VARIABLE STARS

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ABSTRACT

The objective of this paper is to research the causes for variability and identify selected stars within telescope reach. In addition, individual observations of the magnitudes (Mv) of selected variable stars were made and a plan designed for more extensive work on variable stars was developed.

Variable stars are stars that vary in brightness. They can range from a thousandth of a magnitude to as much as 20 magnitudes. This range of magnitudes, referred to as amplitude variation, can have periods of variability ranging from a fraction of a second to years. Algol, one of the oldest know variables, was known to ancient astronomers to vary in brightness. Today over 30,000 variable stars are known and catalogued, and thousands more are suspected. Variable stars change their brightness for several reasons. Pulsating variables swell and shrink due to internal forces, while an eclipsing binary will dim when it is eclipsed by its binary companion. (*Universe* 1999; *The Astrophysical Journal*)

Today measurements of the magnitudes of variable stars are made through visual observations using the naked eye, or instruments such as a charge-coupled device (CCD). The observations made for this paper were reported to the American Association of Variable Star Observers (*AAVSO*) via their website. The AAVSO website lists variable star organizations in 17 countries to which observations can be reported (*AAVSO*).

1. IDENTIFICATION OF STAR FIELDS

Observations were made from Denver, Colorado, United States. Latitude and longitude coordinates are 40°N, 105°W.

1.1. EYEPIECE FIELD-OF-VIEW (FOV)

AAVSO charts aid in locating the target variable. Whether a star field on the chart is 5 arcminutes square, or 5 arcseconds, the observer needs to know the FOV in the eyepiece. If the FOV is known, the amount of time needed to identify the star field and the target variable can be significantly reduced.

The drift method was used to determine the FOV (*AAVSO*). As an example, computing the FOV for the 32mm Plössl eyepiece consisted of locating a star on or near the celestial equator. The star was placed just outside the east side of the eyepiece field of view and the Right Ascension of the telescope disengaged. This allowed the star to "drift" into view from east to west. The time it took the star to drift from the east side of the eyepiece and exit the west side was measured in seconds using a stopwatch. Nine measurements were made for the 32mm eyepiece. This time was converted to arcseconds by using the Earth's rotational speed of 1^o /4-minutes. This is proportional to the FOV in arcseconds (unknown)/FOV in seconds using the drift method. The formula is expressed as:

$1^o/4' = D/m$

D = FOV in arcseconds, UNKNOWN.
m = Measured drift of star across eyepiece in seconds.

For the 32mm eyepiece:

$1^o/4' = D/m$

3600s/240s = D/56.31s

240(D) = 3600/56.31

D = 202,716/240

D = 844.65 arcseconds ⇒ 844.65 arcs/60 = 14.1 arcminutes

D = FOV in arcseconds.

m = Nine measurements averaged to 56.31 seconds.

1^o = 3600 seconds.

4' = 240 seconds.

1.2. STAR CHARTS

One of the first steps to identifying and locating variable stars is to review appropriate star charts. The star charts published by the AAVSO were used for this project.

Two types of charts were used for the observations noted in Table 1: Standard and Preliminary. According to the AAVSO, Standard Charts for variable stars are charts that have been in the AAVSO observing program for decades and have well-established comparison stars. The AAVSO recommends use of this chart whenever possible, especially for the new observer. The Preliminary Charts are variables that have only "recently" been added. The term 'recently' is relative; the chart for variable *TT Boo* (designation 1454+41) for example, is 20-years old! The details in the charts vary from 5 arcminutes/millimeter for 'a' scale, to 2.5 arcseconds for the 'g' scale. Binoculars can be used for the 'a' scale chart, but a large telescope is needed for charts 'e', 'f', and 'g' scales. For this project, the 'e' scale chart was the smallest detailed chart used.

Other stars identified by their magnitude surround each variable star on a chart. These are comparison, or comp stars, which aid in identifying the magnitude of the variable. The comparison stars are identified by their magnitude and measured in tenths. The decimal point is omitted to avoid confusing the decimal with the point of a star, i.e., 10.1 magnitude would be 101 on the chart (*AAVSO*).

