Don't Panic!

The Hitch-hiker's Guide to AAVSO PEP

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Our vision: *High quality photometry of bright, astrophysically interesting stars.*

The AAVSO photoelectric section was founded in the late 1970s. We use old-school technology, but we can get superior results on luminous stars. Compared to CCD systems, our equipment is fundamentally simpler to calibrate and operate, and data reduction is straightforward. What we lack in sensitivity, we make up for in quality. With properly chosen targets and careful technique, we remain a viable research group.

This document is a work-in-progress, representing my best understanding of PEP as practiced at AAVSO. It lacks the polish of conventional manuals, but I think it is more approachable. There are good books available on photometry, but they tend to drown the new reader in specifics. Here, I will try to provide a wide, but not too deep overview in manageable pieces, and discuss topics the books pass over. I will fudge on details, occasionally, in the service of clarity.

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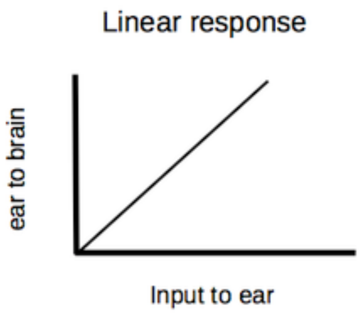
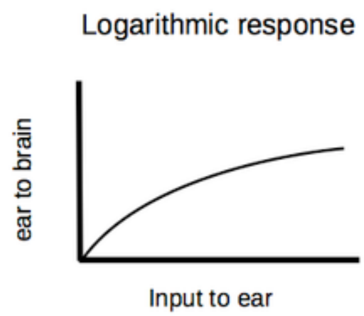
Chapter 1 — Background

1.1 The Magnitude System

We owe magnitude measures to the astronomers in ancient Greece. With their naked eyes, they divided stars into six numerical ranks of brightness, with magnitude one being brightest and six dimmest. This was the start of the trouble—as the stars got dimmer their numerical magnitudes got larger instead of smaller. The other problem was that the Greeks didn't understand how the eye responds to light of different intensities. They assumed the eye was *linear*, that when it told the brain that light A was twice as bright as light B, that meant that A really was twice the physical brightness. Not so. Human senses tend to be *logarithmic*. Hearing works this way, and that's what allows us to distinguish such a huge range of sound intensity. As a sound level rises, the ear compresses the signal before feeding it to the brain. Below are diagrams illustrating the difference between linear response and logarithmic response.





The signal from a "linear" ear that could detect a cricket would blow the brain to bits if it heard an air horn. Logarithmic response lets the ear and brain get along over that wide range, and the eye/brain link works the same way. The Greeks thought of their magnitudes as six levels of linearly increasing brightness. If the brightness of a magnitude six star was *b*, then magnitude five brightness was *2b,* magnitude four was *3b,* and so on, the brightness increasing by the addition of *b* with each step. This meant stars of the top magnitude were six times brighter than those at the bottom (see table, below). But, in fact, magnitude one was 100 times brighter than magnitude six, and each step increased the brightness by a multiplication of about 2.512 ($2.512^5 = 100$). A big difference.

Magnitude —>	**6**	**5**	**4**	**3**	**2**	**1**
Linear-magnitude brightness	b	2•b	3•b	4•b	5•b	6•b
Logarithmic-magnitude brightness	b	2.51•b	6.31•b	15.85•b	39.82•b	100•b

Magnitude to brightness conversion

Actually, the Greek magnitude system did not exactly fit a 100x scale—what we use today is a modern refinement that also includes stars of zero and negative magnitudes, that uses fractional magnitudes, and goes far fainter than human vision. The point to remember is that our photometers measure brightness, but we convert the brightness to magnitude to do our data analysis, a transformation that has benefits.

As if all that were not trouble enough, photometrists must deal with three kinds of magnitude: the magnitude derived from an instrument located under the Earth's light-absorbing atmosphere, the magnitude derived from above the atmosphere, and the magnitude derived from a *standard* photometer, which the photometrist's actual instrument approximates, from above the atmosphere. These quantities are, respectively, the *instrumental* magnitude, the *extra-atmospheric (*or *extinction-corrected)* magnitude, and the *standard* magnitude, denoted as m, m0, and M.

Note: you will see the word "millimags" bandied about as a unit of measurement. A milli-magnitude is 0.001 magnitudes, a convenient unit for small values.

1.2 Time and Date

The civil calendar is not a very convenient time base for recording long-term astronomical data. It is divided into irregular months—with leap years thrown in—and there was a discontinuity when we switched from the Julian to Gregorian calendar. Instead, astronomers use *Julian Date* (JD) to mark time. JD 0 is the first of January, 4713 BCE, and the Julian days are numbered consecutively from there. As of this writing, seven decimal digits are needed to express a Julian Date (eg: 2457477). For convenience, we sometimes use *Modified Julian Date* (MJD), which is the last five digits of JD. There are no "Julian hours" or minutes. Fractions of a JD are expressed as a decimal.

The Julian Day begins at the International Date Line, but in planning and recording our nightly observations, we use Universal Time (UT or UTC), which is referenced to the Greenwich meridian. UT is twelve hours behind "Julian time," meaning that the Julian day advances at noon UT. There is a handy AAVSO utility for converting back and forth between Julian Day and civil day/time (see appendix B). For observers in the western hemisphere, JD conveniently stays the same during one night.

There is a variant of JD called *Heliocentric Julian Date* (HJD). This is JD referenced to the sun instead of the earth. The earth swings 93 million miles to and fro in the course of an orbit, which means that it gets eight light-minutes closer to and further from objects near the plane of our orbit. If we are tracking a phenomenon that takes place on very short time scales, and we want consistent timing records over the course of months and years, this variation becomes significant. HJD provides the stable reference frame for such measurements [the sun also gets moved around a bit by Jupiter, and there is yet another level of time refinement known as *Barycentric Julian Date*, that is referenced to the solar system's center of mass].

1.3 Star Identifiers

Generally, the twenty-four brightest stars in a constellation are identified by Greek letters, with alpha the brightest and omega the dimmest. After that, they are designated by lower-case (a, b, c, ...z), then upper-case (A, B, C,…Q) latin letters. This is the "Bayer" system. Variable stars within this range of designations are known by the Bayer identifier. Post-Bayer variable star designations, which are not in order of brightness, begin with R, going to Z, then go to double designations, like SU. The two-letter identifications proceed in a strange pattern, which we need not go into here. Suffice it to say that all the letter combinations amount to 334 designations. Beyond this, the variables in a constellation are known as V335, V336, V337, etc. "NSV" stands for New Catalog of Variable and Suspected Variable Stars, which is not ordered by constellation.

Various star catalogs made over the years assigned only numbers to stars, and the prefix of the catalog is given with the number. The numbering system generally proceeds in order of Right Ascension. Below are catalogs you may encounter.

Catalog	**Prefix**
Henry Draper	HD
Hipparcos	HIP
Bright Star (Yale)	HR
Smithsonian Astrophysical Observatory	SAO
Bonner Durchmusterung	BD

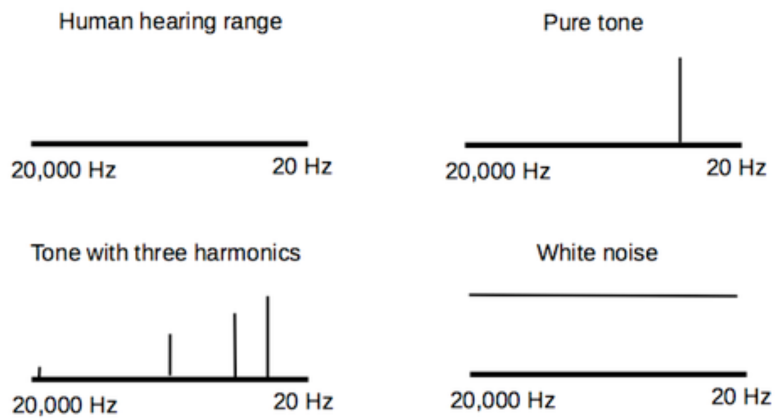
1.4 Photometric bands

Your stereo system may have tone controls to boost or cut the treble, midrange, or bass portions of the audio. These controls are *filters*. Imagine what you could do with very extreme filters. If you were listening to an orchestra concert and cut the treble and midrange deeply, you could, in principle, listen to just the notes from the double-bass players and exclude the other instruments. The filters allow you to select specific information from a broad spectrum of input. We use filters in photometry for just this reason: different bands of color provide unique data about what is going on in a star. No one has devised an optical filter that can boost a desired range of color—our filters only cut out what we prefer to ignore. Filters come in groups known as *systems*. The most common is the *Johnson* system, developed by Johnson and Morgan in the 1950s. The primary filters are U, B, and V. The U filter rejects visible light and permits near-ultraviolet light to pass through, the B filter transmits blue light, and the V filter roughly passes the human "visual" color response in green. Johnson also defined an R filter for red light, and an I filter for red beyond human vision (but not actually infra-red, as the letter might indicate). There are many other color systems in use, but for AAVSO PEP we chiefly use Johnson in B and V, and the R and I filters defined in the *Cousins* system. The color range that a filter lets through is known as its *passband*.

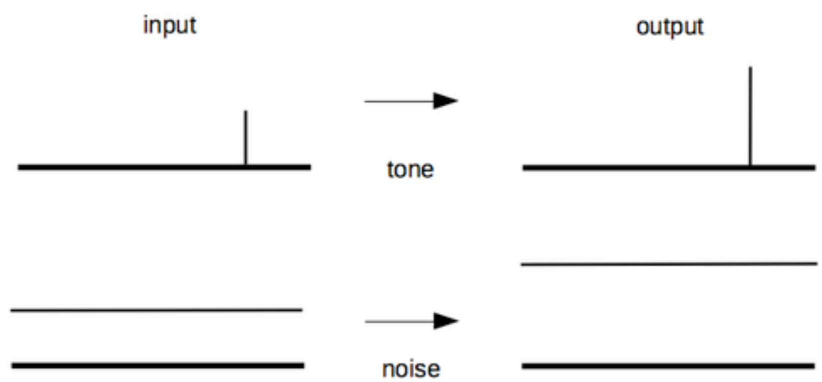
The three magnitude terms we defined, m, m0, and M become realized in specific filter bands by replacing "m" with the filter identifier, so the B band magnitudes are b, b0, and B, and V band, v, v0, and V, accordingly. The only time we actually use the "m" terminology is when we are describing some generic operation that applies to magnitudes in any color band.

1.5 Response Curves

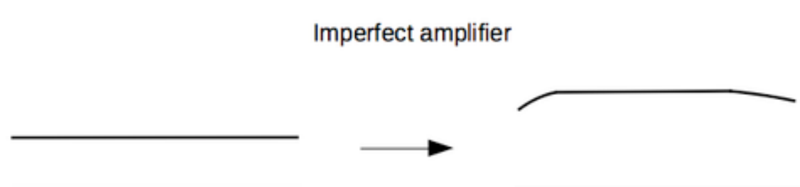
When I was growing up in the 1970s, quality stereo equipment was becoming readily available to the masses. A good amplifier might have a distortion specification of +/- 3 decibels from 20 to 20,000 Hertz (Hz), which roughly covers the range of human hearing. To visualize audio, we use spectrum diagrams, which show the intensity of sound at each frequency (below). A pure electronic tone consists of a single spike. A musical instrument like the flute produces a fundamental tone plus harmonics, or overtones, of decreasing intensity. An orchestra in action would have a vast forest of tones. At the extreme, white noise consists of sound at every frequency.



An ideal amplifier will take the input sounds and do nothing but magnify them uniformly from 20 to 20,000 Hz. In other words, the output spectrum is identical to the input spectrum, only at a higher intensity.



The ideal amplifier has a *flat response* over its operating range, as you can see by comparing the white noise inputs and outputs. Of course, no amplifier is perfect. It may work very well in its frequency mid-range, but suffer at the extremes. Below, our bass and treble lose a bit.

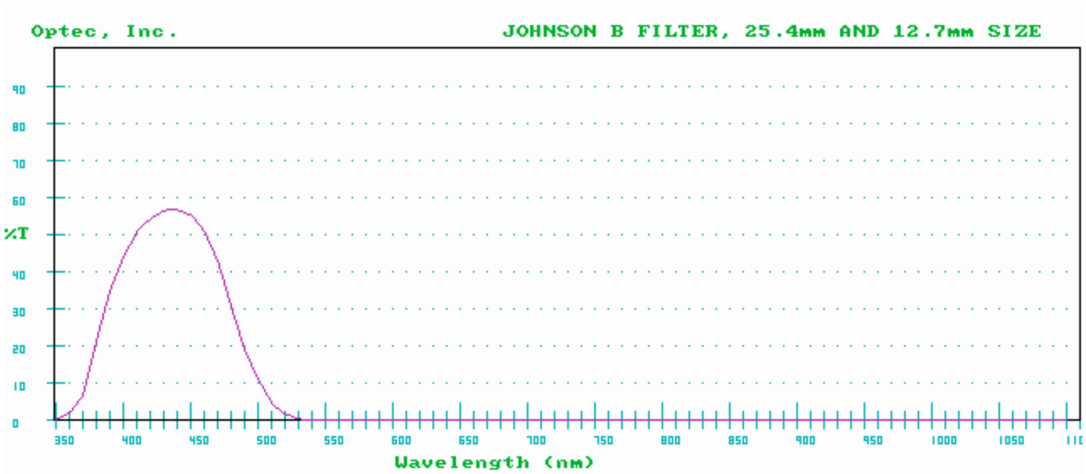


In optical systems, we have similar concerns about response, though we deal in attenuation, not amplification. Any spectrum can be characterized in terms of frequency, as above, or in wavelength. Optical frequencies are huge, inconvenient to describe in Hertz units. Instead, we use wavelengths, usually measured in nano-meters (nm).

Optical wavelengths, nm

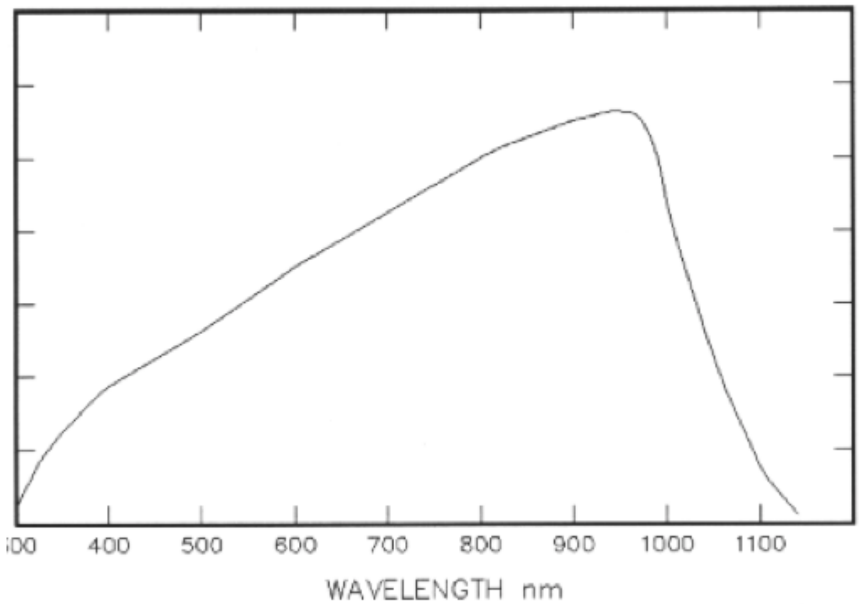
UV	blue	green	red	far red
365	445	550	660	810

One might hope that the U, B, V, R, and I filters would exhibit flat response within their passbands, but they do not. Below is the response curve for the Optec B filter. Not only does the filter fail to sharply chop off at each side, its peak efficiency is only about 55%. This is not a criticism—Johnson's filters were not perfect, either. [Note: the Optec SSP filters are different from their other photometric filters.]



B filter transmission © Optec corp.

Filtering is a very tricky business, even in audio, and flat response curves are not to be had. But the situation is worse than it looks. Our telescope, filter, and sensor form a chain, and each component has its own response curve. The telescope curve is very nearly flat, but not perfectly so. It will transmit different wavelengths of light with slightly different efficiencies. The sensor in our photometer also lacks a flat response, being more sensitive at some wavelengths than others. If we think of these pieces as filters, that each transmit different fractions of the incoming light, we get a total response of scope% • filter% • sensor% at every wavelength.



SSP3 sensor response curve © Optec corp.

We needn't dwell on the details of all this, but remember that the sensitivity of our measurements, in any band, is affected by the combined efficiency of the whole photometric chain.

1.5 Single Channel Photometry

A photometer is nothing but a scientific-grade light meter. At the moment, the PEP group is using Optec SSP[1] photometers almost exclusively. These are what are known as Direct Current, or DC, photometers. The other category of photometer is the pulse-counting, or photon-counting type. The difference is this: when a photon arrives at a "counting" style photometer, the sensor puts out an electronic pulse. This pulse goes to a counter, which is allowed to accumulate over a period of time, known as the *integration time*. The final count reflects the number of photons. In a DC photometer, the arriving photons are not registered individually. They produce a continuous current that is proportional to the number of photons. In the olden days, this current was fed into a chart recorder. The chart pen would deflect according to the strength of the current, and this is why we still call a single photometric sample a *deflection*. This note will skip discussion of pulse-counting, which is usually practiced by highly experienced photometrists. Details of how the SSP devices produce time-integrated counts from a current will be covered elsewhere; the point to understand is that those numbers are not photon counts, and that matters when interpreting the precision of the deflection. We typically operate the SSPs with ten-second integrations, and three consecutive integrations are averaged to produce one deflection. This averaging helps smooth out small fluctuations in the readings.

