

5. COSMIC DISTANCE LADDER II: STANDARD CANDLES

EQUIPMENT

Computer with internet connection

GOALS

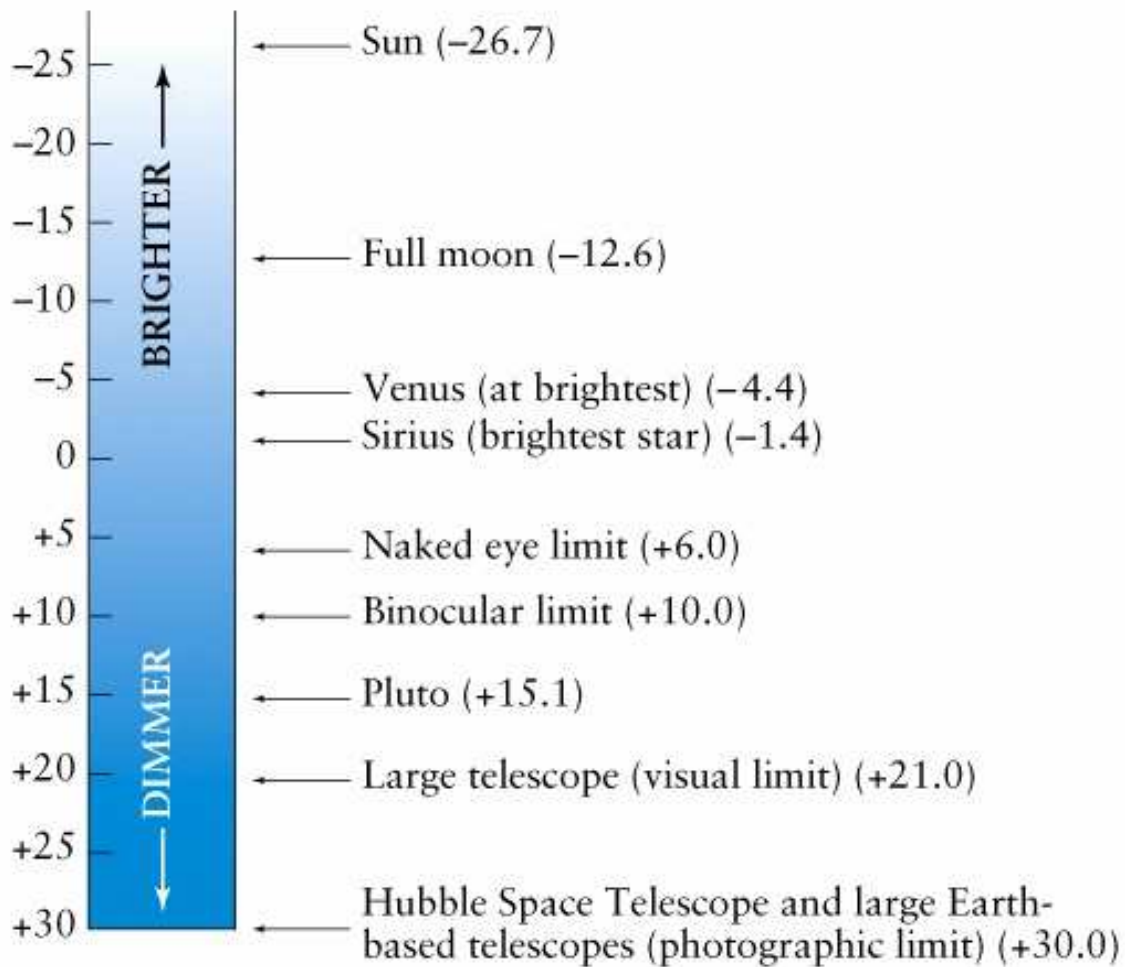
In this lab, you will learn:

1. How to use RR Lyrae variable stars to measure distances to objects within the Milky Way galaxy.
2. How to use Cepheid variable stars to measure distances to nearby galaxies.
3. How to use Type Ia supernovae to measure distances to faraway galaxies.

BACKGROUND

A. MAGNITUDES

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



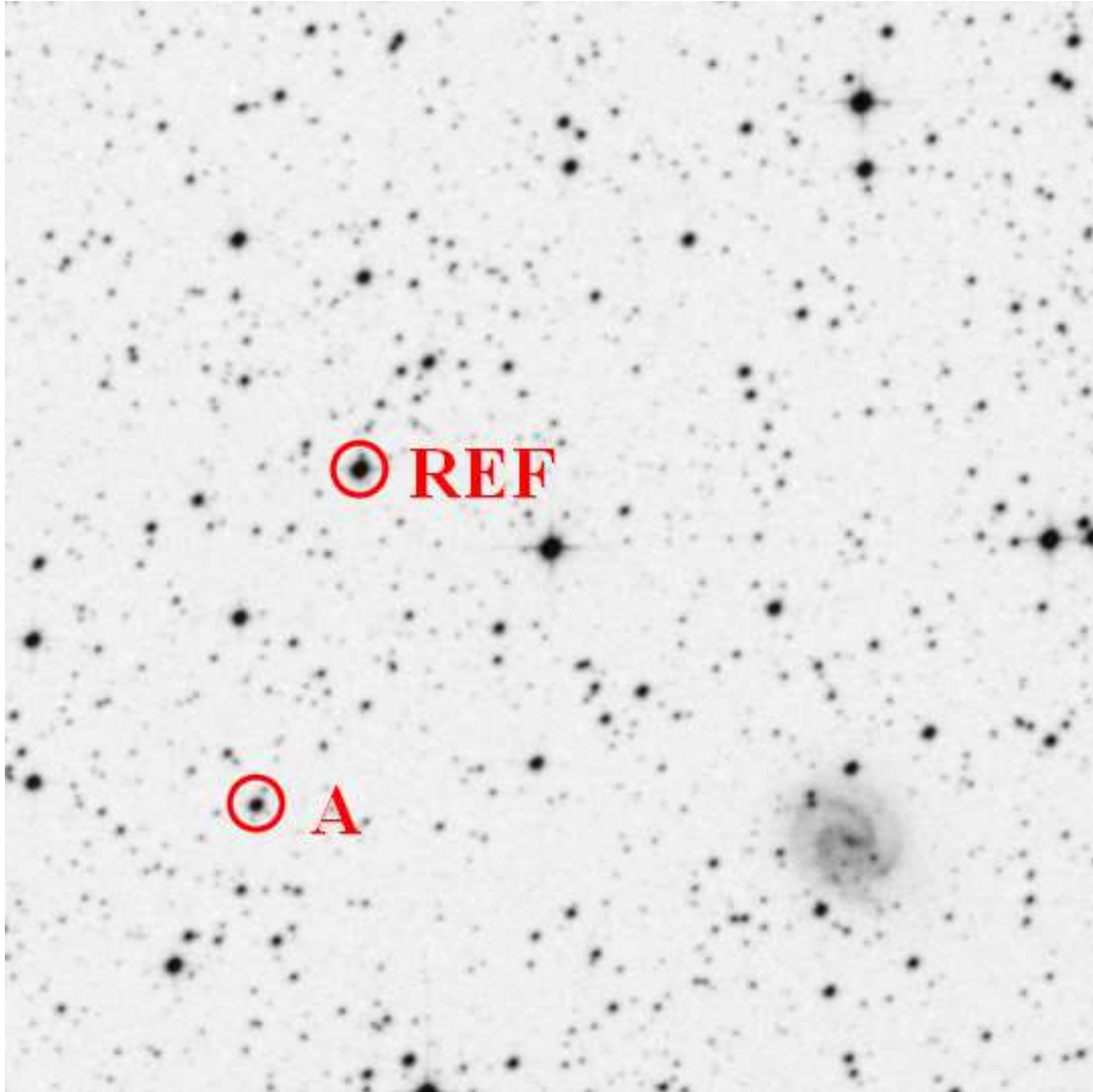
The more negative the magnitude, the brighter the object. The more positive the magnitude, the fainter the object.

