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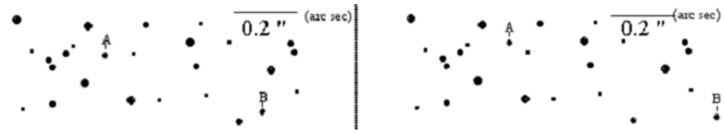

Measuring Distances

Purpose

- Explore and practice using different methods to find distances on astronomical scales: radar ranging, parallax, luminosity, spectroscopic parallax

Equipment

- Meter stick
- Plastic ruler
- Light bulb
- Light meter

Part 1: Radar and the Distance to the Moon

You can measure the distance to the Moon the same way bats measure the distance to a prey: using echo. While bats use sound waves to locate prey, scientists use light waves to measure the distance to the Moon. Radar uses electromagnetic waves that travel at the speed of light (speed c = 300,000km/s). The distance traveled by the radar wave is given by:

$$\text{distance} = c \times \text{time elapsed}$$

Question 1: The New York Times printed an article in 1946 describing the first man-made contact with the Moon. "…on January 10 when the Army Signal Corps beamed a radar signal on it and 2.4 seconds later received an echo reflected by the celestial body…"

a) With the information given in the quote from the article, calculate the distance to the Moon.

b) **ASTR 1102.** When the uncertainty is not given for a value, it is usually assumed to be 1 in the last digit given. What is the percent uncertainty in the time?

c) **ASTR 1102.** Using your calculated time percent uncertainty as the percent uncertainty in the distance calculation, what is the actual uncertainty in the distance?

d) **Both classes.** Is your calculated value of the Earth-Moon distance consistent with the reference value (384,400km)? Comment.

Part 2: Parallax

Hold your thumb out at arm's length. The background should be a far away wall or a window. View your thumb relative to a distant background while you move your head to the left, then to the right.

Question 2: Describe what you see and propose and explanation (draw a top-down diagram of your head, thumb and wall).

Question 3: The angular size of your thumb held at arm's length is about 1 degree. Extend your head as much as you can to the right and to the left. What is the observed parallax of your thumb, in degrees? (How many thumb widths, each way?)

Question 4: Student A places the "zero" end of the meter stick against her/his chin, holding it out horizontally. Student B places a pencil at a distance d = 50cm. Student A alternates opening and closing each eye.

a) How many degrees does the pencil move against the background? Make a careful measurement. Use your thumb to measure 1 degree.

b) Repeat the above for *d* = 25cm and *d* = 1m.

c) Draw a top-down diagram showing the three different situations.

d) Make a concluding comment that relates the parallax (amount the pencil moves) and the distance the pencil is away from you. Call your instructor to check if you found the correct relationship.

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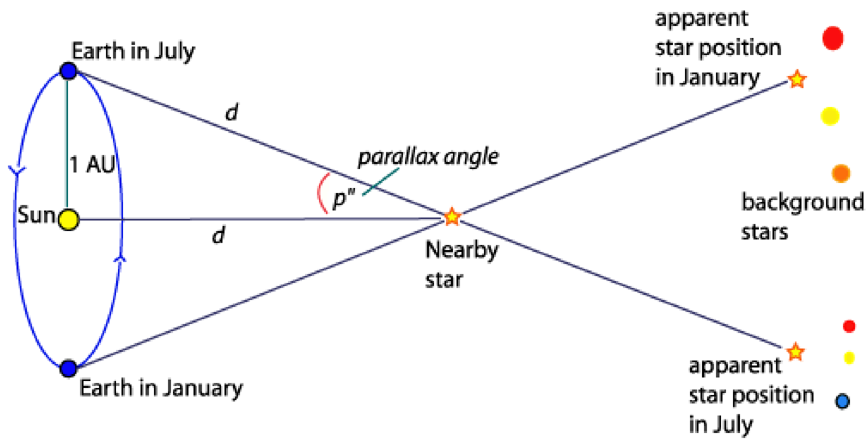
Question 5: Instead of moving their head left to right, astronomers use half an orbit of the Earth around the Sun as the unit for parallax measuring of astronomical distances. This distance is called the baseline and its length is defined as one astronomical unit (1 AU = 149 598 000 kilometers). Parallax is measured in arc seconds: one arc second is one 3600th of your thumb held at arm's length (because 1 degree = 60 arc min/deg × 60 arc sec/arc min). Astronomers measure the distance to distant objects in a unit named parsec: it comes from the words "parallax" and "second of arc". One parsec is defined to be the distance from the Earth to a star that has a parallax of 1 arcsecond.

