

Chapter 3: Equipment and software overview

Since you are using this guide, it is assumed that you already have a telescope, mount, CCD camera and all the associated equipment needed to do photometry. Therefore, there is no point in describing what equipment you should get, but rather how to make the most of the system you have. There are many different types of telescopes, CCD cameras, and software packages. In this chapter, we mainly want to explain the things that all will have in common, and what will generally be required to get good data from any system. You should consider this chapter as being less about doing photometry, and more about the critical step of **preparing** for photometry *before* you get out to your observatory and start observing.

Telescope and mount

Most telescopes can work well with CCDs. Smaller telescopes like the AAVSONet's Bright Star Monitor (BSM), a refractor, are good for imaging brighter stars. Larger diameter telescopes help you go for the fainter variables where increased light-gathering is needed. In general, the simpler the optical systems the better. If at all possible, try to avoid adding a focal reducer (which can cause vignetting) or anything that adds a non-uniform effect to the field. Note that some types of telescopes (Newtonians for example) may have issues like coma that will naturally distort stellar images off axis, and this effect will need to be considered when performing photometry.



Two of the AAVSONet telescopes: BSM-Hamren, 65mm Astro-Tech AT-65EDQ (right) and Coker 30, a 30cm Meade LX-200GPS (above).

One of the difficulties of using a CCD is that the field of view is much smaller than what you may be used to without the camera. In general, the smaller the f /ratio (focal length/aperture) of the telescope, the larger the field of view, which makes finding the field and trying to capture all the comparison stars in the same frame a little easier. You can adjust this for an existing telescope by using a focal reducer, but as mentioned above, doing so has the potential to cause other problems.

It is also important that you try to reduce stray light entering the system. This is generally more of a problem with reflectors. Take your camera off and look through the end of your telescope at the night sky. Look for reflections or glints of light off any of the internal surfaces. If you see anything more than the stars out the end of the telescope, your camera will pick that up as well and will affect your images. You should consider trying to find a way to eliminate that stray light either with paint or by adding some flocking material to the inside of the tube.

Having a good mount for your telescope is absolutely essential to success. Equatorials are a must because alt-azimuth mounts cause field rotation during medium and long exposures, which is very difficult to compensate for. Whether you have a German equatorial mount (GEM) or a fork mount is a case of personal preference but both will work fine. It is important, however, that they be well-aligned and track accurately. It will save you a lot of time and frustration if they also help you find the target field with GoTo controls or will allow your computer to take you to the field. Auto-guiders are not essential, but helpful both for longer exposures and time-series runs.

Finally, there is the question of having an observatory to house your equipment. Although not absolutely essential for getting good data, some sort of permanent mount (with a way to protect it from the elements) will save you a lot of time and frustration setting up and breaking down all of the equipment each night. Even a good, sturdy watertight box on rollers that you can put over your mount, will save hours of setup and alignment time each observing session. With a more substantial structure, you will feel comfortable leaving your CCD camera and computer attached and ready for use. There are many solutions and they don't have to be expensive.



Roll-off roof shed



BSM-HQ's housing

CCD camera

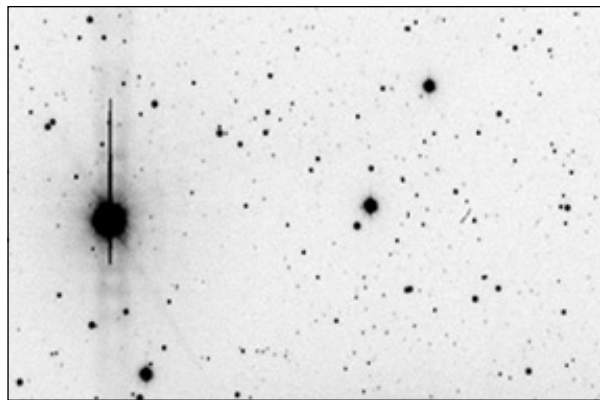
CCD cameras range widely in quality, complexity, and cost, but most can be used quite successfully for photometry. The important thing is that you should get to know your camera well in order to get the most out of it. Then you can use what you know set up your observing program appropriately.

