

# VISUAL PHOTOMETRY

## *The magnitude system*

*Purpose:* This lab is designed to familiarize you with the magnitude system of star brightness and to help you learn how to make simple measurements by direct comparison/calibration. When performing this lab for the 2<sup>nd</sup> time, using a telescope, we will also learn about a current problem astronomers are investigating.

### **Introduction**

The magnitude system was developed in the second century BC, by the Greek astronomer Hipparchus. Hipparchus classified all of the visible stars into 6 groups. The first group contained the brightest stars and the 6<sup>th</sup> group contained the faintest. Eventually, stars in the first group became known as “magnitude 1” stars, and in the 6<sup>th</sup> group as “magnitude 6” stars. Thus, the larger the number of the magnitude, the fainter the star is. The human eye can detect stars brighter than about 6<sup>th</sup> magnitude when in a very dark site (far from city lights). Unfortunately, around El Camino, the eye can barely see 4<sup>th</sup> magnitude stars due to all of the light pollution from the surrounding LA city lights. However, with the additional light collecting power of a telescope, we can see much fainter than 4<sup>th</sup> or 6<sup>th</sup> magnitudes.

This magnitude system, despite its antiquity and obvious problems, has persisted and been adapted to become more numerically rigorous. The standard star used when calibrating the magnitude system was declared to be a fairly bright summer star – Vega. Vega was defined to be a zero (i.e. 0.0) magnitude star at most visible wavelengths. Thus all star brightnesses are now referenced to Vega. Since few stars are brighter than Vega, few stars have a negative magnitude. Recall that since in the original Hipparchus scheme, larger numbers (e.g. 6) represented fainter stars. This is why most visible stars have a numerical magnitude much larger than zero.

Since the eye detectors (rods & cones) respond logarithmically to light, the magnitude system was set up as a logarithmic scale. (Logarithms are the inverse of exponents – they are to exponents what subtraction is to addition.) The scale was calibrated to match the eye and Hipparchus’s original classification scheme. The unaided eye can detect star brightnesses from about 1<sup>st</sup> magnitude (or brighter) to 6<sup>th</sup> magnitude. Numerically, the brightness ratio of 1<sup>st</sup> and 6<sup>th</sup> magnitude stars is about 100, so when the system was numerically calibrated, it was defined such that a difference of 5 magnitudes corresponds to a factor of 100 in brightness. What this means is that each additional “magnitude” corresponds to a brightness decrease of a factor of  $100^{1/5} = 2.511$ . This means that a 1.0 magnitude star is 2.511 times fainter than Vega, which is a 0.0 magnitude star. Another way of stating this is that a magnitude 1.0 star is about 40% as bright as Vega. Similarly, a magnitude 5.0 star is 100 times fainter than Vega (magnitude 0.0) and a 10.0 star is  $100 \times 100 = 10,000$  times fainter than Vega. (Each factor of 100 comes from 5 of the 10 magnitudes.) In general a star that is M magnitudes dimmer than another is actually  $2.511^M$  times fainter.

One last note: the magnitude system usually refers to the brightness of an object as visible from Earth. When this is the case, the magnitude is usually called the “apparent magnitude” because that is how the star appears from Earth. The magnitude system is also used to talk about how luminous an object really is. In this case, the magnitude is called the “absolute magnitude” and is computed by determining the apparent magnitude of that object if it were located at a distance of 10 parsecs (about 33 light years) from Earth instead of its actual distance. A question to ponder: if a star has an absolute magnitude of 5, what would its apparent magnitude be if it were 1 parsec away? (The nearest star to the Sun is a little bit further than 1 parsec.)

## Visual Photometry

### **Task: (adapted from The Trained Eye, by Leon Palmer)**

In this project, you will estimate the visual apparent magnitudes of stars as seen through a telescope. Professional astronomers use a variation of the technique described below to measure star brightnesses (which you can research for **extra credit**).

The procedure for determining visual magnitudes through the telescope is called “visual comparative photometry.” (Photo- = light, meter = measure.) To compute magnitudes, you will visually compare your unknown stars to standard stars of known brightness (magnitude). (Standard star brightnesses are determined by professional astronomers.) The standard stars that are closest in brightness to the unknown star will determine an upper and lower limits for the unknown’s visual magnitude. In other words, if the unknown is fainter than standard 1, but is brighter than standard 2, the visual magnitude should lie between the magnitude of standards 1 and 2.

