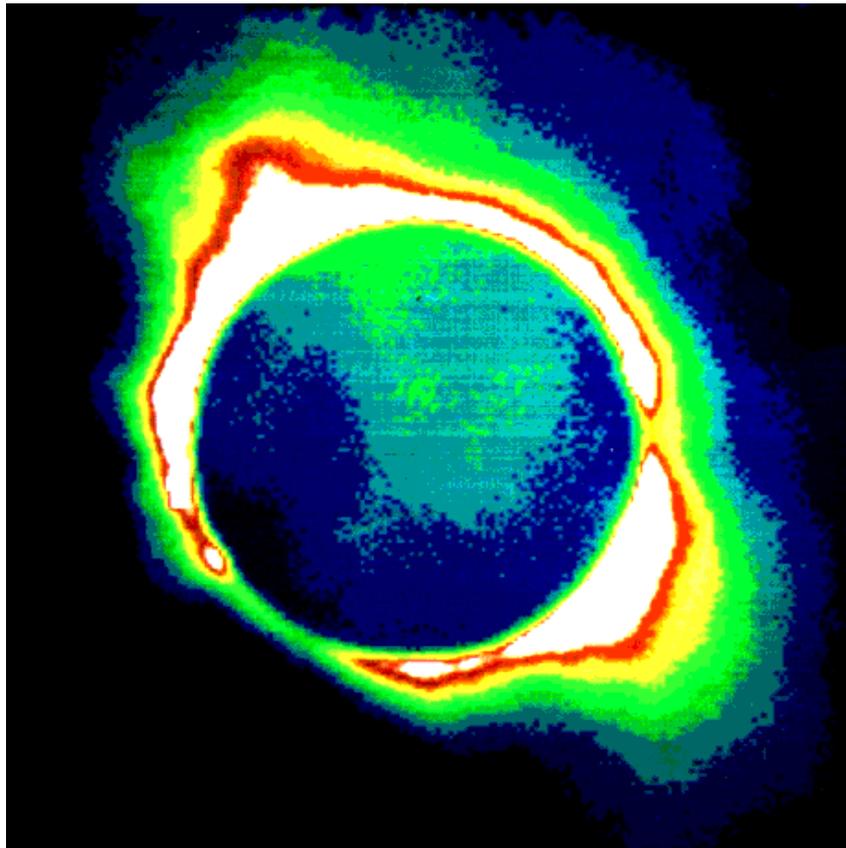


HANDS-ON UNIVERSE

HIGH SCHOOL SCIENCE AND MATH
IN THE CONTEXT OF ASTRONOMY
INVESTIGATIONS

Measuring Brightness



5

by Lawrence Hall of Science
University of California, Berkeley
Lawrence Berkeley National Laboratory
and TERC of Cambridge, Massachusetts



HOU provides a visual and analytic way of exploring the universe.

Use HOU images from professional telescopes, along with HOU image processing software, to pursue investigations of astronomical objects, phenomena, and concepts. Opportunities available to HOU students can lead to accessing professional-grade telescopes via the World-Wide Web for observations as part of research projects such as searching for supernovae and asteroids.

- HOU has been developed and operated by staff at Lawrence Berkeley National Laboratory and Space Science Laboratories at the University of California at Berkeley, California, with generous support from the National Science Foundation (grant # ESI-9252915) and the US Department of Energy. The HOU curriculum was developed by TERC with contributions from the Berkeley staff and teachers. The educational center for HOU currently resides at Lawrence Hall of Science, University of California, Berkeley.
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Measuring Brightness

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Constants Sheet

Planetary Data:

<u>Planet</u>	<u>Mass (kg)</u>	<u>Ave Radius (m)</u>	<u>Ave Orbital Radius (m)</u>
Mercury	3.32×10^{23}	2.44×10^6	5.79×10^{10}
Venus	4.87×10^{24}	6.08×10^6	1.08×10^{11}
Earth	5.97×10^{24}	6.36×10^6	1.49×10^{11}
(Moon)	7.35×10^{22}	1.74×10^6	
Mars	6.42×10^{23}	3.40×10^6	2.28×10^{11}
Jupiter	1.90×10^{27}	6.80×10^7	7.78×10^{11}
Saturn	5.69×10^{26}	5.70×10^7	1.43×10^{12}
Uranus	8.69×10^{25}	2.51×10^7	2.87×10^{12}
Neptune	1.03×10^{26}	2.44×10^6	4.50×10^{12}
Pluto	1.30×10^{22}	1.50×10^6	5.90×10^{12}

Physical and Astronomical Constants:

Gravitational Constant = $G = 6.673 \times 10^{-11} \text{ N}\cdot\text{m}^2/\text{kg}^2$

Speed of Light in a vacuum = $c = 2.9979 \times 10^8 \text{ m/s}$

Earth-Sun Distance = Astronomical Unit = $\text{AU} = 1.496 \times 10^{11} \text{ m}$

Earth-Moon Distance = $3.844 \times 10^8 \text{ m}$

Parsec = $\text{pc} = 206265 \text{ AU} = 3.26 \text{ ly} = 3.09 \times 10^{16} \text{ m}$

Light year = $\text{ly} = 9.5 \times 10^{15} \text{ m}$

Mass of the Sun = $1.989 \times 10^{30} \text{ kg}$

Luminosity of the Sun = $3.83 \times 10^{26} \text{ W}$

Radius of the Sun = $6.96 \times 10^8 \text{ m}$

Brightness Conversion Table

Magnitudes to Brightness (W/m²)

Mag.	I	R	V	B	U	Bolometric
5.0	2.40 x 10 ⁻¹¹	1.65 x 10 ⁻¹¹	3.61 x 10 ⁻¹¹	9.24 x 10 ⁻¹¹	1.83 x 10 ⁻¹¹	2.40 x 10 ⁻¹⁰
5.1	2.19 x 10 ⁻¹¹	1.51 x 10 ⁻¹¹	3.29 x 10 ⁻¹¹	8.43 x 10 ⁻¹¹	1.67 x 10 ⁻¹¹	2.19 x 10 ⁻¹⁰
5.2	2.00 x 10 ⁻¹¹	1.37 x 10 ⁻¹¹	3.01 x 10 ⁻¹¹	7.69 x 10 ⁻¹¹	1.52 x 10 ⁻¹¹	2.00 x 10 ⁻¹⁰
5.3	1.82 x 10 ⁻¹¹	1.25 x 10 ⁻¹¹	2.74 x 10 ⁻¹¹	7.02 x 10 ⁻¹¹	1.39 x 10 ⁻¹¹	1.82 x 10 ⁻¹⁰
5.4	1.66 x 10 ⁻¹¹	1.14 x 10 ⁻¹¹	2.50 x 10 ⁻¹¹	6.40 x 10 ⁻¹¹	1.27 x 10 ⁻¹¹	1.66 x 10 ⁻¹⁰
5.5	1.52 x 10 ⁻¹¹	1.04 x 10 ⁻¹¹	2.28 x 10 ⁻¹¹	5.84 x 10 ⁻¹¹	1.16 x 10 ⁻¹¹	1.52 x 10 ⁻¹⁰
5.6	1.38 x 10 ⁻¹¹	9.52 x 10 ⁻¹²	2.08 x 10 ⁻¹¹	5.33 x 10 ⁻¹¹	1.06 x 10 ⁻¹¹	1.38 x 10 ⁻¹⁰
5.7	1.26 x 10 ⁻¹¹	8.69 x 10 ⁻¹²	1.90 x 10 ⁻¹¹	4.86 x 10 ⁻¹¹	9.63 x 10 ⁻¹²	1.26 x 10 ⁻¹⁰
5.8	1.15 x 10 ⁻¹¹	7.92 x 10 ⁻¹²	1.73 x 10 ⁻¹¹	4.44 x 10 ⁻¹¹	8.79 x 10 ⁻¹²	1.15 x 10 ⁻¹⁰
5.9	1.05 x 10 ⁻¹¹	7.23 x 10 ⁻¹²	1.58 x 10 ⁻¹¹	4.05 x 10 ⁻¹¹	8.02 x 10 ⁻¹²	1.05 x 10 ⁻¹⁰
6.0	9.57 x 10 ⁻¹²	6.60 x 10 ⁻¹²	1.44 x 10 ⁻¹¹	3.69 x 10 ⁻¹¹	7.32 x 10 ⁻¹²	9.57 x 10 ⁻¹¹
6.1	8.76 x 10 ⁻¹²	6.02 x 10 ⁻¹²	1.32 x 10 ⁻¹¹	3.37 x 10 ⁻¹¹	6.68 x 10 ⁻¹²	8.76 x 10 ⁻¹¹
6.2	7.99 x 10 ⁻¹²	5.49 x 10 ⁻¹²	1.20 x 10 ⁻¹¹	3.07 x 10 ⁻¹¹	6.09 x 10 ⁻¹²	7.99 x 10 ⁻¹¹
6.3	7.29 x 10 ⁻¹²	5.01 x 10 ⁻¹²	1.10 x 10 ⁻¹¹	2.80 x 10 ⁻¹¹	5.56 x 10 ⁻¹²	7.29 x 10 ⁻¹¹
6.4	6.65 x 10 ⁻¹²	4.57 x 10 ⁻¹²	1.00 x 10 ⁻¹¹	2.56 x 10 ⁻¹¹	5.07 x 10 ⁻¹²	6.65 x 10 ⁻¹¹
6.5	6.07 x 10 ⁻¹²	4.17 x 10 ⁻¹²	9.13 x 10 ⁻¹²	2.33 x 10 ⁻¹¹	4.63 x 10 ⁻¹²	6.07 x 10 ⁻¹¹
6.6	5.54 x 10 ⁻¹²	3.81 x 10 ⁻¹²	8.33 x 10 ⁻¹²	2.13 x 10 ⁻¹¹	4.22 x 10 ⁻¹²	5.54 x 10 ⁻¹¹
6.7	5.05 x 10 ⁻¹²	3.47 x 10 ⁻¹²	7.60 x 10 ⁻¹²	1.94 x 10 ⁻¹¹	3.85 x 10 ⁻¹²	5.05 x 10 ⁻¹¹
6.8	4.61 x 10 ⁻¹²	3.17 x 10 ⁻¹²	6.93 x 10 ⁻¹²	1.77 x 10 ⁻¹¹	3.51 x 10 ⁻¹²	4.61 x 10 ⁻¹¹
6.9	4.21 x 10 ⁻¹²	2.89 x 10 ⁻¹²	6.33 x 10 ⁻¹²	1.61 x 10 ⁻¹¹	3.21 x 10 ⁻¹²	4.21 x 10 ⁻¹¹
7.0	3.84 x 10 ⁻¹²	2.64 x 10 ⁻¹²	5.77 x 10 ⁻¹²	1.47 x 10 ⁻¹¹	2.93 x 10 ⁻¹²	3.84 x 10 ⁻¹¹
7.1	3.50 x 10 ⁻¹²	2.41 x 10 ⁻¹²	5.27 x 10 ⁻¹²	1.34 x 10 ⁻¹¹	2.67 x 10 ⁻¹²	3.50 x 10 ⁻¹¹
7.2	3.20 x 10 ⁻¹²	2.20 x 10 ⁻¹²	4.80 x 10 ⁻¹²	1.23 x 10 ⁻¹¹	2.44 x 10 ⁻¹²	3.20 x 10 ⁻¹¹
7.3	2.91 x 10 ⁻¹²	2.00 x 10 ⁻¹²	4.38 x 10 ⁻¹²	1.12 x 10 ⁻¹¹	2.23 x 10 ⁻¹²	2.91 x 10 ⁻¹¹
7.4	2.66 x 10 ⁻¹²	1.83 x 10 ⁻¹²	4.00 x 10 ⁻¹²	1.02 x 10 ⁻¹¹	2.03 x 10 ⁻¹²	2.66 x 10 ⁻¹¹
7.5	2.43 x 10 ⁻¹²	1.67 x 10 ⁻¹²	3.65 x 10 ⁻¹²	9.29 x 10 ⁻¹²	1.85 x 10 ⁻¹²	2.43 x 10 ⁻¹¹
7.6	2.21 x 10 ⁻¹²	1.52 x 10 ⁻¹²	3.33 x 10 ⁻¹²	8.48 x 10 ⁻¹²	1.69 x 10 ⁻¹²	2.21 x 10 ⁻¹¹
7.7	2.02 x 10 ⁻¹²	1.39 x 10 ⁻¹²	3.04 x 10 ⁻¹²	7.38 x 10 ⁻¹²	1.54 x 10 ⁻¹²	2.02 x 10 ⁻¹¹
7.8	1.84 x 10 ⁻¹²	1.27 x 10 ⁻¹²	2.77 x 10 ⁻¹²	7.06 x 10 ⁻¹²	1.41 x 10 ⁻¹²	1.84 x 10 ⁻¹¹
7.9	1.68 x 10 ⁻¹²	1.16 x 10 ⁻¹²	2.53 x 10 ⁻¹²	6.44 x 10 ⁻¹²	1.28 x 10 ⁻¹²	1.68 x 10 ⁻¹¹

