Photoelectric Photometry of the Pleiades

Student Manual

A Manual to Accompany Software for
the Introductory Astronomy Lab Exercise
Document SM 2: Version 1

Department of Physics
Gettysburg College
Gettysburg, PA 17325

Telephone: (717) 337-6028
email: clea@gettysburg.edu

Contemporary Laboratory
Experiences in Astronomy

Contents

Goals

You should be able to use photometry to determine the relative apparent and absolute magnitude of stars in a cluster in order to calculate the distance to the cluster.

Objectives:

If you learn to ....

Use a simulated photometer to measure the apparent UBV magnitudes of stars.

Make and compare H-R diagrams to find the relationship between absolute and apparent magnitudes.

You should be able to ......

Determine the distance to a star cluster.

Equipment

Scientific pocket calculator, graph paper, ruler, plastic transparency, black marker pen, MSDOS Computer with Windows 3.1 (VGA graphics), and CLEA Program *Photoelectric Photometry of the Pleiades.*

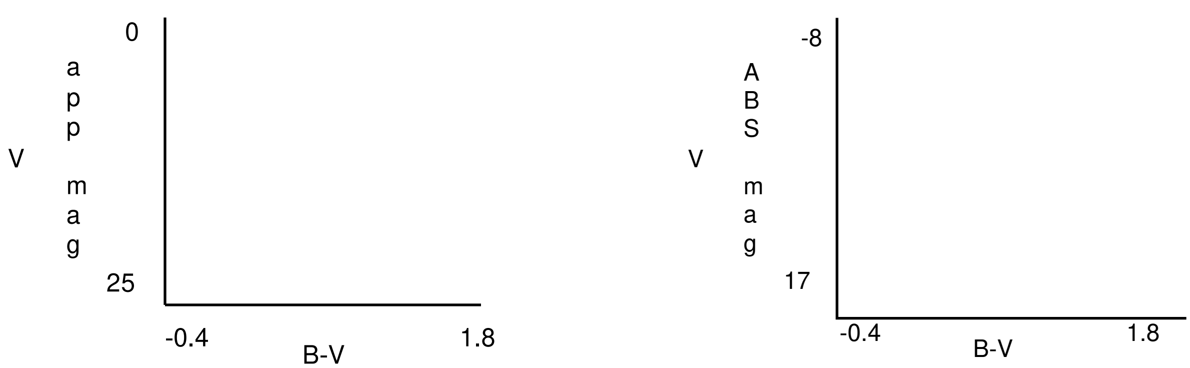
Share the use of the computer and program with your partner to collect data. All calculations and graphing, as well as your narratives, must be your own original work.

Introduction

The computer program you will use is a realistic simulation of a UBV photometer attached to a moderate sized research telescope. The telescope is controlled by a computer that allows you to move from star to star and make measurements. Different filters can be selected for each observation, and the integration time (the length of time the photometer samples the starlight) is adjustable. The computer also does much of the busy work needed to convert photon counts into apparent magnitude and provides an estimate of the quality of the collected data.

You will use this instrument to collect data on 24 stars in the region of the Pleiades star cluster. The apparent magnitudes will be measured for each star, in each of three colors. *We will assume all of these stars are approximately the same distance away*. This is a necessary assumption, and reasonable because all of the stars are members of the same cluster. If we did not make this general assumption, the apparent magnitudes of the stars would also depend on their individual distances, effect we cannot easily take into account in this lab.

From this information you will plot a Hertzsprung-Russell (H-R) diagram which will display the apparent magnitude of the cluster of stars as a function of their color index. The color index, B-V, is the apparent blue magnitude (B) minus the apparent visual magnitude (V). For your H-R diagram, plot the calculated B-V data on the horizontal x axis, and apparent magnitude on the vertical y axis using the chart paper. Recall that the dimmer a star is, the greater the apparent magnitude number. Bright stars have a small apparent magnitude number; in fact, very bright stars actually have negative apparent magnitudes. Plot your y axis in such a way that zero magnitude is at the top, and 25th magnitude (a very dim star indeed) is at the bottom. The x axis should range from -0.4 on the left to 1.8 at the right:



a. Paper Graph

b. Plastic Overlay

Figure 1
The H-R Diagram

Lay out your graph like the above example in Figure 1 (a). Expand this miniature example so it occupies most of a sheet of paper. Be sure your graph's y axis runs from 0 at the top to 25 at the bottom as shown above. Creating too small a graph will make it difficult to plot data accurately.

