

Due: Fri, Oct 23, 2020 11:00 AM EDT

Question

1

Instructions

Lab 5: The Cosmic Distance Ladder II: Standard Candles

Watch the following overview videos and read the background sections before beginning:

[Introduction](#)

[Background](#)

[Procedure](#)

IMPORTANT: Submit observations for Lab 6 immediately. These observations take up to a week to complete, and you must have them to do Lab 6. Instructions for submitting these observations can be found in Lab 6, Procedure, Section B, Part 1.

Also, review your answers to the sources of error questions in the previous lab -- and their answer keys. This will help you to improve your sources of error answers in this lab.

Finally, also remember:

You are permitted 100 submissions per question. Use the submission button to save your work -- not the save button!

If you do not submit your work periodically, you risk losing it when WebAssign times you out. WebAssign does this after a few hours for security reasons.

Do not open multiple copies of this assignment, or multiple WebAssign assignments, or you risk losing your answers upon submitting.

Enter all calculated values to at least three significant digits (unless otherwise specified).

If entering a value in scientific notation, format like "-1.138e-3", not "-1.138x10⁻³".

Do not add units when entering numerical responses. WebAssign will not accept your response.

Do not use special characters when naming files. WebAssign will not accept your file.

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LAB 5 — COSMIC DISTANCE LADDER II: STANDARD CANDLES

GOALS

In this lab, you will:

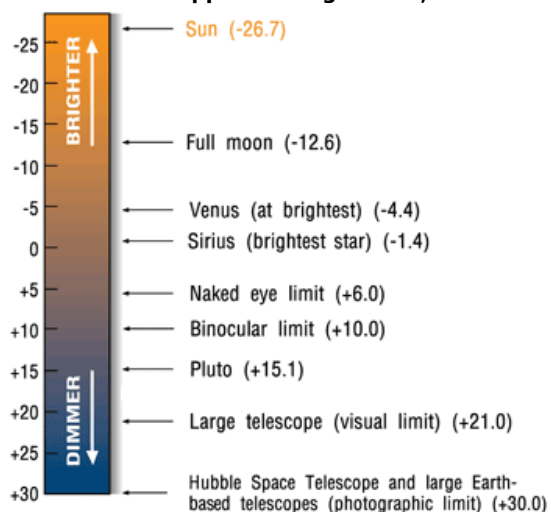
- Use RR Lyrae variable stars to measure distances to objects within the Milky Way galaxy.
- Use Cepheid variable stars to measure distances to nearby galaxies.
- Use Type Ia supernovae to measure distances to faraway galaxies.

EQUIPMENT

Computer with Internet connection

BACKGROUND: A. MAGNITUDES

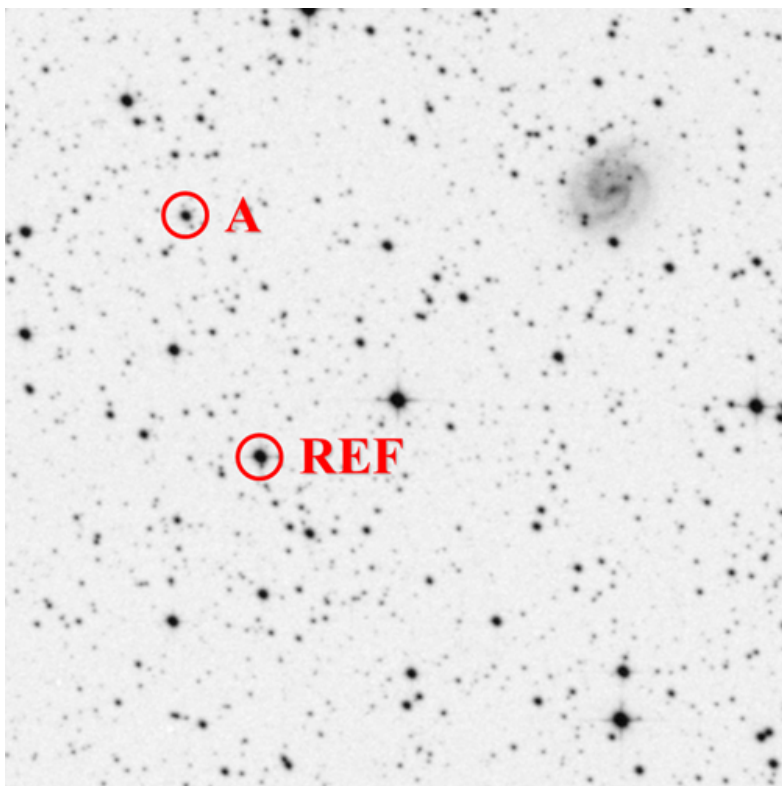
Astronomers use **apparent magnitudes**, which are often referred to simply as magnitudes, to measure brightness.



The more negative the magnitude, the brighter the object. The more positive the magnitude, the fainter the object.

In this [tutorial](#), you will learn how to measure, or **photometer**, uncalibrated apparent magnitudes.

In [Afterglow](#), go to "Data Providers", "Sample", "Astro 101 Lab", "Lab 5—Standard Candles", "CD-47" and import the image "CD-47 8676".



Question: Using the above finder chart, measure the uncalibrated apparent magnitude of star A to two decimal places. (2 points)

mag

Uncalibrated apparent magnitudes are always off by a constant and this constant varies from image to image, depending on observing conditions among other things. To calibrate an apparent magnitude, one must first determine the value of this constant, which we do by photometering a **reference star**—a star of **known** apparent magnitude — in the image.