Here are some things that you should think about with regard to your camera:

Linearity and well depth

Pixels in your CCD camera respond in a linear way to photons: one photon equals X counts, where X is a constant (defined by the *gain*) up to a point. One of the most important things to know about the CCD chip in your camera is that each pixel can handle only a certain amount of light and still give you an accurate readout. If you exceed this amount—called the “full well depth”—in any pixel on your chip, any extra photons striking that pixel will generate electrons that will spill out and contaminate other pixels creating an effect called “blooming” in which spikes appear to come vertically up and down out of the saturated pixel. Before you reach that point, the response of the pixels to photons may also change, becoming “non-linear”.

Some CCD cameras are designed with an “anti-blooming gate” (ABG) to prevent this from happening by siphoning off the spill-over electrons before they contaminate adjacent pixels. This is great for keeping unsightly spikes out of your pretty galaxy photos, but it can be bad for photometry because it can destroy the linearity of your chip and give you inaccurate results.



Reversed color image showing “blooming”

Fortunately, you can still use a camera with ABG as long as you know its limitations and don’t exceed them. Even if you don’t have an ABG camera it is still important to know your camera’s saturation limits. What isn’t so obvious is that pixels can saturate or your chip could become non-linear well before blooming occurs. You have to know what this limit is so you can prevent it from happening to your target or comparison stars.

See the *InfoBox* on page 16 for instructions on how to find the linearity of your camera.

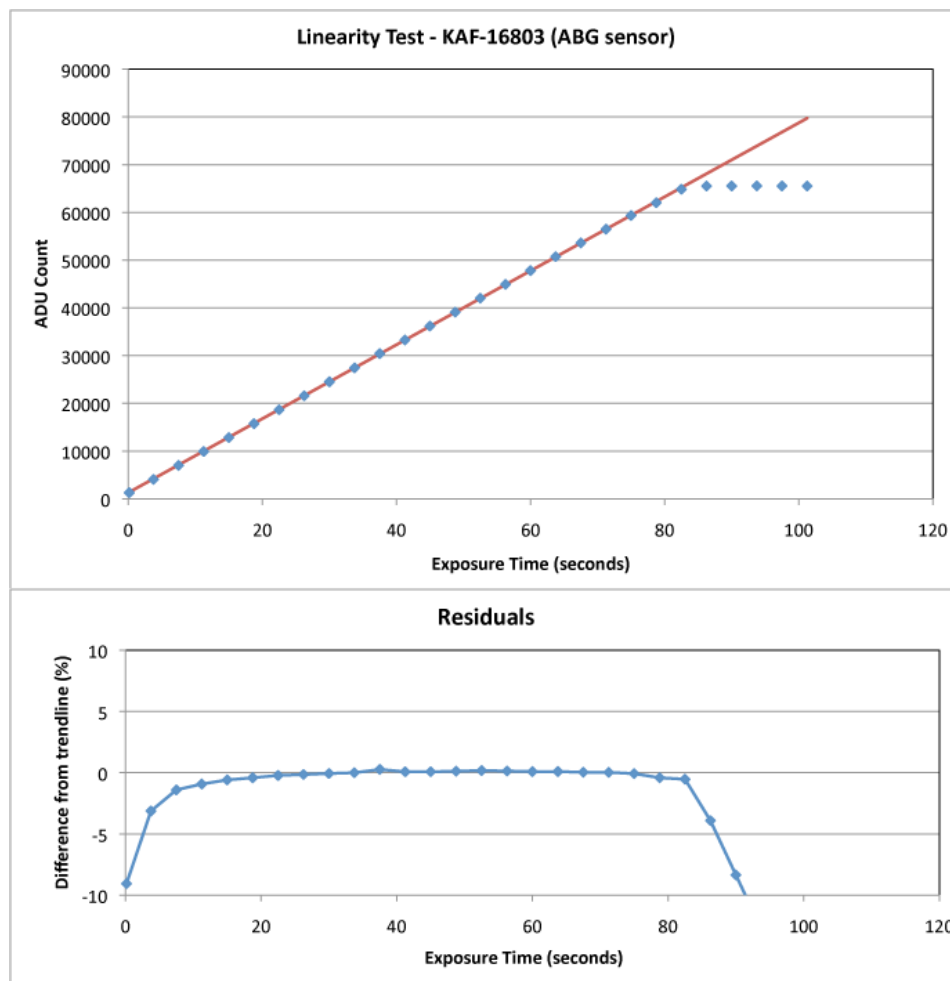
Chip problems

CCD chips can sometimes have (or develop over time) problems such as “hot pixels”, “blocked columns” or other defects. Finding such defects does not usually mean you have to toss it out and buy a new camera! Most defects are not a problem at all and will not affect the quality of your photometry as long as they can be avoided.