Attached are two finding charts for the brighter stars in the open star clusters named the Pleiades (a.k.a. M45), M39, or M44 for the outdoor lab, and M67 for the indoor lab. M39 is the 39<sup>th</sup> object found by Charles Messier that was “fuzzy, but not a comet.” M67 is the 67<sup>th</sup> such object. The Pleiades (M45) is in the constellation Taurus, M39 is in Cygnus, M44 is also known as the Beehive cluster or the Praesepe, and like M67, is in Cancer. Their right ascensions and declinations can be found in the star atlas if necessary.

Listed on the finding charts are standard stars and unknown stars for each cluster. The unknown stars, whose magnitudes you will determine, are assigned letters. The standard stars are numbered by their magnitude – a 3-digit number perhaps followed by a lowercase letter if there is more than one star of the same magnitude. For ease of reading, the decimal points in the magnitudes for the standards has been left out; we don’t want the decimal point to be confused with other stars. Three examples, 1) a star labeled 121 means the star has a 12.1 magnitude, 2) a star labeled 100 would have a magnitude of 10.0, and 3) a star labeled 096a would have a magnitude 9.6. In this last example, there should be another star with the same magnitude elsewhere on the map. Each numbered star is labeled to a tenth of a magnitude.

Follow the process described below for the unknowns in the cluster you have been assigned. When you have finished all the unknowns, record your results in a copy of the first table (i.e. copy this chart for yourself). Then take your data and list them from brightest to faintest (small mag to large mag) in a copy of the second table. Ranking your stars this way will help you review your results to see if they are internally consistent. That is, if you say unknown A is brighter than standard 100, but unknown B is fainter than the same standard 100, then your results should show unknown A brighter than unknown B. If not, you have problems.

#### *Example calculation*

Suppose you want to determine the visual magnitude of star U (a fictional unknown star). First find U on your finding chart, then locate it in the eyepiece (or photo, if working on a cloudy night). Next identify a standard that is near U on the sky and find it on your finding chart, for example standard 28. Compare the two. Which is brighter? Keep track of your observations by making written notes (that you will turn in) like the following:

- Unknown U is fainter than standard 28. (You conclude U is fainter than 2.8 magnitudes.)

In your written notes, you may NOT use the “greater than” (>) or “less than” (<) symbols. You must use words or abbreviated words. Keep notes for each unknown star separate from notes for other unknown stars.

Since you know U is fainter than 2.8 magnitudes, now compare it to a standard that is fainter than 2.8 magnitude and record your results, for example:

- Unknown U is brighter than standard of mag 8.6.

### Visual Photometry

You have now narrowed U's magnitude down to somewhere between 2.8 and 8.6 . Continue to narrow the range. For example, compare it to standard 43.

- Unknown U is brighter than standard of mag 4.3.

You have now narrowed U's magnitude down to between 2.8 and 4.3. Now compare to standard 3.9.

- Unknown U is *slightly* brighter than standard mag 3.9.

Now you know U is between 2.8 and 3.9 magnitudes, but probably pretty close to 3.9. This range is still too large – we want to narrow the range to 0.5 magnitudes whenever possible. Now, find another standard slightly brighter than 3.9 and compare U to it.

- Unknown U is *slightly* fainter than standard of mag 3.6.

At this point, you should have narrowed the visual magnitude of U between 3.6 to 3.9. Now re-compare U to both of these stars. Which is it closer to in brightness? We could call it 3.7 if it appears if it is closer to the 3.6 magnitude standard, or 3.8 if it is closer to the 3.9 magnitude standard. Your complete notes for this star should look something like this:

- U ft 2.8 (this is abbreviation for: Unknown U is *fainter than* 2.8)
- U bt 8.6 (*brighter than* 8.6) --- range: 2.8 – 8.6
- U bt 4.3 --- range 2.8 – 4.3
- U sbt 3.9 (*slightly brighter than* 3.9) --- range 2.8 – 3.9
- U sft 3.6 (*slightly fainter than* 3.6) --- range 3.6 – 3.9
- U ct 3.6 (*closer to*)
- My lab partners and I estimate Unknown U has a magnitude of 3.7.

