Investigating the M103 star cluster

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Abstract
To devise an Imaging and spectroscopic classification of the stars in the selected star cluster M103. First part of lab was aimed at drawing the color-magnitude diagram of the said star cluster by doing an analysis on the raw images obtained using the TOBI telescope. Later on we took spectropic data of the same cluster on one of the stars of the cluster , whereby we plotted its spectrum and tried to compute various properties of the star like its surface temperature and Redshift.

Keywords: astronomy, star cluster, imaging techniques

1 Introduction

STAR CLUSTERS are dense groupings of stars that form from the same molecular cloud. The stars in a star cluster share common origin i.e., their members share similar ages and chemical compositions. Therefore, they are an essential component for astronomers to study stellar populations(i.e., different types of stars within the cluster, such as main sequence stars, red giants, and white dwarfs.), stellar evolution, and the dynamics of stellar systems. Star clusters can be broadly classified into two main types: open clusters and globular clusters.

So. stars of a cluster can be assumed to be born at the same time, so they they have the same age , however they can differ in masses and chemical compositions. stars of different masses have different lifetimes on the main sequence after residing in the main sequence they then evolve away to the giant branch , high mass evolve faster than low mas star. The turnoff point in the CMDS give the mass of the stars that have started evolving away. The time spent by these stars on the main sequence known as the turnoff point, determines the age of the cluster. stars above these point are the blue stragglers.

Open clusters are groups of stars that formed from the same molecular cloud and are held together by gravity. They are often associated with ongoing star formation and are found in the disk of galaxies. They can be easily disturbed by some nearby gravitational activity forcing them to disperse over time. They are different from *globular clusters*, which are much older and contain hundreds of thousands of stars that are densely packed into a spherical or globular shape. The open cluster M103, located in the constellation Cassiopeia, is one such cluster that has captured the attention of astronomers.

Experimental setup

The **TOBI** telescope has a primary mirror diameter of 60 cm and a focal ratio of f/3.3, which makes it well-suited for wide-field imaging of astronomical objects. It is equipped with various instruments for imaging, spectroscopy, and photometry. The CCD camera used with the TOBI telescope has a resolution of 2048 x 2048 pixels and a field of view of 25 arcminutes, which allows for detailed imaging of astronomical objects.

M103(NGC 581) is an open star cluster located in the constellation Cassiopeia, and is one of the most distant open clusters that can be seen with the naked eye. The cluster is estimated to be around 8,000 light-years away from Earth and contains approximately 40 stars. M103 is an open cluster that we have identified as an excellent target for our investigation. Its visibility throughout the night and its well-catalogued stars make it an ideal object for observation with Bicocca's optical telescope TOBi. The cluster's small radius of 0.170 degrees also makes it a great candidate for TOBi's minimum resolution of 0.4"/pixel, allowing us to easily resolve individual stars. Additionally, M 103 is high enough in the sky from November to January to be captured by TOBi, making it a prime target for our investigation. So, we will be investigating the properties of the star cluster M103 using the TOBI telescope.

We used the TOBI telescope to collect raw image data of astronomical objects. To process this data, we used techniques such as bias subtraction, dark subtraction, flat fielding, and image stacking to reduce noise and improve the signal-to-noise ratio of your images. These techniques help to reveal more detail in the images and allow for more accurate scientific analysis.

2 Data measurement and processing

Astronomical observations involves – telescopes collects the radiation and focuses it. Next is measuring that radiation by
(1) detection (ensuring signal is not noise)
(2) processing(/reducing) that astronomical data. The resulting data is 'science ready' data with which photo-metric and spectroscopic measurements can be made.

Detection is done by mostly CCD's. the SNR characterizes the quality of a measurement and detrmines the ultimate performance of the system.

$$SNR = \frac{Sn_0 t_{exp}}{\sqrt{Sn_0 t_{exp} + n_{pix}(Bn_0 t_{exp} + n_0 RN^2)}} \tag{1}$$

where S is the number of electrons per unit time registered by the CCD and coming from the source, n0 is the number of frames you want to take, texp is the exposure time, npix is the number of pixels of the CCD, B is the number of the sky background electrons, D is the dark current and RN is the read noise.

–**Data Acquisition**
Image Data Collection-
Telescope Configuration: The TOBI telescope was appropriately configured for optimal imaging of the open cluster. This includes setting the appropriate exposure time, telescope pointing, and focusing to ensure clear and accurate images.

