ASTR 257 Project 2:
An HR Diagram of the Open Cluster NGC 6819

Overview

The Hertzprung-Russell diagram is the bedrock of modern astrophysics. Photometry of coeval clusters of stars has enabled studies of stellar structure and evolution, populations, the distance ladder, and just about everything else. In this project, we will use the Nickel imager to collect multi-wavelength photometry of stars in the open cluster NGC 6819, which we will use to make an HR diagram and estimate the cluster's age.

Figure 1: NGC 6819

We've already used the Nickel telescope, so operations will be straight-forward. But instead of measuring the positions of stars—astrometry—we will measure the brightness of stars—photometry. We will use the Python library Photutils to measure the relative brightness of each star. We will then convert each star's brightness into a magnitude using well-calibrated stars from the Landolt catalog. This is our most challenging project. Software for crowded-field photometry can be finicky and there are generally a lot of steps to the data reduction and analysis. Hang in there! Your reward will be an evening looking through the 36" Refractor.

Learning Objectives:
- Students will learn to plan and execute imaging observations with the Nickel telescope.
- Students will learn the basics of photometry.
- Students will learn basics of image processing.
- Students will learn basics of database construction.
- Students will learn to present their observations in a standard written format that is appropriate for publication.

Planning Your Observations

Setup
To first order, the observations you will obtain on NGC 6819 are similar to the ones you obtained on Pluto. So, to prepare for NGC 6819, repeat the same steps you used to plan the Pluto observation. Where is NGC 6819 (use SIMBAD instead of JPL Horizons for stars) and when is it observable? How will you know that the Nickel is looking at the NGC 6819 field? What filters should you use? How long should you integrate? What CCD calibrations will you need? Keep in mind that you are also repeating the Pluto observations tonight, so if you can share calibrations between the two programs, you will save time.

Landolt Standards
The usual way to calibrate ground-based optical photometry is to observe stars with known magnitudes, and compare their brightnesses to the star(s) you are studying. Astronomy hero Arlo Landolt has made a career of cataloging extremely precise photometry measurements on non-variable stars. Landolt's catalog is available on various websites. As an example, try the WIYN consortium's listing of recommended Landolt fields:

http://www.wiyn.org/Observe/Landolt/recommendedfields.html

Choose a field that is close in airmass to NGC 6819. Close in RA can be a decent proxy for close in airmass, but make sure to think this through. Landolt provides photometry in the UBVRI filters, so if you were planning to use different filters for NGC 6819, you might want to reconsider.

Note that extinction from the Earth's atmosphere is a function of wavelength and airmass. Most photometrists observe multiple Landolt fields throughout the night to correct for airmass and stellar color, but this is beyond what I expect from you for this class. Just know that if you were publishing an HR diagram in a paper, you would need to correct for airmass and stellar color by observing multiple Landolt fields at different airmasses, and with different spectral type standards.

Mosaics
NGC 6819 is too big to fit on the Nickel CCD. If we wanted to map the entire cluster, we would have to do multiple pointings and then stitch (or mosaic) the different images into one much

larger image. This is enough of a pain that we're going to skip it for this class. Just find one reasonably dense region in the cluster and make an HR diagram from a single pointing.

Approval of Observation Planning
Before we start observing, present your plan of *exactly* what you'll be doing. The more detail the better.

To Be Completed During the Field Trip

Data Reduction
The generic CCD imaging data reduction you did for Pluto applies to this project as well. However, note that CCD pixels can have a wavelength dependent response, so best practice is to take flats in each of the different filters that you use.

Photutils
Ordinarily, photometry of a single star involves adding up all of the counts in a region centered on the star, and then subtracting an estimated background contribution by looking at regions far away from the star of interest. Crowded-field photometry is more complicated because there isn't always a clean region for estimating background, and because stars that are close to each other can be tricky to disentangle.

Photutils is a relatively new software package based on ancient and venerable photometry packages in IRAF and Fortran. In my limited experience with Photutils, I find it reasonably easy to use and well-documented:

https://photutils.readthedocs.io/en/stable/index.html

Use Photutils to perform aperture photometry on your NGC 6819 image (PSF-fitting photometry is a high-performing alternative to aperture photometry, but is harder to use, so let's stick with aperture). It will probably take some trial and error to determine the right input parameters. You will also need to run the same code on your Landolt field. And of course, you will need to run it at multiple wavelengths.

Organization is a key part of data reduction. X has some tips about how you can set this up, which are included in this folder.

HR Diagram
Convert your Photutils photometry into real astronomical magnitudes using the Landolt photometry. Plot your photometry as a color magnitude diagram. Is there a main sequence? Are there outliers? Why?

To estimate the age of NGC 6819, plot the Padova Stellar Evolution Isochrones (isochrones are lines of constant age):

http://stev.oapd.inaf.it/cgi-bin/cmd

Note that there are a lot of options here, and you should read through them, but the default is probably fine.

Writeup (To Be Completed After the Field Trip)

Please write descriptions of your Observations, Reductions and Results. Your Reductions section can be part of the Observations section, or it can be its own separate section. I expect your Observations section to be publication quality, your Reductions section to be clear, but not necessarily at the level of detail seen in publications, and your Results section to be extremely brief, just presenting your HR diagram and age estimate.