RESEARCH CAPABILITIES OF BYU-IDAHO TELESCOPE AND VARIABLE STAR STUDY OF RV URSA MAJOR

by

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Abstract

The BYU-Idaho Physics Department recently acquired a 250mm f/4 Maksutov Newtonian telescope for use by undergraduates and faculty. In order for students to obtain quality images that can be used for research, they must understand several techniques. These techniques include focusing, autoguiding, and image reduction. Images are taken with a SBIG ST-7XME charge-coupled device (CCD). CCDs are employed in many modern astronomical research projects. The CCD solid-state design allows for detailed photometric studies such as variable star studies. Variable stars are those whose apparent brightness changes with respect to the observer. RV Ursa Major is one such star. Following detailed research of RV Ursa Major, its period was found to be 0.46746 ± 0.00395 days. The phase curve of the star was also created based on the results of images taken over an 11-day period in August 2010. This research is designed to guide future projects by BYU-Idaho undergraduates and faculty members.
I would like to acknowledge Dr. Stephen McNeil for mentoring me and providing the information and equipment needed to proceed with this project. I would also like to thank Dr. Tom Davis for his assistance in setting up the telescope and sharing his knowledge with us throughout the project. The entire BYU-Idaho Physics Department should be thanked for their continued patience in teaching and educating myself and other undergraduate physics students. Most importantly I would like to thank my wife, Traci, for being supportive of this project, which required many long nights to be spent away from home while she took care of our son, which is never an easy task.
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Chapter I. Introduction

Astronomy is one of the most ancient of all of the sciences. The stars, planets, and other celestial objects that span the skies have long interested mankind. Technological advances during the past century have allowed scientists to more accurately study the makeup of stars, galaxies, and nebulae. Charge-coupled devices (CCDs) are one such innovation.

CCDs were originally designed to enhance computer memory systems by allowing the computer to store any voltage value within the device’s range, rather than just binary numbers. [1] The chips were later discovered to be an impressive way of recording images. Today, the technology behind CCDs is implemented in the majority of astronomical studies.

Brigham Young University-Idaho recently acquired a 250mm Maksutov-Newtonian telescope to assist students in performing detailed surveys of astronomical objects. The imaging device referenced throughout this paper is the SBIG ST-7 XME. The ST-7 XME contains two CCD chips, one for imaging and the other for auto-guiding. This equipment will allow future students to perform a variety of astronomical studies and make significant and meaningful contributions to modern-day science.

1.1 CCD Technology

CCDs are integrated circuits that rely on the semi-conductive properties of silicon. Scientists at Bell Laboratories originally developed the technology in the 1960s as a method of replacing existing computer memory storage devices. The technology proved to be unsuccessful as a memory storage device; however, it was
soon discovered to be highly capable of converting light energy (photons) into an electric charge.

When energy strikes a silicon CCD photodiode, electrons are excited out of the valence shell of the silicon. The depletion layer of the silicon stores this free electron. [2] During astronomical observations, the CCD lens remains open for a period of time while a large number of photons strike the CCD chip. As time passes, more and more photons excite electrons along the silicon lattice, creating a larger number of electrons stored within the individual potential wells. Upon completion of the imaging process, the total charge stored in each potential well is transferred through CCD gates and converted into a digital unit known as an Analog Digital Unit (ADU).

An important term associated with the process of converting electrical charge to an ADU value is CCD Gain. The gain of a CCD is defined as the total number of electrons in a full well divided by the maximum ADU value possible for each pixel:

\[
Gain = \frac{Electrons \ in \ Full \ Well}{Maximum \ ADU \ Value \ Possible}
\]  

(1)

For example, the BYU-I CCD camera has a maximum ADU value of 65,535 per pixel. The maximum number of electrons that can be held within a single pixel is around 90,000. Solving the equation for gain yields a value of 1.37. This means that every 1.37 electrons captured by a single pixel increases the ADU of that pixel by 1. These numbers show the power and precision of charged-coupled devices.

A computer equipped with CCD imaging software, such as CCDSoft, receives the ADU value for each pixel and creates an image based on the varying values of each individual pixel.
1.2 CCD Research Capabilities

CCD imaging allows astronomers and astrophysicists to more accurately study the stars and other celestial objects. Along with taking “pretty pictures”, CCDs are ideal for photometry and spectroscopy. Photometry is a basic astronomical pursuit and is defined as research “to determine the amount and temporal nature of the flux emitted by an object as a function of wavelength.” [3] In simpler terms, photometry is the study of the amount of light emitted from a given celestial object.

