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Operation Manual

for

Aristarchos Transient Spectrometer

(ATS)

P. Boumis, J. Meaburn, E. Xilouris, A. Liakos, J. Alikakos, N. Nanouris, O. Giannakis

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Panayotis Boumis, Emmanuel Xilouris, Alexios Liakos, John Alikakos, Nikolaos Nanouris, Omiros Giannakis, Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing, National Observatory of Athens, Greece
John Meaburn, Jodrell Bank Centre for Astrophysics, University of Manchester, UK

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1. Introduction

The Aristarchos Transient Spectrometer (ATS – Meaburn, Boumis & Goudis 2004; Meaburn et al. 2007) whose optical layout is shown in Fig. 2, is a low/medium dispersion spectrometer which has been designed and manufactured specifically to obtain spectra of relatively bright (brighter than 18 mag) but transient phenomena. These can include gamma-ray bursts as soon after the events as possible, the variable spectra of Symbiotic stars, Cataclysmic variables, nuclei of nearby Seyfert galaxies, nearby nova events, etc. This spectrometer is sponsored by the Universities of Manchester and Patras and has been constructed by the University of Manchester.

To achieve these aims, any of three gratings can be driven into the beam with present angles. These are:

- a Red 1200 groove/mm grating centered on 6441.6 Å to give ~1.3 Å resolution and 103 Å/mm
- a Blue 1200 groove/mm grating centered on 5074.1 Å to give ~1.4 Å resolution and 95 Å/mm
- a 600 groove/mm grating centered on 5691.5 Å but at 245 Å/mm to give ~3.2 Å resolution.

The CCD camera is an Apogee U47. The detector is a thermo-cooled E2V CCD47-10 AIMO Back Illumination CCD with 1024×1024 13 micron pixels. Ease of operation and rapid serendipitous response are traded for some loss in ultimate sensitivity, i.e., the spectra will be dark-current limited rather than read-out noise limited as with a liquid nitrogen cooled CCD. The CCD47-10 AIMO Back Illumination can be driven using the USB 2.0 port of any Windows PC. The spectrometer’s long slit input is fed by 50 fibers (each 50 micron diameter) in a 10 arcsec diameter bundle in the telescope’s focal plane. Again, ease and rapid target acquisition are traded for some fiber losses when compared to a traditional long-slit spectrometer.

This manual presents information on the performance of ATS on the Aristarchos 2.3m telescope and point out several operational details of the instrument to assist with efficient use.

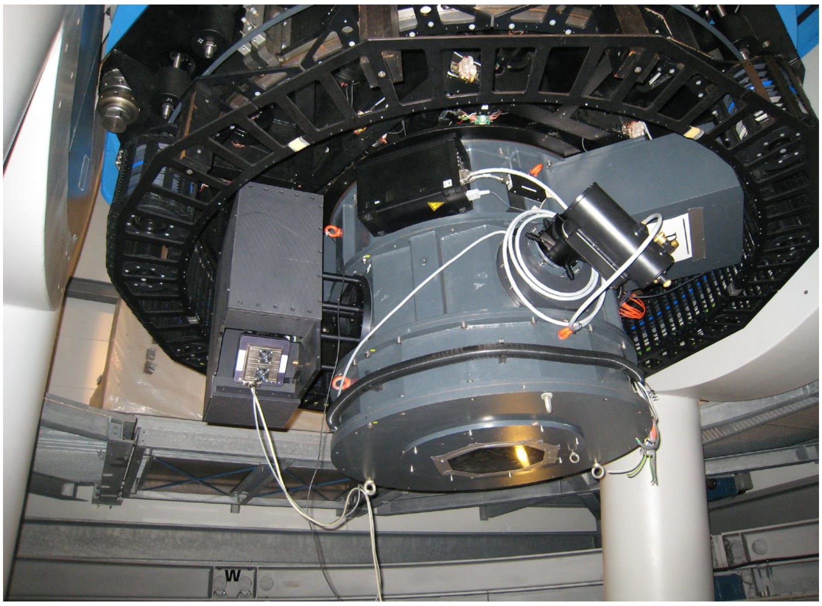


Fig. 1. The ATS spectrometer on the 2.3m Aristarchos telescope

2. Optical and mechanical configuration

The ATS spectrometer has been designed and manufactured to be left running permanently for opportunist over-ride observations of transient events. Survey programmes of relatively bright but transient phenomena can also be carried out. It is not intended for use as a traditional low-dispersion spectrometer found on most telescopes.

The performance of the ATS shown in Figs 2 and 3 (optical and mechanical configurations, respectively) is summarized in Table 1 when combined with the Aristarchos 2.3m telescope.

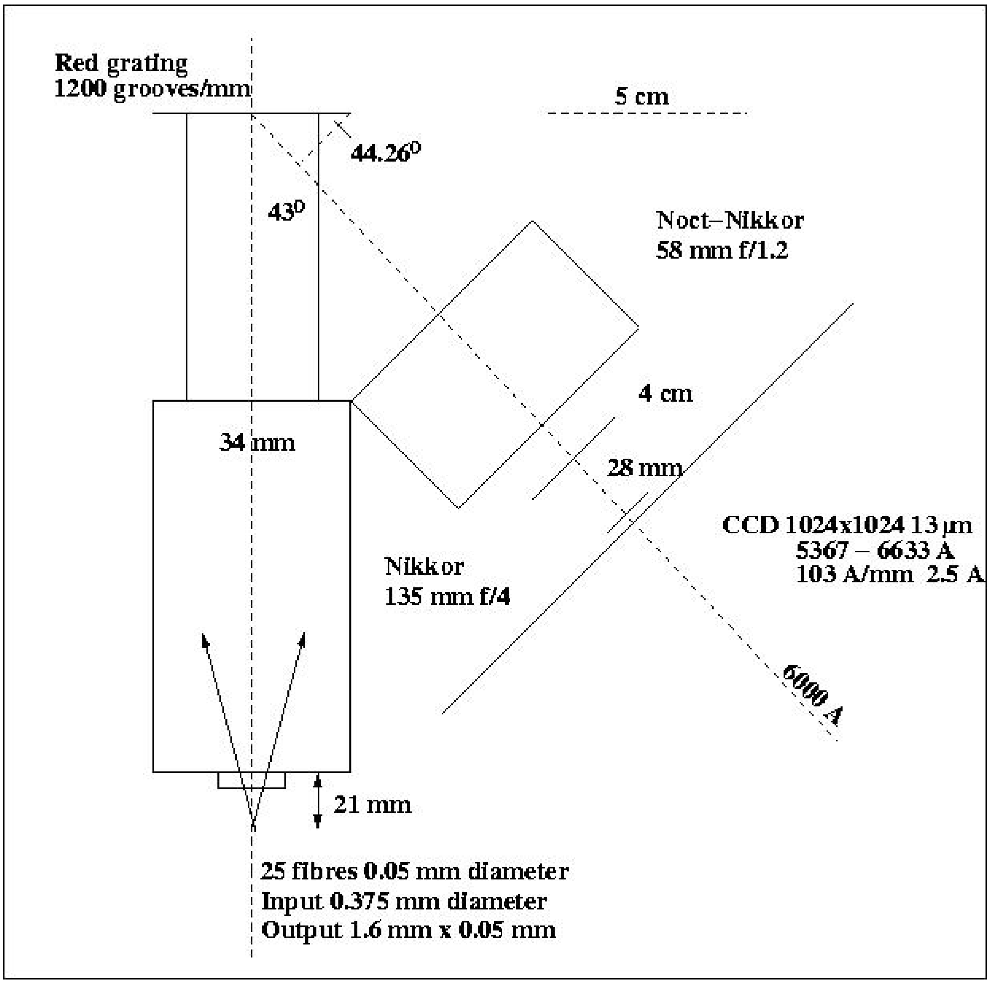


Fig. 2. The optical layout of the Aristarchos Transient Spectrometer (designed by J. Meaburn)

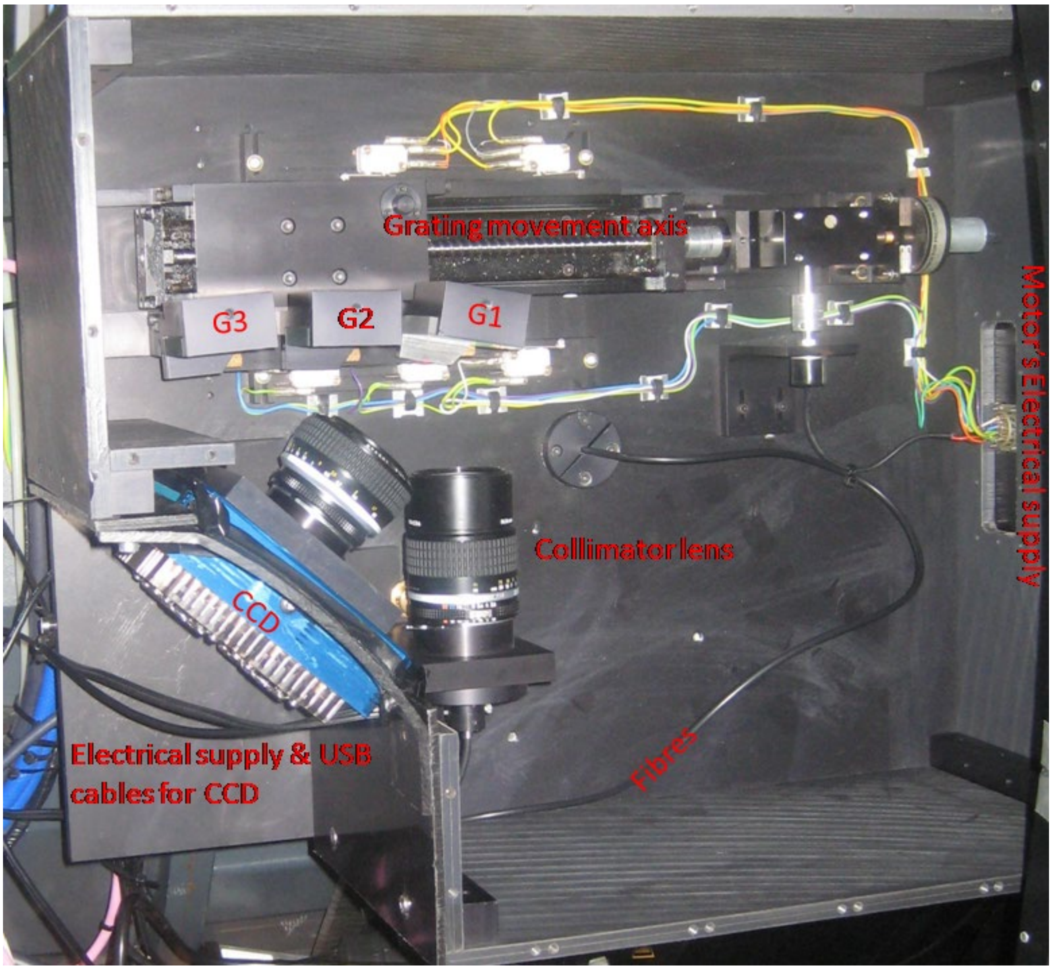


Fig. 3. The mechanical layout of the Aristarchos Transient Spectrometer

Table 1. Parameters at the Aristarchos f/8 focus (f.l. = 17714 mm)

