



**University of
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Astrophotography Practicum AST 244

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Abstract

This work is a summary of the astrophotography practicum (AST 244) taken in July 2016.

It contains all necessary information, e.g. location, devices and software, that were used in order to make an astrophotography picture of the Andromeda galaxy. Because the target is very large, the final result of this work is an image, which is made out of a professional photography from the NOAO observatory underlying the obtained image. It will be shown that a good post process of the pictures allows to see the main features of M31, with an exposure time of four minutes per picture and only five filters (light, red, green, blue, H- α). A brief introduction to the topic of telescopes, CCD cameras and the history of M31 observations will also be given as well as a brief summary and a discussion at the end.

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Chapter 1

Introduction and experimental set up

Astrophotography is the subject of taking pictures of astronomical objects like stars, galaxies, nebulae or planets.

In contrast to everyday life photography, where a simple digital camera is needed, this task is more complicated and it requires a solid knowledge of CCD Cameras. Additionally further knowledge of the night sky, of the astronomical object and the telescope is needed. The desired target and the available equipment need to match up in order to make a good quality picture.

Therefore this report will not only describe the methods which were used but also describe the equipment and target.

This work will begin with the description of the equipment and its corresponding software. A description of the post process and the final result will follow and at the end a brief conclusion and a discussion, about the practicum will be given .

1.1 Telescope

Every telescope that is able to take pictures of the night sky over a long period of time (needed in order to make pictures of deep field objects) consists of three parts:

- The mount
- The tripod
- The tube.

All components will be described in the following two subsections of this chapter, 1.1.1 and 1.1.2.

1.1.1 Mount and tripod

The mount of the employed telescope is an equatorial and electrically powered mount called: EM-200 (Temma 2M). Since such a mount is electrically driven and handled with the help of a computer it has to be polar aligned and connected to the 'Pegasus21' Tracking Software in order to make it functional.

The polar alignment of the mount can be achieved with the help of an internal polar scope and a compass¹, used to place the tripod. The tripod has to be leveled with the help of a spirit level, which is important to assure that all adjustments will be accurate enough and not change with time.

The difficult part of alining the telescope is placing polaris at the right position inside the scope. Therefore, to assure an accurate placement, the free iPad app 'PS Align' was used (see figure 1.1).

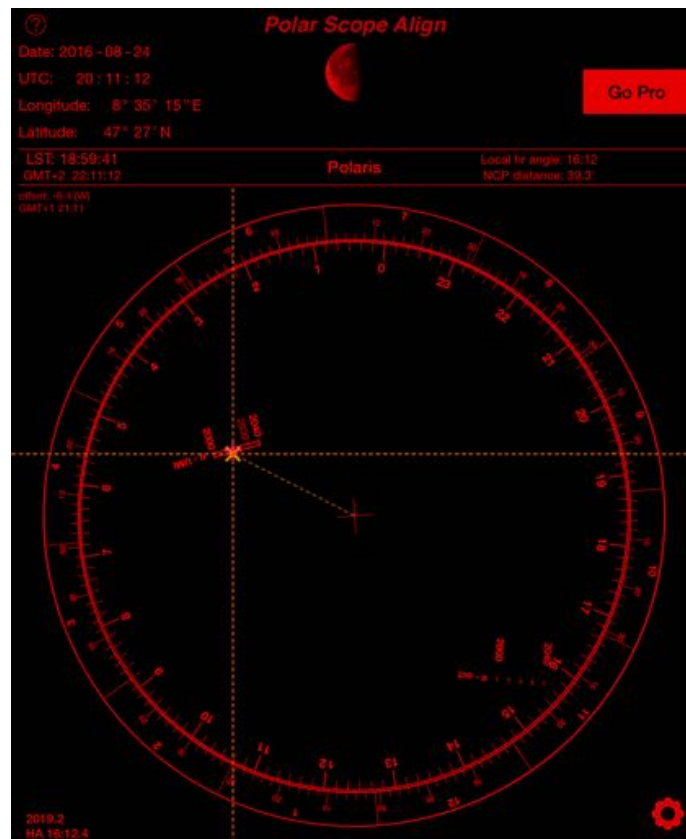


Figure 1.1: Screenshot of the polar scope align software 'ps align'. The app is capable of simulating multiple polar scopes for different telescope models. Source: Screenshot.

¹The internal iPhone compass was sufficient enough

1.1.2 Tube

After positioning the mount and the tripod, the main tube can be installed. In this case the tube is a Takahashi Ortho-Apochromat Triplet Refractor (TOA-130), see table 1.2.

The first refracting telescope was invented by Hans Lippershey, Zacharias Janssen and Jacob Metius in 1608 [18]. Its aim was to combine more information about an object than a normal human eye could ever do. The details of the observed image were captured with the help of focusing lenses, at the end of the tube. An Apochromat Triplet Refractor includes three of those focusing lenses inside the tube (figure 1.1) and therefore it can focus all colors at one single point at the end of the telescope. Due to this feature the telescope can minimize 'false' color halos, which can arise out of the different focal points of each separate color² or more precisely as a result of the change of the focal point as function of wavelength.

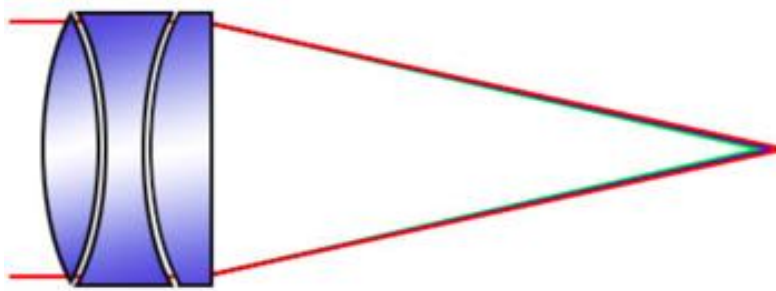


Table 1.1: A schematic illustration of a three lensed system and its ray path. A system like this is called Apochromat. Credit: <http://www.opticaluniversescientificinstrument.com/product-1634522.html>

1.2 CCD-Camera

The CCD Camera employed is, as mentioned at the beginning, more complex than a simple digital camera. In contrast to a normal device, the camera only registers photons and therefore does not output a colored picture, rather just a grayscale picture.

Since the light of astronomical objects is faint, taking images of those objects requires a long exposure. For example the Andromeda galaxy needs an exposure time of at least four minutes in order to show its features.

The advantage of CCD cameras is that they can sum the incoming light over

²Nevertheless this effect is small, about 1/2000th of the focal length.