Photometry will be discussed in more detail in a later chapter. Astronomical spectroscopy is the application of spectrographic techniques to celestial objects. Astrophysicists are able to determine the chemical and physical construction of distant objects based on their emitted spectral lines. The topic of spectroscopy will not be detailed in this paper.*

*The topic of astronomical spectroscopy is discussed in Optical Astronomical Spectroscopy (Kitchin, C.R.) found in David O. McKay Library.
Chapter II. Preparing Telescope for Operation

2.1 Previous Work

BYU-Idaho’s telescope was obtained in 2008 and student work began in the summer, 2010. Cameron Jones, a graduate of BYU-Idaho, was the first student to work with and set up the telescope. The culmination of this project was a written manual intended to assist future students in properly setting up, balancing, and aligning the telescope. [4] This manual can be obtained from the BYU-Idaho Physic’s department.

2.2 Daily Set-Up Procedures

Once the telescope is properly mounted, balanced, and aligned according to instructions given in *Astrophotography Using the Brigham Young University-Idaho Mak-Newt Telescope*, the equipment should not need to be adjusted unless it is bumped or moved. Users of the telescope will simply need to follow the “Daily Procedures” that are noted in this document.

2.2.1 Connecting the ST-7XE CCD Camera

Connecting the CCD device to the computer and to the telescope properly is essential in order to take quality images. The following steps outline how to connect the device properly:

1. Attach the 9-Pin end of the Keyspan cable to one of the RS-232 serial port connections of the GTD Control panel.
2. Attach the USB end of the Keyspan cable to the bottom USB port on the laptop computer.
3. Remove the white protective cover from the telescope’s eyepiece. If viewing with the CCD camera, also remove the first adapter from the telescope’s eyepiece.

4. Remove the black protective cap from the CCD Camera.

5. Fit the CCD Camera onto the telescope’s eyepiece so that the two bars on the back of the camera are parallel to the telescope’s optical tube. See Figure 2. Securely tighten the pin that holds the camera in place.

![Figure 2: Proper orientation for CCD camera attached to telescope's optical tube.](image)

6. Attach camera’s power supply box to the CCD camera and ensure that its cord is properly plugged into an electrical outlet from the observatory.

7. Attach the white cable that leads from the GTD Control Panel’s Motor/Autoguider port into the CCD Camera.

8. Attach the black USB cable into the port labeled “USB” on the CCD Camera. The other end of the USB cable connects into the school’s laptop on the top USB port. The ports on the camera should look similar to Figure 3.
2.2.2 Connecting Camera to CCD Software

There are several software programs that can be used to automatically image using CCD devices. The school currently has access to CCDSoft 5 and Maxim DL 4. Both software packages are used by professionals and only vary slightly. Users can explore both packages and determine which they are more comfortable with. The following instructions are meant to assist users in connecting the CCD device to the school’s current computer: [5]

1. On the school’s computer open up either Maxim DL 4 or CCDSoft (or any other CCD imaging software you prefer to use).*

2. In the CCDSoft Toolbar, click Camera>>Setup. The “Camera Control” window should open. See Figure 4.

* These instructions will refer to CCDSoft software. Maxim DL 4 is similar to CCDSoft and the setup can be followed almost identically, with a few minor adjustments.
3. In the “Setup” tab click on the button labeled “Connect”. This will connect the CCD camera to the computer and allow you to operate it from the computer. If an error message is received, check to make sure that power is running to the camera and that you can hear the internal fan running. The power can also be switched off and then on again to reset the camera.

4. In the Setup tab, click the button labeled “Temperature”.

![CCDSoft Camera Control window]

5. Enter the desired temperature for the CCD camera.

6. Connect the telescope’s power supply to the port labeled “12V” on the GTD Control Panel. If properly connected, the red LED bulb should be on just above the cables.

7. Connect the Astro-Physics hand controller to the GTD Control Panel. The GTD Control Panel should look similar to Figure 5.

---

* The Cooler Power will initially go to 100% while it is achieving desired temperature. Once the camera is cooled, you should set a temperature that only requires 75-80% of the camera’s cooling capacity. If the Cooler Power percentage is higher than this, set a higher cooling temperature. At night, the temperature will generally be between -5.00 and -20.00 C. Every night will be different, depending on the ambient temperature.
8. On the Astro-Physics hand controller, select “Location 1” and enter GOTO button.

9. On the Astro-Physics hand controller, select “Resume Ref-Park 1”.

10. On the desktop of the school’s computer open up “TheSky6.”


12. Make sure that the computer’s clock is set correctly and ensure that TheSky is using the computer’s clock by clicking on the “Use Computer’s Clock” icon.

13. Set your viewing orientation (generally with the zenith up) by clicking on “Orientation” and then selecting preferred orientation.

2.2.3 Using TheSky Software

TheSky 6 Professional Edition is an astronomy program designed to automatically control amateur and professional telescopes. The program contains many features including a planetarium view that depicts a realistic sky that moves over time in order to simulate the motion of celestial objects. When used together with certain telescope mounts (such as the GTO series mount at the BYU-Idaho livestock center), TheSky can automatically point users to specific objects. [6]
There are many features in TheSky that make telescope operation easier and more effective. The following instructions are designed to assist in the basic setup of TheSky. Users should learn how to more effectively use the software to meet their own needs.