You will then create a second graph like the first on a clear plastic sheet. On this second graph you will plot a group of main sequence stars with known absolute magnitudes. By overlaying and aligning these main sequence stars on top of your apparent magnitude H-R diagram, you will be able to relate the apparent magnitude (**m**) of a cluster star to an absolute magnitude (**M**) from the main sequence plot.

Knowing the apparent and absolute magnitude of a star, you can determine its distance (in parsecs) from the equation:

$$\mathbf{d = 10 \times 10^{(m-M)/5}} \qquad \mathbf{(1)}$$

where m = the apparent magnitude
M = the absolute magnitude
d = the distance in parsecs

Operating the Computer Program

First , some definitions:

PRESS Push the left mouse button down (unless another button is specified).

RELEASE Let the mouse button up.

CLICK Quickly press and release the mouse button.

DOUBLE CLICK Quickly press and release the mouse button twice.

CLICK AND DRAG Press and hold the mouse button. Select a new location using the mouse, then release.

First, boot up your computer and start Windows (see your lab instructor if you do not know how to do this). Then, place the diskette titled Photoelectric Photometry into the disk drive slot. *NOTE: The software may already be installed on your computer's hard drive. If so, you will be given information in class as to how to access it.* Run the File Manager and select the disk or directory where the **CLEA_PHO.EXE** file is located. Position the mouse cursor over CLEA_PHO.EXE, and double click the mouse button to run the program.

You will use this program in the following order:

Log in and enter student information.

Access and display the Help screens.

Familiarize yourself with the controls.

Open the observatory.

Take "sky" counts.

Take "star" readings, recording your results.

If the program is running properly the CLEA logo screen should appear in a short time. Position the cursor over the LOG IN... on the menu bar and click the mouse button ONCE to continue to the Student Accounting screen.

Entering Student Accounting Information

Enter your name (first and last), and those of your lab partners. Do not use punctuation marks. Press **TAB** after each name is entered, or **CLICK** in each student block to enter the next name. Enter the Laboratory Table Number you are seated at for this experiment. You can change and edit your entries by clicking in the appropriate field and making your changes. When all the information has been entered to your satisfaction, click **OK** to continue, and click **YES** when you are asked if you are finished logging in. The opening screen of the photometry lab will appear.

Accessing the HELP Files

Click **HELP** on the menu bar, and then click on **GETTING STARTED**. A text window will appear on top of the opening screen. Position the cursor over the lower right hand border of the text window. When the cursor is properly positioned, the cursor changes from a pointer to a diagonal double arrow. Click and drag the corner of the window until you can view the entire width of the text area. Then, click on the word **GETTING STARTED** at the top of the text window and drag the window off to one side so you can see the opening screen again. Use the scroll bar on the right side of the text window to read all information in the help window. You can interactively move back and forth between the text window and the photometry program by clicking anywhere in the desired window.

When you have finished with the GETTING STARTED help screen, close it by double clicking on the gray button in the upper left hand corner of the window.

In the same fashion, select HELP from the menu bar again open and read the **TAKING DATA** help screen in its entirety.

Open the Observatory

Click the **START** option on the menu bar on the opening screen. The center of the screen is the view of the night sky. Controls and readouts are to the left and right of the view. Take a moment to study the various controls available to you using the following explanation:

Telescope and Controls and Readouts (left hand side of photometer)

DOME	Opens and closes the observatory dome. Open the dome to activate the controls
TRACKING	Turns on/turns off the telescope drive. Turning tracking **ON** causes the telescope to counteract the effect of the Earth's rotation and is necessary in order to take measurements. Turning tracking OFF allows the star field to drift through the field of view as the Earth turns.
SLEW RATE	Controls the rate of telescope movement when the **N, E, S, W** direction controls are pressed. The slew rate can be set to **1, 2, 4, 8, or 16**. The larger the number, the faster the movement rate. Slow speeds are useful for centering a star image. Faster rates are useful for quickly moving from star to star.
N, S, E, W	Directional controls. Click one of these buttons to cause the telescope to move north, south, east, or west. When the telescope is moving, a red light next to the direction button glows. Movement in the selected direction continues until the same button is clicked again, or a different direction button is similarly selected.
RIGHT ASCENSION	Displays the celestial coordinates of the center of the field of view. Right Ascension is displayed in hours, minutes and seconds.
DECLINATION	Declination is displayed in degrees, minutes and seconds.