Question: Using the finder chart, measure the uncalibrated apparent magnitude of the marked reference star to two decimal places. (2 points)

mag

Question: The known, true apparent magnitude of this reference star is 12.02. Calculate the correction constant to two decimal places. (2 points)

correction constant = true magnitude of reference star – uncalibrated magnitude of reference star

mag

Question: Finally, calibrate the apparent magnitude of star A to two decimal places by adding the correction constant to it. (2 points)

calibrated magnitude = uncalibrated magnitude + correction constant

mag

The true apparent magnitude of star A is 13.75. Your calibrated apparent magnitude should be within a few hundredths of a magnitude of this value. If it is not, check that you selected the correct stars and check your math, until you arrive at the correct answer.

BACKGROUND: B. STANDARD CANDLES

In Lab 4, we learned that distance is one of the most difficult things to measure in astronomy. In Lab 4, we learned a technique for measuring the distances to nearby stars, called parallax. However, if a star is more distant than about 10 kiloparsecs (about 33,000 light years), its parallax angle is too small to be measured with current technology. Consequently, its distance cannot be determined in this way.

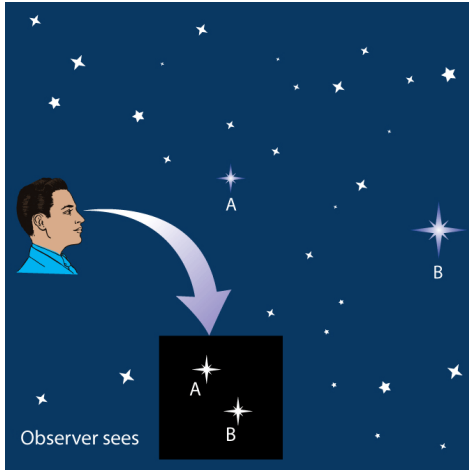
However, **if** the luminosity, L , of the star is known, its distance, D , can be calculated by measuring its brightness, B :

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

Solving for distance yields:

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

Imagine that you see a light off in the distance. You cannot tell how far away it is but you can measure how bright it is. Perhaps it is a low wattage light bulb not very far away. Or perhaps it is a high wattage light bulb very far away. Or perhaps it is something in between. You can measure its brightness **but unless you know its wattage — which is the same thing as its luminosity** — you cannot use the above equation to calculate its distance.



An object of known luminosity is called a **standard candle**. Most stars are not standard candles — their luminosities are not known and consequently their distances cannot be easily calculated. However, some special types of variable and exploding stars do have known, standard luminosities. Consequently, **if you can identify a star as being one of these special types, you know its luminosity**. Then you only have to measure its brightness to be able to compute its distance.

Instead of brightness and luminosity, astronomers use **apparent magnitude, m** , for brightness and **absolute magnitude, M** , for luminosity. The above equation giving D as a function of B and L can be rewritten as an equation giving D as a function of m and M :

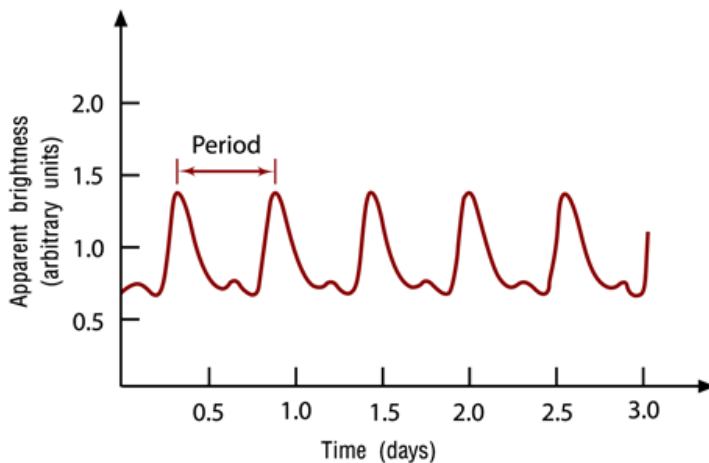
$$D = 0.01 \text{ kpc} \times 1.585^{(m - M)}$$

In this lab, you will measure the distances to three standard candles: two types of variable stars and one type of exploding star, or supernova. For each one, you will (1) confirm that it is a standard candle, (2) use this knowledge to determine its absolute magnitude (think luminosity), (3) measure its apparent magnitude (think brightness), and (4) use the above equation to calculate its distance.

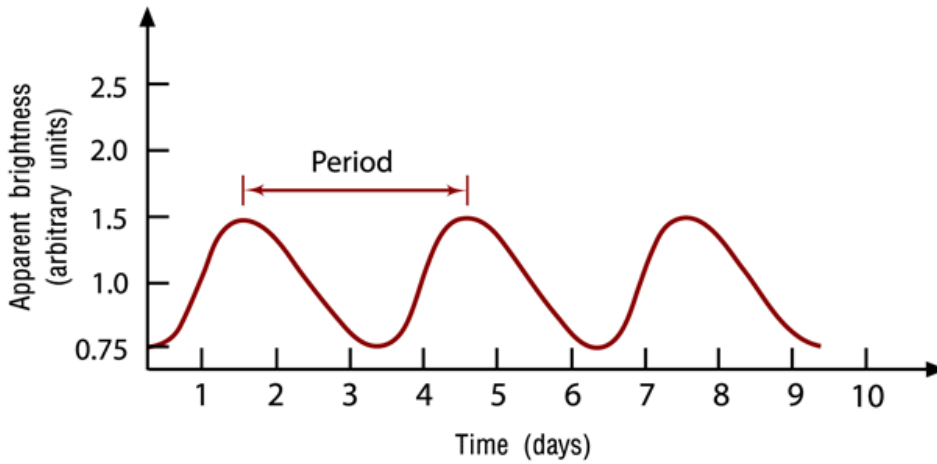
BACKGROUND: C. RR LYRAE AND CEPHEID VARIABLE STARS

RR Lyrae and Cepheid stars are two types of variable stars. Their outer layers expand and contract over and over. They grow brighter as they expand and fainter as they contract.