In the following tutorial, you will learn how to measure, or **photometer**, uncalibrated magnitudes:

<http://skynet.unc.edu/ASTR101L/videos/photometry/>

In Afterglow, go to “File”, “Open Image(s)”, “Sample Images”, “Astro 101 Lab”, “Lab 5 – Standard Candles”, “CD-47” and open the image “CD-47 8676”. Measure the uncalibrated magnitude of star A:

uncalibrated magnitude of star A: _____



Uncalibrated 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 uncalibrated magnitude, one must first measure this constant, which we do by photometering a **reference star** of known magnitude:

uncalibrated magnitude of reference star: _____

The known, true magnitude of the reference star is 12.01. Calculate the correction constant:

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

correction constant: _____

Finally, calibrate the uncalibrated magnitude of star A by adding the correction constant to it:

calibrated magnitude = uncalibrated magnitude + correction constant

calibrated magnitude of star A: _____

The true magnitude of star A is 13.74. Discuss sources of error.

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 0.5 kiloparsecs (about 1,600 light years), its parallax angle is too small to be measured with current technology. Consequently, its distance cannot be determined in this way.

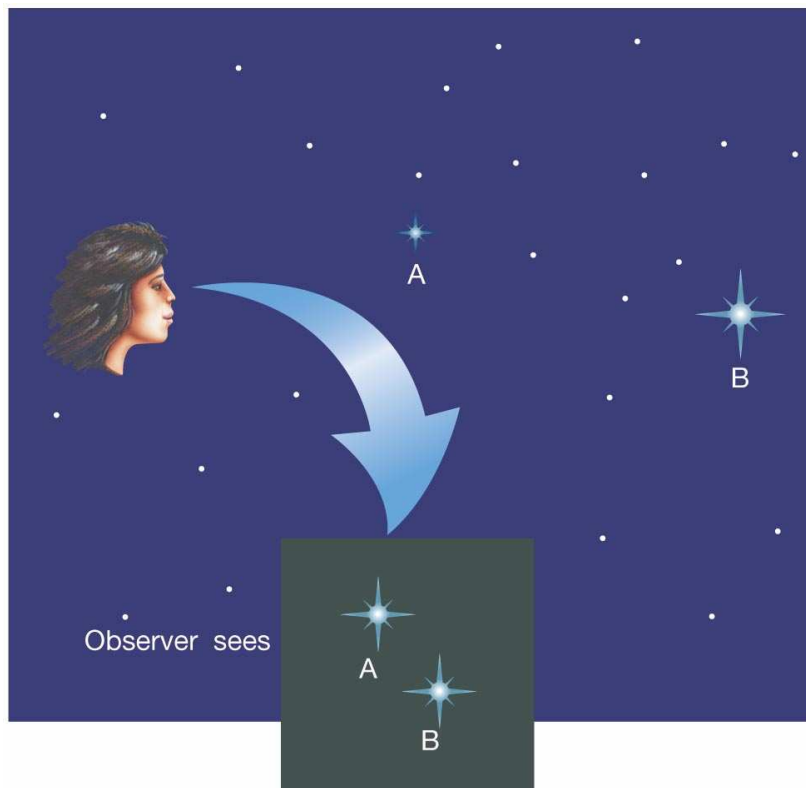
However, if the luminosity, **L**, of the star is known, its distance, **D**, can be calculated by measuring its brightness, **B**:

$$B = L / 4\pi D^2$$

Solving for distance yields:

$$D = (L / 4\pi B)^{1/2}$$

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:

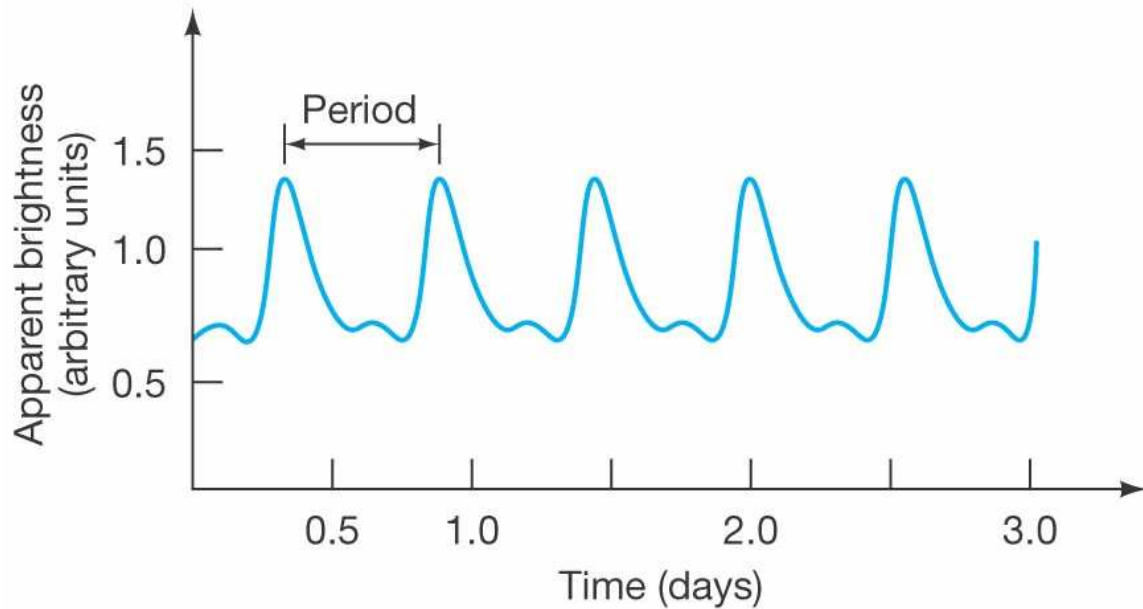
$$D = 0.01 \text{ kpc} \times 10^{(m - M)/5}$$

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 to determine its absolute magnitude (think luminosity), (3) measure its apparent magnitude (think brightness), and (4) use the above equation to calculate its distance.

