F30: CCD photometry in modern astronomy

carried out by

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Abstract

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

Zusammenfassung

Dies hier ist ein Blindtext zum Testen von Textausgaben. Wer diesen Text liest, ist selbst schuld. Der Text gibt lediglich den Grauwert der Schrift an. Ist das wirklich so? Ist es gleichgültig, ob ich schreibe: Dies ist ein Blindtext oder Huardest gefburn? Kjift – mitnichten! Ein Blindtext bietet mir wichtige Informationen. An ihm messe ich die Lesbarkeit einer Schrift, ihre Anmutung, wie harmonisch die Figuren zueinander stehen und prüfe, wie breit oder schmal sie läuft. Ein Blindtext sollte möglichst viele verschiedene Buchstaben enthalten und in der Originalsprache gesetzt sein. Er muss keinen Sinn ergeben, sollte aber lesbar sein. Fremdsprachige Texte wie Lorem ipsum dienen nicht dem eigentlichen Zweck, da sie eine falsche Anmutung vermitteln.

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1 Fundamental principles of astronomical measurements

1.1 Detectors in Astronomy

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1.4 Basics of photometry

What we are observing in our measurements is the **radiation flux** F of the stars which is given by

$$F = \frac{L}{4\pi d^2} \tag{1.1}$$

where d is the distance between the observer and the star and L is his luminosity.
To normalize our measured values we are using the sun as reference for the units we choose. For example the luminosity of the sun is $1\ L_\odot = 3.846 \cdot 10^{26}$ W.
The **Stefan-Boltzmann law** explains the connection between the surface temperature of a star and his flux. It is given by

$$F = \sigma\, T_{\text{eff}}^4 \tag{1.2}$$

with the Stefan-Boltzmann constant $\sigma = 5.67 \cdot 10^{-8}\ \text{Wm}^{-2}\text{K}^{-4}$. To understand the meaning of the effective temperature T_{eff} we need the know what we understand as a black body. A black body is, in theory, an object that absorbs every radiation independent on the corresponding wavelength and does'nt reflect any of it. The effective temperature in (1.2) is the temperature a black body with the same surface as the star would need to emit the same radiation power.
We already introduced a new quantity, the luminosity of a star which is defined as the surface area A times the flux. From this we can derive a relation between luminosity and temperature using (1.2):

$$L = 4\pi R^2 \sigma T_{\text{eff}}^4 \tag{1.3}$$

with the radius R of the star.

1.5 Magnitudes

We need to introduce different magnitude scales due to the fact that every instrumental setup is different but still we need to compare results taken from various observations.

1.5.1 Instrumental Magnitude

1.5.2 Apparant Magnitude

1.5.3 Absolute Magnitude

2 Preparing the telescope

Before we were able to start with our measurements we had to prepare the telescope by cooling it down with liquid nitrogen to prevent disturbing effects such as thermal activation of electrons that could effect our measurements. First of all we evacuated the cryostat to protect the chip of damage cause by freeze out. This process took about three hours. Using a Python script, we took test images every thirty seconds to obtain the current temperature and to be able to see the effects of the cooling process to the quality of the images. With the temperature data we were able to determine the band gap E_g of the semiconductor by fitting the theoretical curve which describes the dependency of the dark current I from the temperature T using Fermi statistics:

$$I = c_0 \cdot T^{\frac{3}{2}} \cdot \exp\left(-\frac{E_g}{2k_B T}\right) \tag{2.1}$$

The Boltzmann constant k_B is given by $k_B = 8.617 \cdot 10^{-5}\ \frac{\mathrm{eV}}{\mathrm{K}}$. The result of our measurement is presented in the following diagram.

