

# Task 1

## Astronomical observations of CY Aquarius with the 70 cm telescope of the LSW

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In this task, you will learn and execute the following basic principles of astronomical observations:

### 1.1 Preparing astronomical observations

### 1.2 Carrying out the observations

### 1.3 Data reduction and analysis

#### 1.1 Preparing astronomical observations

In order to use the telescope and its instrument (a CCD camera) you need first to get familiar with its use. This will be done at the beginning of your observing session, where you will get an introduction by the assistant at the telescope itself.

Since you do not only take astronomical images for your analysis, but also require calibration measurements (biases, darks & flatfields, what it means will you learn later on) you need to find out a couple of things in advance (assume today):

- When does the sun set, when does it rise (in local time)?
- What is the meaning of civil twilight, nautical twilight and astronomical twilight?
- Flatfields are normally taken around the beginning of the nautical twilight. When does it start in the evening?
- Astronomical observations can normally start after the end of/ be done until the begin of the astronomical twilight. At which time can astronomical observations start in Heidelberg?
- What is the meaning of sidereal time? What is the sidereal time at the end of the astronomical twilight in the evening?
- The object, which will be observed as part of the task is CY Aquarius, with the position:  $\alpha = 22^h 37^m 47.82^s$ ;  $\delta = 1^\circ 32' 5.1''$  (2000.0)
- What are the coordinates of CY Aquarius today (Equinox 2011.9)?
- What is the meaning of airmass? What airmass does CY Aquarius have at the beginning of the night?
- You may also observe a Messier object with different filters for fun and create a multi-color image for our own purposes. Select a Messier object of your choice with an appropriate airmass ( $< 1.5$ ) observable about 2hrs after the end of the astronomical twilight. Take into account that we have not only broad-band filters (UBVRI) but also narrow-band filters ( $H_\alpha$ ,  $H_\beta$ , [ O III ]) at our disposal, the latter of which may be used

for observations of gaseous nebulae.

- Since the telescope pointing has to be checked always at the beginning of the night, select a bright star close to the zenith at the beginning of the night. The positions of the targets are normally given for Equinox 2000.0. Determine the positions of the Messier object and the bright star for pointing issues for today (Equinox 2011.9).

Once this is done and everything discussed with the assistant you may start with the observations. Potentially, you'll get an introduction to the "Bruce"-telescope of the LSW, which you may use during your observations for star-gazing in parallel.

## 1.2 Carrying out the observations

The target of the observations is CY Aquarius, which is a short-period Cepheid of type SX Phe with a period of 88 min and V-magnitudes in the range  $m_V = 10.4 - 11.2$ . A finding chart of the target as well as a lightcurve from an amateur astronomer is shown at the end of the script.

### Outline of the observations

**Important:** Make sure to take notes properly (logs can be found at the telescope). You need them later on for the data reduction and analysis.

- Opening dome, startup telescope and setup system.
- Check system by taking a bias frame (not saved).
- Take 10 bias frames first.
- Once it is dark enough, 3 twilight flats in corresponding filters if you plan to observe a Messier object, signal 10000 - 30000 ADU and 5 twilight flats in the V-filter (for CY Aquarius).
- Focusing telescope, determination offset telescope
- Start with the observations of CY Aquarius. In order to have a sufficiently high signal-to-noise, exposure times should be in the range 30-40sec. Make sure that the target is at the center of the CCD and that the bright star  $\sim 5'$  east of Aquarius is on the frame (he will be used for differential photometry). The peak intensities of CY Aquarius and the reference star  $5'$  east should be below 50000 ADU to be sure to work in the linear regime.
- The observations should go on for at least 2hrs to cover a full period of CY Aquarius.
- Do the observations of your Messier object.
- Shutdown system, telescope and closing dome.
- Once everything is done, start some darks using a script (made together with the assistant) with the different exposure times you have used for flatfields and your science exposures, 5 each. Once the script is started you can go home.