gratings	**option 1 (Blue-Red)**	**option 2 (BLUE)**	**option 3 (RED)**
(grooves/mm)	600	1200	1200
(arcsec)	≡ 10	≡ 10	≡ 10
spectral range	4009.0-7257.0 Å	4309.8-5768.8 Å	5736.9-7071.8 Å
resolution	3.2 Å	1.4 Å	1.3 Å
dispersion	245 Å mm^{-1}	95 Å mm^{-1}	103 Å mm^{-1}
centered wavelength	5691.5 Å	5074.1 Å	6441.6 Å

3. Control system

The overall electronic system has been developed to be operated from a PC. For that reason, a user interface has been developed while a mechanical console is connected and is always available for use in case of a computer failure (Fig. 4). Fig. 5 shows the graphical user interface as it is now on the ATS.

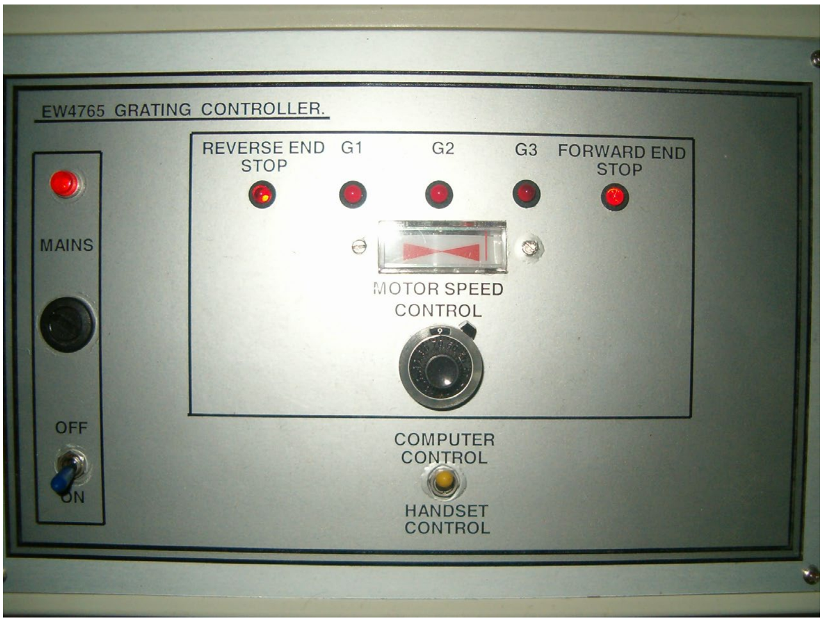


Fig. 4. The backup mechanical console of ATS

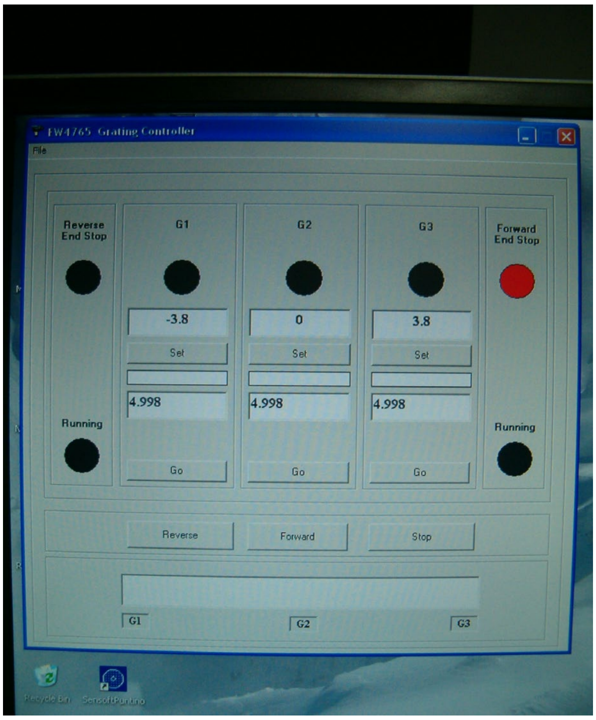


Fig. 5. Graphical user interface used to operate the ATS

4. Operation

Two systems are needed in order to operate the ATS in full; the graphical user interface and the CCD software.

4.1 Grating operation

The graphical user interface shown in Fig. 5 is the first that the user will need to operate in order to use the ATS. There are a number of options that can be used. These are:

G1: Position of first grating (Blue-Red)
G2: Position of second grating (Blue)
G3: Position of third grating (Red)
Reverse: Moves back the gratings support on the trail
Forward: Moves forward the gratings support on the trail
Stop: Stops the movement of the gratings support on the trail

4.1.1 Computer control

All positions are fixed so the user only needs to move to a specific position. In order to set the instrument to a specific grating the user must follow the steps below:

1. Turn on the ATS computer.
2. Switch to the computer control option at the mechanical console (Fig. 4).
3. Turn on the mechanical console (Fig. 4).
4. Open the graphical user interface (grating) by double clicking.
5. Depending on the grating being used (G1, G2 or G3) click the **Set** option and then **Go**. The gratings will start to move onto the linear mechanical rail until the selected one will go to the appropriate position. A red line at the bottom of the graphical user interface always shows that position and the movement. During the movement there is an indication which shows if the movement is forward or in reverse (the black circle becomes red).
6. When the light in the circle below the selected position (G1, G2 or G3) becomes **red** then the grating is on the appropriate position and the instrument is ready for use.

4.1.2 Manual control

In case of a computer failure, the gratings can be moved and positioned by using the mechanical console (Fig. 4). To do that the user must follow the steps below:

1. Switch to the handset control option at the mechanical console (Fig. 4).
2. Turn on the mechanical console (Fig. 4).
3. Depending on the grating to use (G1, G2 or G3) push the **Motor** button on the handset console. The gratings will start to move onto the linear mechanical rail until the selected one will go to the appropriate position. Then stop to push the Motor button. A red line below G1, G2, G3 at the mechanical console always shows the position and the movement. There are also two switches on the handset console where the forward or reverse motion can be selected.

4. When the light in the circle below the selected position (G1, G2 or G3) becomes **red** on the mechanical console then the grating is on the appropriate position and the instrument ready for use.

4.2 Starting up the system

1. On the Monitor computer turn on the outlets 1 (raspberry) and 2 (ATS CCD) of the Network multi plug (Fig. 6). The other outlets should be on the off position.
2. On the FCC computer run the "raspberry vhui.exe" from the respective shortcut on the desktop. Once the software runs, it will perform a quick check in order to find any network USB Hubs. It will discover the "Raspberry HUB" in which there are two options:
   a) Roper scientific (which is the LNCCD), and
   b) **0x0010** (which is the **ATS CCD**).
   If next to the (a) option the message "(In use by you)" is presented, then right click on it and select "stop using this device". Next, right click on the (b) option and choose "auto use this device". If there is no message next to the (a) option, right click on the (b) option and choose "auto use this device" (Fig. 7)