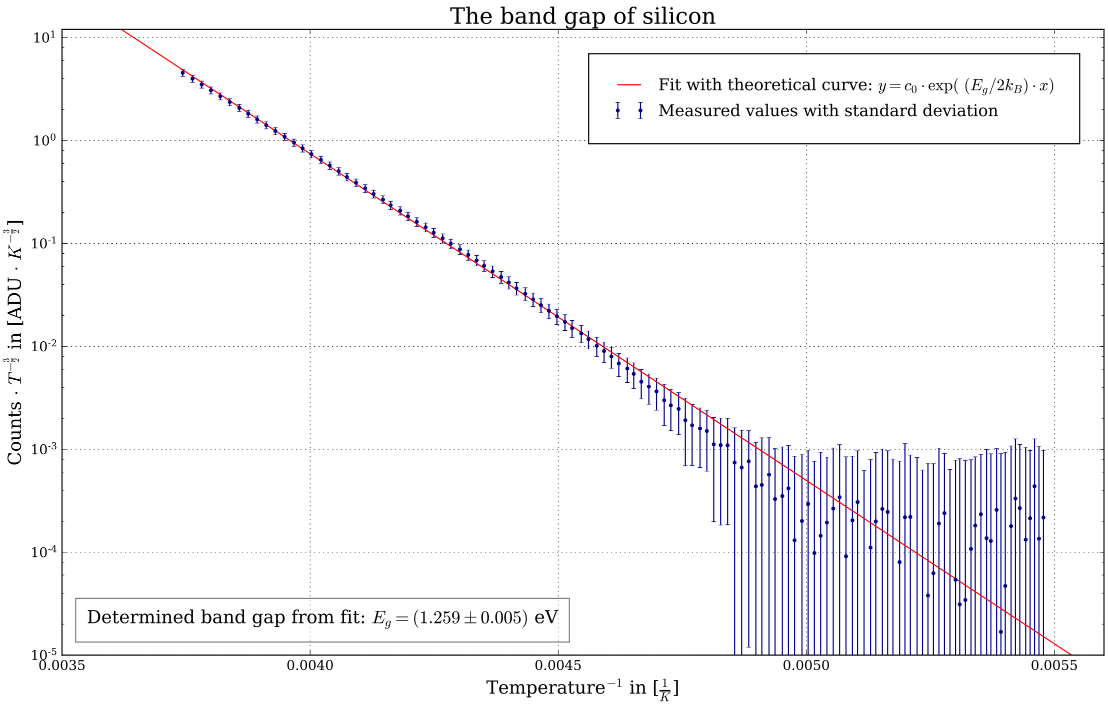

Figure 2.1: Determination of the band gap of silicon as an important characteristic of the experimental setup.

3 Globular Cluster BS90[14]

In this part of the experiment we are analyzing the properties of the globular cluster BS90[14]. Unfortunately the bad weather conditions during our measurement prevented us from collecting data by ourselves. Instead we are working with images taken by the Hubble Space Telescope (HST).
The goal of this part is to perform PSF fitting for two different filter constellations and match both images and finally plot a Color Magnitude Diagram (CMD) to determine age and metallicity of the cluster after fitting isochrones.

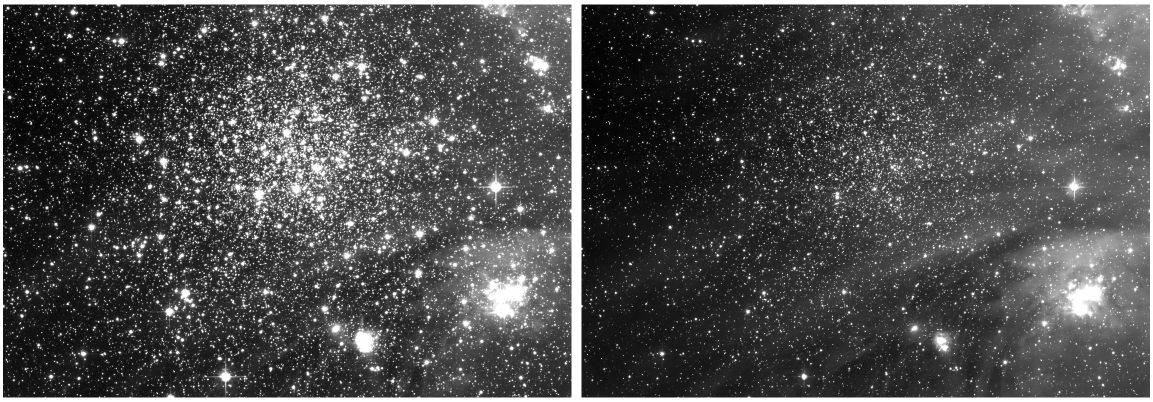

Figure 3.1: Exposures of the globular cluster BS90[14] taken by the Hubble Space Telescope. The image on the left was taken using an I-filter (infrared spectrum), the one on the right using a V-filter (visible spectrum).

3.1 Zeropoint calibration

To calibrate the measured data to a standard scale, which is in this case the apparent magnitude scale, we are comparing the counts of several standard stars with reference values from SIMBAD, an astronomical data base. From these results we can determine the zeropoint p_0 using equation ():

$$p_0 = m_{\mathrm{CATALOG}} + 2.5 \log_{10}(\mathrm{counts}) \tag{3.1}$$

We choose ten suitable stars, e.g. stars that are clearly isolated and bright enough but not yet saturated.

The results of our measurement are enlisted in the following table.