1. INTRODUCTION AND EXPERIMENTAL SET UP

Property	Value
Effective Aperture	130 [mm]
Focal Length	1000 [mm]
Focal Ratio	1:7.7
Resolving Power	0.89 [arcsec]
Limiting Magnitude	12.3
Light Gathering Power	345x
Main Tube Diameter	156 [mm]
Finder Scope	7x50 6.3 [arcsec]

Table 1.2: The main properties of the Takahashi TOA-130.

CCD Chip	ABG	Color mask	Resolution	Pixel size	Imaging area
KAF 8300 Monochrome	>1000x	None	3358 x 2536	5.4 x 5.4 [μm]	18.1 x 13.7 [mm]

Table 1.3: Details about the CCD camera and its main features.

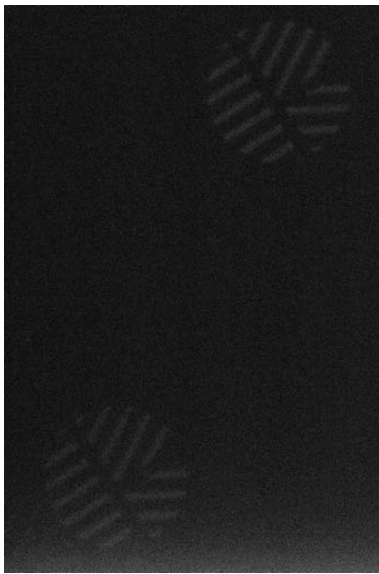
a long period of time and thus depict images which cannot be seen with the naked eye.

The downside of this method is that the camera must be kept in an environment as dark as possible, otherwise it will record also photons which are not from the target.

After the light information reaches the camera (a charge-coupled device (CCD)), it needs to be processed (or mediated) to another device. In order to do this the CCD, records photons and subsequently moves the information via electric currents to pass the information to other systems. Since a CCD can only yield a grayscale picture, some cameras (LRGB cameras) have already three inbuilt filters held in front of the CCD chip, which instantly generate a colorized picture. Despite this method is being easier for the post process, the downside is that the number of filters is fixed and it can not be altered; therefore more detailed pictures in certain narrow wavelength bands are not possible.

The CCD Camera used is a Moravian G2-8300 [6] (table 1.3). In order to produce (after the necessary post processing) a colored picture, the G2 camera comes with four filters and thus five possible recording modes: (a) Visible (No Filter), (b) Red, (c) Blue, (d) Green and (e) H- α .

An important thing to bear in mind is that this device is a high precision device, which means that it will also record thermal noise. To reduce the this noise (made mostly by the camera itself) the camera, or at least the



(a) On this side the unfocused image can be seen. Clearly the Bathinov mask can be seen. Additionally the CCD camera records a multiple pictures on its sensor.



(b) In contrast to 1.2a there is only one focused image. The goal of focussing is to bring out the 'star' shape of the mask and make it as sharp as possible. If this can be reached then the camera is in focus.

Figure 1.2: This two figures show the use of a Bathinov mask. The Bathinov mask is one possibility to focus the telescope and therefore get sharp and precise images.

CCD chip, needs to be cooled. In this practicum the camera was cooled down to a temperature of minus 15 degrees Celsius.

Another problem is that the area of the chip is not overall the same (some pixels might be more sensitive or information might get lost during the transport in certain cells).

Nevertheless this problem, as well as the thermal noise problem, can be reduced with a good post process of the images (see in chapter 2).

In order to make clear and sharp pictures, the camera must be brought into focus. Normal digital cameras will do this automatically or will allow to choose the desired object in the preview window and focus afterwards. In the case of a CCD Camera, this has to be done manually. One way to do this is to apply a Bahtinov mask [17]. An illustration of this process can be seen in figure 2.2.



Figure 1.3: An example image of an unguided image. This has been done before the autoguider has been installed in order to show the difference between an unguided and guided image. It is obvious that the mount movement (after the alignment) is not sufficient for long exposure photography.

CCD Chip	ABG	Color mask	Resolution	Pixel size	Chip area
ICX424AL	yes	None	656 x 494	7.4 x 7.4 [μm]	4.9 x 3.7 [mm]

Table 1.4: Technical details of the autoguider, which was used to obtain the astronomical images.

1.2.1 Autoguider

Since stars are moving in the sky the CCD camera, thus the whole telescope, have to move according to the sky. Although the mount is aligned with the help of the location of the northstar, this procedure is usually not precise enough to keep up with the desired target. The target does not stay at the same position in the camera frame and this yields a pattern along the screen, see figure 1.3. In order to correct for this an auto guider (Moravian G0-0300) can be used. This additional camera looks for stars in the image frame and correct for the insufficient movement of the mount. This leads to a clearer image and the possibility of having long exposures and multiple frames of one target.

1.3 Location and Date

The location needs to be chosen carefully and it should be as dark as possible, quickly reachable³ and allow a good view on the desired target (e.g. no surrounding buildings or walls). For this work I have chosen a rooftop in Kloten (Longitude: 8.5983, Latitude: 47.4612 and a height of 435m). There are several reasons for this choice:

- Many ideal targets can be observed from that position.

³Since the telescope needs to be taken outside for several days in a row.

1.4. Target

Messier Catalogue	Right ascension	Declination	Distance [ly]	Apparent magnitude [mag]	Diameter [ly]
M31	0h 42m 44.31s	+41°16' 09.4''	$2.5 \cdot 10^6$	3.5	140 000
M101	14h 03m 12.6s	+54° 20' 57''	$22 \cdot 10^6$	7.86	170 000
M81	09h 55m 33.2s	+69°03' 55''	$11.8 \cdot 10^6$	3.5	95 000
M33	1h 33m 51.02s	+30°39' 36.7''	$2,8 \cdot 10^6$	5,7	50 000-60 000

Table 1.5: A list of the possible targets, which could be observed from the telescope location. All objects are described by their corresponding Messier Catalogue name. Even if M101 is the largest object it is also the faintest, due to its distance to our solar system. The object which can be observed the best is M31, since it is very close to the earth and its apparent magnitude is the biggest among the picked objects.

- The weak battery requires a location which is quickly reachable (multiple observation days)
- Since the weather proved to be unpredictable during the time of photography such place was ideal, to quickly hid the telescope when needed.

Although the time of disposal of the equipment was a couple of days, the final images were taken on 24.07.2016. During this day the sky became only partially clouded and Andromeda was visible for approximately three hours.

1.4 Target

Before choosing a target it is necessary to make a list of all available targets, which can be observed at the desired date and time in the chosen location. The free program 'Stellarium' [15] can handle this task in advance and also simulate the used telescope. Although Stellarium takes the planetary atmosphere into account it is not possible to consider light pollution, therefore it can be used only as an upper benchmark.

