DSCP-A Final Project

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Topic: Plotting an HR diagram for an open cluster.

Github: https://github.com/Cheng-Lin0318/DSCP_Final

Preface

Since taking courses in astronomy and astronomical observation, I have acquired knowledge in astronomy and skills in capturing, processing, and analyzing astronomical images. Inspired by this, I aim to use Python to visually represent the scientific significance within astronomical images as part of this course.

What is HR diagram?

Hertzsprung–Russell diagram, the x-axis represents color, and the y-axis represents luminosity (absolute magnitude). Astronomers use the HR diagram to observe the relationship between the color and luminosity of stars, inferring their types or evolutionary stages. When applied to clusters, it allows for the marking of all stars within the cluster, helping to assess the distribution of star types and providing an initial estimate of the cluster's age.

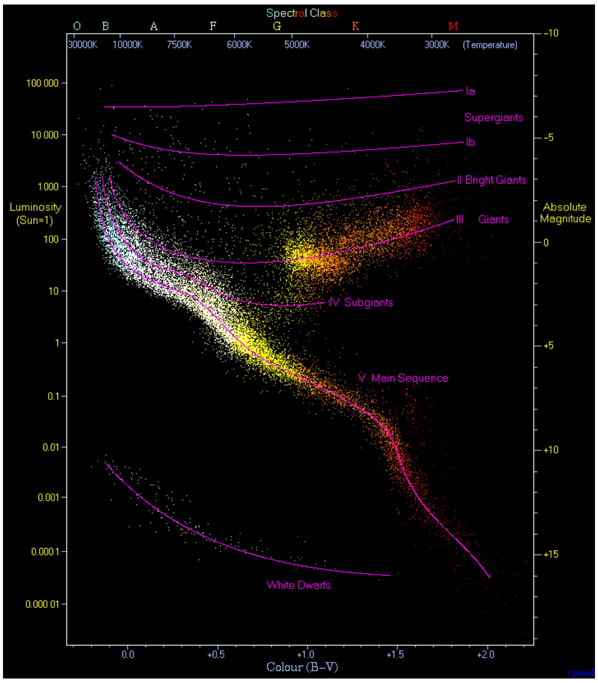

Figure 1. Hertzsprung–Russell diagram. From: wiki

Data

I initially planned to use the observatory of the Department of Earth Sciences, which is located at the top of college of science building to observe Pleiades (M45) . However, as the observable time for M45 increased, it meant approaching winter, as M45 is located in the Taurus. Unfortunately, due to Taipei's frequently poor weather conditions in winter, it became challenging to observe. As an alternative, I decided to analyze data provided by one of the assignments from a course I am currently taking this semester, which target is Butterfly Cluster (M6).

These images were captured using LATTE (Lulin-ASIAA Telescope for Transients and Education) at the Lulin Observatory, located at an elevation of 2862 meters. In Chinese, it is abbreviated as “拿鐵”.

The commonly used file format for astronomical images is FITS. If teacher needs to open them, you can download SAOImageDS9 and place the files in a path with an all-English name before opening.

All the images start from raw datas, including a lot of unwanted noise. Therefore, corrections need to be made using dark, flat, and bias images. While this correction can be achieved using Python, it is not the main focus of this project. Instead, I utilized DeepSkyStacker for these corrections.

You can see that there are 6 corrected images inside the “data” folder, consisting of 3 images each for V and B filters with different exposure times.

The naming format for the images is: Filter_ExposureTime+unit. For example, “V_30s”' corresponds to an image observed using the V filter with an exposure time of 30 seconds.