### 1.3 Data reduction and analysis - to be done in February

Astrophysical measurements in the optical wavelength regime are nowadays basically carried out with CCDs (Charged Coupled Devices). Compared to photographic plates they have a higher quantum efficiency, a larger dynamical range, repeatable and nearly linear characteristics and a broad spectral sensibility. The incident stream of photons  $S(\omega)$  is detected in each pixel in the form of signal electrons  $N_e(x, y)$  and digitized during the the readout ( $ADU(x, y)$ ).

#### Introduction: General elements of the reduction of CCD measurements

A) Subtraction of additive parts, which are detected during the readout independent of the measured photon distribution.

- 1.) "Bias"
- 2.) "Dark current"

Both currents can be measured with reading out the CCD at closed shutter. The bias should only depend on CCD temperature, the dark current only on temperature and time  $\Delta t$  between two readout processes.

B) Calibration and normalization of the relative sensibility of each pixel.

Assuming linearity the measured signal of each pixel should be proportional to the incident light intensity.

$$\mathcal{S}_{ij} = k_{ij} + \alpha_{ij}I$$

Electronical, mechanical and optical problems produce a constant of proportionality  $\alpha_{ij}$  which is is not constant for all pixel but depending on location. If one exposes a homogeneously illuminated area ( $I = const.$ ), a relative calibration of the  $\alpha_{ij}$  can be determined from the measured signal  $\mathcal{S}_{ij}$ .

C) Absolute calibration of the measurement

After subtraction of the additive parts and normalization of the relative sensibility the corrected Signal signal  $\mathcal{M}_{ij} = b \mathcal{I}_{ij}$  is directly proportional to the incident intensity on the detector. For direct images this corresponds to the intensity distribution of the sky in a certain wavelength interval, for more special tasks (e.g. spectroscopy) it corresponds to the intensity distribution as a function of frequency and location.

Thus more steps are necessary for a proper data reduction. For direct images one has to correct e.g. for possible distortion of the optics to get absolute coordinates ( $\alpha, \delta$  etc.) from the detector coordinates ( $x, y$ ). For spectroscopical measurements one has to convert the detector coordinate into a wavelength scale.

The last step is the absolute calibration which consists of a correction for the Earth's atmosphere and the calibration of the total efficiency of the measuring system (telescope, instrument, detector).

D) Extraction of the information

From the corrected images the interesting physical quantities can be determined. In practice some correcting steps from C) are not required.

In the part of the task you will now reduce and analyze the data taken in the previous night and determine a few characteristic properties of the CCD. CCD images are normally processed and analyzed with a software specifically developed for astronomical applications. Here the software package “MIDAS” (Munich Imaging and Data Analysis Software), which is commonly used in Europe and which was developed by the European Southern Observatory (ESO) will be used. It is freely available (also for PC) at [www.eso.org/esomidas](http://www.eso.org/esomidas).

MIDAS is started with INMIDAS and ended with BYE. With the commands CREATE/DISPLAY and CREATE/GRAPHICS separate windows to display two-dimensional images and graphics, respectively, can be opened.

Below the most relevant commands for the present task are listed.

Further specifications and the detailed syntax of commands can be called up by the internal support within MIDAS (HELP LOAD/IMAGE for example).

Useful MIDAS commands:

HELP (try also CREA/GUI HELP)  
CREATE/DISPLAY  
CREATE/GRAPHICS  
LOAD/IMAGE  
LOAD/LUT, TUTORIAL/LUT  
GET/CURSOR  
PLOT/ROW  
READ/DESCRIPTOR (STATISTICS)  
COMPUTE/IMAGE  
AVERAGE/ROW  
AVERAGE/COLUMN  
STATISTICS/IMAGE  
PLOT/HISTOGRAMM  
SET/GRAPHICS (settnng dynamic range of xaxis and yaxis)  
CL/CH O  
\$ xxx (for Linux applications)

Get familiar with these commands (e.g. HELP, HELP CREATE, HELP CREATE/DISPLAY etc ...TAKE YOUR TIME!!!), Load some of the bias, dark current, flatfield or “science” images and choose an adequate display adjustment. Which parameters can you adjust with LOAD/IMAGE? How do they change the displayed image? What is the meaning of the information in the bottom frame? Play with the other commands as well.