As a starting point for the choice of possible targets, the Messier catalogue provides a good overview. After cross-referencing the catalogue with the Stellarium 'simulations' a final target list can be constructed. The potential targets for the chosen locality can be seen in table 1.5.

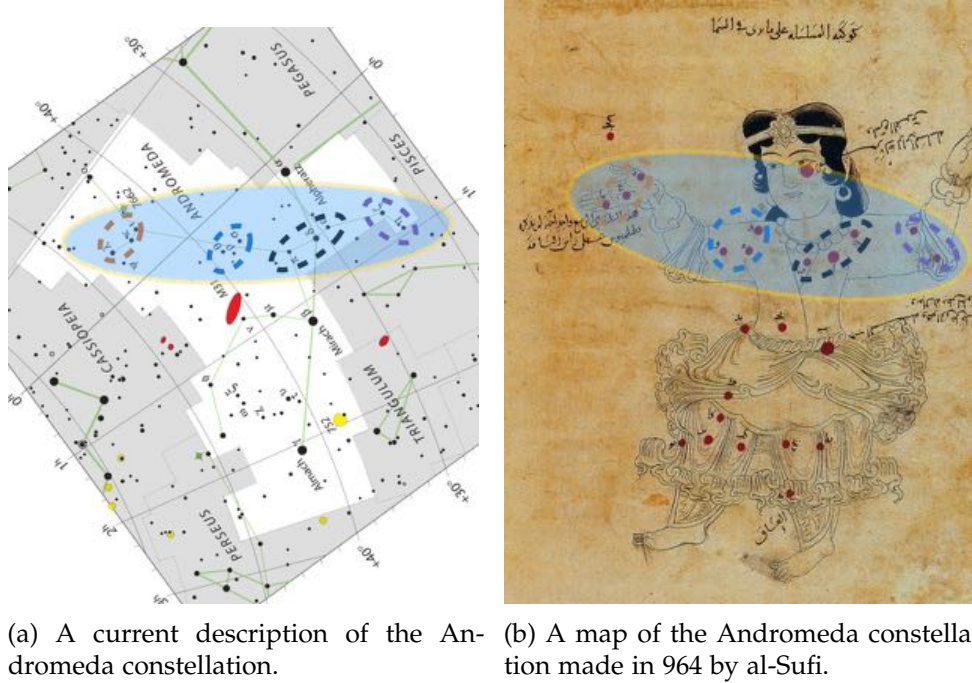


Figure 1.4: A comparison between the star positions in the Andromeda constellation made today and approximately 1100 years ago. The exactness of the right image is remarkable, considering the image has been made only by simple observations.

1.4.1 Andromeda M31

On the observation day, 24.07.2016, the best observable object was the Andromeda galaxy. This section will give a brief overview of the andromeda galaxy and its observational history.

Since the andromeda galaxy can even be seen by the naked eye, it was already discovered in 964 by the Persian astronomer Abd al-Rahman al-Sufi (see figure 1.4b). However al-Sufi identified M31 as a little cloud and not as a galaxy. In 1612 Simon Marius observed Andromeda with a telescope and thought it to be a great nebula. The first picture of Andromeda was made by Isaac Roberts in 1887 [16]. As shown in table 1.5 the Andromeda galaxy can be found within the constellation of Andromeda (a schematic map of this constellation can be seen in see figure 1.4a). A closer look at Andromeda shows a few well known objects: HIP 3447, HIP 3333 and HIP 3293. The M32 galaxy can be also found in the field of view (see figure 1.5); these objects will reveal their importance in the final section.



Figure 1.5: A detailed image of M31. The main features of the galaxy (M32, HIP 3447, HIP 3333 and HIP 3293) are highlighted in order to be used as guiding points later on.

Chapter 2

Post process

After the telescope and the camera are set up as explained in the chapter before and the images are taken, the gained pictures can be processed. This section will explain how to deal with the images produced by the CCD camera, the so called raw images (R).

The original CCD pictures from the camera are really dark and contain a lot of noise (figure 2.1). In order to remove this and bring out the real galaxy features the following procedure was applied:

1. First use the Deep Sky Stacker (DSS) to remove flats, bias and darks from each image and convert the image into tiff format.
2. Work out the visible information on each image with Photoshop. This will make the stars in the images more visible and will allow the DSS software to find an appropriate number of stars for stacking.
3. Stack each filter separately.
4. Post process pictures with Photoshop and use Noise reduction.
5. Stack each filter with Photoshop.

This steps might seem unnecessary or even confusing, but they will be explained in detail in the following chapters.

2.1 Deep Sky Stacker I

Before starting with the stacking process and image enhancement, each picture will be processed individually. This step is needed since light pollution has to be reduced in each image individuals, as the camera noise. In order to achieve this the flat (figure 2.2c), bias (2.2b) and dark (2.2a) frames have to be subtracted from each image. Mathematically this step could be also



Figure 2.1: The output of a single frame by the CCD camera. It is not possible to obtain any information out of this image and the stacking process becomes impossible.

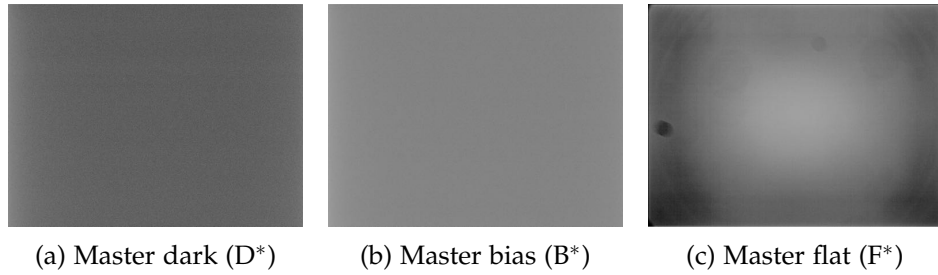


Figure 2.2: Collection of all master frames. For the D^* frame 12 single frames and for the B^* frame 16 frames have been used. To obtain the flat master frame five single frames with exposure of 0.1 seconds have been used.

done after the stacking process, nevertheless the stacking result will be better if each image will get enhanced separately and stacked afterwards. The reason for this is quite simple: The Deep Sky Stacker software [8] searches for fix points in the images and subsequently stacks them. However if an image has less than 8 stars (such original CCD image of 2.1), the software ignores the image and does not stack it. To resolve this issue the software suggests to decrease the threshold radius of a star and search the image again. Applying this method can lead to a radial threshold of a single pixel and therefore pixel noise can be mistaken as a star.

The DSS software uses an inbuilt function which subtracts the flat (F), dark (D) and bias (B) images from the raw image (C). The scheme can be seen in figure 2.3.