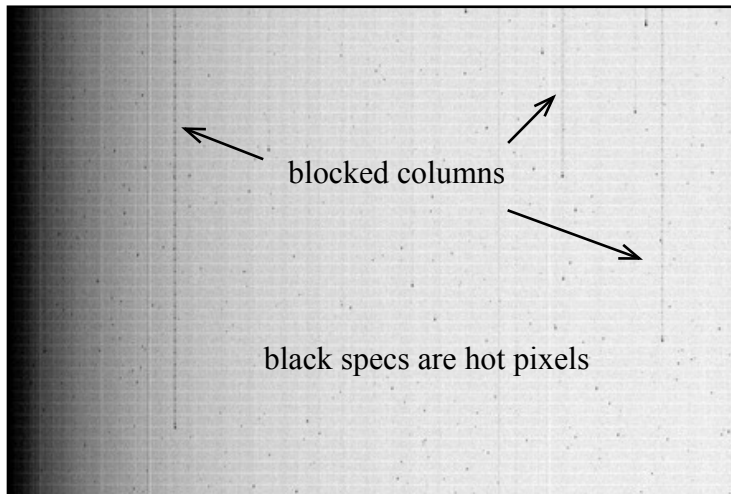
InfoBox 3.1 – How to determine the linearity of your camera

1. Set up a light source by illuminating a white screen. (It does not to be perfectly uniform, just stable).
2. Point the telescope at the screen and adjust the brightness until a 10 second exposure will result in a mean central region ADU count of 10,000.
3. Take a series of images where the exposure time increases in 10 second increments (i.e. 10, 20, 30, 40, etc.) until it obviously saturates.
4. Plot the exposure time versus mean central region ADU count.
5. Take one or two more exposures between each 10–second one through straight sections of the plot, then at even more frequent intervals in places of interest of the plot — e.g. where it begins to curve at either end or in any other non-linear section(s).

From this plot you should be able to determine at what count your camera saturates and if there is any non-linear behavior along the way.



One way to avoid problems caused by chip defects would be to inspect a few of your images carefully and note what you see. You can draw a rough sketch of the defects on the image and include the plate coordinates for each. Also, since CCD chips degrade with time, it would be a good idea to repeat this exercise at least once each year. Having that information at your fingertips as you point your telescope at the field you are imaging will better help you to avoid using any bad areas to measure stars of interest to you.



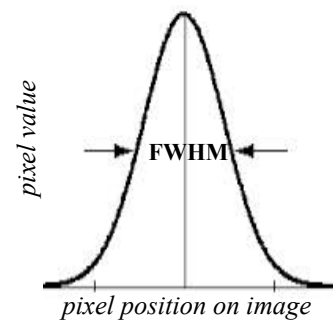
Reversed image of a bias frame showing blocked columns and hot pixels.

Resolution and Field of View

Your camera and telescope work together to define the resolution and field of view (FOV) you can expect from your system. It is important to quantify these and design an observing program that takes advantage of the strengths of your setup.

Sampling

When you inspect the image of a star, you will notice that it is made up of a group of pixels, with some brighter ones near the center and some dimmer ones surrounding it. Ideal images of point sources made by optics have an intensity pattern called an *Airy disk*. However, in practice the light from stars (generally considered to be a point source) has to pass through the Earth's atmosphere which diffuses and expands the pattern. The dot which represents the image of a star on your CCD image is called a *seeing disk* because the seeing conditions have a profound effect on the intensity of the light. In order to measure the intensity of an image like this when it doesn't have sharp edges, scientists use the term, "Full-Width, Half-Maximum" (FWHM). This is defined as the number of pixels that are filled to one-half the dynamic range between the background and the brightest (fullest) pixel in the star's image.



In order to get the best results you can out of your photometry, you should strive to *sample* such that the FWHM of your seeing disk is spread across two to three pixels. This will help to optimize the signal-to-noise ratio (SNR) and improve the accuracy of your measurements.