Some RR Lyrae stars vary with periods as short as seven hours and some vary with periods as long as one day.



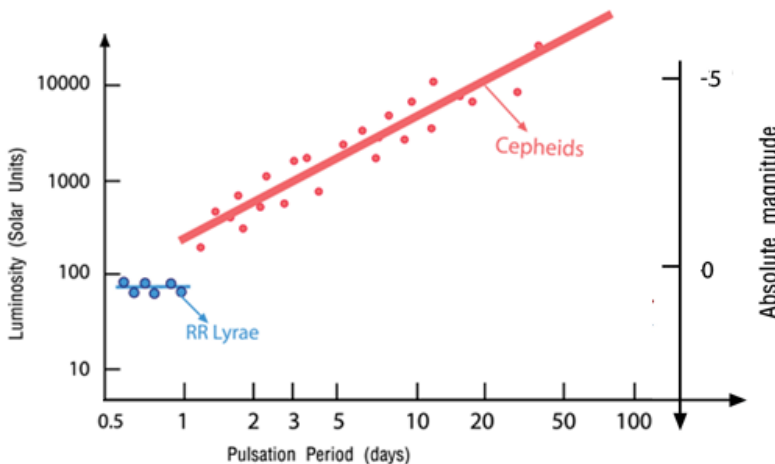
Cepheid stars vary with longer periods, ranging between a few days and a few months.



Distances have been measured to **nearby** RR Lyrae stars in our galaxy using parallax techniques (see Lab 4). These distances, in combination with measurements of the stars' average apparent magnitudes (think average brightnesses), made possible the calculation of their average absolute magnitudes (think average luminosities). **It turned out that all RR Lyrae stars have approximately (although not exactly) the same average absolute magnitude: $M \approx 0.75$.**

Consequently, **if** a variable star's period reveals it to be an RR Lyrae star, its $M \approx 0.75$. This information can be used to calculate distances to **faraway** RR Lyrae stars, such as those in the globular star clusters that orbit our galaxy.

Distances have also been measured to **nearby** Cepheid stars in our galaxy using parallax techniques (see Lab 4). These distances, in combination with measurements of the stars' average apparent magnitudes (think average brightnesses), made possible the calculation of their average absolute magnitudes (think average luminosities). **It turned out that all Cepheid stars have average absolute magnitudes that are approximately (although not exactly) related to their periods in the following way.**



Written as an equation:

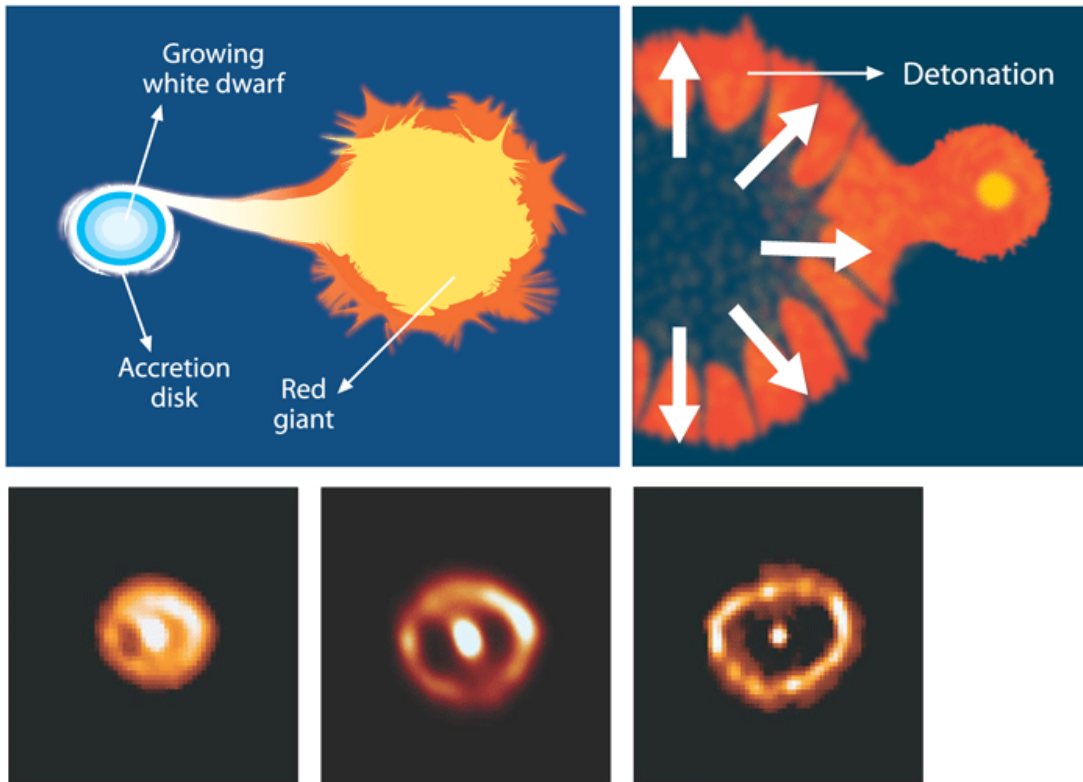
$$M \approx -1.43 - \left[2.81 \times \log\left(\frac{P}{1 \text{ day}}\right) \right].$$

Note: In this equation, "log" is a base 10 logarithm.