A CCD has millions of pixels, but a single channel photometer has only one honking-big pixel. This pixel is much larger than the size of a star image. As a consequence, when we aim the photometer at a star, it also sees a bit of sky around the star. This presents a complication, because the sky is not perfectly dark. Earth's atmosphere glows, even on the darkest night. Furthermore, if you look far enough out into space, any sightline will eventually terminate in a star. Stars that are too dim to see are nonetheless contributing light within the field of view of the sensor. We call all this light *background*,

1 Solid-state Stellar Photometer.

and it contaminates the measurement we make of the target star. To correct for it, every deflection on the star is accompanied by a second deflection on the sky near the star. When we report counts for the star, we subtract these *sky counts* from the *star counts* to get a net count. This procedure is not perfect, but, with care, it works well.

Like most all of AAVSO, we in PEP practice the art of *differential photometry*. That is, we establish the magnitude of a variable star by comparing it against a (hopefully) constant star having (hopefully) a reliably-determined magnitude. Variable stars in the PEP program each have an assigned "comparison" star. Use of the same comparison improves the internal consistency among multiple observers. It should be noted, here, that photometry can be a squirrelly business—studying starlight through the atmosphere poses inevitable problems. Every measurement is subject to perturbations, and truly good reference magnitudes are established by expert observers averaging many observations.

The typical PEP observing sequence interleaves deflections of the variable (or "program") star with deflections of the comparison: comp...var...comp...var...comp...var...comp, the telescope being moved back and forth (sky deflections here omitted). Each variable deflection is referenced against the average of the two comparison deflection that bracket it. Having three samples of the variable not only gives us a more reliable result than a single sample, it allows us to compute a statistical error, or uncertainty, for the observation sequence as a whole.

As noted above, our DC photometers produce counts that are proportional to the number of photons received during an integration. If p photons arrive, we will have a count of $k \bullet p$, where k is a constant for our photometer. The complete reduction of counts to magnitude will be left to another section, but suffice it to say that we will take the logarithm of the counts, so that the magnitude will be of the form $\log(k \bullet p)$. If we get p_v photons from the variable during its deflection, and p_c photons from the comparison during its deflection, then the magnitude difference, ΔM, will be of the form $\log(k \bullet p_v) - \log(k \bullet p_c)$. If we have a reliable magnitude M_c for the comparison, then the magnitude of the variable will be $M_c + \Delta M$. That is fine for me and my photometer, but what about you? Your photometer will have a slightly different value of k. Doesn't that mean our instruments operate on different "scales," like Fahrenheit and centigrade? How can we reconcile our results? The mathematics of logarithms comes to the rescue: $\log(k \bullet p)$ can be re-written as $\log(k) + \log(p)$. This means that the differential magnitude formula can be transformed as follows:

$$\begin{aligned}
\Delta M &= \log(k \bullet p_v) - \log(k \bullet p_c) \quad \text{becomes} \\
&= (\log(k) + \log(p_v)) - (\log(k) + \log(p_c)) \quad \text{[expanding the logarithms]} \\
&= (\log(k) - \log(k)) + (\log(p_v) - \log(p_c)) \quad \text{[re-arranging terms]} \\
&= \log(p_v) - \log(p_c) \quad \text{[canceling terms]}
\end{aligned}$$

My differential magnitude is independent of k, and so is yours. We can compare them directly. This independence applies to all multiplicative factors that affect our respective counts. If your scope aperture is bigger than mine, your photon counts will be higher by a factor. If your filter has a 10% higher transmission efficiency, your counts will be higher. Likewise if your sensor has 5% greater sensitivity, or your integration timer runs 3% slower. All these considerations drop away when we compare stars differentially on a logarithmic scale.

1.6 The Sinkhole

Much photometric ink has been spilled on the distinction between *accuracy* and *precision,* the main source of trouble being that the former term has an ingrained colloquial meaning that is different from its technical usage. There is also the question as to whether you are discussing a single measurement, or a group of measurements. The latter situation is usually illustrated with the infamous "target diagrams:"

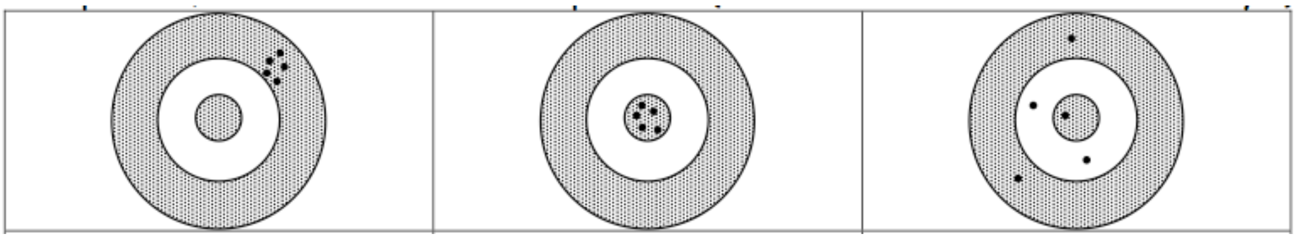


image: haystack.mit.edu

On the left, we have an archer who is precise, but not very accurate. His arrows landed in a tight group, but they missed the center by a wide margin. Moving right, we have an archer who is both precise and accurate, with a tight group on the bullseye. Rightmost, we have an archer who is neither precise nor accurate. Below, we have an archer who might be described as accurate but not precise:

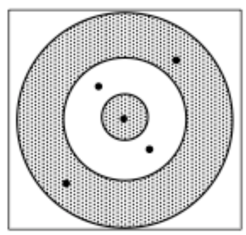


image: haystack.mit.edu

He certainly is not precise, but one can argue that his *average* has high accuracy, in that the mean (x,y) location of his five arrows is right on the money. If his objective was to *locate* the center of the target by the average of his shots, he did very well. However, he still would get a low score in the competition.

Another perspective on accuracy and precision was offered by Arne Henden:

> *It is pretty safe to say that the average CCD observer has very good precision, but pretty poor accuracy. What this means is that the uncertainty from point-to-point in, say, a time series, is excellent. That is why so many observers are able to detect an exoplanet transit (millimagnitude depths) … where the peak-to-peak amplitude may only be a few hundredths of a magnitude. Compare one observer to another observer for the same object and the same night, and you might see far larger separation between the mean levels of the two time series— the"accuracy" part.*

There is a useful distinction in this description: precision defined in terms of the *uncertainty* of the measurements. Every measurement, even a digital one, has some level of uncertainty. So does an averaged group of measurements. Our fourth archer, from a measurement perspective, had high accuracy but also high uncertainty. The first archer had high accuracy and low uncertainty.

In some quarters, there is an effort to sidestep problems with the word "accuracy" by substituting a new word, *trueness*. Trueness is the metric for how close the measured value is to the True value. In the "vision" I proposed, I deliberately stayed away from both accuracy and precision so as not to drag readers into the sinkhole too early. The vision may now be rephrased as *Highly-true, minimally-uncertain photometry of bright, astrophysically interesting stars*. This is what we mean by "high quality." A practical upshot is that if you and I take photometry of the same target at the same time, our results ought to agree, within our mutual uncertainties, and not because our uncertainties are large.

1.8 Our Mascot

Count von Count of Sesame Street

"The Count loves counting; he will count anything and everything, regardless of size, amount, or how much annoyance he is causing the other characters. For instance, he once prevented Ernie *from answering a telephone because he wanted to continue counting the number of rings..."* - Wikipedia

image: wikipedia.org

One...Two...Three...Ahahahaha!!

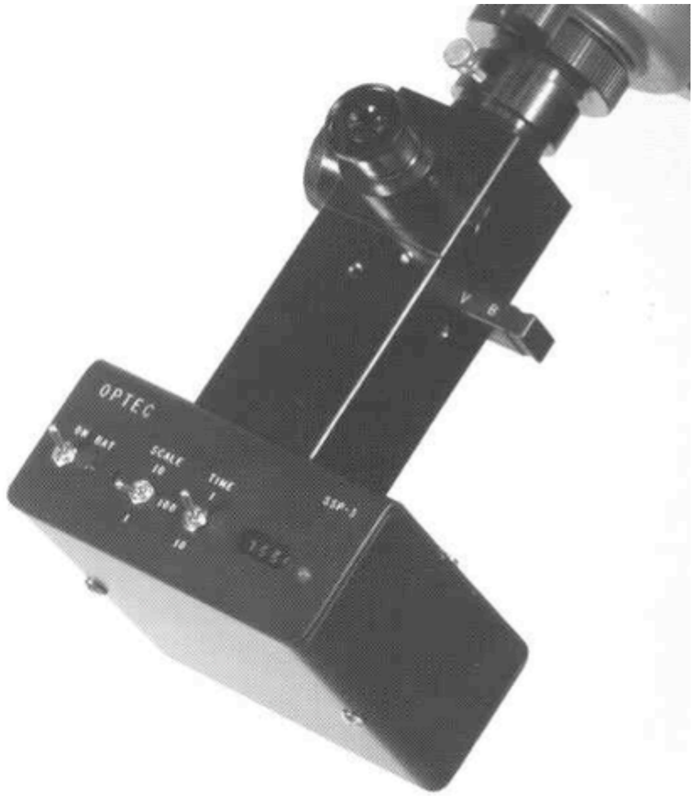
Chapter 2 — Observing

2.1 Scopes and Mounts

At base level, a PEP observer needs a telescope with a tracking mount, a photometer, and at least one photometric filter. The optical tube almost needs to be cassegrain, though a compact refractor is usable. The Optec photometers weigh about 2.5 pounds—you don't want them at the far end of a Newtonian. Likewise, the photometer will turn a long refractor into an amazing pendulum that is no fun to balance. In either case, the photometer, which has a right-angle eyepiece you must look through, would swing all over creation as the tube is moved around the sky. Your mount, surprisingly, need not be equatorial. We will aim the photometer so that the target star is dead-center in the field of view. This means that we do not care about the field rotation that affects altitude-azimuth mounts (I use an alt-az for some of my own work). The mount *does* need to track the sky automatically and well. A GOTO mount is not strictly necessary, but it makes a big difference in the ease of operation. If you plan to operate a GOTO mount strictly with a hand-control, be sure that the controller supports "user defined objects." Life without this is an incredible headache for differential photometry, because the star catalogs in the controllers will not have all the stars you need, or will not have them easily accessible for the back-and-forth pointing we use. If you plan to operate your mount via a computer, there should be no difficulty configuring user objects, and it will be easier to command slewing than with a hand controller. You will still need the handpad for fine adjustments, however, and you will need to have slow speed adjustments that actually work. I once bought a mount that advertised a wonderful range of slew speeds, but it turned out that the two slowest, which I needed for photometry, did not work well, causing endless problems. If your mount is not computerized, it is essential that the manual slow motion controls work very smoothly. A further consideration involves fork (or half-fork) mounts. The photometer sticks out a long way from the back end of the optical tube, and it will hit the base of the mount if you try to swing it between the tines of the fork. If you operate the mount in alt-az mode, a considerable portion of the sky near the zenith will likely be inaccessible. On an old Meade LX-200, you can only get to about 65° altitude. Of course, you can wait for objects to sink to a lower elevation, but sometimes you really want to shoot straight up. If you operate in equatorial mode, some parts of the sky will still be out of reach, but you can aim overhead. German equatorial mounts are fine, unless they are tripod-mounted and the photometer case hits the legs. Finally, your GOTO mount need not have perfect slewing. None of the equipment we can afford will slew right on target—fine adjustments will be necessary. However, it is important for slew errors to be reasonably *predictable*. When you first slew to your program or comparison star, you want to know where it is likely to be, relative to the center of the field. If your desired star is not remarkable in color or brightness, you may find yourself having to choose among possibilities, and end up taking data on the wrong one.

A final word on scopes: you don't need expensive, hyper-corrected optics. We work right on the optical axis, where aberrations are at a minimum. Increased aperture will do you more good than a tighter point-spread function.

2.2 Photometers and Filters



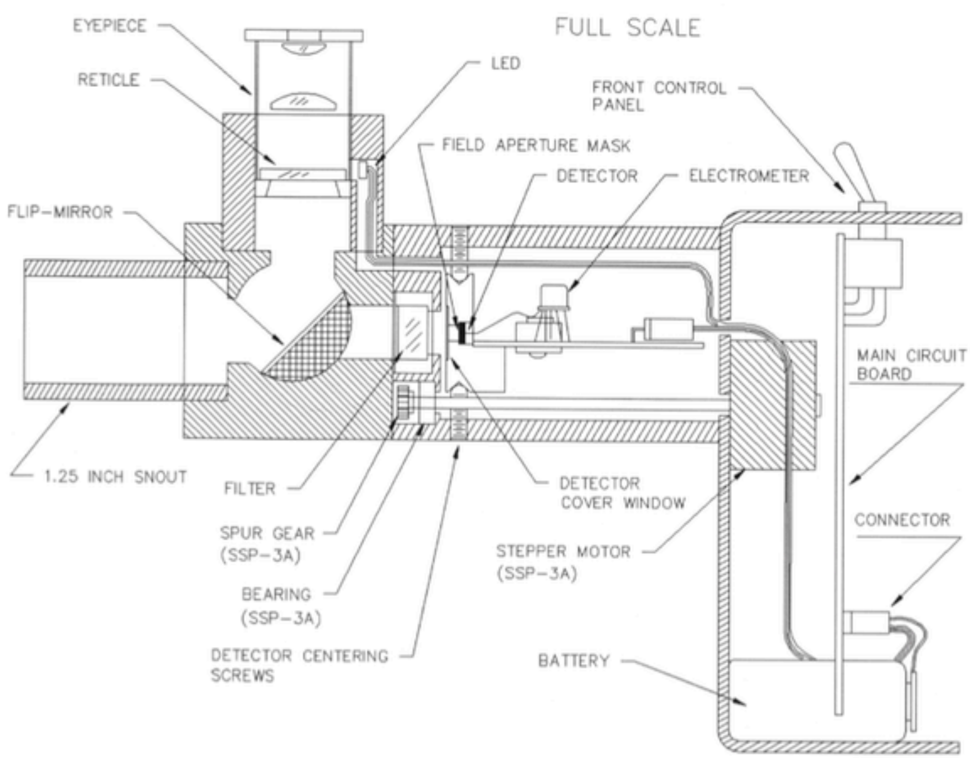
Generation 1 SSP3, © Optec corp.

Your choice for a photometer will likely be an SSP3 or SSP5 by Optec. They are available new and used, “Generation 1” or “Generation 2”, and with or without motorized filter switching. Only Generation 2 models are now sold by Optec. These are computerized and have some definite advantages. The Generation 1 models, however, can be bought cheap on the used market. The going rate for a Gen. 1 SSP3 is about $200+shipping (2015). You may have to be patient for one to appear on eBay or AstroMart, but the devices are out there. If you are new to handling scientific instruments, you probably want to start with an SSP3. These photometers are almost indestructible. I've dropped them four feet onto concrete and had them survive. The SSP5 is more delicate, and if it suffered the same treatment, or got aimed at the moon or a streetlight, you might be out hundreds of dollars for a new photomultiplier tube. The trade-off is that the SSP5 can see much fainter stars, and take much shorter integrations. Of course, it costs more to buy in the first place. Another attraction of the model 3 is that it can be operated off of an internal 9V battery. A rechargeable battery can be used, provided it has a rating of 200mah or more (Optec sells them). You will likely get neither a rechargeable battery nor a power supply with a used unit.

The Gen. 1 photometers have a four-digit LED display that shows the counts. The operator would write down the numbers, or dictate them into a recorder. Gen. 2 can either display those counts, or send them to a computer for automatic logging. An advantage here is that the computerized reporting will handle counts as high as 65535, whereas the on-board display can only go to 9999. The photometers have three gain settings (x1, x10, x100), but if you are observing a var/comp pair where one star is way brighter than the other, the bright star might overflow the display on the gain setting that is appropriate for the dim star. Gen 1. devices have only one and ten second integration times. Gen. 2

also allows five seconds with the display, and programmable intervals over the computer link. Either generation could be fitted with a motor for switching among filters, making it an "A" model. Unmotorized models have a sliding metal bar with mounting holes for two filters. You push-in/pull-out the "slider" to effect a filter change. Motorized models have space for at least six filters in the slider. Optec sells a control/acquisition/reduction program, SSPDataQ for use with the Generation 2 photometers. It runs only on Windows, and communicates over an RS-232 link. The Gen. 2 data protocol is not complicated. You could write your own software package to control it. Also, Generation 1 photometers can be upgraded to Generation 2 at reasonable cost.

