Astronomy 16 – Astrophysics: Stars, ISM, and Galaxies
Fall 2018
Lab 4
Tuesday, November 20

Relative Photometry with Data from the Peter van de Kamp Observatory: Measuring Properties of an Eclipsing Binary

Introduction and Outline

In this lab you will reduce a stack of images of an eclipsing binary and the stars in the surrounding field and then “do photometry” on the binary in order to produce a plot of its relative flux as a function of time, known as a light curve (with one point for each image). The data you will use were taken during several eclipses of this binary system, with at least one primary and one secondary eclipse each. (It will be up to you to figure out which is which!)

This lab assumes familiarity with the techniques for image reduction (see documents from Lab 2). You will do some (but not all!) of the same things for your images of the binary that you did for your Ring Nebula images – apply biases, darks, and flats in AIJ. But you will not align the images in the stack or colorize them.

Data reduction

Preferably before coming to lab, put the raw eclipsing binary data plus calibration files on your computer. They are available here:

http://astro.swarthmore.edu/astro16/labs/eb-lab/

You will find one (large) zip archive with raw data for one night, and two smaller files with reduced data from two other nights. Download all three, and we’ll start with the larger one with raw data. Unpack that zip archive and run the AIJ data processor to produce a set of reduced images (in the “pipelineout” folder). Note that there is data from only one filter. And also

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1 Developed by D. Cohen, E. Jensen, & K. Daniel
note that the flats are in the calibration folder along with the biases and the darks.

The outline of the lab then will be to measure the sky-subtracted brightness of the binary relative to a chosen set of comparison stars in the field in each image and then to plot that relative flux vs. time to produce an eclipse light curve. We’ll then some properties of the binary.

**Photometry procedure**

You will start with the reduced images in the pipelineout folder.

In *AIJ*, open all the images together as a virtual stack: File → Import → Image Sequence, navigate to the folder with the reduced data and make sure “virtual stack” is checked (see image on the next page). In this case, you shouldn’t have to enter any particular filename pattern since you will be using all the files in the folder. (If you have other files in this folder you’d have to use this feature to import the correct files.)

![Sequence Options window](image)

Number of images: 223
Starting image: 1
Increment: 1
Scale images: 100%
File name contains: or enter pattern:
Convert to RGB: 
Sort names numerically: 
Use virtual stack: 
2048 x 2048 x 223 (3568.0MB)

Optionally, scroll through the stack to see if any images are cloudy, affected by airplane trails, etc. If so, you may want to delete those images. To delete them, you can either delete the underlying file from the folder, or
you can use the button with the red “X” (the leftmost button in the row at the top of the image display window - shown in the image below). If you delete the file itself, you may want to close the stack and reopen it. (You may choose to leave a questionable image in the stack, but make note of it. After you produce your light curve you can track down suspicious looking data points...which very well may turn out to come from the images you flagged.)

Note in this case, the image has north at the bottom (see yellow and green arrows/compass at upper left of the image). It's not strictly necessary to fix
this, but it will be convenient to do so. So, use the View → Invert Y menu option and then you should see North up and East to the left. Once you set this once in your AJL installation (which you might have done already in a previous lab) the setting will be remembered for subsequent sessions.
To figure out which star is our target, use the *Tapir* finding chart tool at http://astro.swarthmore.edu/finding_charts.cgi. Enter the coordinates of our target and press “Submit”.

Compare the finding chart to your image, and figure out which star is the target star. It may or may not be exactly centered in the field of view, depending on how the observations were set up.

Next we examine the image to see if any stars are saturated, especially the target star. You can do this by moving the mouse around and pointing it to stars. You will see a field labeled "Peak" at the top right. Any value around 60,000 counts or above is probably saturated. The brightest looking stars are the most likely to be saturated. Take a minute to scan around and look at the “peak” values for the brightest stars in this image and convince yourself that none of the stars appear to be saturated.
Here it appears that the target star in this image (center left with a faint circle around it) has well below 60,000 counts. Even the bright star in the lower right of the image doesn't have a count level that approaches 60,000.