1.3. VIEWING ORIENTATION

Correctly identifying the variable can be one of the most challenging tasks in variable star observing. The observer must be alert to star field orientation in the eyepiece, mental 'ping-pong', and quirks of the human eye.

The observer takes into account whether he/she is using a refractor, reflector, or Schmidt-Cassegrain (S-C) telescope, and if a prism is attached to the eyepiece. A refractor, for example, will invert and flip the image so that north and south are inverted, and east and west are flipped. The eyepiece prism will correct north and south, but not east and west. Giving enough attention to image orientation is crucial to identifying the star field where the variable is located. The AAVSO publishes information on how to use charts and eyepiece orientation.

Once the observer understands how objects will appear in the eyepiece, then he/she focuses on properly orienting the chart. The 'a' scale chart will show north as up, but east and west will be flipped. All other charts will have south as up.

Mental ping-pong occurs when the observer convinces himself/herself that the star field viewed in the eyepiece matches that of the chart. After years of experience in aviation navigation, I can attest to the ease of convincing oneself that the terrain features match the map, even though there may be conflicts. The same applies to star fields, especially if there are star patterns similar to the star chart. Proper orientation of the FOV is essential for accurate observations.

The human eye has several quirks that can affect the quality of an observation. The first is the Purkinje effect of the retina, which makes red stars grows brighter the longer people stare at them. To combat this, keep the eyes moving. Moonlight and light pollution also make red stars look too bright. This is one reason sky conditions should be reported in the observing log. The viewing angle of the eye also affects the way people see. If the star is viewed in the lower part of the vision field, it will appear brighter than if viewed when the head is tilted so the line joining the eye is parallel to the line connecting the two stars under comparison. Most of these quirks can be overcome by using averted vision, where the eye does not stare at the variable but keeps moving (*Sky & Telescope* 1996).

The last human element is one people can do little about: age. The human eye lens yellows over the years, making red stars seem increasingly bright relative to white stars (*Sky & Telescope* 1996). According to Turner, "The human eye is sometimes perceived to be relatively unreliable as a photometric detector" (Percy 1993; Levy 1998), but experiments conducted by Turner "clearly [shows] the human eye can attain a photometric accuracy of ±0.1 magnitude." (Turner 1999)

I have been observing variables for more than two years, and still consider the task of identifying the star field correctly a bit tricky. There were times during those two years that I spent up to two hours identifying one variable. My wife says I should get a life.

2. IDENTIFICATION OF VARIABLE STARS

The Clark 20" telescope at the University of Denver's Chamberlin Observatory is capable of yielding images beyond 16.5 Mv. Of course, this is limited by the sky conditions and its location in Denver, Colorado. Four variables were chosen for this project, primarily for their faintness and the challenge of identifying each. Each variable is identified by a name, its designation, which is the astronomical coordinate, and a brief description of it characteristics. (*AAVSO*)

<u>CR Bootis</u>
CR Boo, designation 1344+08, is a magnetic cataclysmic variable of the type *AM Herculis*. No period of revolution is published, but *AM Her* type variables have periods that can be measured in hours. It has an amplitude variation of 13.0-17.5.

<u>Z Bootis</u>
Z Boo, designation 1401+13, is an M5 spectral class, red giant. It is a Long Period Variable (LPV) of 282 days with strong emission lines (*Universe* 1999) and an amplitude variation of <9.3 -14.8>[a].

<u>RS Virginus</u>
RS Vir, designation 1422+05, is an M6 spectral class, red giant. It is a LPV of 353 days with strong emission lines and an amplitude variation of <8.1-13.9>.

<u>TT Bootis</u>
TT Boo, designation 1454+41, is a cataclysmic variable, *SU Ursae Majoris* sub-class (Dwarf nova). It has a period of approximately 45 days and an amplitude variation of 12.7-15.6.

3. OBSERVATIONS

Four variable stars were observed during seven nights, between March 21 and June 1, 2001, for a total of 28 observations (Table 1). All observations were made using the University of Denver's historic Chamberlin Observatory Alvan Clark 20-inch f/15

[a] < means fainter than, while > means brighter than. Therefore, a magnitude of <9.3 means the variable is fainter than 9.3, and 14.8> means it is brighter than 14.8.

refractor telescope. Four variables were chosen to make the star field easier to recognize and lessen time wasted trying to identify the variable.