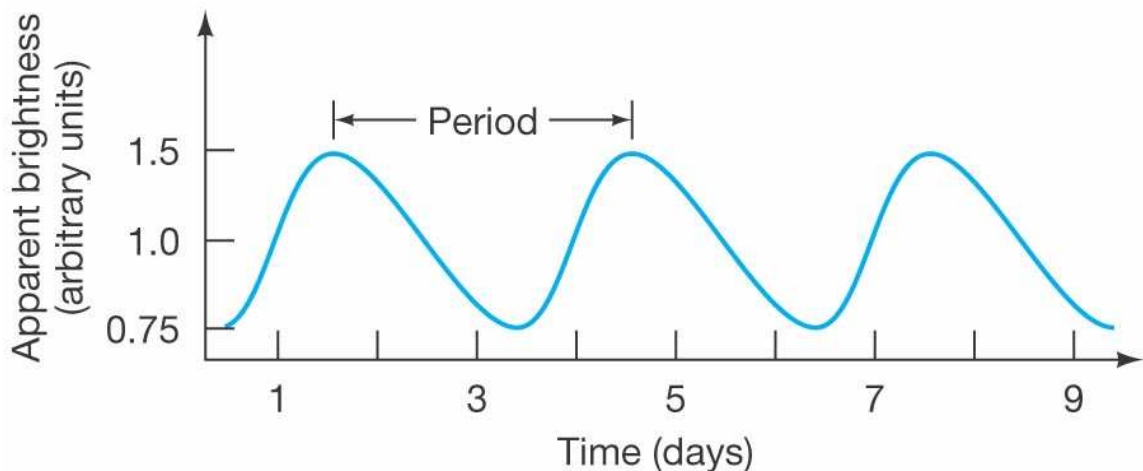
C. RR LYRAE AND CEPHEID VARIABLE STARS

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:

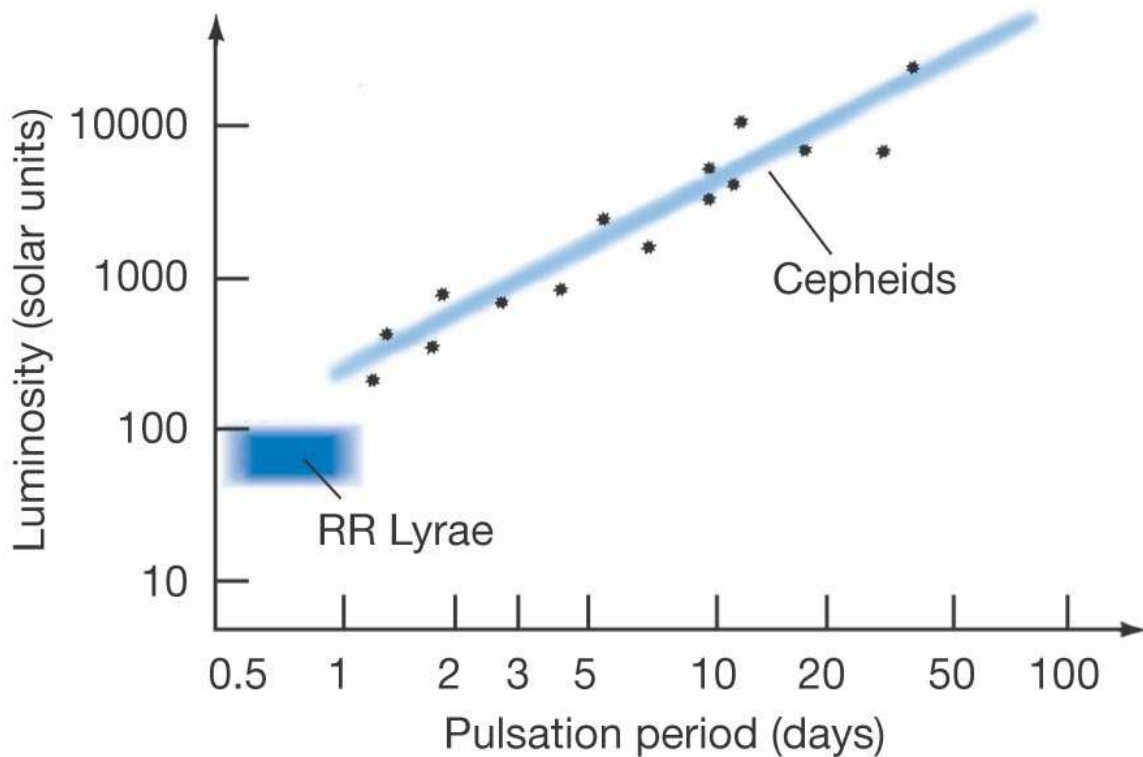


Distances have been measured to **nearby** RR Lyrae stars in our galaxy using parallax techniques (see Lab #4). These distances, in combination with measurements of the stars' average apparent magnitudes (think average brightnesses), made possible the calculation of their average absolute magnitudes (think average luminosities). **It turned**

out that all RR Lyrae stars have about 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 related to their periods in the following way:**



