

HPP Observatory

User Guide, Data Reduction and Experiments

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Abstract

This user guide describes the standard procedure for start-up, operation, and shutdown of the HPP observatory as it is adequate for most student projects (e.g. VP-ASL experiments) or for outreach activities. For more functionalities of the telescope, the mount, or the camera see the corresponding manuals. It also contains experiment descriptions and some administrative information. This guide is partially based on the step-by-step user guide written by A. Bazzon in 2015 and revised by N. Engler in 2016.

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1 Instrument specifications

Telescope Planewave CDK20	
optical design	Corrected Dall-Kirkham
aperture	20 inch = 508 mm
focal length	3454 mm
diffraction limit at $\lambda = 500$ nm	0.2 arcsec
focal ratio	F / 6.8
central obstruction	39 % of the primary mirror diameter
back focus from racked in focuser	147 mm
camera SBIG STX-16803	
CCD	KAF-16803
array	4096×4096 pixels ²
pixel size	9×9 μm^2
CCD dimensions	36.9×36.9 mm ²
CCD type	full frame, antiblooming
shutter	even-illumination mechanical shutter
external ports	USB 2.0/1.x and 10/100 MBs Ethernet
telescope + camera	
field of view	36.7×36.7 arcmin ²
diagonal field of view	51.9 arcmin
plate scale	0.54 arcsec/pixel
magnitude limit	TBC



Figure 1: door locks (*right*) and dome locks (*left*).

2 Start-up

Make sure that you follow the next steps in the described order. Turn on the computer in the control room only after section 2.1-5 have been completed.

2.1 Open the telescope dome

In general, observations are only allowed if the dome can be completely opened and locked in its open position. In the winter make sure that no snow or dirt can fall down onto the telescope when opening/sliding the dome. Only push/pull the dome from the inside so that you can check that the telescope fits through the door opening. The dome opening steps are:

- fully open both doors
- make sure the open doors are snapped into their secure locks (they cannot swing back, see Fig. 1)
- release the dome locks (located inside the dome, see Fig. 1)
- check that the telescope is correctly parked and that it will fit through the doors. (if this is not the case, stop all activities and call the HPP responsible or the VP-ASL supervisor)
- push the dome away into its open position
- engage the dome locks
- close the doors

2.2 Remove mirror cover

When the telescope is parked, in particular when it is not used for a long period of time, the primary mirror should be protected by the corresponding plexiglas cover (see Fig. 2). For removing/installing the cover pull back the spandex stray light cover and pass the mirror cover through the bars as shown in Fig. 2.

2.3 Mounting the SBIG camera

The SBIG camera should always be attached to the telescope. If this is not the case or if you intent to use the telescope without camera, see Appendix C for instructions about how to mount or dismount the camera.



Figure 2: Mirror cover.



Figure 3: Strap to fix the loose cable when camera is detached.

Important: if the camera is detached use the strap at the telescope handle to fix the cables! (see Fig. 3)

2.4 Power-on the instruments

In general, all instruments will be powered-on by activating the main power switch (see Figs. 4, 5).

Default setting:

- remote computer - OFF



Figure 4: Overview of electronics: main power switch (circle), remote computer (A), power adapter GM4000 mount (B), router (B), GM4000 control box (C), Delta-T control box (D), (handles to push/pull dome (E)).

- power adapter GM4000 mount - ON
- Delta-T control box - ON
- Delta-T heater switches (Fig. 6, primary, secondary) - OFF (LEDs off)
- CDK Power (Fig. 7, 8) - ON
- CDK fan switch (Fig. 8)- OFF
- SBIG - ON

The power switch of the remote computer is on the backside (see Fig. 9).

Note that the SBIG does not have an on/off switch. It will start-up and initialize as soon as it is connected to the power supply. Immediately after activating the main power switch you should hear the fan of the camera.

2.5 Turn-on GM4000 mount

The GM4000 is a computerized mount and needs to be booted (and shut down after use, see Sect. 3). To start the mount press the on/off button at the GM4000 control box (Figs. 4, 10). Note that although the button looks like a switch it is actually only a button and it will resume its initial position after pressing it (so press the button only once!). After a few seconds the display of the GM4000 hand control will consecutively read *“booting”*-*“starting-up”*-*“version”*-*“initializing”*. Initialization takes about 30 seconds and the mount is ready to use as soon as the display reads the time and date. At this stage, check that time and date

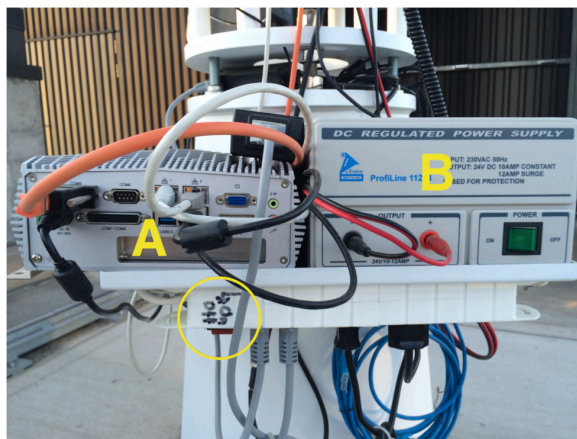


Figure 5: Main power switch (circle). Also indicated are the remote computer (A) and the power adapter for the GM4000 mount (B).

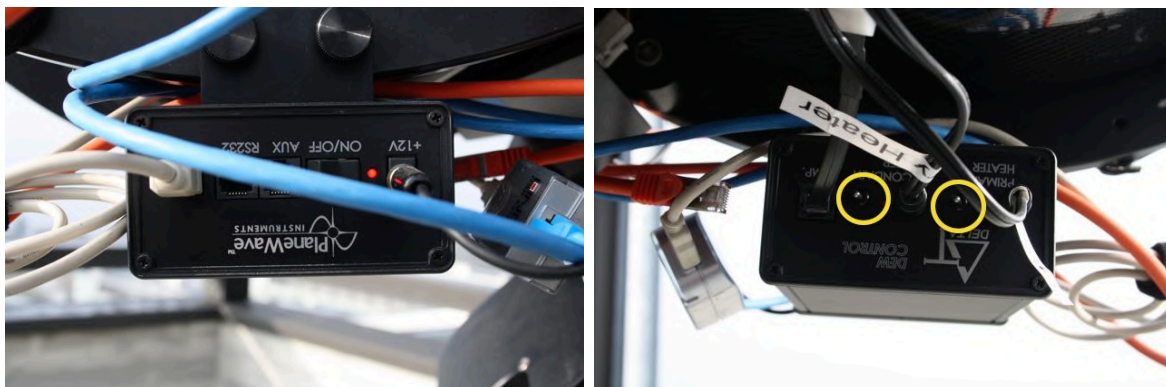


Figure 6: Delta-T control box. Frontside (*top*) and backside (*bottom*). The circles indicate the heater switches in their default positions (OFF, LEDs off).

are correct. In particular, you can check that the time is correct at the second level using <https://time.is>. If incorrect, use the GM4000 hand control to change data and/or time. Go to ‘MENU -> Local data -> Clock -> Date and time’ to change it.

Note that for visual observations the telescope is now ready and can be operated by the hand control. For an overview of the basic functionalities of the hand control see Sect. 4.1.

2.6 Start-up the instrument software

All instruments can be fully operated by software installed on the remote computer outside at the telescope. The computer can be remotely accessed by the control room computer. The computer in the control room has to be turned on **only** after the previous steps have been completed. To connect to the remote computer click on the *Remote Desktop* shortcut (see Fig. 12) and use the login provided by the ASL supervisor. Ignore the warning after clicking on *Connect* and click on *Yes*.

- control room:
username: *optical*
password: *astro%q12*
- telescope computer:

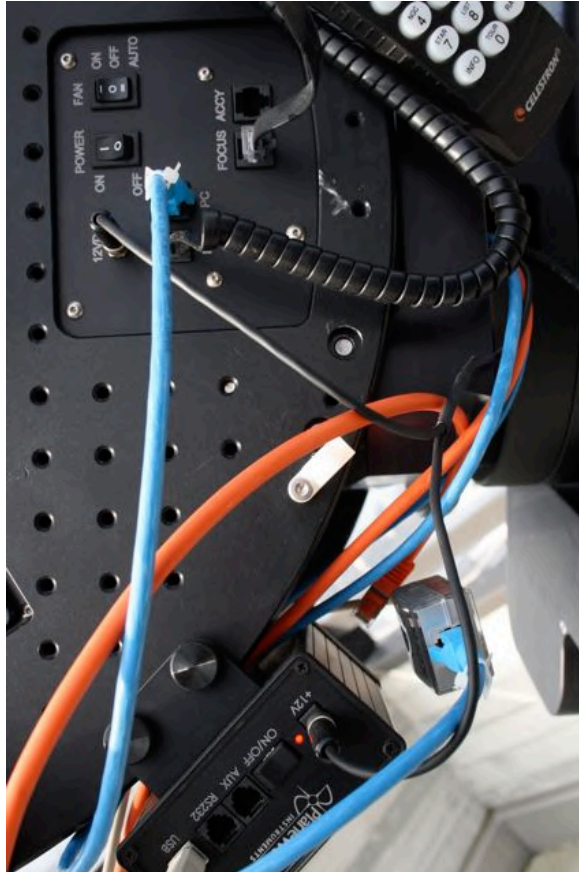


Figure 7: CDK electronics overview with the CDK control panel on top and the Delta-T control box at the bottom (see also Fig. 6).

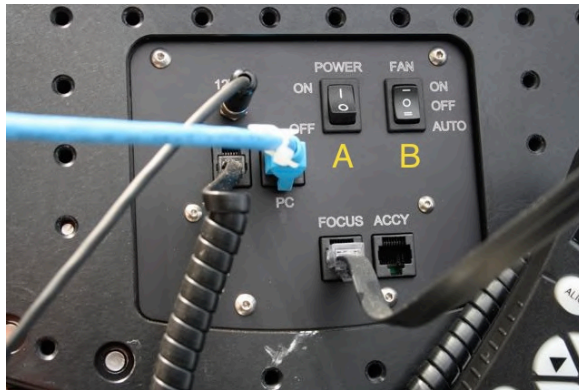


Figure 8: CDK control panel with default setting: Power ON (A), Fan OFF (B).

username: *astrouser*
password: *astro%tel*

Important: make sure to shutdown the remote computer before turning off the main switch (see Sect. 3 for the correct shutdown procedure!)

You find the relevant programs grouped together on the desktop of the remote computer (see Fig. 11):

- main program: **MaxImDL**



Figure 9: Power switch of the remote computer (circle).



Figure 10: On/Off button at the GM4000 control box.

this software is used to control all individual components

- auxiliary software:
 these are the individual software distributions from the manufacturers but they are obsolete when using MaxImDL.
 mount control: **Virtual Keypad**
 telescope control / focus control: **PWI3**
 camera control: **CCDOps**

See the next sections 4 and 5 for operational instructions of the software.



Figure 11: Software shortcuts on remote computer.

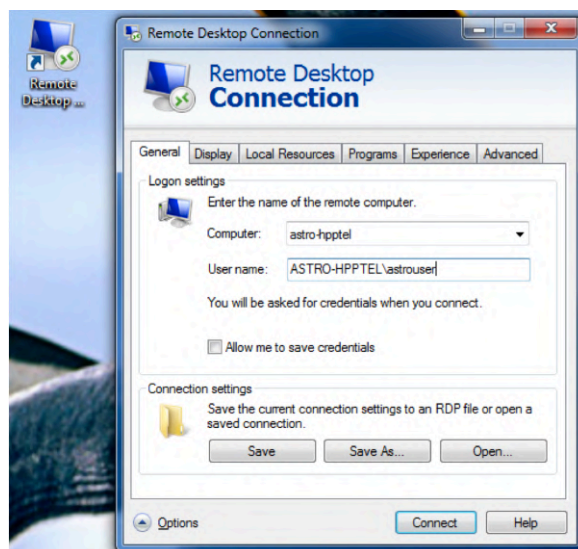


Figure 12: Shortcut and login for remote access to telescope computer. Note: ignore the warning after clicking *Connect* and click on *Yes*.

3 Shutdown

!!! To prevent any damage to the instrument and the software it is very important to follow a correct shutdown procedure !!!

For shutting down reverse the start-up procedure:

- **Shutdown Camera** Disconnect the camera. In **MaxImDL** go to the camera control

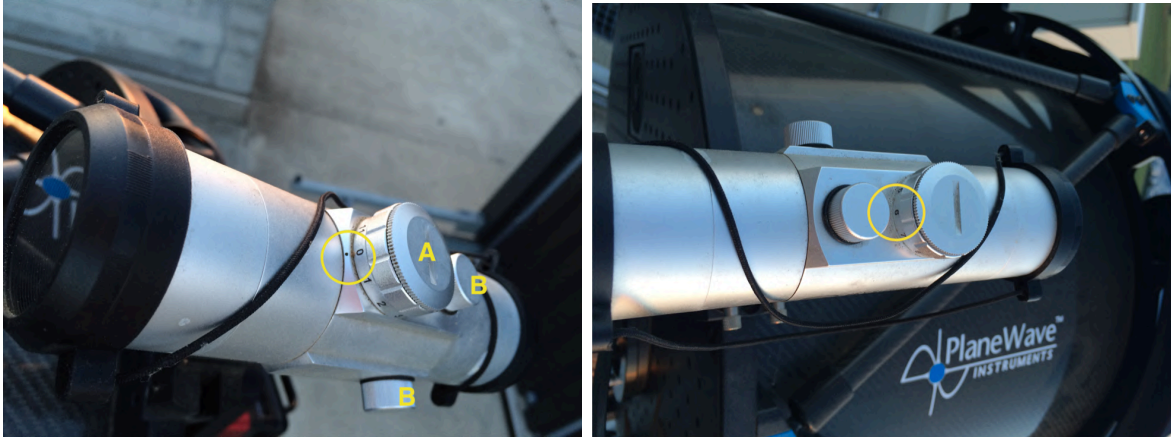


Figure 13: Finder scope. Off position (circle) for the light modulator (A) from the front (top) and the back (bottom). Also indicated are the caps (B) which protect the alignment knobs for x and y direction.

window and click on the *Warm up* button. Wait until duty cycle is 0 % then click on the *Disconnect* button. In **CCDOps** use the *ShtDn* quick launch button. In the pop-up panel then select *Warm Up & Wait*. After a few seconds the software will disconnect the link with the camera and you can close CCDOps.

- **Park the GM4000 mount** (see also comments in Sect. 4.1)
- **Disconnect observatory utilities** In **MaxImDL** go to the observatory control window and individually disconnect the **webcam**, the **focuser**, and the **telescope**. Then press the disconnect button in **PWI3** and close the programs. If the **Virtual keypad** was used disconnect it and close the program.
- Turn off the light of the **Finder scope** (see Fig. 13)
- **Shutdown the GM4000 mount** press the on/off button at the GM4000 control box (Figs. 4, 10). Note that although the button looks like a switch it is actually only a button and it will resume its initial position after pressing it (**so press the button only once!**). **After up to 5 seconds** the mount will start the shutdown procedure and the display will read *shutting down*. Wait until the display gets dark.
- **Shutdown the remote computer** by **alt+F4** and select *Herunterfahren*
- **turn off main power switch** (Figs. 4, 5)
- install mirror cover (see Sect. 2.2, Fig. 2)
- open the dome doors and **lock them in the secure locks**
- release the dome locks
- close the dome **from the inside** so that you can check that the telescope fits through the door opening (i.e. that the correct parking position was set).
- **engage the dome locks**
- close doors and lock the dome

4 Instrument operation using individual software packages

This section gives a short overview of basic functionalities of the instrument software. These should be sufficient for most applications. For more specialized instrument operations see the original user manuals of the instruments.

4.1 GM4000 mount operation

The GM4000 mount is operated by the **Virtual Keypad** software which is effectively only a virtualization of the physical GM4000 hand control. Both the software and the hand control have exactly the same functionalities and menu navigations. After connection of the software (menu *Connection-Connect*) the physical hand control and the software are synchronized and therefore one can still use both (but not at the same time). For a complete overview of the functionalities of the GM4000 mount see the manual, in particular Chapt. 13 (*Menüstruktur*) which is also given in the document *GM4000_menu-structure*.

general

In general navigation through the hand control menus is very intuitive. Start by hitting *MENU* and then use the up/down keys (not the *E-W/N-S* keys!) to navigate through the menu, use *ENTER* for selecting submenus and for initializing actions, and use *ESC* for returning to the superior (sub-)menu. Starting from the main screen (outside the menu, the display reads the RA and DEC coordinates) you can use the quick access/action buttons as indicated on the keys to directly enter various object catalogs for selecting new targets and for using the automatic goto options. The *E-W/N-S* keys can be used for manually slewing the telescope to a given position (after unparking the mount, see below). To change the slew speed go to the main screen and use the up/down keys.

Note when using the automatic goto function the mount will indicate by a beep signal when it has arrived the new position (turn on the PC-speakers when you are using the virtual keypad). The fine positioning can sometimes take a few seconds therefore wait with new operations until you hear the signal.

Note that when the telescope is moving automatically (i.e. by using a goto function) it will immediately stop as soon as you hit one of the *E-W/N-S* keys or the *STOP* key.

unparking / parking of the telescope

For storage inside the dome the telescope needs to be in a fixed parking position predefined in the hand control. As long as the mount is in the parked state it is not possible to move the telescope.

- press *MENU*
- select *ALIGNMENT* (by using the up/down keys, not the *N-S/E-W* keys!) and hit *ENTER*
- select *UNPARK/PARK* and hit *ENTER* twice

Note that in case of unparking the mount will simply change its state but the telescope will stay in its parking position. In case of parking the telescope will automatically move to its parking position (the parking procedure can be started from any telescope orientation).

tracking speed

Depending on the object you need to change the tracking speed:

- *MENU-DRIVE-TRACKING SPEED*

One can choose between *sidereal*, *solar* (for solar system, e.g. planets), *lunar*, *custom* (only for advanced users), and *stop* (no tracking).

slew rate

The slew rate is usually set at 2 degrees per second and it should be kept at this value to avoid mechanical problems with the mount, especially in winter.

4.1.1 Alignment of the telescope

If the pointing of the telescope is bad you can either try to load a different sky model

- *MENU-ALIGNMENT-ALIGNNE DATABASE-LOAD MODEL*

or you have to redo the alignment procedure:

- *MENU-ALIGNMENT-3-STARs* (follow the instructions on the display)

For the alignment procedure the GM4000 mount requires calibration/centering of 3 reference stars plus a few additional stars scattered on the sky for refining the sky model. From the list of available stars (suggested by the software) choose bright stars that you know and that are preferably widely scattered on the sky. The telescope will then slew to the (offset) coordinates of the selected star and you will need to use the *N-S/E-W* keys to center the star on the CCD. After centering the star confirm it and continue with the next star.

Note that for the first 3 reference stars it is not possible to cancel the calibration and to choose a different star if the initially chosen star is not visible (e.g. because of clouds) or not found. After calibration of the 3 reference stars add additional stars for refining the correction model. Here you can abort if the star is not visible. Usually about 6 stars (3 reference stars + 3 additional stars) are sufficient enough for accurate pointing. For later use do not forget to save the new model by

- *MENU-ALIGNMENT-ALIGNNE DATABASE-SAVE MODEL.*

4.2 CDK operation

The software **PWI3** is used for setting/monitoring the mirror temperature and the mirror fan, as well as for operating the automated focusing stage. For the moment the software should only be used for focusing. After launching the software click on the button *CONNECT* as indicated in Fig. 14. If the connection was successful the software will immediately start monitoring and displaying the ambient and mirror temperatures. The best conditions for observation are when the ambient and the mirror temperatures have very similar values, but this requires a long time to be in place, therefore the observations are usually done without this prescription.

Mirror temperature control

Not yet tested, do not use it for the moment.