So how do you know if your system gives proper sampling of the seeing disk? The answer is simple. All you have to do is measure it directly. Just take a well-focused image of any random star field close to the zenith. Most CCD software has a tool for measuring the characteristics of a single star image, including the size (i.e. FWHM) of the seeing disk expressed in pixels. This is your system's sampling of the star image.

Measure several stars around the center of the image that have a good SNR but are not saturated. This may vary a bit across the image because of seeing effects and optical aberrations. It may also change over time as the seeing (scintillation) changes. **You are just looking for an approximate number of 2–3 pixels per FWHM.**

Often, achieving this goal won't be feasible or even possible, given that it is highly dependent on the seeing conditions and limitations of your equipment, but you may be able to tweak it a little. If you are averaging a FWHM of less than 2 pixels, you are probably *under-sampling*. If the FWHM of your seeing disk is more than 3 pixels in diameter, you may be *over-sampling*. Either situation could pose problems for the accuracy of your photometry, though under-sampling is much worse than over-sampling. Fortunately, there are things you can do to remedy the situation.

What should I do if my system is under-sampling?

The goal here is to try to increase the size of the seeing disks on your image. One option would be to **defocus your telescope a bit, then increase the exposure time**. If you have to defocus, then be very careful that other nearby stars are not close enough to affect the photometry. Also try to create flat frames (see the next section) that are defocused to the same degree and always take your images with the same amount of defocusing (which can be very tricky!). You might find that adding a good-quality focal extender or Barlow could also help the situation somewhat.

What should I do if my system is over-sampling?

First of all, check the focus and make sure that the seeing disks are as small as possible. If the FWHM is greater than six pixels, you might consider using a focal reducer. Not only would it reduce your pixel size by decreasing the focal length, but it would also give you a larger field of view. Another option to consider is binning your results.

Binning

Binning is something you can do to increase your effective pixel size by grouping pixels together. Your software can be set up to sample (or bin) a group of 2 pixels by 2 pixels to make those four pixels act as one. There is a tradeoff, however. Resolution will be lost, so you have to be sure that star images have not blurred together with other nearby stars. Also if one of the four pixels in the group is saturated, the accuracy of the photometry will suffer. If you do a linearity test (as described on page 16) you should ensure that you run this test using the same level of binning that you will use for your science frames. Your calibration frames must also be binned to the same degree. *It is not recommended to bin groups larger than 2x2 pixels.*

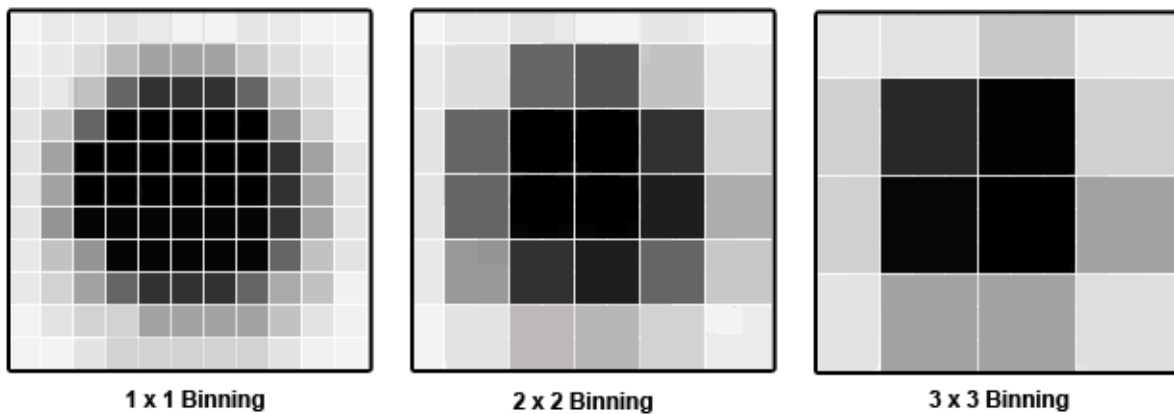


Image Scale (or CCD Resolution)

Another piece of information it would be useful to know about your system is image scale or resolution. The image scale of your system can be computed using this equation:

$$\text{Image scale} = (\text{CCD pixel size}/\text{focal length}) \times 206.265$$

(*image scale in arcsec/pixel, CCD pixel size in microns, focal length in millimeters*)

You should be able to get the CCD pixel size from the manufacturer's specifications on your camera. The focal length of your telescope can also be expressed as f/ratio times the aperture.