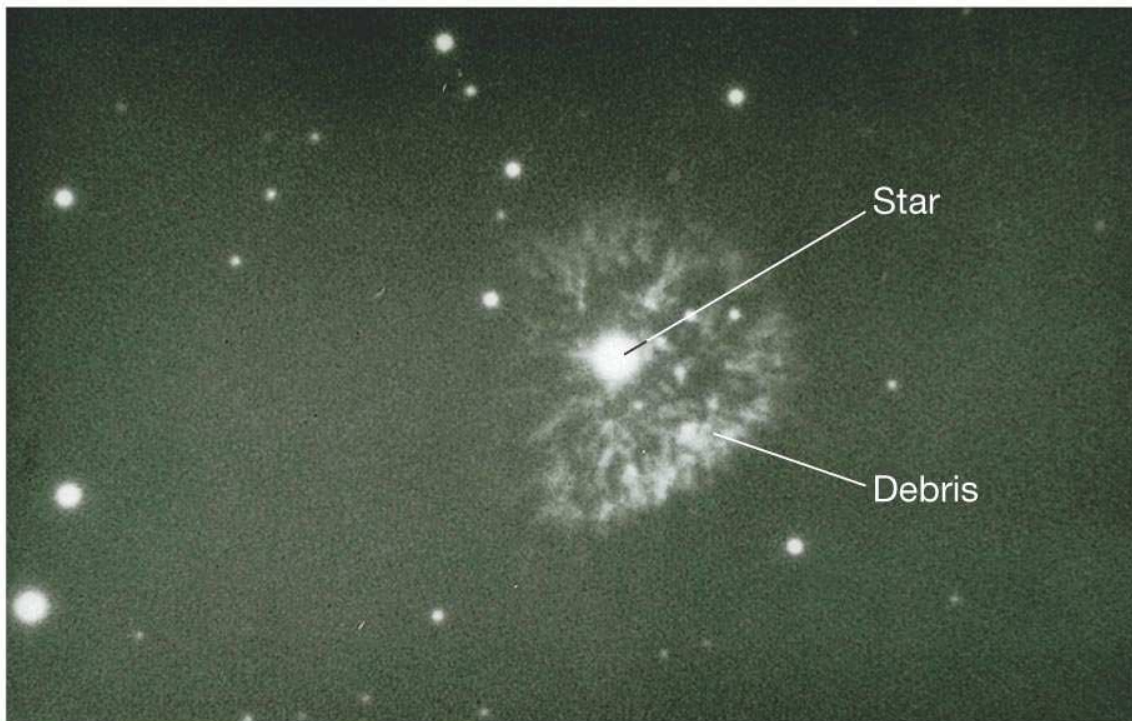
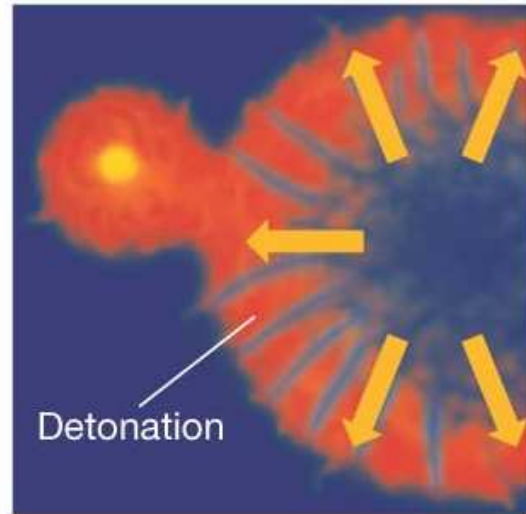
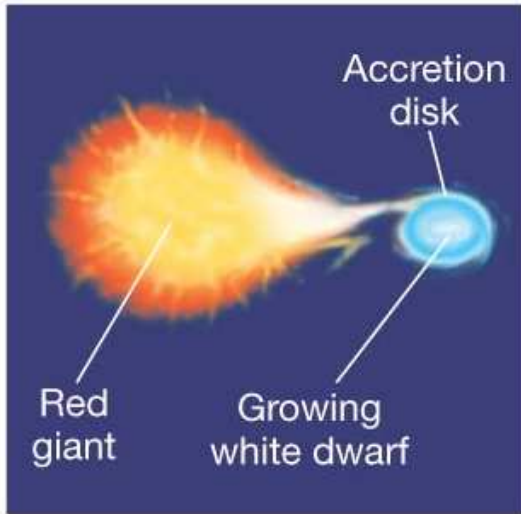
Written as an equation:

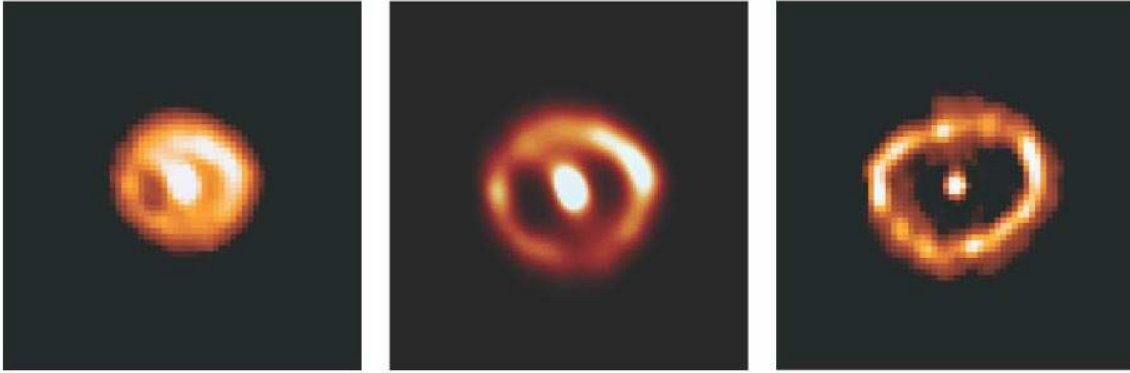
$$M \approx -1.43 - [2.81 \times \log(P / 1 \text{ day})]$$

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

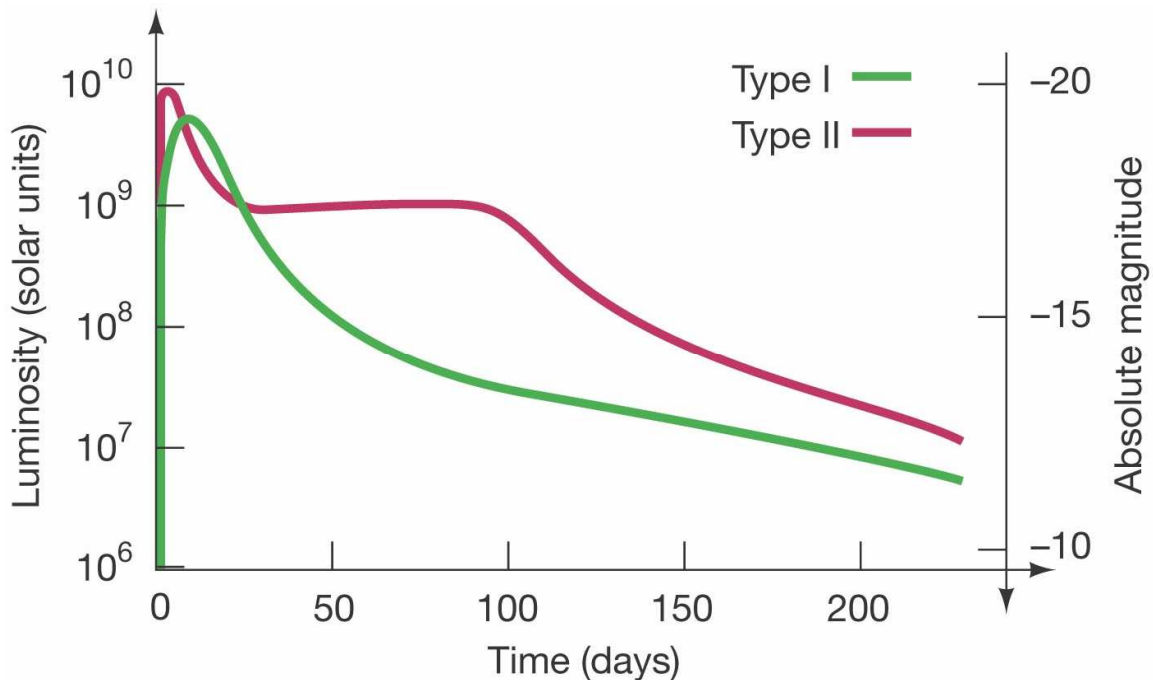
D. TYPE Ia SUPERNOVAE

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 its brightness history, or **light curve**:



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 about 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

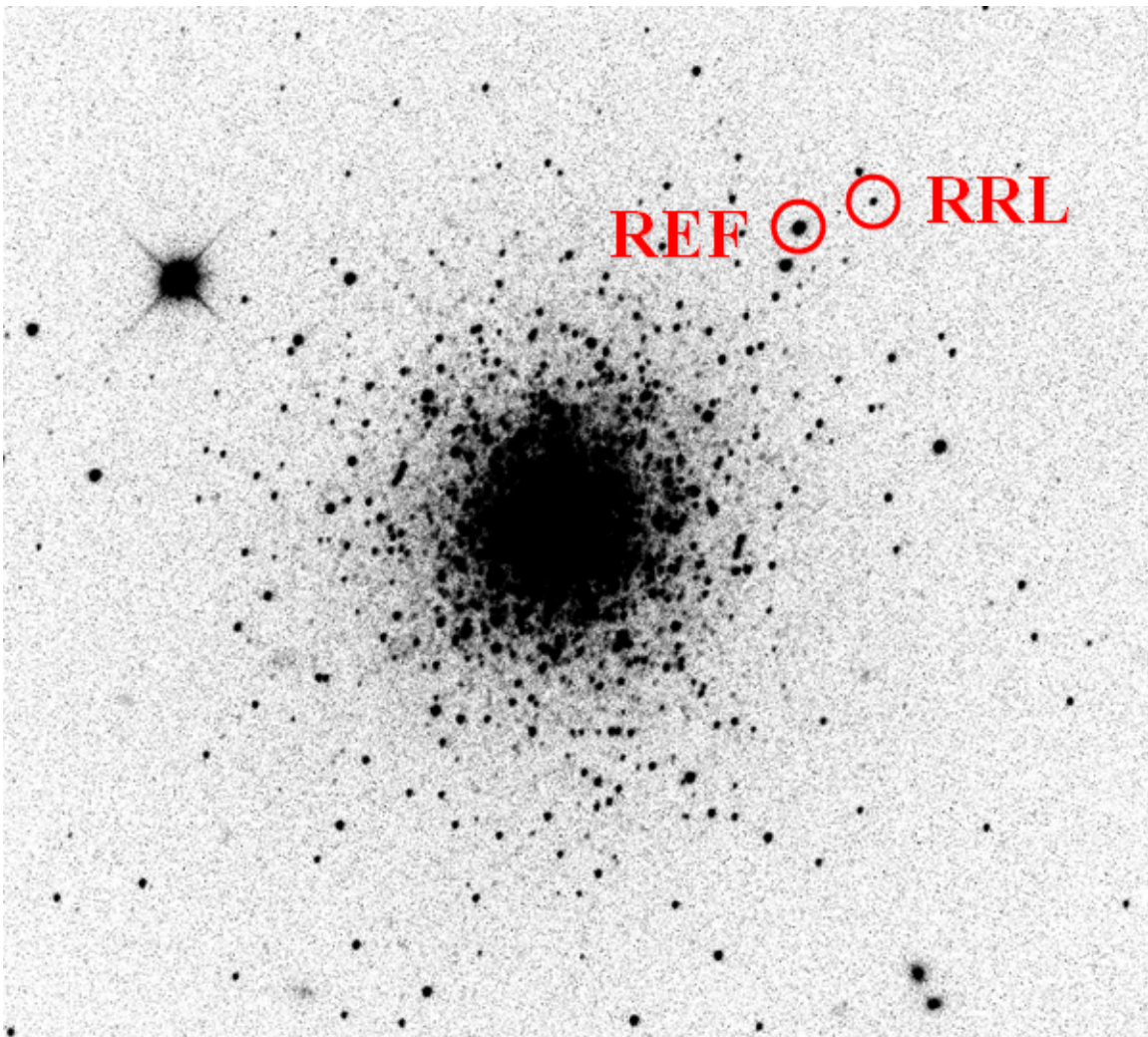
A. DISTANCE TO A GLOBULAR CLUSTER

First, we are going to monitor an RR Lyrae star in a globular cluster once an hour for a week. The following globular clusters are observable from PROMPT for most of the night in different semesters:

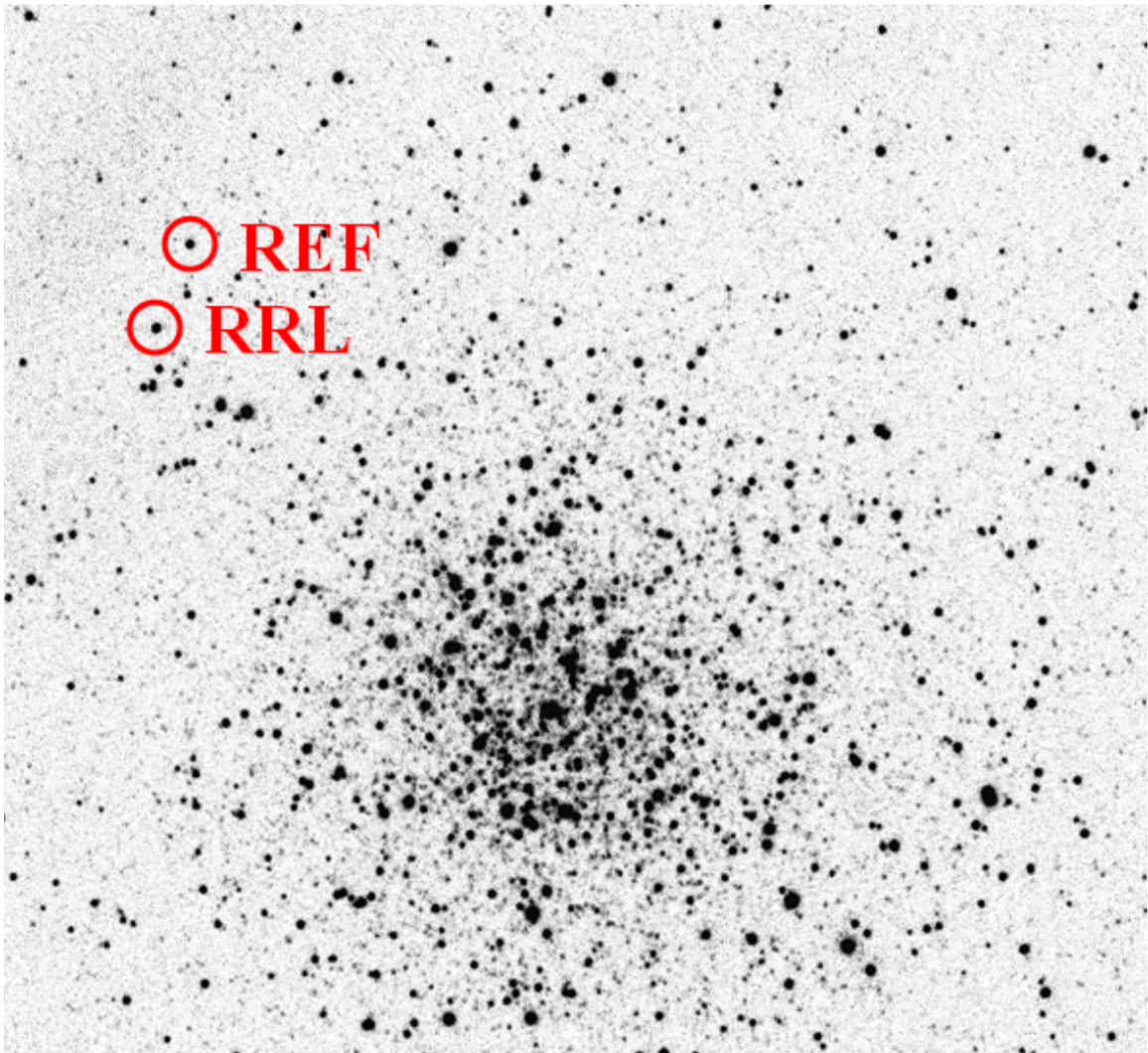
Semester: Fall

Globular Cluster: NGC 1261

Reference Star's Magnitude: 13.87



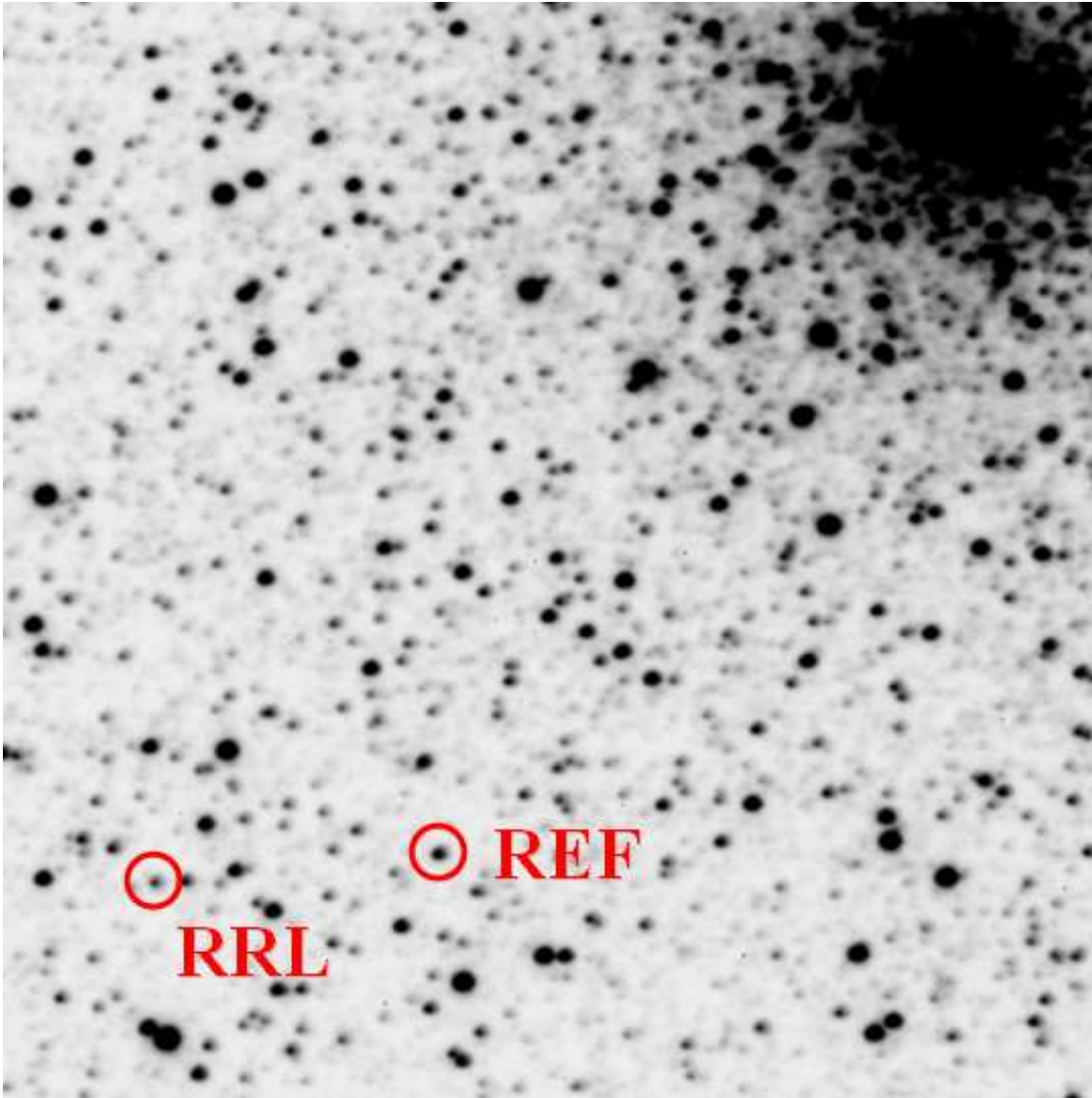
Semester: Spring
Globular Cluster: NGC 3201
Reference Star's Magnitude: 13.60



Semester: Summer

Globular Cluster: M28

Reference Star's Magnitude: 12.98



The RR Lyrae star and a reference star of known magnitude have been marked in each image. The reference star's magnitude 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 of ASTR 101L requests them. Consequently, we will request only one set of exposures per section: Your instructor will request one exposure every hour for 7 days \times 24 hours/day = 168 hours. Each exposure will be 80 seconds in duration and taken through the V filter.

You will be able to access these images once they are completed from your instructor's folder under "Sample Images", "Astro 101 Lab", "Lab 5 – Standard Candles".