Translating this into formulas will yield the same equation for the subtrac-

tions of the D-frames and the F-frames as given in the course notes. To simplify the math, it is assumed that the master frames (marked with a *) are created with the help of simple mean values, although in the real process the median method has been used.

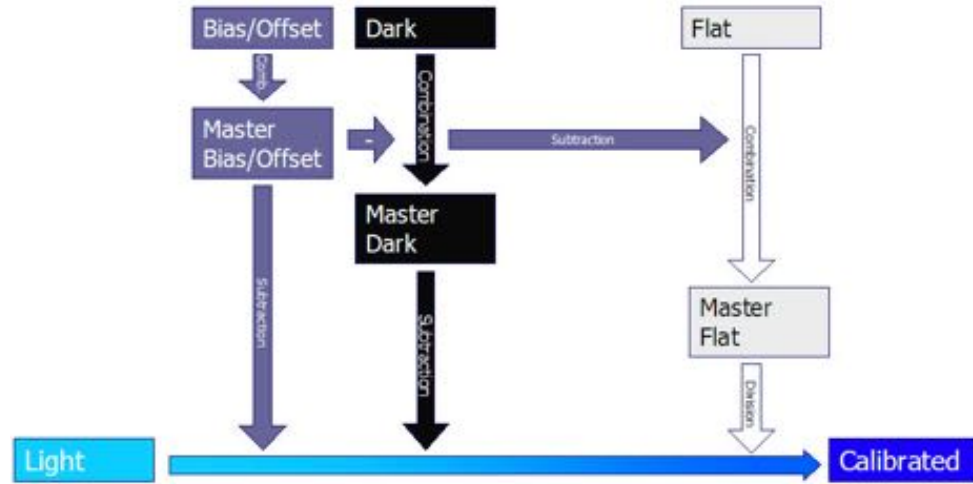


Figure 2.3: A schematic figure of the subtraction of the correcting master frames. First the master bias/offset (B^*) frame gets subtracted from the raw light image (R) and afterwards B^* gets also subtracted from each single dark frame (D) before creating a master dark (D^*). In the next step a master flat (F^*) is generated, by subtracting the D^* from each single flat frame (F). In contrast to the master dark frame, the F^* frame will not be subtracted from the raw image, instead the R will be divided by a normalized F^* and a corrected image (C) will be obtained. The Image is taken from the DSS software help page [9].

- Bias/Offsets:

The master bias frame is calculated as a mean value of all bias frames

$$B^* = \langle B \rangle = \frac{1}{n_B} \sum_{i=1}^{n_B} B_i. \quad (2.1)$$

- Darks:

The master dark is calculated as the the mean value of dark frames

subtracted individually with the master bias frame:

$$\begin{aligned}
 D^* &= \frac{1}{n_D} \sum_{j=1}^{n_D} (D_j - B^*) = \frac{1}{n_D} \sum_{j=1}^{n_D} D_j - \frac{1}{n_D} \sum_{j=1}^{n_D} B^* \\
 &= \frac{1}{n_D} \sum_{j=1}^{n_D} D_j - \frac{1}{n_D} \sum_{j=1}^{n_D} \frac{1}{n_B} \sum_{i=1}^{n_B} B_i \\
 &= \frac{1}{n_D} \sum_{j=1}^{n_D} D_j - \frac{1}{n_D} \frac{1}{n_B} \sum_{i=1}^{n_B} B_i \\
 &= \frac{1}{n_D} \sum_{j=1}^{n_D} D_j - \frac{1}{n_B} \sum_{i=1}^{n_B} B_i.
 \end{aligned} \tag{2.2}$$

- Flats:

The same procedure is used for the master flat frame

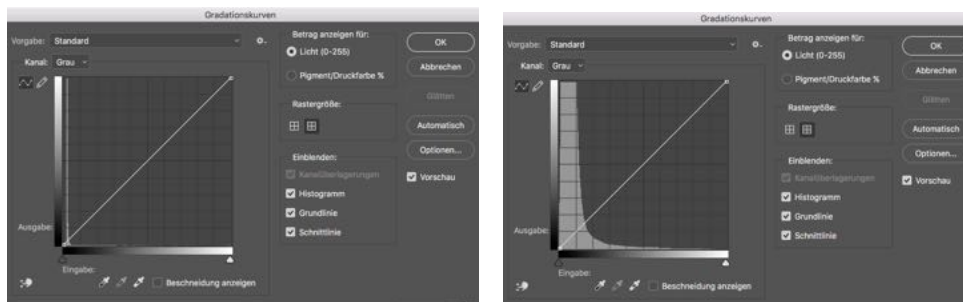
$$\begin{aligned}
 F^* &= \frac{1}{n_F} \sum_{k=1}^{n_F} (F_k - D^* - B^*) \\
 &= \frac{1}{n_F} \sum_{k=1}^{n_F} (F_k - (\frac{1}{n_D} \sum_{j=1}^{n_D} D_j - \frac{1}{n_B} \sum_{i=1}^{n_B} B_i) - (\frac{1}{n_B} \sum_{i=1}^{n_B} B_i)) \\
 &= \frac{1}{n_F} \sum_{k=1}^{n_F} F_k - \frac{1}{n_D} \sum_{j=1}^{n_D} D_j.
 \end{aligned} \tag{2.3}$$

After creating the master frames the program will remove them from the raw image (R) and return a processed image (C):

$$\begin{aligned}
 C &= \frac{R - D^* - B^*}{F^* / \langle F^* \rangle} \\
 &= \frac{R - (\frac{1}{n_D} \sum_{j=1}^{n_D} D_j - \frac{1}{n_B} \sum_{i=1}^{n_B} B_i) - (\frac{1}{n_B} \sum_{i=1}^{n_B} B_i)}{(\frac{1}{n_F} \sum_{k=1}^{n_F} F_k - \frac{1}{n_D} \sum_{j=1}^{n_D} D_j) / \langle F^* \rangle} \\
 &= \frac{R - \frac{1}{n_D} \sum_{j=1}^{n_D} D_j}{(\frac{1}{n_F} \sum_{k=1}^{n_F} F_k - \frac{1}{n_D} \sum_{j=1}^{n_D} D_j) / \langle F^* \rangle} \\
 &= \frac{R - \frac{1}{n_D} \sum_{j=1}^{n_D} D_j}{\frac{1}{n_F} \sum_{k=1}^{n_F} F_k - \frac{1}{n_D} \sum_{j=1}^{n_D} D_j} \langle \frac{1}{n_F} \sum_{k=1}^{n_F} F_k - \frac{1}{n_D} \sum_{j=1}^{n_D} D_j \rangle
 \end{aligned} \tag{2.4}$$

In contrast to the master bias and master dark frame the program does not subtract the master flat but rather divides the raw image by a normalized flat image.