Star	Mag_V	$\#_\text{V}$	$\Delta\#_\text{V}$	$p_{0,\text{V}}$	$\Delta p_{0,\text{V}}$	Mag_I	$\#_\text{I}$	$\Delta\#_\text{I}$	$p_{0,\text{I}}$	$\Delta p_{0,\text{I}}$
1	17.78	908	30	25.175	0.036	16.65	1881	43	24.836	0.025
2	17.77	1371	37	25.613	0.029	16.21	4274	65	25.287	0.017
3	17.67	1345	37	25.492	0.030	16.81	3994	63	25.814	0.017
4	17.50	1052	32	25.055	0.033	16.64	2281	48	25.035	0.023
5	17.24	1511	39	25.188	0.028	15.79	4605	68	24.948	0.016
6	18.45	808	28	25.719	0.038	17.10	1738	42	25.200	0.026
7	18.23	885	30	25.597	0.037	16.23	2073	46	24.521	0.024
8	18.09	790	28	25.334	0.038	16.93	1626	40	24.958	0.027
9	17.97	961	31	25.427	0.035	16.68	1837	43	24.840	0.025
10	17.74	764	28	24.948	0.040	16.85	1694	41	24.922	0.026

Table 3.1: Zeropoint calibration by comparing ten stars with SIMBAD references

We take the mean of the calculated zeropoints p_0 and compute the standard deviation of our errors and the error progation to get the final results:

$$p_{0,\text{V}} = (25.334 \pm 0.004 \pm 0.011)$$
$$p_{0,\text{I}} = (24.953 \pm 0.004 \pm 0.007)$$

3.2 PSF photometry with STARFINDER

We are using `starfinder` to perform statistical PSF fitting, e.g. the IDL takes the positions of about 10 to 30 isolated, unsaturated stars and applies several corrections (subtraction of an average background and normalization of the peak intensities) to both images. Now the software is able to compare the results for all the stars we chose and to determine the final result: an average PSF for the entire image.

3.2.1 Results of the PSF fitting

We chose about 25 stars and selected the most suitables, e.g. those who were as centered and symmetric as possible for the fitting.

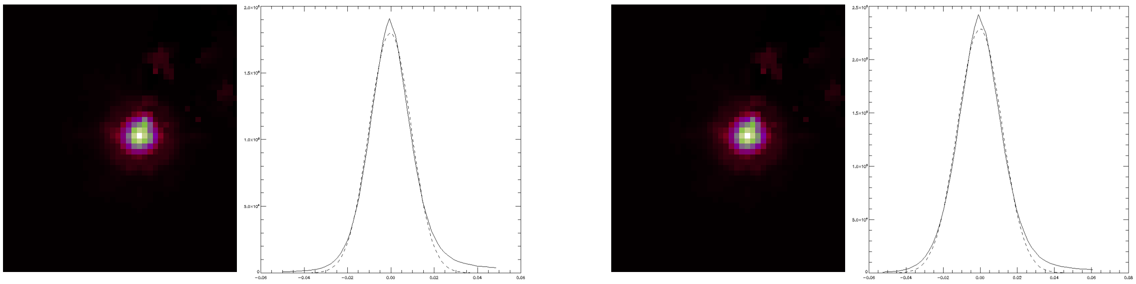

Figure 3.2: Results of the PSF fit for the I-filter (left) and the V-filter(right).

With this result `starfinder` is able to detect all potential stars by dividing the image into smaller parts and checking if the analyzed objects are brighter than the estimated threshold. Using this technique the program is only able to determine the instrumental magnitude if the sources. The result from the zeropoint calibration, performed in (3.1) becomes important now to get the corresponding apparent magnitudes. After finishing the iterative process for both images we get a list of all stars which could be detected by `starfinder`.

3.3 Color Magnitude Diagram for BS90[14]

To finally obtain the CMD for our cluster we need to match the stars found in booth pictures. This cross matching process is done with the help of the Python script `match-stars.py` located on our working computer. We are now able to plot the CMD (V versus V-I) and fit matching theoretical isochrones by varying different parameters in the script used for plotting (`cmdplot.py`)such as the **shift** of the image, the **metallicity** or the **age** of the cluster.
The result is presented in figure (3.3):

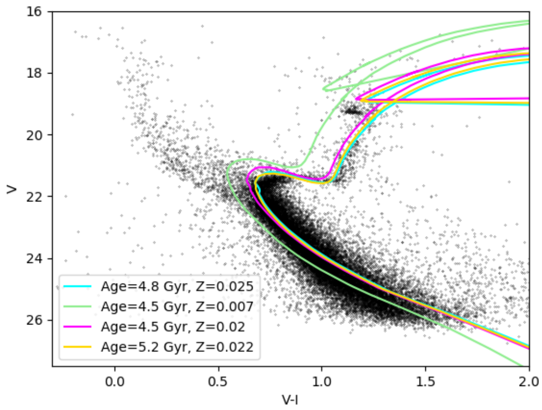

Figure 3.3: Color Magnitude Diagram with theoretical isochrones for BS90[14]

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