Assignment 3: Photometry

Due: Dec. 9

Value: 0% (AST326), 0% (AST325); this is part of your project

This assignment is to help guide you through the reductions and analysis portion of your project. Some of the material (especially on photometric calibration) is taken from the lab exercise in photometry that I did in my undergrad at the University of Victoria.

The photometric calibrations section only works properly if you have good data. If you attempted to tie DV Psc to the standard stars on a non-photometric night, you could wind up with very poor results.

1 Choice of Objects

Before observing, prepare coordinates and finder charts for all objects you may observe. You must be able to verify the pointing of the telescope based on your charts.

Your science target is the variable star DV Psc.

Your extinction standard targets may be drawn from either the Landolt standards or the Stetson standards. Seek the respective papers plus an online source for the standard stars in the catalogues. Identify many fields which contain groups of differently coloured stars (at least $\Delta(B-V) > 0.5$) that will fit on one CCD frame. From this set, identify fields which will be at several airmasses ($X \sim 1.0, X \sim 1.5, X \sim 2.0$) while you observe. Be ready with multiple fields in case you do not observe your standards when you expect to- you may wish to bring a copy of the Landolt paper with you to the telescope so that you can choose new fields on the fly if your original choices are inappropriate (the Landolt paper is filled with handy finder charts).

2 Observations

Collect biases (5-10), and flatfields for each filter. Collect dark frames for your flatfields and object frames. If the temperature is changing rapidly, you will need to take dark frames more frequently.

On a non-photometric night, observe only DV Psc. Choose the field so that several reasonably bright non-variable stars near DV Psc are observed as comparison stars. Get good time coverage of the eclipses by taking repeated exposures until the object sets. Ensure that your field does not drift too much as you observe. Adjust your exposure time so that your peak counts are high, but still well below saturation- aim for perhaps peak values of 1/2 of saturation.

On a photometric night, observe DV Psc in all filters, and observe standard fields in all filters at airmasses from 1.0 to 2.0 or more. The more standard fields you have, the more recourse you have in case some of the standards observations are bad; most people are comfortable using four to six well-populated standard fields. You may wish to take triplicate images- that way, if a cosmic ray or another nasty error hits your star on one image, you'll be able to reject it based on the other two images.

Remember to describe all the vital statistics of your observations in your report- dates, times, conditions, filters, equipment, and approximate exposure times.

3 Analysis

1. If using Canon camera images, split them into their R, G (V-like), and B components. To do this, click the RGB button in MaximDL to convert the frame to a colour image, then click the split button (grayed out until you have converted to colour) to make the R, G, and B frames. Save them all. [If you are good with Visual Basic, you may be able to write a script to do this automatically- providing this script would be a great way to earn some more marks.]

2. If you want to give your frames a WCS coordinate system so that you can use α and δ (instead of pixel coordinates) to locate your targets when doing photometry with IRAF, run Visual Pinpoint on your frames. Then copy them off the dome computer to downstairs.

3. Preprocess all your CCD frames. You may use the ccdproc package, but make sure you check what it is doing- sample images, appropriately scaled, can show you (and your marker) whether you are doing a good job.

4. Measure instrumental magnitudes (2.5log(counts in ADU) + IRAF's default zeropoint) for the stars of interest on all your frames. You may use qphot, or you may read up on daophot's PSF fitting measurement method; how is the PSF fitting technique better, especially in the case of a crowded field? Can you tell how the error on the magnitudes is estimated? Describe how you performed the measurements and why you set the parameters to the values you did.

5. On your photometric data, perform a photometric calibration. This consists of performing the following corrections (either by hand, or by using a set of scripts like IRAF's photcal package, but in any case, make sure you can answer the questions about the nitty-gritty details):

   (a) Exposure time: The instrumental magnitudes are not corrected for the different exposure times. To correct them to a common 1 sec. exposure, add 2.5log(t) where t is the exposure time in seconds. (How would you derive this?)

   (b) Zero point: In the absence of other corrections, this constant must be added to the 1 sec. instrumental magnitudes to get true magnitudes. It is different for each filter, and although it is close to constant in time, we redetermine it for each individual night to get the best calibration. What is the physical meaning of the zero point?

   (c) Colour term: Your CCD and filter are unlikely to exactly match the quantum efficiency and transmission curve of the standard bandpasses. For example, what happens if a red star and a blue star both have the same true B magnitude, but your CCD/filter combination is slightly more sensitive in the red than the standard B bandpass? How will the instrumental magnitudes you observe differ?

   (d) Extinction: A measure of the amount of atmospheric absorption with no clouds. The amount of absorption is proportional to the airmass of a star at the time of its observation. The extinction coefficient (absorption in magnitudes per airmass) is strongly dependent on the wavelength of absorption.