Now that we have opened our reduced images in a stack, identified the target star, and noted any saturated stars, we’re almost ready to do our photometry.

*Photometry* is the quantitative measure of brightness of an object in an image.
The *AIJ* photometry software will (1) draw circles around the target and a number of user-chosen comparison stars, (2) sum up the counts inside each circle, and (3) draw an annulus (ring) around the circle and sum up counts in that. The total counts from the outer ring allow the software to calculate a working estimate for number of background counts per area from the sky. Then the background counts will be subtracted from the source counts (the number of counts in the circle around the star). In this way, the software computes the number of background-subtracted source counts for each user-specified star in each image.

In order to determine the optimal circle (or *aperture*) size, we will want to examine the radial profiles of some of the stars in the image. To do this, alt-click on the star of your choice. This will produce a plot of the *radial profile* of the star, i.e. a plot of pixel counts as a function of radius from the center of the star. *AIJ* will also choose some aperture size to encompass the starlight, and some radii farther out for measuring the sky. These are denoted “source” and “background” as shown in the image on the next page.
If you click the Save Aperture button these values will be remembered for when you do the photometry. You should do this...unless things look weird (e.g. the source doesn't look peaked; this one here doesn't actually look so great, but I'm using it).

Now we are ready to do the photometry.

Click the icon in the toolbar at the top of the image display window that shows two red circles with light blue interiors (but without anything else overlaying the circles - see the image below). If you hover over this, it will say "perform multi-aperture photometry."
This will pop up a dialog that allows you to set various parameters for the photometry. You should see that the aperture radii listed there are the ones derived from the seeing profile above; you can tweak them here if you want, but you probably shouldn't need to. In fact, after you make sure your check boxes are set as shown in the image below, you probably don't have to change anything at all in this dialog. The one exception may be the “First slice” parameter, which you might want to have set to 1.

You will next click the “Place Apertures” button, and then on the image stack window, you’ll click on the target star, and then ten or so stars of
similar brightness. These will be your potential comparison stars. You want stars that are relatively bright, but not saturated. Remember, you can hover over a star to see its peak counts. Also, avoid stars that have other stars very close to them. You don’t have to click exactly on the center of each star; the software will realign each circle (and so when those apertures are applied to each of the other images in your stack, it won’t matter if the images aren’t perfectly aligned – that’s why we don’t have to do the alignment process that we did do in the image processing). So, start clicking - choose your target star first, and then click on a number of other stars in the image as well.

The idea here is that conditions change from image to image (e.g. light cloud cover) affecting (ideally) all the stars in the image the same way. So to get our desired relative brightness of the target star from image to image, we will want to compare the target’s (sky background-subtracted) brightness to an average of a set of well-behaved comparison stars – taking the ratio to correct for image-to-image sensitivity (due to atmospheric transparency) variations.

Each click will put a mark and annotation on your image:
When you've chosen enough stars (maybe eight...or more), then either right click on the image, or hit Enter on your keyboard to stop choosing stars and start the processing. *AIJ* will work through the stack of images, giving you entries in the log window. When it's done, it will beep and pop up several other windows.
One window may already contain a pretty good looking light curve (especially if you made the target star the first star you clicked on – though don’t despair if your curve doesn’t look good/right – we’ll fix it up):
The blue curve is the target’s light curve (ratioed to the sum of all the comparison stars and then normalized so the average value is equal to 1.0). The other light curves are of the comparison stars. It’s encouraging that we see a dip in the target star’s light curve while the comparison stars’ light curves are flat.