Brightness Conversion Table
Magnitudes to Brightness (W/m²)

Mag.	I	R	V	B	U	Bolometric
8.0	1.51 x 10 ⁻¹²	1.04 x 10 ⁻¹²	2.28 x 10 ⁻¹²	5.83 x 10 ⁻¹²	1.16 x 10 ⁻¹²	1.51 x 10 ⁻¹¹
8.1	1.38 x 10 ⁻¹²	9.49 x 10 ⁻¹³	2.08 x 10 ⁻¹²	5.32 x 10 ⁻¹²	1.06 x 10 ⁻¹²	1.38 x 10 ⁻¹¹
8.2	1.26 x 10 ⁻¹²	9.66 x 10 ⁻¹³	1.90 x 10 ⁻¹²	4.85 x 10 ⁻¹²	9.66 x 10 ⁻¹³	1.26 x 10 ⁻¹¹
8.3	1.15 x 10 ⁻¹²	7.90 x 10 ⁻¹³	1.73 x 10 ⁻¹²	4.43 x 10 ⁻¹²	8.81 x 10 ⁻¹³	1.15 x 10 ⁻¹¹
8.4	1.05 x 10 ⁻¹²	7.21 x 10 ⁻¹³	1.58 x 10 ⁻¹²	4.04 x 10 ⁻¹²	8.04 x 10 ⁻¹³	1.05 x 10 ⁻¹¹
8.5	9.55 x 10 ⁻¹³	6.58 x 10 ⁻¹³	1.44 x 10 ⁻¹²	3.69 x 10 ⁻¹²	7.34 x 10 ⁻¹³	9.55 x 10 ⁻¹²
8.6	8.71 x 10 ⁻¹³	6.00 x 10 ⁻¹³	1.32 x 10 ⁻¹²	3.36 x 10 ⁻¹²	6.69 x 10 ⁻¹³	8.71 x 10 ⁻¹²
8.7	7.95 x 10 ⁻¹³	5.47 x 10 ⁻¹³	1.20 x 10 ⁻¹²	3.07 x 10 ⁻¹²	6.11 x 10 ⁻¹³	7.95 x 10 ⁻¹²
8.8	7.25 x 10 ⁻¹³	5.00 x 10 ⁻¹³	1.10 x 10 ⁻¹²	2.80 x 10 ⁻¹²	5.57 x 10 ⁻¹³	7.25 x 10 ⁻¹²
8.9	6.62 x 10 ⁻¹³	4.46 x 10 ⁻¹³	9.99 x 10 ⁻¹³	2.55 x 10 ⁻¹²	5.08 x 10 ⁻¹³	6.62 x 10 ⁻¹²
9.0	6.04 x 10 ⁻¹³	4.16 x 10 ⁻¹³	9.12 x 10 ⁻¹³	2.33 x 10 ⁻¹²	4.64 x 10 ⁻¹³	6.04 x 10 ⁻¹²
9.1	5.51 x 10 ⁻¹³	3.79 x 10 ⁻¹³	8.32 x 10 ⁻¹³	2.12 x 10 ⁻¹²	4.23 x 10 ⁻¹³	5.51 x 10 ⁻¹²
9.2	5.03 x 10 ⁻¹³	3.46 x 10 ⁻¹³	7.59 x 10 ⁻¹³	1.94 x 10 ⁻¹²	3.86 x 10 ⁻¹³	5.03 x 10 ⁻¹²
9.3	4.59 x 10 ⁻¹³	3.16 x 10 ⁻¹³	6.93 x 10 ⁻¹³	1.77 x 10 ⁻¹²	3.52 x 10 ⁻¹³	4.59 x 10 ⁻¹²
9.4	4.18 x 10 ⁻¹³	2.88 x 10 ⁻¹³	6.32 x 10 ⁻¹³	1.61 x 10 ⁻¹²	3.21 x 10 ⁻¹³	4.18 x 10 ⁻¹²
9.5	3.82 x 10 ⁻¹³	2.63 x 10 ⁻¹³	5.77 x 10 ⁻¹³	1.47 x 10 ⁻¹²	2.93 x 10 ⁻¹³	3.82 x 10 ⁻¹²
9.6	3.48 x 10 ⁻¹³	2.40 x 10 ⁻¹³	5.26 x 10 ⁻¹³	1.34 x 10 ⁻¹²	2.68 x 10 ⁻¹³	3.48 x 10 ⁻¹²
9.7	3.18 x 10 ⁻¹³	2.19 x 10 ⁻¹³	4.80 x 10 ⁻¹³	1.22 x 10 ⁻¹²	2.44 x 10 ⁻¹³	3.18 x 10 ⁻¹²
9.8	2.90 x 10 ⁻¹³	2.00 x 10 ⁻¹³	4.38 x 10 ⁻¹³	1.12 x 10 ⁻¹²	2.23 x 10 ⁻¹³	2.90 x 10 ⁻¹²
9.9	2.65 x 10 ⁻¹³	1.82 x 10 ⁻¹³	4.00 x 10 ⁻¹³	1.02 x 10 ⁻¹²	2.03 x 10 ⁻¹³	2.65 x 10 ⁻¹²
10.0	2.41 x 10 ⁻¹³	1.66 x 10 ⁻¹³	3.65 x 10 ⁻¹³	9.30 x 10 ⁻¹³	1.85 x 10 ⁻¹³	2.41 x 10 ⁻¹²

HANDS-ON UNIVERSE™
DISCUSSION SHEET
PHOTOMETRY TECHNIQUES

When you observe stars with your eyes, or with a telescope, you are receiving starlight that has traveled vast distances. Amazingly, the light remains virtually unaffected by the first 99.999999999999% or so of its journey. However, in the trip through the Earth's atmosphere, and even through the optics of the telescope, the light may finally be affected causing the brightness of the star to differ from one observation to the next.

Photometry is the process of measuring the amount of light received from an object. When you display an image using HOU, you can use the cursor to see the amount of light registered by each pixel in the image. This value is given in Counts. The **Auto Aperture** and **Aperture**, routines add up all the Counts within a specific range of pixels to give the total Counts for a star. These routines are designed to subtract background light caused by other objects and give only the Counts created by the star itself. The brightness of the stars in an image also depends on the exposure time for the observation. If the telescope observes the star for a longer period of time, it will gather more light so the star will appear brighter. In most cases, if the exposure time is doubled the amount of light the telescope receives is doubled.

One way astronomers use photometry is to measure the brightness variation of an object such as a variable star or a supernova. To measure variation, images are taken on several successive nights of the same star and its Counts are compared with those of a steady star in the image. Another reason for using photometry is to measure the apparent brightness of a star in order to calculate its distance. This method involves calibration using a standard star. The *Photometry Techniques Unit* explains each of these processes. Photometry words used in the unit are defined as follows:

Counts - The measure of light that each pixel of the CCD receives from the star. This measurement is particular to the equipment used and to the atmospheric conditions during the observation. When we display an image, the grayness or color at each pixel is based on the Counts for that pixel.

Apparent Brightness - The amount of light reaching Earth per second from a star under ideal conditions (as if there were no atmosphere). This is a standard value that anyone could obtain from their measurements after correcting for observing conditions. The units for apparent brightness are Watts/meter².

Luminosity - The amount of light emitted per second by a star. It is an inherent property of the star, unlike Apparent Brightness, and is independent of where the observations were made or what telescope is used. Generally the luminosity of a star cannot be measured directly but must be inferred from other characteristics of the star. The units for luminosity are Watts.