The physical packages for the SSP3 and 5 are almost identical. They have a 1.25" nosepiece that slides into a conventional focuser. The forward rectangular box contains the optical bench, and the box at the rear has the processing electronics. A Gen. 1 SSP3 is illustrated below.



Generation 1 SSP3, © Optec corp.

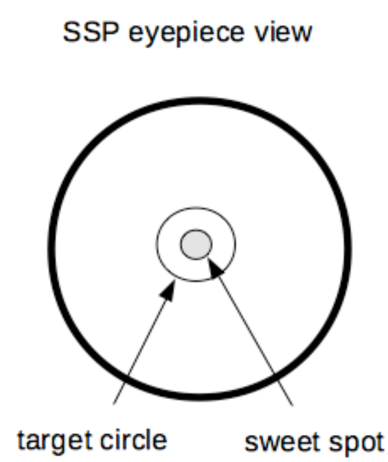
The sensitivity of the SSP3 is such that you will want at least an eight-inch telescope to have a reasonable selection of targets (ten-inch if you want to do B band). Stars in the PEP program are usually bright, but there's no sense artificially limiting your choices. The SSP5 can go about five magnitudes fainter than the 3 (or seven magnitudes if you buy the super-sensor), hence its attraction for experienced observers.

When outfitting your photometer, you will want at least a V band filter, and your next choice should be B band. If you are buying a used photometer that has been sitting around for years, plan to buy new filters (over time, the cement that holds the layers of glass together deteriorates and becomes cloudy). The SSP3 can operate in the R and I bands, but care should be taken to get the right kind of R and I. AAVSO wants R/I data from Cousins filters, but there are observing projects by other groups that have asked for Johnson R and I. Photometric filters are not cheap, so buy what you will actually use[2]. If you use the manual filter sliders, have the filters mounted in the color pairs you will need. If you are going to do both BV and VI photometry projects, get two sliders and put BV in one and VI on the other. Old sliders will have B in the right position, V in the left, so that when the slider is pushed all the way in, the B filter is in the optical path. Optec has since reversed this convention. If you prefer to have your short-wavelength filter on the right, as I do, you need to specify that when ordering (I have BV, VI, and UB sliders).

Don't clean your filters (or telescope objective) unless you need to. Your system must be re-calibrated after such maintenance. There are four screws that adjust the X-Y position of the sensor, and two screws that lock the eyepiece in place. Don't fool with those, or your target reticle may not be centered properly. It is *possible* for you to re-center the system, but I let Optec handle that.

2.3 Basic Operation

The SSP has a flip mirror, which can direct light to either the sensor or the eyepiece. You start with the eyepiece, slewing the scope to put your star in the center of the target circle. The eyepiece has a once inch focal length, so with an 8” F/10 SCT you are working at a magnification of 80x. At this power, the circle is 24 arcmin in diameter. The detector sweet spot is the central 35% by radius. At the rim of the circle, sensitivity may fall to 0. As you begin to experiment with centering a star, you will notice that your left/right/up/down eye position makes a difference, shifting the apparent location of the star in the circle. You'll get used to this, and gradually learn to keep proper eye alignment (keep the whole field stop of the eyepiece in view, if possible). Though I am nearsighted, I don't wear my glasses when making observations. I usually focus the photometer with my glasses on, and then remove them, improving the eye relief.

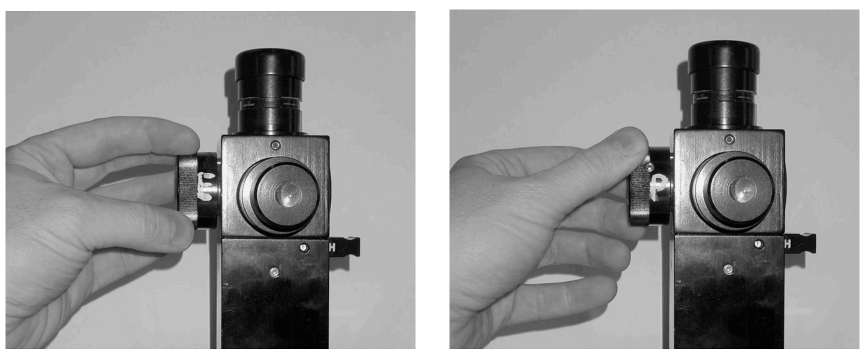


Once the star is well-centered, the flip mirror knob is turned (I have put white letters “E” and “P”

2 The standard SSP5 has zero response in R and I bands, but the extended-sensitivity version will work in R. There are caveats regarding the R and U filters (see section 3.5 on Transformation).

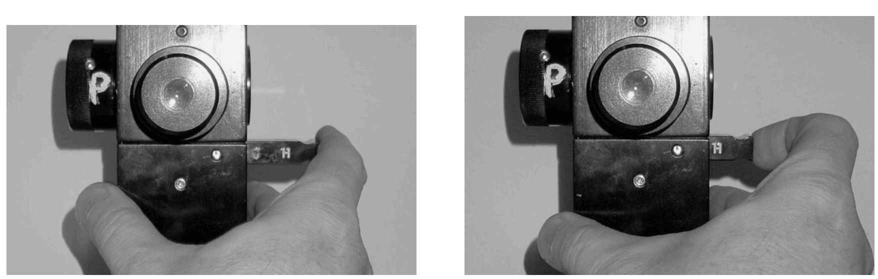
[“eyepiece,” “photometer”] on the knob so it is easy to tell the position in the dark). A series of three integrations can now be taken, but there is a catch: the integration timer is not synchronized to the mirror flip. Integration is actually happening all the time. Every ten seconds the counter is reset, regardless of the position of the mirror. Therefore, the first count you get after flipping the mirror is almost certainly not a full integration, and must be discarded (while an integration is taking place, the display will show the results of the prior integration). Generation 1 photometers have an LED to the right of the display. When the display updates, the light flashes, which is handy if the current and prior counts are the same. Some very early Gen. 1 models do not flash the LED, but you can hack the electronics to fix that (I did).

Unless conditions are exceptional, the values you get for the three integrations will vary somewhat. I like to see the highest reading no more than about 1% above the lowest (this is with modest “eyepiece” counts). If the numbers are dancing around, you have bad sky conditions or bad tracking, the latter indicated by values going down, down, down. It should be obvious that you don't want to manhandle the flip knob: be gentle. Same with the filter slider:



Flipping the mirror: use the fingers, not the wrist

Move slider out: pull with thumb and forefinger, push with index finger



Move slider in: squeeze between thumb and forefinger

If your manipulations vibrate the scope a little, that's ok (let it settle), but a jolt will put you off target.

When you take your second or third deflections on a star, note if the counts are close to those of the first deflection. A mismatch indicates a centering error or changing sky conditions. It cannot be overemphasized to pay attention to the counts and not simply log them. They are your key diagnostic for problems. If your counts are 10,000 or more, the aforementioned LED will come on and stay on. On a Gen. 2 unit, the alphanumeric display will say “OVER.”

Having got your star deflection, flip the mirror and slew nearby for a sky deflection. At a minimum, get the star outside of the target circle by one circle diameter. This is not always sufficient. If your star is very bright, scattered light in the optics may contaminate the field of view beyond the circle. If you suspect this, keep moving the scope further off the star until your counts minimize. Obviously, keep the circle away from any other stars. Don't forget to flip the mirror again afterward! You want counts from the sky, not the inside of the photometer case. If you are doing two-color photometry, the star and sky must each be sampled with both filters. Rather than sampling star&sky in filter 1 then star&sky in filter 2, there is a more efficient pattern: star filter 1, star filter 2, slew, sky filter 2, sky filter 1. This involves only one star-to-sky motion per target.

Taking deflections will seem awkward at first, but you will eventually develop a rhythm for the process. This is why I like my short-wavelength filter in the same position for all of my sliders—it's part of the pattern.

In preparation for taking data, there is an adjustment that must be made with the mirror set for the eyepiece. The photometer has an “offset,” which sets a floor for integration counts. The internal noise of the device generates some counts even with no light. These “dark” counts can vary with temperature, and while we want to minimize them, we don't want our display to underflow as the night gets colder. The offset is adjusted so that there will always be some counts at any integration/gain combination we expect to use that night. For 10 second integrations on a night you plan to use 1x and 10x, it would be appropriate to set the dark counts at about 4-5 while in 1x. The Optec manual says to adjust for this minimum count at 1 second integration and gain 1x. Don't do that unless you are actually using 1 second in practice. The reason is that if you get 5 dark counts at 1 second/1x, you will also get 5000 dark counts at 10 seconds/100x. If you are dependent on the display readout for data logging, those 5000 counts eat up half of your dynamic range.

2.4 The Standard Sequence

We have already touched on the usual order for taking deflections, with program star samples bracketed by comparison samples. The complete sequence, omitting sky deflections, goes as follows:

1. Comparison deflection #1
2. Variable deflection #1
3. Comp #2
4. Var #2
5. Comp #3
6. Var #3
7. Comp #4
8. Check star
9. Comp #5

The "check star" is a safety precaution. We only sample it once, so the measurement is not hugely reliable. However, if the observed check magnitude is seriously out of whack, we need to look for problems. The check is also useful for detecting variation in the assumed-constant comp star. Since each star deflection is accompanied by a sky deflection, a total of eighteen deflections are made. In a single color, this takes about twenty minutes. This sequence has proven reliable, but it is not carved in stone. If you have two variables close together that use the same comp/check, you could do the following:

1. Comp #1
2. Var A #1
3. Var B #1
4. Comp #2
5. Var A #2
6. Var B #2, etc.

But don't push it too far. As the star samples get further apart in space and time, the reliability of the results can suffer. It should also be said that the three-integration pattern could be expanded to four or even five, but I wouldn't use two. Multiple integrations help smooth out variations caused by the atmosphere. With a Gen. 2 photometer, you also have the option of integrating for less than ten seconds, which might be helpful with bright stars. I would not go below five seconds on account of scintillation, which makes the stars flicker on short time scales.

2.5 Gain settings

If I am working with very bright stars, I use a gain setting of 1x, otherwise I use 10x. My feeling is that 100x is just magnifying the noise along with the star signal, and I don't use it. I see the gain setting as just a way to prevent overflow conditions, not a means to extract more information on dim stars. At 100x, my own SSP3 at room temperature has dark counts that change by fifty or even more in a ten-second integration. If you are only getting about 1000 net counts at that gain, internal noise is giving you a 5% variation in star readings before considering any sky effects.

Be very careful about mixing gain settings in the course of one sequence. Verify that *your* photometer gains are really in a 1:10 ratio, don't just assume it. You will need to normalize all your counts to a common gain factor when you reduce them. If you have a Gen. 2 photometer, you can try five second integrations to prevent display overflow. These counts will need to be normalized to ten seconds during reduction.

2.6 Skies: the Good, the Bad, and the Ugly

Our enemies in the pursuit of good photometry are wind, turbulence, heat, light pollution, aerosols, and water vapor. Wind shakes the equipment, turbulence and heat convection shift and distort the light, pollution gives us light we don't want, and aerosols and water absorb our precious photons. It's a tough life, not even considering clouds (CCD observers can actually tolerate a bit of thin cloud cover, but we can't). If what you see in the eyepiece looks bad, wait and hope for improvement.

For the good results on dim stars, you need transparent skies. During the day, note how low-down the sky stays really blue. Look for jet traffic: if the contrails stretch from horizon to horizon, there's lots of water vapor in the sky. If you observe near a nighttime flight corridor, remember that those same contrails can float right in front of your stars.

All-in-all, watch the counts.

2.7 Quirks

Having covered the basics of the SSP, there are some more-esoteric points to attend to.

A. When starting up in the evening, the unit needs to stabilize, both thermally and electronically. Let the device come to ambient temperature before you put it to use. After you power it up, let it idle for five minutes. My SSP3 shows increasing counts during that interval before coming to a stable level. Unless you are going to take a significant hiatus in data-collection during the night, leave the photometer on for the whole observing session.

B. I have seen a unit that had light leaks. I was using it under a dome that had red lights, and I noticed that my sky counts were elevated at times. It turned out that light was getting in through the eyepiece and reaching the sensor. The magnitude of the leak depended upon whether I was standing between the light and the photometer, casting a shadow. If you operate near a light source (eg: computer monitor) and you are seeing some inexplicable dark counts, try exploring outside the photometer case with a flashlight and see if the counts jump.

C. There is a phenomenon where the counts overshoot, then undershoot, then stabilize when switching from a bright star to a dim one. I have seen this on occasion, and so have others. What causes it, I do not know, but it is another reason to pay close attention to the counts. The workaround is to let a few integrations pass.

D. Airplane lights and meteors can cause sudden increases in counts. Watch for them, and re-do suspect integrations. I once had to do photometry during a meteor shower, and got “hit” a few times.

E. Be careful with AC adapters if you own more than one kind of SSP device (eg: a 3 and a 4). The two units use different voltages, and many, many points are taken off for running 12 volts into a 5 volt SSP4. I marked a big, white “4” on my SSP4 adapter, and a “5” on my SSP5's. I put color-coded tape on the ends of the power cables, and matching tape on the bodies of the photometers.

F. If you use an SSP5, turn it off right away when you finish observing, lest you turn on a bright light nearby as you close up shop for the night. The newer 5s are more tolerant of excess photons, but there's no point taking unnecessary risks. On the control panel of my SSP5, I put a note that says, “CAREFUL.”

G. Although you get a 0-65K count range using computer logging, it is still possible to overflow on a bright star at a too-high gain. If you get a data set that has impossibly small counts for a bright target, this is what happened. Do not despair—add 65,536 to the low counts, and use a lower gain next time. This kind of trick does not work for overflows on a Gen. 1 display count.

H.   If your generation 1 SSP3 display is completely blank with no overflow light, the unit is saturated (you're probably playing with it in daylight).

2.8 Tricks of the Trade

For a two-color observations, you nominally center a target star, flip the mirror, take a deflection, flip the mirror again to check that the star is still centered, shift to the second filter, flip the mirror, take a deflection, flip the mirror yet again to verify centering, shift to a sky position, flip the mirror, take the first sky deflection, flip the mirror and check that you have not drifted onto a star, yadda, yadda, yadda. I don't do that. I center the star, take the first-color deflection, slide the filter and take the second color. Then I hold down the “down” slew button on my controller for a short interval and take the sky deflections. Familiarity with my star fields inform me that a certain-length slew will take me away from my target to a clear area, and for only a few targets has it been necessary for me to go in a direction other than down. This is part of the “rhythm.” Once you become used to what the counts (including sky counts) are expected to be, there is no need to re-confirm your pointing if the values are well-behaved.

Chapter 3 — Data Reduction

3.1 Instrumental magnitudes

Having acquired counts from our photometer, what is the conversion to magnitude? We already know that it involves taking a logarithm, and since magnitudes go in the opposite direction of brightness, we must introduce a negative factor somewhere. Further, we want the magnitude to decrease by 5 for a 100x increase in brightness. The formula, then, is

$$m = -2.5 \bullet \log_{10}(\text{counts})$$

This is equivalent to $-5/2 \bullet \log_{10}(\text{counts})$, or $\log_{10}(\text{counts})^{-5/2}$. Let's verify the formula: call the instrumental magnitude of some star, $m_1 = \log(c^{-5/2})$. Consider what happens when c increases by a factor of 100. We have a new magnitude, m_2:

$$m_2 = \log((100c)^{-5/2}) \text{ or}$$

$$\log(100^{-5/2} \bullet c^{-5/2}) \text{ or}$$

$$\log((10^2)^{-5/2} \bullet c^{-5/2}) \text{ or}$$

$$\log(10^{-5} \bullet c^{-5/2}) \text{ or}$$

$$\log(10^{-5}) + \log(c^{-5/2}) \text{ or}$$

$$-5 + \log(c^{-5/2}) \text{ or}$$

$$-5 + m_1$$

Our star is now five magnitudes brighter. Q.E.D. Note that the 2.5 factor is *not* an approximation of the 2.512 brightness ratio between magnitudes.

Because of the properties of logarithms, the differential magnitude between the variable and comparison can be expressed two ways:

$$\Delta m = m_{var} - m_{comp}$$

or

$$-2.5 \bullet \log(\text{counts}_{var}/\text{counts}_{comp})$$

3.2 First-order Extinction

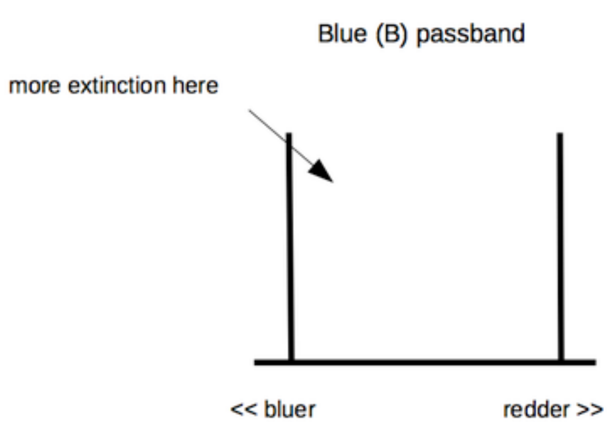
First-order extinction is the simplest consideration in the reduction process. The Earth's atmosphere attenuates starlight, and the more atmosphere through which the light passes, the more attenuation. When collecting data, the variable and comparison stars, though typically close together, are at slightly different altitudes. We compensate for the extinction difference. The quantity of atmosphere is measured in “airmass” units, and the symbol for the value is “X.” Straight overhead is an airmass of one. At thirty degrees elevation, the airmass is two, and it quickly rises as you go lower. To compute the correction, you need two numbers: the differential airmass between variable and comparison (ΔX = var airmass - comp airmass), and the extinction coefficient, “kap,” in units of magnitudes per airmass. Note that ΔX can be positive or negative. The differential extinction is $\Delta X \bullet$ kap, and this value is subtracted from the instrumental magnitude. In V band, this quantity is usually quite small.