Image Calibration: Before acquiring the actual data, calibration frames were obtained to account for various instrumental effects and improve the quality of the images. This involved capturing bias frames, which record the electronic noise of the detector, and flat frames to correct for any uneven illumination across the image. We took flats for the three filters Hα , [SII] and [OIII], so we took 5 frames with 0.5s exposures with each filter.

-Dark Frames: Additionally, dark frames were captured to account for thermal noise and hot pixels in the image sensor.

Target Observation: Once the telescope was configured and calibrated, observations of the open cluster M103 were conducted. We took 4frames and 300s of exposure times and repeated the procedure 3 times with a little shift of the telescope.

standard star: We chose HD3360 as standard star because it also belongs to Cassiopeia constellation and for this reason calibration should be more accurate.

spectroscopic data: Next we mounted the spectroscope to acquire data for the spectroscopic analysis. Again like before we took calibration frames and also some arc lamp calibration spectra. As part of our investigation, we obtained two spectra with different exposure times. Firstly, we acquired the spectrum of HD 3360 with an exposure time of 60 seconds. Subsequently, we selected NGC 581 144, which is one of the brightest stars in the cluster and has a V magnitude of 8.164. We then acquired its spectrum with a longer exposure time of 1200 seconds.

Image Data Reduction-

Detector Calibration

Bias substraction we take the multiple bias images and find mean. The combined mean image is called the 'master bias'. we subtract this from science images. **flat field** we similarly calulated the mean flat and removed bias from it then divided it from the processed images.

dark substraction next we removed the thermal noise. we saw that only some pixels produced significant amount of dark current. We removed mean dark considering only these pixels from the processed images.

Science Calibration

The zero point represents the conversion factor that allows us to convert the measured counts of a star's signal into flux units. By subtracting the sky backgrounds, we eliminated the contribution of unwanted light sources, enabling us to isolate the signal from the star. We used the flux of the standard star **final science image** we computed the final science image.

3 *Data analysis- constructing the colour magnitude diagram and 1-D spectrum of the star*

Observers can't directly measure the luminosity's and absolute temperatures. Instead we quantify this using colour and magnitude. The magnitude is related to the luminosity and the colour is of course related to the temperature.

Magnitude at a given wavelenght:

$$\begin{aligned} m_\lambda &= -2.5log(f_\lambda) + c \\ v &= -2.5log(f_\lambda) + c, && \text{in the v band} \\ m_u - m_v &= 2.5log(f_v/f_u), && \text{colour} \\ M &= n - 5log(D) + 5, && \text{abs mag} \end{aligned}$$

Our analysis involves star selection, centroid averaging, S/N calculation, radius determination, flux conversion, and the construction of a color-magnitude diagram for further interpretation and analysis of the star data.

In the data analysis process, we utilized the star finder module from the photutils(a great package to perform photometry in python, infact we used modules from it like the starfinder, aperture photometry, background subtraction catalougues..) library to identify the genuine stars of our cluster in the image. Based on brightness, we selected only the brighter pixels, specifically those falling within the 4σ tail of the Gaussian distribution representing the overall luminosity of the image. Furthermore, we focused on regions where the cumulative luminosity followed a Moffat distribution with a full width at half maximum (FWHM) of approximately 5. This approach ensured that only the most significant stellar features were considered.

Using the star finder module, we obtained a comprehensive table containing the detected stars along with their centroid positions, flux values, and magnitudes. This allowed us to precisely identify and characterize the stars of interest in our data set. Next we computed the radius at which the signal-to-noise ratio (S/N) is maximized for each star. we observed that the maximum S/N varies between the three filters and differs significantly between fainter and brighter stars.

Now we can move on to constructing a color-magnitude diagram. To do this, we calculated the flux of all the stars in units of (erg per second per square centimeter per angstrom) and converted it to magnitude values for each of the three filters used. We calculated the flux of all stars in and convert it into magnitudes for the three filters. we computed the magnitude for all the stars, We constructed the color-magnitude diagram using the computed magnitudes and colors.

Spectroscopy We similarly computed calibration for spectroscopy like we did for the imaging part. We will first reduce the raw data, extract the star's spectrum, and establish a mapping between pixel positions and wavelengths.

After the data reduction we wanted to extract the stars spectrum but before that we removed any unwanted contributions from the atmospheric or instrumental background that could affect the accuracy of the star's spectrum. We did this by firstly making a rectangular aperture near the star, extract the spectrum from there and then extract the sky background from it. Once the sky background was extracted, we subtracted it from the star's spectrum and obtained the 1-D spectrum in (e/s). Next is to perform wavelength calibration i.e., map pixel positions to wavelengths, to do this we used known emission lines from a calibration lamp and compared them to observed peaks in the red region. Finding a linear relationship for $\lambda > 5000$Å, we further validated this linearity by acquiring an image with a broader range of emission lines. We confirmed that the conversion between pixels and wavelength remained linear in both the blue and red regions.

