

The AAVSO CCD Observing Manual



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Preface

This manual is a basic introduction and guide to using CCDs to make variable star observations. The target audience is beginner to intermediate level CCD observers, although advanced CCD users who have not done any photometry will also find this helpful.

The *AAVSO CCD Observing Manual* had its origins with the AAVSO's CCD observing program itself, which began in the 1990s. Much has changed since the start of the CCD era of variable star astronomy, and you may find things in this document that are out of date. This document is a work in progress and *always under revision*. Let us know where you find it helpful, and where it needs work!

Please send any feedback or suggestions to aavso@aavso.org.

A number of people have contributed their time, knowledge, and expertise to this manual over the past decade, and we are grateful for the contributions of everyone involved. Particular thanks go to the following individuals for their contributions: Aaron Price was responsible for creating the original manual and writing the bulk of its content, much of which remains in this edition. Chapter 4 on photometry was a joint effort by Bruce Gary, Arne Henden, Aaron Price, Gary Walker, Doug West, and Ronald Zissell. Thanks also to the many observers who have commented on and corrected this manual since its first publication.

Clear skies,

Arne Henden, Director
Aaron Price
Matthew Templeton

American Association of Variable Star Observers
Cambridge, Massachusetts
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1.0 Introduction

1.1 Target Audience

The *AAVSO CCD Observing Manual* is meant for anyone with an interest in using CCDs to make variable star observations. Most of the information is written with the beginner and intermediate CCD observer in mind. However, even the most advanced CCD observer will probably find some information useful. CCD photometry has been called an *art* by some because of all the intricate details involved in getting a good result. Art and science both have one thing in common — neither has experts.

If you have any questions we encourage you to contact us at headquarters, or browse our further reading and external links section.

1.2 CCD vs. Visual Observing

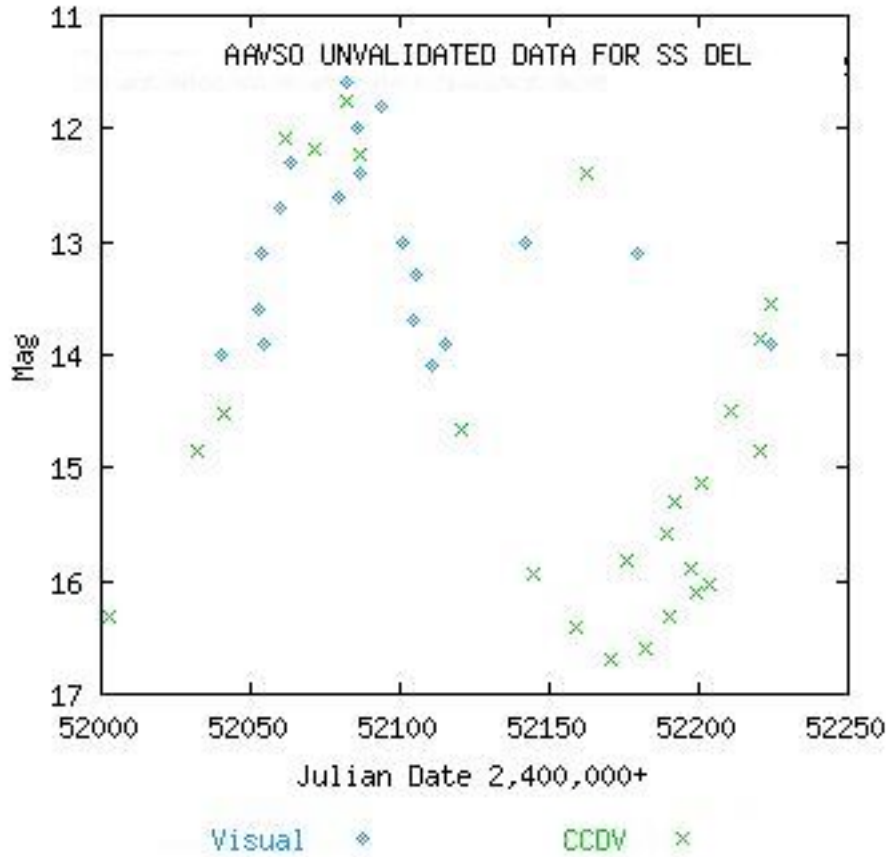
After years of debate on the AAVSO Discussion Group a general consensus has emerged. CCD and visual variable star astronomy are *complementary* rather than *competing* endeavors. Each brings their own strengths and weaknesses to the table:

	Strengths	Weaknesses
Visual	Quick Easier (minimal technology) Less equipment/Less expensive Sufficient accuracy for high-amplitude stars	Cannot go as faint without very large apertures Less precision Affected by observer physiology as well as technique
CCD	Higher precision More accepted by scientific community (if filtered and properly calibrated) Can go much fainter Can be automated	Time consuming Complex technology Requires more equipment and more expense

The most successful observing programs in the AAVSO combine the capabilities of both programs. For example, the eclipsing binary committee routinely uses visual observers to follow an EB to get a general idea for the time of minima. Then the CCD observers schedule a night where they can refine that time. Visual observers are also able to monitor many variables in a given night, and can in principle provide faster notification of important events like outbursts; CCD observers can then concentrate on active objects to obtain high precision time-series or calibrated photometry.

To the right is a light curve of SS Del. You can see how the visual observers took over near maxima (brighter than mag 14) and the CCD observers took over near minima (below mag 14). This is a great example of cooperation to build a terrific light curve.

If you are currently a visual observer and are happy with your current program then there is no need to invest the time and money for CCD work. Only consider CCD work if there are specific programs that you would like to participate in that require the unique benefits of the CCD, or if you are a lover of technology and would just enjoy the challenge it presents.



Remember the goal here — to have fun and collect real data for the scientific community. Both can be achieved by CCD and visual observing programs.

1.3. Are You Ready? (Prerequisites)

Before getting started you should have some experience with your CCD camera. You should:

- Know how CCD cameras operate (well depth, shutter types, linearity, etc.)
- Have basic experience using your CCD camera.
- Have good working knowledge of computers (especially regarding processing data and text files).
- Highly recommended but not required: have some experience doing *visual* variable star estimates.

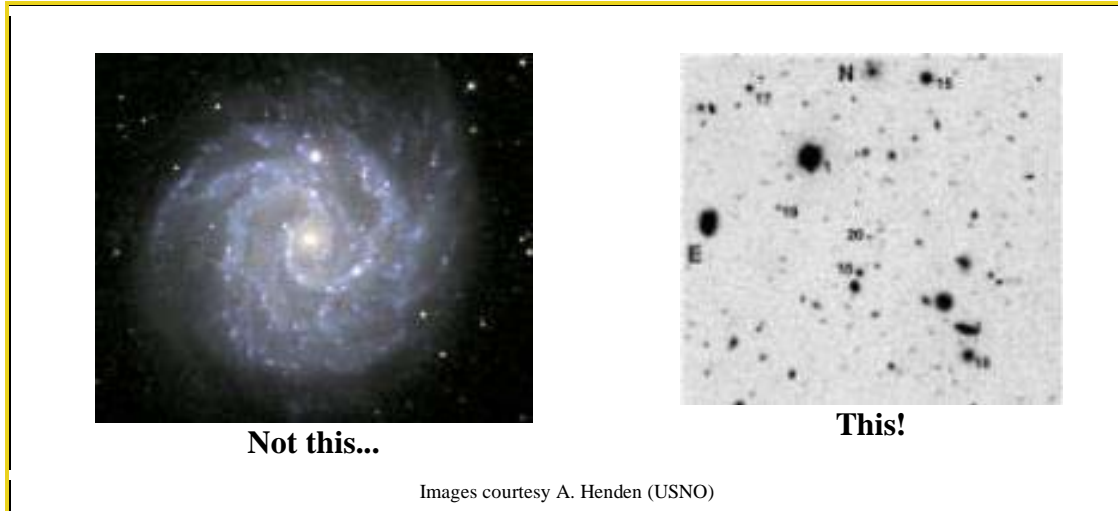
The last item can save you a lot of time. "An ounce of prevention is worth a pound of cure." In general, for every visual variable star estimate you will probably end up saving yourself ten times that amount of time in your CCD learning curve. Try to make at least one hundred visual variable star estimates. Pull out some binocular variables and just follow them once a week for a month. If you haven't already, get a copy and become familiar with the AAVSO's excellent *Manual For Visual Observing of Variable Stars*.

This experience will be key to teaching you how to identify fields, how color affects estimates (important later when we get into filters), the behavior of a star's light curve, how to submit data, and perhaps most importantly – patience! Also, visual observing is usually quite fun and addictive, so practice will help make sure you enjoy variable star observing. After all, for most of us this is a hobby right? CCD Observing has many facets to it. Each one of these areas you gain experience with is one less area you have to be

concerned with while learning CCD observing. Get the basics out of the way now so you can focus on the hard stuff later.

1.4 Expectations

In general, this manual will focus on aspects of CCD observing specific to variable star photometry. With a few exceptions, we won't go into the details about how a CCD works, how to cool it, etc. Also, variable stars are usually just dots in the image so you won't find any help here in taking pretty pictures. (Although to some of us an image of a 17th magnitude cataclysmic variable in outburst is awful pretty!)



You are starting out on a very long journey, be prepared and patient! The good news is that you can start taking useful data almost immediately! However, you'll find the learning curve very long and at some times steep. In the beginning you'll find that choosing equipment is a pretty daunting task. But once that is done you will settle down into a steady routine of making observations and slowly improving your accuracy. After you have mastered the basics such as dark, bias, and flat fielding then it gets pretty tricky in the world of transformation coefficients and all-sky photometry. We'll keep the material in this manual limited to what you'll need to go from having a CCD-equipped telescope to submitting variable star observations to the AAVSO.

Take your time in mastering CCD observing, and enjoy the learning experience. To determine how far you want to push your equipment and abilities you should compare the goals (and requirements) of your observing program against the amount of work you want to put into it. In some cases it can take years of experience before a new observer can master CCD photometry and get their error to the 0.01 magnitude level. So remember to take your time, have fun, and bite off only as much as you can chew!

1.5 Why CCDs?

The two main reasons why CCDs are great for variable star observing is because they are more accurate and more sensitive than the human eye. Additionally, you can archive and automate your observations. Below is a summary of a few of these advantages:

Sensitivity

With a CCD you can see objects much fainter than is possible visually. For example, a 10" telescope with a Starlight Xpress MX916 CCD can get to 16th magnitude in two minutes in light-polluted, suburban skies with a visual limit of 4th magnitude. With a visual telescope you would likely need 16–20 inches of aperture along with crystal clear and dark skies away from the city.

Accuracy

The linear nature of a CCD means that when proper procedures are carefully followed the photometry can be very accurate. In general, the accuracy of your result is in direct proportion to the amount of work you put into the observation. CCDs can easily and quickly get to an accuracy of 0.2–0.3 magnitude. With just a little bit of work you can get that to 0.1 or 0.05 magnitudes. Finally, if you are prepared for a lot of work you may be able to get to 0.01 accuracy or better. Each level of accuracy will require more work and restrictions on what you can observe.

Most visual observers can get to 0.2–0.3 mag accuracy. However, when visual data are combined with those other observers the scatter of the light curve increases due to differences in observer physiology, observing conditions, and skill. The magnitude scatter of some red variables can be as high as 1.5–2.0 magnitudes. CCD observations can be more standardized than visual observations. CCD observers often use standardized filters to make their observations. This makes the bandpass for each CCD observation very similar to each other, meaning that the combined accuracy can be up to .01mag. This is one reason why the scientific community prefers CCD over visual data. The professionals use the same type of filters so they can easily combine their data with those from amateurs.

Archiving

CCD data is recorded digitally by a computer so it can be easily archived. These archives can be sent to others for further review, the data can be recalibrated at a later date (Ex: if the sequence is changed), and any questions that arise over the data can be answered. You can also reanalyze your images at a later time, and even use your images to discover new variable stars.

Automation

Advanced CCD observers can automate their observations to make better use of their observing time. For example, one observer may set an observing plan to image 5 objects all night long while they are asleep. Then all the observer needs to do is wake up a little early to turn off the system and can reduce the data at a later time. Automation isn't easy though, and depends largely on the quality of your mount.

2.0 Equipment

An unknown speaker at the first AAVSO CCD workshop said, "*Calculate the expense of all the required equipment, multiply that by three, and that is what the final cost will be.*"

2.1 Telescope

Purchasing a telescope is a big step. A telescope should be chosen with your entire observing program in mind. Don't just purchase a telescope based solely on CCD requirements unless you plan to never use it visually. Also remember to take into account things like portability and size.