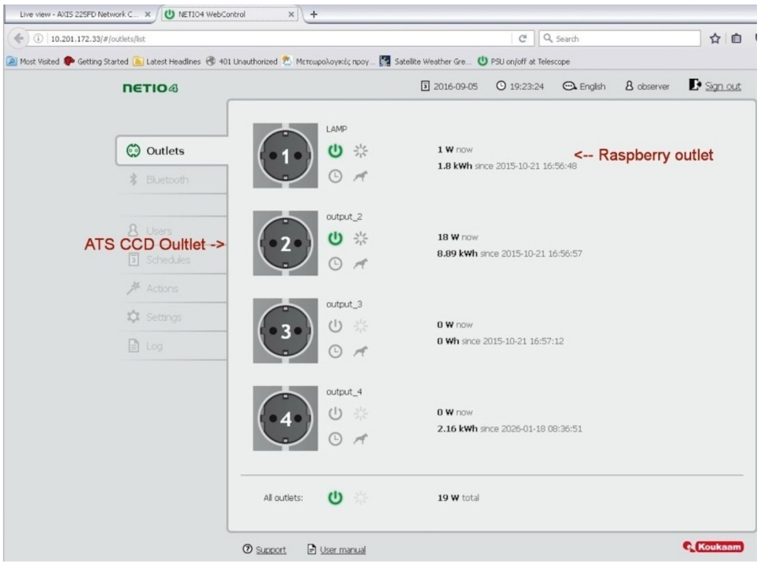


Fig. 6 The Network-multi plug software on the monitor pc

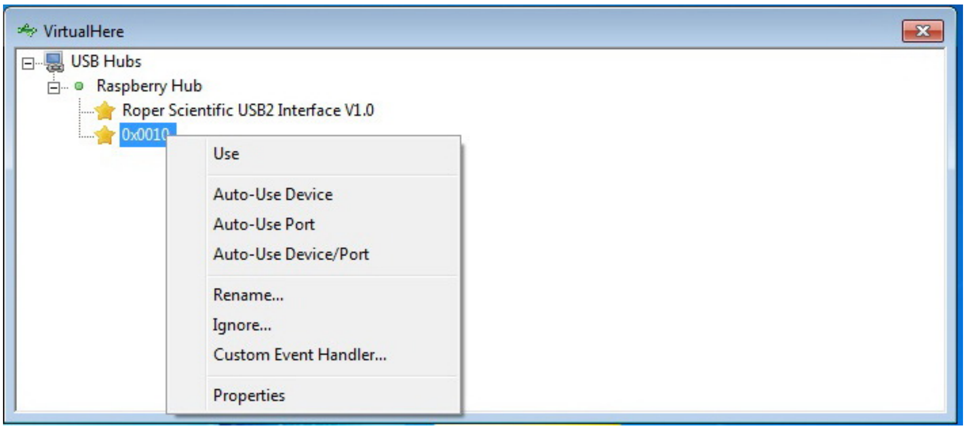


Fig. 7 The raspberry vhui software and the ATS CCD selection

3. On the OPC computer select on the **“Telescope”** operation menu the **“SFM”** – **“Positioning”** (Fig. 8)

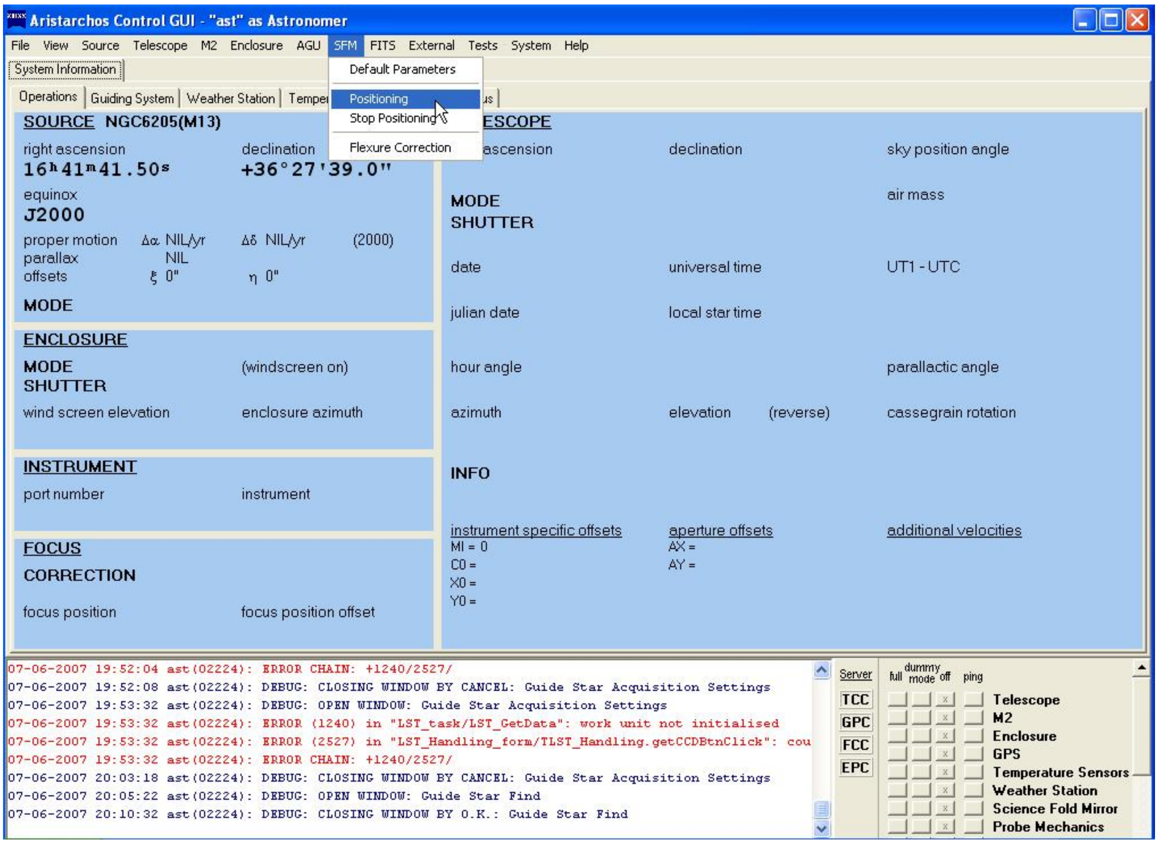


Fig. 8. The telescope operation menu for SFM positioning

Select the **“ATS”** instrument position (Fig.9)

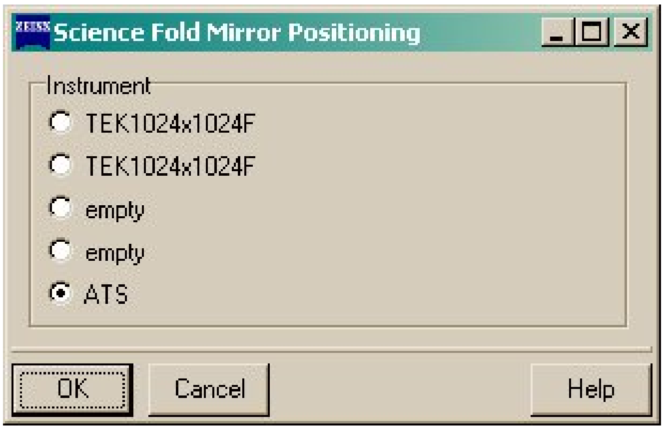


Fig. 9. The SFM positioning of ATS

4.3. CCD operation (Maxim DL software)

4.3.1 Exposure

Start Maxim DL and open the Camera Control window by clicking on the  toolbar button (Fig. 10).

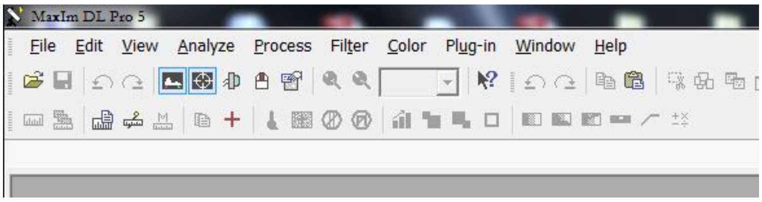


Fig. 10. Start up window of Maxim DL

The **Setup** tab should appear first; if it is not displayed, click on the Setup tab near the upper left corner of the window. Click **Connect** (Fig. 11).

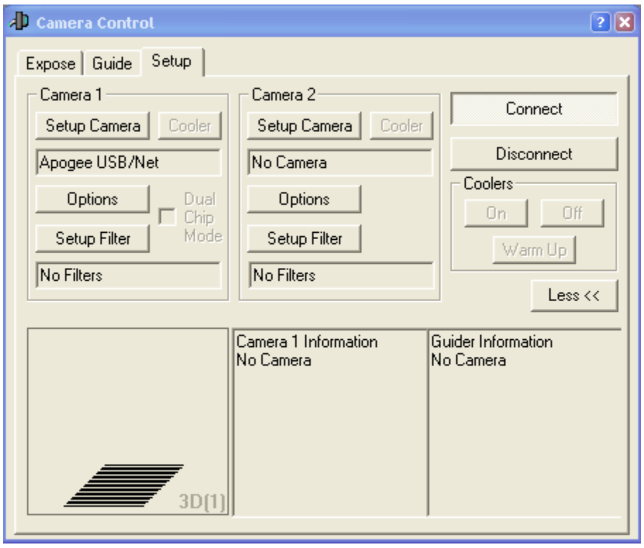


Fig. 11. Camera Control window

Set the Coolers **On** from the respective submenu (Fig. 11 - right side & Fig. 12) to activate the cooling system, and then click the associated **Cooler** button (Fig. 11 - left side) to set the temperature setpoint. Set the temperature setpoint to **app. -35** degrees C (this values depends on the ambient's temperature and can vary) click **OK**. Wait until the temperature reaches the appropriate value (this takes 20-30 min).

Fig. 12. Coolers buttons

Select **Expose** tab (Fig. 13). The **Subframe** option must be **unchecked**. This will ensure that you get full image. Turn off Binning by setting the **X Binning** value to **1** and the **Y Binning** value (if enabled) to **Same**. This will give you the highest resolution image. Set the **Readout Mode** if enabled to **Normal**. Under the Options menu, select **No Calibration**. If you wish to perform calibration (dark subtraction, flat fielding, etc.) as soon as each image is taken, you must first set up calibration frames using the Process menu Set Calibration command. Then select **Full Calibration**. **Simple Auto-dark** can also be used.

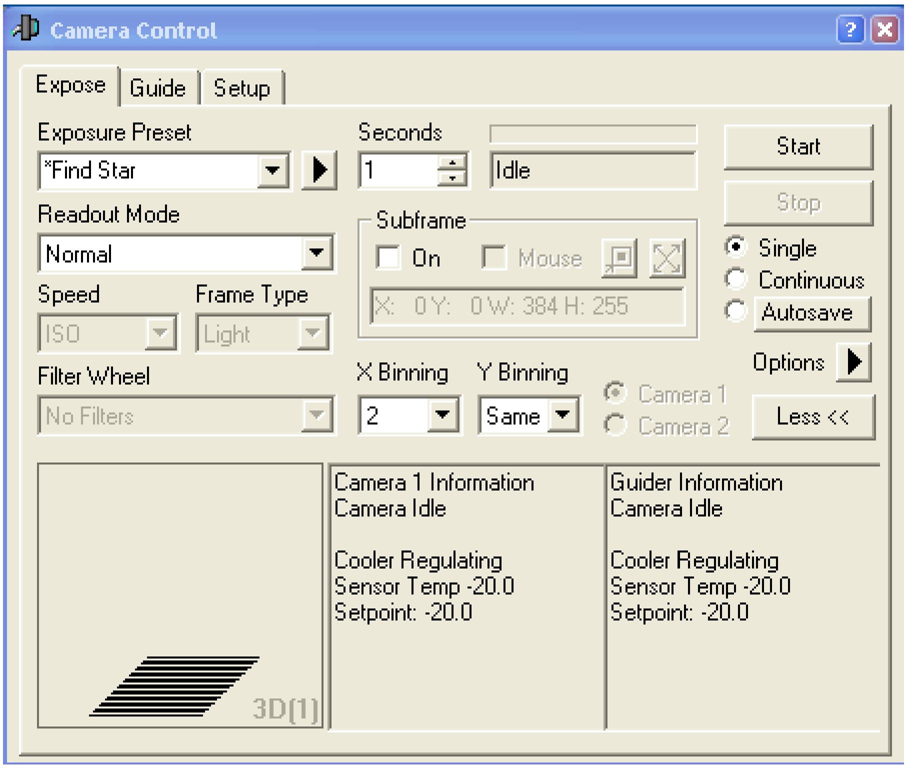


Fig. 13. Expose tab on Camera Control

Set **Frame type** to **Light** (normal image frame). Type in the desired exposure time in the **Seconds** field. Click **Start** and an image will appear (Fig. 13). If you like, you can save the image to disk.