$$1 \text{ Parsec} = 3.08568025 \times 10^{16} \text{ meters}$$



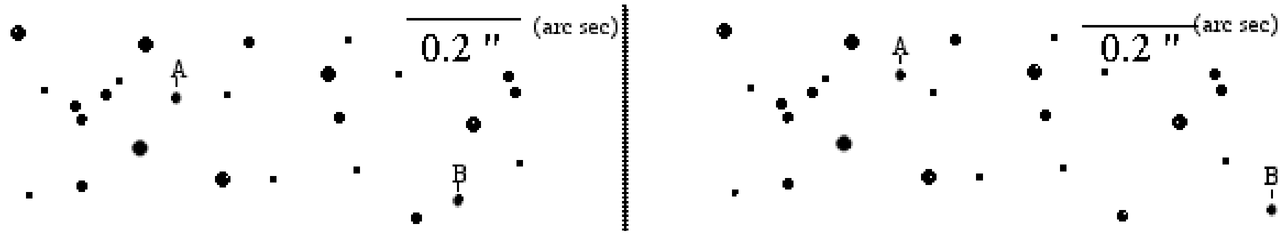
Parallax of nearby star

a) **ASTR 1102.** Based on the relationship you found between distance and parallax (Question 4d) and the information given above, how would you calculate the distance to a star by measuring its parallax angle in arc seconds? You can use whatever unit of distance you wish.

b) Find the equation used by astronomers to relate the parallax of star to its distance to us. Ask for help if you feel lost. You can also use your textbook or internet.

c) Calculate the distances in parsecs to Arcturus (p = 0.090 arc second) and Procyon (p = 0.288 arc second).

d) The following two pictures are of the same star field taken 6 months apart. Calculate the distance to star B (in pc). Hint: you need to use the scale provided.



Part 3: Distance and Luminosity

A light bulb appears to be brighter when you are close to it, and dimmer when you are farther away. The same is true for stars. Your goal is to investigate the relationship between the distance to a star, *d*, and the intrinsic luminosity of the star, *L* (also named "total power", i.e. the quantity of energy produced by the star per second. Unit: Watt, symbol: *W*). What you actually measure from a given distance to the star is the brightness of the star, *B* (Unit: W/m^2). B depends on how far away you are from the star. Another unit for brightness is Lux. To obtain W/m^2 when the measurement is in Lux, divide by 683.

Question 6: Your apparatus will be a light bulb in place of a star and a light sensor in place of a photometer. To save time, your lab instructor will introduce and run a single experiment for the whole class.

a) Complete the following table.

Distance, d (cm)	**Lux**	**Brightness (W/m^2)**
10		
20		
40		
50		
60		
70		

b) Sketch the Lux vs distance graph from the above data. It should look like the one your lab instructor produced.

c) What shape does this graph follow? What is the relationship between brightness and distance?

Question 7: Imagine you fly away from the Sun on board a spaceship equipped with a photometer that measures light intensity.

a) Explain qualitatively how the measurements of the photometer can help you determine your distance to the Sun.

b) If you double your distance to the Sun, the photometer will measure a light intensity:
   i. Four times larger
   ii. Twice larger
   iii. The same
   iv. Twice smaller
   v. Four times smaller

The equation giving the distance to a star knowing its brightness *B* and luminosity *L* is:

$$d = \sqrt{\frac{L}{4\pi B}}$$

c) **ASTR 1102.** You are an astronomer studying a star of luminosity $L = 3.827 \times 10^{26}$ W. Using a ground-based photometer, you measure the brightness of the star to be 2.321×10^{-9} W/m^2. Measured with a photometer attached to a space telescope, you record the brightness $B = 2.517 \times 10^{-9}$ W/m^2. Calculate the distance to the star in kilometers, then in pc. Show your calculations.

d_{ground}

d_{space}

Part 4: Spectroscopic Parallax (note: this method does not use any parallax)

ASTR 3311 students: this section requires some calculations and gives you a taste of what the job of an astronomer is like. Ask for help if you find these calculations overwhelming.

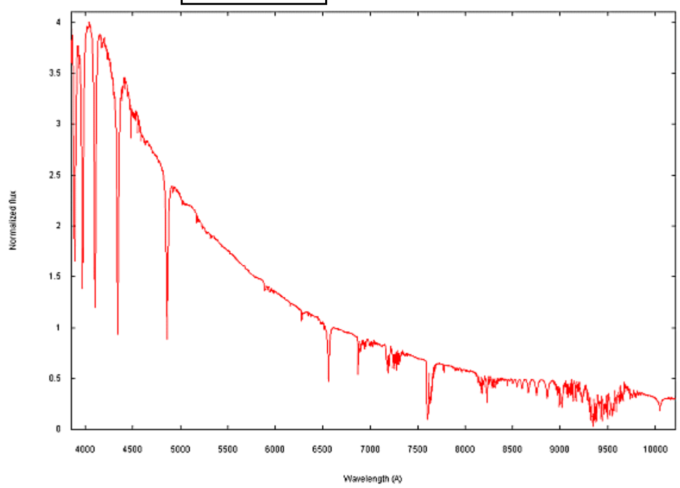
By observing the spectrum of each star, we can determine its spectral type and luminosity class. As we have seen in Part 3, once we know the luminosity of a star, we can calculate its distance. This method ("spectroscopic parallax") is pretty rough (it has an uncertainty of 25%!), but it is the only available method to measure the distance to stars when their parallax is too small to be detected. Your goal is to determine the distances to two stars (Vega and Capella) using spectroscopic parallax, then compare your answers to measurements obtained by another method.