The obtained result is the same as in the lecture notes: $'(raw - dark) / [(flat - dark) * (mean flat - mean dark)]'$.



(a) Before the curves adjustments.

(b) After the curves have been manipulated.

Figure 2.4: An image made by the CCD camera will be mostly black and therefore the curves level will only show a thin vertical line (2.4a). In order to bring out the features of the object, the curve has to be grabbed in the middle and pushed approximate half a square to the top. This step has to be repeated several times (in combination with the mask function, figure 2.6, and the levels, figure 2.5). The final result should look equivalently to figure 2.4b. If the curves tool will start to show peaks in the distribution then the image has been modified to abruptly or already to much.

2.2 Photoshop I

The images have now been cleared from artificial noise, but they still do not show enough features to stack them.

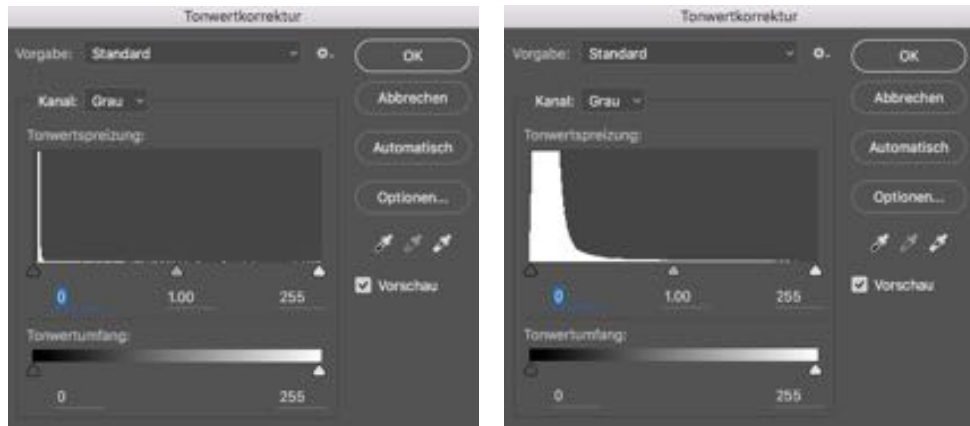
Hence photoshop [2] must be applied in order to highlight the stars in the images. This can be achieved with the curves and level tools, a method advised by nearly all tutorials and books ([13], [5] and [7]).

However applying this methods might yield a large loss of information in the center of Andromeda, since the information gets 'cutted'. In order to avoid this a mask is added to each layer after each single editing step. The whole procedure may be described as the following:

- Application of the curves tool.
- Application of the level tool, cutting of a few cells at the dark corner (left corner), but without cutting of any visible cells.
- Creation of a negative mask, which is applied to the new image (figure 2.6).
- Repetition of those steps until a change as in figures 2.4b and 2.5b in the curves and level tools can be seen.

The application of a mask prevents the level and curves tools to change the regions which are dark in the mask image. Applying this method for approximately 20 steps yields an images similar to figure 2.7.

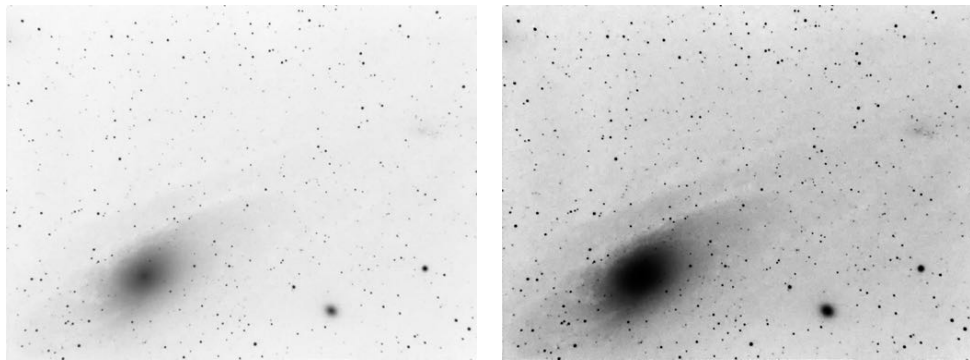
2. POST PROCESS



(a) Starting point of the level tool.

(b) After the adjustments a stretched and slightly cutted histogram can be seen.

Figure 2.5: The levels tool is needed to cut out the pixel which are too dark and therefore allow a better adjustment with the curves tool. The cutting process should only be done in the lower left corner (the dark pixels) and not in right corner, otherwise information of the galaxy details will be lost. The manipulation should be stopped after both the levels and curve tools, yield a satisfying result.



(a) A negative mask at the early post process.

(b) The mask of the same image as in 2.6a to a later moment.

Figure 2.6: If the images would be processed simply as shown in figure 2.4 and 2.5 the details of the galaxy would get blurred out. A solution to this problem is to apply a mask to the image. The dark regions in the mask will be only proceeds according to their darkness: completely dark pixel will not be processed and completely white pixel will be processed as the image pixel without a mask. In between the pixels will be change according to the grayscale level.



Figure 2.7: The result of the first stage of post processing. This image show more details than the same image with no adjustments (figure 2.1). Thus the images can be now stacked with Deep Sky Stacker.

2.3 Deep Sky Stacker II

After preparing the images as described, all images of one filter can be stacked with Deep Sky Stacker. The idea behind stacking is to increase the signal to noise ratio (SNR) and to bring out the details of the observed target (see figure 2.8). For the stacking process there are three pictures for each color filter and five images with no filter available. Each frame has been made with an exposure time of four minutes and the same camera temperature (-15 degrees). The results of the stacking process can be seen in figures 2.9, 2.10 and 2.11. A combination of all images would yield a total exposure time of 68 minutes¹.

Unfortunately, the sky was not as clear as desired and therefore only the best pictures in each filter were chosen. As such, as seen in table 2.1 the total exposure time of the selected images is only 36 minutes. Nevertheless this restriction yields a better result in the end than all 68 minutes combined.

¹Not counting the time for dark, flat and bias frames.



(a) A single not stacked frame.



(b) Stacked image, which contains 32 single frames.

Figure 2.8: An illustration of the stacking process. On the left side a single frame can be seen and on the right sight a stacked image with 32 images can be seen. Clearly the stacked image has a higher SNR and therefore provides a clearer image. Stacking multiple pictures will enhance the final result tremendously. Figure has been taken from the DDS homepage [9].