Now we conducted a detailed analysis of the extracted spectrum of the standard star HD 3360. Upon comparison with the tabulated spectrum, we observed significant differences some dips. To address this issue, we carefully adjusted the conversion factor between pixels and wavelengths until we achieved a perfect match.

Next, we divided the tabulated flux, which was measured in physical units (erg/cm2/s/Å x 1016), by our flux measured in electrons per second. We then fit this result with a continuum model to remove any peaks and obtain the conversion factor between flux in counts per second and flux in physical units. We will use this factor to determine the flux in physical units for our NGC 581 144 from the 1D spectrum measured in electron counts per second.

To be more precise, we fitted the spectrum of HD 3360 with a black body model to calculate its temperature. Our results showed a temperature of (21800 ± 350) K, Our temperature was 21650 K which is comparable to the temperature of the black body temperature .

We did the same for our own star from the cluster. The results were : surface temperature of (9374 ± 74) K, which lies in the range to be classified as an F-star. Also the yielded Redshift that we got to be in the order of $z = (4 \pm 9) \times 10^{-4}$, whereas the tabulated value for NGC 581 144 $z = (1 \pm 0.3) \times 10^{-5}$ and the error was almost 200 % which makes our estimate for Redshift not very reliable.

4 Summary and Results

So, to simplify, we have done the following steps: **1)** Data reduction(bias, flat,... subtraction), **2)**Photometry(Measured flux of the stars using different filters to obtain accurate magnitudes for all stars in the cluster), **3)** Converted the magnitudes to standard magnitudes using magnitudes of known standard stars. **4)** Colour-magnitude plot (colour- difference in magnitudes) **5)** Extracted the spectrum from our Reduced data(using a rectangular region around the star) **6)** subtracted the background from this and mapped pixel position to their corresponding wavelngths **7)** Used standard star with known flux value to convert spectrum from electron counts to fux in physical units and normalize and plotted the spectrum.

OUR FINDINGS: we identify and highlight specific stars in the color-magnitude diagram, such as a star marked in red, which we believe does not belong to the cluster, and a star marked in blue, for which we computed the spectrum and obtained a V magnitude value($V_{mag} = (8.117 \pm 0.002)$.).We could see that the main sequence(mag rannge being:(13-8) color range(0-2)) , beyound this cut-off magnitude are probably the blue stargglers that have evolve off the main sequence, we also mark soe red gaints of the cluster.

The results for spectroscopy were surface temperature of (9374 ± 74) K, which lies in the range to be classified as an F-star. Also the yielded Redshift that we got to be in the order of $z = (4 \pm 9) \times 10^{-4}$, whereas the tabulated value for NGC 581 144 $z = (1 \pm 0.3) \times 10^{-5}$ and the error was almost 200 % which makes our estimate for Redshift not very reliable. Future inferences that can be made:

CMD's obviously change with time for the star cluster, So we can make theoretical model predictions of CMDs, known as isochrones and fit to find out stellar types or evolutionary stages, we can compare with isochrones of different ages to find the age of cluster.

5 Conclusions

The purpose of this report was to examine M 103, an open star cluster also known as NGC 581. Our aim was to create a color-magnitude diagram to gain insight into the cluster's characteristics, including the color of its stars, identifying the main sequence, as well as their age, temperature, and initial mass distribution. We were able to analyze the spectrum of one star in the cluster, NGC 581 144. Which, allowed us to determine its surface temperature and Redshift. In the future a lot of work can be added get more meaningful analysis few being able to compute the initial mass function, Spectroscopic Analysis of More Stars and Stellar Population Modeling.

6 Figures

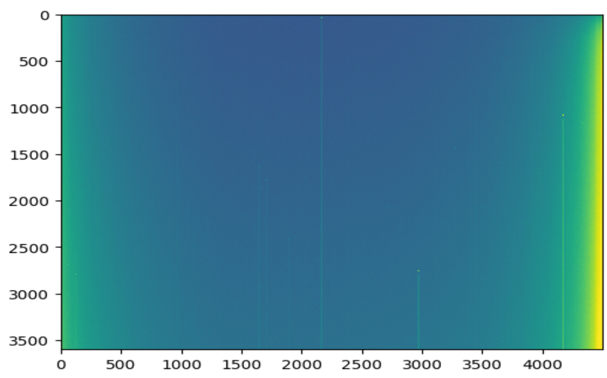

Figura 1: mean-bias, how our stacked image of the bias images look.