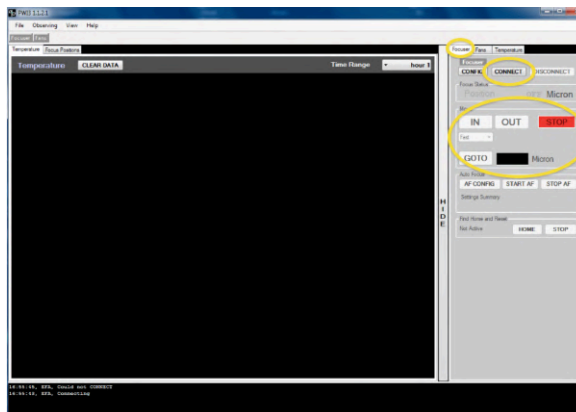


Figure 14: PWI3 panel. Only use functions indicated by circles.

Focusing

In the right side panel select the tab *Focuser* (Fig. 14) to operate the focusing stage. The actual position is displayed in μm . You can change the position by using the *IN/OUT* buttons or you can manually set another absolute position and hit *GOTO*. Note when setting a new position the motor will slightly overshoot and then slowly settle at the given position.

4.3 Camera operation (SBIG STX-16803)

The camera is operated by the software **CCDOps**. After launching the software the camera first needs to be linked to the software. Either use *Camera-Establish COM Link* or go directly to the menu *Camera-Setup* which will both link the camera and open a panel for setting the camera configuration (e.g. CCD temperature, binning mode, readout mode). Both options are also available from the quick launch tab shown in Fig. 15. When linking of the camera was successful this will be indicated in the monitoring panel at the bottom right together with the actual CCD temperature, the duty cycle to stabilize the temperature, and the selected filter (see Fig. 15).

standard operation settings (*Camera-Setup*, see Fig. 16)

- **CCD cooling** In order to reduce dark current the CCD can be cooled by a Peltier-element. Depending on ambient temperature use a setpoint between -20°C and 0°C . As soon as the temperature is reached the duty cycle should drop from 100 % to a value < 75 %. If this is not the case then the camera cannot stabilize the temperature and one should choose a higher setpoint.
- **resolution mode** This sets the on-chip binning value: *high* for no binning, *medium* for 2×2 binning, and *low* for 3×3 binning. Besides for increasing the flux (but lowering resolution) and therefore minimizing the integration time, binning is also used for minimizing the overhead time for downloading the image. In *high* resolution mode the image size is 4096×4096 pixels whereas for *low* resolution the image size is 1365×1365 pixels.
- **other settings** do not change other settings but use default values given in Fig. 16.

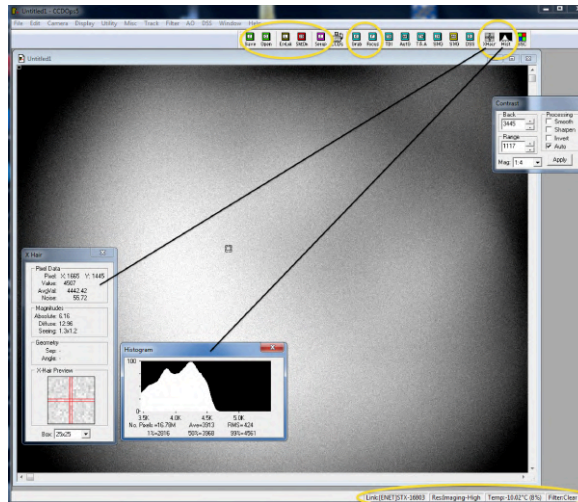


Figure 15: CCDOps main panel. Quick launch options and monitoring panel at the bottom right are indicated by circles. Open sub-panels: *cross-hairs*, *histogram*, and *contrast*.

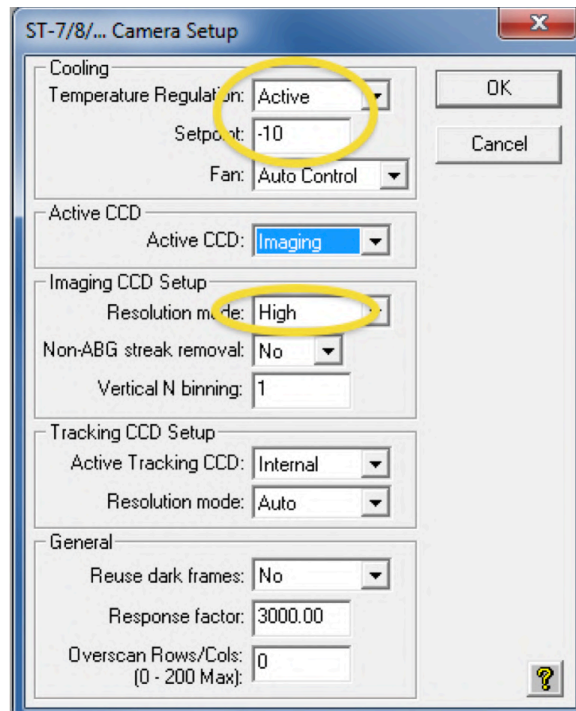


Figure 16: Camera setup panel with default values and user options indicated by circles.

selection of filters

For selecting different filters go to the menu *Filter* and click on the new filter. The monitoring panel at the bottom right will display *Filter:moving* until the new filter is set.

acquiring images

For acquiring images use the quick launch button *Grab* (see Fig. 15). In the pop-up panel one can then choose the following options:

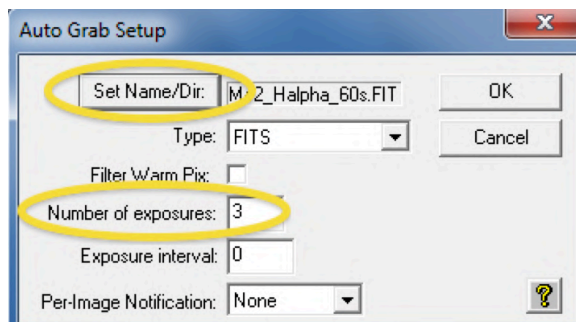


Figure 17: Autograb panel with default values and user options indicated by circles.

- **Exposure Time** Sets the integration time. Note that the shortest possible integration time is 0.12 s. When choosing an integration time < 0.12 s the software will automatically reset it to 0.12 s. Also note that for high precision photometry one should use integration times > 0.5 s or even > 1 s because the shutter might not be reliable for shorter integration times.
- **Dark Frame** Choose *Only* for recording of dark images only, *None* for recording of light images only, and *Also* for recording both light and dark images.
- **Image Size** Sets the (sub)image to be read out. Default is *Full* for reading out the complete CCD-array.
- **Exposure delay** not used, choose *0*.
- **Special Processing** Choose *None* for single image recording and use *Auto Grab* for recording sequences of images. For single recording one can save the image after acquisition by using the quick launch button *Save* (see Fig. 15). If *Auto Grab* is selected a new pop-up window will appear where one can select the root filename and directory using the button *Set Name/Dir*, and the *Number of exposures* to be consecutively acquired. Do not change the other settings (use default values given in Fig. 17).

focusing mode

For focusing one can use the **Focus** button (see Fig. 15) for consecutively acquiring images. In the pop-up panel one can then choose the following options:

- **Exposure Time** Sets the integration time
- **Frame size** (Sub)array to be readout (e.g. to minimize overhead/download time)
- **Turbo Mode** Fast readout of CCD without proper resetting of the charges after readouts (e.g. to minimize overhead time, default is *Off*).
- **other settings** do not change other settings but use default values given in Fig. 18.

image inspection

For quick image inspection use the quick launch buttons *XHair* (cross-hairs), *Hist* (histogram), and/or use the *Contrast* pop-up panel which appears after each readout (see Fig. 15). In the *Contrast* panel one can manually set the greyscale range and select different zoom options (*Mag*).

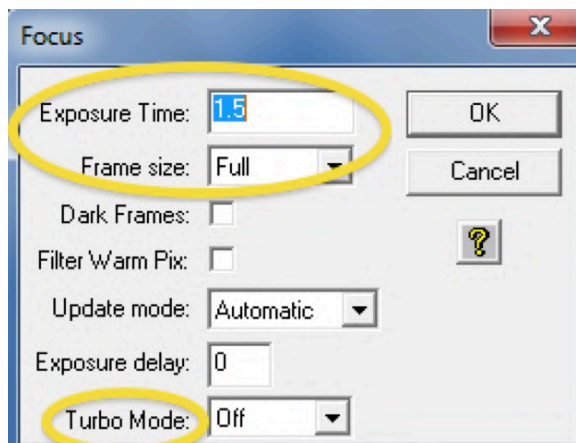


Figure 18: Focus panel with default values and user options indicated by circles.

5 Instrument operation using MaxImDL

The observatory software MaxImDL is based on the widely used ASCOM driver standards for telescopes, cameras, webcams, focuser assemblies, and many other instruments used in Astronomy. Therefore, all the individual components can be controlled by MaxImDL and advanced options, e.g. automatic focusing or planetarium utilities, can be used. In addition the software has a wide range of built-in data reduction utilities and can manage calibration data flows based on fits-header informations.

This section gives a short overview of basic functionalities of MaxImDL. These should be sufficient for most applications. For a first glance into the functionalities of MaxImDL see also the video tutorials (http://www.cyanogen.com/maxim_tut.php) provided by the manufacturer and/or the MaxImDL user manual.

Note: operation using MaxImDL assumes a well aligned telescope. If the pointing is bad or insufficient repeat the alignment procedure using the hand control as described in Section. 4.1.1 and Section 5.2.

5.1 Observatory control

All observatory utilities except the operation of the CCD camera (e.g. telescope pointing, focusing, planetarium utilities; for the camera operation see Sect. 5.3) are controlled by the **Observatory** window (e.g. see Figs. 19-21). The observatory window can be launched by the quick access button in the main panel of MaxImDL (see Fig. 22).

5.1.1 Setup

Go to the **Setup** tab (see Fig. 19). Connect each component separately starting from the top using the corresponding **Connect** buttons. For disconnecting start from the bottom.

Note:

When connecting the *Focuser* the **PWI3** software is launched in the background. Leave it open and only close it after closing MaxImDL.

Note:

The webcam is only used when using the Spectrograph.

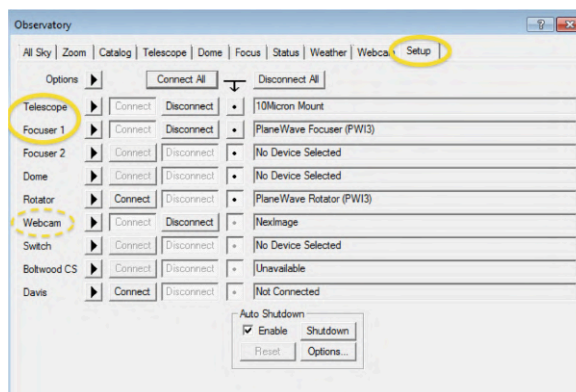


Figure 19: **Observatory:** Setup tab. Connect/Disconnect each component separately. The Webcam is only used for Spectrometry.

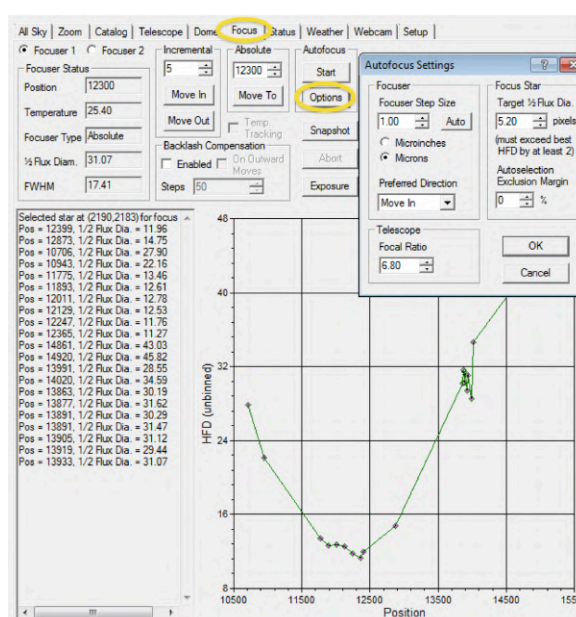


Figure 20: **Observatory:** Focus tab with sub-panel *Autofocus Settings* (accessed by the *Options* button).

5.1.2 Telescope control

The telescope can be controlled manually by the **Telescope** tab (see Fig. 23) or one can use the **Go to** button for known objects given by the **Catalog** tab (see Fig. 24) or by using the right-click option of the mouse by the **All Sky** tab (see Fig. 25) or the **Zoom** tab (see Fig. 26).

Telescope

The information window summarizes the current position, the tracking status and if the telescope is moving or Idle.

Use the *Mount* panel to **Park/Unpark** the telescope and to set **sidereal tracking** on/off. It is only possible to enable/disable *Sidereal Tracking / No Tracking* but setting the *Solar Tracking / Lunar Tracking* is only possible using the hand control (see Section 4.1).

The telescope can be moved manually in a similar way as with the keypad on the hand control

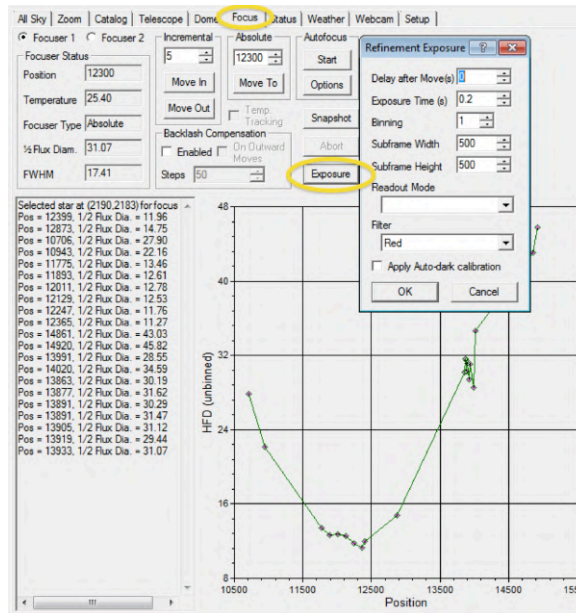


Figure 21: **Observatory:** Focus tab with sub-panel *Refinement Exposure* (accessed by the *Exposure* button).

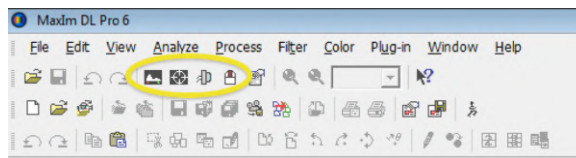


Figure 22: Quick launch buttons for camera control and observatory control (two buttons on the right) and for setting the image cuts (i.e. *stretch*, left button.)

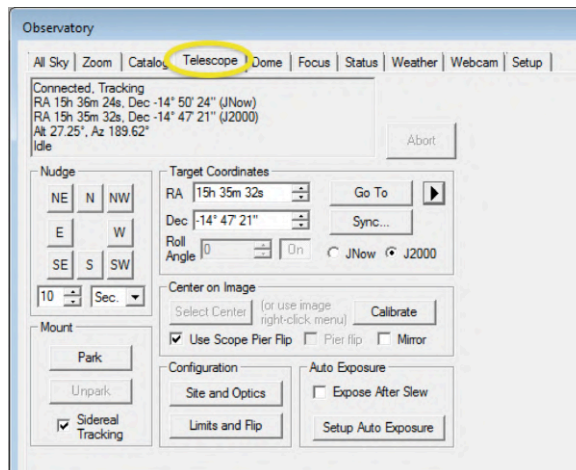


Figure 23: **Observatory:** Telescope tab.

by using the keys in the *Nudge* panel. The speed (the movement corresponding to one mouse click) can also be set there.

To move the telescope to specific coordinates use the *Target Coordinates* panel and click on the *Go To* button to move the telescope.

Search Results: found 8114 objects

ID1	ID2	Type	RA	Dec	Mag	Size	HA	Alt	Az	StewDist
Albireo	Bett Cyg	Star	19h 30m 43s	27° 57' 34"	3.2	20h ...	45.4°	96.6°	139.8°	
Aldebaran	Alp Cep	Star	21h 18m 35s	62° 35' 08"	2.4	18h ...	45.4°	40.0°	125.2°	
Alhaid	Eta UMa	Star	13h 47m 32s	49° 18' 48"	1.9	02h ...	67.8°	287.2°	71.4°	
Alphecca	Alp Crt	Star	15h 34m 41s	26° 42' 53"	2.2	00h ...	66.6°	196.8°	78.9°	
Arcturus	Alp Boo	Star	14h 15m 40s	19° 10' 57"	0.0	01h ...	54.4°	226.5°	59.2°	
Cor Caroli	Alp2 CVn	Star	12h 56m 02s	38° 19' 05"	2.9	03h ...	55.3°	272.0°	57.1°	
Deneb	Alp Cyg	Star	20h 41m 26s	45° 16' 49"	1.3	19h ...	43.4°	65.3°	135.8°	
Dubhe	Alp UMa	Star	11h 03m 44s	61° 45' 05"	1.9	04h ...	47.2°	317.7°	71.9°	
Etamin	Gamma Dra	Star	17h 56m 36s	51° 29' 20"	2.2	22h ...	71.1°	66.9°	108.7°	
Kochab	Bet Umi	Star	14h 50m 42s	74° 09' 20"	2.1	01h ...	62.2°	349.6°	92.2°	
Kornephoros	Bet Her	Star	16h 30m 13s	21° 29' 23"	2.8	23h ...	63.4°	165.1°	89.9°	
Merak	Bet UMa	Star	11h 01m 50s	56° 22' 55"	2.4	04h ...	45.2°	310.4°	66.5°	
Mizar	Zet UMa	Star	13h 23m 56s	54° 55' 31"	2.2	02h ...	64.5°	301.7°	72.9°	
Polaris	Alp UMi	Star	02h 31m 46s	89° 15' 52"	2.1	01h ...	46.8°	0.3°	100.5°	
Ras Algethi	Alp Her	Star	17h 14m 39s	14° 23' 24"	3.5	22h ...	53.7°	149.2°	99.2°	
Rasalhague	Alp Oph	Star	17h 34m 56s	12° 33' 36"	2.1	22h ...	50.1°	143.0°	103.8°	
Thuban	Alp Dra	Star	14h 04m 24s	64° 22' 33"	3.6	01h ...	66.8°	327.3°	83.2°	
Unukalhai	Alp Ser	Star	15h 44m 18s	06° 25' 31"	2.7	00h ...	48.8°	186.6°	75.9°	
Vega	Alp Lyr	Star	18h 36m 56s	38° 46' 55"	0.1	21h ...	68.8°	92.7°	117.7°	
Vindemiatrix	Eps Vir	Star	13h 02m 11s	10° 57' 33"	2.9	02h ...	37.6°	241.0°	39.7°	
Yed Prior	Del Oph	Star	16h 14m 21s	-03° 41' 40"	2.7	23h ...	38.8°	175.9°	81.4°	
HP73	Star	Star	00h 00m 53s	66° 50' 53"	6.9	16h ...	33.1°	23.9°	121.9°	
HP128	Star	Star	00h 01m 39s	73° 36' 43"	6.5	15h ...	37.7°	17.9°	115.5°	
HP207	Star	Star	00h 02m 36s	66° 05' 56"	5.9	15h ...	32.4°	24.4°	122.5°	
HP274	Star	Star	00h 03m 26s	63° 38' 26"	6.2	15h ...	30.6°	26.3°	124.7°	
HP302	Star	Star	00h 03m 52s	66° 42' 44"	6.3	15h ...	32.8°	23.8°	121.9°	
HP379	Star	Star	00h 04m 42s	67° 09' 59"	5.7	15h ...	33.0°	23.3°	121.4°	
HP531	Star	Star	00h 06m 27s	64° 11' 46"	5.6	15h ...	30.7°	25.6°	124.1°	
HP760	Star	Star	00h 09m 20s	78° 12' 53"	6.0	15h ...	41.4°	11.6°	109.7°	
HP1296	Star	Star	00h 16m 14s	76° 57' 03"	6.3	15h ...	39.3°	14.0°	112.1°	
HP1725	Star	Star	00h 21m 42s	67° 49' 23"	6.6	15h ...	32.4°	21.4°	120.2°	
HP2036	Star	Star	00h 25m 51s	71° 48' 26"	6.9	15h ...	35.2°	17.9°	116.4°	
HP2242	Star	Star	00h 27m 07s	80° 03' 08"	6.5	15h ...	41.0°	10.5°	109.1°	

Figure 24: Observatory: Catalog tab.