Filter	Number of frames	Used frames
No Filter	5	3
Red	3	2
Green	3	2
Blue	3	1
H- α	3	1

Table 2.1: Number of frames obtained in each filter and the corresponding number of frames used in the individually stacked master frames.



Figure 2.9: The stacked image of the red filter. The image clearly has a higher SNR compared to a single frame (figure 2.7). Nevertheless the image is not processed to the full potential and still contains details in the dark pixels.

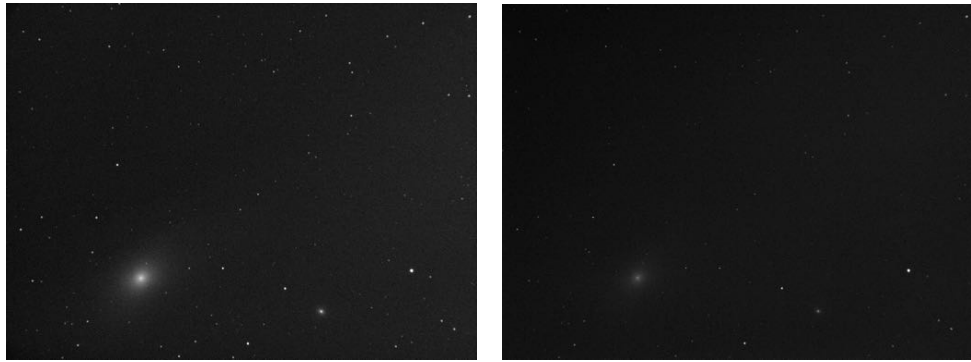


(a) No filter image.



(b) Green filter image.

Figure 2.10: Further results of the stacking process in the different filters.



(a) Blue filter image.

(b) $H\alpha$ filter image.

Figure 2.11: The last two images of the blue and $H\alpha$ filter. Unfortunately both results do not yield a satisfying image.

2.4 Photoshop II

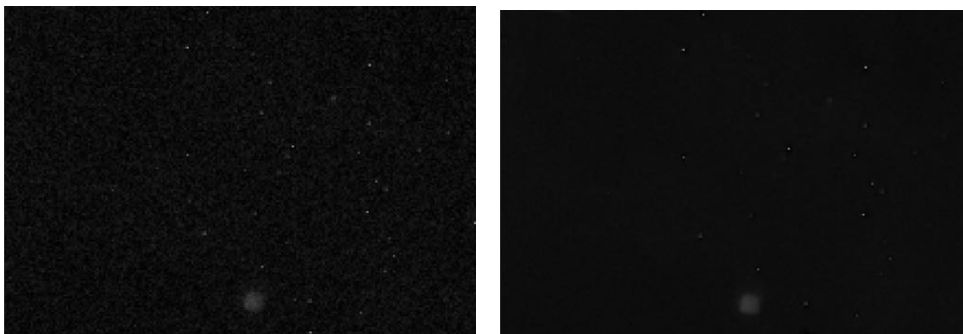
After preparing the master frames for each color the post processing can continue with further refinements achievable through photoshop.

2.4.1 NIK collection

A useful tool in this second photoshop processing is the 'dfine 2' option from the google package 'NIK collection' [10]. This software can be freely downloaded and used with photoshop. The 'dfine 2' option is capable of reducing the noise to a remarkable extend. As an example a small window from a master frame has been taken and processed with the tool (figure 2.12). The improvement achieved through this method is obvious. However if the dfine tool is applied to the whole image it may be possible that some faint features (e.g. stars) could be interpreted as noise and therefore be reduced. In order to avoid this a negative mask, as done in section 2.2, has to be applied once again.

2.4.2 Colored filter images and final adjustments

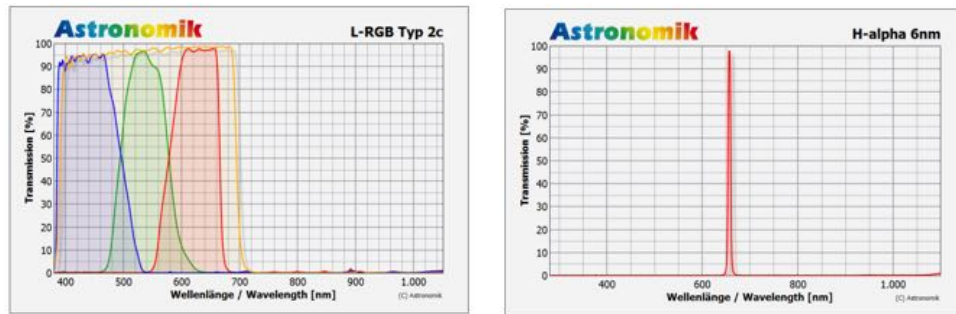
After reducing the noise in each master image the images may be colored accordingly to their physical meaning. As described in section 1.2 the CCD camera was able to record images in four different filters. In figure 2.13a the luminous, red, green and blue image filter wavelength can be seen. It is reasonable to color these filters according to their names, since these are the colors the human eye would perceive. The no filter image is kept as a normal grayscale image, since it will be used later in photoshop as an additional 'luminous' layer.



(a) The input image with a lot of noise. (b) The processed image, where the 'dfine 2' tool was used.

Figure 2.12: A comparison of an unprocessed image and a corrected image by the 'dfine 2' tool from google's 'NIK collection'.

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(a) The wavelengths of the main three filters (RGB) and the whole luminance image. Credit: <http://www.astronomik.com/en/photographic-filters/l-rgb-filtersatz.html>

(b) Graphical representation of the narrow band wavelength filter: H- α . Credit: <http://www.astronomik.com/en/photographic-filters/h-alpha-6nm-ccd-filter.html>

Figure 2.13: The figure shows the different wavelengths used. The color of the lines are the real physical colors as well as their intersection. The overall luminance image ('no filter') is represented as a yellow curve, in order to represent 'light'.

The H- α filter yields a different picture. Since H- α is in the range of the red filter the methodology applied to the other filters would imply that the color for this filter should be also red (2.13b). But obviously this is not desirable, since the additional details due to this narrow band filter would become invisible. To avoid this, the image will be colored, as in most astrophotography pictures, with a dark brown color.

With the help of this new color the HII regions can be seen, which are known as the birthplaces of the stars. The HII regions contain large amounts of ionized hydrogen and therefore they also emit light at the H- α frequency (see figure 2.14).

The colored images can be seen in figures 2.15, 2.16 and 2.17.