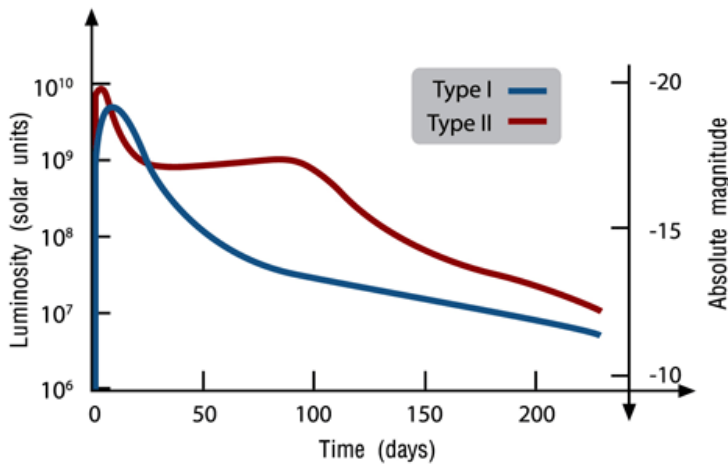
Consequently, **if** a variable star's period reveals it to be a Cepheid star, its $M \approx -1.43 - \left[2.81 \times \log\left(\frac{P}{1 \text{ day}}\right) \right]$. This information can be used to calculate distances to **faraway** Cepheid stars, such as those in nearby galaxies.

□ BACKGROUND: D. TYPE Ia SUPERNOVAE

Type Ia supernovae are a type of exploding star. They occur when a compact star, called a white dwarf, orbits too close to a giant star. Gas flows from the giant star to the white dwarf, increasing its mass until it begins to collapse under its own weight. As the white dwarf collapses, it heats up, until it reaches 6×10^8 K, the temperature at which carbon fusion occurs. Since white dwarfs are primarily made of carbon, the entire star ignites and explodes, resulting in what we call a Type Ia supernova.



Type Ia supernovae can be distinguished from other types of supernovae by their brightness history, or **light curve**. Type Ia supernovae fade away after the peak, but other types of supernovae plateau for months after they peak, before they fade away.



Distances have been measured to **nearby** galaxies in which Type Ia supernovae have occurred by finding Cepheid stars in those galaxies and measuring the distances to them. These distances, in combination with measurements of the supernovae's peak apparent magnitudes (think peak brightnesses), made possible the calculation of their peak absolute magnitudes (think peak luminosities). **It turned out that all Type Ia supernovae have approximately (although not exactly) the same peak absolute magnitude: $M \approx -19.3$.**

Consequently, **if** a supernova's light curve reveals it to be a Type Ia supernova, its $M \approx -19.3$. This information can be used to measure distances to **faraway** Type Ia supernovae, such as those in faraway galaxies.

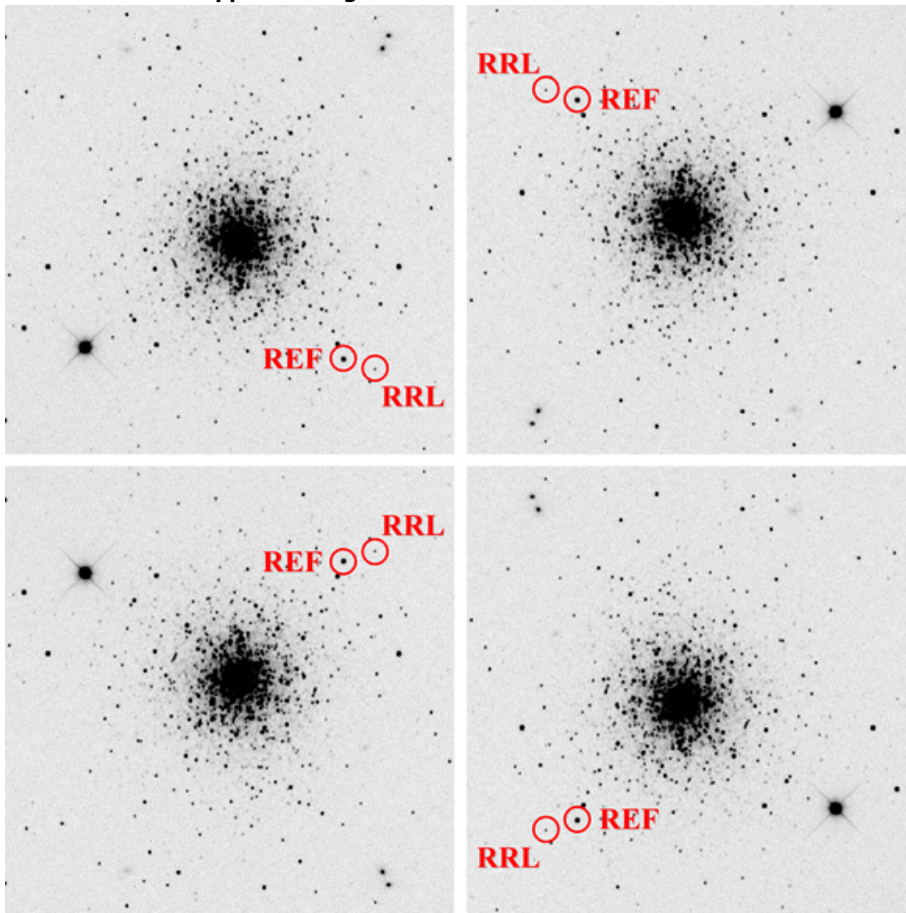
PROCEDURE: A. DISTANCE TO A GLOBULAR CLUSTER - 1. Observe a Globular Cluster

First, we are going to monitor an RR Lyrae star in a globular cluster once an hour for at least a few nights. The following globular clusters are observable from our southern-hemisphere telescopes for most of the night in different semesters.