You will be required to submit written notes like this for each unknown star. Also, you may want to read the questions for the lab before beginning.

### Tricks of the Trade

- 1) Don't zero in on your star too fast by visually picking one that, at first glance, seems to match. Be methodical and careful.
- 2) Look for small patterns of stars (triangles, squares, lines that point to stars, etc.) to find your way around the cluster/photo/finder chart.
- 3) **The last two standards that bracket each unknown should differ by less than 0.5 magnitudes** unless you get the instructors permission for a larger bracket range.
- 4) **Never treat an unknown as a standard** — don't use an unknown to determine the magnitude of another unknown.
- 5) Magnitudes for standard stars are shown next to star with decimal point omitted (e.g., 101 = 10.1 magnitude)

**For clear night labs:** when your bracketing stars are close in magnitude, or if your stars are faint, you may want to switch to a high magnification eyepiece. You also may want to try to defocus the image or to compare the stars in the finder. However, beware that the finder's field-of-view is not oriented the same as the eyepiece's field-of-view. Also, the "reversed" written on the star chart means that the map has been reversed to resemble what you see in your telescope. In your telescope, the orientation is reversed compared to what you would see if you had very high-resolution vision.

**For cloudy night labs:** The finding chart shows the stars photographed in red light while the slide is photographed in multiple colors of light and color-combined to show true color. That's why the sizes and colors of the finding chart don't always match the slide. Towards the end of class, a new photograph of the cluster will be projected. This photograph was taken with a filter, so that all stars appear the same color, and the brightnesses can be compared uniformly in that one color. Professional astronomers always use filters when taking pictures.

*Visual Photometry*

Make copies of tables below on your own paper, and submit them. Don't forget to include the cluster!

CLUSTER: \_\_\_\_\_

Ordered by name	
Unknown	visual mag.
A	
B	
C	
D	
E	
F	
G	
H	
I	
J	

Ordered from bright to faint	
Unknown	visual mag.

*Questions*

In addition to the above charts, you should answer the following questions:

- 1) A) Approximately how many magnitudes difference between the brightest unknown and faintest unknown stars? B) How times brighter is the brightest unknown star than the faintest? [Hint: do NOT divide the two magnitudes. Reread the first page.]
- 2) List 2 or more sources of uncertainty (things that give you trouble) in performing visual photometry. **For the clear night lab**, list those that you gave in the cloudy night lab, if applicable here, as well as 2 (or more) **new sources of error** introduced by doing this experiment using a real telescope.
- 3) Answer the appropriate question:
  - a. Clear night question: Based on your results above, would an 8<sup>th</sup> magnitude star be easily visible, barely visible, or invisible through the FINDER telescope? How about a 12<sup>th</sup> magnitude star?
  - b. Cloudy night question: What properties of the star images are you using to estimate the visual magnitudes of stars on the slide?
- 4) **For the cloudy night only**, if you had any kind astronomical equipment that you desired at your disposal, how would you determine the magnitude of an unknown star? In other words, given “fancy equipment” what improvements would you make to the visual photometry technique. (For **extra credit**, describe the method actually used by professional astronomers. The more detailed, the more credit you get.)
- 5) Optional: Summarize your experience with this lab, including any difficulties you had performing it, understanding the instructions, etc.

Your grade will be determined by how accurate your magnitudes are, whether you used a correct method for determining unknown stars, how many stars you finished, and your answers to the questions above. The grading scheme will be more generous for the outdoor (clear night) version than the indoor version.

**The following material applies only to the clear night lab.** However, some questions are purely theoretical – you might want to read them while working on the cloudy night version.

Below is an abridged table of star magnitude ranges and the number of labeled stars in the Pleiades finder chart with magnitudes in that range. For example, on our Pleiades map, there were 3 stars labeled with a magnitude greater than 8.8 and less than or equal to 9.79. Similarly, there were 2 stars with a magnitude between 3.8 and 4.79.

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Astronomers create tables like these using techniques similar to those you have performed. Tables like these can help answer many questions about stars' life cycles and formation processes.