Reference Star - A star whose apparent brightness and luminosity does not change from one night to the next. The apparent brightness value of the star, however, is typically not known.

Standard Star - A steady star is like a reference star but with a known, agreed upon value of apparent brightness.

Apparent Magnitude - A measure of apparent brightness commonly used by astronomers. The magnitude scale is inverse, meaning brighter stars have lower magnitudes.

Absolute Magnitude - This quantity is analogous to the luminosity but is expressed on the magnitude scale.

Measuring Brightness Variations

Suppose you have images of the same region of the sky taken on two different nights. The region contains two stars. One is your *target star*, the star you have chosen to study. It may be a Cepheid variable star or a star that has just gone supernova or any other star for which you wish to measure brightness variation. The other star is known to have constant luminosity, meaning the brightness of the star itself does not change from one night to the next. This star is called the *reference star*. You do not need to know the exact brightness of the reference star, just that it remains constant. For images of objects beyond our own galaxy, foreground stars are typically chosen. These are stars within our galaxy that are in the same line of sight to the further away object. If the observing conditions did not change from one night to the next, the reference star would have the same brightness in both images. If the second night was clearer than the first, the reference star will be brighter in the second image than in the first. The target star may appear brighter or dimmer in either image, but until changing observing conditions are accounted for, it can be unclear whether the change in brightness in the target star is caused by changing observing conditions or by changes in the star itself.

One way to find the brightness variation of the target star over time is to use the ratio of the Counts measured for the target star to the Counts measured for the reference star in each image. Variations in this ratio are comparable to variations in brightness of the target star.

$$\text{Counts ratio} = C_t / C_r$$

where C_t = Counts measured for the target star

C_r = Counts measured for the reference star

Calibration To Find Apparent Brightness

The Counts ratio gives a way of finding variation in brightness of a star but not the Apparent Brightness value itself. You need a further procedure for finding the brightness of a star that is independent of observing conditions so that anyone, anywhere on Earth, under any observing conditions, will get the same brightness. In addition, each CCD reacts differently to light and yields a different number of Counts for a given brightness. In order to use your data in the context of other observations and reference tables, you need to get the brightness of the star in units that are independent of a particular CCD.

Calibration allows you to deal with both changing observing conditions and different CCDs simultaneously. The process of calibration involves an image of a star whose brightness you want to measure (the target star) and another image of a standard star. The standard star should be in the same region of the sky as the target star so it will experience the same observing conditions as the target star at any given time. It also helps to have a star within the optimal brightness range for the telescope (not too bright and not too dim) to assure a good image. Most importantly, the standard star is a star with known apparent brightness – an agreed upon standard value.

With identical observing conditions for the target and standard stars, the ratio of their Counts is equal to the ratio of their apparent brightness. This means that on the basis of one pair of images, not the series of images over time necessary for measuring variation, the value for the target star's apparent brightness can be calculated.

Let C_t = Counts measured for the target star
 C_s = Counts measured for the standard star
 B_t = apparent brightness of target star
 B_s = apparent brightness of standard star

Then $C_t / C_s = B_t / B_s$ or equivalently $C_t / B_t = C_s / B_s$

HANDS-ON UNIVERSE™
SUPPLEMENTARY ACTIVITY 9
THE EFFECT OF OBSERVING CONDITIONS

Screen Setup: *PTstar1* and *PTstar2*

• Move the cursor around near the center of the bright star in each image. Read the values for Counts in the **Status Bar**. This is a measure of the brightness of each pixel in the area.

1. Which star do you think is brighter?

These images are actually of the same star and the star itself has not changed.
They are taken on two different nights.

2. Think of reasons why the Counts may change from one night to the next.

Alpha Centauri, the closest star to Earth (other than the Sun) is 4.1×10^{16} m away and its diameter is 1.4×10^9 m.

3. Use the Small Angle Approximation,

$$\theta = D/d$$

where θ = the angle subtended in radians

D = the diameter of the star

d = the distance to the star

to calculate the angle in radians subtended by Alpha Centauri. Be sure to use the same units of measurement for D and d . (See *Supplementary Activity 6: Using Angles to Measure Sizes* in the Measuring Size Module for an explanation of radians and of the Small Angle Approximation.)

4. Convert the angle subtended by Alpha Centauri to arc seconds (commonly denoted ")
1 radian = 206,265"

The plate scale of the CCD on the HOU telescope used for this image is 0.67"/pixel. This means that each pixel in the image corresponds to an angle of 0.67 arcseconds in the sky, or 0.67".

5. Under ideal conditions would the light from Alpha Centauri hit more or less than one pixel? Explain your answer.

- Look at the star in the image *PTstar2*. This star is much farther away than Alpha Centauri and roughly the same diameter.

6. Under ideal conditions would you expect the light from this star to cover more than one pixel?

- Move the cursor across the star horizontally and read the x-coordinates on the **Status bar**.

7. What is the approximate width of the star in pixels?

8. Form an hypothesis for why the width of *PTstar2*, even though it is farther away than Alpha Centauri, is more than one pixel.

Date: _____

Name: _____

Answer Sheet
Supplementary Activity 9

The Effect of Observing Conditions

1. I think the brighter star is:
2. Reasons why the Counts may change from one night to the next:

3. Angle in radians subtended by Alpha Centauri:
4. Angle subtended by Alpha Centauri in arc seconds:
5. Why I think the light from Alpha Centauri would hit more or less than one pixel:

6. Why I think the light from the further star would or would not cover more than one pixel:

7. The approximate width of the star in pixels:
8. My hypothesis for why the width of PTstar2 is more than one pixel:

HANDS-ON UNIVERSE™
SUPPLEMENTARY ACTIVITY 10
DEMONSTRATING OBSERVING CONDITIONS

The amount of light the telescope receives from stars depends on the conditions of the sky at the time of the observation. If you go out and look at the sky on one night you may see hundreds of stars (even more if you live in a very remote area) and other nights you may see only the brightest stars.

1. In what type of weather would you expect to see the most stars?
2. If you live near a big city, why might you see more stars at 3 a.m. than at 10 p.m. even in the winter when the sun sets much earlier?

The following demonstrations are designed to help you understand how observing conditions affect seeing stars.

- Use a black ballpoint pen to write a message in very small letters on a piece of paper. Fill a flat, clear container (such as a glass beaker) with clean water and lay it on top of the message. Add a few drops of dark watercolor paint or food coloring (preferably black or blue) so that the water gets cloudy.
3. How does that change the light coming from the message?
 4. What would be the difference if the message were written in light pencil compared to black marker?

When there are pollutants in the air, even just water vapor, the light from stars and galaxies gets absorbed and scattered making these distant objects appear dimmer than on a clear, still night. This is analogous to putting paint in the water. When using images taken on different nights, or even different times during the night, the atmospheric conditions may be different for each image. This could cause all stars to appear brighter in one image than another.

- Have one person stand in front of the class with a flashlight, shining the light at the class. Start with the overhead lights on in the classroom and then turn them off. If possible repeat the experiment with the outside windows uncovered and then covered.

5. Under what conditions does the flashlight appear brightest? Why?

Light pollution affects astronomical observations, particularly city lights or light from a nearly full moon. A bright sky makes it more difficult to distinguish dim stars from the background. An extreme example of this is in the daytime when the sun is the only star we see. There are plenty of stars up there, but because the sun is so bright our eyes cannot detect them. On a good image, the sky brightness is low so there is a stark contrast between stars and the background.

- Imagine sitting around a campfire or looking at the road on a very hot, summer day.

6. Why do things appear wavy as you look through the heat?

- To demonstrate this, use a ball point pen to write a message in very small letters on a piece of paper. Fill a flat, clear container (such as a glass beaker) with clean water and lay it on top of the message. Rapidly stir the water in random directions so that the surface is choppy (but don't splash).

7. Can you read the message when the water is moving?

8. Let the water settle down until you can read the message. Does the water have to be perfectly still to read it?

9. Would it make a difference if the letters were bigger?

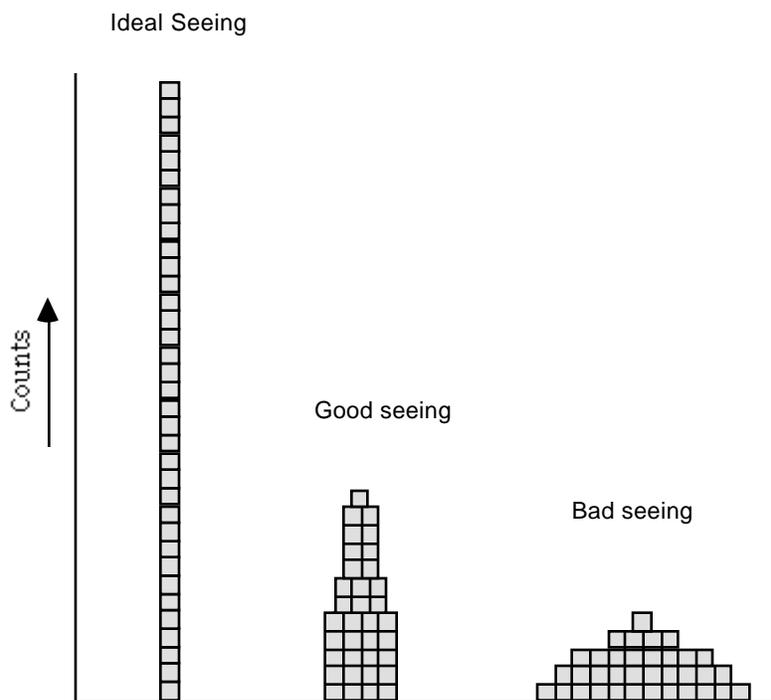
- Cut a small hole in another piece of paper and hold it above the still water so the message appears to just fit inside the hole. Now have someone else shake the water while you continue to look through the hole (be careful to keep the paper at a constant distance away from the water).