When it comes to CCDs, the most important features in a telescope you want to consider are:

- **Aperture:** This one is easy. The larger the aperture – the fainter you can go. However, remember that with CCDs modest sized telescopes can do a lot of work. The vast majority of stars in the AAVSO program are 16th magnitude or brighter, so purchasing a large telescope isn't required. However, we do have some programs which need large aperture like the High Energy Network's Gamma Ray Burst program. Note that bigger aperture has the downside of smaller FOV (for same f -ratio).
- **Field of View:** CCDs are notorious about having small fields of view (although this is changing as technology progresses). Small fields of view make it hard to get the comp stars in the same field as the variable. It also can make it frustratingly difficult to find the object. The smaller the f -ratio the better.
- **The Mount:** This is crucial. The mount's ability to find the object ("goto") and the tracking will profoundly affect your observing experience. Also consider the setup time. A mount that isn't very accurate, takes forever to align, and tracks poorly will leave you so frustrated that you may lose interest in the hobby. If possible, do not skimp on the mount. Equatorials are a must because alt-az mounts cause field rotation during medium and long exposures, which is impossible to compensate for without an image rotator.
- The simpler the optical system the better. Stay away from focal reducers and anything else that can cause vignetting unless you *really* know what you are doing. Also stay away from color corrected systems and in general anything that adds a nonuniform effect to the field or changes the natural color of the incoming starlight. Celestron's Fastar system cannot be used for photometry. Also watch out for poor baffling because it can create ghost images that look like stars in your final image.

The absolutely, positively, best advice you can follow when purchasing a telescope is to talk to people in your local astronomy club. Spend some time looking through their scopes, ask for anecdotes and advice, seek out the CCD observers and see what they use. However, remember that most club members won't know anything about photometry so seek out those with photometric experience.

A final word of advice: Don't worry too much. Most telescopes are great with CCDs. Small scopes have rich fields of view and large ones can go as deep as some professional scopes. Find a scope that you will enjoy. It needs to fit your budget and be easy to setup and use. Remember what Clint Ford said,

"The best scope for you is the one you use the most."

2.2 CCD Camera

The best CCD camera for you depends, like the telescope, a lot on your personal situation. You need to consider the cost, your observing goals, your telescope, and then of course the reputation of various manufacturers and models.

Observing Goals: Do you plan on *only* doing variable star photometry or do you also want to use your camera to also take pretty pictures, hunt for asteroids, et cetera? For pretty pictures, binning and antiblooming can be a big help, but neither are recommended in the world of photometry. Also, resolution is important for pretty pictures but it isn't in photometry. Here we are going to give you advice regarding photometry only. If you plan to use your camera for other targets then seek the advice of groups in that area of interest and choose a good "middle-ground" camera.

What Are You Looking At?: First, get a feel for what observing programs interest you and read up on them. There may be different features on a CCD that will help in some programs. For example, if you are going to do a lot of supernovae hunting or GRB work then you will want a camera with a wide field of view. If you are doing studies of bright LPVs then you will want a camera with a good dynamic range and large well depth.

Sampling and Pixel Size (Telescope compatibility): One of the most important things you need to consider when purchasing a CCD is its pixel size. For most consumer (front-illuminated) chips you want to spread the FWHM of the star across 2 pixels of the CCD for optimal photometry according to "Astronomical Image Processing" by Richard Berry and James Burnell. This will help you optimize your signal to noise ratio and improve accuracy. To get the best FWHM you will need to determine how much of the sky will fall on a single pixel of your CCD camera. This means making a calculation concerning the telescope's aperture, f -ratio, and the size and number of the CCD chip's pixels. If X is the pixel size of your CCD measured in microns, and Y is the focal length of the telescope, the width of the pixels, w , in arcseconds is given by

$$w = (206.265/Y)*X \quad (\text{if focal length is measured in millimeters})$$

$$w = (8.12/Y)*X \quad (\text{if focal length is measured in inches})$$

For example, a 10" f/10 telescope (2540mm focal length) and a CCD with the Sony ICX 083 chip (11.6 X 11.2 micron pixels = 11.4 avg) will give 0.9 arc second per pixel. To see how much sky will fit on the entire CCD we just multiply that by the size of the array (752x582). In general, 1 arc second per pixel would be too small. However, by binning the chip you can double, triple, or quadruple the pixel size. So by triple binning we would get a pixel size of almost 3 arc seconds.

Full-Width Half-What?

FWHM stands for "Full-Width Half-Maximum" and is basically the size of the star on the chip. The size is chosen by counting pixels that are filled to 1/2 the dynamic range between the background and the brightest (fullest) pixel in the star's image. Most software will determine this for you and we'll discuss it in more detail in the Photometry section.

Pixels vs. "Seeing" For most amateurs living in suburban seeing conditions limit your telescope's resolution to between 3 and 4 arc seconds, although it may be smaller for those in great locations or on days of exceptionally good seeing. What you want to do is come up with a telescope + CCD system that will spread this seeing out over 2–3 pixels. For example, if you get seeing conditions on average of 3 arc seconds, you will want a telescope that puts 1.5 arc seconds on each pixel so that the FWHM of the star will cover 2 pixels in your final image. This is called *sampling*.

Binning This is also where binning can help. If your conditions are so bad one night that your seeing blurs the star across 4 pixels, you can do 2x2 sampling to get it back down to 2 pixels. Binning refers to the combining of a group of adjacent pixels into one large pixel. 2x2 binning, for example, takes an array of 4 pixels and makes them act as 1. The downside to this for photometry is that some of the starlight will be landing on the gates dividing the pixels and will be lost. This causes a slight hit in accuracy so binning should be avoided when possible.

Antiblooming (ABG) The "anti-blooming gate" is a feature on some CCDs to prevent electrons from leaking from one pixel to another. This happens when a star is bright enough to "saturate" the pixels on the camera, filling up the wells. What is left over "leaks" onto adjacent pixels. This causes spikes and other artifacts in the image. ABG mitigates this effect by putting "gates" between the pixels. However, this can destroy linearity of the chip and your photometric accuracy will go along with it. It is highly recommended that you purchase a camera without ABG. Many manufacturers sell cameras with ABG removed or else have documentation on how you can remove it yourself (if you are brave and mechanically inclined). Another advantage to not having ABG is your CCD sensitivity will be greater. **However**, if you end up with ABG in your camera all is not lost. In that case, a good rule of thumb is to limit your pixel saturation to 50% of your well depth. Most cameras with ABG stay linear in this range. For example, most 16 bit cameras stay linear to 32,000 units or less per pixel. Your software will be able to tell you the saturation of a pixel and your CCD documentation will tell you the well depth of your pixels.

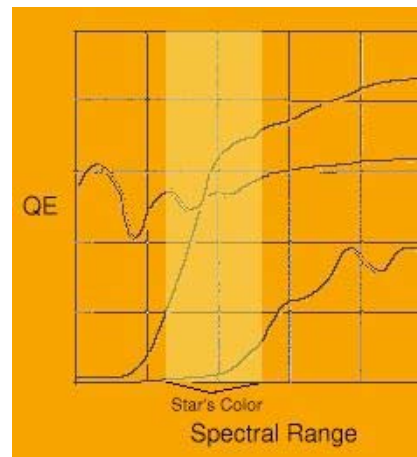
2.3 Filters

Different models of CCD chips have different spectral responses. Because of this, it is vital that one use proper photometric filters when observing variable stars.

Take a look at the diagram on the right. The 3 lines represent the spectral response of 3 popular CCD chips. The highlighted area represents the passband of a photometric filter.

Notice how each CCD chip has a different spectral response in the region of the star's light in the filter's passband. If each user imaged the star unfiltered they would all get wildly different magnitudes!

But don't think that using filters is a bad thing. In fact, this is one of the strengths of CCDs. When you use a filter you equalize the passbands of various CCDs. This means that your data can be added to other CCD observers without the scatter that visual observations can have (because visual observations are unfiltered).



The standard filters most often used for photometric work are:

- **Johnson U** (U): This is in the near ultraviolet range. Very few consumer level CCDs are sensitive in this range.
- **Johnson B** (B): This is the blue range. Cataclysmic variables (CVs) tend to be bright in B, especially when in outburst.
- **Johnson V** (V): This is close to what the human eye sees so the V stands for Visual. It is roughly centered in the green.
- **Cousins R** (R_c): This is red. Miras are bright in R_c .
- **Cousins I** (I_c): This is very near infrared. The human eye cannot see this portion of the spectrum so an I_c filter may look opaque when held up to the light.

Photometric filters can usually be purchased from the same vendor that sells you the CCD. The most popular manufacturers are Optec and Astrodon. Prices can range from around \$50 to \$150 per filter. When using a system with a low f -ratio telescope you may want to get 48mm filters instead of the standard 1.25" filters to account for vignetting at the edges of the filter.

Start With V. To start off, you only need to purchase a V filter. This is the most common filter used and for most stars in the AAVSO program it is all you will need. Over time, you can obtain and use other filters to increase the amount of physical information you gain from the system. But at first, a V filter is the best way to start.

Note that some suppliers call their filter sets various combinations of *Johnson*, *Cousins* and *Kron*. They all have the same V response and the alternate names refer to the designation of filters other than the V filter in their series. However, the Johnson V filter is **different** from a *Tri-color (RGB) green* filter, in that it is more narrow in bandwidth and centered at a different wavelength. The proper filter response is sometimes referred to as a "Bessell" response which refers back to a paper by Mike Bessell, who has extensively studied and written on various photometric systems and filters.

IR Blocking

When using a modern, standard $UBVRcIc$ filter you don't need to worry about using an IR Blocking filter since they are built into the standards for those filters. Some older filters may have IR leaks, so be aware of this if you have older equipment that you're taking off the shelf to start variable star observing, or if you acquire a camera and filters second-hand.

Other filters: the Sloan filters

A recently developed filter set gaining ground among photometrists is the set developed specifically for the Sloan Digital Sky Survey (SDSS). The Sloan filter set, u' , g' , r' , i' , and z' , cover a similar range as the Johnson Cousins set, but with less wavelength overlap between the filters such that the filters sample different regions of the optical spectrum independent of one another. In addition to the original Sloan Survey, the Sloan filters will also be used by the upcoming *Pan-STARRS* and *LSST* massive surveys, as well as the AAVSO's own *AAVSO Photometric All-Sky Survey* (APASS). These filters are less common and (consequently) more expensive, but they may come down in price such that they may be a viable choice for your CCD system in the future.

Unfiltered Observations

Unfiltered CCD observations are not as astrophysically useful as filtered observations because they provide little or no information about the spectral properties of the light you're observing, just a measure of the incoming broad-spectrum flux convolved with the spectral response of your CCD chip. Worse, unfiltered CCD observations can be misleading if the CCD is sensitive to light outside the visual bandpass. For example, an unfiltered CCD observation of a red mag 10 star could show up as mag 3 because of leaks of red light in the CCD. That said, there are a *few* observing programs where unfiltered observations are

acceptable, primarily time series of blue stars (like cataclysmic variables). Any unfiltered CCD observation **must** be submitted to the AAVSO as "unfiltered".

2.4 Computers and Software

Hardware

CCDs do not require powerful computers, and older CCD cameras may require computers with serial ports not typically installed on modern PCs. However, some USB and TCP-IP supported CCD systems may require newer machines with USB ports or properly configured ethernet cards. You should have a good working knowledge of computers before you purchase a CCD. In fact, the more you know about computer "stuff" the easier CCD work will be. Especially useful is knowledge about spreadsheets, databases, and some basic scripting skills. You will likely spend more time manipulating your data on the computer than actually taking the images. The more you know – the more you can automate. Some of the tasks are tedious and can be made easier through scripting.

Windows PCs are the dominant platform for CCD systems. However, some Macintosh systems do exist (SBIG sells a Macintosh adapter for most of their line of CCDs) and the new Macintosh OS X architecture is based on UNIX which opens the door for UNIX-based CCD programs. Speaking of which, support for CCDs under Linux has grown measurably in recent years. Almost any commercial CCD camera will have Linux drivers available (usually third party and free). However, using Linux or a Macintosh to drive a CCD system should be attempted only by those who are thoroughly familiar with their operating system.

Regarding monitors, if you have a very large CCD chip, make sure the monitor and video card can support the image resolution your chip will supply. If it doesn't, you may find yourself scrolling madly or shrinking images.

One final note about your computer, make sure that you have synchronized your computer to a standard time server before you observe! Your variable star observation consists of both a magnitude and a time, and your reported time must be on the same frame of reference as that of every other observer. The clocks in brand new computers will drift slightly over time so it is important to resynchronize it at every observing session. If your data acquisition computer is connected to the internet, you can synchronize the computer with a time server such as the one run by the US Navy. Read the instructions for doing so that came with your operating system. If you're using a laptop, that to take to your observatory, synchronize it right before the observing run. If it is not connected to the internet, synchronize it using the shortwave signal from WWV. Along those lines, make sure you know how your CCD camera records the time: is it the start of the exposure or the midpoint? The midpoint of the exposure is the more correct way to report the time of your observation, so if your CCD system reports the start time, the actual time of your observation is the start time plus *half* of the exposure time.