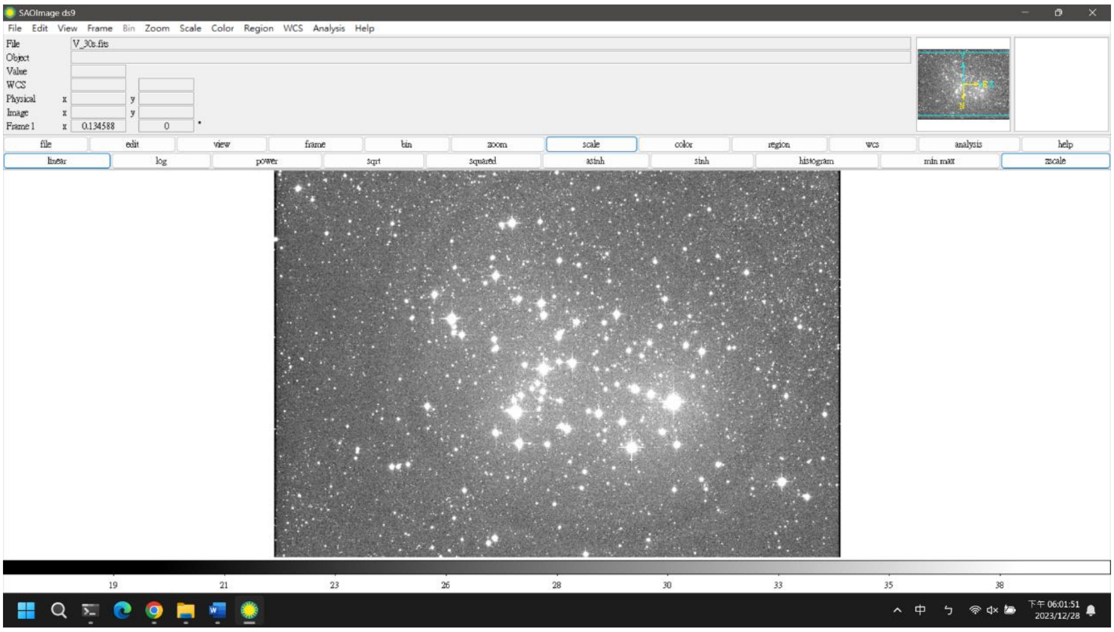

Figure 2. Open V_30s using SAOImageDS9.

Pseudocode and programing process

Analyze the 6 images by grouping them according to different filters but similar exposure times into three sets: (V_3s, B_3s), (V_30s, B_30s), and (5min, B_5min).

1. Import packages
   A. Numpy and matplotlib.pyplot as you known
   B. Astropy import FITS files, calculate coordinates and brightness of background, and use common astronomical units
   C. Photutils detect stars
2. Define functions
   A. grid: grid the pixels of the images and use the Euclidean distance formula for ease of selecting the measurement range of star points
   B. flux_measure: measure the total brightness within a radius of 20 pixels around the center of each star
   C. mag: measure the magnitudes using standard stars.
   D. absolute_Vmag: convert apparent magnitudes to absolute magnitudes using the distance modulus
3. Read the images and calculate the magnitudes
   A. V filter
      I. Get the information of data, header, wcs(RA, Dec)
      II. Calculate the mean flux of background
      III. Detect stars, set fwhm=4.0 threshold=3*standard deviation
         i. List stars that meet the criteria, including information on the center coordinates (X and Y) and peak intensity, as shown in Figure 3.
      IV. Select stars with peak>5,000 and peak<50,000
      V. Select standard stars through [APASS catalog]
         i. Convert (RA, Dec) to Cartesian coordinate system on the image
         ii. Calculate the flux of standard stars in the V filter using flux_measure function
      VI. Calculate the flux in the V filter for the selected stars in step IV, using flux_measure function
      VII. Using the standard star's V-magnitude and flux, calculate the V-magnitude corresponding to the flux obtained in step VI, using mag function
      VIII. Calculate the absolute magnitude (Mv) corresponding to the V-magnitude obtained in step VIII using the distance modulus, using absolute_Vmag function
   B. B filter
      I. Get the information of data, header, wcs(RA, Dec)

II. Calculate the mean flux of background

III. Convert the X and Y centers of the star points obtained in step IV in the V filter to (RA, Dec), and then transform (RA, Dec) to the corresponding XY coordinates in the B filter image

IV. Calculate the flux of standard stars in the B filter, using flux_measure function

V. Calculate the flux in the B filter for the selected star points in step IV in the V filter, using flux_measure function

VI. Using the standard star's B-magnitude and flux, calculate the B-magnitude corresponding to the flux obtained in step V, using mag function

VII. Subtract the V-magnitude obtained in step VII in the V filter from the B-magnitude obtained in step VI, the result is the B-V color index

