Lab 5 – Photometry of a Stellar Cluster from CTO

In this lab we will plan and execute an observing run from the Campus Teaching Observatory. The goal of this lab is to become familiar with how to plan an observing run, from target selection to data acquisition and data reduction.

Scientifically, we will be creating a Hertzsprung-Russel diagram of a (bright) globular cluster observable from CTO. Because these stars belong to an association, they are all approximately the same age and metallicity and also reside at approximately the same distance. This makes our job easier, since all we need to provide is the photometry.

For this lab, you will be utilizing many of the same tools from Lab #2 (photometric time series), as you will be placing photometric apertures around target stars in order to measure their flux in an image and calibrating your images with biases, flat fields, and darks. You may find the python code that you have written for lab 2 directly useable here.

Getting Started

Before we can go to the telescope, we must have an observing plan. On professional telescopes, this is typically done as part of the initial telescope proposal (a telescope allocation committee cannot rank your proposal without knowing what you're proposing to do and why) and the details are filled in as part of a Phase II proposal. Here, we will assemble an observing plan during lab prior to sunset when we will then head to CTO.

1. **Target Selection**

   We want to make an HR diagram of a stellar cluster. So the first thing we must do is select a target that will be visible from Gainesville during the time of our observations (sunset – 10pm, when lab ends). The Milky Way luckily has many stellar clusters. Here are a few and their coordinates:

Cluster	RA	DEC
Messier 2	21h 33m 27s	-00d 49' 23.7"
Messier 4	16h 23m 35s	-26d 31' 32.7"
Messier 5	15h 18m 33s	+02d 04' 51.7"
Messier 13	16h 41m 41s	+36d 27' 35.5"
Messier 30	21h 40m 22s	-23d 10' 47.5"
Messier 53	13h 12m 55s	+18d 10' 05.4"
Messier 68	12h 39m 28s	-26d 44' 28.0"
Messier 72	20h 53m 27s	-12d 32' 13.7"
Messier 79	05h 24m 11s	-24d 31' 28.0"
Omega Centauri	13h 26m 47s	-47d 28' 46.1"

Which of these clusters will be up at the start of the night? (Remember our lecture about airmass and the RA/DEC coordinate system). Select one that will be up at the start of the night to collect your data on.

2. **Observation Plans**

Now that we know which target we will be observing, we should come up with an observing plan. Remember, the goal of this observing project is to obtain enough photometric data to create a Hertzsprung-Russel diagram (a plot of brightness vs temperature, where brightness is the magnitude in one filter and an observational proxy for temperature can be the color, or difference between the star's magnitude in 2 different filters).

An Aside on Photometric Standards: The Landolt Stars

Arlo Landolt was an American astronomer that spent most of his research life turning stars into standard stars – IE measuring their absolute brightness and fluxes in various bandpasses and correcting for the effects of the Earth's atmosphere on any given night. These standard stars are incredibly valuable, as they allow us to correct our photometry on any given night by simply observing a known standard. If the known standard appears dimmer by 0.2 magnitudes due to the atmosphere that night, then we can correct all of our observations for that night by that number.

In reality, it is slightly more complex than this. In lecture, we discussed a couple of ways that the atmosphere can affect our data – through extinction just by looking through more airmass during our observations, and by refraction (the atmosphere bending different wavelengths of light differently). The implication is that the atmosphere can more readily extinct light of bluer colors than redder colors as well. This is known as *differential color extinction* – a star of bluer color will be reddened and lose more light than a star of redder color. We will need to try to estimate this. A typical approach is to fit a set of linear equations:

$$V_{Landolt} = V_{Observed} + a\,(X\text{-}1) + b\,(X\text{-}1)\,(V_{Landolt}\text{-}I_{Landolt}) + ZP$$

Where V is the magnitude in the V band either defined by Landolt or observed by you on that observation night. X is the airmass (we use an X-1 term because the airmass straight overhead is 1), V-I is the difference between the V magnitude and I magnitude and ZP is the Zero Point offset for the magnitude system. We can construct an identical equation using any combination of filters we choose.

Note: In reality, our filters cannot be assumed to be exactly identical to the V filter used by Landolt to define the photometric system. Our "$V_{Landolt}$" would instead be V_{CTO}. We would then need to construct an additional set of linear equations correcting V_{CTO} to $V_{Landolt}$ as a function of color: $V_{Landolt} - V_{CTO} = A + B(V-I)$. We will ignore this for this lab and just assume that our filter system is "close enough" to the standard system

Constructing your observing plan

Now that we know some of the details of what is required to obtain standard photometry, let's construct our observing plan. Here is what we know we need:

Calibrations: Biases, Flats, Darks

Science Observations: Landolt standards, Cluster observations

You can find a list of Landolt standards here:
https://www2.keck.hawaii.edu/inst/common/landolt_stds.html

We know that biases and darks can be taken at any time, and that sky flats must be taken at twilight (when the sky is partially illuminated by the setting sun). Aside from that, we know that to correct our data we need to take observations in multiple filters and to constrain the atmospheric extinction we need to obtain observations of multiple standard stars at different airmasses.

With this information, write down your observing plan. Which cluster and which standard star(s) are you going to observe? Hint: You should select standard stars as close to your target as possible. How often are you going to observe them (are you going to bounce back and forth? Are you going to observe standards before or after your target observation or both? Are you going to do all your V-filter observations first and then your I-filter observations or are you going to do both V and I at the same time?). When you have decided your observing plan, show it to me or Francisco so we can sign off on it.

3. **Execute your observing plan**

Finally, at CTO, execute the observing plan that you came up with above. Be sure to keep a detailed observing log of exactly what you did and what did or did not go right during your observations. Make sure that your images are named appropriately so you know which are which after the fact!

4. **Data Analysis**

Analyze your data similar to how we reduced our data in Lab #2. Correct each of your images for the bias, dark, and flatfield effects with your calibration images so you have fully reduced images in V-band and in I-band of your cluster as well as your Landolt standard(s). Detect the location of as many stars in the cluster as you can as well as your Landolt standard images. Place apertures on your stars to measure the flux from each of your stars. Convert them to magnitudes (recall that magnitudes are a log-based system in flux) and use your standard star observations to obtain the coefficients describing your atmosphere and apply that to your target observations to obtain the magnitudes of as many stars in the cluster as you can. With your magnitude measurements, you can now make an HR diagram of brightness vs color. Since these stars all reside at the same cluster distance, we do not need to worry about distance correction to the brightness, as this would just be a constant offset.

5. THE REPORT

For the lab report, please submit the following:

A) Please submit all the code you used for this lab as a PDF file (Canvas can load PDF files but can't display a jupyter notebook natively).

B) Methodology: What did you do during the lab? This includes a description of what your code does but also the reasoning for your target selections and observing log.

C) Show your results and analysis. This includes everything from images of your target cluster / standard stars to the relevant plots of your data analysis, including plots showing the effects of atmospheric extinction and the quality of your fit to the atmospheric extinction. **If you are in the group observing October 6, the lecture on October 11 will be a refresher on linear least squares fitting so don't panic if you are confused how to fit a model to data**.

D) Conclusion: Summarize your results and what went right and what went wrong. If you could change anything about your analysis or observing strategy, what would it be?