MONITOR Click to select the **FINDER** mode or the **INSTRUMENT** mode. Select **FINDER** to see a wide angle view of the stars. The red square identifies the field of view when in the **PHOTOMETER** mode. The **PHOTOMETER** mode shows a close-up of the star field. It is necessary to select the **PHOTOMETER** mode to use the photometer. The numbers directly beneath the **MONITOR** button display the field of view of the screen, that is , how much of the sky is being viewed.

SET COORDINATES When the dome is open, you can click on this button and enter a desired Right Ascension and Declination to move to. After you have entered the coordinates, clicking on **OK** moves the telescope to the new location in the sky.

Photometer Controls and Readouts (right hand side of the photometer)

FILTER Clicking this button cycles the color filters through **U** (ultraviolet) , **B** (blue) and **V** (visible).

SECONDS Selects the duration of any given integration, or how long light is collected for each reading. The time can be set from 0.1 to 10 seconds. The dimmer a star, the longer the integration time will have to be in order to get an accurate measure of the light.

INTEGRATIONS Adjusts the number of times a measurement is repeated. Multiple readings are averaged.

TAKE READING When the dome is open and the **MONITOR** is set to the **PHOTOMETER** mode, clicking this button begins a set of measurements, (how many is determined by the setting of **INTEGRATIONS**), of a particular time each (how long for each measurement is determined by the setting **SECONDS**), through the filter selected by the **FILTER** button.

NOTE: Before you can start taking readings of stars you must first take initial "sky" readings through all three colored filters. If you forget to take a sky reading, an error message is displayed and a real reading is not taken.

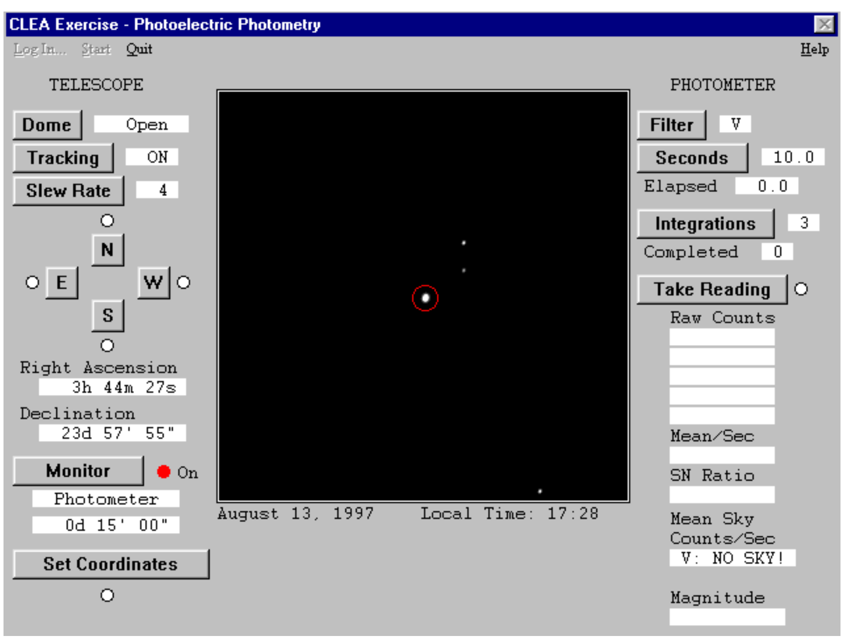


FIgure 2
The photometer

Some additional information is displayed once a reading of the sky or a star is taken:

OBS UT	The UTC, or Universal Coordinated Time, at the prime meridian at Greenwich, England.
JD	The Julian Date of the OBS UT. The Julian Date is a continuous count of the number of days and fractions of a day since the year -4712. The new Julian Day starts at noon UTC.
ELAPSED	The number of SECONDS that have elapsed since any particular reading began.
COMPLETED	The number of INTEGRATIONS done so far in the sequence of readings being taken.
RAW COUNTS	The photometer simulates a photon-counting photometer. The count of the number of photons captured during the individual reading.
SN RATIO	We assume that the only error in the counting if the photons is their randomness defined by quantum mechanics. The square root of the sum of the RAW COUNTS is the fractional error in the reading. A SN RATIO of 100 is needed for a fractional error of 1% (which is 0.01 magnitude). The higher the SN RATIO the lower the fractional error. The SN RATIO, if not high enough, can be raised by increasing the SECONDS or the number of INTEGRATIONS.
MEAN SKY COUNT/SEC	The number of MEAN counts contributed by the sky through a particular filter (determined when the sky reading is taken) divided by the SECONDS, giving a normalized photon rate in counts per second.
MAGNITUDE	The apparent magnitude of the star, through a particular color filter, based on the MEAN of the counts adjusted by the appropriate MEAN SKY COUNTS/SEC.