During the 73 nights in the observing schedule, there were approximately 37 weather nights when no observations were possible. For observations not including variable stars, an observer can log the atmospheric "seeing", as defined by the Antoniadi Scale of I - V, with I=perfect seeing and V=appalling. However, when commenting on the conditions in the report to the AAVSO, "W" is used for weather related problems such as haze, clouds, poor seeing, etc. Other keys include I = identification of variable uncertain, M = moon present, and V = star at or near limit of visibility.

Table 1. Observations

Designation	Variable	Date/Time[1] mmddyyyyhhmm	Mv	Comp. Stars[2]
1344+08	CR Boo	032220010315	<14.1	114,138,141
1401+13	Z Boo	032220010415	<10.9	101,112
1422+05	RS Vir	032220010330	<13.2	124,131,133
1454+41	TT Boo	032220010505	<14.8	128,139,148
1344+08	CR Boo	032420010335	<14.1	138,141
1401+13	Z Boo	032420010405	<10.1	101,112
1422+05	RS Vir	032420010430	<13.3	128,132,133
1454+41	TT Boo	032420010500	<14.8	139,148
1344+08	CR Boo	033120010340	<14.1	138,141
1401+13	Z Boo	033120010405	<9.7	97,101
1422+05	RS Vir	033120010445	<13.3	128,132,133
1454+41	TT Boo	033120010535	<14.8	128,139,148
1344+08	CR Boo	041420010340	<14.1	122,138,141
1401+13	Z Boo	041420010410	9.6	97,101
1422+05	RS Vir	041420010450	<13.3	131,132,133
1454+41	TT Boo	041420010540	<13.9	128,139,148
1344+08	CR Boo	042020010430	14.1	122,138,141
1401+13	Z Boo	042020010455	9.5	97,101
1422+05	RS Vir	042020010535	13.2	131,132,133
1454+41	TT Boo	042020010630	<14.8	128,139,148
1344+08	CR Boo	051220010350	<14.1	122,138,141
1401+13	Z Boo	051220010415	9.8	97,101
1422+05	RS Vir	051220010455	12.8	124,128,131
1454+41	TT Boo	051220010550	<14.8	128,139,148
1344+08	CR Boo	060120010350	<13.8	114,122,138
1401+13	Z Boo	060120010420	10.3	101,103,104
1422+05	RS Vir	060120010510	11.6	112,113,119
1454+41	TT Boo	060120010605	<13.9	128,139

[1] All times Universal Coordinated Time.

[2] Comparison Stars provided on the AAVSO charts, with known magnitudes. The decimal point is eliminated.

For quicker and more accurate identification of each variable, a graduated approach, starting with the widest FOV eyepiece, and moving to the narrower FOV, was used. Note also that the 32mm eyepiece is a super Plössl of good quality. The "out-of-focus" method is used frequently to compare brightness of disks. This basically involves turning the eyepiece focus knob until the point of starlight is an out-of-focused disk, which allows for easier comparison of brightness.

Prior to all observations, I calibrated my watch with the atomic clock in Boulder, Colorado. Unless otherwise noted, all times are Universal Coordinated Time (UT). Daylight Savings Time began April 1, 2001, for the United States, which meant that clocks were advanced one hour, and starting times were later.

4. CAUSES OF VARIABILITY

There are essentially three reasons why stars vary in brightness. In a binary system, one star may eclipse the companion star, causing the observer to see a dimming in brightness; some stars expand and contract resulting in a change in luminosity--we call these pulsating stars. Also there are the stars that show outbursts caused by thermonuclear processes in their surface layers (novae) or deep in their interiors (supernovae) until a critical point is reached and thermonuclear reactions cause the star to eject part of its shell. These are called cataclysmic variables (CV). (*AAVSO*)

An additional product of stars in binary systems and CV's, can be a variable visible only in the non-visual part of the electromagnetic spectrum. Some of these are referred to as pulsars and pulsating x-ray sources because they vary in brightness, but are in a different part of the spectrum than visible light. (*Universe* 1999)

The stars mentioned above comprise two groups of variable stars: **intrinsic**, where variability is caused by physical changes to the star and **extrinsic**, which is caused by the eclipse of one star by another or by the effects of stellar rotation. No extrinsic variables were observed.