4. Analyze the other sets until all three groups have been analyzed
5. Combine the data of B-V and Mv obtained from each set into respective arrays
6. Create a scatter plot with B-V on the X-axis and Mv on the Y-axis using the arrays obtained in step 5

```
  id  xcentroid ycentroid sharpness roundness1 ... sky   peak  flux  mag
----- --------- --------- --------- ---------- ... ---- ----- ----- -----
    1   1293.90      1.03      0.40       0.64 ... 0.00  1.21  1.25 -0.24
    2   1641.08      1.43      0.55       0.79 ... 0.00  1.21  1.04 -0.04
    3   3455.22      1.30      0.42       0.37 ... 0.00  1.21  1.05 -0.05
    4    656.02      2.96      0.55      -0.32 ... 0.00  1.21  1.09 -0.09
    5    828.60      1.97      0.58       0.60 ... 0.00  2.21  1.16 -0.16
    6   2280.95      3.25      0.50      -0.10 ... 0.00  1.21  1.20 -0.19
    7   2606.64      2.27      0.92      -0.74 ... 0.00  3.21  1.24 -0.23
    8   2643.51      2.69      0.52       0.07 ... 0.00  3.21  1.48 -0.42
    9   2723.91      2.27      0.79      -0.70 ... 0.00  2.21  1.05 -0.05
   10   2910.25      2.45      0.41       0.31 ... 0.00  1.21  1.20 -0.20
  ...       ...       ...       ...        ... ...  ...   ...   ...   ...
40608   4608.01   4365.26      0.87      -0.14 ... 0.00  2.21  1.43 -0.39
40609    902.43   4366.74      0.56      -0.07 ... 0.00 75.21 17.64 -3.12
40610   5243.75   4365.96      0.40      -0.26 ... 0.00 36.21  8.34 -2.30
40611   5357.76   4365.97      0.52      -0.08 ... 0.00  0.21  1.08 -0.09
40612   5611.05   4365.74      0.90       0.35 ... 0.00  1.21  1.05 -0.05
40613    903.56   4367.50      0.39       0.67 ... 0.00 56.21 12.23 -2.72
40614   3046.67   4366.87      0.48      -0.30 ... 0.00 16.21  4.25 -1.57
40615    901.58   4369.65      0.37       0.33 ... 0.00 42.21  8.89 -2.37
40616   2635.95   4370.11      0.79      -0.57 ... 0.00  1.21  1.20 -0.20
40617   3043.62   4372.95      0.51      -0.29 ... 0.00  6.21  2.84 -1.13
40618   5636.23   4372.96      0.28      -0.62 ... 0.00  1.21  1.50 -0.44
Length = 40618 rows
```

7. Figure 3. detected stars and its information

In step 3-A-V, concerning the standard stars, I choose as shown in Table 1

Table 1. Standard stars

Image set	1 (V_3s, B_4s)	2 (V_30s, B_40s)	3(V_5min, B_8min)
(RA, Dec) in degree	(264.997309, 32.443306)	(265.039964, 32.445354)	(264.897787, 32.20748)
V-mag	10.011	10.507	14.315
B-mag	9.889	10.51	15.074

However, during the magnitude calculation, there are occasional warning error codes. This is due to some stars being too close to the edge during flux calculation, resulting in nan values. Consequently, it becomes impossible to proceed with the magnitude calculation, as shown in Figure 4.

```
C:\Users\sl\AppData\Local\Temp\ipykernel_14504\929777201.py:12: RuntimeWarning: invalid value encountered in log10
  mag = -2.5*np.log10(choosed/standard)+standard_mag
```

Figure 4. warning error codes

Result

The X-axis represents B-V, the Y-axis represents Mv, and the color bar indicates that a larger B-V value corresponds to a darker in the B filter, suggesting lower surface temperatures and a redder color. Conversely, a higher surface temperature corresponds to a bluer color. By observing Figure 5, it can be concluded that there are more high-temperature stars (M6) in the analyzed results, indicating a younger age. This observation aligns with theoretical expectations based on cluster types.

Wikipedia: *"Most of the bright stars in this cluster are hot, blue B-type stars."* The results of my analysis is closely with this statement from Wikipedia.