There are 3 properties of a star that can determine how bright the star looks from Earth. (We'll ignore things that partially or totally block starlight, such as dust between us and the star.) One of those properties is distance – further stars look dimmer. However, all stars in a cluster are, by definition, essentially at the same distance. (If they weren't, they wouldn't be in the cluster.) So distance does not cause the magnitude/brightness differences between stars in the Pleiades cluster. Those magnitude differences must be caused by properties of the stars themselves.

Magnitude range	# in that range
0 - 2.79	0
2.8 - 3.79	2
3.8 - 4.79	2
4.8 - 5.79	2
5.8 - 6.79	3
6.8 - 7.79	9
7.8 - 8.79	7
8.8 - 9.79	3

- 6) Name two stars you could see from ECC that are brighter than 0<sup>th</sup> magnitude.
- 7) Which magnitude range in the table above had the greatest number of stars in it?
- 8) Besides distance, what are the other 2 properties of a star that determine its brightness? [Star mass is not a correct answer, though it is usually related to the 2 correct answers. You may want to do research to determine these properties. *Hint*: stars are essentially blackbodies.]
- 9) Based on the data you see in the table above (which is similar to data from most other clusters), which kind of star do clusters tend to make the most of? [multiple choice] a) very bright, b) bright, c) dim, or d) very dim. Justify your choice.
- 10) Assume the data only includes stars whose magnitudes are measured reliably. In other words, if you can't get a good estimate of a star's magnitude, you don't include that star in the table above – for the purposes of this table, you ignore that star. Considering this statement, which range (or ranges) of the 8 listed above do you think is most likely to be wrong? Justify your choice, and explain if the value for # of stars should be higher or lower than the value in the table.
- 11) Based on your answer to question 10, how does that affect your answer to question 9, if at all? Why or why not?
- 12) **Extra credit**: make a photocopy of the finder chart for the Pleiades and name the 7 sisters on the map.

In case you're interested, computing real versions of the table above (i.e. an "initial mass function") is a task several astronomers are doing, even for our own galaxy, the Milky Way. We don't have all of the data above to get the "right" answer to question #9 for our own galaxy, yet. But we do have a pretty good idea and see a trend with the data we can measure. If you're interested, some related topics are "L-class" stars, which were discovered in the late 1990's, as well as the newly measured "initial mass function" of galaxies.

## **Grading scheme for this lab**

Your instructor may modify this grading scheme. In particular, the penalty may be reduced for misestimating the faintest stars' magnitudes.

### **Cloudy night version:**

<u>Penalty</u>	<u>Error</u>
1 pt	Inconsistent method for determining magnitudes (poor technique more than once)
3 pts	Very inconsistent method
0.3 pts	Magnitude off by 0.2-0.3 mags
0.6 pts	Magnitude off by 0.4-0.5 mags
1 pt	Magnitude off by 0.6-0.8 mags
1.3 pts	Magnitude off by 0.9-1.5 mags
1.5 pts	Magnitude off by more than 1.5 mags

### *Questions*

- 1) Part a: ½ pt. Part b 1pt.
- 2) 1 pt, ½ for each method
- 3) 1 pt
- 4) 2 pts. Extra credit varies.
- 5) Optional