1. In TheSky6, select a bright object well East of the meridian. The object should be high in the sky and fairly bright.

2. A box labeled “Object Information” should open. In the “Telescope” tab (see Figure 6) click on the “Slew” icon. The telescope should begin to move so that it points at the object.*

3. In CCDSoft, click on the “Focus Tools” tab. Make sure that the Imager is being used, relatively short exposures (less than 2 seconds) are set, a Binning setting of 1x1 is selected, and a Delay of around 2-4 seconds. Make sure that the Continuous box is not checked.

4. Click “Take Image”. This will take a single image and allow observers to inspect whether or not the desired object is in fact at the center of the telescope’s field of view.

* While slewing, make sure that none of the cables catch on anything. Even if you are sure that everything is securely fastened, it is a good idea to stand by the telescope and make sure that the many cables do not catch and pull out the camera or knock over the scope.
5. In the toolbar click Image>>Show Cross Hair. This will create a set of crosshairs that will allow the user to more accurately determine if the object is in fact at the center of the camera.

6. In the “Focus” tab, mark the box labeled Continuous and then click “Start Focus.” The camera will now take continuous images while the object is centered.

7. Using the Astro-Physics hand controller, move the telescope slightly so that the object at the center of the crosshairs.

8. If you have had to move the telescope in order to center the object, go back to TheSky6 and click on the object again. A box labeled “Object Information” should be available with several tabs. Click the “Telescope” tab and then click “Sync”. This tells the telescope that it is now accurately pointing at that position in the sky.

9. If the telescope was moved, it is a good idea to move to a fainter object in the sky (magnitude 5 or 6), and repeat the process of centering the object on the camera. Users should remember to Sync the telescope again if the telescope was moved with the hand controller. If the telescope is even slightly off of the object, it will slowly drift from desired positions as it slews across the sky.

Observers should now be able to click on any object in the sky and click the “Slew” button. If the telescope has been properly synced the telescope to the computer, the object should be very near the center of the camera’s field of view.
Chapter III. CCD Imaging Techniques

3.1 Focusing

Focusing the CCD device is an essential procedure in order to obtain quality images. The following guidelines are designed to instruct users who will manually focus the telescope using CCDSOft 5 or Maxim DL 4. Users who have access to an automatic focuser will require the aid of the user’s guide that accompanies the focuser.

Once the telescope is pointed at the desired object, users will properly focus the telescope. Without proper focusing, objects may appear blurry and not as sharp. The following instructions are designed to assist users in achieving quality focus:

1. Point the telescope to a desired region in the sky using TheSky6.
2. In CCDSOft, open up the “Focus Tools” tab and make sure the following settings are achieved (see Figure 7):
   A. The Imager is marked.
   B. Set the exposure time between 0 and 5 seconds. Depending on the brightness of your object, you will have varying exposure times.
   C. Set binning to 1x1.
   D. Set the Delay between 3 and 5 seconds.
   E. The Continuous box should be marked.
3. Now click on the “Clear Graph” button.

4. Set the Graph to “Sharpness”.

5. Select “Take Image”. The camera will begin to take a series of images.

6. Manually adjust the focus during delay periods in order to achieve the highest possible sharpness value. Begin with the large focus knob until the stars look like round balls, and then use the fine focus to achieve the highest sharpness value. As the sharpness increases a greater focus is achieved. The stars should look like small round balls.

![Figure 7: Screen shot of CCDSoft’s “Focus Tools” window.](image)

![Figure 8: BYU-I Telescope’s focusing knobs. The two black knobs on the side are the rough focusers while the gold knob is the fine focuser.](image)
7. A subframe can also be created to view smaller stars by clicking on a previous image and creating a box. This will allow the user to focus in on a specific star rather than an entire field of view.

8. When finished, click “Abort”.

Once adequate focus is achieved the observer can proceed to imaging.

3.2 Auto-Guiding

The BYU-Idaho CCD contains two different cameras. One of the cameras performs imaging while the other autoguides. Even the most accurately aligned telescope will eventually encounter pointing and drifting errors. Auto-guiding is straightforward and provides extremely high benefits. CCDSoft’s auto-guiding feature assists in measuring the position of a star on the tracking CCD every few seconds. If the star moves on the chip between exposures, CCDSoft sends a signal to the mount to move a given direction, correcting the pointing error.

There are two steps involved in correctly auto-guiding during imaging. The first step is to calibrate the mount and the second is to select a guide star and begin auto-guiding. The following steps will assist users in employing the auto-guiding features of the BYU-Idaho telescope:

1. Open the Camera Control Panel and open the Autoguide tab.

2. Position a bright star on the guide detector. Ideally there will not be another star with similar brightness on the detector.