There are two classes within the intrinsic group of variables: pulsating and eruptive (cataclysmic), and two classes within the extrinsic group: eclipsing binary and rotating stars.

4.1. INTRINSIC VARIABLES

<u>Cataclysmic variable</u> (CV)
A CV (***TT Boo***), as the name implies, is a star that has an occasional violent outbursts, caused by thermonuclear processes either on its surface or deep within its interiors. CV's are also referred to as Eruptive variables. Of the four sub-classes of cataclysmic variable,

the Dwarf Novae is the class within which *TT Boo* is found. These are close binary systems with a white dwarf primary star surrounded by an accretion disk. Dwarf novae have three sub-classes*: U Geminorum, Z Camelopardalis* and *SU Ursae Majoris*. These systems have two distinct kinds of outbursts. One is faint, frequent and short, with duration of 1 to 2 days. A superoutburst is bright, less frequent and long, with duration of 10 to 20 days. (*The Astrophysical Journal*; *AAVSO*)

A review of the reports (Table 2) submitted by observers dating back to February 1998, indicate that *TT Boo* did exhibit several outbursts. Some outbursts reached maximum brightness in a matter of hours, as exhibited by the September 17, 1999 outburst, which reached an amplitude variation of almost 2 magnitudes.

Table 2. TT Boo Cataclysmic Outburst

Outburst Start & End Date	*Maximum & Minimum M_v*	*Amplitude*[3]
Feb 10.5021 (1998)	<14.8	1.9
Feb 12.4833	12.9	
May 24.2188 (1998)	<15.7	2.0
May 26.2375	13.7	
Mar 4.001 (1999)	<14.8	1.4
Mar 7.92	13.4	
Apr 25.054 (1999)	<14.8	1.1
Apr 27.924	13.7	
Jul 14.1 (1999)	<15.0	1.6
Jul 15.1063	13.4	
Sep 17.839 (1999)	<14.8	1.9
Sep 17.852	12.9	
Nov 5.0681 (1999)	<14.8	2.5
Nov 7.75	12.3	
Jan 4.135 (2000)	<15.4	1.6
Jan 9.115	13.8	
Feb 7.5049 (2000)	<15.4	1.8
Feb 8.3361	13.6	
Jul 2.001 (2000)	<13.9	1.4
Jul 3.1208	12.5	
Sep 2.867 (2000)	<14.3	0.7
Sep 5.87	13.6	
Feb 11.1405 (2001)	17.5[4]	4.9
Feb 14.9100	12.6	
Apr 12.8938 (2001)	<15.2	1.7
Apr 13.9270	13.5	
Apr 15.3429	14.6	1.1

[3] Range between maximum and minimum brightness is called the amplitude.

[4] The Feb. 11 observation was taken with a CCD, while the Feb.14 obs was taken visually. All others were visual with no instrumentation.

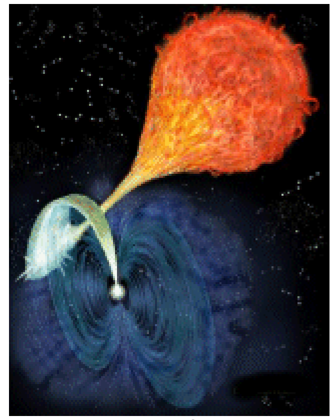
Most outbursts took 2 to 3 days to reach maximum and averaged an amplitude variation of 1.6333. The exception was the outburst recorded on February 11, 2001, which occurred over a period of 3 days and reached an amplitude variation of 4.9 magnitudes. While the CCD is considered to be much more accurate in measuring amplitude than the human eye, the accuracy achieved with the eye should not be underestimated as explained in Section 2.3. (Turner 1999). No "superoutburst" was found during the record review, but there were literally hundreds of observations for *TT Boo* not reviewed by this writer.

