Astronomy 337
Spring 2009
Final Project: Open Cluster Photometry and HR Diagram
Due Tuesday, 28 April

We now have in hand imaging data of the open star clusters M35 and M67 taken with the SBIG STL6303 CCD on the Meade 16-inch telescope in B, V, and R filters.

In this project you will:

1. reduce those data;

   Calibrated and cosmic ray cleaned BVR FITS mosaics for M35 and M67 due on 14 April.

2. create a multiple filter photometry catalog from those observations;

   Merged catalog (mag_table and err_table below) in IDL 'save' format due on 21 April.

3. calibrate that photometry, and finally analyze these measurements using the famous Hertzprung-Russell (color-magnitude) diagram.

   Project report is due 28 April.

1. **Data Reduction**

   Basic image calibration and mosaic construction is always the first job to do.

   (a) Start by downloading all the data using the *ast337data* sync script. All the data and calibration files will get dropped into the ∼/ast337data/24mar09 directory. A scanned version of the observing log will be posted to the class website.

   (b) Reduce them in IDL following the CCD Data Reduction Guide and **keep a notebook** with a detailed record of every step, measurement, and conclusion you make in the process of reducing and analyzing your images:

      i. Make a master bias frame.

      ii. Make a master dark frame.

      iii. Make master flat fields for each filter used.

      iv. Process all your data files with the master calibration frames that you made.

Examine the output of each step carefully and quantiatively, making sure the flux, noise, and appearance of the images make sense.

(c) Make master mosaics of your science target (M35) and standard star field (M67) frames:

i. Move the images for your science target and your standard star field into separate directories.

ii. Combine the dithers for each target (science field and standard star field) and each filter (B, V, R) together to make six mosaics using rob_assemble2.pro:

A. Calling sequence: `IDL> result=rob_assemble2()`

B. Select all of the FITS images to be included in that mosaic.

C. Don't dump any bad images when asked.

D. A side by side image display should appear, with Min and Max level sliders to adjust the grayscale to personal taste.

E. In the left view, click and drag a selection box around a few intermediate brightness stars, leaving some space on all sides. Note that a copy of your box is drawn on the right view. (This is your tracking box; the program will attempt to track those stars automatically through all of your dithers once you click the Submit button.)

F. Click the Submit button and wait... The "Did things register properly?" display window should pop up after a bit, along with that same question as part of a Yes/No dialog window. Compare the two images displayed (a single image on the left and the combined mosaic on the right), and if all features match up, then things most likely went well; answer Yes. If you see multiple copies of a star pattern in the right image that you don't see in the left image, then there was likely a failure in the tracking program; answer No and redo the box drawing process.

G. The combined image is saved on the hard drive as final_mosaic.fits. It is stored in the directory of your source images, under the new subdirectory *<filter>mosaic* (e.g. *Bmosaic* if you fed in a set of B band images).

iii. Apply a fancy automated filter to remove most cosmic ray hits from your mosaics: `IDL> rob_reassemble2`. A directory picking window should appear, and you just select one of the *<filter>mosaic* directories and hit OK. The resulting "cleaned" image named *final_mosaic_clean.fits* will appear in that directory. Do this for each mosaic that you made above.

2. **Source Detection and Photometry**

Now we need to measure the position and brightness of each star in each image in each filter. Start with the three science target images. You will measure the star positions in one image (we'll assume the B band image in the following examples), and then find the same stars in the other two images.

(a) Use PhotVis in IDL to obtain a source list and photometry from one filter's image: `IDL> photvis` . Use the PhotVis Instructions to proceed.

We'll assume from here that you ran PhotVis on your B band mosaic (*Bmosaic/final_mosaic_clean.fits*) and saved the XY results file to *Bmosaic/final_mosaic_clean.fits.pvd*. When you save the file, PhotVis will print the command you'll need later to restore the results file into your IDL session, sort of like this:

```
RESTORE,'Bmosaic/final_mosaic_clean.fits.pvd'
[x,y,rnd,shp,aper,insky,outsky,mag,magerr,sky,skyerr,user_status]
```

You can just copy the RESTORE command and paste it into the IDL command line to restore the '*pv_dat*' table that PhotVis generated for you. The second line that starts with "[x,y,rnd,..." is shorthand notation for the contents of each column in *pv_dat*.

(b) Read your PhotVis source and photometry list into your IDL session. For example, if I saved my PhotVis results table to *Bmosaic/final_mosaic_clean.fits.pvd*, then I would do the following in IDL:

```
IDL> RESTORE,'Bmosaic/final_mosaic_clean.fits.pvd'
IDL> help, pv_dat
IDL> ; print the first row to show what sort of information is in
each column.
IDL> print, pv_dat[*,0]
```

Record in your notebook the minimum and maximum values of the X positions (x), Y positions (y), Magnitudes (mag), and Uncertainties (magerr) from *pv_dat*.