Software

CCD software can be broken into two large categories: **CCD Interfaces** and **Data Reduction**. The first category consists of software that actually controls the CCD during the observing session. The second category is made up of programs that specialize in manipulating the data after it has been recorded. Most CCDs will come with a program that controls the camera well but doesn't do much in the realm of data reduction or telescope control. You can either use this software to control the camera and another software package to reduce the data or you can spend a little more and find a program that will do both.

Some examples of commercial CCD camera control and data reduction packages are:

- AIP4Win (<http://www.willbell.com/aip/index.htm>)
- MaximDL (<http://www.cyanogen.com/>)
- Mira (http://www.mirametrics.com/mira_ap.htm)
- MPO Canopus (<http://www.minorplanetobserver.com/MPOSoftware/MPOCanopus.htm>)

All of the software vendors above have added functionality to export photometry to files in the *AAVSO Extended Format* (see Chapter 6). (**Note:** The AAVSO does not endorse any specific commercial software package.)

Most professionals and some advanced amateurs use IRAF (<http://www.iraf.net/>), a free program originally developed and distributed by National Optical Astronomy Observatory (NOAO). It is a very powerful and flexible collection of CCD reduction packages. Right now it runs on most UNIX platforms, including Macintosh OS X. However, it can be a challenge to learn and should only be attempted by those familiar with UNIX. If you have Perl, Python, Tcl, or other kinds of scripting skills then using IRAF will be much easier.

Choosing the software will be a little like choosing the telescope. You need to consider your hardware requirements (does it support your CCD model and telescope mount? Does it run on your operating system?), cost, and ease of use. For the latter, look for trial versions and, as with the telescope, ask friends about the software they prefer to use. If possible, spend an observing session or two with the friend and let them teach you the ropes. Finally, lots of online support exists for most programs (usually in the form of e-mail discussion groups).

Be Comfortable With Computers

One last thing to remember is that CCD observing is computer intensive. Computer skills are usually the prerequisite lacked most often by new observers. Please make sure you are comfortable using computers before adding CCDs to your hobby. Many observers e-mail us daunted and frustrated by the amount of tedious work they must put in to reduce and format their data. CCD manufacturers don't advertise that! The highway of CCD observing is littered with debris from folks who got frustrated with the technical requirements and threw their equipment out the window. Be patient and jump in when the time is right.

Some things you will need to know or learn might include: How to troubleshoot a bad connection to your camera (i.e. is it a broken serial port? cable too long? temperature too high?) What is the difference between various file formats? (especially RTF, TXT, and other ASCII formats) And can you manipulate text data easily?

CCDs generate *huge* amounts of digital data. You need to be able to manipulate the data to get it into a format acceptable by the AAVSO and the scientific community. Recently it has gotten easier as CCD photometry packages have begun putting in data export features into their software. Most of the software packages mentioned above provide some capability to reduce and photometer your images, and export the resulting photometry to a file in the AAVSO's *Extended Data Format*. This formatted data can then be uploaded to the AAVSO via WebObs.

3.0 CCD Camera Calibration and Image Acquisition

3.1 Calibration Overview

A raw CCD image contains a ton of data. Some of it is good (signal) while some of it you don't want (noise). To get the best data, you must do your best to reduce or account for the noise sources in your data while maximizing the signal from your stars.

Signal

The signal in your system is the starlight itself and nothing else. Those photons that left the star many years ago land on your CCD chip and are converted into electrons. These electrons are counted and then displayed on your screen and stored on your computer in binary form. The trip from CCD to monitor is a dirty one.

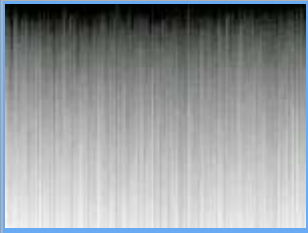





Unwanted Signal

The unwanted signal in the system mostly comes from the sky (both cosmic rays, and optical light from the sky), the telescope (vignetting, reflections), the CCD chip (dust donuts, hot pixels, dark current), the CCD charge-detection node (read-out noise), and the computer (timing). All of these can be accounted for or otherwise corrected with some elementary image processing steps and calibration.

Calibration to the Rescue

Calibration is the proper accounting of signal and noise. Through calibration you can mitigate the effects of each of those sources of unwanted noise. Sometimes you can merely diminish it (read-out noise) and sometimes you can completely eliminate it (cosmic rays). Calibration can be a very tedious and time consuming process. It is also one of the areas of CCD observing where experience helps out the most. In the beginning you may be a poor calibrator. No problem! As time goes on you'll get better and find the best calibration system for you.

There are three important image corrections used in proper calibration that all CCD observers should be familiar with. These corrections involve the creation of *extra images* that try to represent the behavior of the system in the absence of signal. These images can then be used to correct your data frames. They are known as **bias frames**, **dark frames**, and **flat fields**. *Bias Frames* help compensate for read-out noise and interference from the computer. *Dark frames* compensate for the thermal properties of the CCD chip and *flat frames* compensate for imperfections in the light path. All three are applied to your science frames to give you images that best represent the actual image of the field without the imperfections and noise of your telescope and camera. On the next page, you'll see examples of these frames, and how correcting them can improve your data images (and the resulting photometry).

	Frame	Data	Measured magnitude of RX Andromedae
Bias			10.0 +/- .4 Vmag
Dark			10.2 +/- .1 Vmag
Flat			10.25 +/- .05 Vmag

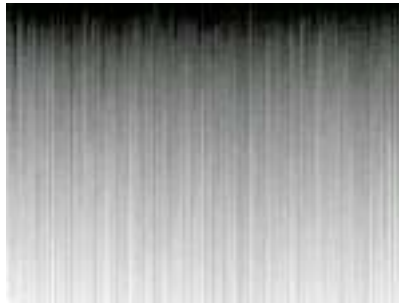
The above illustration is a (somewhat arbitrary) example of what *could* happen during a calibration procedure for an image of RX Andromedae. Notice how the magnitude estimate becomes more precise and the error drops after each step in the procedure. Error estimation is actually far more complicated and discussed in another section. But this gives you a general idea of what the various frames look like and their impact on the final image and data reduction.

In arithmetic terms, the production of a calibrated frame is simple: you subtract the *Bias* and *Dark* frames from the *Raw* data image, and then divide the result by the normalized *Master Flat*:

$$\text{Calibrated} = (\text{Raw} - \text{Bias} - \text{Dark}) / \text{Master Flat}$$

Once you have a properly calibrated science frame, *then* you can begin doing science with your image.

3.2 Calibration: Bias Frames



An example of a bias frame.

The first step in calibration is to prepare a *bias frame*. A bias frame is an image with zero exposure time taken with the shutter disabled. The image will consist only of read-out noise and noise caused by interference of the computer. What a bias frame does is set the zero point of the CCD output and the pixel scales to the same value. This makes the final image more accurate since the zero points are equal and no nonlinear pixel values exist.

Bias frames will have very little signal in a modern quick read-out healthy CCD camera (larger and older cameras will have more signal). They will have virtually no effect on the visual appearance of the image (astrophotographers rarely bother with bias frames). In fact, you may find that the bias value changes by less than one ADU per pixel (your software will be able to determine this). In that case you should take the average value of all the pixels in the frame and apply that average to every pixel. What this does is correct for statistical "accidents". A bias frame will also take into account thermal current that collects while the frame is being downloaded to your computer.

Note: If one uses darks that are the same duration as the light frames, bias calibration is unnecessary because it is included in the dark data. Bias frames are only required if one intends to scale their darks.

Taking Bias Frames

Not all CCDs can take pure bias frames. Some CCDs just are not designed to take an exposure without using the shutter. In those cases you can simply skip the bias frame and go straight to the dark frame (which will include some of the same data as the bias frames) or you can make a pseudo-bias by taking an exposure with the shutter at the shortest possible exposure length and your system completely blocked of any light.

If your camera can take a bias frame, it is likely already setup in your software. A bias frame is a 0 second exposure. After you take it, inspect it for artifacts. In theory, the field should be uniform. But in reality you'll notice some changes in amplitude. If you notice any patterns, they were likely caused by a spurious noise source (computer CPU chip, home electrical surge, etc.). Take a number of bias frames and determine whether you are operating in a "noisy" environment or not.

The more bias frames you take, the better the result. The readout noise in the bias frame will decrease by the square root of the number of frames you take. In very sensitive cameras you may want to take as many as 50 frames! A good rule of thumb is to take as many bias frames as you take darks.

If you found that you are working in a noisy environment then you should *median combine* your bias frames, otherwise *average* your frames together to make a *master bias*.

3.3 Calibration: Dark Frames

A *dark frame* measures the thermal noise of your CCD. A dark frame is an exposure where the shutter is opened but no light is allowed to hit it so it only measures the energy from the CCD itself (dark current). This is normally done by placing a dust cap on the telescope and then covering it with a blanket, cloth, or something opaque to light. Darks also compensate for *hot pixels*, which are defects in the CCD chip that makes pixels look like they are permanently "on" or "lit". **Darks are very easy to take and are the most important calibration step** so there is no reason not to take darks.

Taking Darks

The *Handbook of Astronomical Image Processing* recommends the "Image-Times-Five" rule. The more dark frames you take, the more accurate the frame and the lower the noise. For a sample of 100 electrons, the uncertainty is 10%, for 10,000 it is 1%. A good rule of thumb is to make sure the total exposure time of all your dark frames equals five times that of the image you are calibrating. So if you are taking a 2 minute image, you can do five two-minute darks or ten one-minute darks.



Examples of dark frames. (Left) A standard dark frame that you might see from your system; (right) a ten-minute dark frame showing amplifier glow, commonly seen in older CCD cameras.

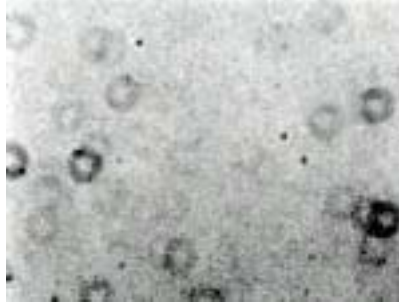
The dark frame also contains readout noise. Readout noise does not scale over time, so your dark frame right now is unscalable. That is a pain if you plan to take exposures of different lengths during your observing session because then you must take a ton of dark frames to match the integration time (times five!) of each image. If you could yank the readout noise then the dark frame only consists of thermal noise, which *is* scaleable. So let's do it! All you need to do is subtract the master bias frame from each dark frame you took. It's that simple.

As the CCD temperature changes during the night, the dark current will adjust. Except in extreme circumstances, you do not need to take darks for each image. A good rule of thumb is to take your dark frames in the middle of the observing session. Another plan is to take some of the darks at the beginning, some in the middle, and some at the end.

For each image remember to subtract the bias. Inspect each frame to make sure that cosmic ray events do not contaminate them. They will appear as a bright spot on your dark frame. It depends on altitude, physical size of the CCD chip, and exposure time but in general expect about 1 cosmic ray event every few minutes of exposure time. When you have a bunch of darks, average them together to create a *master dark*. (You can skip the cosmic ray inspection by *median* combining at least 3 frames instead of averaging them; but then your final dark will have slightly more noise.)

Tip: It is possible to create a *library* of dark frames for different temperatures and operating environments. Some people will create them once a month (during the full moon downtime perhaps?) or once a week. However, these dark frames will never be as good as ones you take during the observing session. Experiment with your own system and see how a library of darks affects your final error and then decide whether the savings in hassle is worth it for your current project.

3.4 Calibration: Flat Frames



A typical flat frame. The circular rings are "dust doughnuts" — out of focus images of dust particles on the optical surfaces of your telescope, filters, and camera.

For the absolute highest quality photometry flat frames must be used to calibrate your image. A flat frame compensates for obstructions, reflections, and other problems in the light path. This is the path light travels from the time it enters the telescope to the moment it strikes the CCD chip. Dust on optical surfaces, reflections from baffles or poorly aligned optics, vignetting, and other noise sources can interfere with your final data.

Flat fielding is the most difficult calibration routine you will have to deal with. There are many things to watch out for and many ways to do it. In fact, some people call it an *art* because it is so intricate and there are so many creative ways you can do it. The key is to be patient and realize that your first few flats will likely not turn out well. Take your time and with experience you'll be able to *master the master flat!*

The Concept

A flat field is a picture of what's wrong with your system in regards to light. (This is an oversimplification but bear with us here.) You will see dust donuts, light gradients, reflections, and more. Now that you have an image of what is bad, you take an image of the star. *That* image is an image with good (star) and bad (noise). You remove the flat field from the image and you are left with only the good. Trim the fat, so to speak.