3. Click Take Image and then click on the guide star.

4. Click Calibrate. The program runs for a few minutes and will inform the user if calibration was successful or not. If users receive an error message, the X and Y
calibration times can be adjusted. Diagnosis of most errors can be found in the CCDSoft User’s Manual.*

5. Click Take Image to confirm the position of the guide star. Then, click on the guide star.

6. Set an exposure time. Typically this value will be between 3-5 seconds, but can be longer if the guide star is not bright enough.

7. Click Autoguide to start the autoguiding process. [5]

![Figure 9: The CCDSoft Autoguide menu.](image)

Auto-guiding is not necessary for all images. Most long imaging sessions will prove to be more useful if the auto-guiding feature is employed, since stars will remain in the same spot on the CCD chip. Additional information can be found in the CCDSoft User’s Manual.

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* Users should be aware that the Auto-guiding feature is not successful while using the Luminance Filter on the school’s filter wheel. The filter does not allow enough light to enter the tracking chip inside the camera.
3.3 Image Calibration

Due to the high sensitivity of CCD devices, they are subject to various types of errors during imaging and data processing. These errors typically result in additional electrons being stored in several of the potential wells. These electrons may be the result of thermal heat acquired as the data processing takes place or from other internal sources. While these electrons do not originate from starlight, differentiating them from photoelectrons proves impossible. Image calibration assists astronomers in reducing these errors. There are three specific types of calibration images: bias images, dark frames, and flat fields.

3.3.1 Bias Images

A bias frame is an image taken with a zero-second exposure time. The CCD shutter remains closed while taking a bias image. The result is an image that contains an underlying noise level that is accompanied by each raw image. This noise is the result of reading out data from the camera to the computer that includes converting the total charge in each of the pixel to the digital ADU value for that pixel. The most effective way to obtain a quality bias image is to average 10 or more single bias frames. [7]
3.3.2 Dark Frames

A dark frame is also an exposure taken with the shutter being closed. The dark frame measures the amount of thermal noise, also called dark current, found on the CCD chip during exposure time. The dark frame should be an exposure lasting the same amount of time as the raw image frame. An astronomer plans to take a 10-minute exposure of an object, should take a dark frame lasting 10 minutes. Dark frames also provide information about “hot” pixels on the CCD chip. “Hot” pixels read higher than average pixels. [7]

CCDSoft gives users the option of automatically taking a dark frame prior to an imaging session and applying it to each image. In most situations, this dark frame will be sufficient, however there are certain types of research that require users to take and apply the dark frame to each image.

3.3.3 Flat-Fields

A flat-field image corrects variations among the thousands of pixels located on an individual CCD chip. Flat-field frames are obtained by taking an open-shutter
image of a uniform backdrop. [7] Flat-field calibration images are much more difficult to obtain than bias or dark frames. For this reason, there are many methods for obtaining a quality flat-field. The two most common methods are detailed below. One way that any astronomer can obtain a flat-field image is to aim their telescope at the twilight sky when it is evenly illuminated. Several shots should be taken and an average will create a quality flat-field. ADU counts should be about half of the full-well capacity.

![Master Flat Image](image)

Figure 11: A master flat used to calibrate images taken with the BYU-Idaho CCD camera.

### 3.3.4 Master Calibration Image

Once each calibration image is taken, CCDSoft can create a Master Calibration Image that can be applied to an entire set of images. This is done by following the steps listed below:

1. In the toolbar, click Image >> Reduce >> Image Reduction.
2. Select “Add Group” and name the image reduction group.
3. Highlight the folder labeled “Bias Frames” and select “Add Frames.”
4. Upload each of the bias images that were taken for that specific set of images.

5. Follow the same procedure for Flat Frames and Dark Frames (if applicable).

Once each of these groups has been uploaded, CCDSoft provides an option to combine the images; this will create a Master Bias Frame, Master Dark Frame, and Master Flat Field. These frames will be used to reduce the raw image in order to reduce the majority of unwanted noise. Image reduction essentially takes the raw image and subtracts the bias frames and dark frames and then divides the entire image by the master flat field, yielding a final reduced object frame:

\[
\text{Final Object Frame} = \frac{\text{Raw Object} - \text{Bias Frame} - \text{Dark Frame}}{\text{Flat Field}}
\]  

(2)

While image calibration may sound difficult in theory, CCD software packages, such as CCDSoft and Maxim DL, make the process simple and effective. Image calibration effectively increases the images Signal-to-Noise Ratio (S/N):

\[
\frac{S}{N} = \frac{N^*}{\sqrt{N^* + np(ns + nd + nr^2)}}
\]  

(3)

Where \(N^*\) is the number of photons collected during observation over the entire area of interest (can be one pixel or many), \(np\) is the number of pixels under consideration, \(ns\) is the number of photons per pixel due to background noise, \(nd\) is the number of dark current electrons per pixel, and \(nr\) is the number of electrons per pixel from readout noise. The goal of image calibration is to make the image’s S/N ratio as high as possible, which happens as the \(ns + nd + nr^2\) term becomes small. The final product of this process is a quality image that can be used for scientific analysis. [3]
Figure 12: Image of M-92 prior to calibration images being applied.