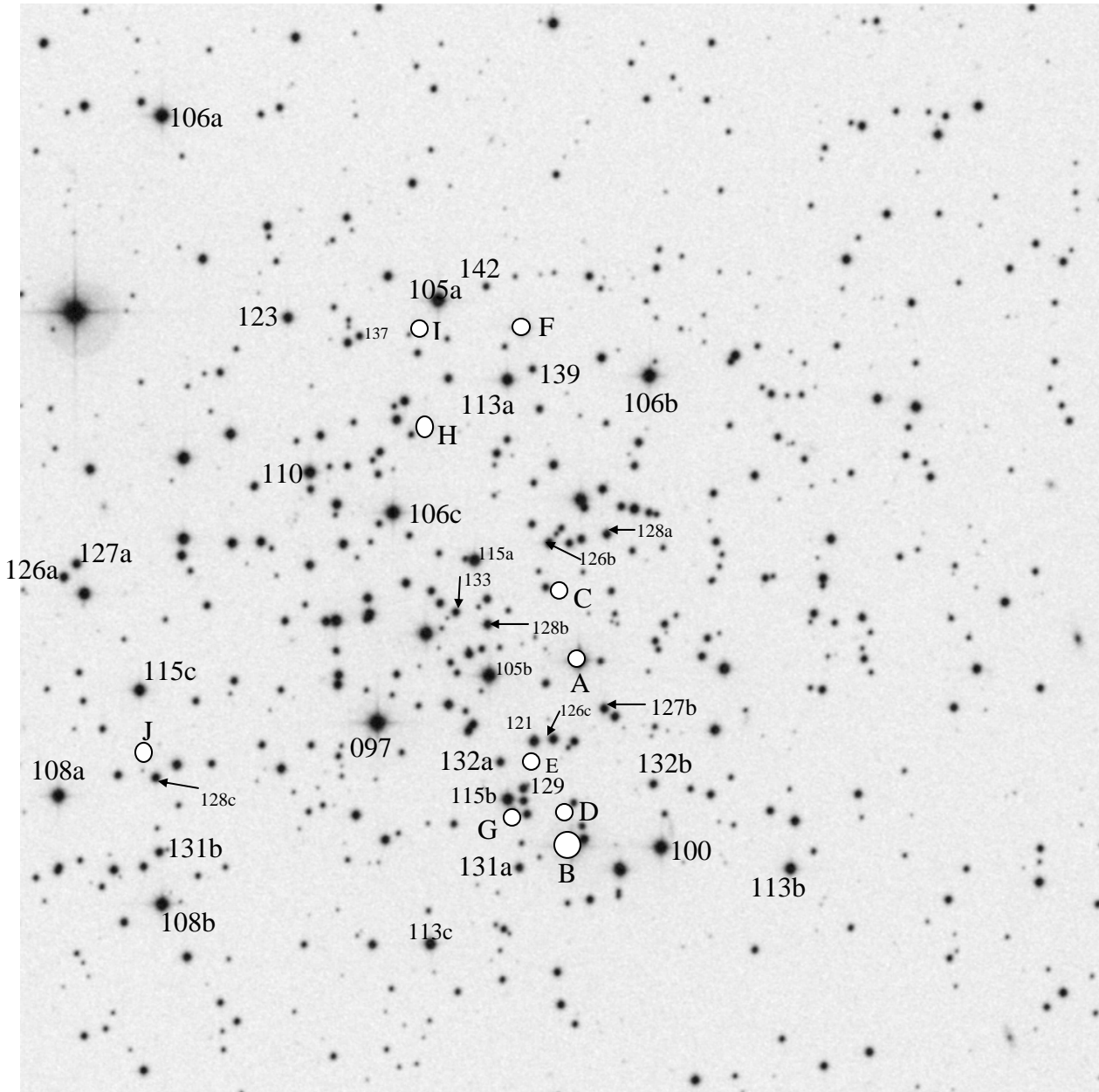
### **Clear night version**

<u>Penalty</u>	<u>Error</u>
1 pt	Inconsistent method for determining magnitudes (poor technique more than once)
3 pts	Very inconsistent method
0.3 pts	Magnitude off by 0.3-0.4 mags
0.6 pts	Magnitude off by 0.5-0.6 mags
1 pt	Magnitude off by 0.6-1.0 mags
1.3 pts	Magnitude off by 1.1-1.5 mags
1.5 pts	Magnitude off by more than 1.5 mags

### *Questions*

- 1) 1 pt total.
- 2) 1.5 pt, ½ for each new method, ½ pt for old methods.
- 3) 1 pt, ½ for each star
- 4) Not applicable
- 5) Optional
- 6) 1 pt, ½ pt each
- 7) ½ pt
- 8) 1 pt, ½ pt each
- 9) 1 pt
- 10) 1 pt
- 11) 1 pt
- 12) Extra credit: 1 pt

Finding chart for M67 [Indoor lab]



*Important Note:* Do NOT use this map to determine your unknowns. Use the projected image. The unknowns have been covered and are not to scale. Also, the two images are taken with different colored filters. This finder chart is taken with a blue filter. Your answers will be graded based on a yellow (V) filter.











Note: There IS NO UNKNOWN "A" STAR IN THIS CLUSTER!