Taking Flats

The first thing you have to do is take *flat darks*. These are dark frames taken to be applied to the flats. So you want to match the integration time with that of your flat, **not** that of your final image. These darks will be separate from your image calibration darks. Other than that, the procedure is exactly the same as above.

The goal is to take an image of a uniform light source (the "flat" field). So the first thing you need is that uniform light source. This is the most difficult part of taking flats. The good news is that once you find a uniform light source that works you can use it forever. There is no fool-proof method of creating the uniform field. How you do it will likely depend on your physical location, mechanical ability (handyman factor) and your level of patience! Here are some of the most popular light sources for flat fields:

- **Domes:** Shining a light on the underside of the roof of a closed dome.
- **Twilight:** For about 15 minutes at dusk and dawn a photometric sky can be a uniform blue.
- **Light boxes:** These are boxes with a light bulb inside that fit on the outside of the telescope's central opening.
- **T-shirts, et cetera:** All sorts of creative ideas have been used to create uniform fields from white cotton t-shirts to film screens to the sides of houses. The limit is your imagination.

Usually the light source will be a dimmable bulb so that the light can be adjusted for the filter you are shooting through. Different filters transmit different amounts of white light so what may be a good source for a V filter may be a weak source for an R filter. If you don't have a dimmable bulb you can adjust the image exposure time, but then you need to take a new set of flats. (This can get complicated pretty quickly!) The light source should be reflected off uniform surfaces before entering some type of diffusing screen. For example, you may want to shine a light on a white poster board which reflects it to a piece of translucent plastic before going into the telescope. The more times you reflect the light, the more uniform the field will be.

Once you have a uniform field, expose your CCD to about 1/2 of the full well depth of your pixels. Take at least 16 flat field images, this is the lowest number required in order to avoid adding noise to your final calibrated image. For .01 mag accuracy photometry keep your signal to noise ratio to 500:1 or better. The exposure time will differ based on what filter you are using since each will pass a different fraction of the light source.

Every time you change an element in the light path, such as removing a filter, you change the light path so you have to take new flats. So you can't take a flat with a V filter, then take it off and put on an R. When you do that the V filter flats should be discarded. (If you are using a high quality filter wheel then you can do all the flats at once since their orientation in the light path will be the same when the filter wheel changes it.)

Applying Flats

The procedure for applying a flat field correction is straightforward. First, you create the flat:

- Average all your flats
- Average or median combine all your darks made specifically for the flats
- Subtract the averaged dark from the averaged flat

What you have left is your *master flat*. Congratulations! This flat will be good as long as you don't change anything in the optical configuration of your system.

Now you can begin taking data (images). Divide the flat into each image after you have dark subtracted it. Most software programs have a way of automatically doing this. Now your images are fully calibrated.

Rejoice!

3.5 Finding the Field

At first this can be one of the most frustrating parts of the learning curve. It is also an area where visual observing experience really begins to pay off. The same problems you have with finding the field visually exist with CCD. The difference is that your field of view will be **a lot** smaller.

Some recommendations:

- **Alignment:** Don't skimp on your alignment procedures.
- **Chart Masks:** Draw a circle on a sheet of plastic indicating the field of view of your CCD and then block out anything outside that field of view. Use this mask on your charts. Make one for D, E, and F-scale charts.
- **Use Big Charts:** Your field of view may fit within an F-scale chart, but bring D and E-scale charts with you while observing. This way if your mount doesn't put you within the F chart you can find yourself on the E or D charts. If the E and D charts don't go faint enough, print out a copy of the field using the DSS option when plotting charts with VSP.
- **Learn to read the charts!**

3.6 Image Integration Style

It is perfectly acceptable to co-register and then stack (a.k.a combine, sum, average) images to improve your signal to noise ratio. However, don't perform any nonlinear calculations on the field as this will destroy the photometry. One advantage to doing a median combine is that you can remove cosmic rays that way, but you do take a hit in your signal to noise ratio.

3.7 Tricks of the Trade

Here are some notes and general rules of thumb from some experienced observers:

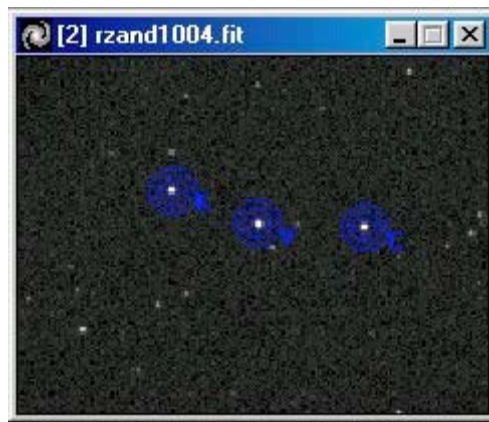
- Don't expose for less than a few seconds. Anything shorter will cause the shutter to affect photometric data (the speed of the shutter opening and closing will affect the amount of light that falls on pixels depending on where the pixels are located in reference to the rest position of the shutter).
- Plug in your camera first when you begin setting up for the night so that it can reach a temperature equilibrium by the time you are ready to take darks. Most modern consumer cameras need 15–30 minutes to stabilize.
- Outside temperature and humidity can affect dark frames quite a bit. Experiment to determine how many degrees of a temperature change your system will handle before you need to take a new set of darks.
- Keep careful written records of seeing conditions, photometry results, how many darks and flats you took, etc. This will come in handy later when you are reducing data. Remember data reduction may take place days or weeks after you took the image when many vital details may have been forgotten.
- Practice, practice, practice. And don't forget to enjoy yourself.
- Develop a personal convention for naming your files so that you'll know what they are without opening them or consulting your notes. This will reduce your observing log burden and speed-up analysis. A straightforward and unambiguous convention would be to include the date, the object name, the filter, and the exposure number if you make multiple exposures of the same object. For example, the following filename would clearly indicate the file is an image of KV Dra, taken on 2009 December 1, with a V filter, and is the first in a series: **kv_dra.2009Dec01_V_001.fit**. If you use a simpler naming convention (like the running exposure number during a night) keep good logs, and make sure the header of the FITS image contains information like the RA/Dec, filter, and exposure time.

4.0 Photometry

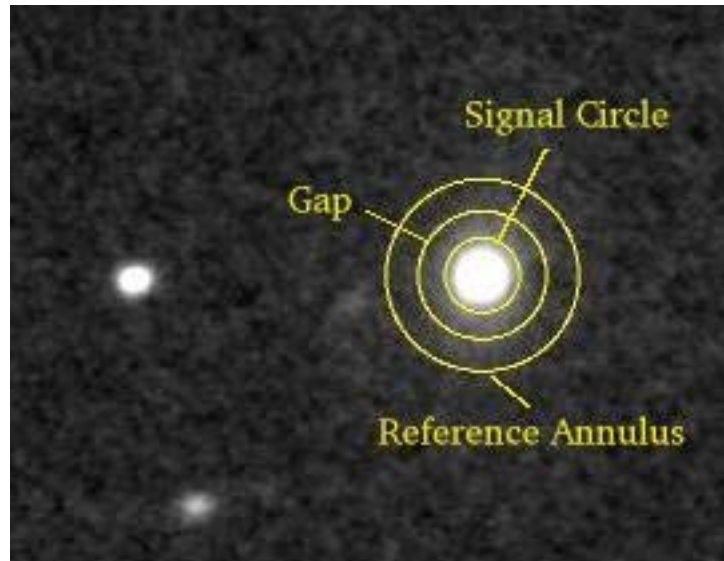
Photometry is the process of measuring the brightness of stars in the sky. Some call it an *art* and some others even call it *black magic* because it can be quite challenging and confusing. But don't let that scare you, it is also very fun. Most importantly, it is neither *art* nor *magic* but **science**. Anyone willing to put in the time and effort to properly acquire and analyze their data is a photometrist regardless of your equipment and your experience. Variable stars are addictive. When you have been following the same star for a long amount of time it can almost seem like part of the family. You expect certain activity, and when it acts up, you get concerned! Photometry is definitely a challenge, but it is a worthy one and a unique area of science where amateur help is not only needed but required.

There are many different methods to photometry. Each has different requirements and results. In general, the more work you put in the more accurate your data will be. In this manual we'll cover the basics of going from your calibrated CCD images to data you can submit to the AAVSO.

4.1 Aperture Photometry: from pictures to data



The easiest way to measure the instrumental magnitudes is to measure the amount of signal contained within an *aperture* centered on the stars in the field. Your CCD software contains an algorithm that establishes a circular aperture around the targets you select, and then simply adds together the values of the pixels contained within that circle. The size of the aperture is set so that it contains (a) the vast majority of the signal from the star itself while (b) minimizing the amount of signal coming from other sources like the background sky. You have probably already realized that stars do not appear as perfect points of light in the image but are spread out into peaks whose width depend upon the aperture of your telescope and the seeing conditions. An aperture radius is usually defined in pixels such that most of the light of the star falls within the measured radius. An additional refinement of this is to draw a second *annulus* around each star — centered on the star, but far enough away such that there is minimal light from the star falling within the annulus. This annulus gives you a measure of *how bright the sky is* around your star, and will thus allow you to subtract out the signal of the sky from the signal in your aperture. Again, your software will probably do this for you once you tell it where to center the aperture, and how wide you want the apertures to be. This entire process is what is known as **aperture photometry**, and is by far the simplest and most common means of performing photometry in uncrowded fields.



There are other ways to perform photometry than aperture photometry. Two that you might hear about are "point-spread fitting" and "image subtraction", both of which are rarely included in commercial CCD analysis packages, but are used in the professional community. For example, you may come across mentions of photometry being performed with a package called "DAOPhot" in your readings. This is a very powerful (but very complicated) PSF-fitting package developed two decades ago at the Dominion Astrophysical Observatory. The benefits of methods like these are that they work in crowded fields where the images of your target star may be blended with nearby stars, or where it is difficult or impossible to measure the sky background without finding a faint star nearby. Again, both of these methods are beyond the scope of this manual, but as you become more experienced, you may want to investigate them on your own. At first, aperture photometry will work admirably well on nearly all variables you will observe.

The results of aperture photometry are what are called **instrumental magnitudes** — calibrated *but not zero-pointed* measurements of the brightnesses of each object in the field for which a statistically significant detection was made. An instrumental magnitude essentially tells you how many photons your CCD camera detected. But the physically important number is how bright the objects in the field are in some common measurement system. In the next section, we explain how to go from these instrumental magnitudes to a true magnitude that you can submit to the AAVSO and compare to data by other observers by performing **differential photometry**.

4.2 Differential photometry

Differential photometry is the easiest type of photometry to learn, and is the only type of photometry that we'll cover in this introductory manual. It is quite similar to visual observing in that you have the variable star (V) in the same field as your comparison ("comp") star (C) and you estimate the difference between the known (C) star and the unknown (V) star. An additional check star (K), whose magnitude is known, is compared with the comp star to make sure it also does not vary.

Differential photometry looks something like this:

$$\Delta V = V_{\text{measured}} - C_{\text{measured}}$$

If you know that your system gives a good measurement of C, then ΔV should represent the difference in magnitudes between the variable and comparison star. How can you know whether your measured C is correct? The best way is to compare C to that of another star in the field, the check star. As long as $(K - C)_{\text{measured}}$ is the same as $(K - C)_{\text{known}}$ and remains constant throughout your observing run, then you can be

reasonably confident that your ΔV is correct. The quantity ΔV that this procedure produces is what is called a **differential magnitude**. Sometimes it is appropriate to stop at that point and keep your magnitudes in differential form, although when you do so *you must remember the identification of the comparison star!* A differential magnitude without a comparison star identification is not useful other than for very basic analysis of your data alone.

We prefer that observers submit **standard magnitudes** to the AAVSO. This includes an extra step of converting your differential magnitude into a true magnitude by adding the known magnitude of the comparison star in your filter to the differential:

$$V = (V-C)_{\text{measured}} + C_{\text{known}}$$

This makes it much simpler to combine your data with those of other observers who may not be using the same comparison star. You should **always** identify your comparison (and check) stars in your data reports regardless of whether you submit standard magnitudes or not. In principle, if everyone were using fully calibrated telescopes and cameras, you could use different comparison stars to observe the same variable at the same time and obtain the same value of V . In practice, you can get *close*, but there will likely be differences in your magnitudes unless you make extra effort to calibrate your system, correct for airmass effects, and transform your data to a standard system (which is why you should include as much information about your observation as you can).