3.3 Color Contrast

Before proceeding further, we must introduce the concept of color contrast, based on *color index*. A star's color index is the difference in standard magnitudes in two passbands. The most common index is B-V, the B magnitude minus the V magnitude. A reddish star will have a bright V magnitude (relative to B), and B-V will be positive. A bluish star will have a bright B magnitude, and B-V will be negative. The difference in indexes, $\Delta(B\text{-}V) = (B\text{-}V)_{var} - (B\text{-}V)_{comp}$, gives the color contrast between variable and comparison. Values of $\Delta(B\text{-}V)$ near zero indicate stars with very similar color. A positive $\Delta(B\text{-}V)$ indicates the variable is reddish relative to the comparison.

3.4 Second-order Extinction in B Band

As wavelengths reach the blue part of the spectrum, extinction increases rapidly. In B, we see an effect caused by measurably different levels of extinction within the passband. At the short-wavelength end, light will experience more attenuation than at the long-wavelength end.

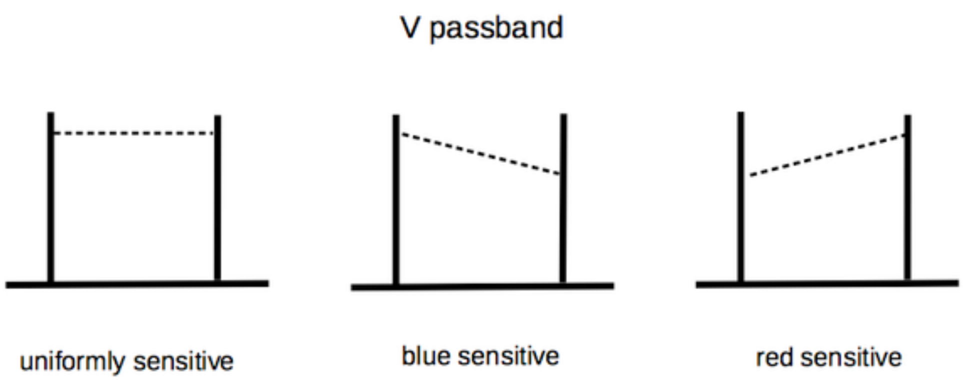


This means that at a given altitude, a star with an excess of blue light will suffer more extinction than a star with an excess of red light. If our variable and comparison have different color indexes, this will affect our results. The correction is expressed as $kkap_B \bullet X_{mean} \bullet \Delta(B\text{-}V)$, where the first term is the second-order extinction coefficient, and the second is the average of the variable and comp airmasses. This value is subtracted from the instrumental magnitude.

Typical $kkap_B$ values are in the range -0.02 to -0.04. Second order extinction can be substantial. For example, if $kkap_B$= -0.03, X_{mean}=1.5, and Δ(B-V)= 0.500, the correction will be +0.022. Second order extinction in V, R, and I is negligible, and in U it is *defined* to be zero (U band is its own strange world).

3.5 Transformation

No two combinations of scope/filter/sensor are identical. In particular, every system has different sensitivity to color across the spectrum of a given passband. Hence, your instrumental results for a star will differ from those of everyone else. As an example, consider the (exaggerated) spectral sensitivities illustrated below. At left is a system with uniform spectral sensitivity; at center, a system with more sensitivity at the blue end of the V bandpass; at right, a system with more sensitivity in the red. In general, measurements by these systems will not agree. Transformation adjusts your instrument to the "standard system," whose data points are comparable for all observers.



To effect transformation in V and B bands, we need coefficients e_v and e_b, known as “epsilon-V” and “epsilon-B” (I am going to skip the “mu” coefficient used to transform the B-V color index). The transformation adjustment is epsilon • Δ(B-V), a value added to the instrumental magnitude. For an SSP3, e_V tends to be around -0.05. Thus, for Δ(B-V)= 0.500, the transformation adjustment is -0.025.

To think about this, imagine that I have the blue-sensitive system. First, consider that my variable and comp have the same B-V. This means that they are equally affected by my non-uniform color response, so a differential comparison of the two will be unaffected (the V transformation is e_v • 0). Now consider my variable to be bluer than the comparison, so that Δ(B-V) < 0. My comp has a comparative excess of red, and that red light will suffer in my response curve, making the comp appear dim relative to the variable. If my comp is dim, that makes the variable appear brighter than it really is. With the e_V and color contrast values both less than zero, the transformation value added to the instrumental magnitude will be positive, making the standard magnitude of the variable dimmer.

Note that the Optec R filter does not transform well to the standard system, and the U filter will not transform at all.

3.6 Complete Magnitude Reduction Formulae

We can now state the formula for converting instrumental magnitudes to standard magnitudes.

standard magnitude = instrumental magnitude - extinction(s) + transformation

$$V = v - kap_V \bullet \Delta X + e_V \bullet \Delta(B\text{-}V)$$

$$B = b - kap_B \bullet \Delta X - kkap_B \bullet X_{mean} \bullet \Delta(B\text{-}V) + e_B \bullet \Delta(B\text{-}V)$$

3.7 Airmass Reduction

Below are my Python procedures for computing airmass. All angles (RA, Dec, latitude) are in radians. Universal Times are in minutes [0..1439), UT fractions are [0, 1).

```
# compute airmass from RA, Dec, location, and UT
def computeAirmass(ra, dec, julianDate, ut, longitude, latitude):
    # get sidereal time
    siderealTime = localSiderealTime(longitude,
                                     julianDate, ut/1440.0)

    # sidereal angle
    siderealHourAngle = siderealTime * 15.0 * degRad

    #  compute hour angle
    meanHourAngle = siderealHourAngle - ra

    #  sin of altitude
    sinAltitude =(math.sin(latitude)*math.sin(dec)) + \
        (math.cos(latitude)*math.cos(dec) * \
             math.cos(meanHourAngle))

    return sinAltitudeToAirmass(sinAltitude)


# compute local sidereal time
def localSiderealTime(longitude, julianDate, utDayFraction):

    # Oliver Montebruck's Practical Ephemeris Calculations (Springer Verlag 1987).
    # Greenwich Mean Sidereal Time (GMST) is the local sidereal time at
    # longitude 0.

    # GMST(in hours) = 6.656306 + 0.0657098242*(JD0-2445700.5) + 1.0027379093*UT

    # where JD0 is the Julian date at UT=0 (note JD0 will always end in .5 --
    # Julian days begin and end at UT noon).

    # The conversion to local sidereal time:
    # LST = MOD [(GMST - (degrees west of Greenwich)*(24/360)),24]

    greenwichST = 6.656306 + 0.0657098242*(julianDate-2445700) + \
        1.0027379094*(utDayFraction*24)

    siderealTime = greenwichST + (longitude/twoPi)*24

    # if we go over 24 hours, reduce to [0-23)
    if (siderealTime >= 24.0):
```

```
        siderealTime -= int(siderealTime/24.0)*24

    return siderealTime


# compute airmass from sine of altitude
def sinAltitudeToAirmass(sinAltitude):
    secant = 1/sinAltitude
    return secant - 0.0018167*(secant - 1) - 0.002875*(secant - 1)*(secant - 1) - \
        0.0008083*(secant - 1)*(secant - 1)*(secant - 1)
```

3.8 Time of Observation

It takes twenty minutes or more to complete a PEP observation sequence. When we assign a time for the observation, we typically choose the time of the second variable deflection. This is the "middle" of the sequence (not counting the check star). Alternately, one could use the average times of the first and fourth comparison deflections. Given our low time-resolution, the exact value is not a big deal.

3.9 Data Reduction Software

I am aware of four different tools in use for reducing AAVSO PEP data:

1. AAVSO WebPEP (V band only)
2. SSPDataQ from Jerry Persha/Optec
3. Homebrew spreadsheets
4. Homebrew programs

All these tools are slightly different. You may hear descriptions of the sort, "Tool A uses the method of chapter 4 in Henden and Kaitchuck." That characterization is fine so far as it goes, but keep in mind that chapter 4 of H&K is not a software functional specification—it does not define an algorithm. Various programmers can read chapter 4 and come up with various implementations. I will give three examples of differences that exist. The first is the use of Δ(B-V) in calculations of transformations or second-order extinction. Δ(B-V) may come from:

1. Static standard value from catalog
2. Measured instrumental value
3. Measured standard value

WebPEP uses catalog B-V values for transformation. This is the only option when observations are gathered in one band. Instrumental Δ(b-v), which is readily available in two-band observations, is sometimes used as an approximation for Δ(B-V), but it is only an approximation. The transformation and second-order extinction coefficients are meant to be used with standard B-V. It is possible, however, to convert Δ(b-v) to Δ(B-V) before the standard B and V magnitudes are known, and this is what my own program does.

Another point of variation in the tools is found in the origin of extinction coefficients. WebPEP assumes a constant kap_V = 0.25 for all observers. Other tools use some form of measurement to establish kap for each band. My program generally uses instrumental magnitudes of standard “extinction stars” over a wide range of airmass, measured separately from variable/comparison magnitudes, to establish kap for a whole evening's observations. The spreadsheets I have seen use the variation in instrumental magnitudes of the comparison star over the course of one variable's observation.

Finally, there are different methods for estimating a single comparison star magnitude from two deflections. In single-channel photometry, we can only sample one star at a time—it is not possible to measure the variable and comparison simultaneously. Therefore, we bracket each variable deflection with two comparison deflections. The simplest estimate is to average the two comparison magnitudes. The spreadsheets I have seen operate this way. WebPEP and TJC_PEP perform time-interpolation. That is, a straight line equation, as a function of time, is computed between the two comparison magnitudes. The interpolated comparison magnitude is taken to be the point on the line corresponding to the time of the variable deflection.

3.10 Metadata

How do metadata affect the reduction of your results? They don't, but they are important when someone comes along later and tries to evaluate your data. Below are sample metadata for a B band reduction I computed for another observer. I used a catalog Δ(B-V) of -0.517, and the e_B was 0.100 (“Tb_bv” is the new AAVSO nomenclature for transformation, it means the B band epsilon in the B-V system). I used an estimated extinction of 0.35, and the second-order extinction was -0.03. The equipment used was an Optec SSP3 on a schmidt-cassegrain, located at 52^o N latitude, 4^o E longitude. TJC_PEP is the name of my program, version 4.1. These metadata would be included in the observation report submitted to AAVSO.

static_dBmV= -0.517;	*Tb_bv= 0.100;*	*kap= 0.35 (est);*	*kkap= -0.030;*
10in_SCT/SSP3;	*52N/4E;*	*TJC_PEP_4.1*	

This kind of information is important if a researcher notes that some characteristic of my data changed during my photometry career. If I switched instrumentation after ten years, that could explain it, and my metadata provide the clue.

3.11 Observational Honesty

We want the data we report to be free of “opinions”—judgement calls by the observer. Human expectations are not always in line with reality, and our magnitudes are supposed to represent reality. Human factors *do* creep in, however, and we must manage them responsibly. For instance, what if I complete a standard sequence on a star, only to find that I forgot a sky deflection along the way? Do I just throw away my data, or try to estimate the background counts? If my background has been consistent over the other deflections, I have no problem using an average background in place of the missing one, but I would put a note with the observation that there was an estimate involved. What if a hot integration slipped through when I was not looking, only to be found during reduction? If integrations have been stable, I would drop the offender and make a note in the record.

A consideration to make when making a call about a data point: will the magnitude need to stand on its own, or is it to be evaluated as part of a larger group? For instance, if we are fitting a line to several magnitude readings, we need not be as picky about a small bias in one of them.

The questions around ratty data can become a philosophical conundrum. If the sky looks bad and I choose not to observe, there is nothing to report. But if I go ahead and try to collect data, am I right to exclude them from some larger analysis because they are of poor quality? In principle, it seems I should report everything, but crummy data may only muddy the story. One needs to be careful about excluding poor results just because they don't agree with expectations.

3.12 Avoiding Embarrassment

Before you submit data to AAVSO, or any other organization, look at your numbers. *Do they make sense?* Some hilariously bad results get reported when people don't perform simple quality control. Just because the computer tells you a value doesn't make it right. If you find problems with your reported observations, fix them and note the revision in comments.

3.13 Reference Magnitudes

If you observe the PEP program stars, reference V magnitudes for the comparison and check stars are given in the PEP database, and B-V are given for both the variable and comp. If you expand to other filter bands, or other stars, you need a reliable source for magnitudes. In the case of B band, we can compute the comp B magnitude from the information in the database. We are given V and B-V, hence, the B magnitude is (B-V) + V.

Beyond B band, we must look elsewhere for reference data. It should be pointed out that there is no documentation for where the database magnitudes actually came from. When we bring more star magnitudes into the PEP ecosystem, we should be careful about their origins. A convenient source of information is the SIMBAD website, but I only use it for casual inquiries regarding magnitudes. A much better choice is the General Catalog of Photometric Data, from which most PEP program magnitudes seem to have been drawn. The GCPD contents have been submitted to a vetting process that seems reasonably thorough and consistent. A drawback is that the index only works with HR and HD star designations, and not SAO numbers, which are common in the PEP database. I think we should avoid introducing any new SAO identifiers into the mix (I have yet to run into any PEP-interesting star—in our range of sensitivity—that does not have an HD number).

Magnitudes are also available via the AAVSO variable star plotter (VSP). When this tool is used to generate a table of comparison stars, it generates an identifier for the table, so it can be recovered in the future. This id needs to be noted in the magnitude reports. When WebPEP submits a report, it uses "PEP" as the chart id to indicate that PEP database magnitudes were used. The VSP magnitudes are drawn from a variety of sources, some of which are not of high precision (look at the uncertainties in parenthesis).

As a general rule, we want to draw magnitudes, in all bands, from the same source for a given comparison, and we want the color index, whether B-V or V-I, etc., of the comparison to be close to that of the variable, so as to minimize transformation problems. If you use a comparison magnitude that is not traceable to a chart ID, you *must* include that magnitude in a comment in the observation record.

3.14 Data Format

If you are reducing your own data, you will need to produce an AAVSO-standard text file that can be uploaded. The format definition is available at https://www.aavso.org/aavso-extended-file-format. A quick excerpt is below:

```
#TYPE=EXTENDED
#OBSCODE=TST01
#SOFTWARE=GCX 2.0
#DELIM=,
#DATE=JD
#OBSTYPE=CCD
#NAME,DATE,MAG,MERR,FILT,TRANS,MTYPE,CNAME,CMAG,KNAME,KMAG,AMASS,GROUP,CHART,NOTES
SS CYG,2450702.1234,11.235,0.003,B,NO,STD,105,10.593,110,11.090,1.561,1,070613,na
SS CYG,2450702.1254,11.135,0.003,V,NO,STD,105,10.594,110,10.994,1.563,1,070613,na
SS CYG,2450702.1274,11.035,0.003,R,NO,STD,105,10.594,110,10.896,1.564,1,070613,na
```

Read the file definition carefully. The comparison and check star magnitudes are *instrumental*, not standard. When you chat with your colleagues, you'll “speak” standard, but use instrumental in the file. If you are using reference magnitudes from the PEP database, the chart will be “PEP.” The definition for TRANS is out-of-date (we don't use Landolt fields). Put “YES” if you transform. I won't go into how to compute Heliocentric Julian Date (HJD)—we don't have much need for that. Below is an example of my own report for P Cyg:

```
#TYPE=Extended
#OBSCODE=CTOA
#SOFTWARE=TJC_PEP_4.2
#DELIM=,
#DATE=JD
#OBSTYPE=PEP
#NAME,DATE,MAG,MERR,FILT,TRANS,MTYPE,CNAME,CMAG,KNAME,KMAG,AMASS,GROUP,CHART,NOTES
P CYG,2457242.8234,5.167,0.004,B,YES,STD,SAO 69101,-5.461,SAO 69803,-4.719,1.01,NA,PEP, dBmV=0.550; Tb_bv=0.097;
kap=0.29 ; kkap=-0.040; 24in_Cass/SSP3; 44N/120W; TJC_PEP_4.2
P CYG,2457242.8238,4.703,0.001,V,YES,STD,SAO 69101,-5.444,SAO 69803,-4.808,1.01,NA,PEP, dBmV=0.550; Tv_bv=-0.045;
kap=0.20 ;  24in_Cass/SSP3; 44N/120W; TJC_PEP_4.2
```

I choose to separate the different parts of my comments with a ';' (and not use ';' anywhere in actual comment text). This makes it easier to automatically parse out the different fields when rummaging through a large download of reports. We should think about standardizing on this or some other formatting.