<u>Magnetic cataclysmic variables</u> (MCV)
MCV's **(*CR Boo*)** are exotic variable stars of the *AM Herculis* (Polar systems) and *DQ Herculis* (Intermediate Polar system) class.

Polars display magnetic field strengths on the order of 10-100 Mega Gauss, a magnetic field so powerful that it locks the two stars of the binary system in synchronous rotation so the white dwarf's spin period is the same as its orbital period, and prevents the formation of an accretion disk around the white dwarf (*The Facts on File Dictionary of*

Astronomy 1994). Thus the white dwarf star spins at the same rate as the two orbit each other - a *synchronous rotation* that is the defining characteristic of an *AM Her* star (AAVSO, Hellier 2001).

In Intermediate Polar systems *(DQ Her stars)*, the spin period of the white dwarf is 10 times shorter than orbital period.



Artistic impression of an AM Her system. The blue haze represents the white dwarf's magnetosphere. *Image copyright* *Russell Kightley Media*

In both Polars and Intermediate Polars, the accretion flow is channeled along the magnetic field lines from the red main sequence secondary star, directly onto the polar cap of the white dwarf primary. Accretion disc are generally absent in polars, due to the strong magnetic field (*The Facts on File Dictionary of Astronomy* 1994).

Pulsating Variables

Pulsating variables, the second subgroup of intrinsic variables, are further divided into four additional classes: Cepheids, RR Lyrae, RV Tauri and Long Period Variables (LPV's).

Cepheids

Cepheids have periods of 1-70 days, although the most luminous have periods of about 100 days (*The Facts on File Dictionary of Astronomy* 1994; *Universe* 1999) and an amplitude of variation of 0.1 - 2.0. The dimmest Cepheids pulsate at a period of 1 to 2 days. These massive stars are very luminous and are of F-spectral[b] class at maximum and G to K at minimum. The later the spectral class, the longer the period. Cepheids obey a strict period-luminosity relationship (*AAVSO*).

RR Lyrae

RR Lyrae stars have periods of 30-100 days and an amplitude variation 0.3 - 3.0. These pulsating old white giant stars have short-periods, usually less than one day, and are predominantly found in globular clusters. RR Lyr stars are usually spectral class A, but range A7 to F5. Compared to Cepheids, RR Lyr stars are older and less massive (*Encyclopedia of Astronomy and Astrophysics; AAVSO*).

Evidence indicates that RR Lyr stars have about the same mean absolute magnitude and can therefore be used for distance indicators out to approximately 200 kiloparsecs. It was RR Lyrae stars that helped astronomers determine the size of the Milky Way galaxy (*Universe* 1999; *The Facts on File Dictionary of Astronomy* 1994).

RV Tauri

[b] Stars are grouped into classes according to their spectra, which is similar to a rainbow of colors, each class varying slightly based on chemical composition. There are seven spectral classes of stars- *O, B, A, F, G, K* and *M* -each with a different temperature range.

RV Tauri stars comprise a small group of very luminous, yellow pulsating supergiants having periods of 20-145 days. They have periods defined as the interval between two deep minima and amplitude of variation up to 3.0. Some show long-term cyclic variations from hundreds to thousands of days. Generally, the spectral class ranges from G to K with some F stars (*The Facts on File Dictionary of Astronomy* 1994; *AAVSO*).

Mira's or Long Period Variables (LPV)
Mira's ***(Z Boo & RS Vir)*** are referred to as LPV's, ranging 80-1000 days and amplitude of variation 2.5 to 5.0 (*AAVSO*). Other sources list the amplitude of variation between 2.5 and 10.0 (*The Facts on File Dictionary of Astronomy* 1994). Their large amplitude makes these red giants and supergiants easy to recognize. About 90% of LPV's can be classified as Me spectra with strong emission lines, while others can be classified as carbon stars (Ce) or zirconium (Se) stars. All exhibit bright emission lines. (*Encyclopedia of Astronomy and Astrophysics; Universe* 1999)

4.2. EXTRINSIC VARIABLES

Extrinsic variables are caused by the eclipse of one star by another, or by the effects of stellar rotation. No variables in this group were observed.