Semester: Northern-Hemisphere Fall (Southern-Hemisphere Spring)

Globular Cluster: NGC 1261

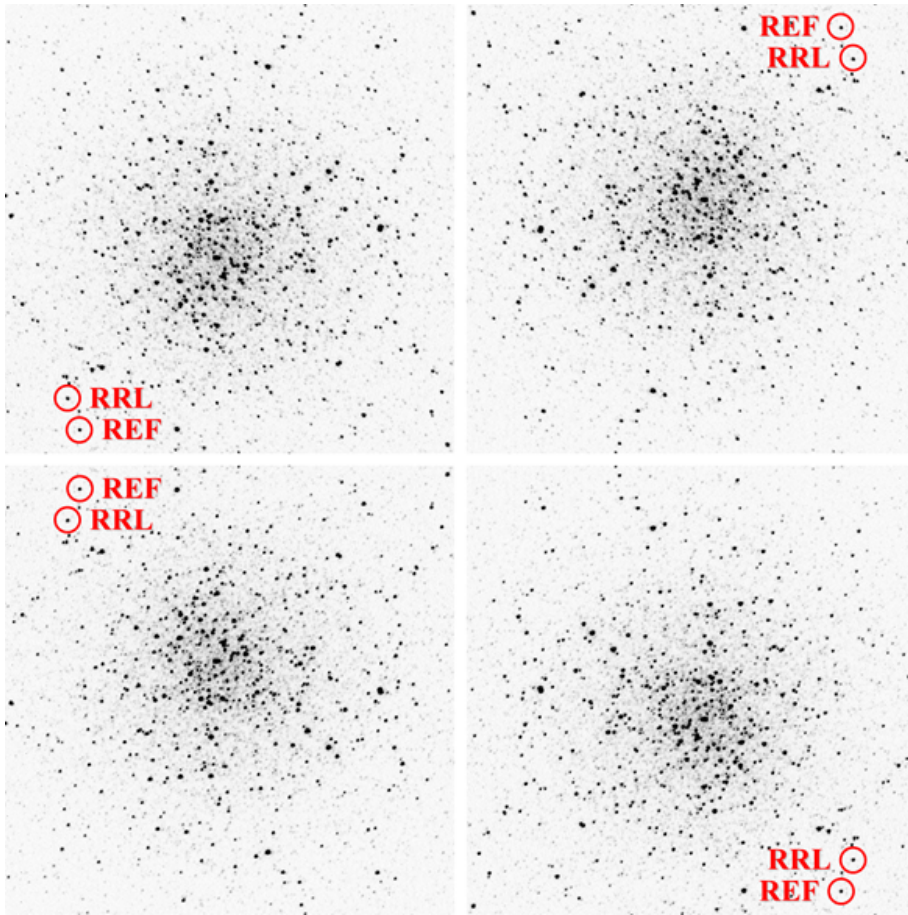
Reference Star's Apparent Magnitude: 13.87



Semester: Northern-Hemisphere Spring (Southern-Hemisphere Fall)

Globular Cluster: NGC 3201

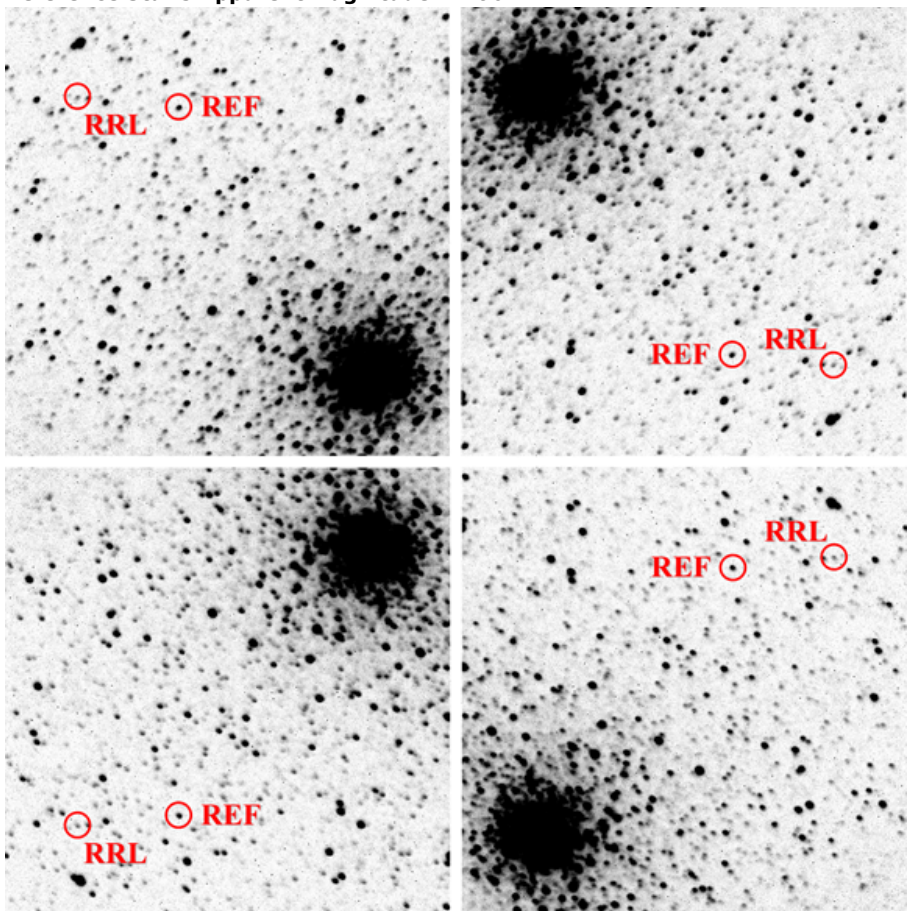
Reference Star's Apparent Magnitude: 13.60



Semester: Northern-Hemisphere Summer (Southern-Hemisphere Winter)

Globular Cluster: M28

Reference Star's Apparent Magnitude: 12.98



The RR Lyrae star and a reference star of known apparent magnitude have been marked in each image (and for each image, different flips and rotations are shown). The reference star's magnitude, which appears above each finder chart, has been corrected for the dimming effects of intervening dust.