3.15 Data Management

If you have a productive career as a photometrist, you will end up collecting a lot of observations. Early on, it is important to develop a strategy to keep your data organized. Don't fall into the trap of giving all your files cryptic names and dumping them into a single directory. There are various ways to structure your personal archive. At the top level, you might break it up by calendar year, or perhaps by variable type (eclipsers, pulsers, etc.), or maybe reverse those two levels of stratification. I presently have top-level directories for each star. The filenames for individual observations are of the form <star_id>_<telescope>_<MJD>_<bands>, where MJD has an integer and fractional part, eg: p_cyg_PMO24_57424.810_BV. My situation is complicated because I use multiple photometers on multiple telescopes, and my reduction code can also accommodate other observers. I had to figure out the minimal amount of information I could put into a filename that would uniquely identify any observation. The key was to realize that one observer could use only one telescope at a time. Thus, star, scope, and JD (to three decimal places) were sufficient[3], but I included the filter bands for convenience. Information about the observer and the photometer are contained inside the files.

I also have "pseudo-stars" for special purposes. For instance, transformation observations of blue/red pairs are prefixed xfm_<constellation>, eg: xfm_lmi_TC9_57445.810_BV. Extinction data files are named like: ext_stars_PMO24_57300.650_BV. Second-order extinction observations, which use the transformation pairs, are prefixed 2nd_<constellation>, eg: 2nd_her_PMO24_57229.760_BV. My database links program stars directly to comparison stars. If I want to use a nonstandard comparison, I append a digit to the star name, like "p_cyg2," to create an independent star/comparison/check combination. I don't claim that this naming convention is ideal, but it lets me keep my fairly diverse set of data files manageable.

Below is the beginning of a typical data file in my system. Lines beginning with a pound sign are comments ignored by my software. The header line has fields for the star identifier, full Julian date, observer code, telescope location (PMO=Pine Mountain Observatory), telescope (PMO24=24 inch PMO cassegrain), photometer (Carlo is an SSP3), filter slider, gain, integration time, transparency for the night, filters actually used, and three spare keywords.

```
#star, JD, obs, loc, scope, photo, slider, gain, integ, transp, filters, spares
P_cyg, 2457228, CTOA, PMO, PMO24, Carlo, BV, 1, 10.0, Measured, BV, NOP, NOP, NOP
#UT hour, UT min, star count, sky count, star S/N, sky S/N, notes
7, 13, 1488.0, 13.33, 447, 28  #  B_1 WARN_SKY_SNR
7, 14, 1487.33, 14.0, 1804, 140  #  V_1
7, 16, 1138.0, 14.0, 2386, 29  #  B_2 WARN_SKY_SNR
7, 17, 1701.33, 13.67, 1353, 30  #  V_2 WARN_SKY_SNR
7, 19, 1487.67, 14.33, 867, 140  #  B_3
7, 20, 1476.67, 14.0, 860, 140  #  V_3
```

The fields in data lines are UT hour, UT minute, star counts, sky counts, star signal-to-noise, sky signal-to-noise, and comments. For files with two filter bands, the band data alternate line by line, with the short-wavelength band first. Now, about those S/N values, which supposedly are not computable for DC photometry: there is an "empirical" S/N that can be deduced for a series of n integrations. That value is the mean count divided by the standard deviation of the n counts. The references I have read do not make it clear if the inputs to this computation are supposed to be net counts or raw counts (I use net counts for the star S/N). I don't ascribe deep meaning to these numbers, I just use them as another diagnostic of potential trouble. In the above file, three sky counts were flagged as low S/N (I set the threshold at 50). I flag star S/N values that are below 100. When a data file is run through my reduction program, these warnings are noted in the console output. Given that the gain was 1 and the sky counts small, it is not surprising that I got warnings for sky counts. Perhaps for low gain I should use an even lower threshold for sky warnings.

The contents of the data files are generated by a pre-processing program. I log my photometer counts with an outboard Arduino computer. Generation 1 photometers have an analog pulse output, which I feed to an interrupt pin on the Arduino. My software counts the pulses over ten second periods, time-tags the numbers, and stores them on an SD card. By using this external signal, I get around the 9,999 count limit of the internal display. I wind up with a file for each observation sequence, which I upload to my computer. The pre-processing program engages me in a dialogue to establish the metadata (values in parenthesis are defaults selected by carriage-return):

3 One one-thousandth of a day is just under 1.5 minutes. I can't image taking data on a shorter time frame for any purpose.

```
starID (): p_cyg
observer (CTOA):
location (BEND): PMO
telescope (TC9): PMO24
photometer (Edsel): Carlo
slider (JH): BV
gain (10): 1
integration (10.0):
extinction (Measured):
filters (BV):
output file: p_cyg_PMO24_57473.770_BV
```

The pre-processing program allows me to keep a fixed input format for the reduction program when I use different integration patterns (eg: five integrations for stars, three for sky). Also, it gives me the instrumental magnitudes I need as input to manually reduce all-sky transformation calibrations. Adding the S/N estimates provides information about scatter in the integrations that would otherwise be lost in reduction (I do keep the raw data files for future reference).

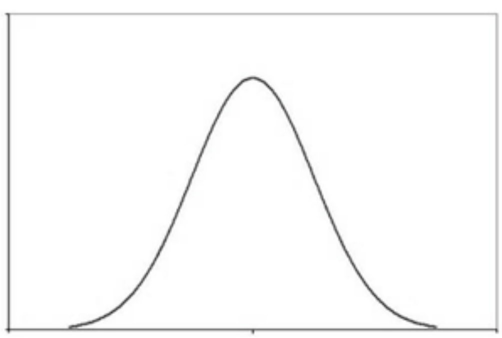
My data management problem is surely more complex than yours. You needn't have all this flexibility in your own data system. But you should still think carefully about how to organize your archive. And remember that calibration data change over time. If you do not preserve your transformation and second-order extinction coefficients, you will not be able to re-reduce old data.

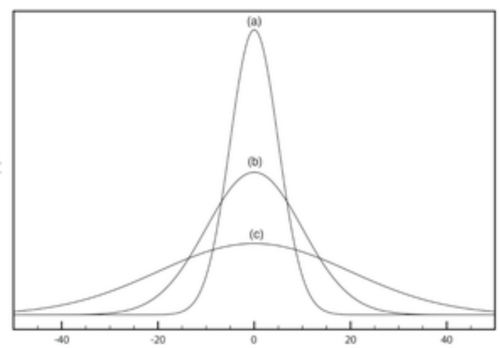
Chapter 4 — A Quick Digression on Statistics

4.1 Precision

No measurement is perfect. The joke about astronomy is that observations that agree within a factor of two of theory are doing well. In photometry, we can do better than that, but we must work at it. Measurements are affected by problems both random and systematic. We call these problems *errors*. A systematic error is introduced when we have dew on the optics, or our tracking goes haywire, or we transcribe counts incorrectly. We strive to eliminate systematic errors by good habits and operating equipment alertly. Random errors cannot be eliminated, but statistical techniques let us manage them.

When we thrice measure the magnitude of a star, we have *sampled* its magnitude three times. What is the character of this sample? We model our measurements as a normal, or Gaussian distribution around the "true" magnitude of the star. The normal distribution is illustrated below:





images: cpp.edu chemwiki.ucdvis.edu

If the true measurement would be at the center, we can expect actual measurements to be distributed around it in proportion to the height of the curve (left). Normal distributions can have different levels of scatter (right). A normal distribution is characterized by its *standard of deviation,* σ ("sigma"). In the right-hand diagram, the tall curve has a small σ, whereas the squat curve has a large σ. If we were making a distribution curve for the heights of a collection of 100 men—a distribution expected to be Gaussian—we could measure all the individuals and compute the σ of that group as:

$$\sigma = \sqrt{\frac{\sum_n (h_i - h\_mean)^2}{n}}$$

Where h_mean is the average height, and the h_i values are heights of individuals

We could also *estimate* the σ by measuring only some of the men. In this case, the formula becomes:

$$\sigma_{est} = \sqrt{\frac{\sum_k (h_i - h\_mean)^2}{k-1}}$$

Where $k<n$, and h_mean is the mean of only k measurements

We divide by k-1 because the estimate based on k is likely too small. As k grows, the difference between k and k-1 narrows, which makes sense since the size of our subset of measurements is approaching that of the whole collection. Our three samples of a star magnitude are regarded as an estimate of a theoretically infinite collection of possible measurements. The precision of our combined measurement is given by dividing the estimated σ by the square root of the number of samples. This value is the *standard deviation of the mean* (SDOM):

$$\sigma_{mean} = \sqrt{\frac{\sum_n (h_i - h\_mean)^2}{n \bullet (n-1)}}$$

This formula is closely related to that for *standard error*, and as n gets large, the formulae converge. This is the error, or uncertainty, that we report with our observations. We expect a 68% chance that the true magnitude is within +/- SDOM of our measured value. This "one-σ" estimate is, thus, not very good. If we double the SDOM, we have a two σ-estimate that has a 95% chance of success. In the interest of full disclosure, the normal distribution is just a model for our measurements. It only truly applies if they are fully independent, and ours are not. Why? Each differential magnitude is based upon two comparison star deflections. The "after" comparison deflection for the first variable sample is reused as the "before" deflection to compute the second variable sample. Also, any statistic computed on just three points cannot be tremendously robust.

By contrast, the photon-counting photometrists, including CCD observers, base their precision on the *Poisson* distribution. You will hear them talking about *signal to noise (S/N)* ratios. A S/N of 100 means a one-σ precision of 0.01 magnitude. In general, their precision is 1/(S/N). It is also true that their data are not strictly Poisson in nature. We, like they, are working with *models* of reality, because the models are mathematically tractable.

4.2 Fitting

The uncertainty calculation gives us a handle on the interpretation of a single measurement, but we must sometimes evaluate groups of measurements, as when establishing extinction or transformation coefficients. How do we cope with the combined errors in a collection of points? This question was resolved as part of the first high-quality mapping project ever undertaken: the survey of France in the years after the revolution. The metric system was then being established, and the length of the meter depended upon the circumference of the earth. Mechanical surveying equipment had reached a new level of sophistication at that time, but the scientists in charge of reducing the survey data knew that there would still be significant random errors involved. In particular, two-dimensional data points that ought to lie on a perfectly straight line would not be expected to do so. How was the true equation of the line to be determined from the noisy data? The solution, proposed by Adrien-Marie Legendre in 1805, was *least squares fitting*.

A line is determined by two parameters, a slope, m and an intercept, b ($y = m \bullet x + b$). For a hypothetical line, the "goodness" of its match to the data would be expressed as the sum of the squares of the y distances to each point from that line. So if we had n points of the form (x_i, y_i), the sum of the squared distances from our hypothetical line would be:

$$\sum_n (y_i - (m \bullet x_i + b))^2$$

If we can select m and b so that this sum is minimized, we will have “fit” the best line to the data. With some help from calculus, this is easily done, and any calculator with Linear Regression functions will do it. In spreadsheet programs, this is a linear “trend line.” It may also be called the *Best Fit Straight Line (BFSL)*.

4.3 Weighted Averaging

We will sometimes have reason to compute the mean of quantities possessing different uncertainties. For instance, we will want to determine our epsilons based on more than one night's data, and each reduction has its own associated error. We want to ascribe the most importance to the values with the smallest errors. For a collection of n (value, error) pairs, the computations are:

$$\text{weighted mean} = \sum_n (\text{val}_i/\text{err}_i^2) \;/\; \sum_n (1/\text{err}_i^2)$$

$$\text{weighted error} = 1 \;/\; \sqrt{\sum_n (1/\text{err}_i^2)}$$

Chapter 5 — Calibration

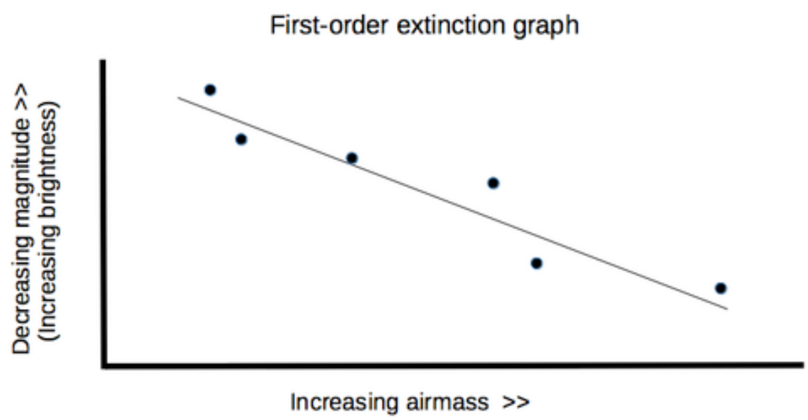
Having introduced the factors needed to reduce our data, we can go into detail about calibrations.

5.1 Nightly Extinction Coefficients

There are three sources for kap:

1. Follow the instrumental magnitude of one star over a range of airmass during the night.
2. For several standard stars at different airmasses, compare the instrumental magnitudes against their standard magnitudes ("Hardie method"). This is done in a brief period.
3. Assume a fixed or seasonal value.

For methods 1 and 2, you are creating a graph of the sort below.



If we will be out for an extended observing run, the single-star/large-range method may be convenient. First thing in the evening, you would take deflections on a star that is either high in the sky, or low in the east. Over the course of the night, sample the star as it changes altitude, and once more before you finish. Ideally, you want samples—I like to have five—over an even distribution of airmasses. This means that you sample your extinction star more often when it is lower. A simple approximation for airmass is 1/sin(altitude). Henden and Kaitchuck provides lists of standard extinction stars for northern and southern hemisphere observers. These are fairly bright stars with a B-V color index close to 0. Why does that matter? Because stars of index 0 are essentially unaffected by second-order extinction in B band. To reduce the extinction measurements, you plot the instrumental magnitudes against airmass, and fit a line to the points, the slope of the line being the coefficient. Because magnitudes *decrease* as brightness increases, the slope of the above line, in magnitudes per unit airmass, is positive.

The disadvantage of the above method is that one needs to be taking data for an extended period, and for the extinction to stay fairly constant during that time. For some observing sites, the latter constraint is a significant problem. Most observers who face this difficulty compute a coefficient separately for every star they observe, based upon the change in extinction of the comp star during the standard sequence. I don't like this method. The twenty or thirty minute duration of the sequence will not place the comp at a significant range of airmasses, leading to noisy results. One can argue that when the star is high in the sky, the differential extinction will be quite small, so the noise is unimportant, and when the star is lower, the airmass range will improve and the noise will go down. I'm still not sure that this approach is any better than just randomly picking an extinction correction between 0 and 4 millimags (in V band), or, with more sophistication, selecting a value from 0 to 4 based upon the amount of differential airmass. In any event, the comparison star almost certainly has a nonzero B-V, introducing the possibility of a skewed estimate of the first-order B extinction.

I typically use the "Hardie" method for measuring extinction, which takes fifteen minutes or less. It depends on having reliable magnitudes in both of your filter bands for a selection of stars that are at a variety of altitudes. I use the H&K first-order extinction stars. The Hardie method is described in Astronomical Techniques, chapter 8. I have pre-selected sets of stars for each month of the year. If my observing run takes place early in the night, I can use the set for the preceding month, and if up very late, use the set for the following month. If I am running for a very long time, I might use sets from two months at different times, just to check for consistency during the night. With the Hardie method, one cannot just plot the instrumental magnitudes, for each extinction star is of different brightness. Instead, one plots the *difference* between the standard and instrumental magnitudes (V-v) against airmass. The fitted line, again, gives the extinction coefficient.

Regardless of the method you use, it is dangerous to perform the fitting calculation without generating a plot and actually looking at it. An aberrant data point can skew the results, and it may be necessary to drop one or more values. A crummy collection of points may indicate unstable extinction that night. Even a crude diagram will suffice for this safety check.

5.2 Transformation, the Easy Way

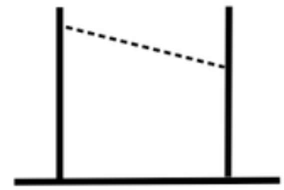
There are three methods to determine the epsilons:

1. Blue/red star pair
2. All-sky (multiple stars, range of colors)
3. Cluster (ditto)

Epsilons are established only once a year but preferably based on multiple observing runs.

What, exactly, is the purpose of transformation? In differential photometry, we measure the difference in instrumental magnitudes between two stars, Δv. That difference is unlikely to match the difference established by a "standard" photometer. In the Johnson photometric system, the results from his photometer *are* the standard. His response curve, like ours, is not flat, but we use his results as the anchor for own our work. Transformation, then, is an adjustment to our Δv so that it matches the ΔV of Johnson; or, so that $\Delta V - (\Delta v + \text{transform}) = 0$.

Let's return to our response curve of the blue-sensitive photometer:



blue sensitive

To establish the V transformation, we will measure the instrumental magnitude difference between a bluish star and a reddish star. ΔV-Δv is the shortfall (or excess) of measured difference, where $\Delta V = V_{blue} - V_{red}$, and $\Delta v = v_{blue} - v_{red}$. Looking at the response curve, we see that a star rich in blue light will fare well, but a red-heavy star will lose a significant fraction of its brightness. Since v_{red} will be more positive (dimmer) than it should be, Δv will be too negative, and $\Delta V - \Delta v$ will be greater than zero. The transformation, which is added to Δv during reduction, must, therefore, be negative.