10. Does the message still fit inside the hole?

When the air is heated from a fire or the sun, the air molecules move faster and, like the moving water, they blur the light traveling through it from distant objects. Notice that it is *not the object* that is moving or wavy (in our case, the letters underneath the beaker of water); it is *the light coming from the object* that is being disturbed by the motion of the medium through which it is traveling (the water). This happens to star light traveling through our atmosphere. As the temperature rises or other atmospheric conditions occur,

the air becomes more *turbulent*, which causes the light from distant objects to blur. As a result, objects may appear bigger because the light coming to us is smeared across a wider viewing area. The total amount of light received from the star is the same, but it is distributed over a greater number of pixels.

The term *seeing conditions* is commonly used to describe how well light is confined to a few pixels. The figure below illustrates this point. The number of Counts measured for a star would be the same for various seeing conditions, but under ideal conditions all the light would come to just one pixel. This never happens in reality with even the best ground-based telescopes, because the atmosphere will always blur the light. Under ‘good seeing’ conditions the light from the star may be spread over only a few pixels, so the peak is still quite high. With “bad seeing,” the light is spread over many pixels so the peak is lower.



The Spreading of Light from a Star Under Different Seeing Conditions

When determining the brightness of a star the software sums the brightness over all of the pixels receiving light from that star. The software is able to determine the number of pixels the star covers, sum the Counts in those pixels, and subtract out the background sky. **Auto Aperture** does this automatically. (See *Supplementary Activity 16: Tools for Measuring Brightness* for further explanation of Auto Aperture.)

HANDS-ON UNIVERSE™
SUPPLEMENTARY ACTIVITY 11
AN EXAMPLE OF CALIBRATION

- Choose an object in your classroom, such as a table, and have several people measure its length by using their hand widths. In particular, make sure that one of the tallest people in the class and one of the shortest are among the measurers.
1. Does each person count the same number of hand widths in the length of the table?
 2. What further piece of information do you need to get an actual length of the table that would be the same for everyone?
 3. Suppose you have one table in the room that you know is 2 meters long. Describe how you could use that table, along with your previous measurements in hand widths, to get the length of an unknown table?
 4. Write an expression for finding the length in meters of a table if you know its length in hand-widths and the length in meters and hand-widths of another table.
 5. If the same person tried to measure the table again by hand, would their measurement be precisely the same? Why or why not?

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PHOTOMETRY TECHNIQUES UNIT

Activity I: Measuring the Counts of a Star

Screen Setup: *PTstar1* and *PTstar2*. You may open and work on these images simultaneously or one at a time.

- Move the cursor around near the center of the bright star in the image. Read the value for 'Counts' in the *Status Bar*. This is a measure of the brightness of each pixel in the area.

1. Which star do you think is brighter? Why?

- Select **Auto Aperture**. Place the cursor on the star in each image and click to find the total number of Counts measured for each star. This is labeled in red on the image and also listed in the Results box.

2. What is the brightness of *PTstar1* in Counts?

3. What is the brightness of *PTstar2* in Counts?

These images are actually of the same star and the star itself has not changed. They were taken on two different nights.

4. What are reasons why the Counts may change from one night to the next.

Activity II: Comparing Two Images of the Same Region

Images for this activity are listed on the next page. In each image the target star is on the left and the reference star is on the right. This is a subset of the images used in the *Cepheid Variable Stars Unit*. The technique you use here for comparing two images is also used in the *Supernova Light Curves Unit* in this module and the *Cepheid Variable Stars Unit* in the Measuring Distance module.

Screen Setup: *PTnight1*, *PTnight2*, *PTnight3*, and *PTnight4*. You may open and work on these images simultaneously or one at a time.

- For each image use **Auto Aperture** to measure the brightness in Counts of the target star and the reference star.
5. What is the brightness of the target star each night?
 6. What is the brightness of the reference star each night?
 7. Calculate the brightness ratios between the target star and the reference star.
 8. What conclusion can you make from the Count ratios about the brightness of the target star on each night?

Activity III: Calibrating Stars on an Image

Screen Setup: *PTtarg*, *PTstan*. You may open and work on these simultaneously or one at a time.

PTtarg contains your target star, H83 (the brightest star in the image)..

PTstan contains a standard star, H55 (the brightest star in the image), whose magnitude through the blue filter = $m(B) = 6.9$.

These images were taken at approximately the same time and contain stars from the same region of the sky.

Note: The images used in this procedure were taken through a blue (B) filter. This filter blocks out almost all light except that in the blue part of the color spectrum. When we calculate the apparent brightness of the target star we must remember that this only refers to the amount of light coming through the blue filter. Astronomers generally use observations through one filter and compare them to other measurements taken through the same kind of filter. It is not valid to compare these values to the total luminosity or total apparent brightness of another star for such purposes as calibration or distance measurements.

With identical observing conditions for the target and standard stars, the ratio of their Counts is equal to the ratio of their apparent brightness.

Let C_t = Counts measured for the target star

C_s = Counts measured for the standard star

B_t = apparent brightness of target star

B_s = apparent brightness of standard star

Then $C_t/C_s = B_t/B_s$ or equivalently $C_t/B_t = C_s/B_s$

9. Rewrite either of these equations to solve for the apparent brightness of the target star. In the following steps you will use this new equation to calibrate the target star.
10. Measure the Counts for both the target star and the standard star using **Auto Aperture**.
11. The apparent magnitude of the standard star through the blue filter, $m(b)$, is 6.9. Use the HOU Brightness Conversion Table in the beginning of this module to find the apparent brightness through the blue filter of this star.
12. Use your measures of Counts for the target star and the standard star and the apparent brightness of the standard star provided above to calculate the apparent brightness of the target star.
13. Use the HOU Brightness Conversion Table to find the apparent magnitude through the blue filter of the target star.

You have found the apparent magnitude of H83, the target star, through the blue filter that is independent of the particular CCD used or the observing conditions. This value should be consistent with measurements by astronomers around the world.

Date: _____

Name: _____

Answer Sheet

Photometry Techniques Unit

Activity I: Measuring the Counts of a Star

1. Brightest star: _____ My reasons why: _____
2. Brightness of *PTstar1* in Counts: _____
3. Brightness of *PTstar2* in Counts: _____
4. Reasons why the Counts may change from one night to the next: _____

Activity II: Comparing Two Images of the Same Region

- | | <u>night1</u> | <u>night2</u> | <u>night3</u> | <u>night4</u> |
|---|---------------|---------------|---------------|---------------|
| 5. Brightness of the target star in Counts: | _____ | _____ | _____ | _____ |
| 6. Brightness of the reference star in Counts? | _____ | _____ | _____ | _____ |
| 7. Brightness ratio of target star to reference star: | _____ | _____ | _____ | _____ |
| 8. What I can conclude from these ratios: | | | | |

Activity III: Calibrating Images

9. The equation for the apparent brightness of the target star: _____
10. Counts for the target star: _____
Counts for the standard star: _____
11. Apparent brightness of the standard star through the blue filter: _____
12. Apparent brightness of the target star through the blue filter: _____
13. The apparent magnitude in blue of the target star: _____

HANDS-ON UNIVERSE™
DISCUSSION SHEET
SUPERNOVA LIGHT CURVES

In the spring of 1994 several HOU students were studying M51, the spiral galaxy also known as the Whirlpool Galaxy. Various HOU images had been requested throughout February and March, and in early April, two girls at Oil City High School in Pennsylvania received an important phone call. They had serendipitously obtained the first images of a supernova in M51.

A supernova is the violent process that a very massive star undergoes when it dies. Many people think of supernovae as explosions, and in some cases this is true, but some stars implode rather than explode when they die. In either case, the brightness of the star increases dramatically during a supernova and then fades off continually until it is no longer visible. The rate at which the brightness increases and then fades is one indicator of what type supernova has occurred and what type of star is involved. In the *Supernova Light Curve Unit* you will use images taken by HOU students to create and study a plot of the brightness of a supernova as it changes over several weeks. This plot is called a light curve.

In order to measure the brightness variation of the supernova itself, you must eliminate effects caused by changing observing conditions. This is done through the use of a reference star. Since the reference star and the supernova are within the same image, the observing conditions are identical for both objects. The reference star should have constant luminosity which means if the observing conditions remain constant from one night to the next, the Counts of the reference star will remain the same. In general, observing conditions do change, so the number of Counts measured for the reference star will increase or decrease depending how much light the atmosphere lets through on a given night.

If the luminosity of the supernova candidate were to remain constant from image to image even though the observing conditions change, the ratio of Counts for the supernova and the reference star would also remain constant - the candidate is not a supernova. However, for a supernova that grows brighter and then fades, the brightness ratio changes accordingly. By measuring this ratio for each image, you can plot the true light curve for the supernova.

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SUPERNOVAE LIGHT CURVES UNIT

Activity I: Look What We Found!

Screen Setup: *M51img1* and *M51img2*

These are two images of M51, the whirlpool galaxy. Scott Miller, an HOU student at Oil City PA requested the first image of M51, *M51img1* on February 12, 1994. The core of the galaxy is the bright spot near the bottom of the image. The bright spot near the top is a companion galaxy. Heather Tartara and Melody Spence, Scott's classmates, requested the second image, *M51img2*, on March 31, 1994, to further study the galaxy. Heather and Melody received some surprising news soon after obtaining their image.

Screen Setup: *M51img1*, *M51img2*, and *M51img3*

- Use **Log Scaling** and adjust the **Min/Max** on both images to see more detail within the region of the core of M51 and try to find what all the excitement was about. It is quite tricky and you may have to move on to the next screen setup to find out.

The image *M51img3* was requested by Vincent Prosapio, an HOU student at Alan B. Shepard High School in Palos Heights, IL, on April 7, 1994.

- Use **Log Scaling** and adjust the **Min/Max** to see the galaxy.

1. Use drawings and words to compare the three images.

2. Approximately how many times brighter than the Sun is the supernova?

The core of M51 (the bright spot in the center) is about as bright as a million Suns. Use **Aperture** to compare the brightness of the supernova to the core of the galaxy. **Aperture** asks you to specify a Star Radius and Sky Radius each time you use it. For this unit, you may use Star Radius = 7 and Sky Radius = 14. For more information on **Aperture**, Star Radius, and Sky Radius please refer to *Supplementary Activity 16: Tools for Measuring Brightness: Auto Aperture & Aperture*.