Knowing the image scale of your system is handy for figuring out how the seeing conditions are in your location on any given night. Simply use this equation:

$$\text{Seeing} = \text{Image scale} * \text{FWHM}$$

Generally in most suburban locations, seeing averages between 3 and 4 arcsec, but it certainly varies from location to location and could be better or worse on any given night.

Field of View

Knowing the field of view (FOV) of your system ahead of time is essential to helping you find the exact area of the sky you wish to image. It is also a good idea to check it against a star chart or your planetarium software to see if your field is indeed large enough to contain the variable star you wish to image as well as all the comparison stars you will need for the photometry at the same time. If it isn't, you may find yourself having to compensate by adjusting the effective focal length of your system.

To calculate the FOV you will have with your system, use the image scale computed above, along with your detector size in pixels:

$$\text{FOV} = (\text{image scale} \times \text{width}) \text{ by } (\text{image scale} \times \text{height})$$

(FOV in arcsec, image scale in arcsec/pixel, height & width of the chip in pixels)

Below are two examples of systems using the same CCD camera :

CCD Camera: SBIG ST402 (KAF-0402 chip), Chip Size = 765 × 510 pixels

Example 1:

Telescope: Takahashi refractor, Image scale = 3.5 arcsec/pixel (low resolution)

FOV = Height: 3.5 arcsec/pixel × 765 pixels = 2677 arcsec

Width: 3.5 arcsec/pixel × 510 = 1785 arcsec

44' × 30'

Example 2:

Telescope: Celestron 11" SCT, Image scale = 0.66 arcsec/pixel (high resolution)

FOV = Height: 0.66 arcsec/pixel × 765 pixels = 505 arcsec

Width: 0.66 arcsec/pixel × 510 = 337 arcsec

8.4' × 5.6'

Good photometry can be performed on images regardless of whether your FOV is large or small. Having a large FOV is good for bright stars and targets having comparison stars that could be a bit farther away from the variable. A system with a smaller FOV is good for fainter stars or resolving stars in more crowded fields.

Filters

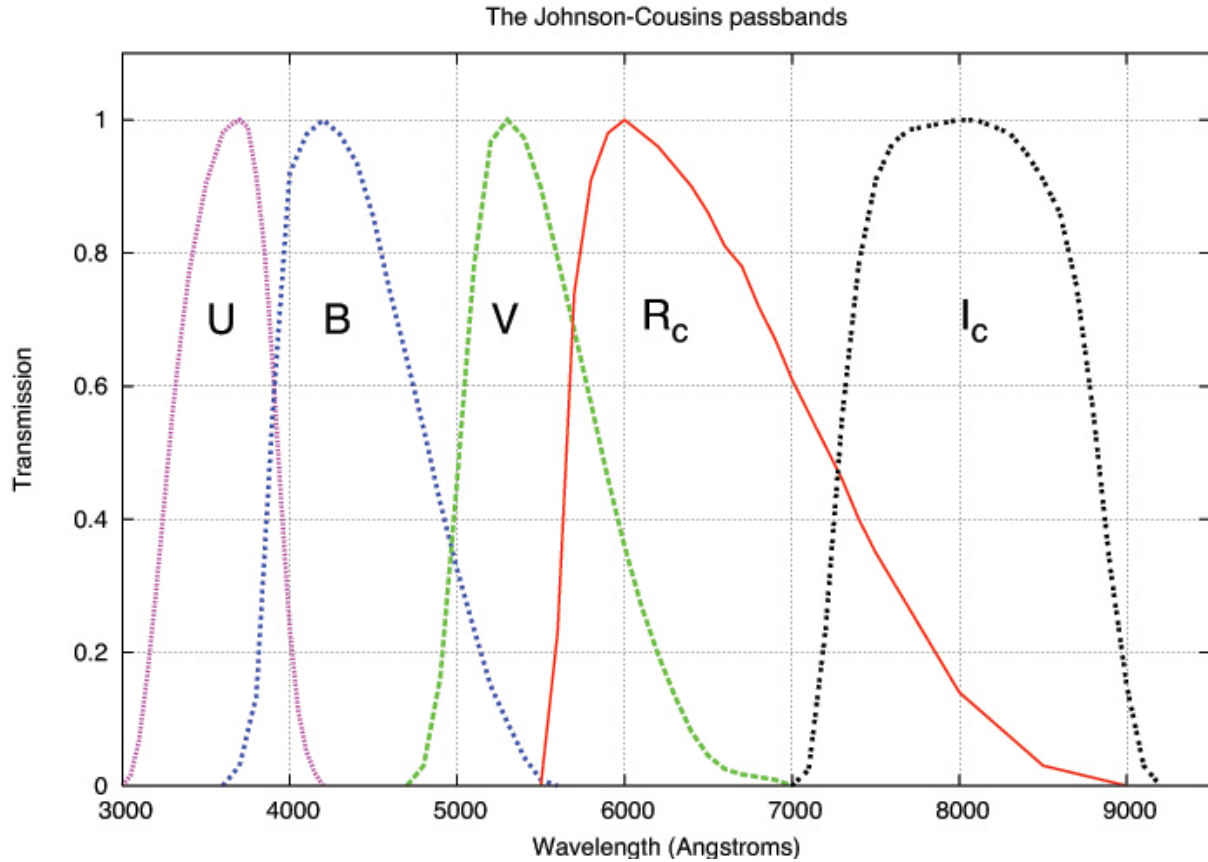
Many CCD camera systems will include some option to place filters of various kinds into the beam path between the telescope and the CCD detector. In photometry, filters limit the wavelength range of data coming into the detector at a given time. This gives you the ability to measure the spectrum of a source at well-defined points, providing more physical information about the emission. In one sense, filtered photometry is like (very) low resolution spectroscopy. This can provide additional physical information about the object that you're observing, and in general, can increase the usefulness of your observations. Using filters can be valuable—and is sometimes required—but they are a trade-off in terms of work. Less signal gets to your camera, so your exposure times are longer. However, you—and the researchers using your data—will learn more physical information about the stars as a result.