   The transformation equations show how one uses these corrections to convert from the 1 sec. instrumental magnitudes *ubvri* to the true apparent magnitudes *UBVRI* (you may not have used a five filter system, in which case you don't use the irrelevant equations):

   $$U = u+\alpha_U(U-B)-k_U secz+\zeta_U B = b+\alpha_B(B-V)-k_B secz+\zeta_B V = v+\alpha_V(B-V)-k_V secz+\zeta_V R = r+\alpha_R(V-R)-k_R$$

   where the α values are colour terms, the k's are extinction coefficients, and the ζ values are zero points. Why do the colour terms get multiplied by a colour, and why do the extinction coefficients get multiplied by an airmass?

   Subtracting some of the equations from other ones gives colourized forms (why are these useful, especially in slightly cloudy conditions?):

   $$U-B = \alpha_{u-b}(u-b)-k_{u-b}secz+\zeta_{u-b}B-V = \alpha_{b-v}(b-v)-k_{b-v}secz+\zeta_{b-v}V-R = \alpha_{v-r}(v-r)-k_{v-r}secz+\zeta_{v-r}R-I = \alpha$$

   together with a single unmodified equation from the original set to tie the colours to the true apparent magnitudes:

   $$V = v + \alpha_V(B-V) - k_V secz + \zeta_V$$

   The first step in solving these equations is to determine the colour terms α. If the stars that you observed at each airmass cover a wide range of colour, you can plot B-V against b-v, V-v against B-V, V-R against v-r, etc., and use a least squares fit to determine the α_{b-v}, α_V, α_{v-r}, etc.

   If you use all your Landolt stars at once, what will happen? Why might it be a good idea to calculate the α's of each field separately, then average or median the results? (Derive how a least squares fit gives you the colour terms by showing how the transformation equations can be reduced to the form y=mx+b in the case where all the stars are at the same airmass. What is m and what is b here? How good was your fit?) How is the determination of the colour terms affected by small amounts of "grey" cloud? What if the cloud was coloured?

   The next step is to determine the extinction coefficients (this requires photometric conditions). First, derive how the transformation equations can be reduced to the form y=mx+b now that we know the colour terms (y, x, m, and b are now different than they were when you were doing the colour terms- what are they now?). Plot $(B-V)-\alpha_{b-v}$ against sec z, and $V-\alpha_V(b-v)$ against sec z, etc., and determine the extinction coefficients by least squares fitting. If this analysis works, then the zero points will also fall out of the least squares fit above.

If you use these extinction coefficients to correct the data to a common airmass in the colour terms determination above, you may be able to iteratively improve your calibration.

An alternate method for obtaining extinction is to follow one field of stars as they rise or set, tracking the changes in magnitude with airmass for each star. What are the pros and cons of this alternate method for deriving the corrections in the transformation equations?

Finally, now that you have your calibration coefficients (how good are they?), use them with the transformation equations to derive the true apparent magnitudes of DV Psc.

6. On your series data where you repeatedly imaged DV Psc over a few hours, perform differential (relative) photometry in all filters for which you have data:

   (a) Even though you can't determine true apparent magnitudes on a cloudy night, you can still do a good job of determining how much the magnitude of a target star changes over that night. This is because all the neighbouring stars will be dimmed by the same amount if the cloud is big relative to the telescope's field of view.

   (b) Choose a few "comparison stars" on your DV Psc field. We are going to assume that the sum of the flux from these stars is constant in time. Why should this be a reasonable assumption (what stars should you never knowingly pick as comparison stars)? You should choose fairly bright (but nowhere near saturated) comparison stars- why? How would adding measurements of lots of faint stars affect the signal-to-noise ratio of your measurement of the sum of the flux?

   (c) Plot the instrumental magnitudes of your comparison stars as a function of time. Can you point out any times when a moderate layer of cloud passed overhead?

   (d) Plot the FLUXES (arbitrary units, but recall the conversion between flux and magnitude) of your comparison stars and of DV Psc, and the sum of the fluxes of your comparison stars.

   (e) At each epoch of observation, divide the fluxes of your comparison stars and of DV Psc by the sum of the fluxes of your comparison stars. Plot the results of this pointwise division. Explain what this correction did. Are any of your comparison stars obvious variables? Did you see eclipses of DV Psc? Can you estimate the uncertainty in your differential photometry? How does this compare with the uncertainties in your magnitudes from your photometric calibrations? If you got a good photometric calibration, normalize your corrected fluxes to be equal to 100% at the instant you did your photometric calibration. Then, convert your fluxes to true apparent magnitudes using your photometric calibration. How does the magnitude at maximum light compare with the literature values?

   (f) What are the percentage depths of the primary and secondary eclipses? What is the orbital period of the system? What other parameters, and what science about the system, can you extract? Compare your values with values available in the literature. Are your results consistent? If not, are there any reasons why?