You could photometer and calibrate the RR Lyrae star in each image separately, but this would be a lot of work. In the following tutorial, you will learn how to photometer objects in many images simultaneously:

<http://skynet.unc.edu/ASTR101L/videos/batch/>

Use Afterglow to photometer the RR Lyrae star and the reference star in each of your images:

1. Select "Centroid Sources" and "Stellar Method (PSF)". Select "Use WCS".
2. In one of your images, select the RR Lyrae star and label it. Select the reference star and label it.
3. Select "Find Sources In All Images". Check a few of your other images to confirm that Afterglow did this correctly. Note that some of the images might be rotated 180°, depending on which side of the meridian the mount was on.

In the following tutorial, you will learn about period folding:

<http://skynet.unc.edu/ASTR101L/videos/folding/>

In the following tutorial, you will learn how to graph your data and measure a variable star's period in days.

<http://skynet.unc.edu/ASTR101L/videos/graph-variable/>

Make a graph of calibrated magnitude vs. period-folded Julian date.

Note: When using "Fourier View" to get a first guess for the period, set "Start Period" to 0.3 days, "Stop Period" to 1 day, "Step Size" to 0.001 days, and make sure that "Period Folding" is turned off.

The time between peaks (or troughs) is the period:

Period (in days) = _____

Is this period consistent with the star being an RR Lyrae star? If so, what is the star's average absolute magnitude (think average luminosity)?

Absolute magnitude = _____

Halfway between the peak and the trough is the average apparent magnitude (think average brightness) of the star. Estimate it to 0.1 magnitudes:

Apparent magnitude = _____

Calculate the distance to the RR Lyrae star, and hence to the globular cluster, using its absolute and apparent magnitudes:

Distance = _____

Google the true distance to the globular cluster and compute your percent error. Discuss sources of error.

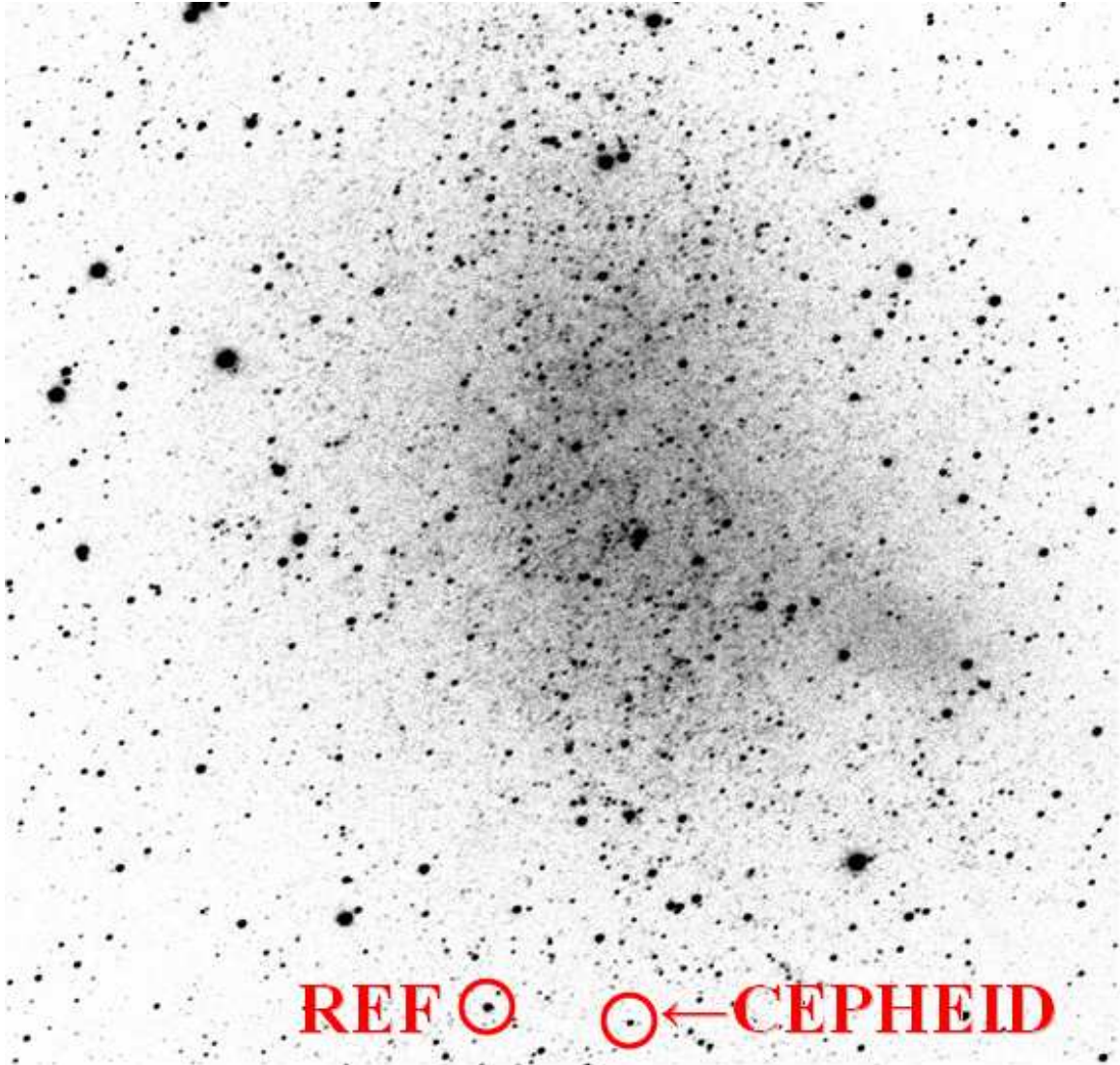
In your lab report, include your graph of calibrated magnitude vs. period-folded Julian date, and your distance calculation.

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 Magnitude: 15.25



The Cepheid star and a reference star of known magnitude have been marked. The reference star's magnitude has been corrected for the dimming effects of intervening dust.

Since this observation takes months to complete, we have carried it out for you in advance. You will be able to access these images under “Sample Images”, “Astro 101 Lab”, “Lab 5 – Standard Candles”, “Nearby Galaxy NGC 6822”.

Use Afterglow to photometer the Cepheid star and the reference star in each of your images:

1. Select “Centroid Sources” and “Stellar Method (PSF)”. Select “Use WCS”.
2. In one of your images, select the Cepheid star and label it. Select the reference star and label it.
3. Select “Find Sources In All Images”. Check a few of your other images to confirm that Afterglow did this correctly. Note that some of the images might be rotated 180°, depending on which side of the meridian the mount was on.

Make a graph of calibrated magnitude vs. period-folded Julian date.