Figure 13: Image of M-92 after calibration images have been applied.
Chapter IV. Photometry

In astronomy, photometry is the process of measuring the brightness of stars in the sky. [8] Photometric studies prove extremely useful for astronomers seeking to determine luminosities, magnitudes, and distances of stars and other objects. More advanced techniques can yield information about an object’s temperature or chemical make-up. Photometry is also employed when studying variable stars, active galactic nuclei, and supernovae, as well as searching for minor or extrasolar planets.

CCD devices are ideal for photometric evaluations because they can distinguish small differences in brightness. The research outlined in this paper is based on the use of the SBIG ST-7 XME camera in order to observe the period of the variable star RV Ursa Major. While variable star studies can be effectively completed using the BYU-Idaho telescope set-up, there are also many other types of projects that will be detailed later on.

4.1 Variable Stars

A variable star is any star whose brightness changes over time. The change in brightness can vary from a few hundredths of a magnitude to as much as 10 or 15 magnitudes. The time scale for this change might be a few minutes or several years. All of these changes and time scales depend on the type of variable star in question. Several databases have been set up to organize and catalog the more than 100,000 variable stars that have been observed by professional and amateur astronomers. [9]
Databases used for this project include the AAVSO online catalog, and the General Catalogue of Variable Stars (GCVS) found within TheSky6 Professional Edition Astronomy Software package.

There are six main types of variable stars that can also be classified into further categories:

1. **Eruptive Variable Stars** – EVS stars release large amounts of energy suddenly that cause the brightness to increase by as much as 200 times within a short period of time. A violent process such as stellar flares causes this energy release. Variability in an EVS star can be difficult to track because the time between eruptions is random.

2. **Pulsating Variable Stars** – PVS stars experience periodic expansion and contraction, similar to lung respiration in humans. These periodic changes in size can be uniform across the star or distributed only on a single side, depending on the stability of the star’s surface.

3. **Cataclysmic Variable Stars** – CVS stars experience outbursts that are caused by intense thermonuclear processes. Large novae are an example of a CVS. In most cases, CVS stars are extremely close binary systems.

4. **Rotating Variable Stars** – RVS stars are irregularly illuminated and may be brighter on one side than the other, or have a distinct shape that makes one side appear brighter than the other. While the star’s brightness does not actually change, it appears to vary from the astronomer’s point of view as the star rotates on its axis.

5. **Eclipsing Binary Stars** – EBS star systems are two or more stars that interact in such a way that they periodically eclipse one another, causing the apparent magnitude of the system to change with respect to the observer.
6. Optically Variable X-Ray Sources – This distinct type of variable star can only be observed through the use of specialized equipment that monitors the x-rays emitted from a given stellar object. The school does not currently have capabilities to perform such research. [10]

RV Ursa Major, the variable star studied throughout this project, is a specific type of pulsating variable star known as RR Lyrae stars. More commonly, RR Lyrae variables are considered part of a class of variables known as Cepheids.

4.2 Observing Variable Stars

Observing variable stars requires some practice, but with the right equipment it can be done successfully and accurately. Many of the stars found in databases require periodic observations in order to ensure accuracy and note any changes in the period or luminosity of the star. These databases provide various tools that assist observers in making accurate measurements. For instance, the American Association of Variable Star Observers (AAVSO) provides star charts that assist in finding specific variable stars. These star charts also indicate all standard stars that are found within the field of view of a given telescope. Standard stars will be discussed further in section 4.3.

Once the coordinates for the variable star have been located, TheSky6 can automatically point the telescope to that star. TheSky also contains a large database of variable stars and their positions in the sky.

Depending on the expected period of the variable star, images should be taken at distinct intervals. If the period of a variable star is several months or years, one or two images might be adequate per night. However, if the period is over the course of
a few hours or days, images should be taken more frequently. CCDSof can make this
process easy by simply being set up to take an image automatically at a given time
interval, allowing observers to take hundreds of images during the course of the
night without actually being near the telescope.

4.3 Aperture Photometry Measurements

CCDs have made measuring the relative magnitudes of variable stars simple.
Once a set of images has been taken, a sophisticated computer program found
within Maxim DL can create a set of data points that correspond to the relative
magnitude of the variable star for each image.