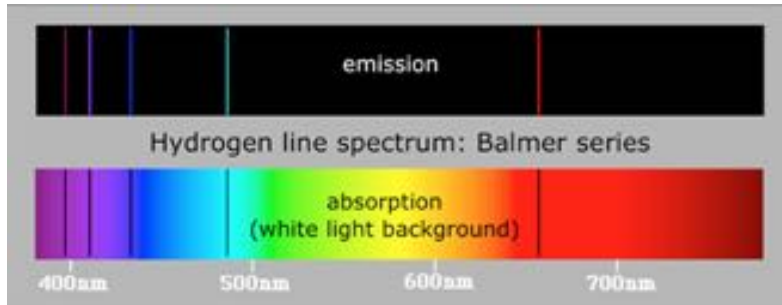


Figure 2.14: The first five emission lines of the Balmer series of an ionized hydrogen atom: H- ϵ , H- δ , H- γ , H- β , and H- α (from left to right). Thus with a narrow band filter at 656.28 nm the H- α line and therefore the ionized hydrogen can be observed. Credit: <http://www.quarkology.com/12-physics/98-quanta-quarks/98A-bohr-model.html>

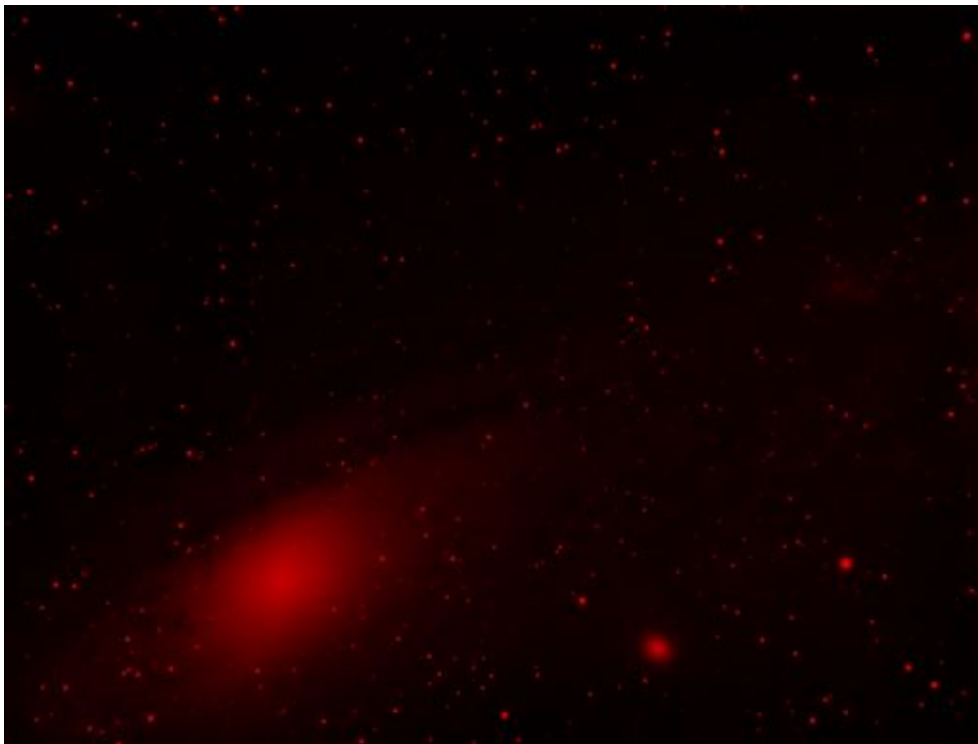
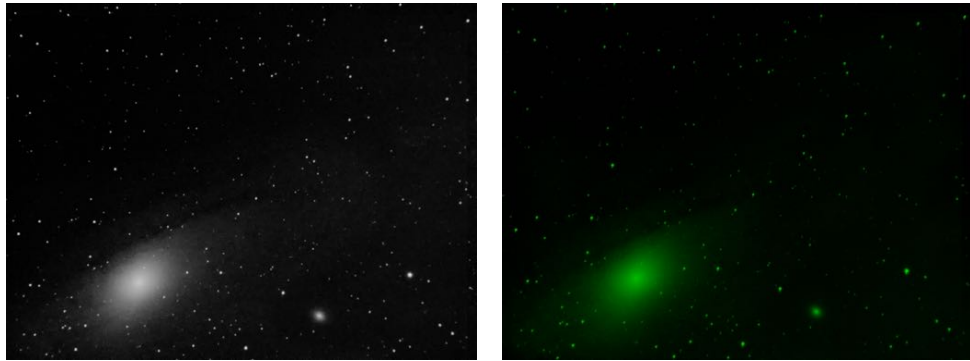


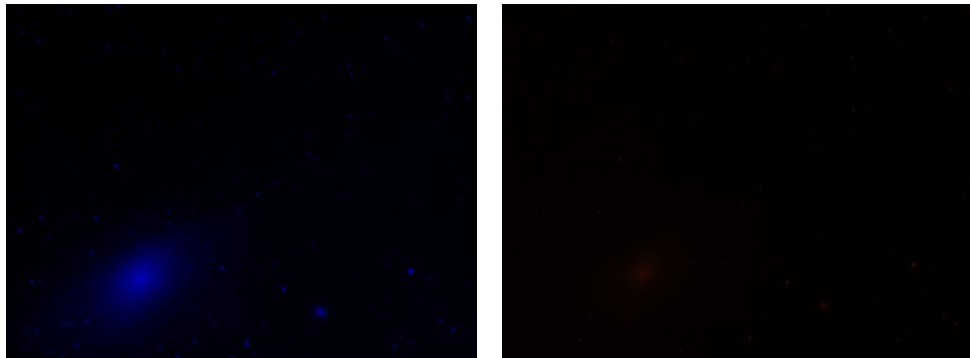
Figure 2.15: The red colored filter. This image was made out of the two best frames made by the red filter, after they were stacked and post processed with Photoshop.



(a) A light image stacked from three single light frames.

(b) The green channel image composed from two individual frames.

Figure 2.16: Colored and post processed image of the green color filter and a stacked light image.



(a) A single blue image processed to its limits with photoshop.

(b) H- α filter image. In order to represent this filter a dark brown color has been chosen.

Figure 2.17: Simple frames colored according to their filter and post processed with Photoshop.

2.4.3 Final stacking

Normally the processed images would get stacked again with the DSS software, but as in this case the software might have problems to handle the colors of the separate filters. As it can be seen from see figure 2.18 the separate images are aligned perfectly [the offset is also calculates with great precision], but the different colors are not being combined to a single RGB image. Instead, the image shows the color of the dominating layer and, therefore, single colored areas can be seen in the final image. In order to cre-



Figure 2.18: The result of the stacking process with DSS.

ate a normally stacked colored RGB image, the single pictures are stacked with photoshop.