## Characteristics of a CCD, calibration of the CCD, data reduction

The bias images, the dark images and the flatfield images you have been taken shall be used to study:

- a) the read-out-noise
- b) the homogeneity and stability of the bias
- c) minimization of the degradation using the standard correction

Tasks and questions:

- 1) How large is the bias value?
- 2) Is the bias value homogeneous across the field of view and constant as a function of time?
- 3) How can you determine the read-out-noise?
- 6) Which reasons lead to the spatial dependence of the sensibility? Why is  $\alpha_{ij}$  a matrix and not a scalar?
- 7) Plan a best possible strategy for correcting the additive parts of the bias and dark current of raw images and the normalization of sensibility ("bias"-, "dark"- and "normalization"-correction).
- 8) Correct one of your object images and discuss the noise contributions in the raw and reduced images.

A few hints on how to speed up the process: you may create an image-catalog to work on several images in one shot. An image catalog can be created via the MIDAS-command: "creat/icat Katalog Inputbilder", e.g. "creat/icat bias bias\*.bdf". You can average or median-combine images via "aver/ima outputbild = Katalog ? ? median/mean", e.g. "aver/ima biasmedian = bias.cat ? ? median".

## Photometry and lightcurve of CY Aquarius

Since you have many images of CY Aquarius they will be reduced and analysed via scripts with catalogs as input.

Copy first your median-combined Dark- and Flatfield-images to the directory, where your full set of CY Aquarius images is located. In this directory you will find the scripts "photo.prg" and "copy.prg". There you will also find a catalog "in.cat" (with images of CY Aquarius, named "CY\_Aqui\*") and a catalog "out.cat" with the images of CY Aquarius and prefix "r", i.e. "rCY\_Aqui\*"). Now you are ready to reduce and analyse your images in the following order:

- Corection of all images for Dark:  
"exec/cata comp/ima out.cat = in.cat - Darkframe (for your images)"
- Flatfielding of all your images:  
"exec/cata comp/ima out.cat = out.cat / flatfield"

The basic data reduction is now done on all images.

- Now you need to determine the positions of the target and your reference star on all images and to perform aperture photometry of the target and reference star on all images via the script “photo.prg”. The script basically uses two MIDAS-commands. One is “center/gauss” which you will use interactively to determine the positions, the other is “magnitude/rectangle”, which performs automatically the aperture photometry on the stars whose centers you just determined. What you have to do is:
  - To start the script “@@ photo out.cat”
  - The script will load the first image and you get a box in the image display, which you need to center on CY Aquarius first, than click left on mouse, move to the reference star, click again left mouse and finally exit with click on center mouse. Than the photometry is carried out and the next image loaded. Continue until you have worked on all your images. Now you have created n Tables (corresponding to your n Images, with names “grCY\_Aqui\_n) which contain the positions and magnitudes of your target and reference star.
  - In case you need to redo the centering/photometry on one individual image, there is no need to go through the entire catalog again. Just start the script with “@@ photo NameOfImage” and the script will run on just that image.
  - Now you have produced the tables with the positions and magnitudes of your target and reference star. The next step is to merge this information in just one table. Run the script “@@ copy.prg”, which creates a table “photo”, copies magnitudes and their errors from the tables you just made and copies from the headers of the images the exposure time and the start of the observations into it. It finally calculates the differential magnitude between your target and reference star and the error. Finally, it shows you the first 5 entries of the table “photo” in order to judge whether the script went well.
  - Finally, the lightcurve will be displayed. If you have not already done, open a graphics window and plot the contents of the table via:
    - “plot/tab photo :start\_time :diff” (makes the lightcurve)
    - “over/error photo :start\_time :diff :error” (overplots the errors).
  - You can now inspect the lightcurve, estimate the timescale of the variation and its amplitude. You can sent the plot to the printer via “copy/grap laserh”. Once this is done a final discussion on the lightcurve will follow.