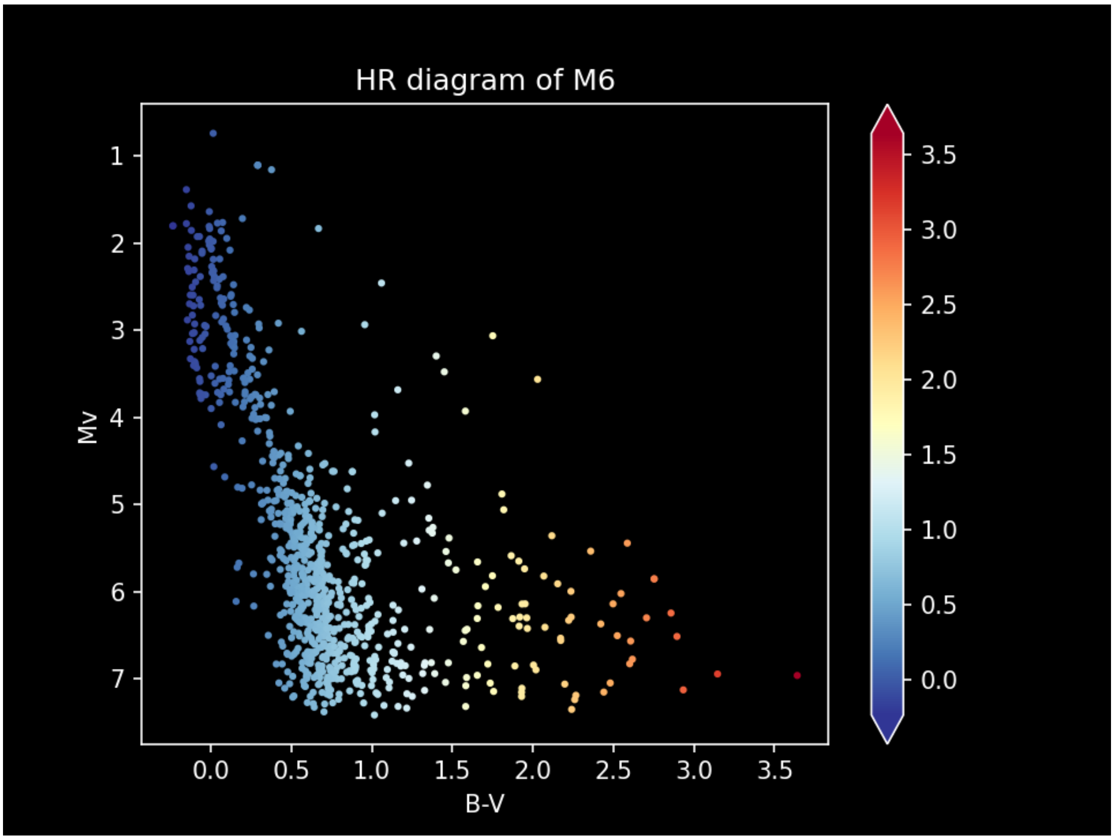

Figure 5. HR diagram of M6 cluster

Discussion

1. All measurements come with inherent uncertainties, including errors in standard star magnitudes, instrument errors, etc. However, this analysis did not consider error values, so it cannot be considered close to perfect
2. Only one standard star was chosen for analysis in each set of images, but it is advisable to select multiple stars (ideally 3-5). Additionally, the flux range of the standard stars should cover as much as possible the flux range of the selected star points (5000 < peak < 50000) to reduce magnitude errors
3. The positions of standard stars should be close to the center of the image because the errors produced by pixels at different positions may not necessarily be linear. Therefore, positioning them closer to the target helps minimize errors
4. Standard stars were not excluded when selecting star points, and these standard stars may not be members of the star cluster but are marked on the HR diagram.

Future work

1. Use error propagation to incorporate error ranges into the calculations
2. Select multiple standard stars, and ensure their positions are close to the center
3. Exclude standard stars when selecting the stars for analysis
4. Write functions to encapsulate the analysis steps and calculations for each group of images, facilitating the analysis of a large number of image sets
5. Exclude stars that are too close to the edge, leading to nan results in calculations