The limit to differential photometry is that you must have a comp and check star in the same CCD field of view as the variable. This usually means using a star chart made by the AAVSO for a star with an existing comparison star sequence. Also, your final magnitude estimate is subject to errors in the measurement of the comp star. The strengths include simplicity, and (more importantly) the canceling out of differences in air mass and atmospheric conditions between variable and comparison stars, which is one reason why differential photometry is easier than all sky.

Some CCD software packages can also allow you to perform what is called **ensemble photometry**. In this method, you (and the software) pick more than one comparison star in the field, and then compute a standard magnitude for each pair of $(V-C)$ measurements. You then perform a weighted average of these values to obtain a single magnitude for the variable. The benefit of this is that it reduces errors in the differentials by using a number of independently-measured stars. The downside is that it is more complicated, and typically involves more interaction with the photometry package. For example, you might find that one of your comparison stars is an undiscovered variable, or that it is noisier than the rest of your comparison stars (due to a bad pixel, interference by an optical defect, or a cosmic ray hit). You can improve the resulting magnitude by removing that one pair of $(V-C)$ from the ensemble. This is a slightly more advanced form of differential photometry; at first, you should try performing differential photometry and see how well you do. Once you understand that to your satisfaction, then move on to trying an ensemble. Consult the manual or vendor of your software to see whether and how you can perform ensemble photometry with it.

There are a few other things to keep in mind:

- Clouds and out of focus images are okay for differential photometry since they affect both the variable and the comp star the same but they may add some scatter/error to your observations.
- If you do everything with care you can have an accuracy of 0.05 mag without taking flats, however with flats differential photometry can get you errors well below 0.01 mag.
- To increase precision, set up your signal circle diameter to 3–4 times the FWHM. In a pinch (depending on seeing and crowding), you can lower it to encompass 80% of the FWHM to increase your SNR. 80% is the theoretical limit for best SNR on faint objects. However, in practice it is hard to make 80% work. Variable seeing will change the star's FWHM making it difficult to keep a constant and accurate annulus. Shortcomings regarding pixel measurement and imperfect annulus placing by commercial software packages also add to the mix. So 80% may be perfect for the lab, but not in reality.

- Sometimes the field may be very crowded and other stars will interfere with the sky annulus. Change the size of the gap annulus to remove the star from the sky annulus. If the field is too crowded for aperture photometry, you will either need to accept larger than typical photometric errors, or try a different method such as PSF-fitting.

4.3 Calculating and submitting uncertainties

Any observation has some inherent uncertainty, and the formal calculation of these uncertainties is an important part of variable star observing. Any CCD observation that is submitted to the AAVSO should also include an uncertainty. Your CCD photometry software almost certainly has the capability to compute the uncertainty of your observations, either in magnitudes, or as a signal-to-noise ratio. If your software provides you with the "one-sigma" ($1-\sigma$) uncertainty of your photometry in magnitudes, then the uncertainty of the variable star magnitude you submit would be the quadrature sum of the uncertainty of the variable and comparison star magnitudes used to determine ($V - C$). Simply square each of the variable and comparison star errors, add them together, take the square root of the result, and submit that value as your uncertainty. If your software provides the signal-to-noise only, then the one-sigma error in magnitudes σ_m is close to the inverse of the signal-to-noise, or $\sigma_m \sim 1/(S/N)$. Compute the uncertainty using the inverses of signal-to-noise values of the variable and comparison star just as if they were magnitudes.

If, for some reason, your software doesn't compute the uncertainties (or if you just want to do it yourself), you can. The calculation isn't as difficult as it is made out to be, and it is worth working through the derivation of the "CCD equation" to make it clear.

First, imagine we don't have to worry about noise sources or the CCD camera or sky background and we just want to know what is the intrinsic uncertainty in our measurement of photons coming from a light source? In the absence of noise, the errors are purely Poisson, and are proportional to the square root of the number of photons received in a given time. If you were to receive 10000 photons from your source during a given integration, the Poisson error is 100, or one percent. We could then express the signal-to-noise ratio as $N_*/\sqrt{N_*}$. That's very straightforward.

Next, let's add in the noise sources. Our signal is still N_* but what about the noise? If we consider the noise to be the uncertainty in the total number of photons received, then we would need to consider all of the photons from the star (N_*) and all of the other photons and other "counts" that fell within our measurement aperture. For the most part, this includes three things: the brightness of the sky itself, the dark current of the CCD which is effectively like a light source, and the readnoise. All three of these affect each pixel within your image, including those within your measurement aperture, so they're added to the term within the denominator.

Let's deal with sky and dark counts first, since they're easiest. Suppose your measurement aperture contains n pixels. If each pixel receives N_s photons from the sky, and N_d "photons" of dark current, then you'd have

$$S/N = N_*/\sqrt{(N_* + n(N_s + N_d))}$$

Next, the readnoise. Readnoise is shot noise and not a Poisson process, and its errors do not go as the square root, but are linear. Since it will go inside the square root, let's add the square of the readnoise counts, N_r^2 , since squaring cancels out the square root:

$$S/N = N_* / \sqrt{(N_* + n(N_s + N_d + N_r^2))}$$

This is a simple version of what is called the "CCD equation". In most (not all) observing situations you'll encounter, this equation provides most of what you need to consider in error calculation, particularly if you're doing most of your photometry on bright stars where N_* is fairly large compared to the other terms. If you're doing photometry of faint stars, N_s may be of the same order as N_* . (If N_* and N_s are less than N_d or N_r , then you're probably not exposing long enough!)

Now, when your computer records the numbers of photons received, it is actually recording ADUs or "Analog to Digital Units" rather than the raw number of photons you received. Each pixel on your CCD holds photoelectrically generated electrons, and your camera's electronics counts the electrons and converts these counts to ADUs. The gain of the CCD is the number of electrons it takes to create one ADU. If your CCD has a gain of 5, then 5 electrons will yield 1 ADU. If the gain is 100, it will take 100 electrons to get 1 ADU.

The CCD equation assumes you're talking about electrons rather than ADU, so in order to use it, you have to include the gain in the calculation. You multiply all of the terms given in ADU by the gain to obtain the number of photons/electrons:

$$S/N = N_s(\text{ADU}) g / \sqrt{ N_s(\text{ADU}) g + n (N_s(\text{ADU}) g + N_d(\text{ADU}) g + N_r^2(\text{ADU}) g) }$$

In the simple case, this simply amounts to multiplying the S/N obtained putting the ADU values into the CCD Equation by the square root of the gain.

Now we're practically done. Remember that we are submitting data in magnitudes rather than in the signal-to-noise of the counts, so to find the one-sigma uncertainty in magnitudes, take the inverse of the S/N of each of the variable and comparison star, and add them in quadrature. The result is the one-sigma uncertainty in your magnitude.

For a more detailed explanation of this, as well as a derivation of some second-order terms useful in faint-source photometry, see Chapter 4.4 of Steve Howell's Handbook of CCD Astronomy, 2nd edition (2006). The topic of error calculation will be one of many extensively covered in Arne Henden's upcoming book on CCD Photometry.

4.4 Bright Star Photometry

A good discussion of short exposure photometry occurred on the AAVSO_Photometry Discussion Group in July 2004. This discussion can be found in the mailing list archives here:

<http://mira.aavso.org/pipermail/aavso-photometry/2004-July/subject.html>

There are two main problems with high-precision short-exposure photometry. First, bright sources tend to get overexposed, especially if any nearby comparison star is fainter than the target. Antiblooming gate (ABG) CCDs typically saturate at about 50% of their full well depth, and many non-ABG chips saturate before the limit of their Analog/Digital Converters (ADCs). Second, the atmosphere itself conspires to degrade the photometry through a phenomenon called scintillation, where the turbulent bubbles of gas act like lenses, increasing or decreasing the amount of flux entering the front of your telescope. The twinkling of naked eye stars is caused by scintillation.

To counteract saturation, first test your CCD camera to find out the limits of its linearity and where full well occurs in the dynamic range of your ADC. Then keep the signal level within the linear range and below the full well. For very bright sources, you may reach a limit where you cannot take a short enough exposure to prevent saturation. Techniques to go even brighter include:

- Stopping down the aperture of your telescope by using a mask with a cutout hole. You can often place the cutout so that the incoming light avoids the central obstruction and spiders.
- Using a photometric filter, especially a blue one. The filter decreases the bandwidth and therefore decreases the amount of light reaching the CCD, enabling longer exposures. Using a blue filter further moves the incoming light to a wavelength regime where the CCD is less sensitive, enabling longer exposures.

- Defocusing. While you don't want images with "donuts", you can often increase the image profile by a factor of two or more, thereby decreasing the central peak intensity.
- Using a Barlow lens. Increasing the image scale spreads the starlight over more pixels, decreasing the peak intensity.
- Wait for a night of poor seeing! 6. Often a night with uniform cirrus can be used, since such clouds decrease the incoming flux.

Scintillation can be tricky. It is stronger nearer the horizon where you are looking through more atmosphere. It is also stronger for smaller telescope apertures, where each blob of atmospheric gas is closer to the telescope aperture size (bigger telescopes average many blobs). It is also a function of wavelength (redder is better) and exposure time (longer is better).

Tips to avoid scintillation:

- Use relatively long exposures (10 seconds or longer). Use the techniques listed above to increase exposure time if necessary.
- Don't work close to the horizon. We usually recommend staying above airmass 2.5 if possible.
- Take multiple exposures and average to beat down the effects of scintillation.

Here is a formula posted by Radu Corlan (CXR) for estimating scintillation without taking altitude into consideration:

$$\Delta m_{\text{scint}} = (0.09 * A^{7/4}) / (D^{2/3} * \text{sqrt}(2 * t))$$

where A is the airmass, D is the aperture in cm and t is the integration time in seconds.

It is taken from a series of papers by Dravins et al. that begin with "Atmospheric Intensity Scintillation of Stars, I. Statistical Distributions and Temporal Properties" 1997, PASP. 109, 173.

End note: The discussion of bright star photometry given above still applies today as it did in 2004. However, many observers have begun using other kinds of imaging equipment to take images of the sky. The most common of these today is photometry made using camera lenses mounted on digital SLR cameras, or "DSLR photometry". This is an exciting new area of astronomy as it enables observers to target long-neglected bright variables that are simply too bright to observe easily with larger aperture telescopes. Des Loughney of the British Astronomical Association has written an article for the Journal of the British Astronomical Association (February 2010) that discusses bright star photometry with DSLR systems. You can access this paper and its figures at the following URLs:

<http://www.citizensky.org/sites/default/files/JBAA2.doc>
<http://www.citizensky.org/sites/default/files/epsaurfigure4.jpg>
<http://www.citizensky.org/sites/default/files/UCepfig1.jpg>
<http://www.citizensky.org/sites/default/files/rhocasfig2.jpg>
<http://www.citizensky.org/sites/default/files/rhocasfig3.jpg>

References

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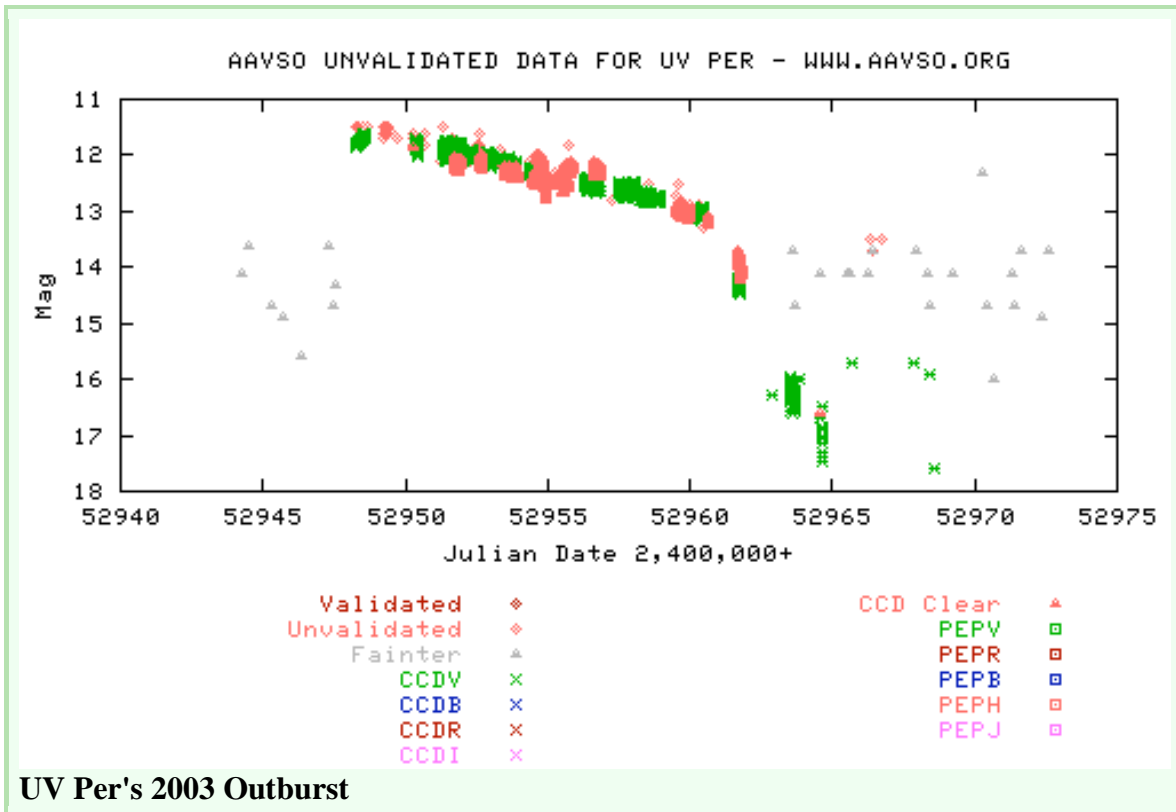
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- Newberry, M.V., 1991 "Signal-to-Noise Considerations for Sky-Subtracted CCD Data", *Publications of the Astronomical Society of the Pacific*, 103, 122– 130.
- Lyons, L., 1991, *A Practical Guide to Data Analysis for Physical Science Students*, Cambridge University Press