For any given pair of stars, the amount of transformation will depend on the color contrast: less contrast = less transformation. Therefore, we normalize our measured shortfall/excess by dividing it by the color contrast, to give us a coefficient of transformation, e_V:

$$e_V = (\Delta V - \Delta v)/\Delta(B-V) \quad (*)$$

When we apply transformation to a variable/comparison combination, the correction will be $e_V \bullet \Delta(B-V)$.

So this seems simple, in practice: measure a blue/red pair. Well, not so fast—I was loose with terminology. We actually need to measure $\Delta v0$, the extinction-corrected instrumental magnitude, not Δv. Anytime we throw extinction into the mix we are adding a complication that is best avoided. The solution has been to find blue/red pairs that are very close together. When such a pair is near transit, the extinction for the two stars is very nearly the same. Since the extinction corrected magnitudes are $v_{blue} - kap_V \bullet X$ and $v_{red} - kap_V \bullet X$, the corrected differential magnitude is:

$$(v_{blue} - kap \bullet X) - (v_{red} - kap \bullet X) \quad \text{or}$$
$$(v_{blue} - v_{red}) - (kap \bullet X - kap \bullet X) \quad \text{or}$$
$$v_{blue} - v_{red}.$$

The extinction drops out. Unfortunately, bright blue/red pairs are hard to come by. The AAVSO PEP webpages list a total of 12 in both hemispheres. The standard magnitudes listed for these pairs are of varying reliability. By reputation, the Leo Minor and Orion pairs are best.

The transformation observation for a pair is an extension of the standard sequence, but with no check star. The blue star is treated as the variable, and the red as the comparison. Instead of three variable star deflections, we take seven, bracketed by eight comparison deflections. The mean Δv so obtained is used in formula (*). We take seven deflections because we want this measurement to be very reliable, and it is customary to compute the error of the seven differential magnitudes to quantify their consistency. Clearly, we want good skies for this measurement, but we do not need ideal transparency. What we need is *consistent* transparency during the sequence. The AAVSO procedure calls for conducting the sequence within one hour of transit for the pair. This minimizes differential extinction.

For pairs at high declinations, you can push the time envelope.

The formula for e_B is very similar to that for e_V, needing only a correction for second-order extinction:

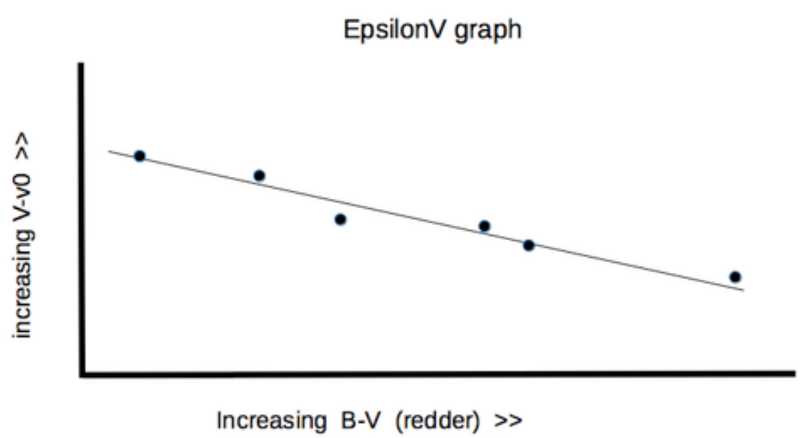
$$e_B = (\Delta B - \Delta b - X \bullet kkap_B \bullet \Delta(B-V))/\Delta(B-V)$$

Which means that you must measure second-order extinction before reducing an e_B sequence (you can still collect the e_B data beforehand). Some people use a fixed estimate of $kkap_B$ to get around this. A value of -0.04 seems common for the Optec systems.

5.3 Transformation, the Hard Way

As noted, above, blue/red pairs are hard to find, and good calibration is dependent on high-quality reference magnitudes. Further, we want Δ(B-V) to be large, and we also want Δb and Δv to be large. Satisfying all these conditions is not easy. Our alternative is an *all-sky* calibration. Here, we sample multiple standard stars of varying B-V, which usually requires us to make the measurements over a large portion of the sky. These measurements must be corrected for first-order extinction, and therein lies the rub. If your skies are not uniformly transparent in space and time, proper extinction correction may not be possible.

An all-sky or cluster calibration is illustrated below. For standard stars of varying color, the difference between the standard and extinction-corrected[4] instrumental magnitudes is plotted versus their standard color index. This measures the gap between standard and instrumental magnitudes as a function of color index, which should be linear. Epsilon is the slope of the fitted line. A cluster calibration, which uses stars in a single open cluster, has the advantage of not needing the extinction correction, making it more reliable (you should do this near transit, like the blue/red pairs). The problem is that calibration stars in the "standard" clusters are too dim for the SSP3, unless you have a monster telescope.



In the case of a star pair calibration, you are effectively doing the above fitting operation with just two points. Hence, it is important that the standard magnitudes be very reliable and the stars be as different

4 Including second-order extinction for B.

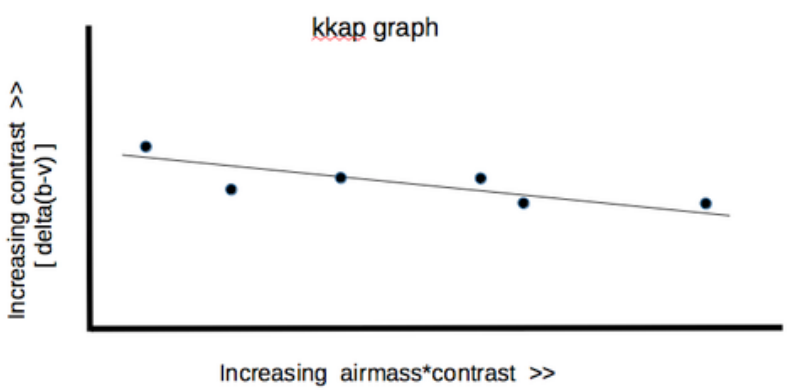
in B-V as possible. Note that when establishing e_B, a second-order extinction correction must be applied to the instrumental B magnitudes.

5.4 Second-order Extinction

For calibrating second-order extinction, we return to the blue/red pairs. Instead of observing near transit, we follow a pair from high in the sky to low. We plot the instrumental color contrast against the product of contrast and airmass. Since we deal in instrumental data, we are not dependent upon high-quality reference magnitudes for the star pair. We do need the stars to be close together, however, to minimize differential extinction. Like first-order extinction, we want the pairs reasonably evenly-spaced in airmass, and to cover as wide a range in airmass as is feasible. If your pair transits near an airmass of 1.0, you could sample them at X=1.2, 1.4, 1.6, 1.8, 2.0, and 2.2, which will come at decreasing time intervals. Your latitude, the declination of the pair, and your horizon will determine the range over which you can sample.

The coefficient is determined yearly, by plotting the instrumental contrast, Δ(b-v), versus the product of airmass and contrast, X•Δ(b-v). As the airmass increases, the contrast will decrease (the blue star will get redder, and the red star will not change much). kkap is the slope of the line fitted to the data points.

Since we revise kkap only occasionally, you might ask just what changes we are tracking. Clearly, it is not anything in the atmosphere. What we measure are changes in our friend the response curve. For instance, if we gain a little sensitivity at the blue end of the passband, second order extinction will increase.



Chapter 6 – War Stories

If you stick at the photometry business, you will eventually find yourself trying to untangle mysteries in the observational data of yourself and others. I want to at least touch on some factors that come into play in these investigations. "Debugging" differential photometry requires thinking about measurement problems in a new way.

For starters, every reduced magnitude is based upon two star measurements, not one. A magnitude problem could be caused by trouble with either measurement, or both. A latent problem could be hidden when errors cancel out, only to emerge with different targets. Let's consider variable *V* and comparison *C,* where *V* is brighter than *C*. The differential magnitude $\Delta M = M_V - M_C$ will be negative.

		C		*V*			
M:	<< dim	2.0	1.0	0.0	-1.0	-2.0	bright >>

$\Delta M = -2.0$

If we make a "hot" measurement of *V*, one that is too bright, M_V moves further to the right on our scale, and ΔM becomes more negative. This makes our reduced magnitude, $M_C + \Delta M$, more negative, brighter. But if our measurement of *C* is hot, the M_C moves closer to M_V, and ΔM becomes less negative. Our reduced *V* magnitude will become dimmer, not brighter. Conversely, "cold" measurements will have the opposite effects. As an exercise, try swapping the relative positions of *V* and *C* on the magnitude scale.

What might cause a hot measurement? An example: In 2014 I started taking B band data for the first time. One of my targets was CH Cygnus. This star was also being followed by Jerry Persha, inventor of the SSP devices. I was alarmed to see that my B band magnitudes were about 0.25 brighter than his —a very large amount—but my V magnitudes agreed well. I reduce my data with a homegrown program, so I first assumed that I had a software bug. But I couldn't find any problem with the B band code, and, furthermore, my check star magnitudes were reasonable. Jerry used the same Optec filters as I, so filter problems did not seem to be an explanation, but he suggested that I might have a "red leak" in my B filter. A filter leak allows light from outside the intended passband to reach the sensor. This will make the star appear brighter. A quick check on the catalog magnitudes of CH Cyg in increasingly red bands (left-to-right) showed:

B	V	I	J	H
8.77	**7.08**	**5.345**	**0.76**	**-0.35**

(J and H are actually near-infrared). The clue here is the huge difference between B and J: J is eight magnitudes brighter. If the blue filter were letting even a little of that light through, we could have trouble. But why wouldn't Jerry have this same problem with his filter? The answer was that he had a leak, too, but his photometer couldn't *see* it. Jerry uses an SSP5, the photomultiplier-based photometer. The photomultiplier tube was insensitive to light redder than the R band. I had an SSP3, which uses a photodiode sensor that, in principle, might detect the J band light. But how to prove this? The solution was some inventive filter-swapping by Jim Kay between an SSP3 and a near-infrared SSP4. The two-step process worked as follows: first, the JH filters from the SSP4 were installed in the SSP3, and the

SSP3 pointed at an IR-bright star. Jim confirmed that J band light was getting detected by the SSP3 sensor, even though such light was outside the nominal wavelength range of the device. Next, Jim put the BV filters on the SSP4, and confirmed that it could detect light through the B filter. The SSP4 photodiode is definitely not sensitive to B band, so near-IR must have been leaking through it. (Optec has now come out with a new B filter). Optec never saw this leak in quality-control testing, because the range of wavelengths to which the B filters were subjected did not extend to the near-IR. Observers had not noticed it because so few stars have such a huge IR excess. My check star did not have the excess, so it was unaffected.

This kind of detective story is not uncommon, and it illustrates the thought process needed to explain aberrant readings—particularly the need to think about your photometry rig as a *system* of interacting components. Other leak stories exist in the photometric history books. An interesting one took place during Nova Delphinus 2013, where certain observers where getting hot magnitudes in V band. In PEP-land, we use Optec filters almost exclusively, but the CCD observers buy their filters from a variety of sources. Each manufacturer's filters will have slightly different characteristics, compounding the difficulty of making everyone's measurements agree. In this case, the V filters from one vendor had a passband that extended too far into the red. We don't demand that all filters have identical cutoffs—that's one of the reasons for transformation. But just to the red side of V band is the location of the hydrogen-alpha emission line, which was a strong radiator in the nova. Broad-band photometry does not cope well with emission lines. A proper V filter will not pass that line, but the suspect filters had such a long tail on the red side that some of the Hά was sneaking through.

Afterword

Early in the life of the PEP group, science advisor Dr. John Percy penned some words of wisdom for the participants. Below is a sampling that is just as relevant today:

> *Photoelectric photometry should be enjoyable as well as satisfying. Don't forget what the word "amateur" means.*
>
> *There are definite advantages to working with a group on an established program or campaign. You get more feedback that way.*
>
> *Choose a program which fits your equipment, site, ability, and time available.*
>
> *Even if your site is mediocre [weather-wise], a few well-chosen observations in a night are quite worthwhile. Choose stars with relatively long periods.*
>
> *Strive for the greatest accuracy you can attain by making your observations carefully and correcting carefully for extinction, gain settings, and color effects.*
>
> *Computer acquisition...of data is acceptable, but is no substitute for careful observation.*
>
> *Keep detailed, accurate records of all aspects of your observing and data reduction procedures.*

Finally, the following comment was made in regard to working in the presence of clouds, but I think it applies to the whole practice of photometry:

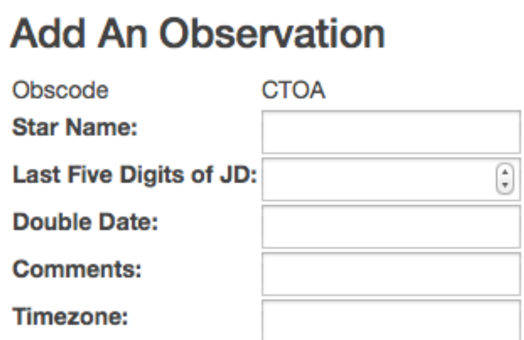
> *A dubious observation is worse than no observation at all.*

Watch the Counts!
Tom

Appendix A: WebPEP

Observations processed on the AAVSO website go through a reduction program called WebPEP. WebPEP operates in concert with two databases: a star catalog, and observer information. The catalog has coordinates, magnitudes, and color indexes for the variable, comparison, and check stars. These data are based upon the “starparm” file found on the PEP group home page. The observer database has latitude and longitude, and the V band transformation coefficient for each observer, along with a note of how eV was established.

Data for WebPEP are actually entered through a web application, PEPObs, accessed via the WebObs page under the “Data” menu of the AAVSO home page. You are presented with a form in which to enter star identification, date and time, and deflections. The “Double Date” is the pair of evening/morning civil dates for the night in question. This field is not parsed for format, it is just a note that may later be used by AAVSO staff if there is a later question about the correct date. The “Comment” field will be included in the data record stored for your observation. Your observer code is automatically populated (you must be logged-in on the AAVSO site to submit data).


Add An Observation

Obscode CTOA
Star Name:
Last Five Digits of JD:
Double Date:
Comments:
Timezone:

The form then continues with a series of cryptically-numbered lines, each having a time, count, and gain.

Time	Target	Deflection	Gain
4:25	3	1000	10
0:00	4	20	10
4:27	1	800	10
0:00	4	23	10
4:28	3	1004	10
0:00	4	21	10
4:29	1	799	10
0:00	4	18	10
4:30	3	1010	10
0:0	4	22	10
4:32	1	812	10
0:00	4	24	10
4:33	3	1007	10
0:00	4	22	10
4:35	2	750	10
4:36	4	26	10
4:37	3	1002	10
0:00	4	25	10

Add this observation to the report

The numbers refer to the following pattern: 3=comp deflection, 4=sky deflection, 1=var deflection, 2=check deflection. The sky deflections are implicitly associated with the immediately-preceding star deflection, and the time associated with a sky deflection is not used. The time format is hh:mm. Deflection counts are entered as integers, so you will round your average of three integrations.

When you "Add" the observation, some consistency checks are performed, and, if passed, the observation is added to a list at page top.

Current Report

Star Name	JD	Magnitude
ALF ORI	2457456.6870	4.289

Submit this report

You can then enter data for more stars, or submit what you have.

Below is an artist's conception of how WebPEP reduces variable star (not check) data. A preprocessing step has already computed net counts for each star deflection.