This observation will require many exposures—too many for Skynet to complete if everyone in every section requests them. Consequently, your instructor will put in one observation to be shared by the whole class. Or, with your instructor's permission, you can instead use archival images that have been collected by Skynet staff and placed into [Afterglow's](#) "Sample", "Astro 101 Lab", "Lab 5 — Standard Candles" directory.

Your instructor can rewatch this [tutorial](#) from Lab 3, or watch this [shorter version](#) specific to Lab 5, to review how to monitor an object over an extended period of time.

Remember: Select the V filter and then all *southern-hemisphere* PROMPT telescopes to which you have access. Select "Generic 16-inch" or "PROMPT-5" as your design telescope. Request one 80-second exposure. Do **not** flag this observation as a TOO. Select and request "Repeat this observation 50 times with at least 1 hour between each" and select "Continue on next available telescope if interrupted". Change the cancel time to 2 weeks from now.

Your instructor will let you know where to find the observation, in your group's directory. Be sure to use the images in the "Reduced Images" subfolder.

Question: Which globular cluster is your section observing? (1 point)

- NGC 1261
- NGC 3201
- M28

PROCEDURE: A. DISTANCE TO A GLOBULAR CLUSTER - 2. Determine the Distance to the Globular Cluster

Next, you must photometer the RR Lyrae star, and calibrate its apparent magnitude, in each image. You could do this for each image separately, as you did in Background Section A, but this would take a long time and become monotonous. Instead, in this [tutorial](#), you will learn how to photometer objects in many images simultaneously. This is called *batch* photometry.

Use [Afterglow](#) to batch photometer the RR Lyrae star and the reference star in each of your images.

Remember: The following should be selected: "Sky Coordinate Mode", "Centroid Clicks", "Show Sources From All Files", "Source Labels", and "Auto-phot". Then, select (1) the RR Lyrae star and (2) the reference star in one of your images. To find these stars, use your globular cluster's finder chart in Section A.1.

Note: The finder chart includes four—but not all—possible flips and rotations that you may encounter. You may still have to flip or rotate your image to match it up with one of these four possibilities.

Note: It is very important that you select the correct stars!

Also remember: Confirm that these stars have also been selected in your other images (check at least a few of them). Then, select (1) both stars and (2) all of the images that you wish to batch photometer. Remember to close the selection drop-down menu by clicking off of it, and submit the job. Download the resulting csv file.

In this [tutorial](#), you will learn about period folding.

Go to this [website](#) and select "Variable".

In this [tutorial](#), you will learn how to graph your data and measure a variable star's period.

Make a graph of calibrated apparent magnitude vs. period-folded time.

Remember: Upload your csv file. Under "Light Curve", calibrate the variable star's apparent magnitudes by (1) subtracting the reference star's uncalibrated apparent magnitudes and (2) adding the reference star's known apparent magnitude. Do (1) by identifying which star is the variable (the subtraction will then occur automatically), and do (2) by entering the reference star's known apparent magnitude (it is listed above your globular cluster's finder chart in Section

A.1).

Also remember: Use the "Periodogram" tool to get a first guess for the variable star's period. Set "Start Period" to 0.1 days and "Stop Period" to 1 day. Find the period of the highest point. Enter this in the "Period Folding" tool, and then fine-tune it until the data form two, repeated cycles of the light curve. Save your final graph as a png file.

Question: Upload your final png graph. (Submit a file with a maximum size of 4 MB.) (5 points)

No file chosen

Question: The time between peaks (or troughs) is the period. Record the period (P). (1 point)

days

Question: Is this period consistent with the star being an RR Lyrae star? (1 point)

- Yes
- No

Question: If so, what is the star's average absolute magnitude (M) (think average luminosity) to 0.01 magnitudes? (1 point)

Halfway between the peak and the trough is the average apparent magnitude (think average brightness) of the star.



Question: Estimate the average apparent magnitude (m) to 0.05 magnitudes. (1 point)

Question: Calculate the distance (D) to the RR Lyrae star, and hence to the globular cluster, using its absolute and apparent magnitudes. (1 point)

kpc

Show your work. (1 point)

Question: Wiki and record the true distance (D) to the globular cluster. (1 point)

kpc

Question: Calculate your percent error. (1 point)