Eclipsing Binaries
These are binary systems with an orbital plane which lies near the line-of-sight of the observer. The two stars periodically eclipse one another, causing a decrease in the apparent brightness. The period of the eclipse can range from minutes to years *(AAVSO)*. Eclipsing binaries can be subdivided into Algol variables, W Serpentis stars and W Ursae Majoris stars (*The Facts on File Dictionary of Astronomy* 1994). One publication revealed that there were approximately 17 groups, sub-groups and classes listed for eclipsing binaries (*General Catalog of Variable Stars* 4^{th} Ed).

Algol Variables
Algol variables (β Persei stars) are close binary stars where, due to mass transfer, the now less massive star originally contained most of the systems mass. The brighter and more massive star is on main sequence. This is referred to as the Algol Paradox. The massive hot main-sequence star, which has gained its mass through accretion, is roughly the same size as its low-mass subgiant companion. The subgiant eclipses the bright main-sequence star. (*Universe* 1999; The *Facts on File Dictionary of Astronomy* 1994)

W Serpentis Stars
These stars are also close binary systems, which involve mass transfer. W Ser stars differ from β Per stars in that the mass transfer occurs very rapidly. The transfer is so rapid that up to 85% of one star's mass can be transferred and the system ends up as an Algol variable. (*The Facts on File Dictionary of Astronomy* 1994; *The Astrophysical Journal*)

W Ursae Majoris
W UMa stars are contact eclipsing binaries involving mass transfer. The orbital periods are short, measured in hours. The two stars are approximately equal in brightness, but not in mass that can be a 12:1 ratio. (*Universe* 1999; *The Facts on File Dictionary of Astronomy* 1994)

Rotating Stars
Rotating stars show small changes in light that may be due to dark or bright spots, or patches on their stellar surfaces called "*starspots"*. Many dwarf Me stars show this effect. Rotating stars are often binary systems *(AAVSO).*

The variables cited comprise only a few of the many types of variables. Others include dwarf Cepheids, Delta Scuti stars, semiregular (excluding RV Tauri stars) and irregular variables, Beta Cephei stars, flare stars such as UV Ceti, novae, recurrent novae, spectrum variables, R Coronae Borealis stars, pulsars, pulsating x-ray sources, and spectroscopic binaries whose variability results from both intrinsic and extrinsic agencies. *(The Astrophysical Journal; Universe*1999)

5. THE TELESCOPE

Alvan Clark and Sons of Cambridge, Massachusetts, United States, manufactured the 20-inch objective lens, which was cast in France at a cost of $11,000. This is the same Alvan Clark who first glimpsed Sirius B in 1862. Although the lens of the Clark 20" telescope is considered of excellent quality, especially when it was manufactured over 107 years ago, it does exhibit curvature at the edges. Under ordinary viewing situations, this presents no problem. The lens also exhibits some coma, but this is confined to the edges. Near the center of the field of view, there is little aberration. The University of Denver and the Denver Astronomical Society installed encoders to the telescope in early 2001, and routed to a computer running The Sky astronomy software. This aided tremendously in locating the FOV of the variable using the General Catalog of Variable Stars in the software.

6. REPORTING OBSERVATIONS

Observations recorded in Table 1 were reported to the AAVSO via their website.

7. THE PLAN: MORE EXTENSIVE WORK ON VARIABLE STARS

In August 2000, I spent one week atop Mt. Evans, Colorado, at the Meyer-Womble Observatory recording images of variable stars with the twin 28.5" R-C binocular telescopes. Over 75 images, some down to 20.0 magnitude, were captured with the CCD attached to the telescope. Those images were analyzed with photometric software and the results reported to the AAVSO.

This season I will be making two trips to the Meyer-Womble Observatory, located at 14,160 feet, to continue the work started last year. With the knowledge I've gained from this project and during this semester, I've decided to outline a plan to best utilize the time and facilities allotted me.

My plan for more extensive work on variables is outlined in four parts.

Phase 1: Preliminary Planning
Review the August 2000 images and sort out the LPV's, such as Miras, for further study. There will be 200-300 days between last year's data and this season's data. Since time and weather dictate the number of hours available each night, the LPV's will be listed in order of priority. Part of the observing night will be dedicated to the listed LPV's, the other part of the night for the cataclysmic variables.

