelgeuse is magnitude 0.5, How much more light (in terms of brightness) do we receive from it than from the star whose magnitude you estimated in Question 1 of part 2? Show your work. Hint use the appropriate equation listed in the introductions handout.