Once an image is obtained (no matter if it is dark, light etc) it is recommended to select the "view"--> "graph window" (or simply press **ctrl+G**) in order to plot the image area where the spectrum is shown (Fig. 14). Once this option is selected, select "Horizontal box", use the mouse to select the area you want to plot, and then in the graph window select either to plot the row with the "maximum" intensity (very useful to check if your spectrum is saturated) or the "mean" values of the rows included in the area you selected. If you wish, you can save the values of the plot in a csv format file using the "export" option.

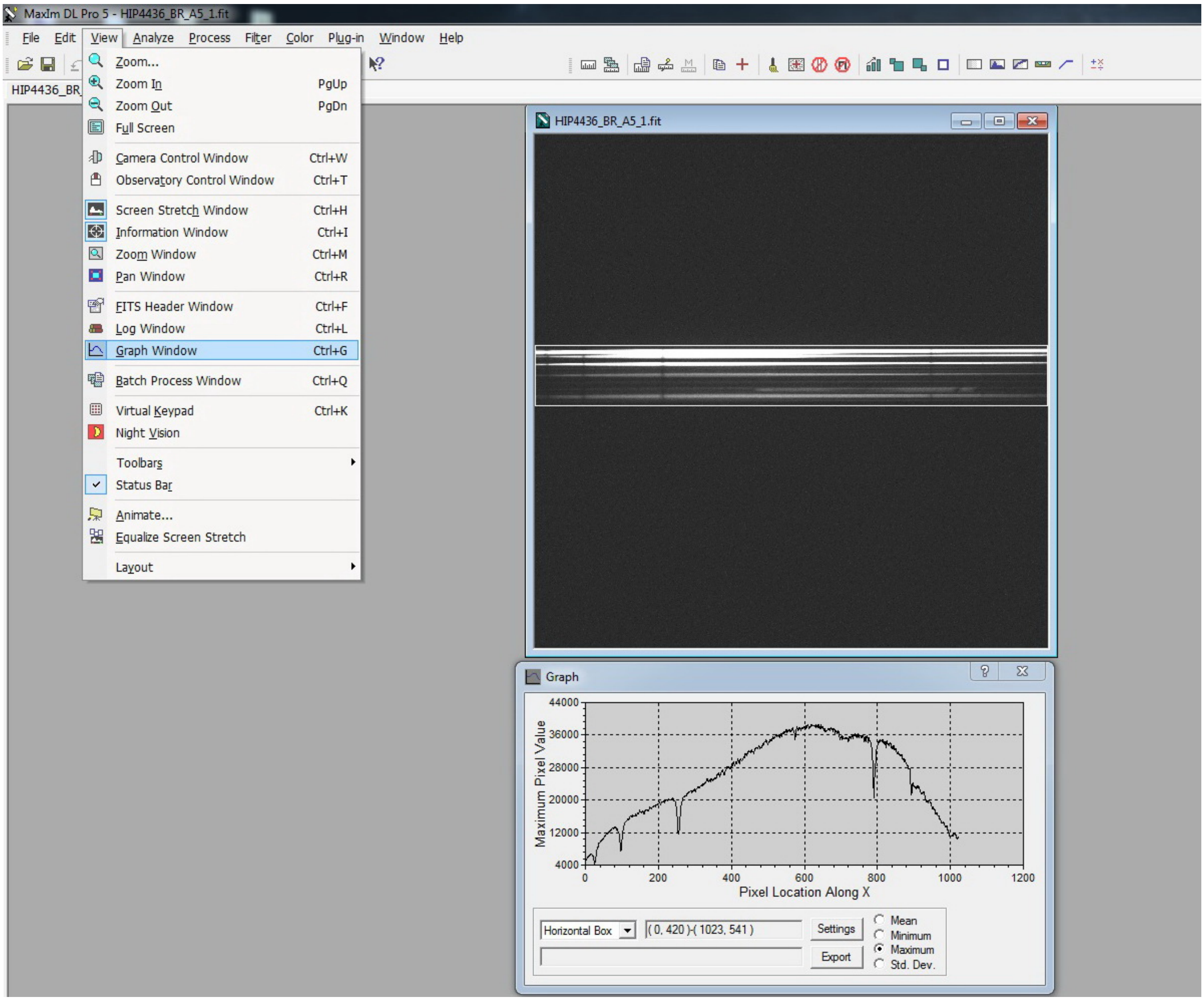


Fig. 14. CCD spectrum image and the graph window

4.3.2 Shutdown Procedure

1. Warm up the CCD cooler before closing Maxim DL, unless you plan to restart the software. This can be triggered using the **Warm Up** button on the **Setup tab** (Figs 12 & 15). When the camera is warmed up (i.e. its temperature is close to the ambient's temperature--that takes ~30 min).
2. Press the Coolers **Off** button**,** wait ~5 sec and then press the **Disconnect** button and close the software.

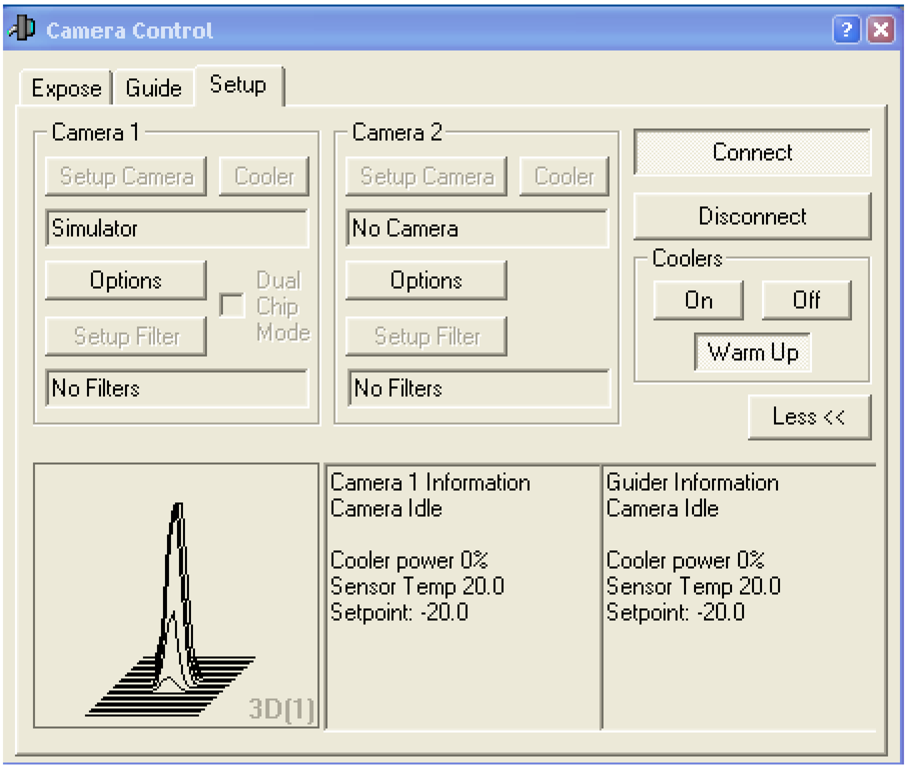


Fig. 15. Warm Up the CCD

3. In the raspberry vhui software, right click on the "0x0010" and select "stop using this device" (Fig. 7).
4. In the monitor pc, and in the IP-multi plug software turn off the outlet number 2 (Fig. 6).

4.4 Observing a target

In order to observe a target there are three steps to be followed: a) set initial offsets and focus position for the ATS in the telescope software, b) find the best focus and approximate offset values for a bright star near the target, and c) find the best offsets for the target. In total, the following procedure should be followed:

4.4.1 Initial offset and focus settings

1. To select the **instrument offsets for ATS**, do the following steps:
Select the **"Options"** menu on the **"Telescope"** operation menu (Fig. 16)

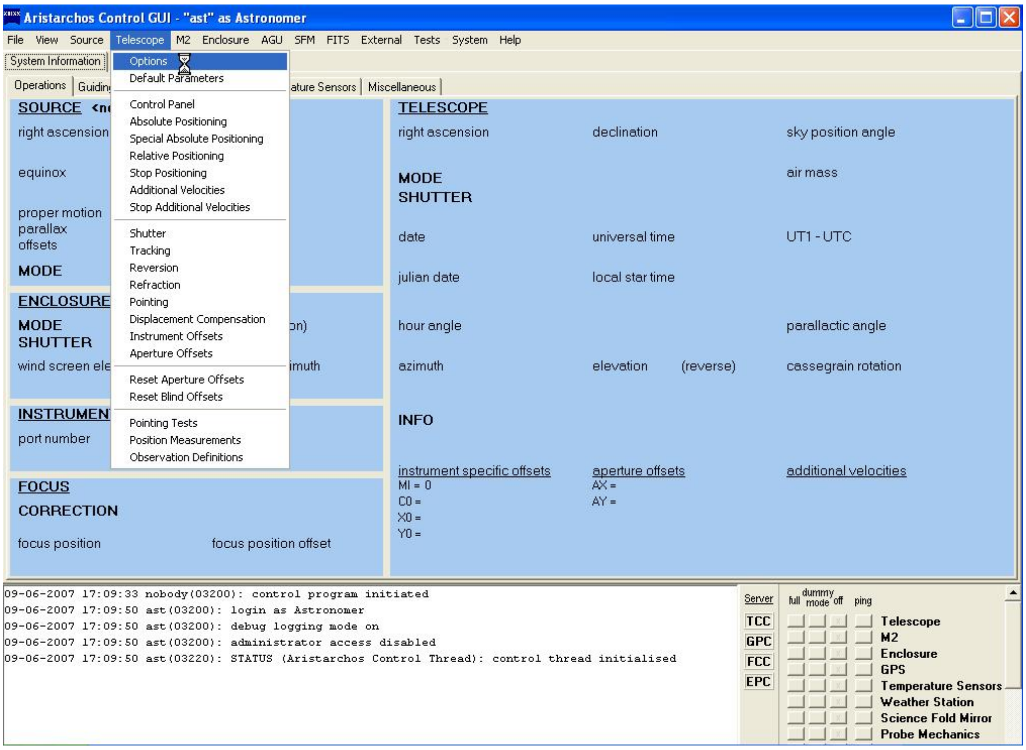


Fig. 16. The telescope operation menu for telescope options

2. Select the **"instrument offsets"** menu (Fig. 17).
3. Put the following values: On the "**x instrument offset**"→ **+ 0° 1′ 40″** and on the "**y instrument offset**"→ **+0° 2′ 30″** (**ATT**: these values are only the initial ones and <u>not</u> necessarily the appropriate for observing the target).