5.0 Observing Programs

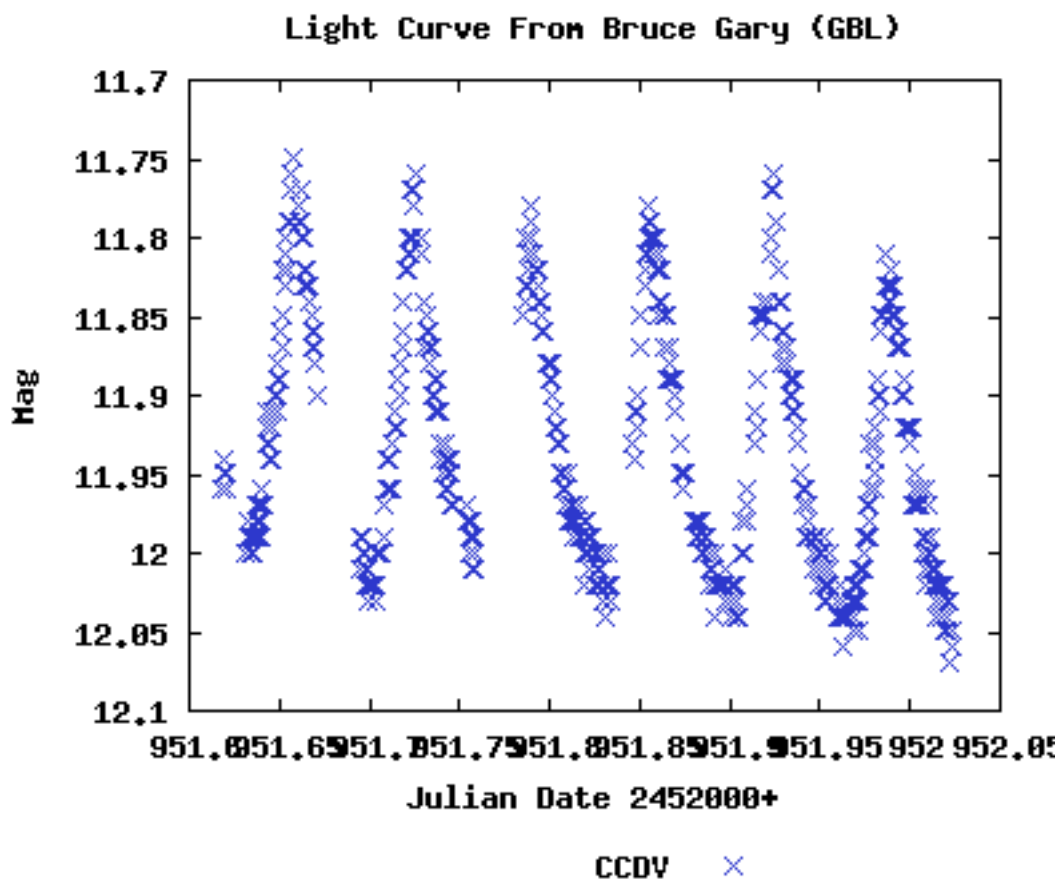
5.1 Cataclysmic Variables

Cataclysmic variables (CVs) are unpredictable stars. Their changes in brightness can be tiny (.01 mag) or steep (>6 mags!) and can occur every few minutes or every few decades.

Most CVs are monitored until they experience a sudden change in brightness, usually either an *outburst* or a *fade*. During this period of activity they are monitored closely for small variations in their light curve.



It is this second phase where CCD observers are especially needed. High time-cadence imaging of a star in outburst, for example, can discover *superhumps*. These superhumps can help determine the orbital period for the binary star and setup models for the system. Discoveries of previously unknown or changing superhump periods can be worthy of publication. However, you need very accurate photometry to detect superhumps in most systems, usually 0.01 magnitude accuracy.



Example of superhumps detected by Bruce Gary (GBL). This data, combined with data from 18 other observers, refined UV Per's superhump period and measured its evolution. It was published in IBVS #5488.

CVs are a great opportunity for visual and CCD collaboration. Visual observers can monitor the CVs every night and then notify the CCD observers when they go into outburst. At that point the CCD observers can try to detect superhumps or other behavior. CCD observers can also help by observing very faint CVs at quiescence.

For more information on observing CVs and recent research news, please visit the website of the AAVSO CV Section:

<https://sites.google.com/site/aavsovcvsection/>

5.2 Long Period Variables

Long Period Variables (LPVs) are red giants that have long periods. They are among the easiest targets for CCD observers since they don't need to be monitored every night and tend to be fairly bright. Miras and other LPVs are less commonly observed by CCD observers despite their prominence in the AAVSO archives and their importance in astrophysics. The AAVSO receives more data requests for LPV data than any other type of variable star, and both visual and CCD observations are quite valuable.

LPVs need to be observed only once a week. Since they tend to be red, using a photometric filter is critical to obtaining an accurate measure of their optical brightness. Multiwavelength observations taken with different filters are one way that CCD observers can make an important contribution. Another is to observe Miras and other large-amplitude LPVs when they are too faint for most visual observers to reach (typically below magnitude 14–15). Some large surveys like the *All-Sky Automated Survey* (ASAS) also cut out at about 15th magnitude, and so a CCD observer capable of going fainter than magnitude 15 can stake out some important research ground for these variables.

For more information on observing LPVs please visit the AAVSO LPV Section website:

<https://sites.google.com/site/aavsolpvsection/>

5.3a Gamma Ray Bursts

The AAVSO International High Energy Network consists of a worldwide network of observers dedicated to searching for optical counterparts of gamma-ray bursts (GRBs) through a coordinated rapid response network.

What does this mean? They await word that a GRB has been detected (usually by satellite). When that word comes, they head to their telescopes and attempt to image the GRB using CCD cameras. Time is of the essence here and that is where the AAVSO GRB Network comes in.

Through a connection with the GCN at NASA's Goddard Space Flight Center, notifications of recent GRB detections by orbiting satellites is distributed to the AAVSO. Our network takes these notices and distributes them, in turn, to our members based on a set of filters each observer specifies. The distribution method is via e-mail, and can be sent to any valid address including cell phone addresses.

Depending upon the satellite that detected the GRB, the entire process can take as little as a few seconds. The speed of notification is key because most optical counterparts to GRBs discovered so far have been faint and very quickly became even fainter. The faster we react, the better chance we have of finding the counterpart and/or creating a light curve.

GRBs may hold one of the keys to better understanding our Universe. They are the most powerful explosions of energy yet discovered. They may be used as distance markers, glimpses into the early days of our universe, and much more. But none of this can happen unless we obtain more information on these strange events.

There is a large amount of background information on GRBs and the AAVSO High Energy Network to be found at the web site for the AAVSO International High Energy Network. Please visit the following URL for more information:

<http://www.aavso.org/observing/programs/hen>

5.3b Blazars

The AAVSO International High Energy Network also observes blazars — highly variable quasars that are also bright gamma-ray sources — both for long-term monitoring purposes and in support of ground- and space-based high-energy observing programs of the blazar research community. Blazars vary on all timescales (from minutes to years) and at all wavelengths, and are a rich field of astronomical research. For more information on the AAVSO's blazar research program, please visit the blazar section of the High Energy Network web pages (<http://www.aavso.org/observing/programs/hen>).

Different CCD observing strategies are used with blazars. Since they vary so much campaigns of different lengths are devised. All objects are monitored monthly to set a baseline of behavior. Beyond long-term monitoring, specific campaigns looking for intraday (timescales of 4, 8, or 12 weeks) and microvariability (resolution of several minutes for many days) are also requested. For information on recent and current observing campaigns on blazars, visit the High Energy Network web pages, or see the "Observing Campaigns" section of the AAVSO website (<http://www.aavso.org/news/campaigns.shtml>).

5.4 Eclipsing Binaries

The Eclipsing Binary Committee is a superb example of CCD and visual observers working together to do good science. The visual observers will follow a recently discovered or suspected eclipsing binary star (along with doing archival research) to try and determine a time of minimum. Then the CCD observers will refine that time and together they usually publish an IBVS paper.

The Eclipsing Binary Committee can tell you what you need to do to observe and report data. They can also give you interesting targets and help coordinate observing programs if you would like to work with others.

5.5 Low Amplitude Stars

It is difficult for visual observers to record variations below a magnitude. CCD observers, on the other hand, can record variations down to the error level of their system. This makes CCD observations ideal for stars that may be bright but vary by small amplitudes. Such stars may be very red also, which increases visual scatter even more. If one wants to detect variations below 0.1 magnitude then precision photometry is essential.

The AAVSO PEP Program (<http://www.aavso.org/observing/programs/pep/>) monitors many bright low amplitude stars like pulsating red giants and RS CVn (spotted, rotating) variables. CCD observers could, for example, follow the fainter stars that also have small fluctuations in brightness which cannot be detected visually. CCD observers can also take data with a higher cadence than photoelectric observers, and so can track stars with short periods or rapid variations (e.g. delta Scuti stars). CCD observers have been extremely successful in observing delta Scuti stars and other pulsating variables with amplitudes much less than one magnitude (see for example the recent paper on VX Hydrae by Templeton et al., 2009, PASP 121 1076, <http://arxiv.org/abs/0909.5409>).

As with the PEP program, full calibration and transformation of magnitudes to a standard photometric system (not covered in this manual) greatly increases the value of such observations. Once you have experience observing other, larger amplitude variables, you might consider beginning a program on lower amplitude stars.

5.6 Supernovae/Novae Patrols

Most supernovae and novae patrols these days are done with automated systems. However, non-automated systems still have their place and discover tens of supernovae/novae per year. For novae, the key is to have a wide field of view. Many people will simply connect their CCD to a standard 35mm camera lens and then point at the sky along the galactic plane. For supernovae, the best method seems to be to select a group of galaxies to monitor and then image them as often as possible. In both cases, *blinking* the image will reveal new sources. Blinking is a term referring to flipping back and forth between two images of the same field. There are many programs that can help automate this process.

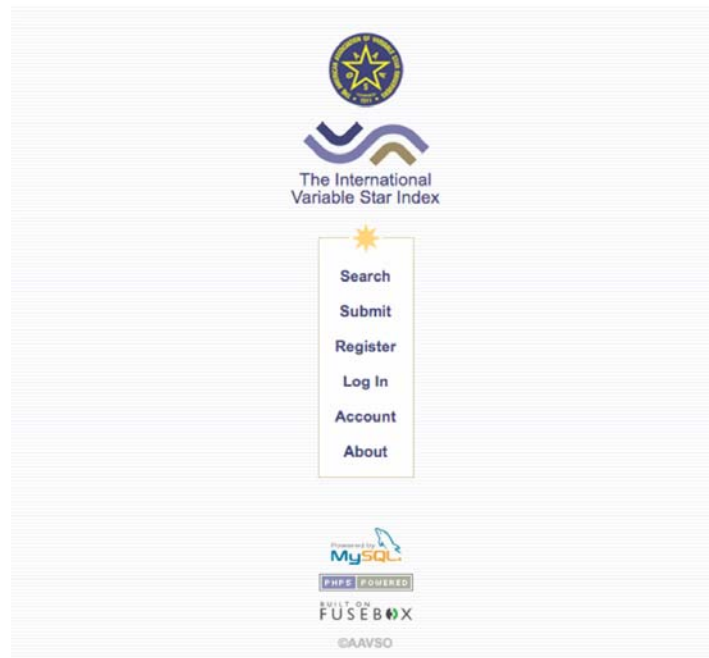
CCD observers can also help monitor previously discovered supernovae. Supernovae brighter than mag 13.0 are announced in an Alert Notice if they are well placed within their host galaxy. Fainter supernovae

may also be announced if they are Type-I and discovered during rising light. Performing photometry of supernovae is very difficult because of the interference of the host galaxy, so be prepared for some "hands-on" photometry.