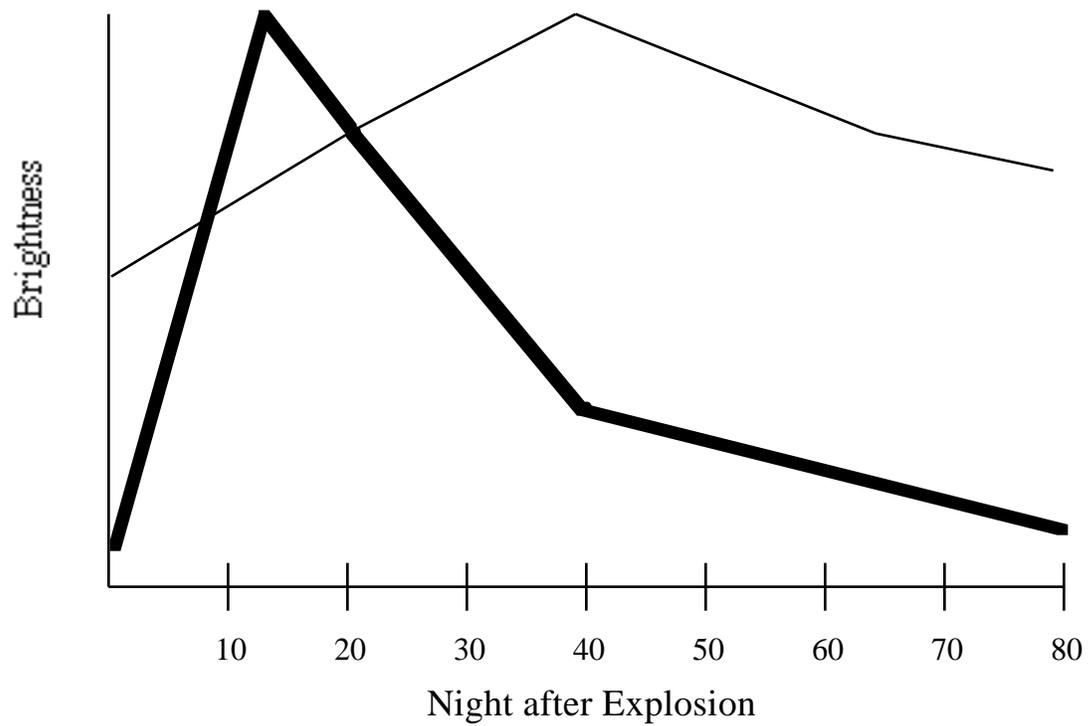
3. Use a new image of M51 requested by your class or a recent image of the galaxy from the HOU database. Compare the new image to the images from Spring of 1994. Describe your findings.

Activity II: Plotting the Light Curve of SN1994i

Screen Setup: *SNimg1* through *SNimg12*. It is probably easiest to use one image at a time and repeat the procedure below for each one

These twelve images of the supernova were taken in April and early May of 1994. The date of observation and other information are listed under **Image Info**. To create a light curve you must use only images through the same filter. All these images were taken through the I filter, which lets through infrared light. The images you examined in Activity I used the V filter (letting through mostly yellow light) so they cannot be used together with these images to create the light curve.

- Find the night number by counting the number of days between the observation date and March 31, 1994.
 - Use the bright star at approximately 45° to the lower left of the galaxy core as a reference star. You may use **Auto Aperture** to measure the Counts for the reference star, but you should still use **Aperture** for the supernova since it is so close to the center of the galaxy (see *Supplementary Activity 16: Tools for Measuring Brightness: Auto Aperture & Aperture* for further explanation).
 - Divide the Counts for the supernova by the Counts of the reference star to get the Count ratio for each night. (See the *Photometry Techniques Discussion Sheet* for more about the Count ratio, B_{SN}/B_R as a measure of brightness changes.)
4. Make a light curve for SN1994i by plotting the Count ratio versus night number.
 5. Compare your light curve with those shown on the following page and infer the type supernova for SN1994i.



Type I SN **—**
Type II SN —

Date: _____

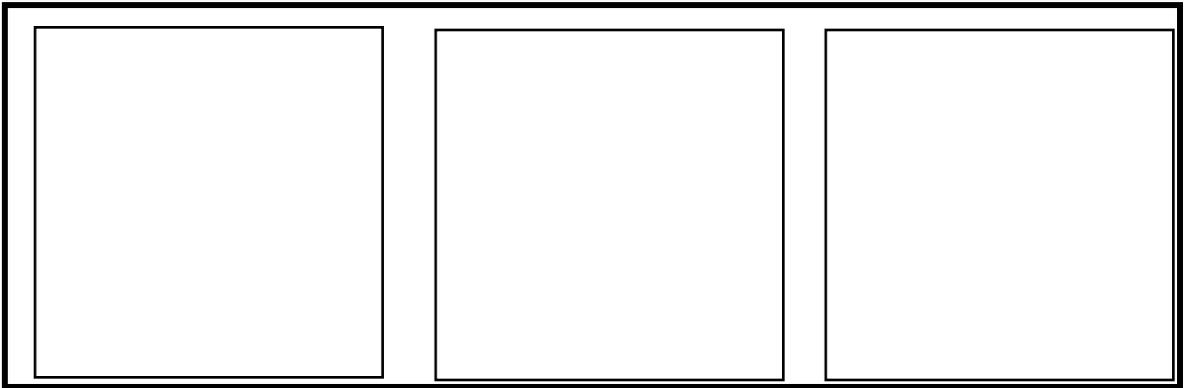
Name: _____

Answer Sheet

Supernova Light Curves Unit

Activity I: Look What We Found!

1. Findings from the images:



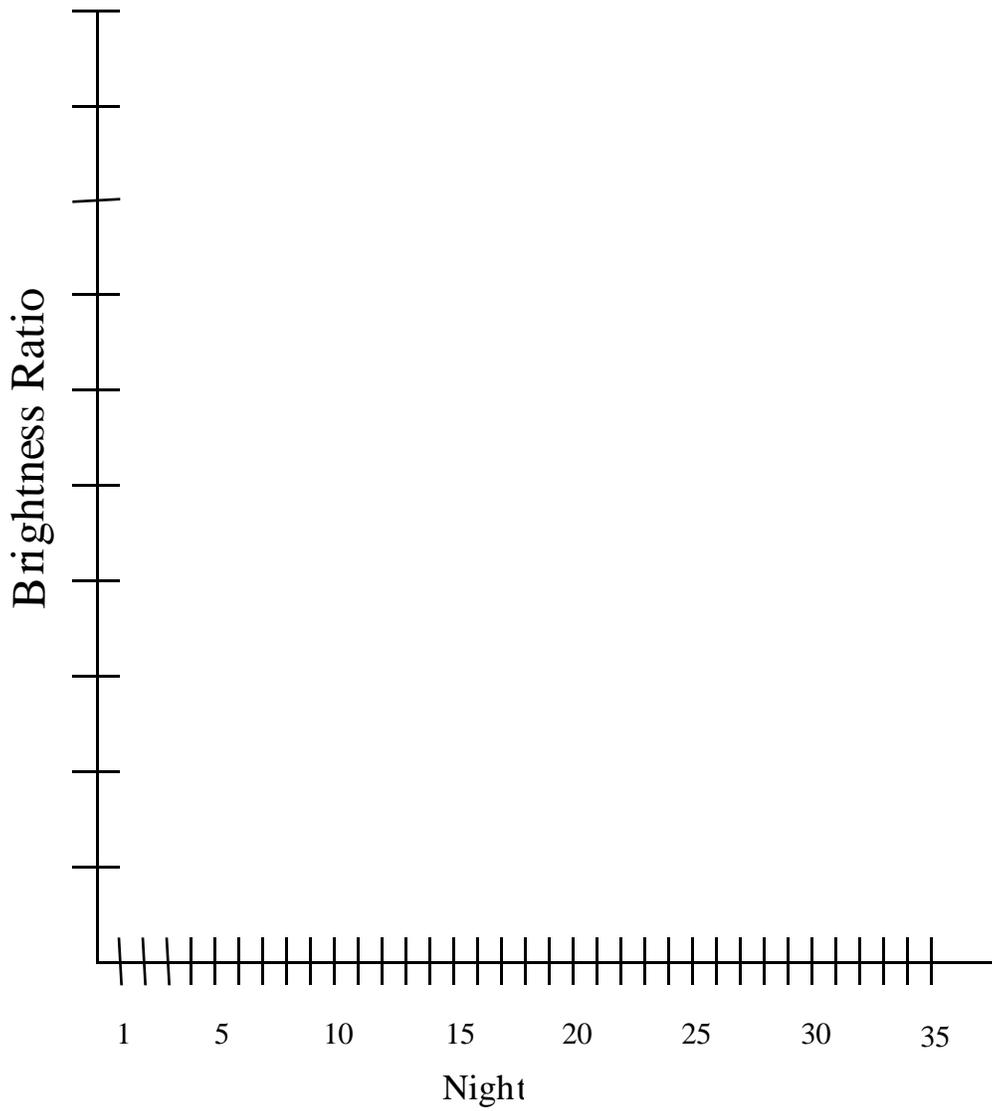
m51img1

m51img2

m51img3

2. How many times brighter the supernova is than the Sun:
3. Comparison of the new image to the previous images of M51:

4.



5. SN1994I is a type ___ supernova:

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DISCUSSION SHEET
SCIENCE OF A SUPERNOVA

Introduction

Suppose you were out looking at the sky on a dark, starry night and suddenly you saw a star that wasn't there a moment earlier? You might think your eyes were playing tricks on you. You could check by taking a photograph of the region of the sky and comparing it to a photograph taken earlier of the same region. Normally, these photos would be roughly the same. Certain objects, such as planets, may have changed position relative to the background stars, and the brightness or size of the stars may appear different from night to night, but the arrangement of the stars relative to each other generally does not change over a period of nights, years or even centuries.

A supernova could be an explanation for seeing a new star. The term comes from the Latin word "nova" meaning new, though ironically a supernova is actually the event associated with the death of a star. Astronomers have studied various types of supernovae and have created possible explanations for the processes that could cause such events. Certain types of supernovae can give important clues to the puzzle of the age, size and fate of our universe, as well as contribute to our evolving understanding of the structure of stars.

Although the study of supernovae is a very active field in astronomy, theories are constantly being challenged about the different types of supernovae and the stars that produce them. Currently more than sixty supernovae are discovered each year, but often times they are sighted after the maximum peak of the light curve so some of the scientific information is lost.