Maxim DL employs a technique known as aperture photometry. The software
generates an aperture over the star and adds up each of the ADU counts for every
pixel found within the aperture. A similar aperture is placed over the standard star
and the total number of counts for each star is compared. This gives a ratio of the
number of photoelectrons that reached the CCD device from one star over the
number of photoelectrons from the standard star. The program also takes into
account any background noise found throughout the image in order to ensure more
accurate results.

Measuring the relative magnitude of a variable star requires knowledge of three
objects in each image: standard stars, check stars, and the variable star.

1. Standard Stars – Standard stars are an essential part of variable star observation.
These stars are regularly monitored and have been shown to not vary in brightness.
This gives the observer a way to compare the variable star’s brightness to a
standard brightness. If a star’s luminosity appears to change with respect to the standard star then it is considered a variable star.

During measurements, the standard star is assigned its accepted magnitude in each of the images. For example, in the results found in Appendix B the standard star was assigned a magnitude of 12.56. The ADU counts of the check and variable stars can then be compared to the ADU value of the standard stars and assigned a magnitude relative to the standard star.

2. Check Stars – The check star is used to calculate the uncertainty in the images. When more than one standard star is found within the field of view, one is assigned to be the standard star while the other is the check star.

The magnitude of the check star is determined by comparing the number of photoelectrons within its aperture to the number of photoelectrons in the standard star’s aperture. Because the check star is also a standard star, ideally it will be measured to have the same magnitude in every image.

In less than ideal situations, the magnitude of the check star will vary from image to image. This variation is due to errors in the imaging process, atmospheric turbulence, and other imperfections in the measurement process. The standard deviation of the check star magnitudes results in the standard deviation in each of the stars of that image and can be reported as the error in the variable star’s magnitude calculations.

Appendix B shows the measurements of the check star magnitude in each of the images used in the research of RV Ursa Major. The standard deviation of the check star can be found in the results section of Chapter 5.
3. **Variable Star** – The variable star is the object in the image whose magnitude changes with time. The aperture that is placed around the variable star adds up the total number of photoelectrons and compares that number to the number of photoelectrons found in the check star. A relative magnitude is then calculated and assigned to the variable star for that specific image.

The magnitude of the variable star is expected to change over time, so the method for calculating the error in the variable star is to assign the same standard deviation to the variable star’s magnitude as the check star’s magnitude.

![Figure 14: A typical star field with indicators showing the locations of the variable star, standard star, and check star.](image)

In order to access the photometry tool in Maxim DL, users should open up all of the images intended to be analyzed and follow the instructions listed below:

1. In the toolbars, select Analyze >> Photometry.

2. Under the Mouseclick Tags option, select “New Object.”
3. Click on the object that is being analyzed. The preset settings in Maxim DL allow the program to automatically select the same object in each of the remaining images that are being analyzed, so this only needs to be done in one image.

4. Under the Mouseclick Tags option, select “New Reference Star.”

5. Click on the region where the standard star is found in the image.

6. Input the known magnitude of the reference star.

7. Under the Mouseclick Tags option, select “New Checkstar” (if applicable).

8. Scan through each of the images to ensure that apertures have been placed around each of the important objects. If an image is not high quality and does not include the apertures, it can be excluded by selecting “Exclude Image.”

9. Select “View Plot.” The software will analyze each of the images and after a few minutes will upload a graph showing Magnitude along the y-axis and Julian Date along the x-axis.

10. Select “Save Data.” Maxim DL will save the data as a CSV file that can be opened in most spreadsheet applications, such as Microsoft Excel.

![Figure 15: A screen shot of the Maxim DL Photometry tool in action. The apertures can be seen around the variable, reference, and check stars.](image-url)
Once the data is obtained, analysis can be made and a light curve can be created. A light curve indicates the period of the variable star, along with the maximum and minimum magnitudes. In order to obtain accurate magnitudes, the magnitude of both check and reference stars should be precisely known.

As is the case with all scientific studies, variable star studies have a margin of error associated with them. Standard procedure for error calculation in variable star studies is to calculate the standard deviation of the magnitude values obtained for the check star. [11] Maxim DL will automatically assign the designated magnitude to the reference star of each image. The check star will then vary in accordance with the error of the image (See Appendix for check star magnitude values and sample error calculations). An ideal situation will report the same magnitude for the check star on each of the images taken. In most cases, however, a standard deviation between 0.01 and 0.1 is obtained. Photometric studies that result in a standard deviation larger than 0.1 is often considered to be too erroneous to be useful.
Chapter V. RV Ursa Major Variable Star Study

In this chapter we report on the findings of a photometric evaluation of the variable star RV Ursa Major. This star is located in the Ursa Major constellation at Right Ascension 13:33:18.09 and Declination +53:59:14.60 (2000). According to the AAVSO, this star has a period of 0.46806 days and has reported maximum magnitudes of 9.8 and minimum magnitudes of 11.3. A star chart of the region can be found in the Appendix.