5.7 Designing Your Own — Using AAVSO VSX

Everyone has a favorite object, type of star, and/or method of observing. When designing a personal observing program think of what you can do with the CCD that visual or PEP observers cannot. Focus on those items to get the most out of your system. Also, be realistic with what you can do. For example, if you don't have the patience to take numerous careful flat and dark fields throughout the night then don't try to detect and report .01 mag variations in a star. Instead, go for an LPV program where .1 mag accuracy is enough.

You will probably find that as you become more experienced you will take a little from here and there and end up with a custom program. You can always send feedback to the AAVSO for help in planning a personal observing plan. Another great way to look for interesting variable stars is to use the AAVSO's *Variable Star Index* or VSX. This is a section of the AAVSO website first developed by Christopher Watson that has now become one of the largest repositories for information on variable stars as well as a clearing house for new discoveries.



You can use VSX to search for variable stars by coordinates, constellation, maximum and minimum brightness, period, and type. It also allows you to report new discoveries and add new information on existing stars. The VSX interface is very easy to use and includes online help with specific kinds of searches. You can access the Variable Star Index through the AAVSO website, or via this URL:

<http://www.aavso.org/vsx>

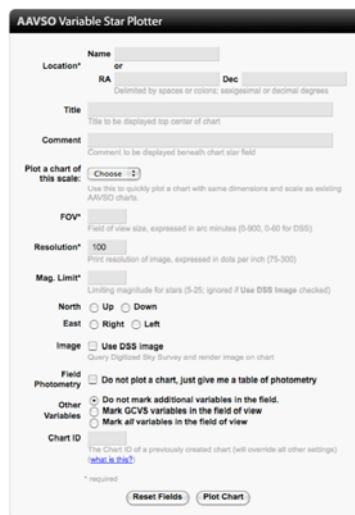
6.0 Observing Variable Stars: from your telescope to the AAVSO International Database

At this point, we assume that you are able to (a) operate your telescope and CCD camera, (b) acquire observations of stars and star fields, and (c) use your CCD software to reduce and photometer your images. From Chapter 5, you should also have some idea of what kinds of variable stars are out there, and what projects you might like to get involved in. Knowing all of these, where do you go next?

The AAVSO provides several important services to the astronomical community, most critically the maintenance and distribution of data contained within the AAVSO International Database (AID). As an AAVSO observer, your observations of variable stars are what we archive and serve to the astronomical community. Along with our maintenance of the AID, we also have to help observers contribute data, and that is what we explain in this section.

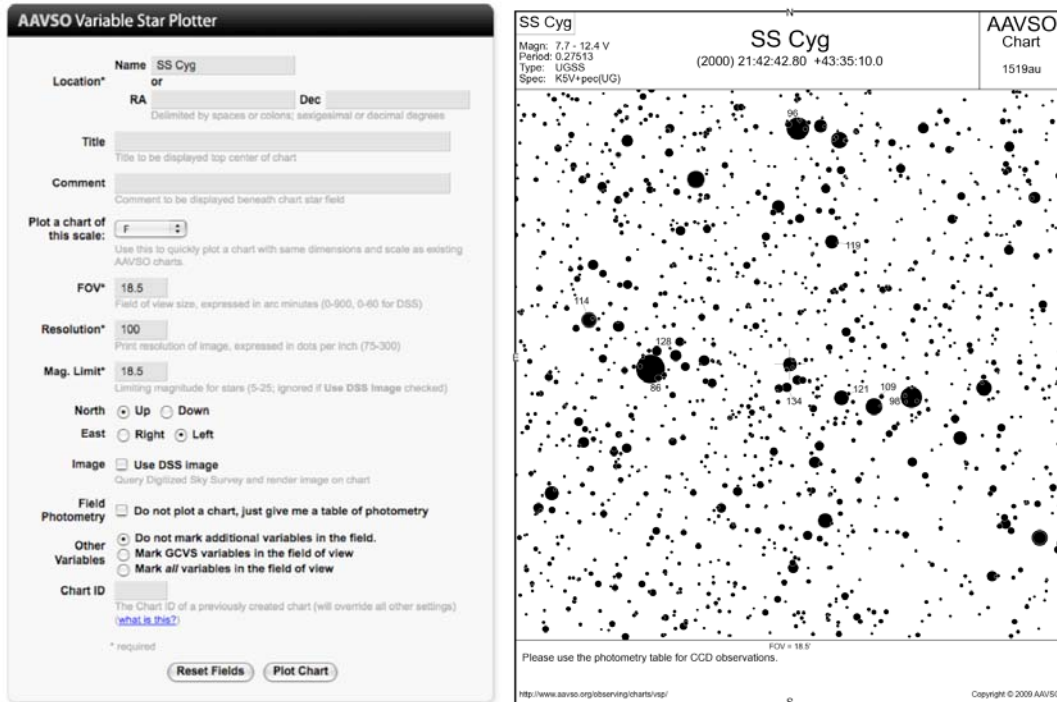
6.1 Using the AAVSO Variable Star Plotter (VSP) to make star charts

The AAVSO has its own variable star sequences, and requests that observers use these sequences if at all possible. The primary means of generating variable star charts is via the AAVSO's Variable Star Plotter (VSP) utility on the AAVSO website. This is a web-based program that allows you to generate customized variable star charts for any known variable star or for a specific set of coordinates. If a sequence is available for that star or in that region of sky, calibrated comparison star magnitudes are shown on the chart, along with markers for the target variable and, if desired, all other variables within the chart's field of view. You are also given the chart's "AAVSO Chart ID" which must be reported with every observation that you make. In addition to a graphical chart, you may also generate a text-based list of available comparison stars (by selecting the "Do not plot a chart, just give me a table of photometry" button). Charts are highly customizable, and cover the entire sky regardless of whether variable stars or sequences are available.

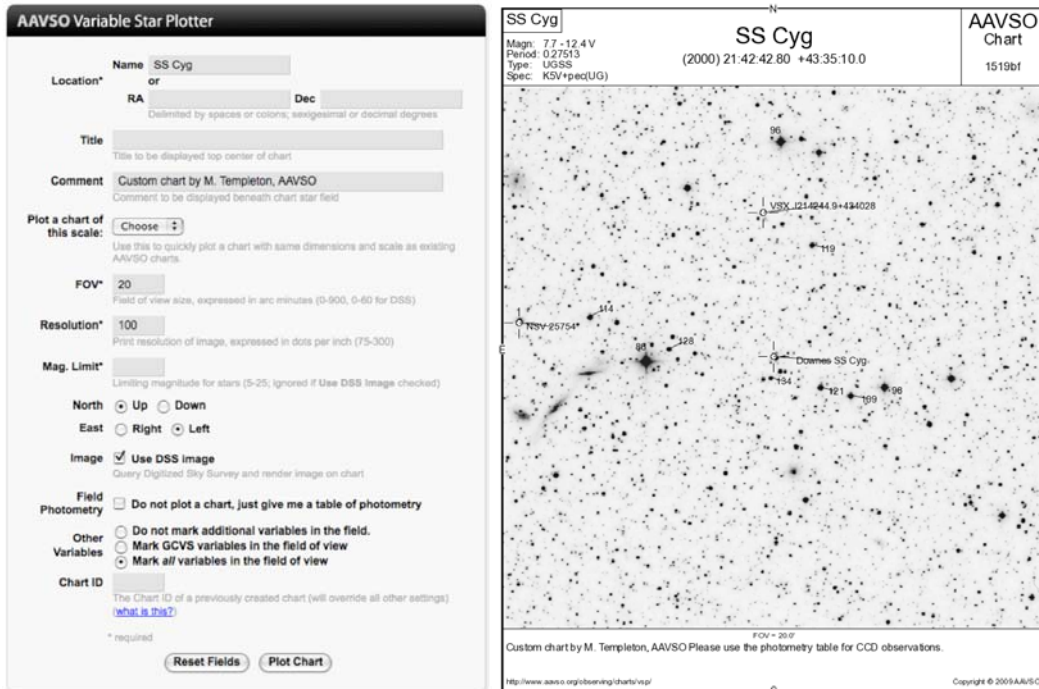


The AAVSO Variable Star Plotter interface. To generate your own charts, visit the VSP website: <http://www.aavso.org/observing/charts/vsp/>

The following two examples show you how to create customized charts of the field around the cataclysmic variable SS Cygni. First, here is a simple F-scale machine-plotted chart with North at the top and East at left, showing only SS Cyg and comparison stars:



Next, here is a slightly more complicated version, with a customized size and notes, including all GCVS variables in the field, and using the Digital Sky Survey plate for the field rather than machine-plotted dots for stars:



Finally, here is an example using VSP to obtain photometry of all of the comparison stars in the field of SS Cyg (note the button next to "Do not plot a chart" is checked here):

AAVSO Variable Star Plotter

Name: SS Cyg
 Location*: or
 RA: Dec:
 Title:
 Comment:
 Plot a chart of this scale: F
 FOV*: 18.5
 Resolution*: 100
 Mag. Limit*: 18.5
 North: Up Down
 East: Right Left
 Image: Use DSS Image
 Field Photometry: Do not plot a chart, just give me a table of photometry
 Other Variables: Do not mark additional variables in the field. Mark GCVS variables in the field of view. Mark all variables in the field of view
 Chart ID: [realt is this?](#)

Field Photometry for SS Cyg From the AAVSO Variable Star Database

Data includes all comparison stars within 0.151666666666667° of RA: 21 42 43.80 (121.67631) & Decl.: 43 35 30.30 (43.58811)

AUID	RA	Dec	Label	U	B	V	Re	Ic	J	H	K	Comments
000-BCP-215	21 43 08.68 (123.794194)	43 35 01.6 (43.503042)	85	11.513 (0.113) ¹⁰	9.872 (0.094) ⁹	8.558 (0.084) ⁸	7.857 (0.075) ⁷	7.333 (0.064) ⁶	6.932 (0.057) ⁵	5.536 (0.051) ⁴	5.136 (0.045) ³	
000-BCP-212	21 42 41.31 (123.672124)	43 34 53.4 (43.738743)	96	-	10.403 (0.097) ⁹	9.630 (0.091) ⁸	9.091 (0.084) ⁷	8.633 (0.077) ⁶	7.624 (0.069) ⁵	7.126 (0.062) ⁴	7.003 (0.057) ³	
000-BCP-198	21 42 20.24 (123.584224)	43 34 43.3 (43.567942)	98	10.480 (0.102) ¹⁰	13.162 (0.131) ¹¹	9.794 (0.097) ⁹	9.481 (0.094) ⁸	9.423 (0.091) ⁷	8.228 (0.075) ⁶	8.007 (0.072) ⁵	4.877 (0.048) ²	
000-BCP-202	21 42 27.27 (123.413224)	43 34 44.6 (43.562342)	109	11.520 (0.115) ¹⁰	11.412 (0.112) ¹⁰	10.898 (0.107) ⁹	10.391 (0.102) ⁸	10.207 (0.101) ⁷	9.862 (0.097) ⁶	9.407 (0.091) ⁵	9.369 (0.090) ⁴	
000-BCP-241	21 43 30.12 (121.833634)	43 36 39.8 (43.615744)	114	-	12.026 (0.120) ¹¹	11.413 (0.114) ¹⁰	11.051 (0.105) ⁹	10.720 (0.103) ⁸	10.246 (0.101) ⁷	9.976 (0.099) ⁶	9.921 (0.098) ⁵	
000-BCP-207	21 42 54.97 (123.848724)	43 39 47.1 (43.654744)	119	12.387 (0.122) ¹¹	12.486 (0.123) ¹¹	11.866 (0.119) ¹⁰	11.507 (0.116) ⁹	11.343 (0.114) ⁸	10.438 (0.102) ⁷	10.392 (0.102) ⁶	10.319 (0.101) ⁵	
000-BCP-206	21 42 33.24 (123.639694)	43 34 42.3 (43.567942)	121	16.111 (0.161) ¹¹	13.851 (0.137) ¹⁰	12.072 (0.120) ⁹	11.005 (0.109) ⁸	10.056 (0.101) ⁷	8.461 (0.083) ⁶	7.488 (0.074) ⁵	7.378 (0.073) ⁴	
000-BCP-236	21 43 04.02 (123.740724)	43 35 27.5 (43.930054)	138	13.613 (0.136) ¹¹	13.438 (0.134) ¹¹	12.807 (0.128) ¹⁰	12.418 (0.124) ⁹	12.014 (0.120) ⁸	11.109 (0.111) ⁷	11.312 (0.113) ⁶	11.165 (0.111) ⁵	
000-BCP-221	21 42 43.38 (123.649744)	43 34 23.5 (43.572044)	134	14.121 (0.141) ¹¹	13.409 (0.134) ¹⁰	13.363 (0.133) ¹⁰	13.151 (0.131) ⁹	12.827 (0.128) ⁸	12.127 (0.121) ⁷	12.167 (0.121) ⁶	12.192 (0.121) ⁵	

Report this sequence as **SS Cyg** in the chart field of your observation report.