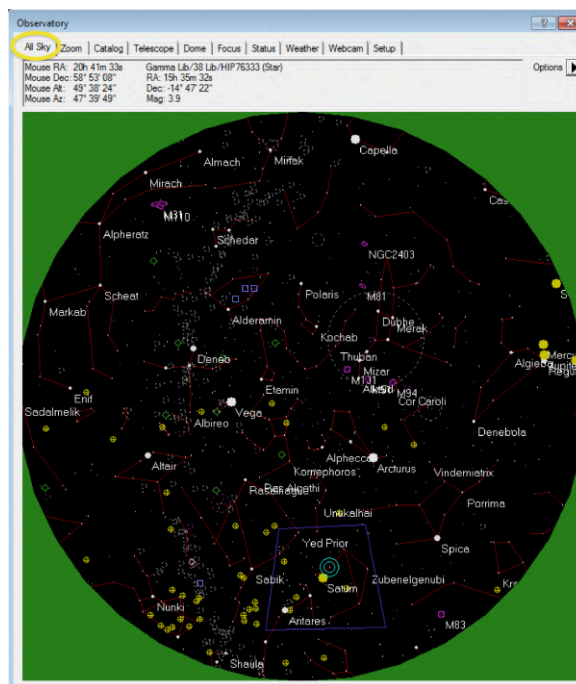


Figure 25: Observatory: All Sky tab.

All the other options in this panel should already be correctly set. For example the *Site and Optics* settings are directly loaded from the GM4000 mount (see Fig. 27). Note that *Alt/Az* can only be displayed by the different panels if the *Site and Optics* settings are correctly set.

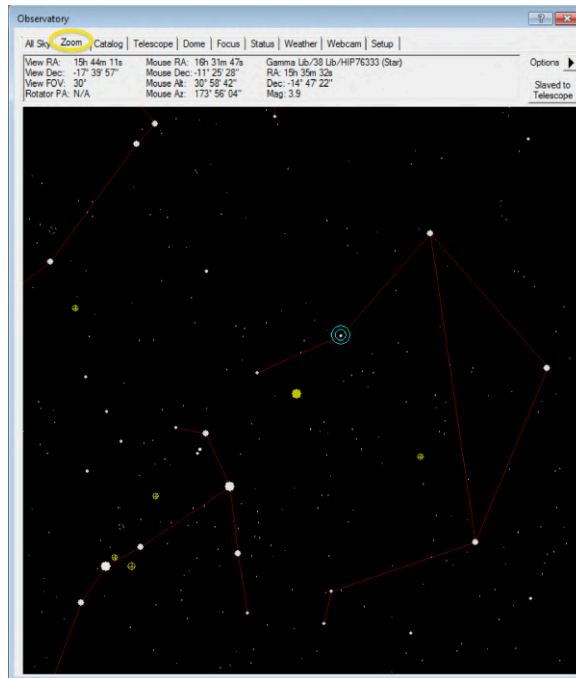


Figure 26: **Observatory:** Zoom tab.

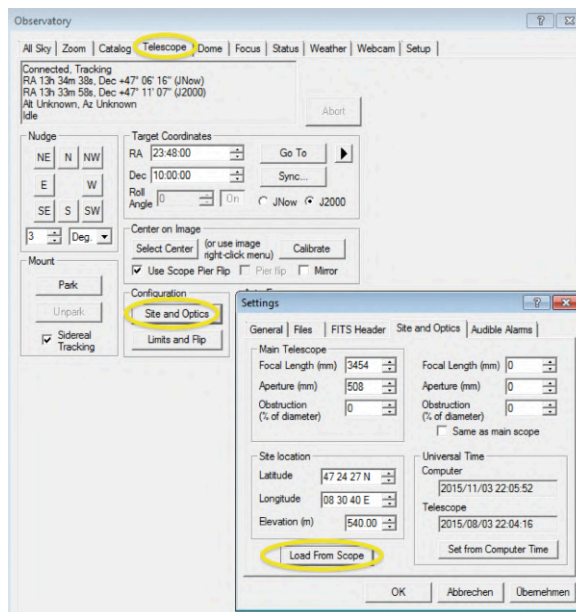


Figure 27: **Observatory:** Telescope tab with *Site and Optics* sub-panel.

Catalog

To find a specific object one can either display objects using *Search ID* for searching for the object's name or one can restrict the list of all available objects by defining different *Search Region* options. For example by specifying a minimum altitude one can only display all currently visible objects.

To move the telescope to an object highlight the object in the list and click on the *Go to* button.

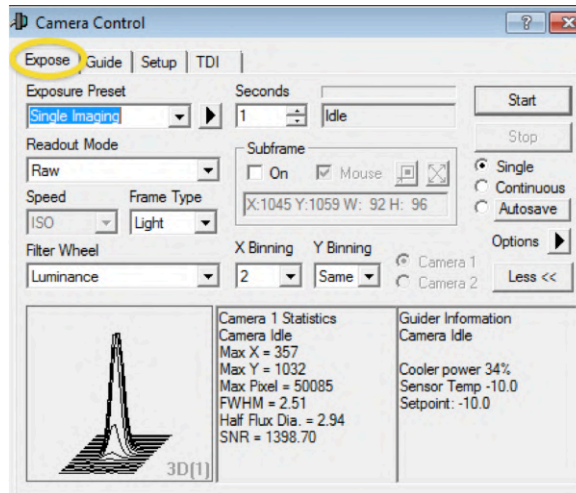


Figure 28: **Camera control: Expose tab.**

All Sky and Zoom

This tab shows a map of the sky. Use the *Options* button to change the *density* or *type* of the displayed objects and turn on/off the *object labels*. See also the mouse right-click and scrolling options, e.g. to zoom in/out or to move the telescope to the current mouse position.

5.1.3 Focusing options

The automated focuser is operated by the **Focus** tab in the observatory window (see Fig. 20). The *Focuser Status* panel displays the current focuser position and the results of the last focus measurement.

There are two approaches for focusing the image onto the camera:

Manual focusing

Use both the **Camera Control** window (see Sect. 5.3) and the **Observatory/Focuser** window:

- Take multiple exposures (see Sect. 5.3 and Fig. 28) while moving the focuser in/out by using either the *Incremental* or the *Absolute* panel (see Fig. 20). To speed up the image acquisition choose a subframe around the object to be focussed (see Sect. 5.3).
- Optimize the *FWHM* or the *Half Flux Dia.* values given by the information panel in the Camera Control window.

Automatic focusing

Use the *Autofocus* panel in the **Observatory** window (see Figs. 20, 21):

- click on the *Options* button and set the options as given by Fig. 20.
- click on the *Snapshot* button to acquire a full-field image, using the current settings given in the **Camera Control** window.
- in the full-field snapshot image MaxImDL automatically selects the brightest star as focus reference. If another star should be used for focusing click on this star. The Information panel in the **Observatory/Focus** window will then display the coordinates of the chosen reference star.

- click on the **Exposure** button to define the exposure settings for automatic focusing (see Fig. 21), i.e. define the *Exposure Time*, the *Binning* mode, the size of the *Subframe*, and the *Filter*.
- Finally, click on the **Start** button in the **Autofocus** panel to start the automatic focusing procedure.
- MaxImDL then automatically acquires images of the chosen reference star for different focus positions. The results are continuously displayed in the Information panel and a *HFD / Position* plot is created (see Fig. 20).
- As soon as the minimum of the *HFD / Position* plot can be determined click on the **Abort** button to stop the focusing.
- Use the **Absolute** panel to move the focuser to the Minimum position.

5.2 Star alignment with MaxImDL

The alignment procedure is a fundamental part of the calibration steps. It allows the mount to create a model of the sky at that location and therefore it allows to track objects and perform long exposures. As explained in Section 4.1.1, to start the alignment use the virtual keypad and go to *MENU-ALIGNMENT-3-STARS*. The alignment is based on centering 3 reference stars plus few additional ones to refine the model. The stars need to be chosen such that they are as far away as possible from each other, covering the sky uniformly. Once the first star is chosen, the telescope slews towards the star and it asks the user to center the star in the field of view. To visualize the star position, take a short exposure ($\sim 1 - 5$ seconds depending on how bright the star is) with the camera. To help you understand how far from the center the star is, right click on the preview image and enable the crosshair display. At this point, all you have to do is place the star in the center of the image. You can use the nudge panel to move the telescope in the different directions, changing the speed of the single movement depending how far the star is from the center of the image. Once the star is centered, press *ENTER* on the Virtual keypad and proceed to the next stars.

Note: recently, a plug-in has been installed in MaxImDL that allows the telescope to center a specific point of the image by just right-clicking on the image location and selecting *center telescope here*.

5.3 Camera control

All camera operations (e.g. *setup* and *image acquisition*) are controlled by the **Camera Control** window (e.g. see Figs. 28, 29). The camera control window can be launched by the quick access button in the main panel of MaxImDL (see Fig. 22).

Setup

Go to the **Setup** tab (see Fig. 29). Click on **Setup Camera** to set the camera model. Use the settings according to Fig. 29 and only change the model (i.e. STX-16803 for standard imaging or ST-1603 for spectroscopy (Sect. D)). Click on **Setup Filter** to set the filter settings (e.g. filter names, see Fig. 30). When using the ST-1603 camera set *Filter or Controlling Camera Model* to *No Filter* else use *SBIG Universal*. Note that the filter settings can only be accessed and changed when the camera is disconnected. If the filter settings are still ok (default situation) click on the **Connect** button. The camera should now be connected and some basic information (e.g. cooling status) is displayed in the information area (see Fig. 29).

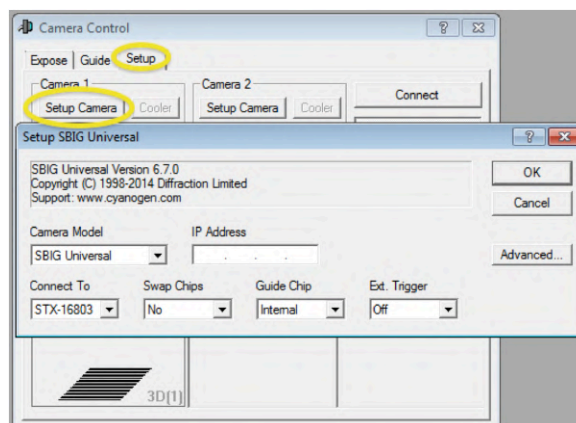


Figure 29: **Camera control:** Setup tab with *Setup Camera* sup-panel.

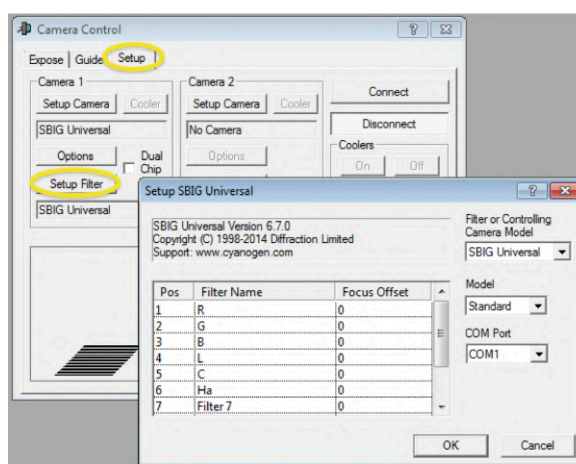


Figure 30: **Camera control:** Setup tab with *Setup Filter* sup-panel.

Activate the cooling by clicking on *Coolers on* and set a setpoint value by clicking on *Cooler* for Camera 1.

- **CCD cooling** In order to reduce dark current the CCD can be cooled by a Peltier element. Depending on ambient temperature use a setpoint between -20°C and 0°C . As soon as the temperature is reached the duty cycle should drop from 100 % to a value $< 75\%$. If this is not the case then the camera cannot stabilize the temperature and one should choose a higher setpoint.

Image acquisition

For acquiring images go to the **Expose** tab (see Fig. 28). Here one can define all exposure settings and also define named presets for often used settings.

In particular use the following options:

- **Exposure Preset** Sets basic settings for commonly used camera presets (e.g. *Single Imaging*, *Continuous Imaging*, *Dark*). Choose the preset that matches your intention and adapt some of the settings below to optimize the exposure. Note: whenever one of the pre-defined settings of the chosen preset is changed this is indicated by a star (e.g. **Single Imaging*).

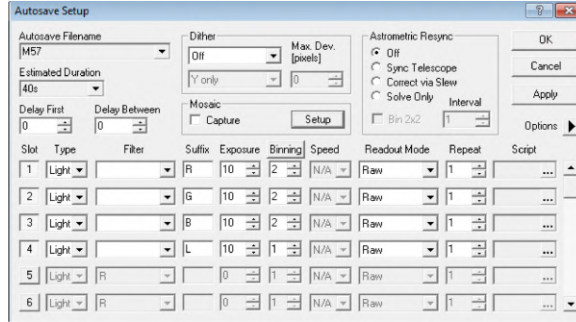


Figure 31: **Camera control:** Sub-panel *Autosave Setup* accessible by the Expose tab (see Fig. 28).

- **Seconds** Sets the integration time. Note that the shortest possible integration time is 0.12 s. When choosing an integration time < 0.12 s the software will automatically reset it to 0.12 s. Also note that for high precision photometry one should use integration times > 0.5 s or even > 1 s because the shutter might not be reliable for shorter integration times.
- **Frame Type** Choose *Light* for recording normal images with shutter open and *Dark* for dark images with the shutter closed.
- **Filter Wheel** Select different filters. The monitoring panel at the bottom right will display *Waiting for Filter wheel* until the new filter is set.
- **Binning** Set the on-chip binning value (1 for no binning). Besides for increasing the flux (but lowering resolution) and therefore minimizing the integration time, binning is also used for minimizing the overhead time for downloading the image.
- **Subframe** Sets the (sub)image to be read out. Click *On* and draw the subframe using the mouse.
Note: for the ST-1603 Subframe does not work and needs to be de-activated!
- **Acquisition settings** Choose *Single* for single exposures, *Continuous* for multi-exposures, or *Autosave* for multiple exposure settings (see also Fig. 31).
- more **Options** (e.g. automatic dark exposure/subtraction) are available using the *Options* button.
- **Start / Stop** Start or stop the exposure with the chosen settings.

5.4 Autoguiding with MaxImDL

A precise star-alignment (Section 5.2) allows the observer to take long exposure images of targets. However, even with a perfect alignment, the mount tracking is not enough when we want to conduct observations longer than ~ 5 minutes. In order to do that, we need to use the auto-guider. The SBIG STX-16803 camera has a secondary chip that can be used as auto-guider for the telescope mount. In order to enable the use of the secondary chip for auto-guiding, we need to tick the box ‘Dual Chip Mode’ in the Camera Control window (Figure 32). This step needs to be done before pressing ‘Connect’ (see Section 5.3). After that you can connect and cool the camera.

Move the telescope to the specific target for observation (e.g., star, planet or galaxy) and take an exposure between 10 and 60 seconds depending on the observing conditions. The secondary chip on the camera points to a region of sky that is off-axis with respect to the main chip center (red box in Figure 33). Look for stars in this region of the sky. If there are

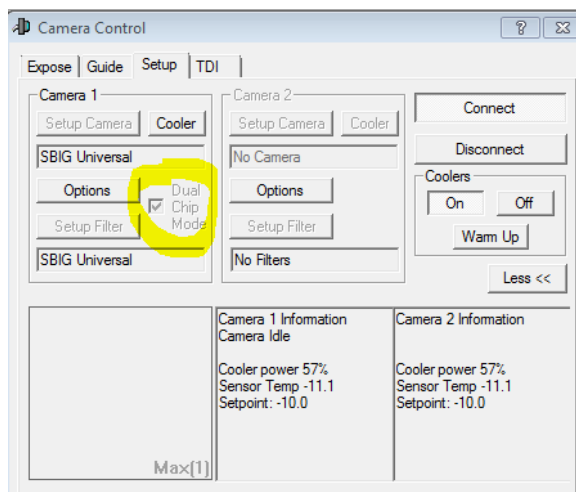


Figure 32: Dual chip mode box in Camera control window.

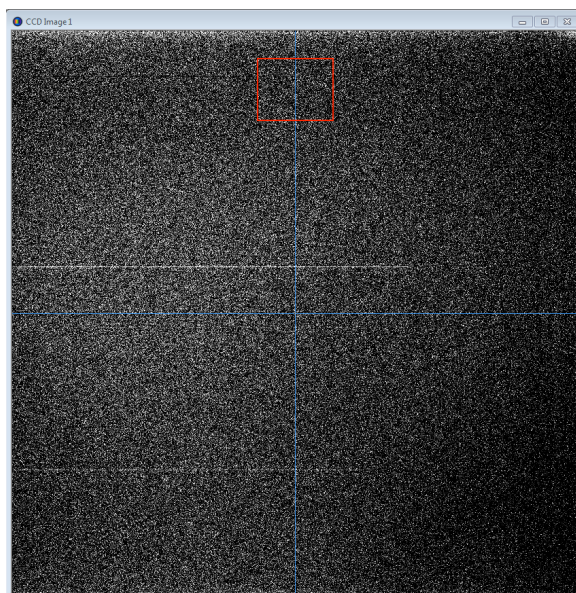


Figure 33: The red box is the approximate field of view covered by the guiding chip.

no stars, you would need to move the telescope slightly by keeping the target always in the field of view of the main chip. Once there is a star in the proximity of the box, click on the 'guide' tab of the Camera control window (Figure 34) and select 'Camera 2'.

At this stage, you need to take an exposure with the guiding chip to see whether a star actually falls in its field of view. Choose the amount of seconds to expose (5-10 seconds), select 'Expose' in the guide tab of the Camera control window and press 'Start'. A smaller window will appear with the exposure shot by the guiding chip. If there is a bright enough star in the center of the image, then you can proceed further, otherwise you will have to move the telescope to do so. Remind to keep the actual target of observation in the field of view of the main chip.

After the star is centered, click on 'Calibrate' and press 'Start'. The guider will change the parameters into the 'guider settings' window (Figure 35) to adjust for the guiding star movement. This calibration step can be done manually, but it strongly advisable to let the

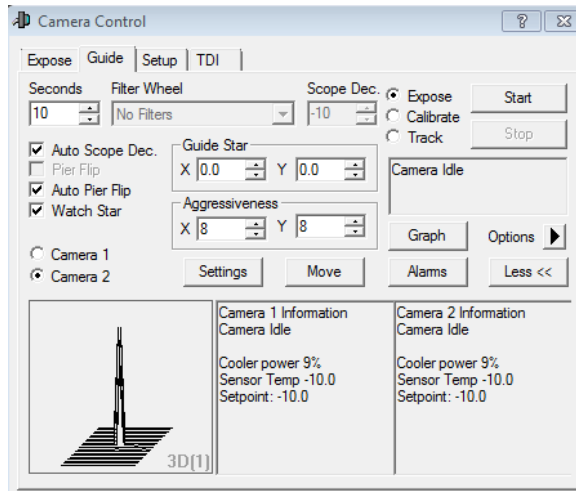


Figure 34: Guide tab in the Camera control window.

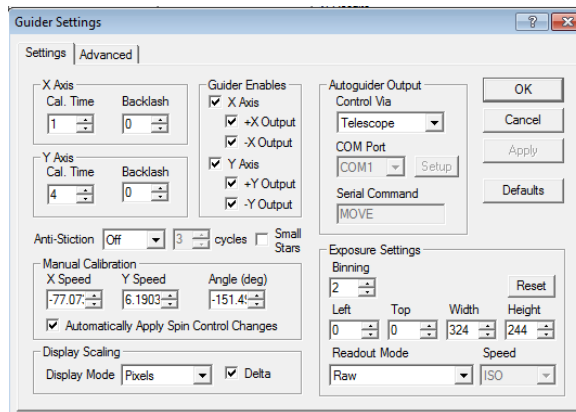


Figure 35: Guide settings in the Camera control window.

software do it. If during the calibration an error pops up concerning the movement of the guiding star, change the ‘Aggressiveness’ parameter in the Guide tab (Figure 34).