Astronomers have classified supernovae into two kinds, Type I and Type II, based on the amount of hydrogen observed in the material surrounding the explosion of the star. Type I have no observed hydrogen, leading astronomers to believe the outside layers were already shed. Hydrogen is observed from Type II supernovae so they are generally believed to be explosions of higher mass stars. This theory is consistent with the fact that Type II supernovae are only found in spiral galaxies, and usually in the arms, where high-mass star formation is thought to be more prevalent, whereas Type I supernovae are found in both spiral and elliptical galaxies.

Most elements heavier than hydrogen and helium are predominantly created inside stars or in the process of the supernova explosion itself. These elements are ejected into space by supernovae and then reused to form new stars and planets such as the Earth. The atoms that make up almost every substance that you deal with everyday, including the chair you are sitting in, the food you eat, and even your body itself, were once inside a star. You are made up of star matter.

Type I Supernovae

Most stars in the universe are found in multiple star systems, meaning that two or more stars are in a gravitational orbit around a common center point. When these stars are very close together the material from one star can spill over onto another star, greatly effecting the evolutionary process of each star. Current theories suggest that Type I supernovae occur in binary systems containing a white dwarf and a massive star.

A white dwarf is the very compact remnant of a low mass star that has burned up all the hydrogen and helium in its core leaving a very dense remnant of mostly carbon. The outer layers of unburned hydrogen were blown off during a burst of helium fusion that created a planetary nebula around the white dwarf. A white dwarf is always less than 1.4 times the mass of the Sun. Any additional mass will cause the white dwarf to collapse and create a different type of remnant called a neutron star.

When a white dwarf is part of a binary, mass can be exchanged between the white dwarf and its companion. Each star has an imaginary shell around it within which all matter is gravitationally bound to that star. Astronomers refer to these regions as the Roche lobes for the binary system (see figure 1). As the companion star evolves, its radius will expand due to thermal pressure. This may cause some of its outer material to overflow its Roche lobe and fall onto the white dwarf. The white dwarf gains more and more mass by this method until it reaches the critical threshold of 1.4 times the mass of the Sun, where it can no longer support itself. In a violent implosion, called a Type Ia supernova, the white dwarf succumbs to the increased pressure and, in turn, heats up to the point where it can burn fuel again. This time the fuel is carbon. The ignition of the fuel results in a tremendously bright flash, which then fades over a period of days or weeks. Discoveries of these supernova have been made out to the edge of the visible universe.

The critical threshold of 1.4 times the mass of the Sun is the same for all white dwarfs. This means that no matter what the mass or temperature was for the original star, it will implode with the same amount of fuel left to burn. Since the mechanism for ignition is the same and the amount of fuel is the same, it follows that the luminosity resulting from the rapid ignition is the same for all white dwarfs undergoing a Type Ia supernova. Astronomers call such an object a “standard candle”, meaning that its luminosity is known so we can use it as a point of reference from which to compare other objects. We can observe the apparent brightness of the supernova as seen from earth, and knowing its absolute brightness as a standard candle, we can then determine its distance away from us.

Type I supernovae are often categorized as Type Ia, Type Ib, or Type Ic supernovae. The different letters refer to differences in the specific elements detected after the explosion and the rate at which its brightness fades. Theories that attempt to explain the differences among the various categories of Type I supernovae focus on the specific mass of the original star. It is thought that a Type Ib or Ic supernova may be caused by the remnant of a very high mass star, such as a neutron star that is part of a binary system.

Type II Supernovae

High mass stars undergo even more violent explosions called Type II supernovae (see figure 2). High mass stars achieve much higher temperatures inside so they are able to burn heavier elements than low mass stars. A very dense core of iron builds up within the center of the star as a result of the burning, with the lighter elements in the surrounding layers. This configuration is sometimes referred to as an onion-skin model because of the spherical shells of various elements.

Through energy-producing nuclear fusion, only elements as heavy as iron can be produced. Any nuclear reactions producing heavier elements require an input of surplus energy. Therefore the star only continues to burn fuel until iron is produced in the core and then fusion stops. After the fuel runs out, the core cools to the point where the gravitational pressure causes the star to come crashing in on itself. The implosion is so strong that the outer layers of the star crash into the hard iron core and bounce back out with tremendous energy. This is called a shock wave. The shock wave ignites the material in the outer layers of the star and the result is a sudden explosion that can be one billion times as bright as the original star. The remnant of the core of a Type II supernova will either be a neutron star or a black hole, depending on the original mass of the star.

The intense brightness of a Type II supernova is caused by the burning of the lighter elements that are in the outer layers of the star. This material is thrust outward by the explosion creating an expanding bright nebula or halo that can remain visible for thousands of years. The explosion releases such tremendous amounts of energy that the surplus energy required for nuclear fusion of elements heavier than iron is available. In fact, it is believed that supernova explosions may be responsible for the creation of all material heavier than iron or at least for providing "seed" iron elements that are the fuel for further nuclear and chemical evolution. This includes elements such as lead, zinc, gold, and silver.

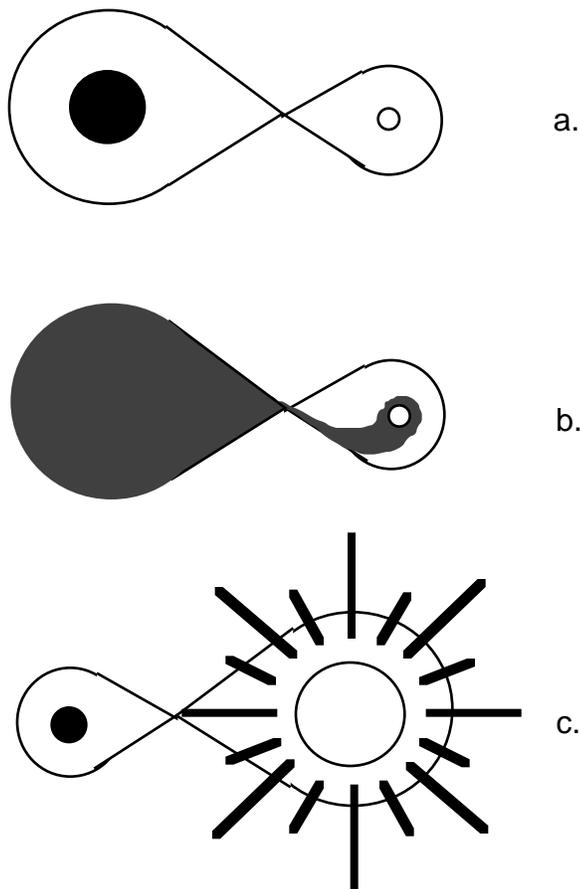
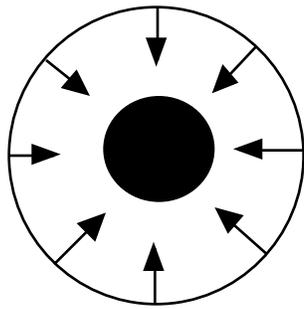
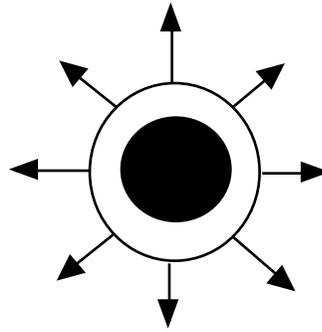


Figure 1

- a) A star and its companion white dwarf within their Roche lobes.
- b) The star blooms into a red giant and its outer layers overflow the Roche lobes. The overflowing matter falls onto the surface of the white dwarf.
- c) The white dwarf implodes and ignites fusion causing a bright flash called a Type I supernova



a.



b.

Figure 2:

- a) In a Type II supernova the outer layers of a high mass star come crashing in and
- b) bounce off the dense core sending a shock wave outward.

HANDS-ON UNIVERSE™
DISCUSSION SHEET
THE MAGNITUDE SCALE

An ancient Greek astronomer, Hipparchus, devised a system to classify stars according to their brightness. He divided all of the stars he could see on a dark, clear night into six groups with magnitude 1 stars being the brightest group and magnitude 6 stars being the dimmest. Hipparchus did not have a telescope back in those days so the stars he classified were only those visible to the naked eye. Astronomers still use the magnitude scale to describe the brightness of stars. Since human eyes see light in a logarithmic fashion, the mathematics of the magnitude scale is based on logs.

When astronomers considered the stars that Hipparchus must have seen when creating his magnitude scale, they found the magnitude 1 stars are about 100 times brighter than the magnitude 6 stars. In order to make this true mathematically, each change of one in magnitude must correspond to an increase in brightness by a factor of about 2.51 since $2.51 \times 2.51 \times 2.51 \times 2.51 \times 2.51$ equals approximately 100.

$$\begin{aligned} \text{mag 1} &= (2.51)^1 \text{ times brighter than mag 2} \quad \text{-or-} \quad B_a = 2.51 \times B_b \quad \text{when } m_b - m_a = 1 \\ \text{mag 1} &= (2.51)^2 \text{ times brighter than mag 3} \quad \text{-or-} \quad B_a = 6.30 \times B_b \quad \text{when } m_b - m_a = 2 \\ \text{mag 1} &= (2.51)^3 \text{ times brighter than mag 4} \quad \text{-or-} \quad B_a = 15.8 \times B_b \quad \text{when } m_b - m_a = 3 \\ \text{mag 1} &= (2.51)^4 \text{ times brighter than mag 5} \quad \text{-or-} \quad B_a = 39.7 \times B_b \quad \text{when } m_b - m_a = 4 \\ \text{mag 1} &= (2.51)^5 \text{ times brighter than mag 6} \quad \text{-or-} \quad B_a = 99.6 \times B_b \quad \text{when } m_b - m_a = 5 \end{aligned}$$

(B is brightness, m is magnitude, and subscripts a and b are for two stars.)

By the same principle each half magnitude corresponds to a brightness factor of 1.6 (1.6×1.6 roughly equals 2.5).

Some of the brightest stars in the sky were not visible in Hipparchus' region so new magnitudes had to be created to accommodate them. Thus, we now have negative numbers on the magnitude scale to describe very bright objects.