Move to a Star

Once the observatory is opened, the directional controls can be clicked to move the telescope around in the sky. The red square in the center of view is the field of view seen by the photometer when you engage the **PHOTOMETER** mode (by clicking on **MONITOR**). When you are in the **PHOTOMETER** mode, the small red circle in the center of the field of view is called the photoelectric aperture and is the portion of the sky being examined by the photometer. The desired star must be carefully centered within the aperture. Otherwise, some of the light from the star spills out of the aperture and is missed during measurement.

The rotation of the earth will cause the stars to drift through the view. Observe this phenomenon by carefully watching the stars with **TRACKING** turned off. Does the Earth rotate to the east or to the west?

Earth rotates to the ______________

Do the stars seem to drift east or west?

The stars drift ________________

Telescopes are equipped with a motor drive which moves the telescope in a direction opposite to the drift and at the same rate. The motor (often called the clock drive) cancels the effect of the earth's rotation and the star seems to stand still permitting extended study. Click on **TRACKING** and note how the stars cease to drift. You must have the telescope tracking before you can operate the photometer.

The directional controls, **N, E, S, W**, move the telescope with respect to the sky. Moving the *telescope* to the west appears to make the *stars* move to the east. Try it. The **SLEW RATE** control adjusts in steps and changes how much the telescope is moved when the directional controls have been activated. Try various settings of the **SLEW RATE** and move the telescope around in all directions.

Set up and Take SKY Readings

Since the aperture is much larger than the star under study, and the sky is not perfectly dark, the sky within the aperture contributes a certain number of photons. These unwanted photons are counted by taking a sky reading. The star to be measured is then centered in the aperture and a star reading is taken. It is important that both the sky and the star reading be taken through the same color filter. Then the true photon count for the star by itself is approximated by the star reading minus the sky reading.

Make sure the **TRACKING** is on, and click on the **MONITOR** button to turn on the **PHOTOMETER** mode. Move the telescope until the aperture (red circle) is free of any star. Select a **FILTER**. Set SECONDS to 10 seconds, and **INTEGRATIONS** to 5. Then click on **TAKE READINGS** and wait for the reading. Repeat the procedure for each color filter and record the results below

Sky Readings

Filter	**Mean Sky (Counts/sec)**
U	___________________
B	___________________
V	___________________

Table 1

Take a Reading and Record the Results

The right ascension and declination of the aperture center are displayed in the upper right of the screen. Select a filter (U, B, or V - they cycle when clicked). Select an integration time. Use short integration times for bright stars to save time, and long integrations for faint stars. Integration times are in seconds. Bright stars generate many photons, and cause high counts.

Carefully center a star in the aperture and take a reading. The computer will take a series of integrations depending upon the setting of INTEGRATIONS, and display the individual and average photon counts in the raw count box on the right.

After the integrations are completed, the computer considers the appropriate sky reading for the filter you used and the apparent magnitude of the star is displayed in the lower right corner of the photometer.

Also displayed is the signal-to-noise ratio or **SN RATIO** of the reading. A high SN RATIO means you have a lot of desired photons, and only a little noise. You should strive for SN RATIOs of 100 or more. You can increase the SN RATIO by *increasing* the integration time because the SN RATIO is directly proportional to the square root of the total collected raw counts.

For each star on the **Photoelectric Photometry Data Sheet** (located at the end of this manual), use the right ascension and declination to locate the star. Carefully center the star in the aperture and measure the B and V apparent magnitudes. Collect data thorugh the U Filter, too, if directed by your instructor. Record all magnitudes to the nearest 0.001 magnitude on the data sheet. Turn off the tracking and close the observatory when you are done.

Calculate the color index B-V for each star to the nearest 0.01 magnitude and record it on the worksheet. Hot blue stars have low, and even negative B-V. Cooler red stars have B-V values somewhat over 1.