When the calibration has been successful, select ‘Tracking’ in the Guide tab and press ‘Start’. A new window will appear (Figure 36). This shows the tracking error graph for the x and y directions. What we want is that both the errors on x and y need to be smaller than 1. Wait until these errors are stably under 1 and then you can start taking long exposures of your scientific target. If the tracking error in one of the directions is larger than 1 for several seconds, then the calibration needs to be performed again.

Once the target observation is finished, you need to stop tracking by pressing the ‘Stop’ button in the Guide tab. Remember that when moving from one target to the other, you must stop the tracking. Once the new target is centered, the calibration step needs to be performed again.

5.5 Image inspection

For quick image inspection use the stretch button (see Fig. 22) to manually set the greyscale range and use the **mouse-click options**:

- **scrolling** for zooming in/out

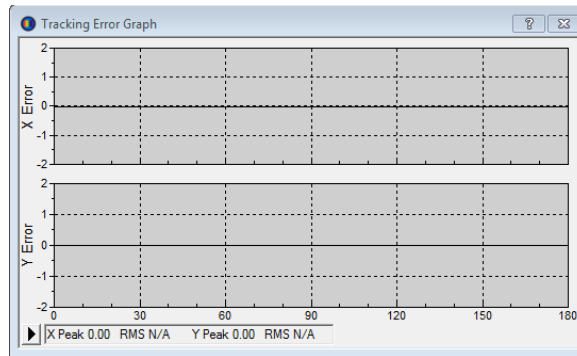


Figure 36: Tracking error graph.

- **dragging** + **Shift** + **left-click** for adjusting brightness and contrast (similar to DS9 functionality)
- **dragging** + **Ctrl** + **left-click** for shifting the image

6 A Brief Guide to Data Reduction

Based on version 1.1 of the manual ‘A Brief Guide to Data Reduction’ by Luca Tortorelli https://ethz.ch/content/dam/ethz/special-interest/phys/particle-physics/quanz-group-dam/documents-old-s-and-p/Courses/vp-asl-astro/tortorelli_data_reduction_steps.pdf. This part of the manual is intended to give a brief overview on how to go from the raw images to the fully astrometrically and photometrically calibrated ones.

6.1 Software requirements

The data reduction is performed mostly in Python, but additional softwares may be required such as ds9, Source Extractor, SCAMP, SWARP and/or DeepSkyStacker and IRIS (the last two if you use Windows OS).

6.2 Python Installation

Python comes pre-installed on Linux and MacOS, while on Windows it is not prepackaged.

Windows users can download and install Python from its website <https://www.python.org/downloads/windows/>. My suggestion is either to install Python 2 with the latest 2.7 version or to install Python 3 with one of the 3.6.* versions. You can find an example of a step by step guide at <https://www.howtogeek.com/197947/how-to-install-python-on-windows/>.

The next step is to setup a Python environment. There are two ways of doing that: creating a virtual environment or installing Anaconda. The latter is easier to setup and install, but, especially for Linux and MacOS users, I strongly suggest the use of virtual environments.

6.2.1 Virtual environment

For **MacOS** users:

- Install homebrew as described at <https://brew.sh/> (when you run the shown comand press RETURN to answer the first question).
- Run 'brew install python2' and 'brew install python3'.
- Execute

```
$ which python2
```

and

```
$ which python3
```

to check if they are installed into the folder '/usr/local/bin'.

- Run

```
$ pip2 install -U pip setuptools
```
- Run

```
$ pip2 install virtualenv
```
- Alter your '~/.profile' so that the locale and language is set properly:

```
$ cat .profile
$ export LC_ALL=en_US.UTF-8
$ export LANG=en_US.UTF-8'
```

- If you changed your '~/.profile' file reload the changes by either opening a new terminal or by executing:

```
$ source .profile
```

For **Linux** users:

- Check if you can submit

```
$ python2
```

and

```
$ python3
```

from the command line. If not, use your linux distributions package manager to install python2.7 and a 3.6* version of python3. On Ubuntu this is

```
$ sudo apt install python2
$ sudo apt install python3
```

- Next check if you can run

```
$ pip2 --help
$ pip3 --help
```

Again use the package manager to install the packages, e.g. on Ubuntu use

```
$ sudo apt install python-pip
$ sudo apt install python3-pip
```

- Next install virtualenv globally for Python 2:

```
$ sudo pip2 install virtualenv
```

- Alter your '~/.bashrc' so that the locale and language are set properly:

```
$ cat .bashrc
$ export LC_ALL=en_US.UTF-8
$ export LANG=en_US.UTF-8'
```

- If you changed your '~/.bashrc' file reload the changes by either opening a new terminal or by executing: 'source ~/.bashrc'.

For both MacOS and Linux users, the actual activation of the virtual environment is the following:

- Python 2: run

```
$ cd <folder\_name>
$ virtualenv venv
```

By typing 'ls venv' the folders 'bin', 'include' and 'lib' should be listed.

- Python 3: run

```
$ cd <folder\_name>
$ python3 -m venv venv
```

To use the local interpreter and packages installed into this virtual environment, you have to activate it first:

```
$ cd <folder\_name>
$ source venv/bin/activate
```

By typing 'which python', the path to the bin folder into the virtual environment should be displayed, e.g., 'venv/bin/python'. This has to be done again every time you open a new terminal window or tab.

Every time you have to install a new python package, you simply type

```
$ pip install <package\_name>
```

For **Windows** users: if you install Python2 >2.7.9 or Python 3 >3.4 from <https://www.python.org/downloads/windows/>, then 'pip' should be already installed. To check for that, type

```
$ pip --help
```

in your Command Prompt, if 'pip command not found' is displayed, then download 'pip' from <http://pip.readthedocs.io/en/stable/installing/#do-i-need-to-install-pip> and save it to your Desktop. Then in your Command Prompt, navigate to Desktop with

```
$ cd Desktop
```

and execute get-pip.py with

```
$ python get-pip.py
```

The actual installation of the virtual environment is the following:

- In your Command Prompt navigate to the folder where you want to install the virtual environment and then type

```
$ virtualenv env
```

- On Windows, virtualenv creates a batchfile with the extension '.bat', so to activate the virtualenv you have to run the activate script in the Script folder, Example:

```
$ C:\Users\'Username'\venv\Scripts\activate.bat
```

Every time you have to install a new python package, you simply type

```
$ pip install <package\_name>
```

6.2.2 Anaconda

For all users, Anaconda can be download from <https://www.anaconda.com/download/>. Download and install either the 2.7 version or the 3.6* version. The installation procedure is very detailed, so simply follow the instructions on <http://docs.anaconda.com/anaconda/install/>. On the same website you'll find also guides on how to activate the environment and install new packages.

6.2.3 List of Python Packages

The following is the list of Python packages you need for the data reduction:

- numpy
- Astropy
- photutils
- astrocrappy
- astroalign
- pyfits (needed for Cosmics.py)
- Jupyter notebook (optional)

6.3 DS9

DS9 displays FITS images and it can be download and installed for all the platforms from <http://ds9.si.edu/site/Download.html>.

6.4 Source Extractor

MacOS users can easily install Source Extractor with 'brew' or 'Macports'. However remember that you must have your virtual environment deactivated when you use 'brew' or 'Macports'. In your terminal, run

```
$ brew install homebrew/science/sextractor
```

or

```
$ brew install brewsci/science/sextractor
```

since sometimes packages change directory. If you want to install it with Macports, then first you have to install it according to your operating system <https://www.macports.org/install.php>. Then simply type in your terminal:

```
$ sudo port install sextractor
```

For **Linux** users, the simplest way to have SExtractor up and running is to install the standard binary package the comes with your Linux distribution. Run, e.g.,

```
$ apt-get install sextractor
```

(on Debian) or

```
$ dnf install sextractor
```

(on Fedora) as root and SExtractor, as well as all its dependencies, will automatically be installed. Alternatively, you can follow the instructions at <https://sextractor.readthedocs.io/en/latest/Installing.html>.

Source Extractor can't be installed on **Windows**. In Windows 10, however, you can activate the Unix terminal. Maybe there it works, but I have never tested it.

The instructions on how to use it are at <https://sextractor.readthedocs.io/en/latest/Using.html>.

6.5 SCAMP

SCAMP computes the astrometric solution of astronomical images. Since I provide also a website where to do it, it is not strictly necessary that you install it.

MacOS users can easily install SCAMP with 'Macports'. Simply type

```
$ sudo port install scamp
```

in your terminal window.

Linux users have to follow the instructions on the website <https://scamp.readthedocs.io/en/latest/Installing.html>.

SCAMP can't be installed on **Windows**. In Windows 10, however, you can activate the Unix terminal. Maybe there it works, but I have never tested it.

6.6 SWARP

MacOS users can easily install SWARP with 'Macports'. Simply type

```
$ sudo port install swarp
```

in your terminal window.

Linux users have to follow the instructions on the website <https://www.astromatic.net/software/swarp>.

SWARP can't be installed on **Windows**. In Windows 10, however, you can activate the Unix terminal. Maybe there it works, but I have never tested it.

6.7 DeepSkyStacker

DeepSkyStacker performs the same steps as SWARP, but with a graphical interface. It works only on **Windows** (Mac or Linux users may try using it via Wine) and it can be downloaded at <http://deepskystacker.free.fr/english/index.html>. The website contains several tutorials on how to use it.

6.8 IRIS

IRIS is an astronomical images processing software that works under Windows OS. It can be used to perform the analysis steps highlighted in Section 6.9. The website to download it is <http://www.astrosurf.com/buil/iris-software.html>. This page contains several tutorials on how to use it for different astronomical applications.

6.9 Data Reduction Steps

In this section we go through the different data reduction steps, with some example code on how to perform the different tasks. The code can be run either in the terminal or inside a Jupyter notebook. Some glossary: 'raw science frame' refers to a single exposure image of the target galaxy or star without any post-processing applied to it, i.e. as it is taken at the telescope; 'dark for flat' refers to a dark image taken with the same exposure time as the single flat field image, while 'dark for science' refers to a dark image taken with the same exposure time as the 'raw science frame'.

6.9.1 Dark Subtraction and Flat Fielding Correction

The bias, dark subtraction and the flat fielding correction are applied to the 'raw science frame' according to the following:

$$\text{science frame} = \frac{\text{raw science frame} - \text{master dark} - \text{master bias}}{\text{master flat} / \langle \text{master flat} \rangle} \quad (1)$$

'science frame' refers to the 'raw science frame' after bias, dark subtraction and flat fielding correction. 'master bias' refers to the median image of all the bias frames. 'master dark' refers to the median image of all the 'dark for science' images, the latter being subtracted for the 'master bias'. 'master flat' refers to the median image of all the flat images after 'dark for flats' subtraction and 'master bias' subtraction. $\langle \text{master flat} \rangle$ is the mean value of the 'master flat' image.

Images can be read with the Astropy package. In the terminal, type

```
$ from astropy.io import fits
$ data = fits.getdata('path_to_image', ext=0)
$ head = fits.getheader('path_to_image', ext=0)
```

to get the electronic counts in each pixel and the metadata (header file) of an image. The 'data' variable stores the image in the form of a 2D array (i.e. a matrix), therefore operations such as sum, difference, ratio etc. can be done simply as

```
$ diff = data1 - data2
```

In order to create a median image, you can for example store each 'data' variable for each image as element of a list or create a 3D array having size as the number of images times the number of pixels for each side of the image. Then you simply run

```
$ import numpy as np
$ median_image = np.median(image_list, axis=0)
```

The variable 'median image' will contain the median of the electronic counts of the different images pixels. To create an image that can be displayed also in DS9, run

```
$ fits.writeto('out_image_path', median_image, head, overwrite=True)
```

Once you create the different median images, you can perform the dark subtraction and the flat fielding corrections as in 1.

An alternative way of performing this data reduction tasks is by using IRIS. One needs to follow the tutorial in http://www.astrosurf.com/buil/iris/tutorial3/doc13_us.htm adapting it to our case. First, select the image file format from the *Settings* command of *File* menu as FIT (see figure 1 in http://www.astrosurf.com/buil/iris/tutorial3/doc13_us.htm) and set the working path as the one where you store your images. Then, you create a master bias, a master dark and a master flat following the sections 'Create the master Offset image', 'Create the master Dark image', 'Create the master Flat-field image' in http://www.astrosurf.com/buil/iris/tutorial3/doc13_us.htm. IRIS allows you also to create a bad pixel map for the image following the section 'Create a pixel bad list'. The bias, dark subtraction and flat field normalization is performed following the section 'Preprocessing' in http://www.astrosurf.com/buil/iris/tutorial3/doc13_us.htm. Further information can be found also in http://www.astrosurf.com/buil/iris/tutorial2/doc8_us.htm and http://www.astrosurf.com/buil/iris/tutorial2/doc9_us.htm.

6.9.2 Cosmic Ray Rejection

The cosmic ray rejection can be performed with Astroscrappy¹ or cosmics.py.

The syntax for Astroscrappy is the following:

```
$ from astroscrappy import detect_cosmics
$ from astropy.io import fits
$ data = fits.getdata('path_to_image', ext=0)
$ head = fits.getheader('path_to_image', ext=0)
$ mask, _clean = detect_cosmics(data, inmask=None, sigclip=4.0,
                               sigfrac=0.3, objlim=5.0, gain=1.15,
                               readnoise=6.5, satlevel=65536,
                               pssl=0.0, niter=4, sepmed=True,
                               cleantype='meanmask', fsmode='median',
                               psfmodel='gauss', psffwhm=2.5,
                               psfsize=7,
                               psfk=None, psfbeta=4.765, verbose=False)
$ fits.writeto('path_to_image_cr.fits', _clean, head, overwrite=True)
```

The values as just for reference. Read the documentation and figure out by yourself the correct ones. Gain can be read from the header of each image, while saturation and readout noise can be found in the CCD camera manual.

Cosmics.py can be downloaded from https://obswww.unige.ch/~tewes/cosmics_dot_py/. Put the file in your working folder. The syntax is the following:

```
$ import cosmics
$ data = fits.getdata('path_to_image', ext=0)
$ head = fits.getheader('path_to_image', ext=0)
$ c = cosmics.cosmicsimage(gal_raw, gain=1.15, readnoise=0, sigclip = 5.0,
                          sigfrac = 0.3, objlim = 5.0, satlevel=65535)
$ c.run(maxiter = 4)
$ cosmics.tofits('path_to_image_clean.fits', c.cleanarray, head)
```

The values as just for reference. Read the documentation and figure out by yourself the correct ones. Gain can be read from the header of each image, while saturation and readout noise can be found in the CCD camera manual.

IRIS performs the same tasks by creating a bad pixel map for the image following the section 'Create a pixel bad list' in http://www.astrosurf.com/buil/iris/tutorial3/doc13_us.htm or following the section 'Manual hot-spot removal procedure' in http://www.astrosurf.com/buil/iris/tutorial8/doc23_us.htm.

6.9.3 Background Subtraction

The background subtraction can be performed using 'photutils'. First you estimate the background following <https://photutils.readthedocs.io/en/stable/background.html> for every 'science image'. Then you subtract the background image from each science image. Have a look at the image after background subtraction, the process is not trivial and you have to play with parameters in order to obtain a good result.

An example code for a 1D background subtraction is the following:

```
$ data = fits.getdata('path_to_image', ext=0)
```

¹<https://github.com/astropy/astroscrappy>

```

$ head = fits.getheader('path_to_image', ext=0)
$ mask = make_source_mask(data, snr=2, npixels=5, dilate_size=11)
$ mean, median, std = sigma_clipped_stats(data, sigma=4.0, mask=mask)
$ backsub_data = data - mean
$ fits.writeto('path_to_image_backsub.fits', backsub_data, head,
              overwrite=True)

```

The background subtraction can be performed with IRIS following the section ‘The final touch’ in http://www.astrosurf.com/buil/iris/tutorial2/doc8_us.htm.

6.9.4 Astrometric Calibration

The astrometric calibration is performed through the website astrometry.net. You need to upload either a single image or a tarball (.tar, .gz), containing fits images to <http://nova.astrometry.net/upload>. It will recognize stars in the image and it will give you back the same input images, but with the astrometric solution included.

The same steps can be performed using SCAMP. See <https://scamp.readthedocs.io/en/latest/Using.html> for a tutorial on how to use it. SCAMP needs a list of catalogues and a configuration file in order to work. First, you need to run Source Extractor on each image. Look for the ‘default.param’ file and uncomment the lines containing the following parameters: ‘XWIN_IMAGE’, ‘YWIN_IMAGE’, ‘ERRAWIN_IMAGE’, ‘ERRBWIN_IMAGE’, ‘ERRTHETAWIN_IMAGE’, ‘FLUX_AUTO’, ‘FLUXERR_AUTO’, ‘FLAGS’, ‘FLAGS_WEIGHT’, ‘IMAFLAGS_ISO’, ‘FLUX_RADIUS’, ‘ELONGATION’. Then, look for the ‘default.sex’ file, open it and change ‘CATALOG_TYPE’ in ‘FITS_LDAC’ and ‘PARAMETERS_NAME’ in the path to ‘default.param’. The rest of the parameters is up to you to discover what they do and which value to choose. Now you can run Source Extractor:

```

$ sex image_path -c default.sex -CATALOG_NAME 'path_to_catalogue_name'

```

These catalogues that you have created for each image will be read by SCAMP. First, create an ASCII file where each line contains the path to the Source Extractor output catalogues, preceded by . Then look for the configuration file (usually it ends with ‘*.conf’) and check that the ‘SOLVE_Astrom’ parameters is set to ‘Y’. Check the manual for the other parameters meaning and values. Then run SCAMP with

```

$ scamp catalogue_list -c scamp.conf

```

Alternatively, you can use a Python package called ‘astroalign’ (<https://github.com/toros-astro/astroalign>). You can install it with

```

$ pip install astroalign

```

This package finds similar 3 point asterisms in an input and reference image and computes the affine transformation between them. It may not work on images of extended objects with few point-like sources or in very crowded fields. However, also in these cases, one of the three methods will do the job. An example code is

```

$ from astropy.io import fits
$ import astroalign
$ data = fits.getdata('path_to_image', ext=0)
$ reference_img = fits.getdata('path_to_ref_image', ext=0)
$ reference_head = fits.getheader('path_to_ref_image', ext=0)
$ aligned_image = astroalign.register(data, reference_img)
$ fits.writeto('path_to_aligned_image.fits', aligned_image, reference_head,
              overwrite=True)

```

IRIS contains a tool to perform astrometric calibration. You can follow the tutorial in http://www.astrosurf.com/buil/iris/tutorial13/doc31_us.htm.

6.9.5 Stacking

Stacking consists of combining several astronomical images. In order to do that, images have to be aligned one respect to each other.

There are 3 options to perform this task:

- DeepSkyStacker: it has a graphical interface that makes things easy to perform, however it works only under Windows. Tutorials on how to use it can be found in the website.
- IRIS: first you need to align the single exposures. To do that, just follow the section ‘Align the images’ in http://www.astrosurf.com/buil/iris/tutorial3/doc13_us.htm or follow the tutorials in http://www.astrosurf.com/buil/iris/tutorial2/doc10_us.htm or http://www.astrosurf.com/buil/iris/tutorial2/doc11_us.htm. After the alignment, you can stack the single exposure by following the section ‘Stack a set of images’ in http://www.astrosurf.com/buil/iris/tutorial3/doc13_us.htm or follow the tutorial in http://www.astrosurf.com/buil/iris/tutorial2/doc121_us.htm.
- Python-based: first you align all the images to a reference one with ‘astroalign’. Then those images can be combined by adding them

```
$ final_science = aligned_image_1 + aligned_image_2
```

if you want to obtain a deeper image (e.g., for galaxies), or they can be combined by averaging them

```
$ list = [aligned_image_1, aligned_image_2]
$ final_science = np.mean(list, axis=0)
```

for example when you have star images, e.g., a standard star. This method does not work for images downloaded from ‘astrometry.net’, since it only computes the astrometric solution, but it doesn’t change the pixel position of objects.