When measuring a star on a CCD image, you get its brightness in Counts. To see the magnitude scale in terms of this brightness value, let's assume a magnitude 0 star has brightness = 10000 (note: we are just using an arbitrary value to demonstrate the scale). Based on this brightness value, the following magnitudes would have the associated brightness:

<u>Magnitude</u>	<u>Brightness</u>
-1	25000
0	10000
1	4000
2	1600
3	640
4	256
5	102.4
10	1.0
15	0.01

Chart: A Magnitude-Brightness Example

The chart points out an interesting problem. The brightest star in the night sky in the Northern Hemisphere is Sirius, a magnitude -1 star. On the above scale Sirius would have a brightness of 25000, which is near the upper limit of the CCD and the image processing software. In the same image, with Sirius at the upper limit of the CCD, a magnitude 15 star or even a magnitude 10 star is so dim that the software would not even identify it as a star.. To see dim stars you need to choose a longer exposure time but bright stars will now saturate.

HANDS-ON UNIVERSE™
SUPPLEMENTARY ACTIVITY 12
SOME EXPONENTIAL GAMES

Logarithmic Games

1. Suppose you invest one penny on the first day of the month. Each subsequent day you double the amount currently in the bank; e.g., day 2 you put in two pennies, day 3 you put in four pennies, day 4 you put in eight pennies, etc. What will be the total amount of money you will have at the end of a thirty day month ?

2. Assume that, on average, each person has three children in his or her lifetime. Start with one person (call that generation zero) and draw a tree diagram for six generations, counting the number of people in each generation.
 - A. Write an algebraic expression to calculate the total number in any generation.
 - B. Write an expression that predicts which generation will have 2187 people.

Star Cards Game

Form pairs of two and use the star cards and fake money to play the following card game:

Deal out all of the star cards so that each person gets the same number of cards. Put any remainder aside. Each person starts with \$10,000,000 in a variety of bills. Both people put out a star card. The person with the dimmer star (higher magnitude) must pay the other person an amount equal to 25 raised to the power of the difference in magnitudes. For instance:

- if the difference in magnitudes = 1, then the loser pays the winner \$25
- if the difference in magnitudes = 2, then the loser pays the winner \$625
- if the difference in magnitudes = 3, then the loser pays the winner \$15,625
- if the difference in magnitudes = 4, then the loser pays the winner \$390,625
- if the difference in magnitudes = 5, then the loser pays the winner \$9,765,625

If the difference in magnitudes is zero, go on to the next turn. The game is over when the star cards run out or when one person runs out of money.

HANDS-ON UNIVERSE™
SUPPLEMENTARY ACTIVITY 13
MAGNITUDE CALCULATIONS

The magnitude scale uses the following definitions (See *The Magnitude Scale Discussion Sheet* for more information.):

A difference of 1 magnitude means a factor of 2.5 times in brightness.

A difference of 5 magnitudes means a factor of 100 times in brightness.

A difference of 0.5 magnitudes means a factor of 1.6 times in brightness.

The following examples use this information to determine how many times brighter one star is than another:

A 10th magnitude object compared to a 20th magnitude object. A 10th magnitude object is 100 times brighter than a 15th magnitude object, and a 15th magnitude object is 100 times brighter than a 20th magnitude object. So a 10th magnitude object is 100×100 times brighter than a 20th magnitude object; in other words, 10,000 times brighter.

A 7th magnitude star compared to a 14th magnitude star. A 7th magnitude object is 100 times brighter than a 12th magnitude object; a 12th magnitude object is 2.5 times brighter than a 13th magnitude object, and a 13th magnitude object is 2.5 times brighter than a 14th magnitude object. So a 7th magnitude object is $100 \times 2.5 \times 2.5$ times brighter than a 14th magnitude object; in other words, 625 times brighter.

A 5th magnitude star compared to a 11.5 magnitude star. A 5th magnitude object is 100 times brighter than a 10th magnitude object; a 10th magnitude object is 2.5 times brighter than a 11th magnitude object; and a 11th magnitude object is 1.6 times brighter than a 11.5 magnitude object. So a 5th magnitude object is $100 \times 2.5 \times 1.6$ times brighter than a 11.5 magnitude object; in other words, 400 times brighter.

A negative 5th (-5th) magnitude star compared to a 7th magnitude star is $100 \times 100 \times 2.5 \times 2.5 = 62,500$ times brighter.

An 8th magnitude star compared to a 15.5 magnitude star is $100 \times 2.5 \times 2.5 \times 1.6 = 1000$ times brighter.

A -20th magnitude star compared to an 8.5 magnitude star is $100 \times 100 \times 100 \times 100 \times 100 \times 2.5 \times 2.5 \times 2.5 \times 1.6 = 250,000,000,000$ times brighter.

Now, you try a few. How many times brighter is:

1. A 5th magnitude star compared to a 10th magnitude star?
2. A 7th magnitude star compared to a 17th magnitude star?
3. A 3rd magnitude star compared to a 5th magnitude star?
4. A 3rd magnitude star compared to a 6.5 magnitude star?
5. A 12th magnitude star compared to a 22.5 magnitude star?
6. Our sun (-26 magnitude) compared to a 15th magnitude star?

Ask the reverse question. Here are some examples. What is the magnitude of the star if:

It is 100 times brighter than a 15th magnitude star. A difference of five magnitudes means a difference of 100 times in brightness. Also, a lower number means a brighter star, so the star must be a magnitude 10 star.

It is 10,000 times dimmer than a 15th magnitude star. A difference of 10 magnitudes means a difference of 10,000 times in brightness. Also a higher number means a dimmer star so the star must be a magnitude 25 star.

It is 6.25 times brighter than an 8th magnitude star. A difference of 1 magnitude means a difference of 2.5 times in brightness. $6.25 = 2.5 \times 2.5$, so the stars must differ by two magnitudes. A lower magnitude star means a brighter star, so the star must be a 6th magnitude star.

It is 2.5 times dimmer than a 17th magnitude star. A difference of 1 magnitude: 18th.

It is 250 times brighter than a 14th magnitude star. A difference of 6 magnitudes: 8th.

It is 625 times brighter than a 9th magnitude star. A difference of 7 magnitudes: 2nd.

Now you try a few. What is the magnitude of a star if:

7. It is 100 times dimmer than a 12th magnitude star?
8. It is 10,000 times brighter than a 12th magnitude star?
9. It is 625 times brighter than a 11th magnitude star?
10. It is 25,000 times dimmer than a -5 magnitude star?
11. It is 100,000,000 times brighter than a 5th magnitude star?

Date: _____

Name: _____

Answer Sheet

Supplementary Activity 13

Magnitude Calculations

How many times brighter is:

1. A 5th magnitude star compared to a 10th magnitude star: _____

2. A 7th magnitude star compared to a 17th magnitude star: _____

3. A 3rd magnitude star compared to a 5th magnitude star: _____

4. A 3rd magnitude star compared to a 6.5 magnitude star: _____

5. A 12th magnitude star is compared to a 22.5 magnitude star: _____

6. Our Sun (mag = -26) compared to a 15th magnitude star: _____

What is the magnitude of a star if:

7. It is 100 times dimmer than a 12th magnitude star: _____

8. It is 10,000 times brighter than a 12th magnitude star: _____

9. It is 625 times brighter than a 11th magnitude star: _____

10. It is 25,000 times dimmer than a -5 magnitude star: _____

11. It is 100,000,000 times brighter than a 5th magnitude star: _____

HANDS-ON UNIVERSE™
SUPPLEMENTARY ACTIVITY 14
Comparing the Magnitudes of Stars

It is a common practice in Astronomy to compare the brightness of stars on the same image or on two different images. You may want to observe the same star using different filters to determine its color, or the same star at different times to see if its brightness is variable, or you may want to observe two different stars and compare their brightness to each other. In any case, the ratio of brightness can be expressed as a difference in magnitudes.

Suppose the brightness of star1 = B_1 and the brightness of star2 = B_2 . We could express this in magnitudes using m_1 = the magnitude of star1 and m_2 = the magnitude of star2.

1. If $m_1 - m_2 = 1$ then $B_2 = (2.5)^1 \times B_1$
and if: $m_1 - m_2 = n$ $B_2 = (2.5)^n \times B_1$

Derive the following expression for the difference in magnitudes using log base 10 (which is the base commonly used by astronomers):

$$m_1 - m_2 = 2.5 \log(B_2/B_1)$$

When comparing two stars on the same image, the ratio of Counts for those stars is equivalent to the ratio of brightness:

$$m_1 - m_2 = 2.5 \log(C_2/C_1)$$

where C_1 & C_2 = Counts of star1 & star2

2. Rewrite the equation to solve for m_1 .
- Open the image *Mgclust*. The brightest star on this image has magnitude, $m(v) = 8.0$.
3. Using **Find**, get the brightness of stars in small part of the image. Try another part to see if the range of dim stars is similar.
4. Knowing the apparent magnitude of the brightest star, use your equation to calculate the apparent magnitude of each of the stars in one of your samples. A spreadsheet is one way to do these calculations.
5. How much brighter is the brighter dim star than the dimmest? Calculate this two ways: one based on the difference in magnitudes and one based on the ratio of Counts. These two values are probably not the same. Why not?

HANDS-ON UNIVERSE™

SUPPLEMENTARY ACTIVITY 15

ABSOLUTE MAGNITUDE

So far we have only been dealing with apparent magnitudes, which are the measure of how bright stars appear to us here on Earth. Another interesting quantity is Absolute Magnitude which refers to how bright the star is intrinsically, independent of its distance away. A quantity related to the absolute magnitude is Luminosity. The luminosity of a star is the amount of energy it emits per second. Using absolute magnitude, Luminosity measurements can be converted to the magnitude scale..

The absolute magnitude of a star can be obtained from the apparent magnitude if the distance to the star is known. Astronomers have defined the absolute magnitude to be the apparent magnitude that a star would have if it were 10 parsecs¹ from Earth. This definition allows all stars to be measured on a scale that is independent of distance away from the observer.

The apparent brightness of a star can be calculated as follows:

$$\text{apparent brightness} = \frac{\text{luminosity}}{4\pi d^2}$$

where d = the distance to the star; therefore $4\pi d^2$ is the surface area of the sphere over which the light is spread.