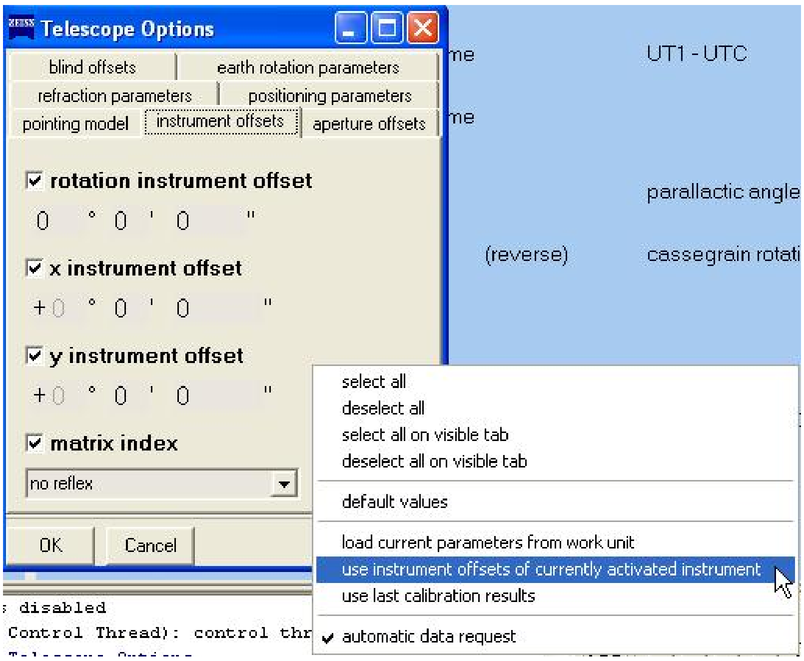


Fig. 17. The instrument offsets menu

4. To activate the instrument offsets select the **“Instrument Offsets”** on the **“Telescope”** menu (Fig.15)

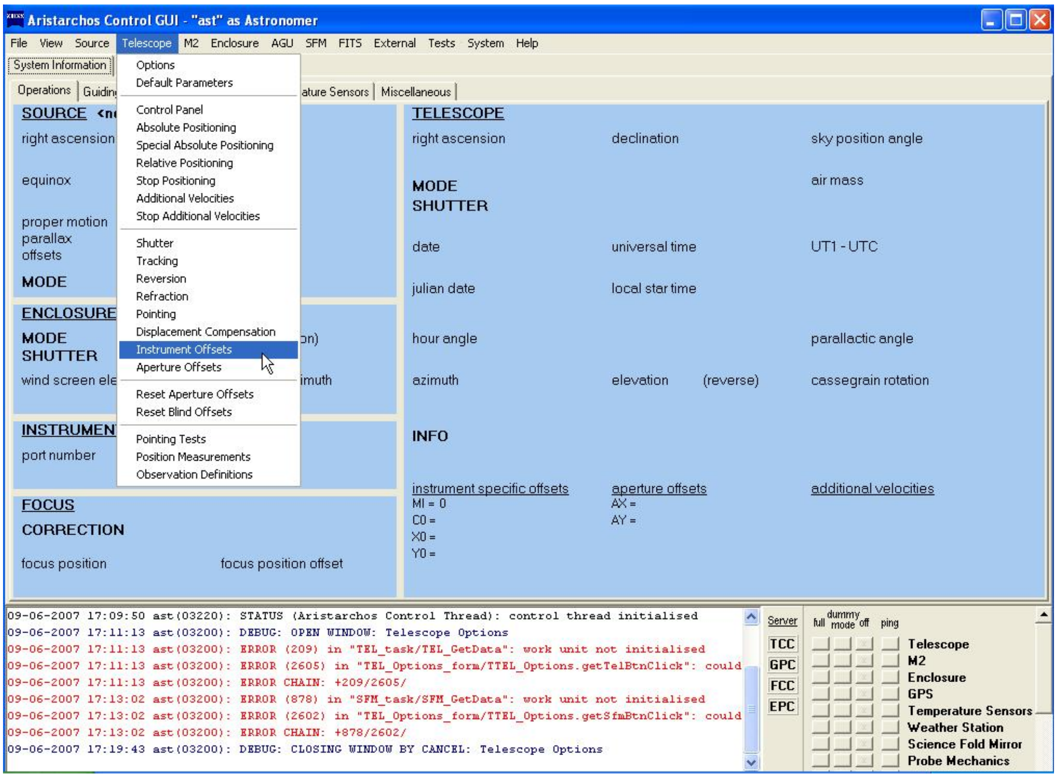


Fig. 18. The telescope operation menu for instrument offsets

5. The focus value using **“M2”/”Absolute positioning”** should be set initially on **-2.4 mm**.

4.4.2 Best focus and approximate offsets determination using a bright star

In order to find the best focus value and the approximate offset values for a target, you must send the telescope to relatively bright star (e.g. 6-9 mag) as close as possible to your target (e.g. few-several arcmin).

1. In the MaximDL (Fig. 13), select: a) Continuous, b) 1-3 sec exposure time, c) binning 2x2 or 3x3.
The less exp. time and the smaller binning mode should be used for the very bright stars, while 3x3 binning mode and greater exp. times for the fainter stars. However, these values depend also on the seeing of the night. Finally, press "Start".

2. If there is no spectrum "trace" you must scan the area around the given offsets using a step of 5" or less. Keep in mind, that you must keep the one offset constant when changing the other.

The area that you should search is:

For X_0: 0° 0′ 35″ --- 0° 2′ 00″ and
for Y_0: 0° 2′ 00″ --- 0° 2′ 50″

For changing the offset values follow the steps 2 and 3 of section 4.4.1.

Keep in mind that the FoV of the fibers cover 10" in the sky, while a bright star (e.g. 6-7 mag) with a seeing of ~1" covers 2-3" in the sky. Therefore, you expect that only a portion of the fibers will be filled. Once, a "spectrum trace" is detected, follow very carefully the following:

a) Note the value of X_0, Y_0.
b) Change the value of ONLY one of the two offsets to one direction with very small steps (e.g. increase the X_0 by ~2").
c) Once the spectrum trace is totally lost, note that value (e.g. X_0, 1 = 0° 0′ 45″)
d) Move the same offset to the opposite direction with the same step (e.g. decrease the X_0 by ~2")
e) You should see the counts increasing, and decreasing again. Once the spectrum trace is totally lost, note that value (e.g. X_0, 2 = 0° 0′ 35″)

Therefore, the best position for this offset is the mean value of the two extreme positions (X_0, 1 and X_0, 2) +/-1". According to the example, the correct offset is Xo= 0° 0′ 40″

For the other offset axis (Y_0), follow the steps b-e with the X_0 in the correct value.

After finding the correct Y_0 value, you now know the best X_0, Y_0 offsets for this star.

3. Without changing the offsets, change with small steps (0.05 mm) the focus of the telescope (step 5 in section 4.4.1). The focus value producing the highest values of ADUs in the spectrum is the best focus.

Note: It is expected that a 7th mag star will reach ~35,000-40,000 ADU's using the B-R grating, in Binning **3x3** and with an exp. time of 2 sec, while its light will "fill" the 1/3 to 1/2 of the total number of fibers (50).

4.4.3 Offset adjustments for the target

Now it is the time to send the telescope to the desired target. It is assumed that the target is much fainter (e.g. 10-15 mag) in comparison with the bright star of section 4.4.2. If not, you can skip this section. If this is the case, then use the offsets you found in the step 2 of section 4.4.2 as initial values. It is expected that the best offsets for the target are close to these values, but that depends on the distance between the bright star (section 4.4.2) and the target. Once the telescope reaches the target:

1. In the MaximDL (Fig. 13), select: a) Continuous, b) 3-5 sec exposure time, c) binning 3x3 and press "Start".

2. If there is no spectrum "trace" you must scan the area around the initial offsets using a step of 2-3" likely step 2 of section 4.4.2. Keep in mind, that you must keep the one offset constant when changing the other.

3. Once the offsets are determined for the target, change the binning mode, the exposure time, and set "single" in the MaximDL (Fig. 13). Press start.

ATTENTION: Once the spectrum of the target is downloaded, in the MaximDL command bar (upper left) choose "file"-->"save as" (e.g. IEEE FLOAT or 16 bit fits format) and browse for the directory you want.

Note 1: For long-exposures (i.e. greater than 5 min) it is recommended to enable the autoguiding system of the telescope.

Note 2: A 12.5th mag star will reach ~5,000-6,000 ADU's using the B-R grating, in Binning **1x1** and with an exp. time of 900 sec, while its light will "fill" the 1/4 to 1/3 of the total number of fibers (50).

5. Closing down the system

1. For the ATS CCD disconnection follow the four steps described in section 4.3.2,
2. Turn off the mechanical console,
3. Close down the graphical user interface,
4. Turn off the ATS computer.