The primary expectation of the results is to obtain a period of the RV Ursa Major that is comparable to the accepted 0.46806 days. The maximum and minimum magnitudes are not expected to be observed similarly to those listed by the AAVSO, mainly because those are the outer limits reported to the database, and most extreme values are only recorded occasionally. We also expect to be able to create a phase curve detailing the period of RV Ursa Major and the shape of its curve.

The reported results were obtained between 8-17-2010 and 8-27-2010 at the BYU-Idaho livestock center using a 10” Maksutov-Newtonian telescope with an attached SBIG ST-7 XME camera. The images were taken using the standard clear filter of the SBIG CFW-10 filter wheel.
5.1 Results

Figure 16: Magnitudes found over an 11-day period. Data for this figure can be found in the Appendix. Uncertainty in magnitude over the entire range of data is found in the bottom corner of the graph.

The data represented in Figure 16 is all of the data obtained during the 11-day analysis of RV Ursa Major. It can be noted that several maxima and minima are found in the data. In order to determine the average period of RV Ursa Major, the time difference between the last reported maximum and the first reported maximum is calculated and then divided by the total number of periods that are expected during that time. In this study, the number of expected periods is determined based upon the accepted period of 0.46806 days. The following equation represents this relationship,

\[
\frac{(2455435.67131 - 2455426.78939)\text{days}}{19\text{ periods}} = 0.46746 \text{ days/period} \tag{4}
\]

and is also expressed in Table 1.

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<th>Maximum (JD)</th>
<th>Difference (JD)</th>
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<th>Average Period</th>
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Table 1: The first and last maxima observed over an 11-day period with the average period reported as the time difference divided by the expected number of periods over the given time. The uncertainty calculated is based on a standard deviation of the average periods in Table 2.
If the expected number of periods were unknown, observers would need to acquire sufficient data in order to determine an estimated period from a chart similar to Figure 16.

The uncertainty in the period is also determined by using a standard deviation, similar to the uncertainty in the measurements of the magnitude. The data used to determine the error in the period are found in Table 2. Each of the Julian dates listed are measured maxima of RV Ursa Major and the Difference (JD) column shows the time difference between each measured maximum. The column labeled “Number of Periods” is the expected number of periods that have passed between maxima based on the accepted periodicity of 0.46806 days. The Average Period is the difference in time between periods divided by the number of periods expected to have passed.

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Table 2: The Julian Date of each of the observed maxima along with the average period reported between the observed maxima.

Variable star data is often reported in a phase curve. Phase is a quantity between 0 and 1 assigned to each image that describes the place in the period or variation of the variable star. Due to the length of time of the period of RV Ursa Major, it is not possible to record an entire period, or phase, of the light curve over the course of one night. A different technique must be employed.

To create the star’s phase curve, as seen in Figure 17, each of the data points must be assigned to a given part of the period. This can be done once the average
period of the star has been determined. The elapsed time from the initial image to the image in question can be calculated and then divided by the average period of the star. The total number of periods that have passed is then subtracted from the value, resulting in each image being assigned a value between 0 – 1.

![Figure 17: Phase curve of RV Ursa Major detailing the general shape of the light curve of the variable star.](image)

5.2 Analysis of Results

The measured period of RV Ursa Major between 8-17-2010 and 8-27-2010 was 0.46746 ±0.00395 days. The accepted value of 0.46806 is within the range of error for this measurement. The maximum magnitude measured during the period of observation was 10.350 and the minimum magnitude was 11.116.

The phase curve plot accurately describes the activity of RV Ursa Major and correlates well with what most Cepheid variable phase curves show. The star quickly reaches its maximum magnitude and slowly dims for several hours before again dramatically increasing in magnitude. It is noted, however, that many more
data points vary from the expected phase curve during the dimmest portions of the period compared to those at the brightest portions of the period. This is possibly due to a larger natural variation in brightness during this part of the period.

The margin of error in the magnitude measurements was ±0.03091 for the entire range of data. The first two days of measurements were much less accurate and contributed primarily to this standard deviation. The margin of error for the first two nights was ±0.05312. More accurate focusing resulted in the remaining days yielding a margin of error of ±0.02350. These results show the importance of achieving accurate focus prior to imaging.

Future data is expected to be much more accurate due to the assistance of Dr. Tom Davis. Dr. Davis is a local expert in amateur astronomy and assisted in properly collimating and aligning the telescope. A properly collimated telescope can yield signal-to-noise ratios that are 5 or more times as high as those achieved during this project.
Chapter VI. Conclusion and Future Research

6.1 Findings

The main research goal of this project was to analyze and understand the periodicity of the variable star RV Ursa Major. The variable star exhibits features of other Cepheid variable stars. The star has a short period of 0.46746 ±0.00395 days and its light curve is similar to other periodic and Cepheid variable stars.