// WebPEP Pseudo-Code

```
// Parameters for observation
varStarId= “rho Cas”;           // variable
compStarId= “SAO 35761”;  // comparison
observer=”CTOA”;              // photometrist
date=2457455;                   // Julian date
float kapV=0.25;               // first-order extinction coefficient

// Data structure for deflections
Struct Deflection
{
  int netCount;        // net counts
  UTime time;         // Universal Time of deflection
}

// Program input:  4 comp deflections + 3 variable, in time-order
Deflection deflections[7];

// Data for processing one comp/var/comp tuple
Deflection compBefore, compAfter, variable;

// Processing variables
float differentialMag                          // differential instrumental magnitude
float extraAtmosphericMag                // diff. magnitude above the atmosphere
float standardDifferentialMag;           // standard diff. Magnitude (we get 3 of them)
float runningTotal;                            // sum of intermediate diff. Magnitudes
float averageDifferentialMagnitude    // average of above
float standardMagnitude                    // final reduced magnitude

//  Observer transformation coefficient
float observerEpsilonV = LookUp_Transformation(observer);

// B minus V color indexes
float compBmV= LookUp_ColorIndex(compStarId);
float variableBmV= LookUp_ColorIndex(varStarId);

// color contrast
float deltaBmV = variableBmV – compBmV;

// transformation value
float transformation = deltaBmV*observerEpsilonV;

// deflection loop index
int index=0;

// continues...
```

```
// WebPEP, continued

// Processing loop
while index < 7     //  Even-numbered deflections are comp, odd are variable
 {
   // Extract deflection data
   compBefore= deflections[index];
   variable= deflections[index+1];
   compAfter= deflections[index+2];

   ////////////////////////////////////////////////////////////////////
   //  Compute differential magnitude

   //  Start with instrumental magnitudes
   beforeMag= -2.5*log(beforeComp.netCounts);
   variableMag= -2.5*log(variable.netCounts);
   afterMag= -2.5*log(afterComp.netCounts);

   // Time-interpolate the two comparison magnitudes to the time of variable deflection
   timeSpan= compAfter.time – compBefore.time;  // change in time
   compMagChange= afterMag – beforeMag;         // change in magnitude

   // compMagChange divided by timeSpan is the slope of the line segment
   // joining the points (beforeTime, beforeMag) and (afterTime, afterMag).
   // We interpolate along this line:
  //  interpolation = beforeMag + slope*(fractionOfTimeSpan)

   slope = compMagChange/timeSpan;
   variableTimeOffset = variable.time – compBefore.time;

   interpolatedCompMag =
         beforeMag + compMagChange*(variableTimeOffset/timeSpan);

   differentialMag = variableMag - interpolatedCompMag;


  // continues...
```

```
   // WebPEP, continued

   ////////////////////////////////////////////////////////////////////////
   //  Apply extinction correction.

   // Get airmass (X) at time of variable deflection for both stars
   compX= ComputeX(compStarId, variable.time, date, observer);
   variableX= ComputeX(varStarId, variable.time, date, observer);

   differentialX= variableX – compX;
   extinctionCorrection= kapV*differentialX;

   extraAtmosphericMag = differentialMag – extinctionCorrection;

   ///////////////////////////////////////////////////////////////////////
   // Apply transformation

   standardDifferentialMag = extraAtmosphericMag + transformation;

   // remember this reduction
   runningTotal += standardDifferentialMag;

   index = index + 2;  // go to next comp/var/comp tuple
}

averageDifferentialMag = runningTotal/3;
standardMag= averageDifferentialMag + LookUp_Vmag(compStar);

return(standardMag);
```

For the check star, there is only one comp/target/comp tuple, and WebPEP does not correct the check magnitude for either extinction or transformation (I don't know why). If you go into the WebObs tool (described below) and inspect an example reduction, you find:

		Star	JD	Calendar Date	Magnitude	Error	Filter	Observer	Collapse All Expand All
☐	Edit Delete	EG AND	2456536.8201	2013 Sep. 01.32010	7.146	0.003	V	CTOA	Collapse...

Comp Star	Check Star	Transformed	Chart	Comment Codes	Notes
SAO 54074 (7.364)	SAO 54147 (7.565)	Yes	PEP	–	PEPHQ; Check: 7.5651; D(B-V)=0.735;

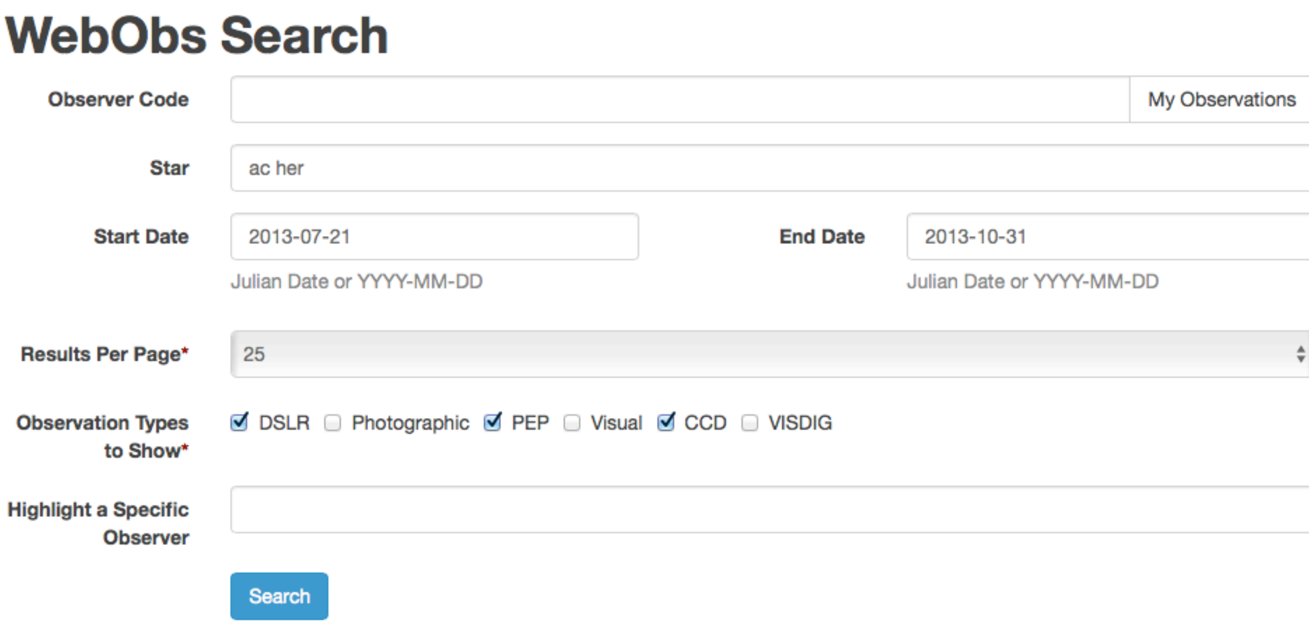
[The magnitude you see here for comp is the "catalog" magnitude. WebObs shows only highlights from the observation—to see the complete record you need to download the complete data record via file transfer.]

There are bugs in WebPEP. The most serious is that it calculates sidereal time incorrectly (fast by 18 minutes, as I recall). Another: if you succeed in collecting some *very* consistent deflections, WebPEP can report an error of 0.0 due to rounding. The program should never give an error of less than 0.001 (keep this in mind if writing your own reduction program).

Appendix B: Other AAVSO Tools

1. WebObs

WebObs provides quick access to archived data. It is found on the "Observing" drop-down menu on the AAVSO home page. The selection criteria are fairly flexible: you can enter a star, an observer, and a date range, and filter by type of observation (visual, PEP, CCD, etc). You can specify a star without an observer (all observers are selected), or an observer with no star (all the observer's stars are selected).



Example output is given, below. Note that for my own observations (CTOA), WebObs gives me the option to edit or delete the records. WebObs has a maddening fault: if you give the observer code in lower case, it will puke and demand that you re-type it in upper case.

WebObs Search Results

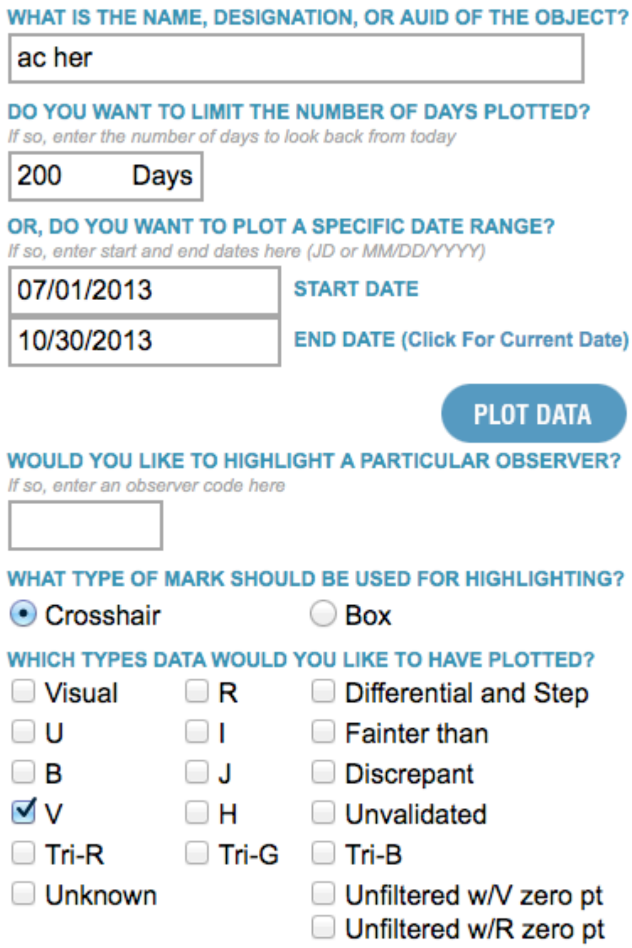
Showing *34* observations for *AC Her* from *5* observers between *July 21, 2013* and *November 1, 2013*

- Plot a Chart
- Generate a Light Curve
- Search VSX

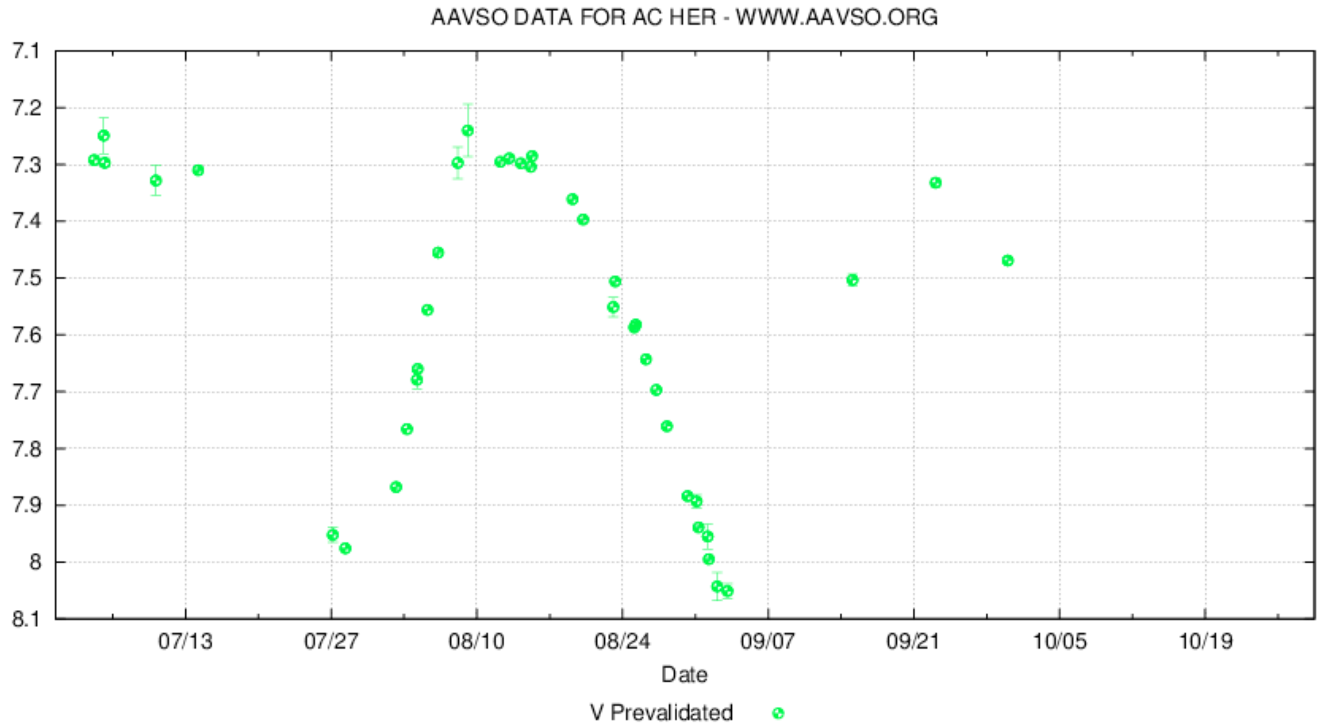
		Star	JD	Calendar Date	Magnitude	Error	Filter	Observer	Collapse All Expand All
		AC HER	2456565.52169	2013 Sep. 30.02169	7.469	0.006	V	DMPA	Details...
		AC HER	2456558.58941	2013 Sep. 23.08941	7.332	0.007	V	DMPA	Details...
		AC HER	2456550.60258	2013 Sep. 15.10258	7.503	0.010	V	DMPA	Details...
		AC HER	2456538.58684	2013 Sep. 03.08684	8.051	0.013	V	DMPA	Details...
		AC HER	2456537.59764	2013 Sep. 02.09764	8.043	0.025	V	KSQ	Details...
	Edit Delete	AC HER	2456536.7938	2013 Sep. 01.29380	7.995	0.003	V	CTOA	Details...
		AC HER	2456536.68439	2013 Sep. 01.18439	7.955	0.022	V	KSQ	Details...
	Edit Delete	AC HER	2456535.7986	2013 Aug. 31.29860	7.939	0.003	V	CTOA	Details...
		AC HER	2456535.61084	2013 Aug. 31.11084	7.893	0.012	V	KSQ	Details...
	Edit Delete	AC HER	2456534.7384	2013 Aug. 30.23840	7.884	0.002	V	CTOA	Details...
	Edit Delete	AC HER	2456532.7674	2013 Aug. 28.26740	7.761	0.005	V	CTOA	Details...
	Edit Delete	AC HER	2456531.7440	2013 Aug. 27.24400	7.697	0.002	V	CTOA	Details...
	Edit Delete	AC HER	2456530.7437	2013 Aug. 26.24370	7.643	0.001	V	CTOA	Details...
		AC HER	2456529.7750	2013 Aug. 25.27500	7.582	0.005	V	CCB	Details...

2. Light Curve Generator

To see plotted magnitudes, you will use the Light Curve Generator (LCG), which is found under the "Data Access" option of the "Data" drop-down menu on the AAVSO home page.



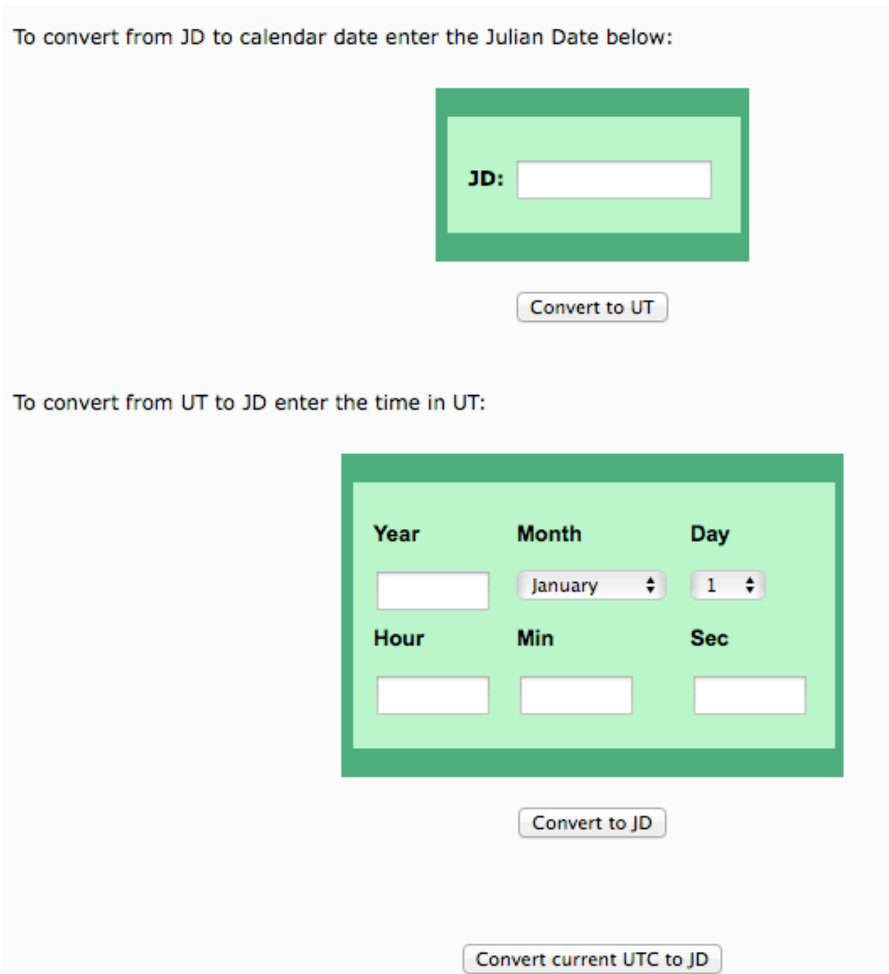
Note the differences between WebObs and LCG: LCG allows filtering by photometric band, WebObs does not. LCG does not allow filtering by sensor technology (PEP, CCD, photographic), WebObs does. Finally, LCG and WebObs use different formats for civil dates. When you first enter LCG, the parameters are set for a 200-day curve ending at the current JD. The "current" JD does not automatically update for subsequent curve requests—if you return to the LCG page the next day and make another plot, you will not see observations from the night before. If your magnitudes from last night are not showing up in the curve, this may be why. Click on "End Date" to get the latest JD.



The plot is accompanied by a list of the contributing observers.

3. JD calculator

There is a handy utility for translating to/from Julian Date. It is found on the "Observing" drop-down menu of the AAVSO home page.



4. VSP

The Variable Star Plotter generates charts and photometry tables. With a GOTO scope, you won't have much need for the former, but we sometimes want a table of "approved" comparison stars. An example table is created below. Unfortunately, there is no way to translate the nine-character AAVSO identifiers for the stars to HD or HR numbers. If you use such a table, keep track of the associated "sequence" number, so that it can be exactly reconstructed in the future.