(c) Measure the X and Y pixel offsets for the other two mosaics relative to the image you ran through PhotVis. For example:

```
IDL> fits_read,'Bmosaic/final_mosaic_clean.fits',im1,hdr1
IDL> fits_read,'Vmosaic/final_mosaic_clean.fits',im2,hdr2
IDL> offsetsv = rob_reg(im2,im1) ; Note:  order of inputs matters
here!
IDL> print,offsetsv ; these are X and Y offsets in pixels.  Ignore
the third element.
```

(d) Use the X and Y positions in the *pv_dat* array (the first two columns), offset by the image offsets measured above, to measure the brightness of the same stars in the other two images with the same aperture and sky annulus sizes you used for the first image. For example, following the example above, you might do the following:

```
IDL> ; Note that we read in the V band mosaic into the im2 variable
above.
IDL> aper,im2,pv_dat[0,*]+offsetsv[0],pv_dat[1,*]+offsetsv[1],$
IDL> magv,errv,skyv,skyerrv,phpadu,pv_dat[4,0],pv_dat[5:6,0],$
IDL> /silent,/exact,/nan ; do aperture photometry on V mosaic
IDL> ; Now save your work to ''restore'' later!
IDL> save,magv,errv,offsetsv,file='Vmosaic/photometry_v.sav'
```

Now adjust the variable names above (for example, change ‘magv’ to ‘magr’, etc.) and repeat the above process for the R band image, such that you have photometry for all three images saved.

(e) Construct a table of your B, V, R photometry in IDL with one row per star (restore your photometry tables for each filter first, if needed):

```
IDL> mag_table = fltarr(3,n_elements(magv))
IDL> err_table = fltarr(3,n_elements(errv))
IDL> mag_table[0,*] = pv_dat[7,*]
IDL> mag_table[1,*] = magv
IDL> mag_table[2,*] = magr ; reapply the example above for R band
first!
IDL> err_table[0,*] = pv_dat[8,*]
IDL> err_table[1,*] = errv
IDL> err_table[2,*] = errr ; reapply the example above for R band
first!
IDL> ; Now save your work to ''restore'' later!
IDL> save,err_table,mag_table,file='my_m35_photometry_table.sav'
```

3. **Calibrate the Photometry**

Next we use the M67 images to obtain an absolute calibration for our M35 photometry.

(a) We obtained BVR images of the open cluster M67 *with identical exposure time to our science data* to use for photometric standard stars. Consult the image and table in Schild (1983) to identify and find the BVR magnitudes of at least three stars in M67.

(b) Use the photometry mode in *atv* interactively with the same aperture and sky parameters as you used in PhotVis to measure the total background-subtracted signal S_* for each standard star in each filter.

(c) From these measurements, calculate the instrumental (uncalibrated) magnitude for each standard star, $m_{\rm inst} = -2.5\log(S_*)$.

(d) Using the published magnitudes and your instrumental magnitudes, calculate the magnitude zeropoint offset for each filter, i.e. the difference in magnitudes between the published value and your measured value.

4. **Analyze the Photometry**

   (a) Apply the magnitude zero point offsets to your M35 photometry values to obtain the true B, V and R magnitudes of each target star. Make a table of all the flux data in magnitudes, and be sure to include error estimates.

   (b) Make a Hertzprung-Russell diagram! Plot B or V on the y-axis (with bright up!) and $B - V$ or $V - R$ on the x-axis for all stars in the target cluster. Include a display of the typical (median) error bar on the plot but offset from your data points, for clarity.

   (c) Optional: you can also make a "2-color" diagram showing $B-V$ on the x-axis and $V - R$ on the y-axis.

   (d) Optional: you can use the three final images of M48 to make a three-color JPG image of the cluster using threecolor in IDL.

   (e) Write a report describing your project and summarizing your findings. Include the following:

      i. Brief description of scientific motivation for making an HR diagram, brief description of what you did to make this one.

      ii. Printouts of your final images.

      iii. Table of observing run details (date, location, exposure times, number of exposures).

      iv. Table of results (magnitude zero points, magnitude ranges of stars used in each filter, number of stars used)

      v. Any figures you've made including at least your HR Diagram.

      vi. Comment on the appearance of the HRD. Identify any patterns you recognize. What sorts of stars have you detected in the star cluster? According to your HRD, how massive are the most massive stars left on the main sequence, and how old is the cluster? Find at least one reference in the literature against which to compare your results.

      vii. List any references you've used in your project.