- AUID is the AAVSO Unique Identifier for the star. When reporting a problem, please include this AUID.
- Coordinates are in J2000 equinoctial format, followed by decimal degrees.
- Click here for a search of variable stars in this field via VSS.
- Label is that star's label when plotted on an AAVSO chart, this is usually that (not always) its V magnitude rounded to the tenth.

Source Reference Table

Field/Star	Source	Field/Star	Source
1	Hylio-2	11	CVCAT
2	GC 12	12	Hipparcos
3	GC 2.2.1	13	Deepen, Deeper Ext.
4	USNO A2	14	NSV
5	USNO B1	15	AAVSO Charts from ~2006
6	GCVS	16	USGS
7	USNO Antaglyphs	17	ASAS3
8	2MASX	18	Swedish Research Obs.
9	AAVSO Charts from ~2006-2009	19	Other
10	London USNO Irs	20	ICATD

This kind of output from VSP is most useful when you're doing photometry on your images. The resulting table provides you with critically important information: the positions of the comparison stars, the magnitudes and colors of the comparison stars, and their AAVSO Unique Identifier code (AUID). If you were to perform differential photometry using any of these comparison stars, you would use the AUID as the name, and you would perform differential photometry using the stated filter magnitude as "C" (or "K" if using it as a check star).

One important thing in common with all three of these examples is that you are given a "Chart ID" with each result returned. For the plotted charts, look in the upper right corner; for the table, look just below the photometry table. When you report observations to the AAVSO, you must provide this code in the "Chart" field. This will allow future researchers to look up the sequence that you were using and (if necessary) apply corrections to your observations if improved comparison star photometry becomes available in the future.

6.2 Reporting Observations to the AAVSO

The AAVSO receives close to one million observations per year from observers around the world. This total is split roughly evenly between visual observations (made by eye, looking through the telescope) and CCD observations. (Observations from other sources like photoelectric photometry and photography represent a smaller but very important fraction of the total.)

All observers are asked to submit data through the WebObs utility of the Blue & Gold section of the AAVSO website. Blue & Gold is the primary way that observers and members submit data, make changes to their email and postal subscriptions, and register for AAVSO services. If you have been assigned observer initials, then you may register for Blue & Gold and will have access to WebObs.

Method 1: Manual entry

The WebObs utility allows observers to manually enter information about their visual, CCD, or other observations, or to upload pre-formatted data files in formats suitable for either instrumental or visual observations. CCD observers wishing to manually enter observations via WebObs will see the following data entry form when they enter the CCD section of WebObs:

Enter a CCD or PEP Observation

<u>Star Identifier</u> *	<u>Date</u> Click here for possible formats	<u>HJD</u> <u>Format?</u>	<u>Star Mag</u>	<u>Fainter</u> <u>Than</u>	<u>Mag Error</u>	<u>Mag Type</u> *
<input type="text"/>	<input type="text"/>	<input type="checkbox"/>	<input type="text"/>	<input type="checkbox"/>	<input type="text"/>	Standard ▾
<u>Comment</u> <u>Codes</u>	<u>Trans-</u> <u>formed?</u>	<u>Filter</u>	<u>Comp</u> <u>Label</u>	<u>Comp</u> <u>Mag</u>	<u>Check</u> <u>Label</u>	<u>Check</u> <u>Mag</u>
<input type="text"/>	<input type="radio"/> No <input type="radio"/> Yes	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
<u>CCD or</u> <u>PEP?</u> *	<u>Airmass</u>	<u>Group</u>	<u>Chart</u> Leave blank to load previous		<u>Notes</u>	
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>		<input type="text"/>	

* required

Submit Observation to AAVSO Database Clear Fields

You can then enter in all of the relevant information for your CCD observation, including the time of the observation, the magnitude and its error, the filter, the comparison and check star identifications, and any other information you may have:

Enter a CCD or PEP Observation

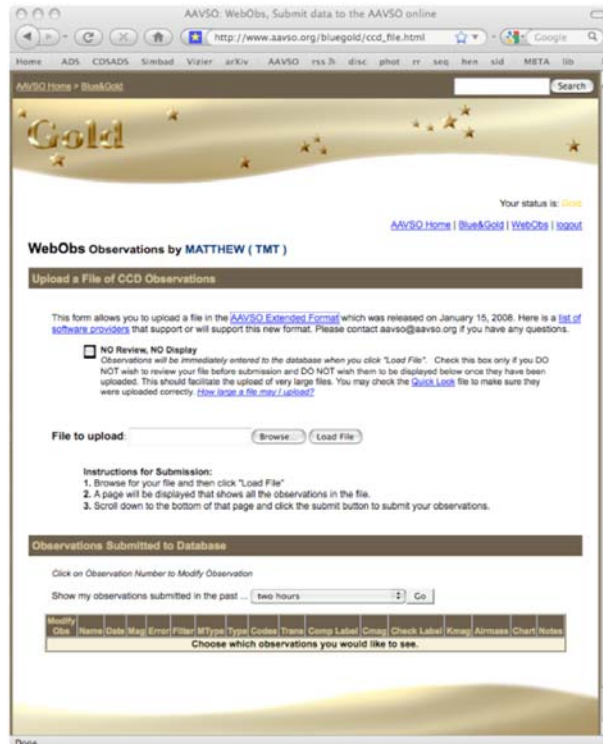
<u>Star Identifier</u> *	<u>Date</u> Click here for possible formats	<u>HJD</u> <u>Format?</u>	<u>Star Mag</u>	<u>Fainter</u> <u>Than</u>	<u>Mag Error</u>	<u>Mag Type</u> *
KV Dra	2455159.6739	<input type="checkbox"/>	16.05	<input type="checkbox"/>	0.2	Standard ▾
<u>Comment</u> <u>Codes</u>	<u>Trans-</u> <u>formed?</u>	<u>Filter</u>	<u>Comp</u> <u>Label</u>	<u>Comp</u> <u>Mag</u>	<u>Check</u> <u>Label</u>	<u>Check</u> <u>Mag</u>
<input type="text"/>	<input checked="" type="radio"/> No <input type="radio"/> Yes	Johnson V	000-BBV-708		000-BBV-718	
<u>CCD or</u> <u>PEP?</u> *	<u>Airmass</u>	<u>Group</u>	<u>Chart</u> Leave blank to load previous		<u>Notes</u>	
CCD ▾	<input type="text"/>	<input type="text"/>	1071MPM		<input type="text"/>	

* required

Submit Observation to AAVSO Database Clear Fields

Method 2: Batch Upload

If you have large amounts of data to upload, such as time series observations, then you should use the WebObs CCD Batch Upload tool. This tool allows you to upload a file in the AAVSO's Extended Format. The page to upload these observations looks like this in Blue & Gold:



Several commercial CCD software packages are capable of exporting your photometric data in the AAVSO Extended Format (see Chapter 2). The AAVSO now requires that you use this format for batch uploads — other kinds of data upload are no longer supported. Since your software package may already support this option, you do not necessarily need to know the conventions of the AAVSO Extended Format file. However, if you use a different data analysis package, or if you store your data in simple text files or spread sheets, you may want to write your own software or utility to convert your data to this format. A full description of the AAVSO Extended Format with examples was published on January 15, 2008, and is available on our website:

<http://www.aavso.org/observing/submit/extended.shtml>

As always, if you encounter any problems submitting data, please contact us at aavso@aavso.org — we're happy to help!

6.3 Using the MyNewsFlash System

The MyNewsFlash is a completely customizable and automated system to have variable star observations sent to you. It is a way to monitor your favorite stars or classes of stars and/or to be notified when something interesting is in outburst or reaches some predetermined threshold of interest to you. Subscriptions to MyNewsFlash are available to everyone via the AAVSO website:

<http://www.aavso.org/publications/newsflash/myflash.shtml>

6.4 Using AAVSO Special and Alert Notices

The AAVSO Special and Alert Notices announce interesting or otherwise notable occurrences in variable stars, as well as requests for observations from the research community. Special Notices are typically used to highlight interesting phenomena where observations by AAVSO observations are encouraged. They are also sometimes used to update previously issued Alert Notices or make announcements regarding existing Observing Campaigns. AAVSO Alert Notices are used to announce important phenomena like Galactic Novae and bright extragalactic supernovae, rare outbursts of interesting stars (e.g. WZ Sge stars), or announce important observing campaigns or requests for observations where AAVSO participation is critically important and strongly desired. As an example of the latter, the AAVSO often receives requests to perform optical, ground-based photometry of variable stars being observed with larger ground- or space-based telescopes like the *Hubble Space Telescope* or *Chandra X-Ray Observatory*.

AAVSO observers have made critically important contributions to many important projects, and have been an important partner of the variable star research community for many decades. Please consider subscribing to AAVSO Special and Alert notices, and if you receive a Notice for which you are able to observe, please contribute!

A complete description of the AAVSO Alert and Special Notices is available on the AAVSO website:

<http://www.aavso.org/news/announcement.shtml>

and you can subscribe to either or both publication here:

<http://www.aavso.org/publications/email/index.shtml#alerts>

7.0 For More Information

7.1 Discussion Groups

The AAVSO's mailing lists are one of the best ways that you can ask questions of the AAVSO observer community. Many people on these lists have decades of experience with photometry and, more importantly, many started out just like you did and may have had similar experiences and problems when *they* got started. The AAVSO Photometry mailing list was established in part to serve the needs of instrumental photometrists of the AAVSO as a place where they can ask questions, share ideas, and discuss research programs. The archives of the photometry list are a rich resource to turn to as well, and can be searched via the search box on the AAVSO website. To go directly to the photometry mailing list page, visit this URL:

<http://www.aavso.org/mailman/listinfo/aavso-photometry/>

There, you can access the archives and subscribe to the mailing list. There are also two more special-purpose mailing lists that involve two of the observing programs mentioned in Chapter 5: the RR Lyrae list, and the High-Energy Network list. Their information pages are available here:

http://www.aavso.org/mailman/listinfo/aavso-rr_lyr/
<http://www.aavso.org/mailman/listinfo/aavso-hen/>

Finally, if you're an AAVSO observer or just a variable star enthusiast, the AAVSO's general discussion list (aavso-discussion) a great place to chat and hold general discussions (although it might not be the best place for technical questions about CCD Photometry). Its information page is here:

<http://www.aavso.org/mailman/listinfo/aavso-discussion/>

7.2 Mentoring

The AAVSO has an active Mentoring program for new visual and CCD observers. Many experienced observers are willing to share their knowledge, expertise, and advice with new observers, and all AAVSO observers are welcome to request assistance from the AAVSO Mentoring program. For more information on the Mentoring program please visit our webpage:

<http://www.aavso.org/aavso/about/mentor.shtml>

There you'll find resources for new observers and (perhaps) find an answer to questions you may have about observing or variable star astronomy. If you'd like some one-on-one help from an AAVSO Mentor, please email aavso@aavso.org to request one.

7.3 Links

- The AAVSO CCD Photometry Page: <http://www.aavso.org/observing/programs/ccd/>
- Meeting archives from the CCD workshop of the 90th Annual Meeting of the AAVSO: <http://www.aavso.org/aavso/meetings/fall01sounds.shtml>

- A guide to photometry by W. Romanishin (Oklahoma U.):
<http://observatory.ou.edu/book2513.html>
- Starizona's Guide to CCD Imaging: <http://starizona.com/acb/ccd/ccd.aspx>
- CCD User Observing Tips by Bruce Gary:
<http://reductionism.net.seanic.net/ObservingTips/ObsgTips.html>

7.4 Additional References

- Howell, Steve B., 2006, *Handbook of CCD Astronomy, 2nd Edition* (Cambridge: Cambridge U. Press)
- Berry, Richard and Burnell, James, 2005, *The Handbook of Astronomical Image Processing* (Richmond, VA: Willman-Bell)
- Henden, Arne and Kaitchuck, Ronald, 1990, *Astronomical Photometry* (Richmond, VA: Willman-Bell)