%

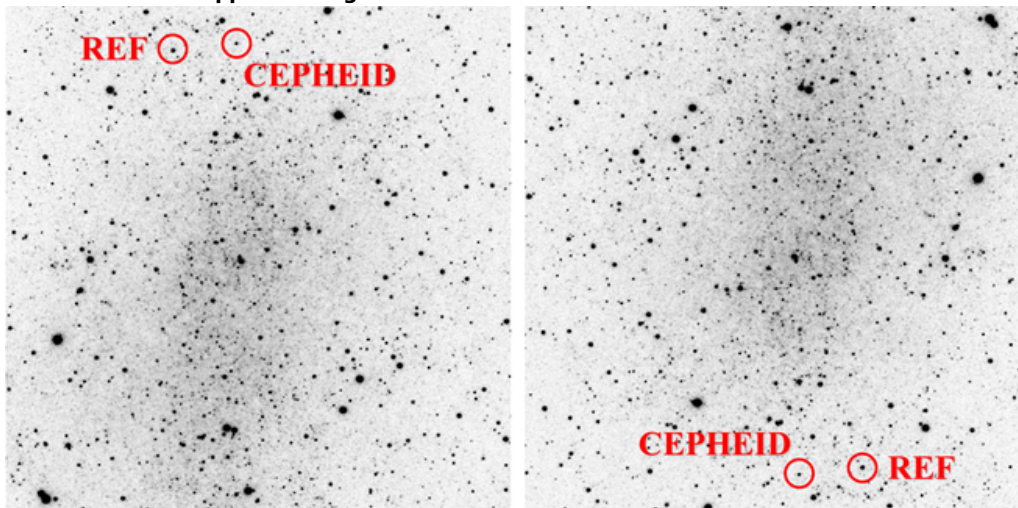
Question: Discuss significant sources of error. (2 points)

PROCEDURE: B. DISTANCE TO A NEARBY GALAXY

Next, we are going to use a Cepheid star to measure the distance to a nearby galaxy:

Galaxy: NGC 6822

Reference Star's Apparent Magnitude: 15.25



The Cepheid star and a reference star of known apparent magnitude have been marked (and different rotations are shown). The reference star's magnitude, which appears above the finder chart, has been corrected for the dimming effects of intervening dust.

Since this observation takes months to complete, Skynet staff have already carried it out for you. You can find these images in [Afterglow's](#) "Sample", "Astro 101 Lab", "Lab 5—Standard Candles", "Nearby Galaxy NGC 6822" directory.

Use [Afterglow](#) to batch photometer the Cepheid star and the reference star in each of your images.

Remember: The following should be selected: "Sky Coordinate Mode", "Centroid Clicks", "Show Sources From All Files", "Source Labels", and "Auto-phot". Then, select (1) the Cepheid star and (2) the reference star in one of your images. To find these stars, use the finder chart.

Note: *The finder chart includes both rotations that you may encounter.*

Note: *It is very important that you select the correct stars!*

Also remember: Confirm that these stars have also been selected in your other images (check at least a few of them). Then, select all of the images that you wish to batch photometer. Remember to close the selection drop-down menu by clicking off of it, and submit the job. Download the resulting csv file.

Go to this [website](#) and select "Variable".

Make a graph of calibrated apparent magnitude vs. period-folded time.

Remember: Upload your csv file. Under "Light Curve", calibrate the variable star's apparent magnitudes by (1) subtracting the reference star's uncalibrated apparent magnitudes and (2) adding the reference star's known apparent magnitude. Do (1) by identifying which star is the variable (the subtraction will then occur automatically), and do (2) by entering the reference star's known apparent magnitude (it is listed above the finder chart).

Also remember: Use the "Periodogram" tool to get a first guess for the variable star's period. Set "Start Period" to 1 day and "Stop Period" to 100 day. Find the period of the highest point. Enter this in the "Period Folding" tool, and then fine-

tune it until the data form two, repeated cycles of the light curve. Save your final graph as a png file.

Question: Upload your final png graph. (Submit a file with a maximum size of 4 MB.) (5 points)

No file chosen

Question: The time between peaks (or troughs) is the period. Record the period (P). (1 point)

days

Question: Is this period consistent with the star being a Cepheid star? (1 point)

- Yes
 No

Question: If so, calculate the star's average absolute magnitude (M) (think average luminosity) to 0.01 magnitudes? (1 point)

Show your work. (1 point)

Question: Half the distance between the peak and the trough is the average apparent magnitude (m) (think average brightness) of the star. Estimate this to 0.05 magnitudes. (1 point)

Question: Calculate the distance (D) to the Cepheid star, and hence to the nearby galaxy, using its absolute and apparent magnitudes. (1 point)

kpc

Show your work. (1 point)

Question: Wiki and record the true distance (D) to NGC 6822. (1 point)

kpc

Question: Calculate your percent error. (1 point)

%

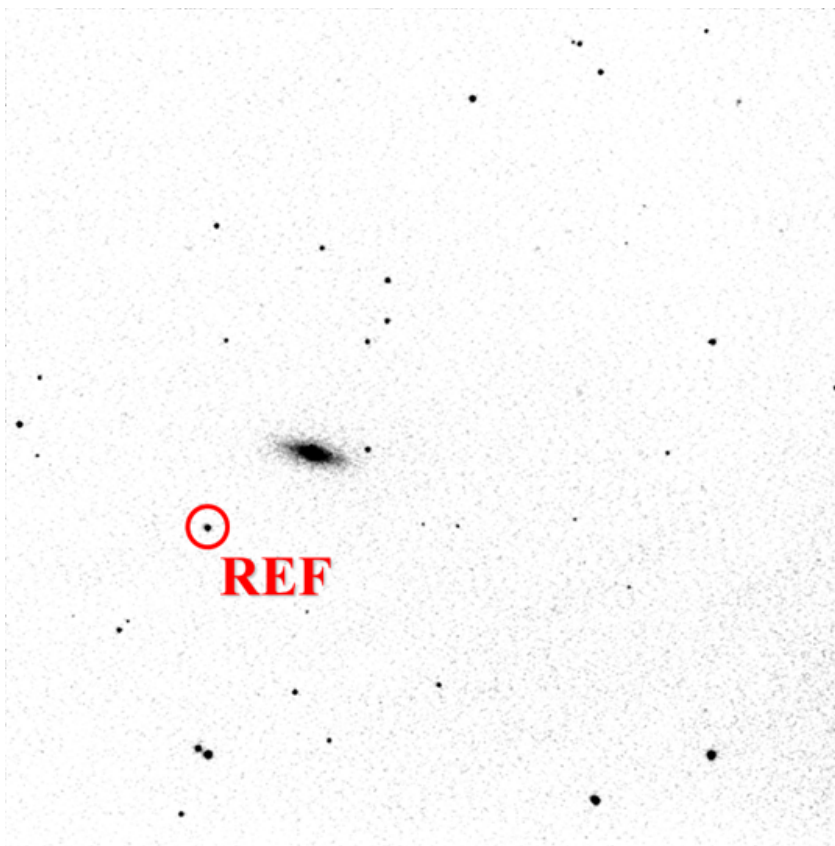
Question: Discuss significant sources of error. (2 points)