The absolute magnitude, M, is defined as the apparent brightness of a star 10 pc away

The apparent brightness of a star 10 pc away is:

$$\text{apparent brightness of a star at 10 pc} = \frac{\text{luminosity}}{4\pi(10\text{pc})^2}$$

Using the equation from *Supplementary Activity 14: Comparing the Magnitudes of Stars*:

$$\implies m_1 - m_2 = 2.5 \log(B_2/B_1)$$

$$m - M = 2.5 \log [(L/4\pi(10\text{pc})^2) / (L/4\pi d^2)]$$

where m = the apparent magnitude of the star

M = the absolute magnitude of the star

L = the luminosity of the star

d = the distance to the star in parsecs

¹A parsec, pc, is a unit of distance commonly used in Astronomy. The Conversions are:
1 pc = 3.26 light years = 3.09×10^{16} m.

1. Use algebra and the rules for logarithms to derive the following equation, called the distance modulus, for the difference between apparent and absolute magnitude:

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

2. Given that a star is 2000 pc away and that it has an apparent magnitude of 7.0, calculate its absolute magnitude.
3. Assume that the star measured in *SA 14* is 1400 pc away. Calculate its absolute magnitude.

HANDS-ON UNIVERSE™
SUPPLEMENTARY ACTIVITY 16
TOOLS FOR MEASURING BRIGHTNESS:
AUTO APERTURE & APERTURE

- **Open** the image *PTstar3*.
- Select **Auto Aperture**. The cursor now changes to an icon with a pair of cross hairs inside a circle. Click on the star in your image. The brightness is printed on the image, and a Results box will appear giving information about the star including its 'Brightness'. This value is the total number of Counts of star light measured for the star.

1. Record the brightness Counts for the star.

To get a sense of how the **Auto Aperture** routine calculates this value, you will estimate the sum of the star light yourself. Since the brightness in the image of the star is from both star light and background sky light, this will include subtracting the sky light in order to get the brightness of the star alone.

- Move the cursor around the sky away from the star to get an estimate of the background sky value for the image. Counts at each pixel are shown in the **Status Bar**. Get readings for enough sky pixels so you feel comfortable that you have a good average.

2. What is your average Counts for the sky pixels?

- Move the cursor around within the star, one pixel at a time using the arrow keys. You must judge where the edge of the star is, based on a significant change in Counts from the background sky. Find the brightest pixels and dimmest pixels within the star and estimate an average value for the Counts of the star pixels.

3. What is your average Counts for the star's pixels?

To get the Counts within the star that are exclusively due to star light, subtract the average sky pixel Counts from the average star pixel Counts.

4. What is your average Counts of star light per pixel?
5. Estimate the number of pixels within the star. (Area of a circle = r^2)
6. Calculate the total number of Counts of star light for all the pixels within the star.
7. The software automatically subtracts the background sky light. How does your answer compare to the answer from **Auto Aperture**?
8. What could be some reasons for discrepancies?

When you look at the Results box after using **Auto Aperture**, the table lists the Brightness and indicates it is from using **Aperture**. This is because **Auto Aperture** calls the **Aperture** routine to calculate the brightness of the star. As the Status Bar states when you place the cursor on the icon: "Performs Aperture with automatically calculated radii." **Aperture**, on the other hand, allows you to set your own values. This can be important in a crowded part of an image where light may be spilling over from nearby stars and gas clouds.

The software uses the sky radius to determine the average number of Counts per pixel coming from background sky. This average background sky is subtracted from each star pixel, the Counts within the star radius are summed, and the result is the star light in Counts within the star radius. The value is listed as 'Brightness' in the Results box.

The figure below shows how these radii might appear if positioned on an image of a star.

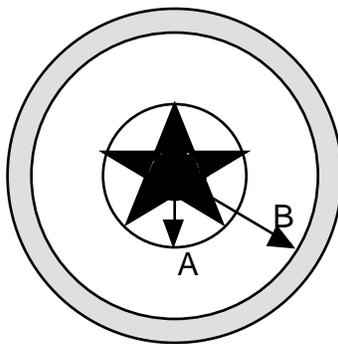


Figure: Star radius and Sky radius

The arrow A is the star radius and the arrow B is the sky radius. The dotted ring shows the region the software uses to determine the background sky. This ring is 3 pixels wide.

It is a common practice to use 1.5 times the Full Width at Half Maximum, FWHM, as the star radius. (See *Supplementary Activity 17: Measuring the FWHM of a Star* for an explanation of FWHM.) On a Slice graph the FWHM is usually easier to measure than the width of the base because it is often hard to discriminate on the graph where the peak begins and the background sky ends. The FWHM is an approximate measure of the radius of the star since it is roughly half the width of the base. In most cases using 1.5 times FWHM assures getting the number of pixels needed to approximate the total Counts of the star while not adding in too much of the background light. The sky radius can then be estimated as 3 times FWHM, which is the same as twice the star radius.

Do your own experimentation to see how to choose the star and sky radii. For an isolated star there will be a limiting value for the Counts of the star. In other words, if you choose a star radius large enough, then any subsequent increase to the star radius should not change the sum of Counts for the star. This is because you have already included all the pixels needed to account for all of the starlight and pixels outside the star's light will be background sky. Since background sky is subtracted from each pixel within the star radius, sky minus sky will be zero for these extra pixels.

9. Set up a table to record your two radii and the Brightness for the five trials plus the final three class trials for the following sequence.

- **Open** the image *PTstar3*
- Use **Slice** to determine the FWHM of the star.
- Estimate the star and sky radii using the guidelines above.
- Select **Aperture** under **Data Tools**. Are the default values for 'Star Radius' and 'Sky Radius' the same values you have determined using your value of FWHM?
- Enter your own values for 'Star Radius' and 'Sky Radius'. Click on **OK**.
- Click on the star in your image to get the Brightness. This value is the number of Counts attributable to star light only in the pixels within the star radius.
- Choose four more values for star radius and sky radius (always making sure the sky radius is greater than the star radius) and compare answers.
- Work as a class to find an optimal value for the sky and star radii for this image (the smallest value where the sum does not change by more than 3-5% when you increase the radii).

Date: _____

Name: _____

Answer Sheet
Supplementary Activity 16

Tools for Measuring Brightness: Auto Aperture & Aperture

1. Counts for the star using **Auto Aperture**:

2. My average Counts for the sky pixels:

3. My average Counts for the star's pixels:

4. My average Counts of star light per pixel:

5. My estimate of the number of pixels within the star:

6. Total number of Counts of star light for all the pixels within the star:

7. Comparison of my answer to the value from **Auto Aperture**:

8. Some reasons for discrepancies:

9. My table (see reverse side ____ /see separate sheet ____)

HANDS-ON UNIVERSE™
SUPPLEMENTARY ACTIVITY 17
MEASURING THE FWHM OF A STAR

When determining the brightness of a star, the software sums the brightness over all pixels receiving light from that star. To do this the effective width of the star must be determined for each image before measuring the brightness of the stars on that image. Astronomers use a measure called the *Full Width at Half Maximum, FWHM*, for estimating the width of a star on an image. The FWHM is given when a star is measured using the **Find** option under **Data Tools**; however, this activity explains how to measure the FWHM for yourself.

One way to estimate the FWHM is to look at a **Slice** across the star. The **Slice** graph will probably look something like the diagram on the next page (without the arrows and denotations). The base of the slice is at the value for the background sky. The top of the peak represents the Counts measured in the brightest pixel along the slice within the star. The FWHM is the number of pixels across the graph where the brightness Counts are half way between the base and the peak. (See the figure on the next page.)

• **Open** the image file *PTtarg* and select **Slice** to draw a line across the star.

1. Estimate the height of the peak.
2. Estimate the width of the base.
3. Estimate the FWHM.
4. Compare your estimate with the value determined by the computer using **Find**.

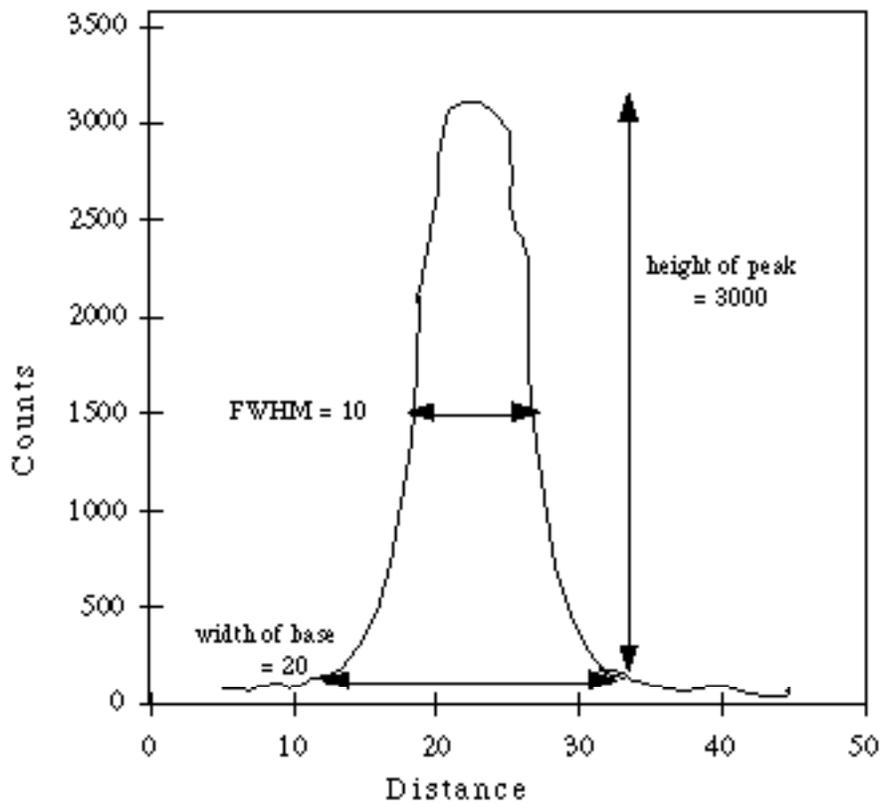


Figure: Example of a Slice

It is important to realize you are measuring the smeared out radius of the star as the light comes through our atmosphere. The real radius, if there was only a vacuum between the telescope and the star, would be less than 1 pixel.