6.2 Future Research

Aside from the variable star study, this project was intended to guide future research by BYU-I students. Students at BYU-Idaho who have little or no previous experience in astronomy can obtain research experience at the telescope sight. The following is a list of several of the many possible projects that could be performed by students:

1. **Variable Star Studies** – There are literally hundreds of thousands of variable stars in the sky that must be monitored and reported to groups such as AAVSO. Additional information and a list of resources can be found at www.aavso.org.

2. **Spectroscopy** – While the school does not currently have access to the instruments needed to analyze the spectroscopy of stellar objects, it is a possibility in the future for interested students. Various types of filters can be purchased which allow observers to record the amount of hydrogen, helium, and other elements found within an object and thus determine its structure.
3. **Minor Planet and Comet Searches** – The BYU-Idaho telescope currently has the capabilities to search for and monitor minor planets in our own solar system as well as discovering and monitoring comets, asteroids, and other orbiting objects.

4. **Data Analysis, Image Combining and Reduction Techniques** – In order to obtain the most accurate results and produce the highest quality images possible, projects could be performed to determine the most effective way to reduce, combine, and analyze images. These types of projects would greatly benefit future students and guide future research.

   Many resources are found on campus ranging from library books and senior papers, to faculty members with prior experience. If future students take initiative and desire to produce quality research with the BYU-Idaho telescope, they will have an opportunity to gain research skills and contribute to real science.
Bibliography


Appendix A—RV Ursa Major Star Chart

The star chart located on this page was provided courtesy of the American Association of Variable Star Observers. The organization was set up in order to provide assistance to amateur astronomers across the world. Numbers indicate standard stars whose known magnitudes are also listed on the website.
### Appendix B—Data

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Appendix C—Calculating Uncertainty

Most of the sources cited in this report give detailed instructions on calculating the uncertainty of the findings. This section summarizes the most basic method for calculating error. More intensive projects may require additional methods to be applied in order to determine the uncertainty. Researchers are referred to sources cited in this text, specifically Koppelman [11].

The most basic method for calculating uncertainty is to determine the standard deviation of the check star magnitudes. The standard deviation is defined as,

$$\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (x_i - \bar{x})^2} \quad (5)$$

where $N$ is the number of samples, $x_i$ is the magnitude of the check star for the image in question, and $\bar{x}$ is the average value for all of the check star magnitudes in question.

For example, given the following data which is partially taken from actual data used in this report,

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<th>Standard Star</th>
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the standard deviation would be calculated to be 0.03074. The only values that are considered are the check star magnitudes. From this calculation it can easily be seen that the larger the sample size, the more accurate the standard deviation will be in determining the uncertainty of the data set.
Appendix D—Telescope Set-up Steps

1. Uncover telescope.
2. Attach Dew Shield.
3. Attach 9-Pin Keyspan cable to RS-232 serial port and USB end to computer.
4. Securely attach CCD Camera to telescope eyepiece.
5. Connect power supply to CCD camera.
6. Connect Autoguiding cable to the CCD camera and the GTD Control Panel.
7. Connect CCD USB from the camera to the computer.
8. Open either Maxim DL 4 or CCDSoft. *Note: These instructions are directed more specifically to CCDSoft users. Maxim DL users will find that the commands are somewhat similar.*
9. Connect the CCD device to the computer.
10. Set the device’s temperature.
11. Connect telescope’s power supply.
12. Connect Astro-Physics hand controller to the GTD Control Panel.
13. Select “Location 1” and then “Resume Ref-Park 1”.
15. Establish the link between the computer and the telescope.
16. Check to make sure the computer’s clock is set correctly and that TheSky is using the computer’s clock.
17. Set viewing orientation.
18. Sync the telescope to a bright object that is east of the meridian. See section 2.2.3 in *Research Using BYU-I Telescope and Photometry of Variable Star RV Ursa Major.*
19. Focus the CCD device.
20. Take calibration images. *Note: Bias Images can be taken any time; dark frames should be taken just prior or just after imaging session, or both; flat fields will generally be taken when during twilight hours when the sky is most evenly illuminated.*
21. Point telescope at stellar object to be imaged.
22. Set up the auto-guiding feature.
23. Set image time, number of images to be taken, filter to be used, and any other preferences desired for the image.
24. Begin imaging.
25. Save image. *Note: Autosaving is a feature available that will automatically save all images taken while enabled.*
26. When finished imaging, turn off temperature control and allow the CCD device to cool down for several minutes.
27. Return telescope to Park Position 1.
28. Turn off power supplies, unplug all cables and store them in a safe place.
29. Remove Dew Shield and place black lid back on the telescope.
30. Remove CCD device and replace white cover over the eyepiece.
31. Cover telescope securely with tarps provided.