- SWARP: this is the most precise method, but it requires images having the astrometric solution in their headers. Therefore, it requires as input images downloaded from ‘astrometry.net’ or that have been processed with SCAMP. SWARP manual can be found at <https://www.astromatic.net/pubsvn/software/swarp/trunk/doc/swarp.pdf>. Look for the configuration file (it should end with ‘*.swarp’) and check that the ‘COMBINE’ parameter is set to ‘Y’. Check the manual for the other parameters meaning and values. If you have images from ‘astrometry.net’, you can create an ASCII file with image paths (as in SCAMP) and then you run SWARP with

```
$ swarp image_list -c hpp.swarp
```

to obtain as output a coadded (combined) image. Exposure times, gains etc. will be updated accordingly. If you have catalogues from SCAMP, then it will output a .head file that can be read by SWARP by setting the ‘HEADER_ONLY’ parameter to ‘Y’ (see manual for more details).

6.9.6 Photometric Calibration

The photometric calibration requires the image of a standard star that has gone through all the data reduction steps we mentioned so far. The theory behind the photometric calibration is very well explained in <http://slittlefair.staff.shef.ac.uk/teaching/phy241/>

[lectures/L07/index.html](#). Since you need to perform aperture photometry on your standard stars (or galaxies or HII regions, depending on the experiment), you can use the routines provided by the 'photutils' Python package <https://photutils.readthedocs.io/en/stable/aperture.html>. By following the two tutorials, it should be quite straightforward to obtain the magnitude zero-point of the image.

6.9.7 Seeing Estimate

For different experiment it may be needed to estimate the point spread function (PSF) of the image. The PSF is the response of the detector to a point-like source. In the absence of the atmosphere, this is close to the Airy patterns produced by diffraction. Since we perform observations on the ground, the image of a point-source breaks into speckle patterns that rapidly vary with time. It is the turbulence and the temperature gradients of the atmosphere to give rise to this effect. How much the atmosphere perturbs the image of stars seen through a telescope is often referred to as seeing. Its most common measurement is through the full width at half maximum (FWHM) of stars in the image.

There are different ways to measure the seeing of images. The simplest ones consists in fitting the 2D distribution of star light with either a Gaussian or a Moffat profile. One needs to identify stars in the image, then cut stamps around the stars (one can use the 'Astropy Cutout2D' python module). These stamps need to be large enough to contain the full flux from the star, but no other nearby sources. Then one writes down the functional form of the 2D Gaussian or 2D circular Moffat profile and fit those to the star light distribution using the 'scipy curve_fit' Python module. The best-fitting FWHM can be used as estimate of the seeing. The result will be in units of pixel. It can be turned into arcsec units by multiplying it for the pixel scale of the image.

6.9.8 Credits

Credits to Uwe Schmitt for the virtual environment installation description and to Jason Fitzpatrick for how to install Python on Windows.

Python Software Foundation. Python Language Reference, version 2.7.

Anaconda Software Distribution. Computer software. Vers. 2-2.4.0. Anaconda, Nov. 2016. Web. <<https://anaconda.com>>.

Homebrew was created by Max Howell. Website by Remi Prevost, Mike McQuaid and Danielle Lalonde.

SAOImage DS9 development has been made possible by funding from the Chandra X-ray Science Center (CXC) and the High Energy Astrophysics Science Archive Center (HEASARC). Additional funding was provided by the JWST Mission office at Space Telescope Science Institute to improve capabilities for 3-D data visualization.

E. Bertin and S. Arnouts. SExtractor: Software for source extraction. *A&AS*, 117:393-404, 1996.

E. Bertin, Y. Mellier, M. Radovich, G. Missonnier, P. Didelon, and B. Morin. The TERAPIX Pipeline. In D. A. Bohlender, D. Durand, and T. H. Handley, editors, *Astronomical Data Analysis Software and Systems XI*, volume 281 of *Astronomical Society of the Pacific Conference Series*, 228. 2002.

Credits to <http://deepskystacker.free.fr/english/index.html>.

van Dokkum 2001, *PASP*, 113, 789, 1420 <http://adsabs.harvard.edu/abs/2001PASP..113.1420V>.

Credits to <https://github.com/toros-astro/astroalign>.

This research made use of Astropy,² a community-developed core Python package for Astronomy (Robitaille et al. A&A 558, A33 (2013)).

Phoutils: DOI 10.5281/zenodo.1340699

Credits and many thanks to Stuart Littlefair <http://slittlefair.staff.shef.ac.uk>.

7 Experiments

This section describes the proposed scientific experiments that can be performed with the HPP telescope. They range from the Solar System to the Galactic and Extragalactic regime. Students are invited to read chapter 1 of [1], chapters 1, 3, and 6 of [2] and some of the notes from the courses <http://slittlefair.staff.shef.ac.uk/teaching/phy241/> and <https://quanz-group.ethz.ch/education/lectures/astrophysics-I-hs2019.html> to understand astronomical instrumentation and data analysis. Further references for astronomical data analysis can be found in the ‘CCDObservations’ manual <https://ethz.ch/content/dam/ethz/special-interest/phys/particle-physics/quanz-group-dam/documents-old-s-and-p/Courses/vp-asl-astro/CCDObservations.pdf> and in Section 6.9. These experiments require a basic prior knowledge of how to program in Python.

7.1 Experiment 1: Hertzsprung-Russell diagram of star clusters

7.1.1 Brief theory

Stars show a large variety of luminosities and surface (or effective) temperatures that can be represented in the Hertzsprung-Russell diagram (hereafter HR diagram). This diagram is a scatter plot of stars that shows the relationship existing between a star luminosity and its surface temperature (Figure 37). Stars at different stage of their lifetime span different locus in this diagram. The specific path followed in time by stars on the HR diagram is a function of their initial mass when they start to burn Hydrogen through nuclear fusion reactions.

Stars spend most of their lifetime on the Main Sequence (the diagonal line in Figure 37). The specific position on the Main Sequence is given by the star mass. On the Main Sequence, stars burn hydrogen in their cores transforming it into Helium through nuclear fusion reactions. The larger the star mass, the lower the time a star sits on the Main Sequence. Once the star runs out of hydrogen in the core, it starts burning first hydrogen in the outer core layer and then helium in center and it moves from the Main Sequence to the Red Giant branch. Eventually, stars of different masses have different fates. Solar-kind stars end their lives as white dwarfs, heavier stars ($> 8 M_{\odot}$) explode as core collapse Supernovae.

Estimating a star luminosity and effective temperature is not an easy task because it involves e.g. estimating the star distance. Therefore, the HR diagram is usually represented as a color-magnitude diagram. The absolute magnitude is a proxy for the luminosity, the color a proxy for the surface temperature. Usually, the observer HR diagram is plotted as absolute magnitude in the V-band as a function of the B - V color. To estimate the absolute magnitude, one needs to know the distance to the star. However if all the stars that we examine are at the same distance, then the absolute magnitude can be substituted by the apparent magnitude. This happens in open clusters or globular clusters that are concentration of stars in well defined region of space, where we can assume that each star has the same distance to us observers.

²<http://www.astropy.org>

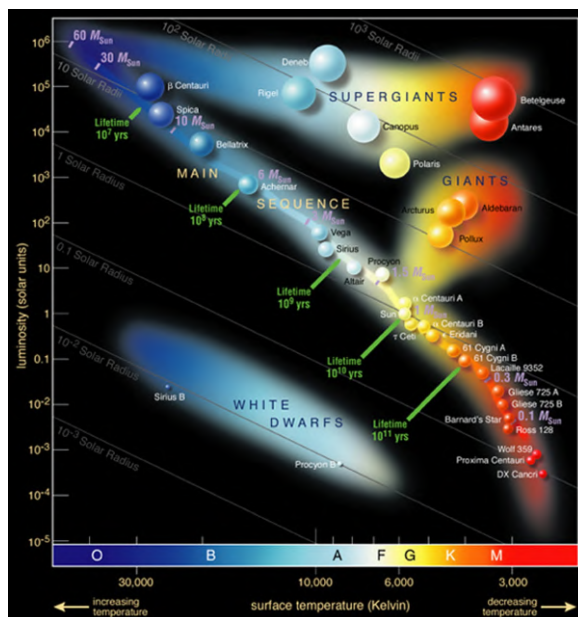


Figure 37: Hertzsprung-Russell diagram. Credits to ESO, <https://www.eso.org/public/images/eso0728c/>.

Further references students need to read for the experiment are chapter 3 in [1] and chapters 8.2, 10.6, 13, 15.1, 16.1, 16.2 in [2].

7.1.2 Aim of the experiment

The aim of the experiment is to build the HR diagram using either open clusters or globular clusters and identify the different evolutionary stages of stars on the HR diagram. Students need to identify suitable targets for the experiment using either lists of open clusters (e.g., https://en.wikipedia.org/wiki/List_of_open_clusters) or the Nasa Extragalactic database search feature <https://ned.ipac.caltech.edu/byparams>. During the observations, students need to collect the calibration images (bias, dark, flat) and images of their targets in the B and V bands. Students need also to collect images of a standard star to estimate the photometric zeropoint. Lastly, they need to perform a data reduction and analyse data to create the HR diagram.

7.1.3 Data Analysis steps

After data acquisition, students need to perform the data reduction steps described in Section 6.9 for both the actual targets and the standard star. The standard star is then used to measure the magnitude zeropoint of each image in each band. This produces target images that have been astrometrically and photometrically calibrated, i.e. every pixel has a specific sky position assigned and the magnitude zeropoint of the image is known.

For this experiment, students need to measure the magnitudes for each star belonging to the star cluster. They can perform these tasks using the Python packages ‘photutils’ and ‘Astropy’:

- Perform source detection: following <https://photutils.readthedocs.io/en/stable/detection.html>, students need to detect and extract sources from the image. The provided positions of the objects are in pixel units.

- Convert pixel to sky coordinates: following <https://docs.astropy.org/en/stable/wcs/>, students need to convert the pixel coordinates of sources into sky coordinates, i.e. Right ascension (RA) and Declination (DEC) at J2000.
- Match with external catalogue: in order to know which stars belong to the star cluster, students need to download a reference catalogue for the star cluster from <http://vizier.u-strasbg.fr/viz-bin/VizieR> and match this catalogue with the detected sources via sky coordinates, following <https://docs.astropy.org/en/stable/coordinates/matchsep.html>.
- Perform photometry: students need to measure magnitudes in the B and V bands for each star belonging to the star cluster following <https://photutils.readthedocs.io/en/stable/psf.html>.
- Plot the HR diagram: students need to plot the HR diagram using the measured magnitudes and identify the different evolutionary stages on it. If the single star cluster contains few stars, then different star clusters stars may be put on the same plot, provided that their absolute magnitude has been estimated.

Similar steps need to be performed on the standard star image in order to measure its instrumental magnitude and therefore the magnitude zeropoint of the image.

7.2 Experiment 2: Period-Luminosity relation with Cepheids

7.2.1 Brief theory

Cepheids are a class of pulsating stars that vary their luminosity in a periodic way. The luminosity of these objects depends only on the size and composition (metallicity) of the star. These stars are not located on the Main Sequence of stars of the Hertzsprung-Russell (HR) diagram. Indeed, they oscillate between the Main sequence and the instability strip (Figure 38). Being Cepheids rare, their pulsation is a transient phenomenon.

Several mechanisms can produce stellar pulsations. In short, the Cepheid acts like a gigantic heat engine of which the volume and pressure change in time similarly to a thermodynamic cycle. Since the oscillation period depends only on the properties of the star such as its mass and composition, once we know composition (through spectroscopy) and period of oscillation, we can deduce its luminosity. As a matter of fact, for most Cepheids there is a very specific relationship between their period and their absolute magnitude, the so-called period-luminosity relation. This relation has been empirically calibrated in different wavebands by astronomers. By measuring the period of the star and by then measuring its brightness, one can deduce the distance to the star. Cepheids are indeed called standard candles.

Further references students need to read are chapter 2.2.7 in [3] and chapter 8.2, 10.6, 13, 14 in [2].

7.2.2 Aim of the experiment

The aim of the experiment is to estimate the distance to the Cepheid stars using the calibrated period-luminosity relation in the V-band. Students need to identify suitable targets for the experiment using e.g., the Nasa Extragalactic database search feature <https://ned.ipac.caltech.edu/byparams>. During the observations, students need to collect the calibration images (bias, dark, flat) and images of their targets in the V-band. Students need also to collect images of a standard star to estimate the photometric zeropoint. Students need to create the light curve of Cepheid variables, therefore multiple nights of observations are

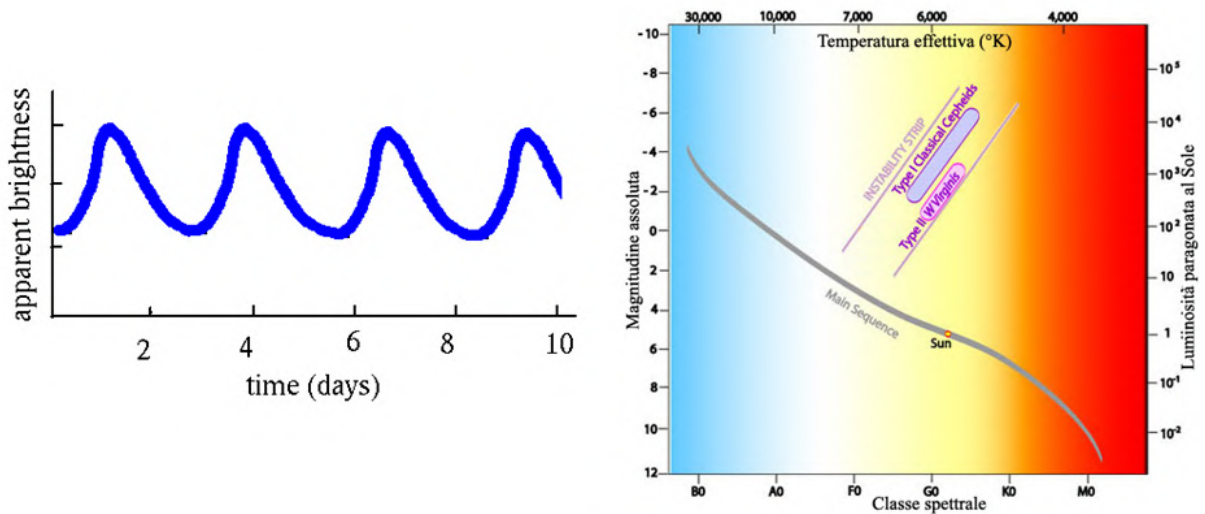


Figure 38: Cepheid light curve and position on the HR diagram. Credits to <http://www.eanweb.com/2012/le-variabili-pulsanti/>.

required for this experiment. Once data are collected, students perform a data reduction and data analysis to estimate the period from the light curve and then the distance to the star through the period-luminosity relation.

7.2.3 Data Analysis steps

After data acquisition, students need to perform the data reduction steps described in Section 6.9 for both the actual targets and the standard star. The standard star is then used to measure the magnitude zeropoint of each image in each band. This produces target images that have been astrometrically and photometrically calibrated, i.e. every pixel has a specific sky position assigned and the magnitude zeropoint of the image is known.

For this experiment, students need to measure the magnitudes as a function of time (epochs) for each Cepheid star. They can perform these tasks using the Python packages 'photutils' and 'Astropy':

- Perform source detection: following <https://photutils.readthedocs.io/en/stable/detection.html>, students need to detect and extract sources from the image. The provided positions of the objects are in pixel units.
- Perform photometry: students need to measure the Cepheid magnitudes in V-band for the multiple epochs following <https://photutils.readthedocs.io/en/stable/psf.html>.
- Period: students need to plot the light curve of Cepheids and measure their pulsation period.
- Distance: using the calibrated period-luminosity relation in the V-band, students need to measure the distance to each Cepheid variable.

Similar steps need to be performed on the standard star image in order to measure its instrumental magnitude and therefore the magnitude zeropoint of the image.

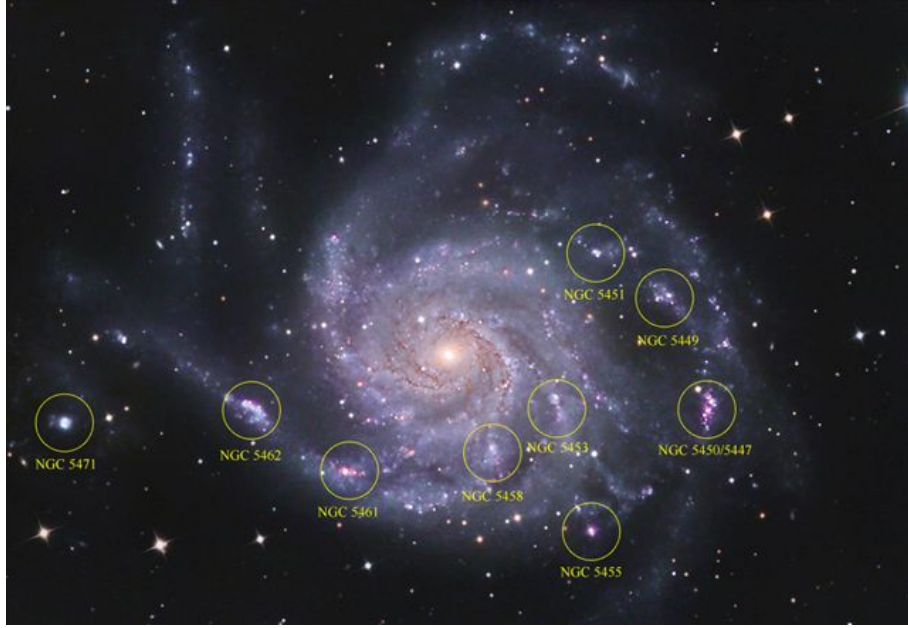


Figure 39: M101 and its HII regions of ongoing star-formation. Credits to George Golitzin (<https://www.cloudynights.com/topic/333679-hii-regions-in-m101/>).

7.3 Experiment 3: Star-formation rate of galaxies with the $H\alpha$ line

7.3.1 Brief theory

Different kind of galaxies produce stars at different rates during the course of their lifetime. The amount of stars produced by galaxies is generally defined as star-formation rate (SFR) and it indicates the amount of stars in units of solar masses produced per year. Elliptical galaxies generally have a low SFR, while spiral galaxies a higher one. Star-formation occurs in the dense regions of molecular clouds, i.e. regions where molecular hydrogen is available. When stars ignite their hydrogen burning in the core, they emit a large number of ionizing photons that ionize the surrounding medium giving rise to the so-called HII regions (Figure 39).

An indicator for the ongoing star-formation in galaxies is the $H\alpha$ luminosity. During the formation of stars, especially heavy ones, a great amount of ionizing photons is produced. These can ionize the surrounding hydrogen gas. When the protons and electrons recombine, they might recombine into an excited state instead of into the hydrogen ground state. By emitting photons, these excited states can fall back to the ground state. The $H\alpha$ line corresponds to the $n=3$ to $n=2$ transition in the Balmer series and it emits a photon at a wavelength of 656.28 nm. By measuring the $H\alpha$ luminosities in galaxies and using the calibrated relations between luminosities and star-formation rates, we can measure the ongoing SFR in galaxies in units of solar masses per year.

Further references students need to read for the experiment are chapters 6.6, 6.6.4, 9.1,9.2 in [1], chapter 25 in [2], chapters 3.1, 3.3.1, 3.3.2, 3.9.4, 3.9.5 in [3], https://ned.ipac.caltech.edu/level5/Sept12/Calzetti/Calzetti1_2.html and <https://ned.ipac.caltech.edu/level5/Sept01/Rosa/frames.html>

7.3.2 Aim of the experiment

The aim of the experiment is to measure the SFR of a sample of local spiral galaxies using the $H\alpha$ line. Students need to identify suitable targets for the experiment using e.g., the Nasa Extragalactic database search feature <https://ned.ipac.caltech.edu/byparams>. During the observations, students need to collect the calibration images (bias, dark, flat) and images of their targets in the $H\alpha$ -band. Students need also to collect images of a standard star to estimate the photometric zeropoint. Once data are collected, students perform a data reduction and data analysis to measure the flux from the HII regions, convert it into luminosities using the distance to the object and then measure the SFR using the empirical relation between luminosity in $H\alpha$ and SFR.