In addition to the LPV's above, I will research and list between 10 and 20 CV's for imaging. With the instruments and software available, detailed photometry measurements can be made in a wide spectrum and later analyzed. The celestial coordinates of the LPV and CV must be observable between the hours 2100 and 0500 hours local Mountain Time, on specified dates, in order to be placed on the list for imaging.

Phase 2: Observing Session/Image Capture
Priority will be given to the list of CV's. Dependent upon the orientation of the celestial sphere and location of the stars on the two lists, LPV's could be available for imaging prior to the CV's. This will not be known until the actual planning starts. Of course, *all plans are subject to change depending on environment, weather and a person's physiology at 14,160 feet altitude.*

Phase 3: Initial Data Reduction
Each day following an observing run, the data will be organized and images reviewed. A quick review will be done using the software flip comparator to compare star fields for any anomalies. Adjustments, such as time allocation, will be made for the next observing run.

Phase 4: Detailed Data Reduction & Reporting
After the observing sessions, the data on the LPV's and CV's will be reviewed in detail and final measurements reported to the AAVSO. This will also give me the chance to use light curve generator to graph changes in the variables amplitude.

Although I consider this plan to be fairly comprehensive, I recognize that my knowledge is limited. I welcome, even encourage, suggestions on how this observing plan can be modified to achieve a truly professional approach. Is my plan worthy of the instruments and facility, which are available? My goal here is good science.

8. SUMMARY

The purpose of this project was to research the causes for variability and identify which stars are within telescope reach. In addition, individual observations of the magnitudes of selected variable stars were made and a plan was designed for more extensive work on variable stars.

Today, measurements of the magnitudes of variable stars are made through visual observations using the naked eye, or instruments such as a CCD. The observations made for this paper were reported. The AAVSO website lists variable star organizations in 17 countries, to which observations can be reported.

So, why observe variable stars? The information gathered provides professionals with data necessary to analyze this behavior and make computerized theoretical models of variable stars. As amateur astronomers, we gather variable star information because professional astronomers have neither the time, nor the unlimited telescope use to gather information on variables.

The byproducts of variable stars, which go supernova, are the ingredients needed to make all things, even humans. We are truly children of the stars.

9. REFERENCES

- *American Association of Variable Star Observers (AAVSO),* http://charts.aavso.org, http://charts.aavso.org/howtouse.stm, http://www.aavso.org/links.stm
- *Astrophysical Journal*, *The* University of Chicago via Swinburne University.
- *Denver Astronomical Society,* Measurements on Clark 20", February 2000, http://www.denverastro.org/
- Dickinson, T. & Dyer, A. 1995, *The Backyard Astronomers Guide*, pp. 150.
- *Facts on File Dictionary of Astronomy, The* 1994, Third Edition, pp. 9-10, 260, 286, 422-424.
- *General Catalog of Variable Stars* 4th Ed., GCVS Variability Types and Distribution Statistics of Designated Variable Stars According to their Types of Variability.
- Kaufmann & Freedman 1999, *Universe,* , pp. 477, 483-484, 528-534, 546, 569, 580.
- Levy, D.H. 1998, *Observing Variable Stars: A Guide for the Beginner,* Cambridge U. Press, New York.
- *MacMillan Online Encyclopedia of Astronomy and Astrophysics* - Guest Access, http://www.ency-astro.com/
- Percy, J.R. 1993, *The Physics Teacher,* pp. 31, 541.
- *Sky & Telescope* Magazine, March 1996.
- Software Bisque, *The Sky Astronomy Software,* Level IV, Version 5.00.012 http://www.bisque.com/
- *Starry Night Pro* Astronomy Software, V 3.0, Sienna Software, Inc. 1991-1999.
- Swinburne Astronomy Online CD, *Exploring the Stars and the Milky Way*, Module 11, Activity 1, Variable Stars.
- Turner, D.G. 1999, *Observing Bright Cepheids without Optical Aids*, Journal of the AAVSO, Vol. 28, No.2, pp.116.

- University of Denver, Chamberlin Observatory, http://www.du.edu/~rstencel/Chamberlin/

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