Note: When using “Fourier View” to get a first guess for the period, set “Start Period” to 1 day, “Stop Period” to 200 days, “Step Size” to 0.5 days, and make sure that “Period Folding” is turned off.

The time between peaks (or troughs) is the period:

Period (in days) = _____

Is this period consistent with the star being a Cepheid star? If so, estimate the star’s average absolute magnitude (think average luminosity) to 0.1 magnitudes?

Absolute magnitude = _____

Half the distance between the peak and the trough is the average apparent magnitude (think average brightness) of the star. Estimate it to 0.1 magnitudes:

Apparent magnitude = _____

Calculate the distance to the Cepheid star, and hence to the nearby galaxy, using its absolute and apparent magnitudes:

Distance = _____

Google the true distance to the nearby galaxy and compute your percent error. Discuss sources of error.

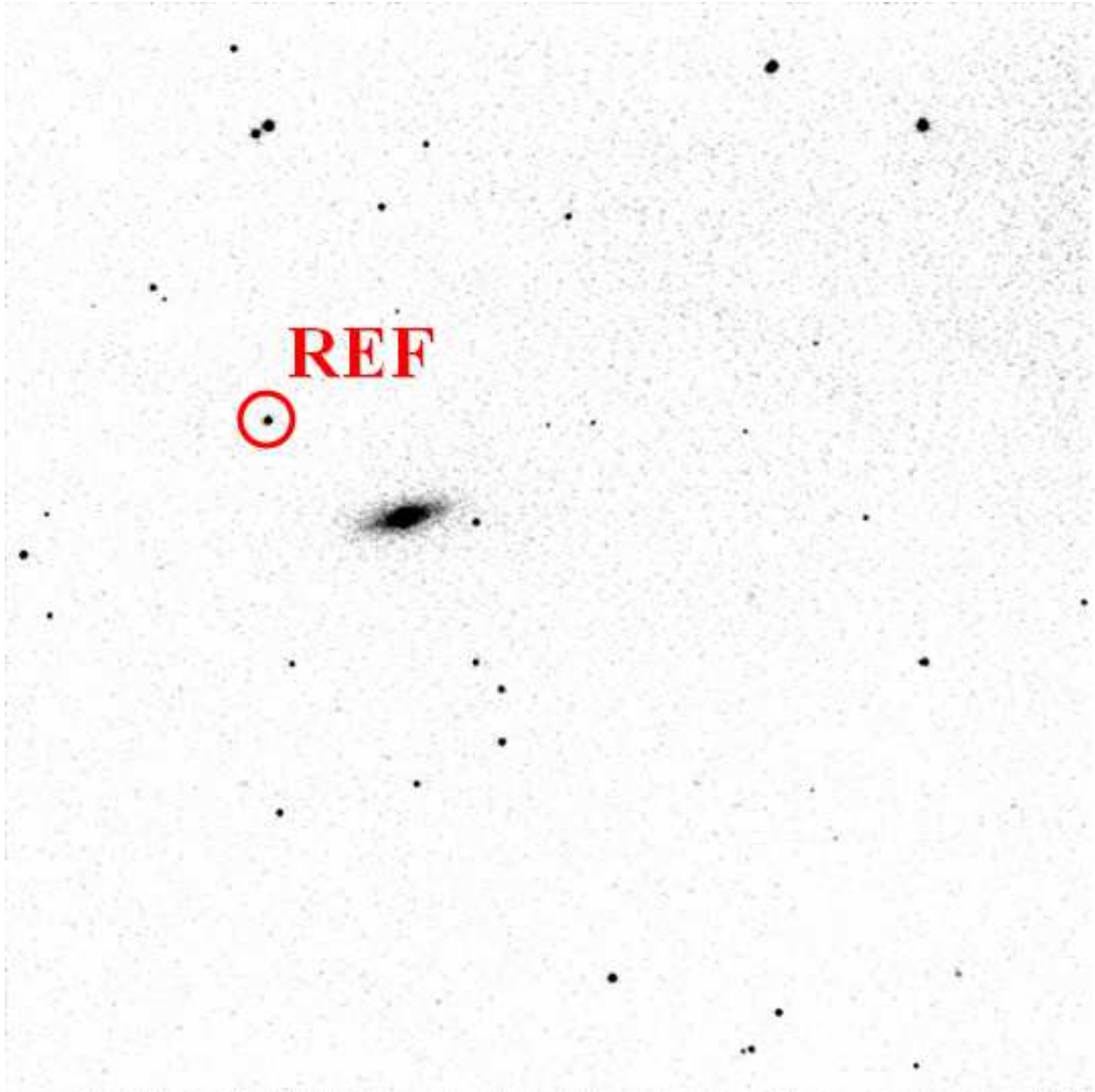
In your lab report, include your graph of calibrated magnitude vs. period-folded Julian date, your average absolute magnitude calculation, and your distance calculation.

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 the leading discoverer of supernovae in the southern hemisphere):

Galaxy: NGC 2765

Reference Star's Magnitude: 14.39



A reference star of known magnitude has been marked. The reference star's magnitude has been corrected for the dimming effects of intervening dust.

You will be able to access these images under “Sample Images”, “Astro 101 Lab”, “Lab 5 – Standard Candles”, “Faraway Galaxy NGC 2765”.

First, use Afterglow to identify which object is the supernova:

1. Select and align all of the images from this telescope. For “Alignment Method”, select “One Star Manual”. For “Cropping Method”, select “Overlap Only”. Select “Centroid Sources” and “Stellar Method (PSF)”. In your first image, identify a bright, but not saturated, star that is not on the edge of the image. Align to this star in each of the images.
2. Turn your selected and aligned images into a movie. The supernova will be the fading object. Download your movie.

Use Afterglow to photometer the supernova and the reference star in each of your images:

1. Select “Centroid Sources” and “Stellar Method (PSF)”. Select “Use WCS”.
2. In one of your images, select the supernova and label it. Select the reference star and label it.
3. Select “Find Sources In All Images”. Check a few of your other images to confirm that Afterglow did this correctly. Note that some of the images might be rotated 180°, depending on which side of the meridian the mount was on.

Make a graph of calibrated magnitude vs. Julian date.

Is the light curve consistent with the supernova being a Type Ia supernova? If so, what is the supernova’s peak absolute magnitude (think peak luminosity)?

Absolute magnitude = _____

Estimate peak apparent magnitude (think peak brightness) of the supernova to 0.1 magnitudes:

Apparent magnitude = _____

Calculate the distance to the supernova, and hence to the faraway galaxy, using its absolute and apparent magnitudes:

Distance = _____

The true distance to NGC 2765 is 56 Mpc. Compute your percent error. Discuss sources of error.

In your lab report, include your movie of the fading supernova, your graph of calibrated magnitude vs. Julian date, and your distance calculation.