Properly reduced, your observations will relate better to those of other observers when you use standard photometric filters. The reason is that each CCD chip model has a slightly different spectral response. Without a filter, your observations could possibly still be useful for period analysis, but the magnitudes you derive may be unphysical and differ greatly from those of other observers. Not only will the results reflect the qualities of your particular CCD chip, but the fact that you are imaging the entire spectrum of a star at once means that your observations could be many magnitudes brighter than what was seen visually or imaged with a V filter. There are typically three cases where unfiltered observations are useful: when the source is known to have a neutral color - where all wavelengths are equally bright (typically in hotter objects like CVs in outburst), when the object is very faint, and simply detecting the source has great value (as in gamma ray bursts) or where period-determination is the overriding scientific goal.

Some people use non-photometric filters for their observations. The problem with these is that they are non-standard and it is difficult (if not impossible) to convert your results to the standard system. You will not be able to use the published magnitudes of the comparison or check stars—which are usually given using the standard colors—or compare your results with those of other observers.

If you use only one filter, the best choice would be Johnson V. This is because magnitudes obtained from images made with this filter most closely mimic observations made visually. If you wish to use a second filter, the next most useful is Johnson B followed by Cousins I, Cousins R and Johnson U in that order. “Johnson” and “Cousins” simply denote standard filter band passes developed by Harold Johnson and Alan Cousins respectively.

Since filters tend to degrade over time, it is important to inspect your filters annually, make new calibration images frequently (see next chapter) and clean them using the manufacturer's instructions.



*Figure 3.1 – Plot of transmission versus wavelength in each of Johnson–Cousins filters.
(courtesy of Michael Richmond, RIT)*

Computer and software

Since you most likely will be spending more time working with your data at the computer than actually taking images at the telescope, it is important that you have some basic computer skills. You should also understand the software you are using very thoroughly; not only how to use it, but the basics of what it does. Taking some time to learn how to use your software correctly will quickly pay off.

There are many good software packages available and some perform several or all of the functions listed below. The AAVSO does not endorse any of them in particular and this guide will not attempt to explain how to use them. What you choose depends on personal preference and compatibility with your system. Since you will be spending more time at the computer than at your telescope, it is important that you choose software that you can be comfortable with and that you spend the time getting to know it well. In most cases, you can download trial versions so you can do some research before buying. It can also be useful to discuss the choices with other observers to learn about the strengths and weaknesses of each product.