The window that looks like this:

![Image of a window used to control axis ranges](image1.png)

can be used to control the axis ranges etc. The window that looks like this:

![Image of a window used to add comparison stars](image2.png)

enables you to add more comparison stars to the plot, and controls some other aspects of the plot (including the arbitrary scaling of each star’s light curve so that they don’t lie on top of each other on the plot).
And this window:

![Multi-plot Reference Star Selection](image)

enables you to control which comparison stars are used for the ratioing with the target star. Potential comparison stars with noisy or variable looking light curves should be eliminated.

It is a good idea to tweak the normalization of the target light curve by adjusting the “Norm/Mag Ref” pull down menu for the target:

![Normalization Menu](image)

Ask for help/advice about how to do this.
After renormalizing the target star’s light curve and eliminating some of the comparison stars (as shown above), adjust the y-axis range so that only the target light curve is included in the plot. Now, click the “Redraw Plot” button:
These steps produced a light curve that looks something like this:

![Light Curve Diagram]

This is a pretty good looking light curve! The depth can be measured via the numbers on the y-axis and the duration by the numbers on the x-axis. How would you talk about the depth of this eclipse? How about the duration?

How would you characterize the uncertainties on the measurements plotted here?
We can show you how to normalize the out-of-eclipse portion of your light curve to 1.00 so that it’s easier to measure the eclipse depth by reading off of the y-axis.

Before you go any further with your analysis, do two things:

(1) save your light curve image as a png, and
(2) do a file > save all

This will save a bunch of files that can later be used to restore your AIJ session to the state you left it in.

**Measuring some properties of the eclipsing binary**

Now that you have a plot of one eclipse, we can use it (along with some other eclipse measurements) to measure some properties of the binary. Our goal is to answer three questions:

1. What is the binary orbital period?
2. Does the binary have a circular orbit?
3. What is the ratio of the effective temperatures of the two stars in the system? (Looking at one of your previous homework problems may help with this one!)

To figure out these things, you’ll need to look at more than one eclipse. There are two more datasets in the files you downloaded, but you don’t have to do through the process above – they have already been reduced for you, and the photometry has been done as well. To look at one of these eclipses, do the following:

- Close all open windows in AIJ except for the main toolbar. (Alternatively, you can just quit and restart AIJ.)
- Open the Multiplot window by clicking on the icon that looks like a plot of a sine curve.
- On your computer, open the folder for one of the other eclipses, and drag the file ending with “measurements.txt” onto one of the open AIJ windows.
You should see the dataset load, and a plot of the lightcurve appear. When you drag a measurements file like this, AIJ also reads the various settings files in the same folder, and reconfigures the various windows in the way they were set up before. So now you’re ready to analyze the data. After you’re done examining the current light curve, do the same thing to open the third one.

To determine the eclipse timings more precisely, you can fit them with AIJ’s planet transit tool. While an eclipsing binary and an exoplanet transit don’t produce exactly the same light curve, they are close enough (and the model is flexible enough) that you can get a decent fit.

To fit a transit model, find the option labeled “Fit mode” in the AIJ window where you select which data to plot:

Choose the option that looks like a transit or eclipse, as shown, and AIJ will fit a model to your lightcurve, and display a window with the best-fit parameters. You have to be careful in interpreting the displayed fit parameters, since many of the transit model assumptions don’t hold for an eclipsing binary. However, the central eclipse time (labeled Tc in the model fit) should be just fine.

Once you have determined your best estimates of the answers to the three questions above, go the eclipsing binary simulator at http://astro.unl.edu/naap/ebs/animations/ebs.html. Enter as much information as you can there from your measurements, and then play around with the sliders for the other parameters (which mostly have to do with spatial orientation of the orbit with respect to Earth) and see what you can figure out about likely values of those parameters. (Using
information from the stars’ colors, the hotter star of the two has an effective temperature of about 7200 K, so use that information in the simulator, along with what you found from the eclipses.)

**To complete the lab**

Write up a description of how you measured each of the three quantities above, and show any plots and measurements you used to do so. Also comment on what you found from the simulator, in terms of what you could or couldn't determine about the orbit.