7.3.3 Data Analysis steps

After data acquisition, students need to perform the data reduction steps described in Section 6.9 for both the actual targets and the standard star. The standard star is then used to measure the magnitude zeropoint of each image in each band. This produces target images that have been astrometrically and photometrically calibrated, i.e. every pixel has a specific sky position assigned and the magnitude zeropoint of the image is known.

For this experiment, students need to measure the flux from HII regions in the spiral galaxies. They can perform these tasks using the Python packages ‘photutils’ and ‘Astropy’:

- Perform source detection: following <https://photutils.readthedocs.io/en/stable/detection.html>, students need to detect and extract sources from the image. The provided positions of the objects are in pixel units.
- Perform photometry: students need to measure the flux from HII regions in the $H\alpha$ -band following <https://photutils.readthedocs.io/en/stable/aperture.html>.
- Estimate luminosity: students need to measure $H\alpha$ luminosities using fluxes and distances from galaxies.
- Star-formation rate: using the calibrated relation between luminosity and star-formation rate, students need to measure the latter and compare it to literature values.

Similar steps to those highlighted in Section 7.1.3 need to be performed on the standard star image in order to measure its instrumental magnitude and therefore the magnitude zeropoint of the image.

7.4 Experiment 4: Galaxy morphology with GALFIT

7.4.1 Brief theory

Galaxies in the Universe show a wide range of morphologies. They range from spheroidal aggregation of stars such as elliptical galaxies to disk objects with spiral arms such as spiral galaxies to irregularly shaped galaxies resulting from interactions or feedback from the interstellar medium. One of the very first morphological classification of galaxies was performed by Edwin Hubble in its famous tuning-fork diagram (Figure 40).

The visual morphological classification of galaxies is a task that requires a lot of experience and expertise. Even professional astronomers may find difficult to classify a galaxy, especially if the galaxy is far away and the resolution of the telescope is poor. An alternative way of morphologically classify a galaxy is by looking at its light distribution, i.e. the intensity of light as a function of the galaxy radius. The most general light profile distribution is the Sérsic light profile (Sérsic 1963) where the intensity of light scales as $I(R) \propto e^{-bR^{1/n}}$, with

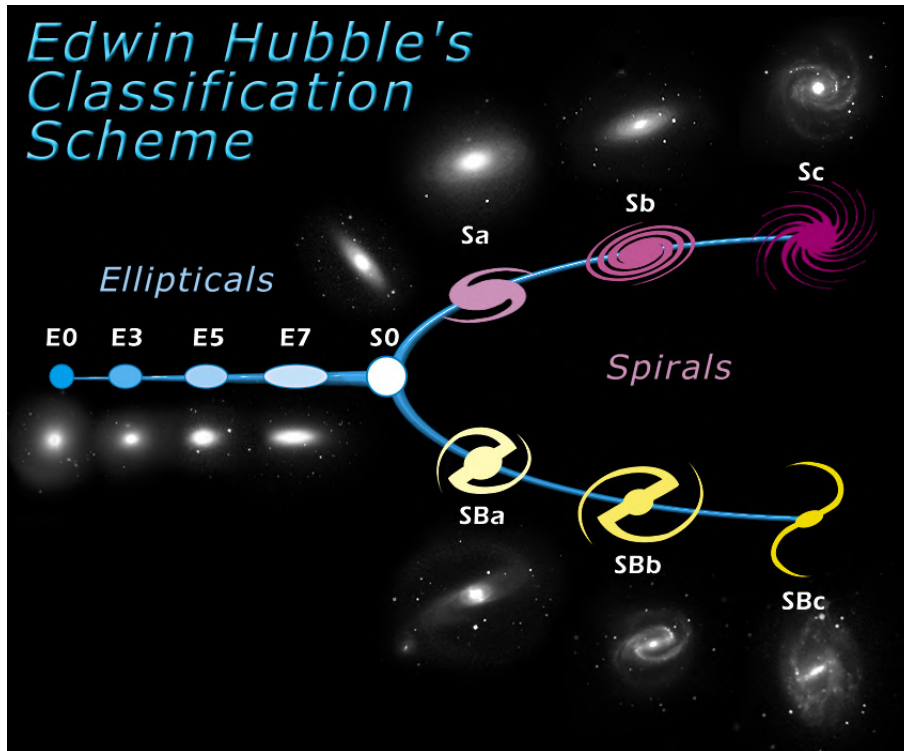


Figure 40: Hubble tuning-fork diagram. Credits to NASA & ESA.

n being the Sérsic index. n is usually equal to ~ 4 for elliptical galaxies and ~ 1 for spiral galaxies. Different softwares are available to measure the galaxy light profile. One of the more robust ones is GALFIT (Peng et al. 2010) that is a two-dimensional fitting algorithm designed to extract structural components from galaxy images.

Further references students need to read for the experiment are chapters 9.1,9.2 in [1], chapter 25 in [2], chapters 3.1, 3.2.1, 3.2.2, 3.2.3, 3.3.1, 3.3.2 in [3], Galfit manual and <https://ned.ipac.caltech.edu/level5/Sept11/Buta/frames.html>.

7.4.2 Aim of the experiment

The aim of the experiment is to morphologically classify a sample of local elliptical and spiral galaxies using the software GALFIT. Students need to identify suitable targets for the experiment using e.g., the Nasa Extragalactic database search feature <https://ned.ipac.caltech.edu/byparams>. During the observations, students need to collect the calibration images (bias, dark, flat) and images of their targets in the B, V and R bands. Students need also to collect images of a standard star to estimate the photometric zeropoint. Once data are collected, students perform a data reduction and data analysis to fit the galaxy light profiles with GALFIT and estimate the best-fitting total magnitude, half-light radius and Sérsic index. On the base of the Sérsic index value, students need to classify their galaxies and compare their classification with the literature one.

7.4.3 Data Analysis steps

After data acquisition, students need to perform the data reduction steps described in Section 6.9 for both the actual targets and the standard star. The standard star is then used to measure the magnitude zeropoint of each image in each band. This produces target images



Figure 41: Jupyter and its moons from an amateur telescope. Credits to Thomas Bresson and Rochus Hess.

that have been astrometrically and photometrically calibrated, i.e. every pixel has a specific sky position assigned and the magnitude zeropoint of the image is known.

For this experiment, students need to use GALFIT to fit the galaxy image with a Sérsic light profile following the examples in <https://users.obs.carnegiescience.edu/peng/work/galfit/galfit-ex.tar.gz> and the rules of thumb in <https://users.obs.carnegiescience.edu/peng/work/galfit/TOP10.html>. Students also needs to use ‘photutils’ and ‘Astropy’ for specific tasks.

- Data reduction: images need to be photometrically and astrometrically calibrated.
- Model of the PSF: GALFIT convolves the light profile with the point-spread function (PSF) of the telescope+detector, therefore a model image of the PSF needs to be created. Students can follow <https://photutils.readthedocs.io/en/stable/epsf.html#build-epsf> to build a model of the PSF.
- Initial guess: an initial guess for the parameters of the Sérsic model needs to be provided to GALFIT. One example is to measure the magnitude and half-light radius in an elliptical aperture following <https://photutils.readthedocs.io/en/stable/isophote.html>. An initial guess of $n=2.5$ is good enough for our purposes.
- galaxy fitting: students perform a galaxy image fitting with GALFIT. They need to report the best-fitting parameters, together with the model and the residual images. A morphological classification needs to be performed according to the best-fitting Sérsic index value.

Similar steps to those highlighted in Section 7.1.3 need to be performed on the standard star image in order to measure its instrumental magnitude and therefore the magnitude zeropoint of the image.

7.5 Experiment 5: Mass of Jupyter and Saturn

7.5.1 Brief theory

The two largest planets of the Solar System, Saturn and Jupyter, are also the ones having the largest number of moons. By inspecting their orbital motion, it is possible to estimate the mass of these two gas giants. If we assume that the moons move on circular orbits around

Jupiter and Saturn and if we assume that their mass is negligible with respect to the planet, then we can equate Newton's law

$$F_G = G \frac{m_1 m_2}{r^2} \quad (2)$$

where G is the gravitational constant, m_1 and m_2 the mass of the attracting bodies, r the distance between the two bodies, with the centripetal force

$$F_C = m\omega^2 r \quad (3)$$

where m is the mass of the moving object, ω its angular velocity and r the distance from the center of its orbit. By equating them and using the relation between angular velocity and period for circular orbit we obtain

$$\frac{T^2}{r^3} = \frac{4\pi^2 G}{M} \quad (4)$$

where M is the mass of Jupiter or Saturn.

Further reference students need to read for the experiment is chapter 21 in [2].

7.5.2 Aim of the experiment

The aim of the experiment is to measure the mass of Jupiter and/or Saturn using their moon orbits 41. This experiment is not always available given the different relative positions of Sun, Earth and Jupiter/Saturn during the years. During the observations, students need to collect the calibration images (bias, dark, flat) and images of their targets in the B, V and R bands. Students need also to collect images of a standard star to estimate the photometric zeropoint. They need to take multi-epoch observations of Jupiter/Saturn and their moons in order to reconstruct the orbit of the objects. Multiple days of observations are therefore required to obtain optimal results. Students need to perform a data reduction and analyse the data to estimate Jupiter/Saturn mass.

7.5.3 Data Analysis steps

After data acquisition, students need to perform the data reduction steps described in Section 6.9 for both the actual targets and the standard star. The standard star is then used to measure the magnitude zeropoint of each image in each band. This produces target images that have been astrometrically and photometrically calibrated, i.e. every pixel has a specific sky position assigned and the magnitude zeropoint of the image is known.

For this experiment, students need to measure the relative distances between the moons and the planet as a function of time. They can perform these tasks using the Python packages 'photutils' and 'Astropy':

- Perform source detection: following <https://photutils.readthedocs.io/en/stable/detection.html>, students need to detect and extract sources from the image. The provided positions of the objects are in pixel units.
- Convert in absolute distances: by using simple trigonometry, students need first to convert the distance in pixel between sources in angular distance (using the pixel scale) and then in absolute distance in meters by using the Earth-Jupiter distance at the time of observation.
- Plot the distance: students need to plot the obtained distances as a function of time and, assuming a circular motion, compute the period, amplitude and phase of the orbital motion of the moons. They can use the `scipy curve_fit` function to fit the curve to the data.

- Compute the mass: using the best-fitting period, students need to derive the mass of Jupiter/Saturn together with the error on this estimate.

7.6 Experiment 6: Planetary Albedo

7.6.1 Brief Theory

Planets do not emit light through nuclear reactions as the Sun does. They have other physical processes that emit light, but the amount of radiation is too small to make them visible from Earth. Planets absorb and reflect light from the Sun and this latter effect makes them visible from Earth. The amount of radiation that a planet reflects is called ‘albedo’. The albedo depends on the characteristics of its surface and atmosphere. For example, a planet covered in ice is going to reflect a lot more light than a planet with a rocky surface. Calculating this quantity with empirical data can therefore help us get some information about the composition of the planet outer shell. The ratio between the incoming L_{in} and reflected radiation L_{out} from a planet is given by:

$$A = \frac{L_{\text{out}}}{L_{\text{in}}} = p \cdot q \quad (5)$$

where p and q are the geometric albedo and the phase integral, respectively. p gives information about the intrinsic properties of the planet, q includes the phase angle dependence. p has a value between 0 (absorbs all radiation) and 1 (reflects all radiation). The formula to compute the geometric albedo is

$$p = \left(\frac{r\Delta}{aR} \right) \cdot 10^{-0.4(m-m_{\odot})} \quad (6)$$

where Δ is the distance Earth-planet, a is the Sun-Earth distance in AU, r is the planet-Sun distance, R the planet radius, m is the planet apparent magnitude and m_{\odot} is the Sun apparent magnitude.

Further reference the students have to read is chapter 7 in [4].

7.6.2 Aim of the experiment

The aim of the experiment is to measure the geometric albedo of the Solar system planets. The targets for the experiment depends on which planets are observable from Earth in the specific semester of observations. During the observations, students need to collect the calibration images (bias, dark, flat) and images of their targets in the B, V and R bands. Students need also to collect images of a standard star to estimate the photometric zeropoint. They then measure the calibrated apparent magnitudes and the geometric albedos in the B, V and R bands.

7.6.3 Data Analysis steps

After data acquisition, students need to perform the data reduction steps described in Section 6.9 for both the actual targets and the standard star. The standard star is then used to measure the magnitude zeropoint of each image in each band. This produces target images that have been astrometrically and photometrically calibrated, i.e. every pixel has a specific sky position assigned and the magnitude zeropoint of the image is known.

For this experiment, students need to measure the albedos of planets. They can perform these tasks using the Python package ‘photutils’:

- Perform photometry: students need to measure the background subtracted fluxes from the planets following <https://photutils.readthedocs.io/en/stable/aperture.html>. Then they can translate that into magnitudes using the photometric zero-point estimated from the standard star.
- Estimate the geometric albedo: using the formula in section 7.6.1, students need to measure the geometric albedo and its error and compare it to literature values. The values for the apparent magnitude of the sun, the distance of the planet from Earth and Sun can be easily found in literature.

7.7 References

- [1] Astrophysics for Physicists, Arnab Rai Choudhuri, Cambridge University press
- [2] An Introduction to Modern Astrophysics, Bradley W. Carroll, Dale A. Ostlie, Pearson International edition
- [3] Extragalactic Astronomy and Cosmology, Peter Schneider, Springer
- [4] Fundamental Astronomy, Hannu Karttunen, Springer

A List of Standard Stars

A Liste von UBVR I Standardsterne

UBVRI Standard Star List for Epoch =2000.0

BS=HR No.	Flamsteed/Bayer Designation		RA h m s	Dec ° ' "	Spectral Type	V	U-B	B-V	V-R	V-I
21	11 beta	Cas	00 09 10.7	+59 08 59	F2 III	+2.27	+0.12	+0.34	+0.31	+0.51
39	88 gamma	Peg	00 13 14.2	+15 11 01	B2 IV	+2.84	-0.86	-0.23	-0.10	-0.29
45	89 chi	Peg	00 14 36.2	+20 12 24	M2 ⁺ III	+4.80	+1.93	+1.57	+1.34	+2.47
63	24 theta	And	00 17 05.5	+38 40 54	A2 V	+4.61	+0.05	+0.06	+0.08	+0.09
113			00 30 19.9	+59 58 39	B9 IIIIn	+5.94	-0.36	+0.01		
130	15 kappa	Cas	00 33 00.0	+62 55 54	B0.7 Ia	+4.16	-0.80	+0.14	+0.14	+0.20
321	30 mu	Cas	01 08 16.4	+54 55 13	G5 Vb	+5.18	+0.09	+0.69	+0.63	+1.04
437	99 eta	Psc	01 31 29.0	+15 20 45	G7 IIIa	+3.62	+0.74	+0.97	+0.72	+1.22
493	107 theta	Psc	01 42 29.8	+20 16 07	K1 V	+5.24	+0.49	+0.84	+0.69	+1.12
553	6 beta	Ari	01 54 38.4	+20 48 29	A4 V	+2.65	+0.10	+0.13	+0.14	+0.22
617	13 alpha	Ari	02 07 10.4	+23 27 45	K2 ⁻ IIIab Ca - 1	+2.00	+1.13	+1.15	+0.84	+1.46
718	73 xi ²	Cet	02 28 09.5	+08 27 36	A0 III ⁻	+4.29	-0.11	-0.06	+0.02	-0.03
753			02 36 04.9	+06 53 13	K3 ⁻ V	+5.82	+0.79	+0.97	+0.83	+1.36
875			02 56 37.4	-03 42 44	A3 Vn	+5.17	+0.05	+0.08	+0.11	+0.16
996	96 kappa	Cet	03 19 21.7	+03 22 13	G5 V	+4.84	+0.19	+0.68	+0.57	+0.93
1034			03 28 03.1	+49 03 46	B3 V	+4.98	-0.55	-0.10	+0.01	-0.09
1046			03 30 00.2	+55 27 07	A1 V	+5.10	+0.05	+0.04	+0.09	+0.08
1084	18 epsilon	Eri	03 32 55.8	-09 27 30	K2 V	+3.73	+0.58	+0.88	+0.72	+1.19
1131	38 o	Per	03 44 19.1	+32 17 18	B1 III	+3.83	-0.75	+0.05	+0.12	+0.12
1144	18 theta	Tau	03 45 09.7	+24 50 21	B8 V	+5.65	-0.36	-0.07	+0.03	-0.04
1165	25 eta	Tau	03 47 29.1	+24 06 18	B7 IIIIn	+2.87	-0.35	-0.09	+0.03	-0.01
1172			03 48 20.9	+23 25 16	B8 V	+5.45	-0.32	-0.07	+0.05	-0.01
1228	46 xi	Per	03 58 57.9	+35 47 28	G7.5 IIIIf	+4.04	-0.93	+0.02	+0.16	+0.15
1346	54 gamma	Tau	04 19 47.6	+15 37 39	G9.5 IIIab CN 0.5	+3.65	+0.81	+0.99	+0.73	+1.20
1373	61 delta	Tau	04 22 56.1	+17 32 33	G9.5 III CN 0.5	+3.76	+0.82	+0.99	+0.73	+1.20
1411	77 theta ¹	Tau	04 28 34.5	+15 57 44	G9 III Fe - 0.5	+3.83	+0.72	+0.95	+0.71	+1.18
1409	74 epsilon	Tau	04 28 37.0	+19 10 49	G9.5 III CN 0.5	+3.54	+0.87	+1.01	+0.73	+1.23
1412	78 theta ²	Tau	04 28 39.7	+15 52 15	A7 III	+3.39	+0.12	+0.18	+0.18	+0.27
1543	1 pi ³	Ori	04 49 50.4	+06 57 41	F6 V	+3.19	-0.01	+0.46	+0.42	+0.68
1552	3 pi ⁴	Ori	04 51 12.4	+05 36 18	B2 III	+3.68	-0.81	-0.17	-0.05	-0.21
1641	10 eta	Aur	05 06 30.9	+41 14 04	B3 V	+3.18	-0.67	-0.18	-0.05	-0.22
1666	67 beta	Eri	05 07 51.0	-05 05 11	A3 IVn	+2.79	+0.10	+0.13	+0.14	+0.22
1781			05 23 42.2	-00 09 35	B2 V	+5.70	-0.88	-0.21	-0.08	-0.27
1791	112 beta	Tau	05 26 17.5	+28 36 27	B7 III	+1.65	-0.49	-0.13	-0.01	-0.11
1855	36 upsilon	Ori	05 31 55.8	-07 18 05	B0 V	+4.62	-1.07	-0.26	-0.12	-0.38
1861			05 32 41.3	-01 35 31	B1 V	+5.35	-0.93	-0.19	-0.05	-0.24
1938			05 40 36.0	+31 21 30	B7 V	+6.04	-0.21	+0.05	+0.11	+0.16
2010	134 theta	Tau	05 49 32.9	+12 39 04	B9 IV	+4.91	-0.16	-0.07	+0.02	-0.06
2047	54 chi ¹	Ori	05 54 22.9	+20 16 34	G0 ⁻ V Ca 0.5	+4.41	+0.08	+0.59	+0.51	+0.82
2382	12 lambda	Mon	06 32 19.2	+04 51 21	K0 III	+5.83	+0.78	+1.00	+0.72	+1.25
2421	24 gamma	Gem	06 37 42.7	+16 23 57	A1 IVs	+1.92	+0.05	0.00	+0.06	+0.05
2693	25 delta	CMA	07 08 23.5	-26 23 36	F8 Ia	+1.84	+0.54	+0.67	+0.51	+0.84
2763	54 lambda	Gem	07 18 05.6	+16 32 25	A4 IV	+3.58	+0.09	+0.12	+0.12	+0.17
2782	30 tau	CMA	07 18 18.4	-36 44 03	O9 II	+4.40	-0.99	-0.15	-0.04	-0.22
2787			07 18 42.4	-24 57 15	B3 Ve	+4.67	-0.79	-0.10	+0.10	+0.05
2852	62 rho	Gem	07 29 06.7	+31 47 04	F0 V ⁺	+4.18	-0.02	+0.32	+0.32	+0.51
2990	78 beta	Gem	07 45 18.9	+28 01 34	K0 IIIb	+1.14	+0.86	+1.00	+0.75	+1.25
3249	17 beta	Cnc	08 16 30.9	+09 11 08	K4 III Ba 0.5	+3.53	+1.77	+1.48	+1.12	+1.90
3314			08 25 39.6	-03 54 23	A0 Va	+3.90	-0.03	-0.02	+0.03	-0.02
3427	39 theta	Cnc	08 40 06.4	+20 00 28	K0 III	+6.39	+0.83	+0.98	+0.72	+1.19
3454	7 eta	Hya	08 43 13.5	+03 23 55	B4 V	+4.30	-0.74	-0.20	-0.07	-0.26
3569	9 iota	UMa	08 59 12.4	+48 02 30	A7 IVn	+3.14	+0.07	+0.19	+0.22	+0.29
3579			09 00 38.4	+41 46 58	F7 V	+3.97	+0.06	+0.43	+0.40	+0.62
3815	11 lambda	LMi	09 35 39.6	+35 48 37	G8 IV - V	+5.41	+0.44	+0.77	+0.62	+0.99
3974	21 lambda	LMi	10 07 25.8	+35 14 41	A7 V	+4.49	+0.07	+0.18	+0.18	+0.25
3982	32 alpha	Leo	10 08 22.3	+11 58 02	B7 Vn	+1.35	-0.36	-0.11	-0.02	-0.12
4031	36 zeta	Leo	10 16 41.4	+23 25 02	F0 IIIa	+3.44	+0.19	+0.31	+0.31	+0.50
4033	33 lambda	UMa	10 17 05.8	+42 54 52	A1 IV	+3.45	+0.06	+0.03	+0.08	+0.07
4054	40 lambda	Leo	10 19 44.1	+19 28 15	F6 IV	+4.80	+0.01	+0.45	+0.45	+0.68
4112	36 lambda	UMa	10 30 37.6	+55 58 50	F8 V	+4.84	-0.01	+0.52	+0.48	+0.76
4133	47 rho	Leo	10 32 48.7	+09 18 24	B1 Iab	+3.85	-0.95	-0.14	-0.05	-0.21
4456	90 lambda	Leo	11 34 42.5	+16 47 49	B3 V	+5.95	-0.65	-0.16	-0.06	-0.24
4534	94 beta	Leo	11 49 03.6	+14 34 19	A3 Va	+2.14	+0.08	+0.08	+0.06	+0.08
4550			11 52 58.8	+37 43 07	G8 V P	+6.45	+0.17	+0.75	+0.66	+1.11