Create an H-R diagram of your data, as explained in the Introduction section. Use regular graph paper. Complete the following:

1. Identify the main sequence. Sketch a line through it, and label it clearly.

2. Identify, by RA and Dec, three possible red giant stars.

Star Number	RA	DEC
____________	__________________	__________________
____________	__________________	__________________
____________	__________________	__________________

Table 2

3. Consider the star near RA $3^{h}\ 44^{m}$ and Dec 24^{d} 35". It seems curiously out of place with respect to the main sequence. What type of star might this be? Upon what did you base your decision?

Distance to the Cluster

Place the clear plastic over your graph, and using the ruler trace both x and y axes. Label and scale the x axis the same as the graph paper, but number the scale of the y axis of the plastic overlay to range from -8 (at the top) to +17 (at the bottom). Label this new y axis V **ABSOLUTE MAGNITUDE** (See figure 1 (b)). Leave the plastic laying on the graph paper so you can use the grid lines.

Now plot these calibration stars on the plastic overlay. They are main sequence stars for which absolute visual magnitudes have been determined (adapted from Allen, Astrophysical Quantities). The table of these values is located.on the following page.

(V) Absolute Magnitude	B-V	Spectral Type
-5.8	-0.35	O5
-4.1	-0.31	BO
-1.1	-0.16	B5
-0.7	00.0	AO
2.0	0.13	A5
2.6	0.27	F0
3.4	0.42	F5
4.4	0.58	GO
5.1	0.70	G5
5.9	0.89	KO
7.3	1.18	K5
9.0	1.45	MO
11.8	1.63	M5
16.0	1.80	M8

Table 3
Absolute Magnitude of Main Sequence Stars

Slide the plastic overlay up and down until the main sequence on the overlay best aligns with the main sequence on your paper graph. Keep the y axes precisely parallel and over top one another. Seek a best fit for the central portion of the combined patterns. The cool red stars in the lower right of your *paper* graph are quite scattered and may not fit very well.

Consider what you are doing: You have graphs of two groups of main sequence stars. One graph is in terms of visual apparent magnitude (**m**) and the other one in visual absolute magnitude (**M**). When the patterns are matched, it is clear that each star of the combined main sequence can be described either in terms of **m** (by reading the y-axis on the graph paper) or **M** (by reading the y-axis on the plastic overlay). It just depends on which scale you read.

Notice that once the two main sequences are aligned, a fixed relationship is established between the apparent and absolute magnitude scales, no matter where you read the y axis or which star you pick. So, pick *any* convenient magnitude on the absolute magnitude scale and read its corresponding apparent magnitude on the paper scale. Read each scale to the nearest 10th of a magnitude.

V Apparent Magnitude	(big M: read from plastic overlay)
Corresponding V Apparent Magnitude	(small m: read from graph paper)

Use the equation (1) in the Introduction to calculate the distance to the cluster in parsecs. Then convert your answer to light years. Show all work in the space provided.

Distance to cluster: ____________________________ parsecs

Distance to cluster: _____________________________ light years

In 1958, H.L. Johnson and R.I. Mitchell calculated the distance to this cluster to be about 410 light-years. As a percentage, how does your calculated value compare? SHOW YOUR WORK.

Extra Credit

Using only your graphs and results, calculate the apparent magnitude of the Sun if it were located in the Pleiades cluster. Explain your procedure in a narrative, and show all your math.

> **HINT**: You'll need the absolute magnitude of the Sun. The Sun is a type G2 star with a B-V of about +0.62. Now, you can use the clear plastic graph to estimate its absolute magnitude.

Photoelectric Photometry Data Sheet

Star	RA hr min sec	Dec deg min sec	U	B	V	B-V
1	3 41 05	24 05 11				
2	3 42 15	24 19 57				
3	3 42 33	24 18 55				
4	3 42 41	24 28 22				
5	3 43 08	24 42 47				
6	3 43 08	25 00 46				
7	3 43 39	23 28 58				
8	3 43 42	23 20 34				
9	3 43 56	23 25 46				
10	3 44 03	24 25 54				
11	3 44 11	24 07 23				
12	3 44 19	24 14 16				
13	3 44 27	23 57 57				
14	3 44 39	23 27 17				
15	3 44 39	24 34 47				
16	3 44 45	23 24 52				
17	3 45 09	24 50 59				
18	3 45 27	23 17 57				
19	3 45 28	23 53 41				
20	3 45 33	24 12 59				
21	3 46 26	23 41 11				
22	3 46 26	23 49 58				
23	3 46 57	24 04 51				
24	3 47 29	24 20 34				