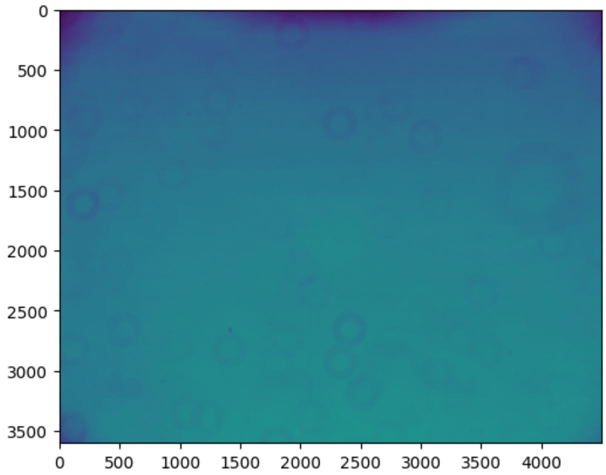

Figura 2: mean-flatHa, i.e., master flat obtained after stacking all the flat image from Ha filter.

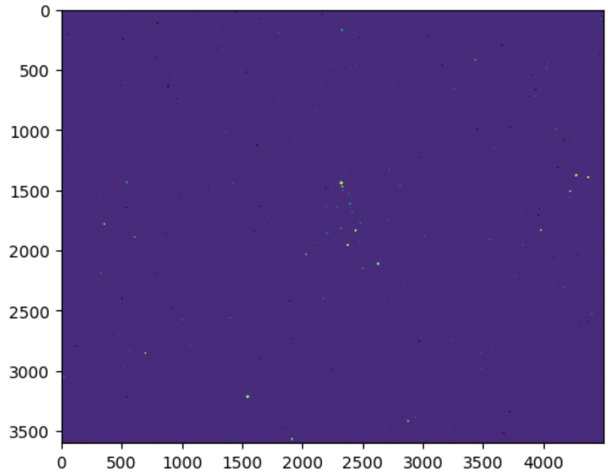

Figura 3: final calibrated imaged with bias,flat and dark current removed

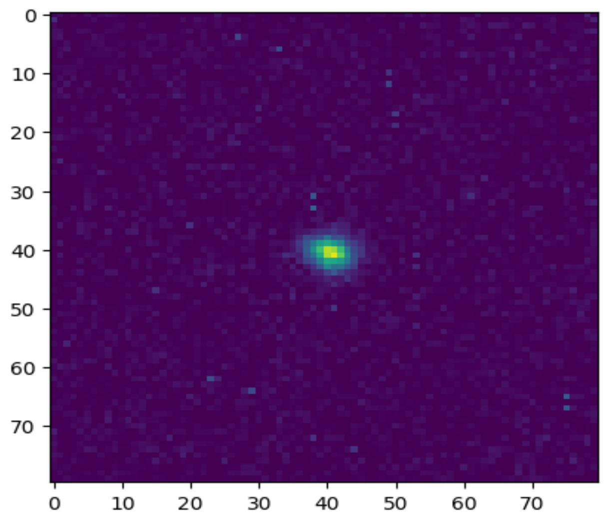

Figura 4: Target star cutout, stacked and aligned image with Ha fliter

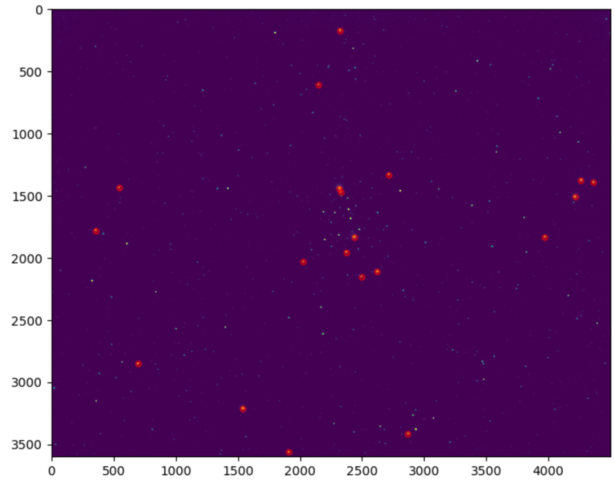

Figura 5: final processed Stacked image of our cluster with Ha filter, red dots are the stars found using the photoutilts, star finder with a FWHM of 5