4554	64	gamma	UMa	11 53 49.8	+53 41 41	A0	Van	+2.44	+0.03	0.00	0.00	-0.03
4623	1	alpha	Crv	12 08 24.8	-24 43 44	F0	IV - V	+4.02	-0.02	+0.32	+0.30	+0.48
4660	69	delta	UMa	12 15 25.6	+57 01 57	A2	Van	+3.31	+0.07	+0.08	+0.06	+0.06
4662	4	gamma	Crv	12 15 48.4	-17 32 31	B8p	Hg Mn	+2.58	-0.35	-0.11	-0.04	-0.13
4707	12		Com	12 22 30.3	+25 50 46	G5	III + A5	+4.81	+0.27	+0.49	+0.47	+0.80
4751				12 28 44.6	+25 53 57	A0p		+6.65	+0.08	+0.22	+0.15	+0.23
4752	17		Com	12 28 54.7	+25 54 46	A0p	(Si)	+5.29	-0.10	-0.06	+0.02	-0.06
4785	8	beta	CVn	12 33 44.5	+41 21 27	G0	V	+4.27	+0.05	+0.59	+0.54	+0.85
4983	43	beta	Com	13 11 52.4	+27 52 41	F9.5	V	+4.26	+0.08	+0.58	+0.49	+0.79
5019	61		Vir	13 18 24.3	-18 18 41	G6.5	V	+4.74	+0.26	+0.71	+0.58	+0.94
5062	80		UMa	13 25 13.5	+54 59 17	A5	Vn	+4.02	+0.08	+0.16	+0.17	+0.24
5185	4	tau	Boo	13 47 15.7	+17 27 24	F7	V	+4.50	+0.05	+0.48	+0.41	+0.65
5235	8	eta	Boo	13 54 41.1	+18 23 52	G0	IV	+2.68	+0.20	+0.58	+0.44	+0.73
5264	93	tau	Vir	14 01 38.8	+01 32 40	A3	IV	+4.26	+0.13	+0.10	+0.15	+0.21
5340	16	alpha	Boo	14 15 39.7	+19 10 57	K1.5	III Fe - 0.5	-0.05	+1.28	+1.23	+0.97	+1.62
5359	100	lambda	Vir	14 19 06.6	-13 22 16	A5m:		+4.52	+0.09	+0.13	+0.10	+0.14
5447	28	sigma	Boo	14 34 40.8	+29 44 42	F2	V	+4.47	-0.08	+0.37	+0.34	+0.53
5511	109		Vir	14 46 14.9	+01 53 34	A0	IVnn	+3.73	-0.03	-0.01	+0.07	+0.05
5570	16		Lib	14 57 11.0	-04 20 47	F0	IV--	+4.49	+0.04	+0.32	+0.32	+0.49
5634	45		Boo	15 07 18.1	+24 52 09	F5	V	+4.93	-0.02	+0.43	+0.40	+0.61
5685	27	beta	Lib	15 17 00.4	-09 22 59	B8	IIIIn	+2.61	-0.37	-0.11	-0.04	-0.14
5854	24	alpha	Ser	15 44 16.1	+06 25 32	K2	IIIb CN 1	+2.64	+1.25	+1.17	+0.81	+1.37
5868	27	lambda	Ser	15 46 26.6	+07 21 12	G0--	V	+4.43	+0.10	+0.60	+0.51	+0.83
5933	41	gamma	Ser	15 56 27.2	+15 39 42	F6	V	+3.86	-0.03	+0.48	+0.49	+0.73
5947	13	epsilon	CrB	15 57 35.3	+26 52 40	K2	IIIab	+4.15	+1.28	+1.23	+0.89	+1.51
6092	22	tau	Her	16 19 44.4	+46 18 48	B5	IV	+3.90	-0.57	-0.15	-0.09	-0.26
6175	13	zeta	Oph	16 37 09.5	-10 34 02	O9.5	Vn	+2.56	-0.85	+0.02	+0.10	+0.06
6603	60	beta	Oph	17 43 28.4	+04 34 02	K2	III CN 0.5	+2.77	+1.24	+1.17	+0.82	+1.39
6629	62	gamma	Oph	17 47 53.6	+02 42 26	A0	Van	+3.75	+0.04	+0.04	+0.04	+0.04
6705	33	gamma	Dra	17 56 36.4	+51 29 20	K5	III	+2.22	+1.88	+1.52	+1.14	+1.99
7178	14	gamma	Lyr	18 58 56.6	+32 41 22	B9	II	+3.24	-0.08	-0.05	-0.03	-0.04
7235	17	zeta	Aql	19 05 24.6	+13 51 48	A0	Vann	+2.99	-0.01	+0.01	+0.01	+0.01
7377	30	delta	Aql	19 25 29.9	+03 06 53	F2	IV - V	+3.36	+0.04	+0.32	+0.25	+0.41
7446	39	kappa	Aql	19 36 53.5	-07 01 39	B0.5	IIIIn	+4.96	-0.87	0.00	+0.06	+0.02
7602	60	beta	Aql	19 55 18.8	+06 24 24	G8	IV	+3.72	+0.49	+0.86	+0.66	+1.15
7906	9	alpha	Del	20 39 38.3	+15 54 43	B9	IV	+3.77	-0.21	-0.06	0.00	-0.04
7950	2	epsilon	Aqr	20 47 40.6	-09 29 45	A1	III--	+3.77	+0.02	0.00	+0.07	+0.07
8085*	61	v1803	CygA	21 06 54.6	+38 44 45	K5	V	+5.22	+1.11	+1.17	+1.03	+1.68
8086*	61		CygB	21 06 54.6	+38 44 45	K7	V	+6.03	+1.23	+1.37	+1.17	+2.00
8469	22	lambda	Cep	22 11 30.7	+59 24 52	O6	If	+5.05	-0.74	+0.24	+0.28	+0.43
8622	10		Lac	22 39 15.7	+39 03 01	O9	V	+4.88	-1.05	-0.20	-0.09	-0.30
8781	54	alpha	Peg	23 04 45.7	+15 12 19	A0	III - IV	+2.48	-0.06	-0.04	+0.01	-0.02
8832				23 13 17.0	+57 10 06	K3	V	+5.57	+0.89	+1.00	+0.83	+1.36

References

- [1] Unsöld, A, Baschek, B, Der neue Kosmos, Springer
- [2] Roth, G.D., 1989, Handbuch für Sternfreunde, Springer
- [3] Kitchin, C.R., 1995, Telescopes and Techniques, Springer
- [4] Walker, G. .1987, Astronomical Observations, Cambridge University Press
- [5] Buil, C., 1991, CCD Astronomy, Willmann-Bell
- [6] Radledge, D., 1997, The Art and Science of CCD Astronomy, Springer

B Administrative Notes

This document describes the administrative preparations (observatory access, computing access) for the advanced student lab (ASL) at the Institute for Astronomy (IfA).

B.1 Registration

The ASL is part of the course “advanced physics lab” (VP), and the students need to subscribe for the experiment in HPP H 12 similar to a standard VP experiment. After registration the students will contact the ASL supervisor at the institute for having a first discussion and an introduction into astronomical observations. Note that because of the strong weather dependency of the observations the number of students per semester is limited. Admission is based on subscription date at HPP H 12. Therefore, to avoid interference the supervisor has to make sure that the students have officially subscribed for the experiment before they start.

Because of the strong weather dependency of the observations the subscription of the ASL experiment is for the complete semester, whereas in parallel the students can subscribe for other standard VP experiments (but not for another ASL experiment).

In general the workload of the ASL astronomy experiment will count for two standard VP experiments (4 credit points). The decision is based on the evaluation by the ASL supervisor who needs to confirm this on the marked student report.

B.2 Access to HPP building (by ETH card)

Outside regular opening times the ETH card can be used as an access badge. However, students only have access to a limited number of buildings. In general the HPP building is not included but the IfA administration can organize temporary access for the students.

In case that it is the first time the students will use their ETH card as access badge they also need to activate their card and to set a password. They can do both by themselves at www.bi.id.ethz.ch/eAdressen/index_en.jsp

B.3 Access to HPP observatory

The students need to have keys for the control room HPP Q12, the roof, and the telescope “dome”. Keys need to be organized via the IfA administration who will contact the ISC (Info and Service Center). As soon as the keys are ready the IfA administration will hand out a printed form to the students which allows them to pick up their keys at ISC located in HPV F 55. Note that it is important that the students pick up their keys by themselves because they will be fully responsible for any possible loss or misuse of the keys.

Required keys (Anlage LA004840):

- Durchgang zum Kontrollraum Q 12 / Durchgang aufs Dach (Schlüsselgruppe 703)
- Kontrollraum Q 12 / Schutzbox Teleskop (Schlüsselgruppe 11352/1)
- (Option “Gebäudehülle” für HPP-Zutritt mit ETH-Karte)

B.4 Access to astro servers

TBD (perhaps not required anymore if we switch to python?)



Figure 42: Attach the camera power cable and the USB cable.
 Note: in this image instead of the USB cable the Ethernet cable is used. However, only use the USB-cable!



Figure 43: SBIG camera with attached filter wheel. For storage attach the cover plate (*top*). For mounting the camera loosen all four 5/64" Allen screws at the camera flange.

B.5 Installation of python package

TBD

C Mounting the SBIG camera

IMPORTANT

Mounting or dismounting the camera requires two people. Do not try it on your own!

DISMOUNTING

Make sure the SBIG power cable and the USB cable are unplugged (see Fig. 42)!
 Do not unplug the filter wheel cable and the autoguider cable.

DISMOUNTING

Never dismount the filter wheel which is directly attached to the camera (see Fig. 43)!
 For storage attach the camera cover as shown in Fig. 43.

Mounting or dismounting the camera requires two people. One person holds the camera and

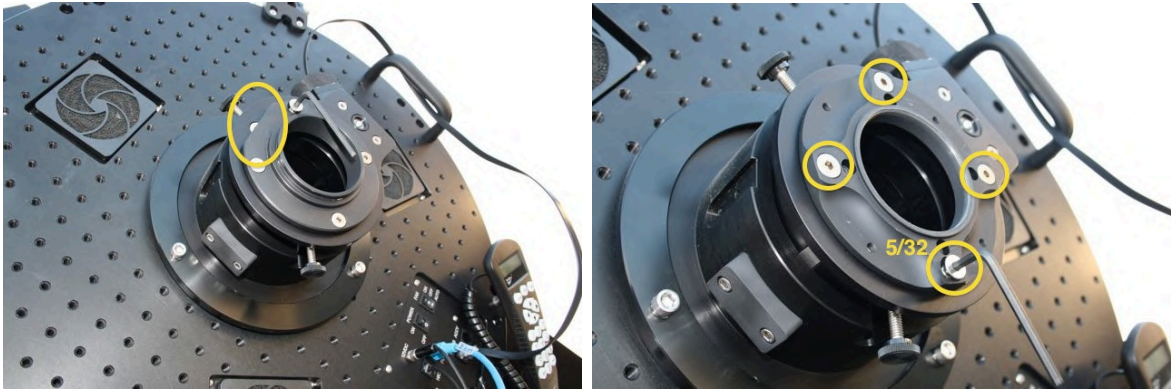


Figure 44: Adapter plates for the camera (*top*) and for the eye-pieces (*bottom*). Note the wedge side facing upwards (away from the CDK control panel). Use the 5/32" Allen key to mount the plates.

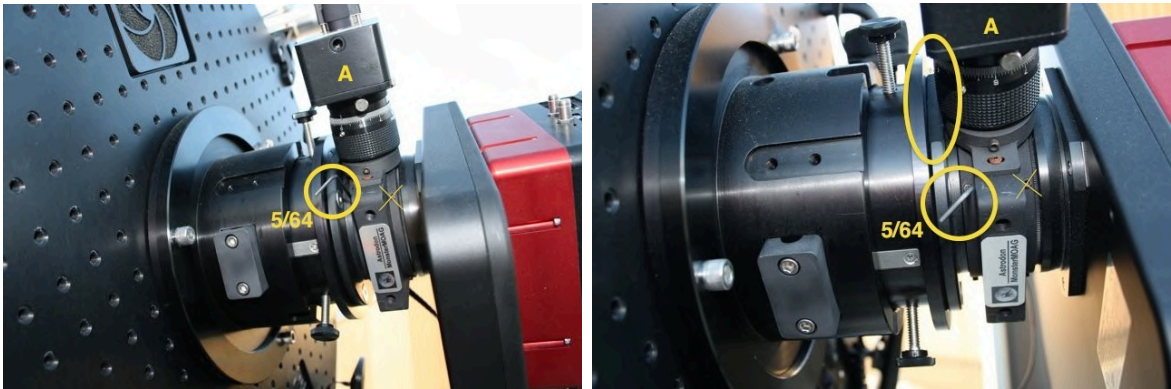


Figure 45: Mounting the camera. Note the autoguider head (A) is at the same side as the wedge of the adapter plate. Make sure the camera flange tightly fits to the camera adapter plate and then tighten all four 5/64" Allen screws.

the other person tightens/loosens the screws. Note that you need to use the US Allen key set (red set, blue set is metric). For using the camera mount the adapter plate that has an edge whereas for visual observations with eye-pieces use the round adapter plate (Allen screw 5/32", see Fig. 44).

- Attach the camera adapter plate to the CDK according to Fig. 44 (with the wedge side facing upwards, use the Allen 1/32" key).
- Loosen all four 5/64" Allen screws at the camera flange (Fig. 43).
- Mount the camera according to Fig. 45 with the autoguider head on the same side as the wedge of the adapter plate. Align the camera parallel to the wedge. Make sure the camera flange tightly fits to the camera adapter plate and then tighten all four 5/64" Allen screws.
- Plugin the SBIG power cable and the USB cable (Fig. 42)

D Spectroscopy with the DADOS spectrograph

D.1 General comments

Operation of the DADOS spectrograph has been tested successfully (see Appendix E) but the observing procedure and the calibration strategy still need to be improved and established respectively.

Next steps:

- determine approximate correlation between the μm screw positions and observed spectral region
- determine best focus positions for the Slitviewer-Webcam and the spectrum on the ST-1603 camera.
Note: use the calibration lamp and solar spectrum
- Improve and mark alignment of the Webcam with respect to the slits. In principle all slits fit onto the field-of-view of the webcam (see Fig. 46).
Note: align the slits horizontally as in Fig. 46 for N-S and E-W movement of the target.
- align the spectrograph assembly and the ST-1603 camera to the telescope N-S / E-W movement of the target.
- observe different spectral standard stars at different pointing directions and test tracking quality for target on the slit.
- investigate manual tracking options.
Note: for very small pointing corrections of a few arcsec the mount first moves away a greater distance and then slowly comes back to the corrected position (compensation of gear-wheel errors). This is not practical for manual tracking corrections but it might be possible to switch-off or relax this setup for the mount.
- check whether it is more practical to use an external Webcam software (instead of MaxImDL) to simultaneously have the webcam and the telescope controls open
- establish full calibration procedure
Note: see DADOS tutorial by Bernd Koch from Baader planetarium (<http://www.baader-planetarium.de/dados/download/tutorial-dados-d.pdf>)
- check impact of Barlow-Lens, i.e. check vignetting with/without lens.
Note: the spectrograph is optimized for F/10 but the telescope is F/6.8. The barlow lens should correct for that.

D.2 Spectrograph assembly and setup

See Figs. 47-48 for an overview of the packing of all the components and their assembly for observation. See Fig. 49 for the calibration assembly using the neon calibration lamp.

The spectrograph consists of the following sub-parts:

- **DADOS spektrograph:**
 - 3 reflection gratings (200 L/mm, 900 L/mm, 1200 L/mm)



Figure 46: Optimized slit orientation on the webcam.

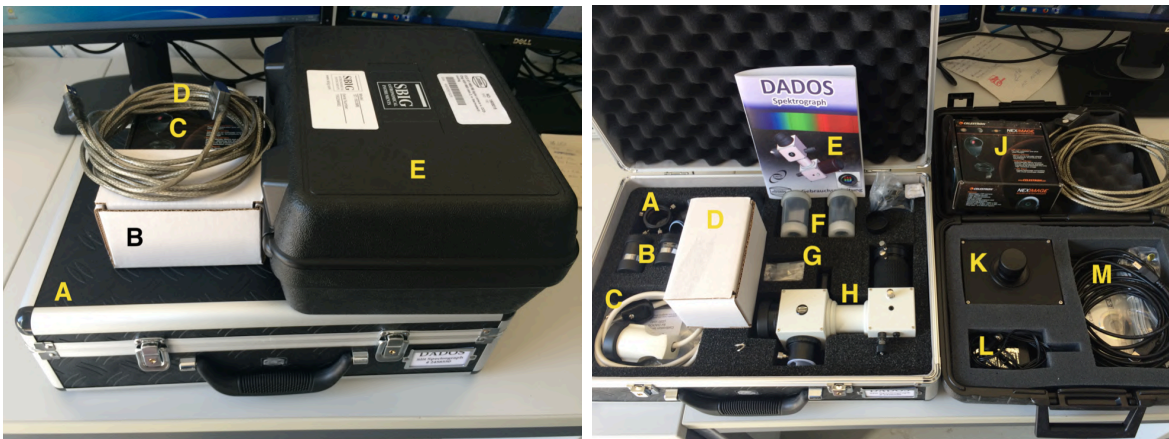


Figure 47: Spectrograph assembly: packing.