PROCEDURE: C. DISTANCE TO A FARAWAY GALAXY

Finally, we are going to use a Type Ia supernova to measure the distance to a faraway galaxy. Since supernovae occur unpredictably, we will use one that has already been discovered, and monitored, with PROMPT (PROMPT is one of the leading discoverers of supernovae in the southern hemisphere), in this galaxy:

Galaxy: NGC 2765

Reference Star's Apparent Magnitude: 14.39



A reference star of known apparent magnitude has been marked. The reference star's magnitude, which appears above the finder chart, has been corrected for the dimming effects of intervening dust.

You can find these images in [Afterglow's](#) "Sample", "Astro 101 Lab", "Lab 5 — Standard Candles", "Faraway Galaxy NGC 2765" directory.

First, you will have to identify which star is the supernova. In this [tutorial](#), you will learn how to subtract images taken at different times, to identify sources, such as supernovae, that faded between these times.

Use [Afterglow](#) to identify which star is the supernova.

Remember: Use [Afterglow's](#) "Aligner" tool to align the first and last images in the sequence. "Active Image File" can be set to anything. "Mode" should be set to "astrometric". "Overwrite Files" should be checked. Submit the job.

Also remember: Use [Afterglow's](#) "Image Calculator" tool to subtract these, now aligned, images. The tool should be set to "Simple" and "Mode" should be set to "Image". Select the first image, subtraction, and then the last image. Do **not** check "Overwrite Files". Submit the job, which will create a new image—the *difference* image.

Finally, also remember: Split [Afterglow's](#) screen, select both the difference image and the first image, and sync their orientations. Zoom in to the galaxy, and use the difference image to identify the supernova in the first image. Mark and label it in the first image. Save both images as jpg files.

Question: Upload your zoomed-in jpg difference image. (Submit a file with a maximum size of 4 MB.) (3 points)

No file chosen

Question: Upload your zoomed-in, marked, and labeled jpg image of the galaxy and supernova. (Submit a file with a maximum size of 4 MB.) (3 points)

No file chosen

Use [Afterglow](#) to batch photometer the supernova and the reference star in each of your images.

Remember: The following should be selected: "Sky Coordinate Mode", "Centroid Clicks", "Show Sources From All Files", "Source Labels", and "Auto-phot". Then, select (1) the supernova and (2) the reference star in one of your images.

Note: You may have to flip and/or rotate your image to match it up with the finder chart.

Note: It is very important that you select the correct stars!

Also remember: Confirm that these stars have also been selected in your other images (check at least a few of them). Then, select all of the images that you wish to batch photometer. Remember to close the selection drop-down menu by clicking off of it, and submit the job. Download the resulting csv file.

Go to this [website](#) and select "Variable".

Make a graph of calibrated apparent magnitude vs. time.

Remember: Upload your csv file. Under "Light Curve", calibrate the supernova's apparent magnitudes by (1) subtracting the reference star's uncalibrated apparent magnitudes and (2) adding the reference star's known apparent magnitude. Do (1) by identifying which star is the supernova (the subtraction will then occur automatically), and do (2) by entering the reference star's known apparent magnitude (it is listed above the finder chart).

Note: Your graph should be dominated by fading, not noise. If it is dominated by noise, you selected the wrong star for the supernova. Try again!

Also remember: The supernova does not vary periodically, so do not use the "Periodogram" or "Period Folding" tools. Save your final "Light Curve" graph as a png file.

Question: Upload your final png graph. (Submit a file with a maximum size of 4 MB.) (5 points)

No file chosen

Question: Is the light curve consistent with the supernova being a Type Ia supernova? (1 point)

- Yes
 No

Question: If so, what is the supernova's peak absolute magnitude (M) (think peak luminosity) to 0.1 magnitudes? (1 point)

Question: Estimate the peak apparent magnitude (m) (think peak brightness) of the supernova to 0.1 magnitudes. (1 point)

Question: Calculate the distance (D) to the supernova, and hence to the faraway galaxy, using its absolute and apparent magnitudes. (1 point)

 kpc

Show your work. (1 point)

Question: The true distance (D) to NGC 2765 is 56,000 kpc. Calculate your percent error. (1 point)

%

Question: Discuss significant sources of error. (2 points)

Assignment Details

Name (AID): **Lab 5: Distance Ladder II: Standard Candles (V) (17349112)** **Feedback Settings**
Submissions Allowed: **100** Before due date
Category: **Homework** Response
Code: After due date
Locked: **Yes** Question Score
Author: **Reichart, Dan** (dan.reichart@gmail.com) Assignment Score
Last Saved: **Oct 12, 2020 01:33 AM EDT** Publish Essay Scores
Permission: **Protected** Key
Randomization: **Assignment** Question Part Score
Which graded: **Last** Solution
Mark
Help/Hints
Response