Some of the most popular software packages include:

- AIP4Win
- AstroArt
- CCDOps
- FotoDif (Spanish language software)
- IRAF
- LesvePhotometry
- MaxIm DL
- MPO Canopus
- VPhot

Here are the functions that you will need software to perform:

CCD interface – controlling the CCD camera itself, selecting filters, making exposures. Often, your CCD camera will come with its own imaging software.

Data reduction – processing images, applying calibration frames.

Astrometry – also known as “plate solving” to find the RA and Dec position of each of your target stars.

Photometry – To do brightness measurements and create an AAVSO report in the proper format.

Obviously, you will need to have a computer available to run this software. There are no fixed requirements here but Windows is the most commonly used operating system. Some of the software packages mentioned above will only run on Windows machines and there may not be a Mac or Linux version available. It is also helpful to have plenty of USB ports as you will need one to run your camera along with any other peripherals you may use.

The images you create with your CCD camera will be saved in the FITS file format. FITS (Flexible Image Transport System) is the standard method of storing scientific images into computer-readable files, and is supported by all software packages. A useful feature of the FITS format is that information about the image (such as target name, time of exposure, etc.) can be stored in a human-readable format along with the image itself.

Another necessary function for a computer is to keep accurate time. If you have internet access at your observing site, you can get accurate time from the USNO Master Clock (<http://tycho.usno.navy.mil/simpletime.html>). Otherwise, you may have to get it from another source such as a broadcast time signal like WWV in the USA or the equivalent in other parts of the world. There is also software available to check and correct your system’s time drift. Either way, it is important that you update your computer’s clock often to show the most accurate time possible since this is the time which will eventually end up in the FITS header of your images. Without frequent updates, your computer’s built-in timekeeper could be off by several seconds (if not more) in a very short period of time. This may not seem like much, but for measuring short-term variations in some stars, or doing occultation work, it could make a critical difference in the usefulness of your data.

The other important function of a computer is for data storage and archiving. As you will soon discover, it won't take long for you to begin accruing lots of images that will consume a lot of storage space on your computer. You should decide how you will handle this in an organized manner *before* you start. Everyone makes mistakes or misses problems with images once in awhile, and it is not uncommon for observers to find a processing error, a comparison star sequence change, or some other reason to retrieve images from the past. Therefore, it is essential that your files are complete and organized so you can find what you need as easily as possible.

These are the things you should keep in your files:

- Nightly logs containing notes on what is being observed, weather, the moon phase, etc.
- Calibration images
- Nightly raw images
- Calibrated images (flat field and dark subtracted images)
- Logs of observations
- Notes regarding processing

Charts

Using proper variable star charts is an important part of any variable star observing program and the AAVSO has created an online tool to make this easy for you. You can find the “Variable Star Plotter” (VSP) along with links to help pages on the AAVSO website here:

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

Some of the options you might find helpful for CCD observing in particular include the following:

Choose a chart orientation – selecting the CCD option will create a chart with North up and East to the left, much as your camera should see it.

Do you want a chart or list of field photometry? – You may choose to plot a chart or simply a table of field photometry. It is recommended that you use both. The photometry table will be useful as you select comparison stars to use since it gives position, color, and magnitude information using different filters. The comments field is also useful as it alerts you to possible problems or things to watch out for when using a comparison star.

It is also important that you plot a chart of the part of the sky you are imaging so you can use it to check to see that you have identified the field correctly. Inspect the chart very carefully and if necessary, create a large scale (zoomed in) chart, so that you can use it to check for close companion stars near the variable or any of the comparison stars you plan to use.

The AAVSO comparison star sequences have been carefully chosen and calibrated so please use them! Using non-AAVSO sequences does not necessarily mean that your data will be useless, but it likely won't compare well with observations made by others in the AAVSO International Database.

Many software packages (like VPhot) already include AAVSO comparison star information so you won't need to type it in, but you should still check to be sure it is not out-of-date. Revisions, updates and new sequences are being produced all the time—largely as a result of requests from observers.

Would you like to display a DSS image on the chart? – This option will overlay an image from the Digitized Sky Survey on your chart. This can also help with field identification as it shows the stars in a way that more closely resembles what you will see coming from your camera.