Top:

(A) DADOS case, (B) Barlow-lens, (C) Webcam, (D) USB Extender-cable, (E) ST-1603 case

Bottom:

(A) Mounting accessories, (B) Eyepieces, (C) Calibration lamp Neon, (D) Barlow-lens, (E) DADOS manual, (F) additional Gratings, (G) DADOS tools, (H) DADOS spectrograph, (J) Webcam, (K) ST-1603 CCD, (L) ST-1603 power cable, (M) ST-1603 accessories

- 2 eyepieces + focus lens for using eyepieces as slit viewer - different adapter pieces for telescope and camera

- **Webcam** slit viewer + USB Extender-cable
- **ST-1603 CCD camera**
- 1.5x **Barlow-lens** to extend telescope focal ratio of F/6.8 to \sim F/10
- **Neon calibration lamp**
- telescope adapter piece

For attachment to the telescope use the adapter piece as shown by Fig. 50. For the **Webcam** use the USB-Extender cable and connect it to the remote telescope computer. For the **ST-1603** use the same USB-cable as for the *STX-16803* which is already laid through the GM4000 mount and connected to the remote computer. Connect the **ST-1603** power

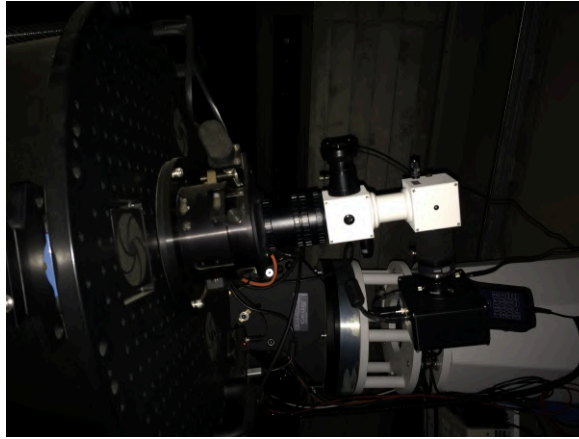


Figure 48: Spectrograph assembly attached to the telescope.
 Note: in this image the webcam is mounted 180° opposite to the recommended position (see Fig. 50).

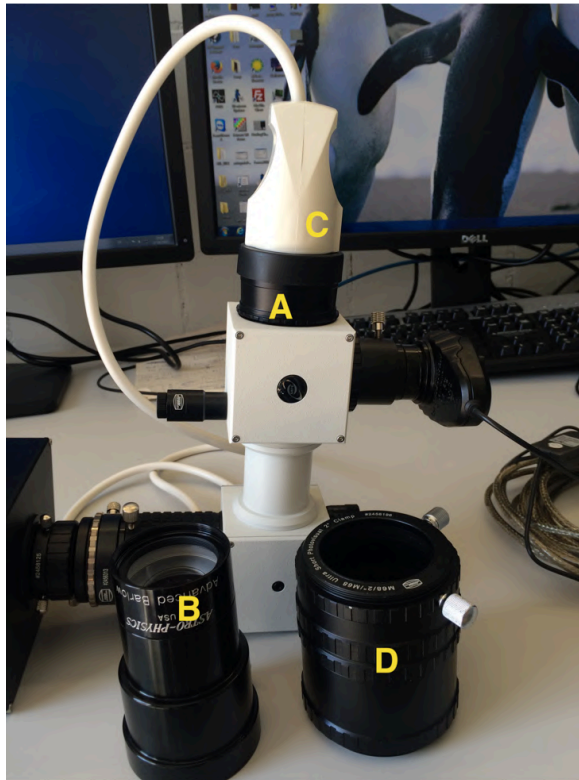


Figure 49: Spectrograph calibration assembly:
 Replace the Barlow-lens by the 2" receptacle and attach the Neon calibration lamp. Note: for storage of the Barlow-lens attach it to the barlow-lens adapter piece.
 (A) 2" receptacle, (B) Barlow-lens on adapter piece for storage, (C) Neon calibration lamp, (D) telescope adapter piece (not used for calibration)

adapter to the power outlet box belonging to the main power switch (see Fig. 5).

IMPORTANT: Always make sure that the webcam USB cable and the ST-1603

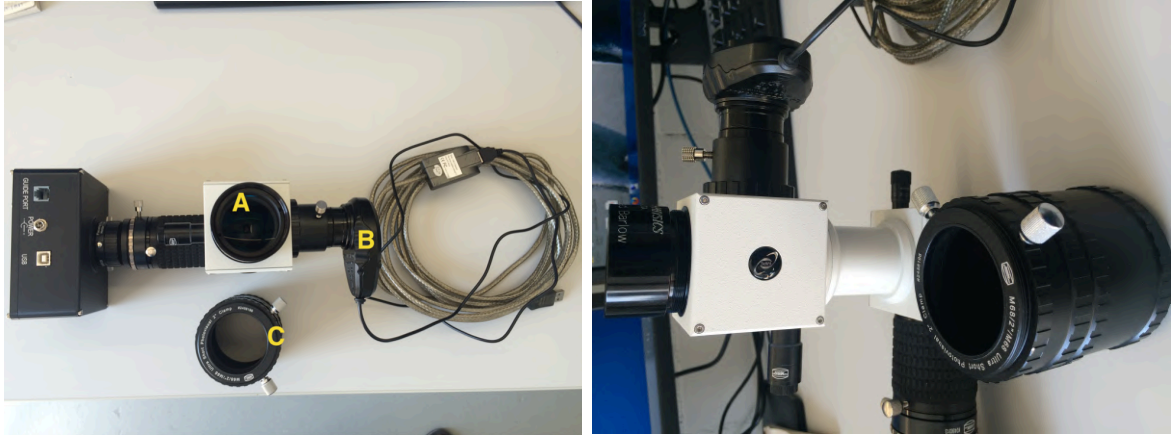


Figure 50: Spectrograph assembly:

Complete assembly with attached Barlow-lens and Webcam ready to be attached to the telescope. Note that this webcam orientation will produce the slit-image as in Fig. 46. The telescope adapter piece as shown is optimized for focusing the target onto the slit.

(A) Barlow-lens, (B) Webcam, (C) Adapter piece for telescope

power cable cannot get stuck when moving the telescope!

IMPORTANT: Make sure that the Barlow-lens is tightly screwed into the DADOS spectrograph and that the complete spectrograph assembly is securely attached to the telescope and all the attachment screws are tight!

IMPORTANT: see DADOS manual for exchanging the gratings. Only exchange the gratings in a clean environment with electrostatic shielding! Use the optical gloves and never touch the gratings by hand!

D.3 Alignment

D.3.1 Spatial orientation

Attach the *ST-1603* and the *Webcam* with orientations as indicated by Fig. 50. This makes sure that all three slits are visible and horizontally oriented in the webcam (see Fig. 46). When attaching the *complete spectrograph assembly* to the telescope make sure that it is oriented horizontal or vertical with respect to N-S / E-W. This makes it easier to move the target onto the slit using the telescope N-S/E-W keys.

Important: Before attaching the spectrograph assembly to the telescope make sure that the focal alignment is done (using the calibration lamp, see next Section)!

D.3.2 Focal alignment

The focal alignment needs to be done off the telescope using the *slit illumination* and the *Neon calibration lamp*:

A) slits on Webcam:

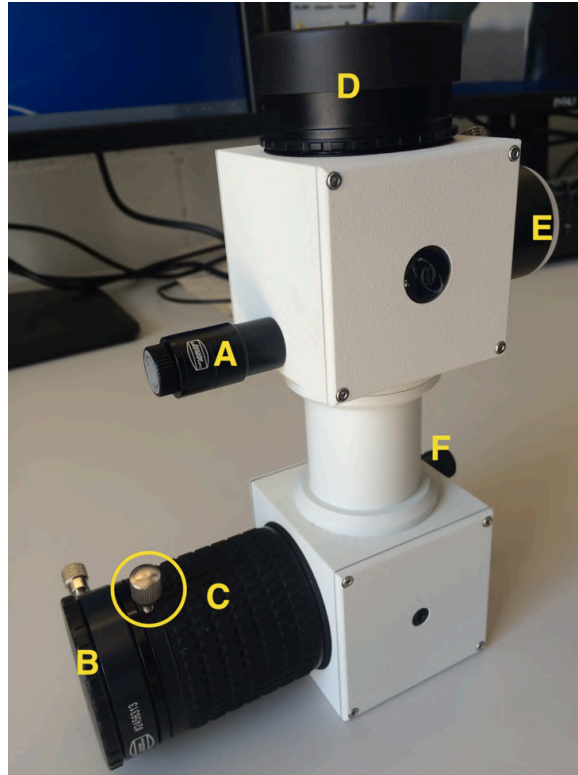


Figure 51: Spectrograph assembly: DADOS spectrograph.
 (A) Slit illumination, (B) towards ST-1603, (C) Focuser for ST-1603 with fixation screw (circle),
 (D) towards telescope, (E) Slit viewer, (F) μm screw for grating position

- turn on the *slit illumination* (see Fig. 51).
- *focus the slits* onto the webcam by moving the webcam in/out.
i.e. the slit-image should look similar to Fig. 46 or better
- tightly fix the webcam position
- turn off the slit illumination

B) spectrum on ST-1603:

- Attach the *calibration lamp* to the spectrograph assembly according to Fig. 49.
i.e. replace the Barlow-lens by the 2" receptacle to attach the lamp
- loosen the *Focuser fixation screw* (see Fig. 51)
- start continuous imaging by the ST-1603 camera
- *focus the Neon spectrum* onto the ST-1603 camera by using the camera Focuser of the DADOS spectrograph. (see Figs. 51, 52)
- tighten the Focuser fixation screw
- detach the calibration lamp and re-attach the Barlow-lens

Important: Also make sure that the spatial orientation of the webcam, the camera, and the complete spectrograph assembly is correct (see previous Section)!

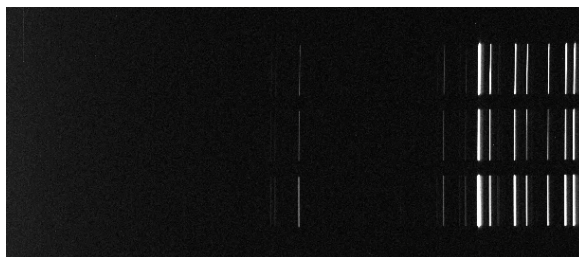


Figure 52: Neon calibration spectrum.

D.4 Operation

All sub-components required for the operation of the Spectrograph (i.e. the telescope, the ST-1603 CCD camera, and the Webcam) are controlled by MaxImDL. See Section 5 for operational instructions for the telescope and the CCD camera. In particular note how to setup and connect the ST-1603:

Important: When using the ST-1603 camera set *Filter or Controlling Camera Model to No Filter!*

Important: for the ST-1603 *Subframe* does not work and needs to be de-activated!

The webcam is also connected by the **Observatory** window (e.g. see Fig. 19) and operated by the **Webcam** tab (see Fig. 53).

General operation procedure:

- slew telescope to target
- if required: **focus target** onto slit focal plane imaged by ST-1603 by using the **MaxImDL Focus** tab.
 - when using telescope adapter piece as in Fig. 50 focus position $\sim 24913 \mu\text{m}$ (**TBC**)
- **center target onto desired slit** by using the N-S/E-W buttons of the telescope control (see Figs. 23, 53):
 - select step size 10 Sec. or less
 - if required turn On/Off slit illumination
- turn Off slit illumination
- **acquire spectrum** with ST-1603 (see Fig. 55)
- change spectral range by using the grating μm screw (see Fig. 56 and comments therein)
- check target-slit alignment
- **acquire spectrum** with ST-1603
- change spectral range by using the grating μm screw
- check target-slit alignment
- **acquire spectrum** with ST-1603
- ...

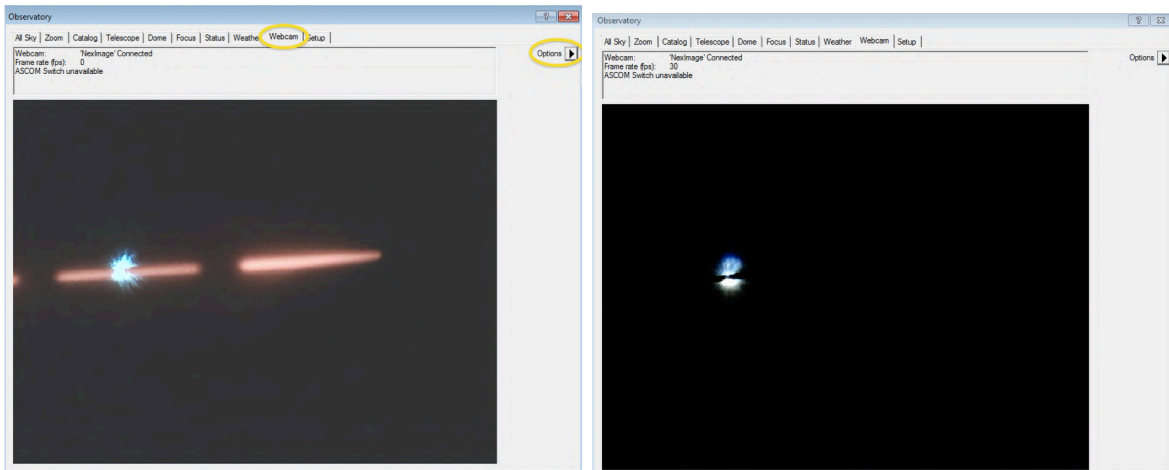


Figure 53: Webcam operation with *slit illumination* **On** (top) and **Off** (bottom). Settings for the webcam are accessible by the *Options* button. Note that in these images the webcam orientation is not in the recommended position (see Figs. 50, 46)

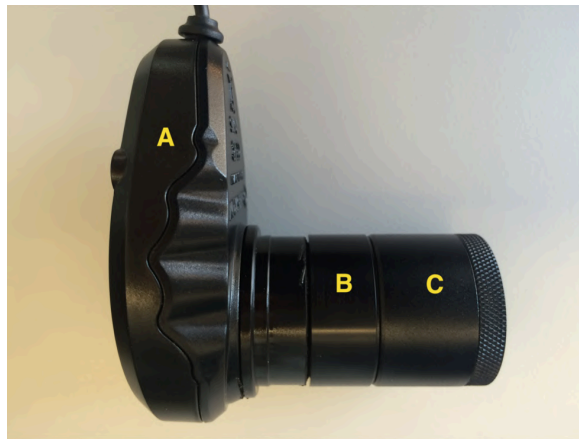


Figure 54: Spectrograph assembly: Webcam
The webcam has been modified by an adapter piece to attach the slit-viewer focusing lens. (A) Webcam, (B) adapter piece, (C) Focusing lens.

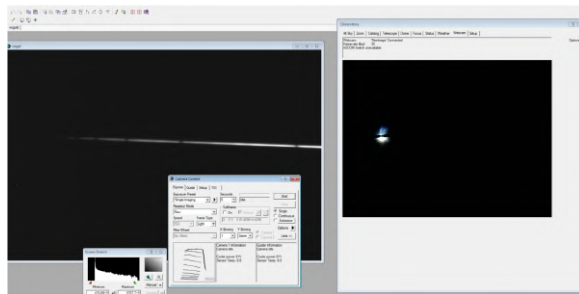


Figure 55: Commissioning image of Vega spectrum.
Note that in this image the webcam and spectrograph assembly orientation are bad. For the recommended orientations see Sect. D.3 and Figs. 50, 46.

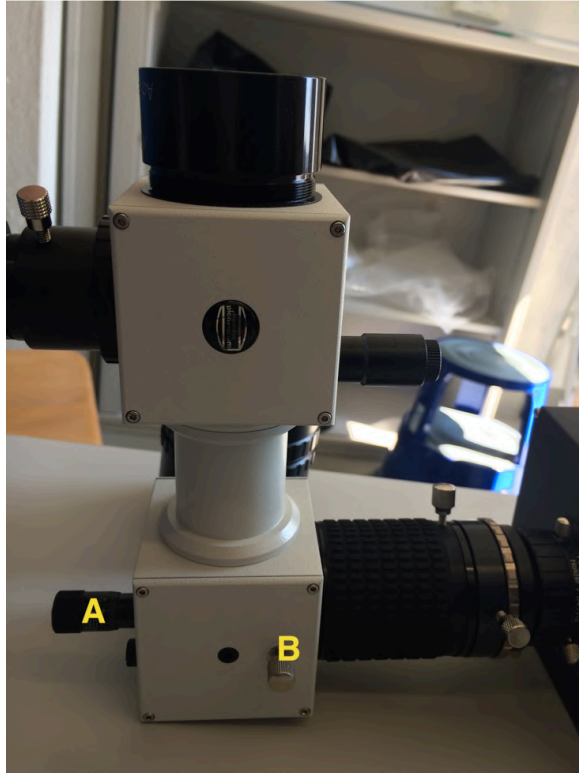


Figure 56: Changing the grating position to change the spectral range: Loosen the fixation screw (but do not completely remove it!) and use the μm screw to change the illumination angle of the grating. Note that pushing the grating (μm screw goes in) works better than pulling (push fixation screw sideways to support pulling the grating with μm screw): (A) μm screw, (B) fixation screw

D.5 Calibration (TBD)

TBD

see also <http://www.baader-planetarium.de/dados/download/tutorial-dados-d.pdf>

E First light of DADOS spectrograph

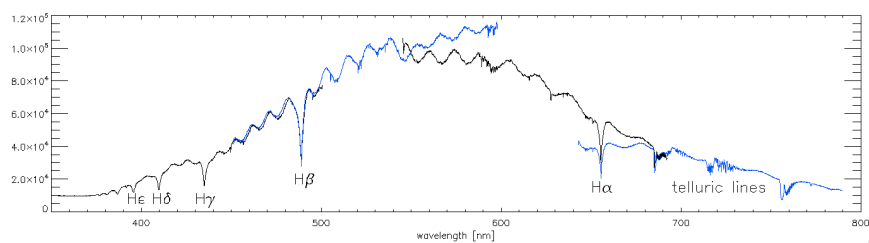


Figure 57: Uncalibrated Vega spectrum using the 900 L/mm grating. The different spectral regions are not calibrated but simply scaled to match each other. The plate scale is ~ 0.096 nm/pixel which was determined using the solar spectrum and the Neon calibration spectrum.

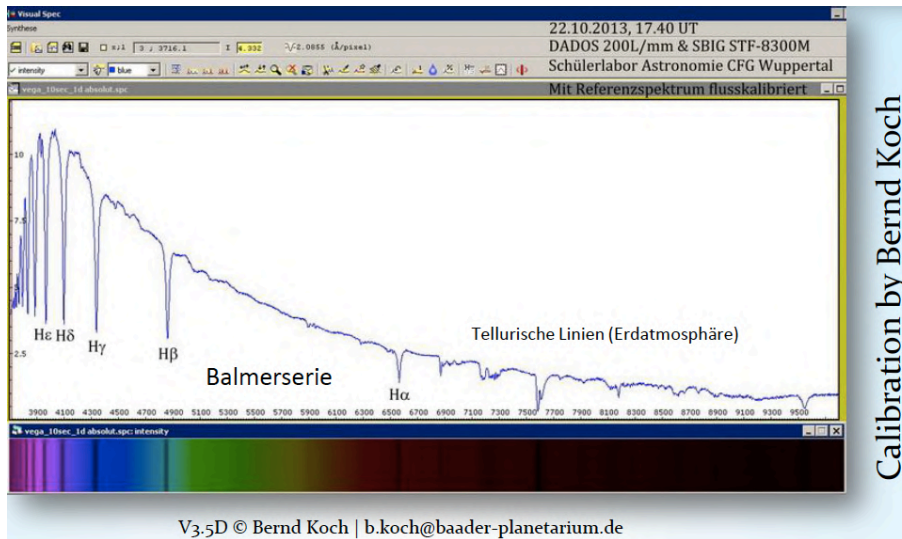


Figure 58: As comparison to our uncalibrated first light spectrum (Fig. 57):
 Flux calibrated Vega spectrum by **Bernd Koch: DADOS Tutorial Baader Planetarium**
 (<http://www.baader-planetarium.de/dados/download/tutorial-dados-d.pdf>).