6. TECHNICAL INFORMATION

6.1. Fibre focus position, fibre alignment, CCD focus position

In order to focus the fibre, the following steps must be done:

1. The system NIKON Lens 135mm[f/2.8] + fibre must be placed outside the ATS (on a bench).
2. Set the NIKON Lens 135mm (collimator) parameters to:
   Focus: ∞, **Aperture: 2.8 (max)**
3. Set the NIKON Lens 58mm[f/1.2] (camera lens) parameters to:
   Focus: ∞, **Aperture: 1.2 (max)** (note that this Focus will change later)
4. Set a small telescope opposite to the lens with the same aperture and **Focus:** ∞**.** The small telescope must have an eyepiece on its end in order to see the fibre.

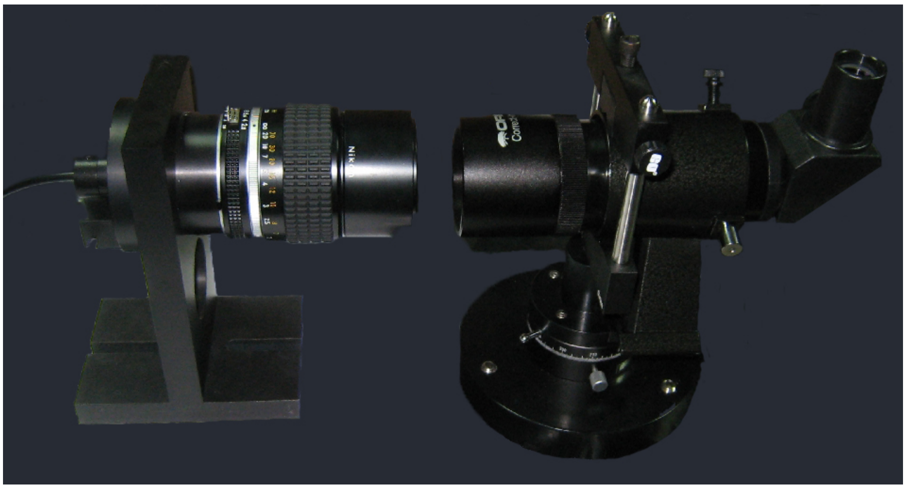


Fig. 19. Collimator lens opposite a small telescope

5. Use a light source (a simple lighter can do the job) for illumination of the fibre. In order to achieve an f/5 beam, you can set the lamp at a distance of 5 times the diameter of the lamp.

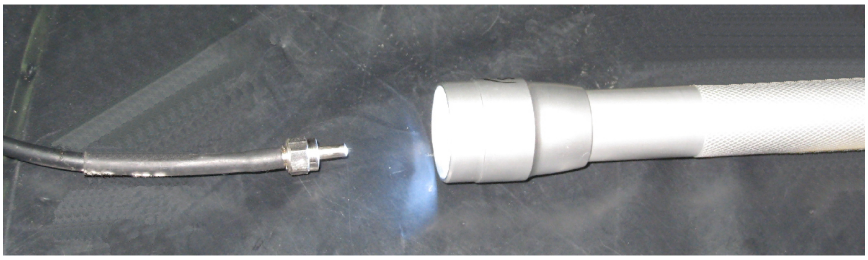


Fig. 20. Fibre illumination by a light source

6. Illuminate input fibre end with the f/5 beam from the lamp which has been carefully placed on the axis.
7. Have the collimator lens (being fed by the fibre) detached so that you can look directly into the lens.

Fig.21. Collimator lens aligned with the small telescope

8. Focus the small telescope on infinity with your eye. Put the collimator lens on its infinity setting and then move fibres until it is in focus. Make sure they are orientated vertically (long slit) then clamp. Do not clamp with too much pressure or the fibre bundle will be damaged.

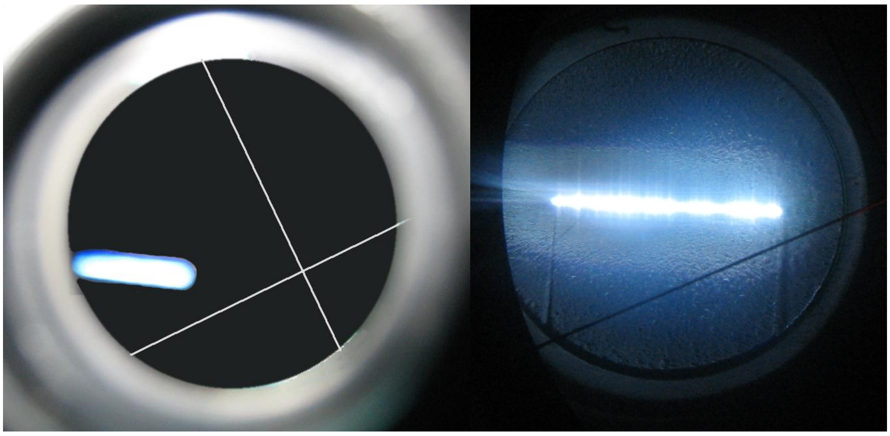


Fig. 22. Fibre image through the eyepiece. Out of focus on the left and focused on the right.

9. Put collimator and camera lenses back in place and change camera focus until:
   a) Spectrum over the whole wavelength range and
   b) fibre images
   are simultaneously in focus. You need CCD images to do this.

   Important notice:

   If this does not happen, the fibre is not in the right position - it is very sensitive to any change and you might need to go through this process multiple times before getting the exact condition.

   Once achieved do not change the fibre position into the collimator.

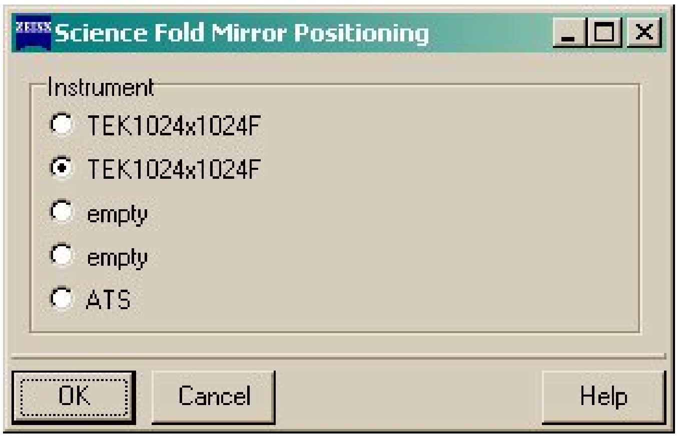
6.2 ATS integration on telescope control system

This document gives an overview about the integration of the ATS in the control system. The ATS has an aperture of 10″ only. To be able to hit an object, instrument offsets and the focus offset have to be determined well. Because sky orientation of the fibre is not of interest, the instrument offsets MI and C0 can be set to 0. The only values to determine are X0 and Y0.

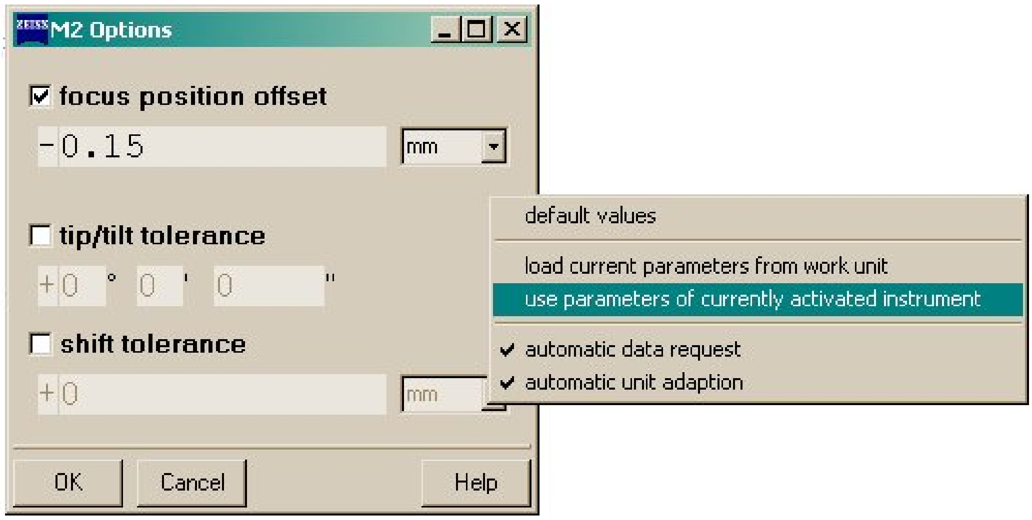
It is impossible for the ATS to see the focal plane. Therefore, the instrument offsets have to be determined by trial and error. This means the telescope has to be moved by changing its instrument offsets while exposing with the ATS in an endless loop (focus mode).

For the first search, we selected a bright star (1mag) and centred it to the rotation centre with the science camera delivered (TEK 1024×1024). Following steps were done:

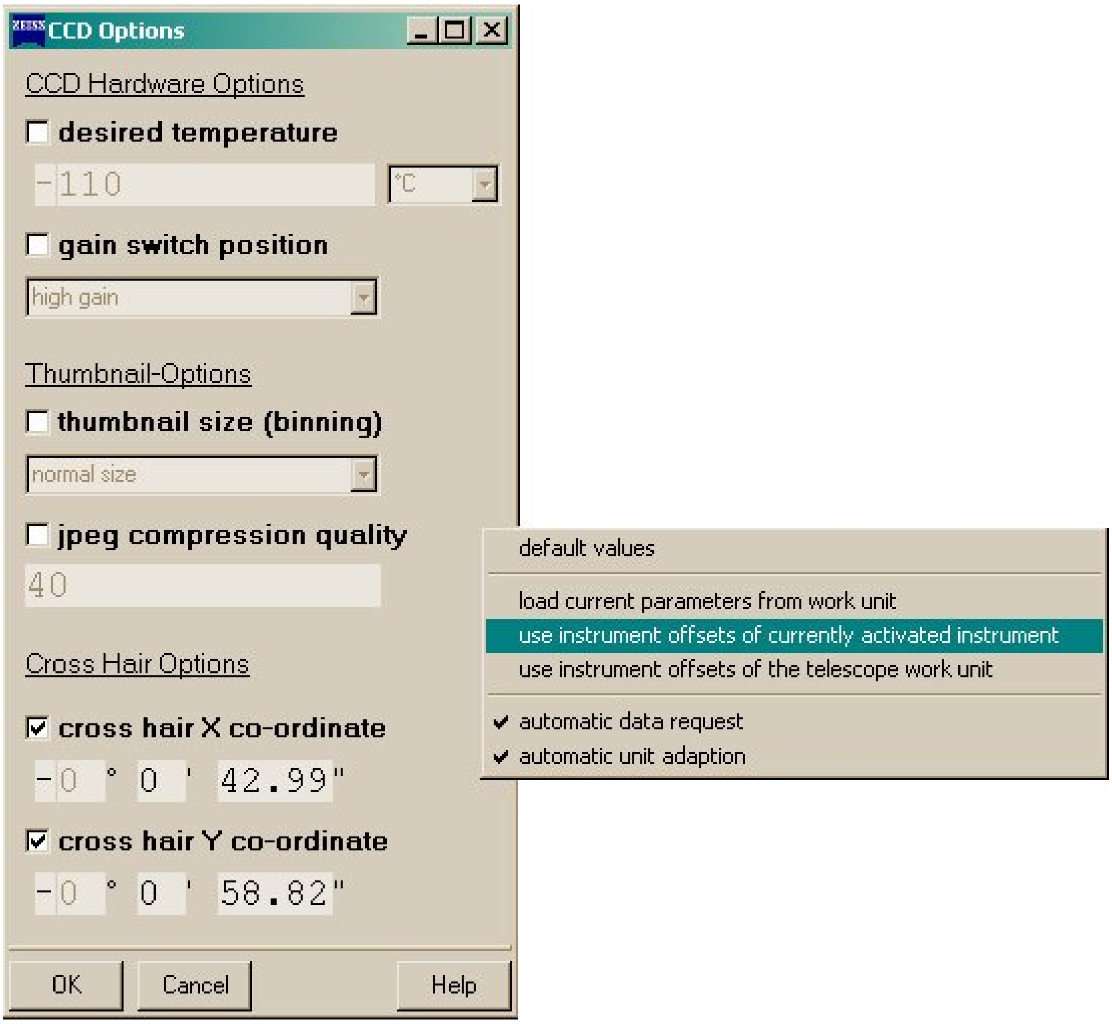
Select the instrument (installed on side port A):
SFM => Positioning
then wait until instrument is selected…



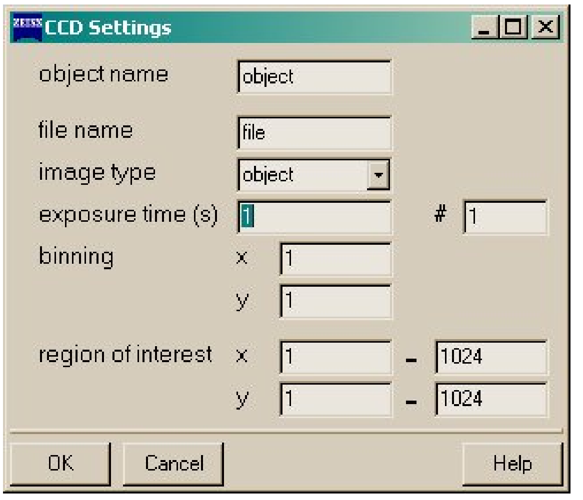
Set the correct focus offset for the science camera:
M2 => Options



Set the cross hair to the rotation centre on the science camera:
External => CCD => Options

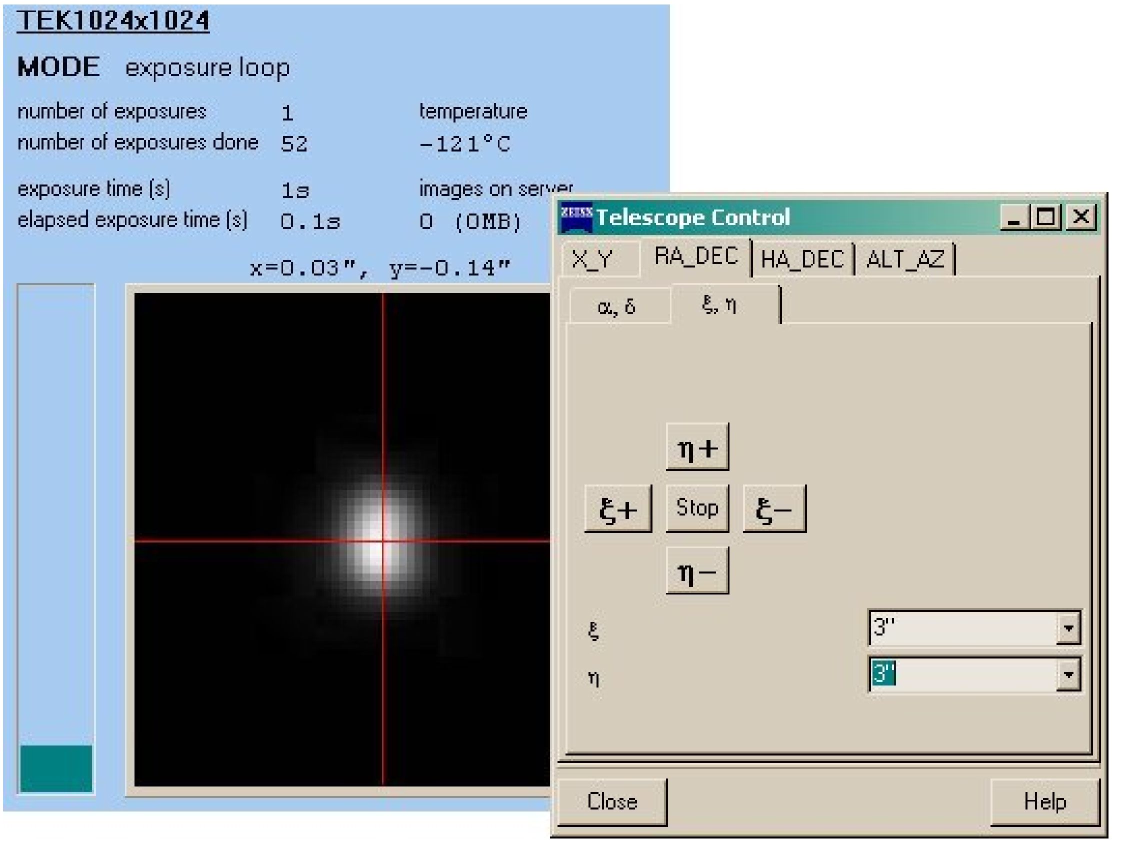


Prepare the science camera for exposure loop:
External => CCD => CCD Settings

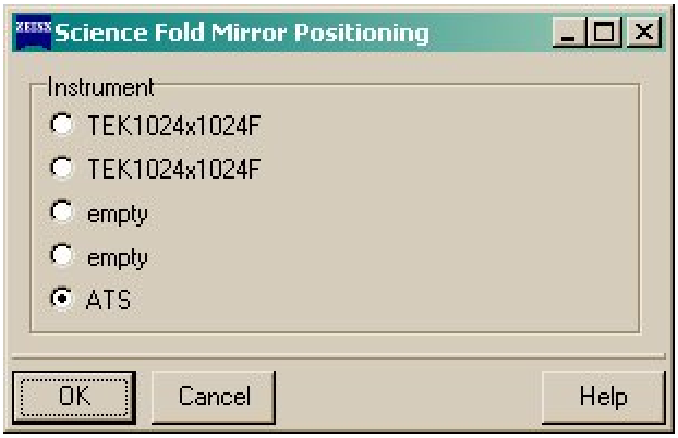


Then switch the exposure loop on:
External => CCD => Exposure Loop

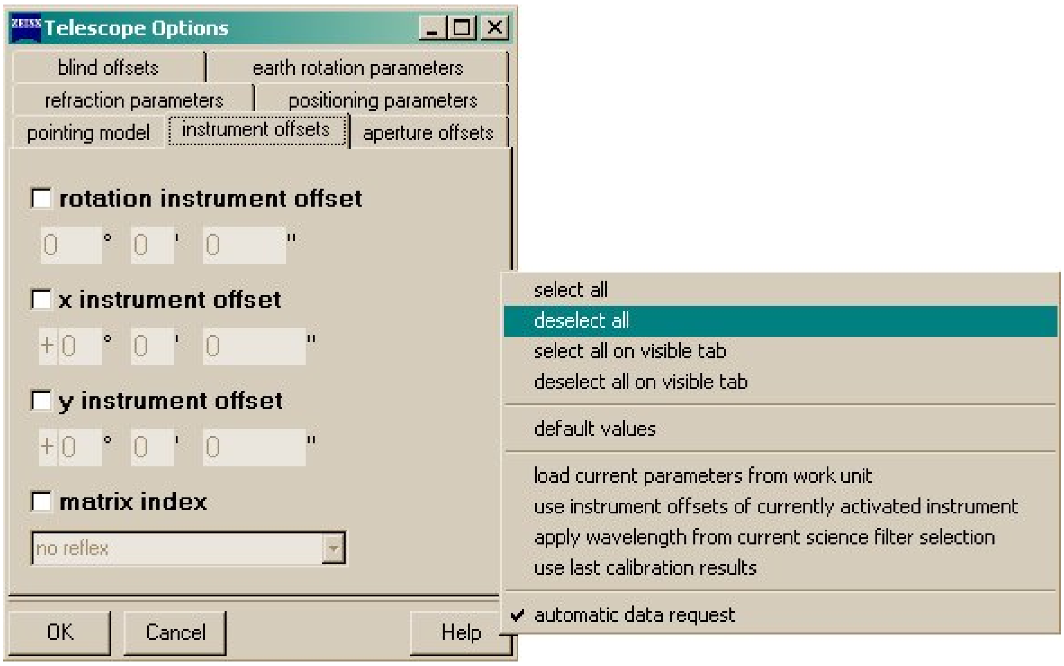
Now select an object (from PPM catalogue) and centre it:
for centring: Telescope => Control Panel (RA_DEC, xi and eta tangents)