Would you like a standard field chart? – You may find this option useful when you are preparing to image a standard field for the purpose of computing your transformation coefficients. Selection of this option means that comparison star labels will be omitted from all but the “standard stars”. See Chapter 6 for more on transformation.

Figure 3.2 – The AAVSO’s Variable Star Plotter (VSP) with the CCD–specific options enlarged.

Variable Star Plotter (VSP)

VARIABLE STAR PLOTTER

WHAT IS THIS?

The Variable Star Plotter (VSP) is the AAVSO's online chart plotting program that dynamically plots star charts for any location on the sky, or for any named object, currently in the Variable Star Index (VSI). By creating charts this way, every chart utilizes the most current data available. Through the use of unique Chart IDs generated by the Variable Star Plotter, one user can plot a chart, and another user in different part of the world can plot an identical chart by simply using the same Chart ID. The Variable Star Plotter is the tool you should use to create any chart that you would like to use.

WHAT CAN I DO?

By entering an object name or its coordinates on the sky, the Variable Star Plotter can produce a star chart for that object or location, and tailor it to your specific observing requirements. Many different parameters are adjustable via this interface, allowing you to get the perfect chart for the job. Customizable field of view, print resolution, magnitude limit, and orientation can be set for any chart plotted, or these values can be auto-assigned by selecting from one of the legacy chart scales familiar to many of our long-time observers. The charts produced by this tool include comparison star sequences for visual magnitude estimations.

HOW CAN I GET HELP?

For detailed instructions on using VSP, consult the [help guide](#). We also provide a [S&T method API](#) for embedding charts in your website or custom software. If you need further assistance, you can email us at avso@avso.org.

PLOT A QUICK CHART...

WHAT IS THE NAME, DESIGNATION, OR ALIAS OF THE OBJECT?
Required if no coordinates are provided below

CHOOSE A PREDEFINED CHART SCALE
A is larger, slower; G is smaller, faster.

CHOOSE A CHART ORIENTATION

Visual Reversed CCD

DO YOU WANT A CHART OR A LIST OF FIELD PHOTOMETRY?

Chart Photometry Table

PLOT CHART

ADVANCED OPTIONS

DO YOU HAVE A CHART ID?
A Chart ID will allow you to reproduce prior charts

PLOT ON COORDINATES
Required if no name is provided above

RIGHT ASCENSION
 DECLINATION

WHAT WILL THE TITLE FOR THIS CHART BE?
Displayed at the top-center of the chart

WHAT COMMENTS SHOULD BE DISPLAYED ON THE CHART?
Displayed beneath the chart star field

MISCELLANEOUS OPTIONS

FIELD OF VIEW *
 MAGNITUDE LIMIT *
 RESOLUTION *

WHAT NORTH-SOUTH ORIENTATION WOULD YOU LIKE?

North Up North Down

WHAT EAST-WEST ORIENTATION WOULD YOU LIKE?

East Right East Left

WOULD YOU LIKE TO DISPLAY A DSS IMAGE ON THE CHART?
If Yes, retrieves and displays an image from the Digitized Sky Survey

No Yes

WHAT OTHER VARIABLE STARS SHOULD BE MARKED?

None GCVS only All

WOULD YOU LIKE ALL MAGNITUDE LABELS TO HAVE LINES?
If Yes, this will force lines to be drawn from all magnitude labels to the stars

No Yes

HOW WOULD YOU LIKE THE OUTPUT?
If HTML, headers/footers and other extra information will be shown

HTML Printable

WOULD YOU LIKE A BINOCULAR CHART?
Binocular charts omit comparison star labels not useful for binocular viewing.

No Yes

WOULD YOU LIKE A STANDARD FIELD CHART?
Standard field charts omit comparison star labels not included in the standard field.

No Yes

RESET ALL **PLOT CHART**

CHOOSE A CHART ORIENTATION

Visual Reversed CCD

DO YOU WANT A CHART OR A LIST OF FIELD PHOTOMETRY?

Chart Photometry Table

WOULD YOU LIKE TO DISPLAY A DSS IMAGE ON THE CHART?
If Yes, retrieves and displays an image from the Digitized Sky Survey

No Yes

WOULD YOU LIKE A STANDARD FIELD CHART?
Standard field charts omit comparison star labels not included in the standard field.

No Yes