Question 8: The spectra of these two stars are given below and the spectra of some reference stars are given at this link.

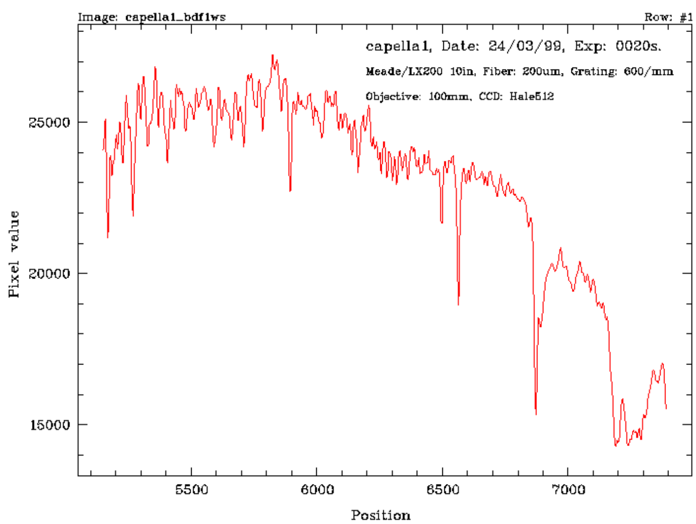
http://langaraphysics.com/Tyron/SpectralCatalog.htm

a) Compare these spectra to those in the catalog and determine the spectral type of each star. When comparing two spectra, focus on the position and strength of the spectral lines.

Vega



Capella



b) Based on your classification in (a), locate each star on the HR diagram (attached as the last page) and estimate its luminosity. Explain.

If you do not want to mess up big numbers and complex unit conversions, we can use a reference star. This method is described in detail in your textbook. If the equations for the brightness of an interesting star and a reference star are given by

$$B = \frac{L}{4\pi d^2} \qquad\qquad B_{ref} = \frac{L_{ref}}{4\pi d_{ref}^2}$$

then the brightness of the star can also be calculated using the following equation. For this exercise our reference star is Sirius (B_{ref} = 1.167×10^{-7} W/m^2, L_{ref} = 25.4 L_{Sun}, d_{ref} = 2.64 pc), the brightest star in the night sky:

$$B = B_{ref}\frac{L}{L_{ref}}\left(\frac{d_{ref}}{d}\right)^2 = \left(1.167\times10^{-7}\right)\frac{L}{25.4}\left(\frac{2.64}{d}\right)^2 = \left(3.20\times10^{-8}\right)\frac{L\ (\text{in } \mathrm{L_{Sun}})}{\left(d\ (\text{in pc})\right)^2}$$

Then the distance to the star we are interested in is then given by:

$$d\ (\text{in pc}) = \sqrt{\left(3.20\times10^{-8}\right)\frac{L\ (\text{in } \mathrm{L_{Sun}})}{B\left(\mathrm{W/m^2}\right)}}$$

c) Calculate the distances to Vega (B = 2.7×10^{-8} W/m^2) and Capella (B = 1.5×10^{-8} W/m^2).

d) We can also calculate the distances to Vega and Capella through parallax observations. The parallax of Vega is p = 0.129 arc second and the parallax of Capella is p = 0.0773 arc second. Calculate the distance to the two stars using the relation between d and p as you did in Part 2.

e) Compare the distances you obtained for each star from part (c) and (d). Hint: To compare two values of a given variable, you can calculate the percentage discrepancy between two values, i.e. the difference between the two values expressed in percent. For example, if you measure 0.133 and you want to compare this number to a reference value of 0.129, the discrepancy is: (0.133-0.129)/0.129=0.03 or 3%.

f) Comment on the accuracy of spectroscopic parallax.

Conclusions / Discussions: Write a summary of what your learned today. This summary should be detailed enough so that you can use it to review the material of this lab for a test.

Instructor's initial:____________________

HR Diagram (for Question 8, P.8)