For this purpose a new RGB picture is opened and the separate filters are copied in the appropriate color channels. Additionally a new 'luminescence' layer is made containing the grayscale image (no filter). Afterwards a new color channel for the H- α filter can also be made. However the resolution of the H- α filter image was not good enough and had to be left out of the final image.

After copying all single frames in the new RGB image, they need to be aligned. This can be achieved with the help of the DSS software, which already calculated the values for the offsets and rotations during the first

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stacking attempt.

Finally the image can be processed one last time with photoshop, e.g. to erase remaining noise, apply *define 2* or to adjust the curves tool. The final image obtained can be seen in figure 2.19.



Figure 2.19: The observed Andromeda galaxy image obtain after the whole procedure. This image contains of four different filters and a total exposure time of 32 minutes using only the best images obtained on the 24.07.2016.

Chapter 3

Discussion

As already mentioned one of the main problems during this practicum was the short battery lifetime. In a couple of cases it was not possible to obtain any images since the first attempts to set up the telescope lasted about 2-3 hours. Thus the telescope had to be disassembled again before any image could be done. Due to that problem it took about three days to be able to align the telescope, install the needed software and learning how to handle the telescope with the computer. Therefore, if the telescope and the camera could be powered by a normal electrical outlet the results could probably massively improve.

As described in the lecture notes the first images of the camera looked awful and the preparation of the camera and the interplay of a long exposure time and an overexposure of the image took a long time.

Another difficulty was also the connection of the telescope with the computer, since the supplied USB hub was not working. Installing the required software on a different windows notebook solved the problem, thus the telescope and the camera were controlled by two different laptops. To minimize the incoming light from those sources, the computer which aligned the mount was closed¹ and the other one was darkened as soon as the camera started and only switched on after the camera had finished its exposur².

Everything that was needed to obtain an image of an astronomical object was provided and with some additional research easy to operate. The only improvement which could be suggested is an additional screen for the flat images. The obtained flat images in this work have been done with the help of a white computer screen and a white clove to cover the lens [12]. But this is obviously not ideal and could be easily enhanced with a white screen.

¹As tested, the tracking worked even with a closed computer

²Another possibility was a 'red screen', but it did not work very well.

Chapter 4

Conclusion - The bigger picture

After processing the images with photoshop one question arises:

'Is this picture after those enhancements still representing a physical object?'

A first step in answering this question is to look at different images of the Andromeda galaxy and compare them. A good image to start with is the Andromeda image from the National Optical Astronomy Observatory (NOAO), which can be found in the official NOAO homepage [1]. This image was made by a ground based telescope and shows the entire galaxy, including the M101 galaxy.

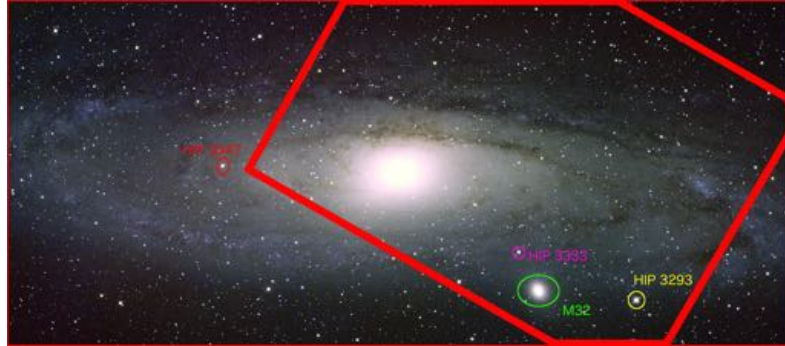
In order to analyze the exact position of the obtained image and of the stars within, the picture is overlapped with the professionally made image of M31 (as seen in figure 4.1). Through this procedure it can be surely verified that the light sources of the obtained image are not due to noise or photoshop enhancement, rather to actual stars. Even though the image was altered with photoshop no artificial stars or details were added. A great achievement of this image is that it contains no light pixels without any background star. This leads to the conclusion that the subtraction of bias, dark and flat frames was successful.

Clearly, not the whole Andromeda galaxy could be captured, since this would require a wider field of view. Nevertheless the main features of M31 could be captured and thus be well compared.

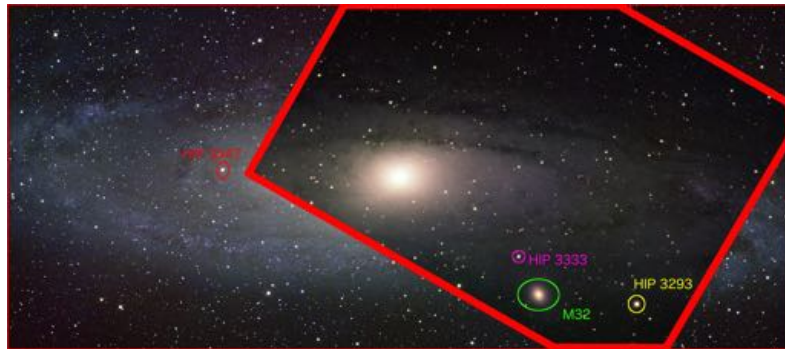
Even though no $H-\alpha$ frame could be added to the final picture the dense spiral arms are still visible. A good picture of the $H-\alpha$ emission lines would enhance this feature even more and a more detailed image of the star forming regions could be made.

Furthermore the picture could also be enhanced if the telescope and the camera would be better focused. Normally this can be achieved with the help of the focus tab in the SIPS software, but since that procedure was not well

4. CONCLUSION - THE BIGGER PICTURE



(a) A picture of Andromeda with M101 and M32. The red square is the position of the obtained image in the practicum. Credit: Bill Schoening, Vanessa Harvey/REU program/NOAO/AURA/NSF



(b) In this frame the final image from the project is overlapped with a transparency of 60 %. It can be seen that the obtained image adapts to the NOAO image very well. The main stars in the image HIP 3333 and HIP 3293, as well as the galaxy M32, are a perfect match.



(c) The final image overlapped with the main NOAO image.

Figure 4.1: A series of different transparencies of the practicum image with a detailed image of M31 from NOAO.

known at that time, the focussing was done with the help of the eyepiece and afterwards with the normal exposure tab. However focussing simply with the help of the bathinov mask is insufficient in order to compare the picture with a well calibrated ground based telescope.

Further improvement could imply a longer exposure time, more single frames and a better clearer sky in front of M31. Unfortunately those parameters are dependent of the weather conditions and the location. The location could be changed (especially the altitude) in order to obtain a less light polluted picture, but in as far as the weather is concerned an enhancement would be only possible with a longer time of disposal of the equipment¹.

All things considered this practicum made all astrophysical observations even more appreciable and showed how much effort has to be done in order to obtain a single astronomical picture.

¹Which is obviously not possible for a practicum.

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