PLOT A QUICK CHART

WHAT IS THE NAME, DESIGNATION OR AUID OF THE OBJECT?

ac her

Required if no coordinates are provided below

RIGHT ASCENSION

Allowed Formats: HH:MM:SS, HH MM SS, DDD.XXXX. Required if no name is given above

DECLINATION

Allowed Formats: ±DD:MM:SS, ±DD MM SS, ±DD.XXXX. Required if no name is given above

CHOOSE A PREDEFINED CHART SCALE

C (120arcmin)

A is larger, slower; G is smaller, faster

CHOOSE A CHART ORIENTATION

(•) Visual ( ) Reversed ( ) CCD

PLOT A FINDER CHART OR A TABLE OF FIELD PHOTOMETRY? *

( ) Chart (•) Photometry

CHART ID

A Chart ID will allow you to reproduce prior charts. Overrides all other fields in this form.

Plot Chart Clear Form

partial results...

Field photometry **for ac her** from the AAVSO Variable Star Database

Data includes all comparison stars within 1.0° of RA: **18:30:16.24 [277.56766667°]** & Dec: **21:52:00.6 [21.86683333°]**

Report this sequence as **X16073N** in the chart field of your observation report.

AUID	RA	Dec	Label	V	B-V	Comments
000-BJS-873	18:31:44.94 [277.93725586°]	21:54:08.4 [21.90233421°]	**69**	6.917 (0.032)[1]	1.157 (0.057)	BINO_COMP
000-BCC-539	18:30:58.98 [277.74575806°]	21:39:17.0 [21.65472221°]	**74**	7.404 (0.032)[1]	1.057 (0.057)	BINO_COMP,NSV 10958 Do Not Use For CCD
000-BJS-875	18:29:51.42 [277.46426392°]	22:00:40.0 [22.01111031°]	**82**	8.237 (0.032)[1]	0.214 (0.058)	BINO_COMP
000-BKS-256	18:33:54.08 [278.4753418°]	21:49:38.8 [21.82744408°]	**85**	8.524 (0.020)[12]	0.138 (0.031)	BINO_COMP
000-BJS-876	18:29:58.73 [277.49472046°]	21:31:23.5 [21.52319527°]	**88**	8.810 (0.033)[1]	0.111 (0.059)	BINO_COMP
000-BCC-459	18:29:17.03 [277.32095337°]	21:48:52.9 [21.81469345°]	**89**	8.862 (0.012)[17]	1.161 (0.047)	
000-BKS-194	18:30:58.88 [277.74533081°]	21:29:34.2 [21.49283409°]	**90**	8.989 (0.033)[1]	0.511 (0.060)	BINO_COMP
000-BKS-195	18:33:33.95 [278.39144897°]	21:56:40.7 [21.94463921°]	**93**	9.255 (0.034)[1]	0.625 (0.062)	BINO_COMP

5. VSX

The Variable Star Index is the master AAVSO catalog of variable stars. It is found on the "Variable Stars" drop-down menu on the AAVSO home page. Stars get listed here based upon reports in the scientific literature, and a caveat is in order: some reports are more reliable than others. The reports are listed under "References." If the only reference is from the pre-electronic era (say before 1950), I regard it with skepticism. Be on the lookout for stars of "CST" variability type—they are stars once thought variable, but now considered "constant." The "External Links" lead to a cornucopia of other information, including Hipparcos light curves.

Search VSX

Special searches Changes in last week... » Go

Select a Special search above, or enter information in the fields below, then click **Search**.

Name ac her

Examples: SS Cyg, V456 Sgr, NSV 1009
%And, ASAS %+%, Mis V%
Search by AUID also available

» **Capture coordinates for object to Position field**

Const. --

Filters search results by boundaries of selected constellation

Include ☑ V **Variables** ☑ S **Suspects** ☑ N **Non-variables**

Order by GCVS sequence ☐ **Descending**

Click **More** for coordinate-based searches.

More | Clear | Reset | Search

Name	V **AC Her**	
AAVSO UID	000-BCC-490 (40636 observations)	
Constellation	Hercules	» **Sequence**
J2000.0	18 30 16.24 +21 52 00.6 (277.56767 +21.86683)	» **Search nearby**
B1950.0	18 28 09.09 +21 49 53.2	
Galactic coord.	50.493 +14.241	
Other names (Internal only)	*Please note that aliases shown in grey link to obsolete records.* AAVSO 1826+21 · ASAS J183016+2152.0 · BD+21 3459 HD 170756 · HIP 90697 · HV 3588 SAO 86134	(Not logged in) » Add name
Variability type	RVA	
Spectral type	F2pIb-K4e(C0,0)	
Mag. range	6.85 - 9.0 V	
Discoverer	--	
Epoch	06 Apr 2006 (HJD 2453831.8)	» **Ephemeris**
Outburst	--	
Period	75.29 d	
Rise/eclipse dur.	--	

Remarks

Some references may be clicked to view in new window. Roll over index number to view submission details.

1	GCVS Team	P var. The Table gives current elements valid since JD2442000. Mean P = 75.4619d [V.P.Zessewitsch, Astron. Tsirk. N128, 1952.]. The magnitude in Max varies with Delta(m) = 1.6m **[C.Payne-Gaposchkin, V.K.Brenton, S.Gaposchkin, HA 113, N1, 1943.]**.

(Not logged in) » Add remark

References

Click reference title/citation to view in new window. Roll over index number to view submission details.

1	**Beobachtungen veranderlicher Sterne**	Trudy Tashkentskoj Astronomicheskoj Observatorii, vol. 1, pp.33-86
2	**G.Pojmanski, Acta Astronomica 52, 397, 2002.**	2002AcA....52..397P
3	**M.Nakagiri, Y.Yamashita, Tokyo Bull, ser. II, N260, 1979.**	1979IBVS.1565....1N
4	**C.Payne-Gaposchkin, V.K.Brenton, S.Gaposchkin, HA 113, N1, 1943.**	1943AnHar.113....1P

External Links

Links open in a new window. Not all links may be valid for this particular target.

Location -- Select -- » Go Select a **Location** for more details.

Be aware of a quirk in naming conventions. Looking up "mu Cep" in VSX will get you MU Cep, not μ Cep. Likewise "nu Cep" returns NU Cep, not ν Cep. VSX uses "miu" for μ and "niu" for ν. I have seen some tools that use "mu." and "nu." for these designations.

Appendix C: References

<u>Books:</u>

Photoelectric Photometry of Variable Stars, Hall & Genet; especially chapters 9-14.
Astronomical Photometry, 2^{nd} edition, Henden & Kaitchuck; esp. chapter 4, appendices G, H.
Software for Photometric Astronomy, Ghedini
Astronomical Techniques, various authors; chapter 8 on PEP reductions by Hardie
SSP3 Generation 1 Technical Manual, Optec Corp.
SSP3 Generation 2 Technical Manual, Optec Corp.
SSP5 Generation 2 Technical Manual, Optec Corp.

Photoelectric Photometry is readily available on the used market, and *Astronomical Photometry* is still in print. The former is more approachable, but both spend a lot of time discussing pulse-counting systems. *Software* and *Astronomical Techniques* are harder to come by, but there exists a digital scan of the latter floating around AAVSO. Generation 2 SSP manuals are available on the Optec website (http://optecinc.com). The Generation 1 SSP3 manual can be found at the Internet Archive (http://archive.org). I can't locate a Gen. 1 SSP5 manual. A word of caution as you start exploring outside of this document: historically, photometrists have worked a lot with V, B-V, and U-B in place of V, B, and U. This had certain advantages, but required different math (eg: the transformation coefficient for B-V is mu (μ), and for U-B is psi (ψ)).

<u>Websites:</u>

http://obswww.unige.ch/gcpd/indexform.html GCPD main index
http://simbad.u-strasbg.fr/simbad/sim-fbasic SIMBAD main index
http://www.aavso.org AAVSO home page
http://www.aavso.org/content/aavso-photoelectric-photometry-pep-program PEP home page

Appendix D: PEP Program Stars

Stars known to the WebPEP reduction system are found on the PEP home page, under "Current list of target, comparison, and check stars." Below is a summary of the list, including SIMBAD descriptions. The WebPEP configuration file, unfortunately, departs from standard variable star nomenclature in some cases, because it was set up to use only upper-case characters for star identification. Thus, the star MU Cep is actually mu (μ) Cep, NU Tuc and NU Vir are nu (ν) Tuc and nu Vir, and D Ser is d Ser. The table below is given in order of right ascension.

```
star           SIMBAD description
----------------------------------------------------
YY PSC      Long Period Variable candidate
AD CET      Long Period Variable candidate
KHI PEG     Variable Star
T CET       S Star
TU CAS      Variable Star of W Vir type
AG CET      Semi-regular pulsating Star
TV PSC      Semi-regular pulsating Star
EG AND      Symbiotic Star
NSV 293     Semi-regular pulsating Star
NSV 305     Pulsating variable Star
BQ TUC      Long Period Variable candidate
GAM CAS     Be Star
WW PSC      Long-period variable star
CC TUC      Long-period variable star
V442 AND    Be Star
AR CET      Semi-regular pulsating Star
NSV 15429   Star
WZ PSC      Semi-regular pulsating Star
AV ARI      Semi-regular pulsating Star
NSV 748     Variable Star
OMI CET     Variable Star of Mira Cet type
NSV 805     Variable Star
ALF UMI     Classical Cepheid (delta Cep type)
15 TRI      Pulsating variable Star
Z ERI       Semi-regular pulsating Star
RR ERI      Semi-regular pulsating Star
RZ ARI      Semi-regular pulsating Star
EH CET      Semi-regular pulsating Star
RHO PER     Semi-regular pulsating Star
BET PER     Eclipsing binary of Algol type (detached)
NSV 1273    Variable Star of delta Sct type
PI ERI      Long Period Variable candidate
NSV 1316    Variable Star
BE CAM      Long-period variable star
X PER       High Mass X-ray Binary
NSV 1558    Variable Star
V1142 TAU   Long Period Variable candidate
OMI1 ORI    S Star
NSV 1777    Variable Star
EPS AUR     Eclipsing binary of Algol type (detached)
ZET AUR     Eclipsing binary of Algol type (detached)
V398 AUR    Variable Star of gamma Dor type
WZ DOR      Semi-regular pulsating Star
CE TAU      Semi-regular pulsating Star
WX MEN      Long Period Variable candidate
V725 TAU    High Mass X-ray Binary
UPS AUR     Variable Star
ALF ORI     Red supergiant star
PI AUR      Long-period variable star
SW PIC      Long Period Variable candidate
SS LEP      Symbiotic Star
ETA GEM     Spectroscopic binary
UW LYN      Long Period Variable candidate
NSV 2912    Variable Star
mu GEM      Eclipsing binary of beta Lyr type (semi-detached)
IS GEM      Semi-regular pulsating Star
V614 MON    Semi-regular pulsating Star
BQ GEM      Semi-regular pulsating Star
UY LYN      Long Period Variable candidate
EW CMA      Be Star
OME CMA     Be Star
NSV 3469    Variable Star
```

NSV 3486	Variable Star
NSV 3485	Variable Star
NSV 3550	Variable Star
RU CAM	Variable Star of W Vir type
U MON	Variable Star of RV Tau type
VZ CAM	Semi-regular pulsating Star
UPS GEM	Variable Star
NZ GEM	S Star
BET GEM	High proper-motion Star
DU LYN	Semi-regular pulsating Star
NSV 3741	Variable Star
BC CMI	Semi-regular pulsating Star
BL CNC	Long-period variable star
NSV 17814	Eclipsing binary of Algol type (detached)
BP CNC	Semi-regular pulsating Star
NSV 4093	Variable Star
AK HYA	Semi-regular pulsating Star
PI2 UMA	Star
BO CNC	Long Period Variable candidate
X CNC	Semi-regular pulsating Star
FZ CNC	Semi-regular pulsating Star
RHO UMA	Variable Star
RS CNC	S Star
NSV 4429	Variable Star
IN HYA	Semi-regular pulsating Star
LAM LEO	Variable Star
NSV 4510	Variable Star
NSV 4506	Variable Star
NSV 4545	Spectroscopic binary
PSI LEO	Variable Star
PI LEO	Variable Star
U UMA	Variable Star
NSV 4829	Spectroscopic binary
NSV 4936	Variable Star
RX LMI	Semi-regular pulsating Star
ETA CAR	Blue supergiant star
VY UMA	Carbon Star
VY LEO	Long Period Variable candidate
VW UMA	Semi-regular pulsating Star
NSV 5059	Variable Star
CO UMA	Long-period variable star
NSV 5107	Variable Star
V535 CAR	Long-period variable star
OME VIR	Long-period variable star
VX CRT	Semi-regular pulsating Star
nu VIR	Semi-regular pulsating Star
TV UMA	Semi-regular pulsating Star
GK COM	Semi-regular pulsating Star
FW VIR	Semi-regular pulsating Star
NSV 5947	Variable Star
PSI VIR	Long-period variable star
TU CVN	Semi-regular pulsating Star
NSV 6046	Variable Star
FS COM	Semi-regular pulsating Star
SW VIR	Semi-regular pulsating Star
FH VIR	Semi-regular pulsating Star
CL CVN	Long-period variable star
FP VIR	Semi-regular pulsating Star
EV VIR	Semi-regular pulsating Star
FS VIR	Long Period Variable candidate
CY BOO	Semi-regular pulsating Star
CI BOO	Long-period variable star
W BOO	Semi-regular pulsating Star
RR UMI	Semi-regular pulsating Star
TAU4 SER	Semi-regular pulsating Star
ST HER	S Star
V368 NOR	Semi-regular pulsating Star
AT DRA	Long-period variable star
NSV 7676	Variable Star
V2105 OPH	Semi-regular pulsating Star
ALF SCO	Double or multiple star
NSV 7896	Variable Star
AZ DRA	Long-period variable star
V884 SCO	High Mass X-ray Binary
VW DRA	Semi-regular pulsating Star
NSV 8556	Variable Star
V642 HER	Semi-regular pulsating Star
V449 SCO	Star
NSV 9800	Variable Star
V533 OPH	Semi-regular pulsating Star
V2388 OPH	Eclipsing binary of beta Lyr type (semi-detached)
V441 HER	Semi-regular pulsating Star
V2048 OPH	Be Star
V2118 OPH	Variable Star of gamma Dor type
V669 HER	Variable Star

KAP LYR	Variable Star
V4028 SGR	Semi-regular pulsating Star
NSV 24420	Variable Star
V2291 OPH	Eclipsing binary of Algol type (detached)
d ser	Double or multiple star
AC HER	Variable Star of RV Tau type
XY LYR	Long-period variable star
DEL SCT	Variable Star of delta Sct type
V3879 SGR	Semi-regular pulsating Star
NSV 11271	Spectroscopic binary
V4405 SGR	Semi-regular pulsating Star
CX DRA	Be Star
R SCT	Variable Star of RV Tau type
NSV 11536	Spectroscopic binary
R LYR	Semi-regular pulsating Star
CH CYG	Symbiotic Star
V2365 CYG	Eclipsing binary of Algol type (detached)
V973 CYG	Semi-regular pulsating Star
KHI CYG	S Star
V395 VUL	Be Star
NSV 12759	Variable Star
V2008 CYG	Variable of RS CVn type
V4434 SGR	Long-period variable star
NSV 12981	Variable Star
P CYG	Blue supergiant star
NSV 13076	Variable Star
EU DEL	Semi-regular pulsating Star
U DEL	Semi-regular pulsating Star
EN AQR	Long-period variable star
NSV 13408	Variable Star
NSV 13419	Double or multiple star
V832 CYG	Be Star
NSV 13454	Variable Star
FZ CEP	Semi-regular pulsating Star
V1070 CYG	Semi-regular pulsating Star
V426 CEP	Long-period variable star
SX PAV	Semi-regular pulsating Star
BET CEP	Variable Star of beta Cep type
AB CYG	Semi-regular pulsating Star
W CYG	Semi-regular pulsating Star
NSV 13834	Double or multiple star
V1339 CYG	Semi-regular pulsating Star
mu CEP	Semi-regular pulsating Star
HK LAC	Variable of RS CVn type
AR LAC	Variable of RS CVn type
DM CEP	Long-period variable star
BO OCT	Semi-regular pulsating Star
RW CEP	Semi-regular pulsating Star
DEL CEP	Classical Cepheid (delta Cep type)
V412 LAC	Red supergiant star
nu TUC	Long Period Variable candidate
NSV 14213	Pulsating variable Star
LAM AQR	Long-period variable star
IM PEG	Variable of RS CVn type
EW LAC	Be Star
V509 CAS	Semi-regular pulsating Star
OMI AND	Be Star
V342 PEG	Ellipsoidal variable Star
KX AND	Be Star
SZ PSC	Variable of RS CVn type
KHI AQR	Semi-regular pulsating Star
NSV 14484	Variable Star
DR TUC	Long-period variable star
HW PEG	Long Period Variable candidate
NSV 26113	Variable Star
LAM AND	Variable of RS CVn type
NSV 14679	Variable Star
TX PSC	Carbon Star
HH PEG	Long Period Variable candidate
PHI PEG	Semi-regular pulsating Star
SAO 91548	Star
XZ PSC	Long-period variable star
RHO CAS	Semi-regular pulsating Star
II PEG	Variable of RS CVn type
NSV 26170	Variable Star