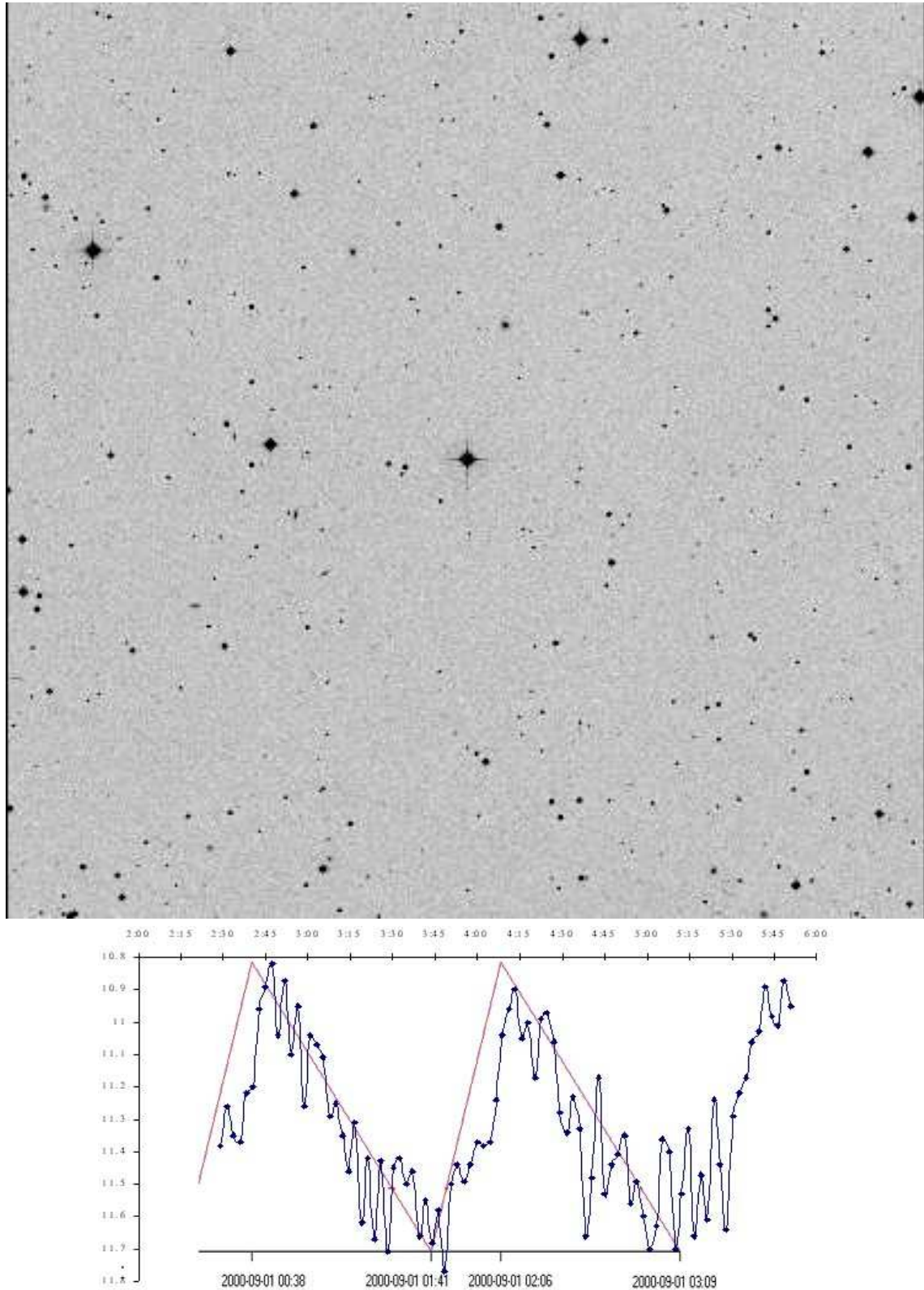


Figure 1: Top: Finding chart for CY Aquarius, field of view  $23' \times 23'$ , north is up, east to the right, object is in the center.

Position:  $\alpha = 22^h 37^m 47.82^s$ ;  $\delta = 1^\circ 32' 5.1''$  (2000.0)

Bottom: Lightcurve of CY Aquarius from an amateur astronomer.