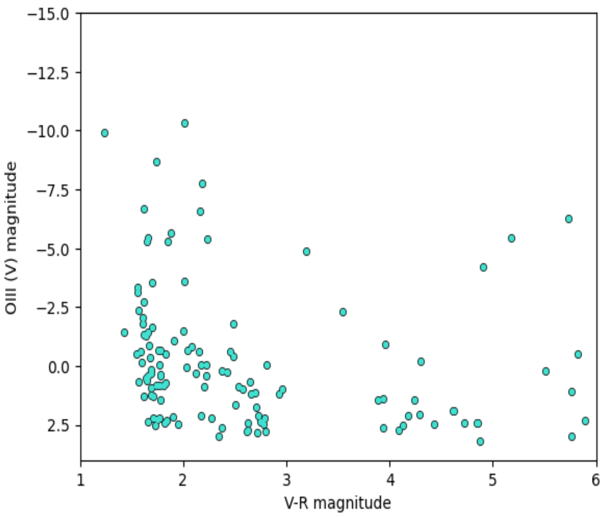

Figura 6: The colour magnitude diagram of our star cluster M103,

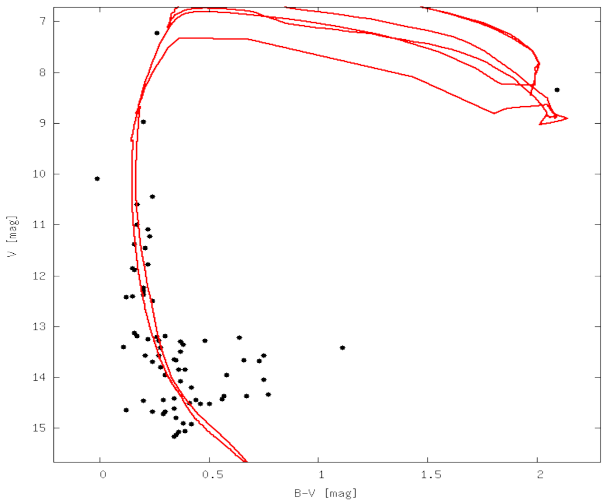

Figura 7: Isochrone Plot for NGC 581, plotted from webda,physics, using 73 stars from the cluster.

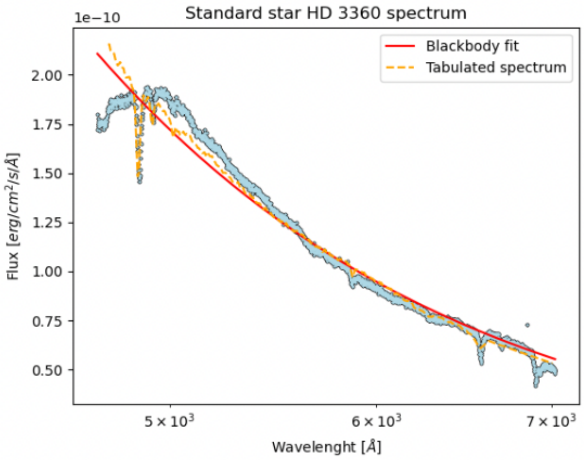

Figura 8: 1-D spectrum of the standard star HD3360 fitted with a black body emission model. We observe two noticable drops at wavelenghts corresponding to Ha, Hb absorption lines

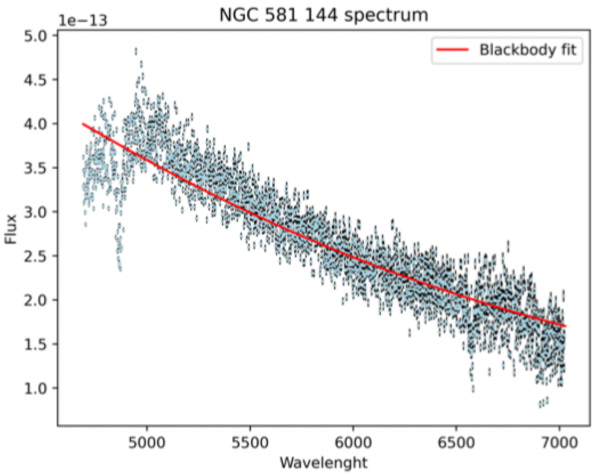

Figura 9: Spectrum of our target star from the the M103, (NGC 581 144) fitted with a black body emission. Again we notice two promonent absorption lines.

Referências

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