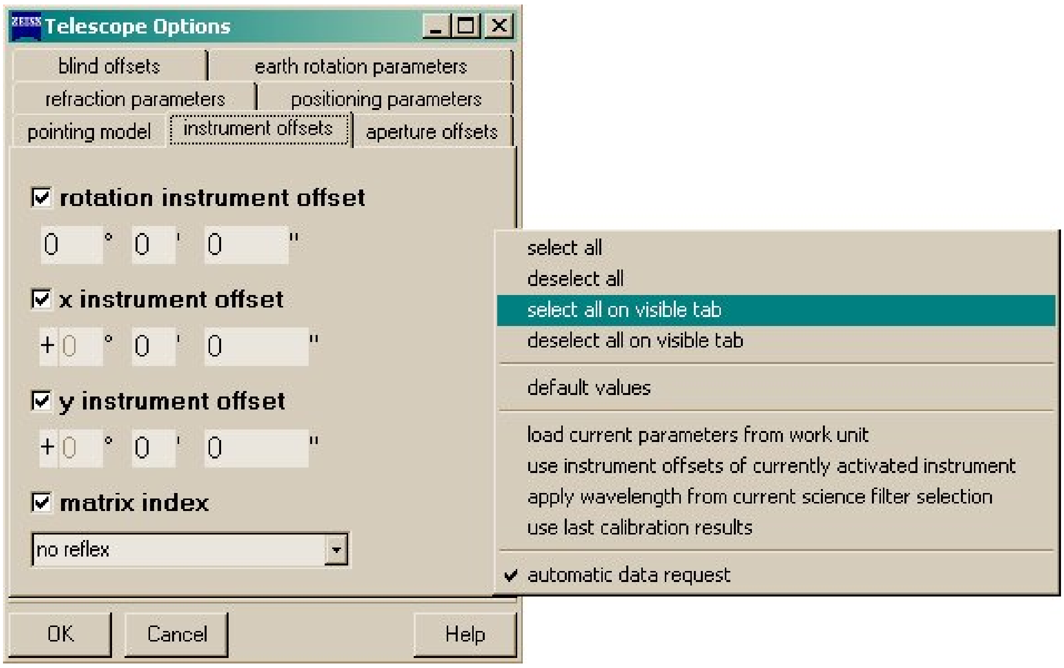


Now the star is centred to the rotation centre. We will proceed without guiding because focus is not known.
Switch the science fold mirror to the ATS:
SFM => Positioning
Wait until finished…



Set all instrument offsets to 0:
Telescope => Options (select “instrument offsets” tab sheet)
Popup: default values
Popup: deselect all
Popup: select all on visible tab





Switch instrument offsets on.
Telescope => Instrument Offsets

Now we are prepared to look for a signal. This can be done by changing the instrument offsets and watching the signal. If we want to scan an area of several arcmin with a step size of 15´´ than we have to repeat these steps several hundred times. A script will help to avoid this effort (see the next outline):

```
TEL_SetParameters x_instrument_offset=0" y_instrument_offset=0" rotation_instrument_offset=0"
            matrix_index=0 x_aperture_offset=0" y_aperture_offset=0"
TEL_ApertureOffsetsOFF
TEL_InstrumentOffsetsON
TEL_WaitForStatus time_interval=180000 status_up={POSED&IOFFS}
status_down={POSINIT&AOFFS}
Sleep time_interval=10000
#

TEL_SetParameters x_instrument_offset=-15" y_instrument_offset=15"
Sleep time_interval=10000
TEL_SetParameters x_instrument_offset=0" y_instrument_offset=15"
Sleep time_interval=10000
#
TEL_SetParameters x_instrument_offset=15" y_instrument_offset=15"
Sleep time_interval=10000
TEL_SetParameters x_instrument_offset=15" y_instrument_offset=0"
Sleep time_interval=10000
#
TEL_SetParameters x_instrument_offset=15" y_instrument_offset=-15"
Sleep time_interval=10000
TEL_SetParameters x_instrument_offset=0" y_instrument_offset=-15"
Sleep time_interval=10000
#
TEL_SetParameters x_instrument_offset=-15" y_instrument_offset=-15"
Sleep time_interval=10000
```

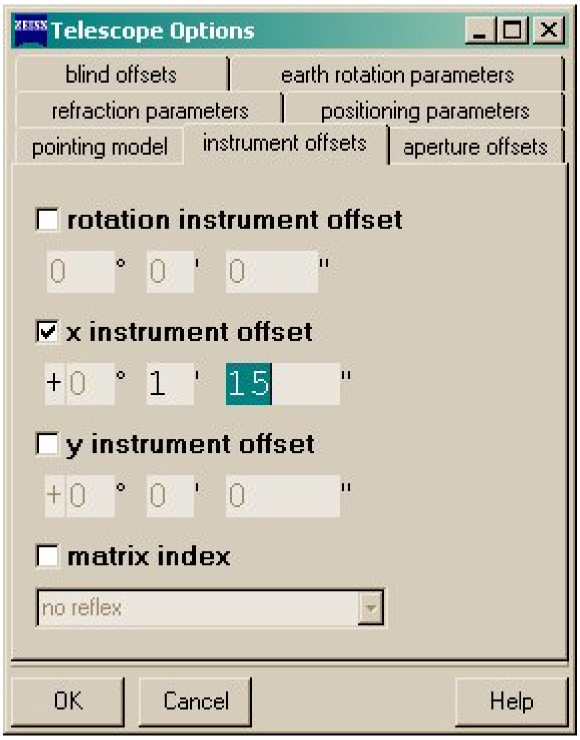
```
TEL_SetParameters x_instrument_offset=-15" y_instrument_offset=0"
Sleep time_interval=10000
#

TEL_SetParameters x_instrument_offset=-30" y_instrument_offset=30"
Sleep time_interval=10000
TEL_SetParameters x_instrument_offset=-15" y_instrument_offset=30"
Sleep time_interval=10000
TEL_SetParameters x_instrument_offset=0" y_instrument_offset=30"
Sleep time_interval=10000
TEL_SetParameters x_instrument_offset=15" y_instrument_offset=30"
Sleep time_interval=10000
#
TEL_SetParameters x_instrument_offset=30" y_instrument_offset=30"
Sleep time_interval=10000
TEL_SetParameters x_instrument_offset=30" y_instrument_offset=15"
Sleep time_interval=10000
TEL_SetParameters x_instrument_offset=30" y_instrument_offset=0"
Sleep time_interval=10000
TEL_SetParameters x_instrument_offset=30" y_instrument_offset=-15"
Sleep time_interval=10000
#
TEL_SetParameters x_instrument_offset=30" y_instrument_offset=-30"
Sleep time_interval=10000
TEL_SetParameters x_instrument_offset=15" y_instrument_offset=-30"
Sleep time_interval=10000
TEL_SetParameters x_instrument_offset=0" y_instrument_offset=-30"
Sleep time_interval=10000
TEL_SetParameters x_instrument_offset=-15" y_instrument_offset=-30"
Sleep time_interval=10000
#
TEL_SetParameters x_instrument_offset=-30" y_instrument_offset=-30"
Sleep time_interval=10000
TEL_SetParameters x_instrument_offset=-30" y_instrument_offset=-15"
Sleep time_interval=10000
TEL_SetParameters x_instrument_offset=-30" y_instrument_offset=0"
Sleep time_interval=10000
TEL_SetParameters x_instrument_offset=-30" y_instrument_offset=15"
Sleep time_interval=10000
…
```

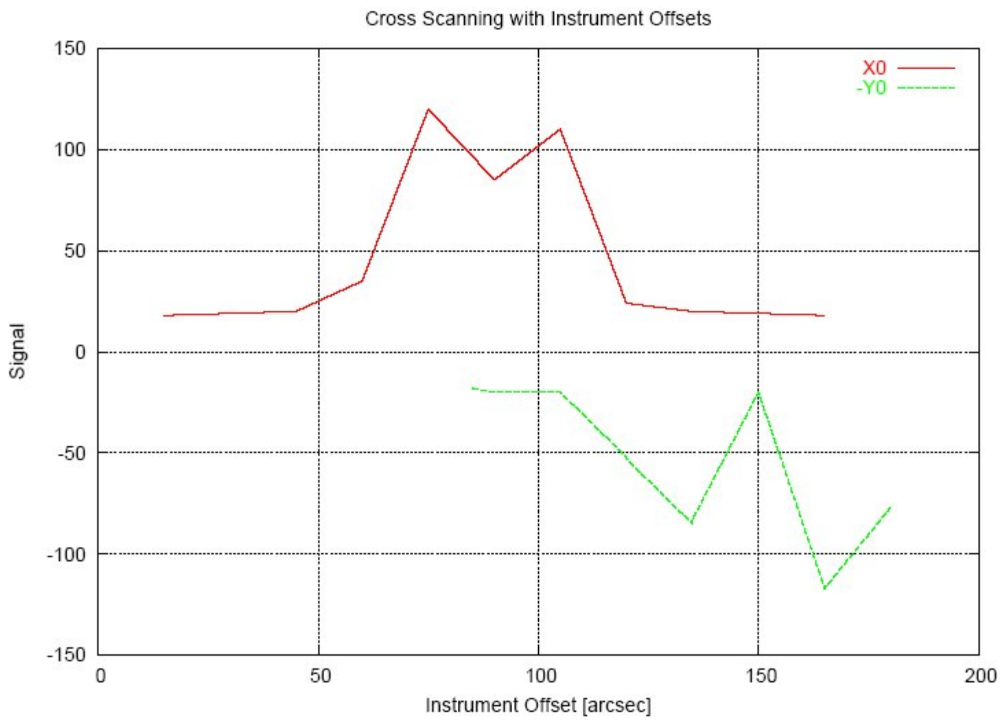
The script sets the telescope every 10 seconds by changing the instrument offsets. The 10 seconds must be applied to get at least one signal measurement. The order of stepping is from the centre outwards. Our first attempt to find the signal of a bright star comprised a scanning area of 4×4 arcmin (this corresponds to 289 steps).

We found the signal in the upper right part of the scanning area (X0 ca. 1’30”, Y0 ca. 2’). Next, we made a scan in both dimensions to determine a function of the object’s signal depending on the instrument offsets. For this purpose, we measured the signal at different instrument offsets.

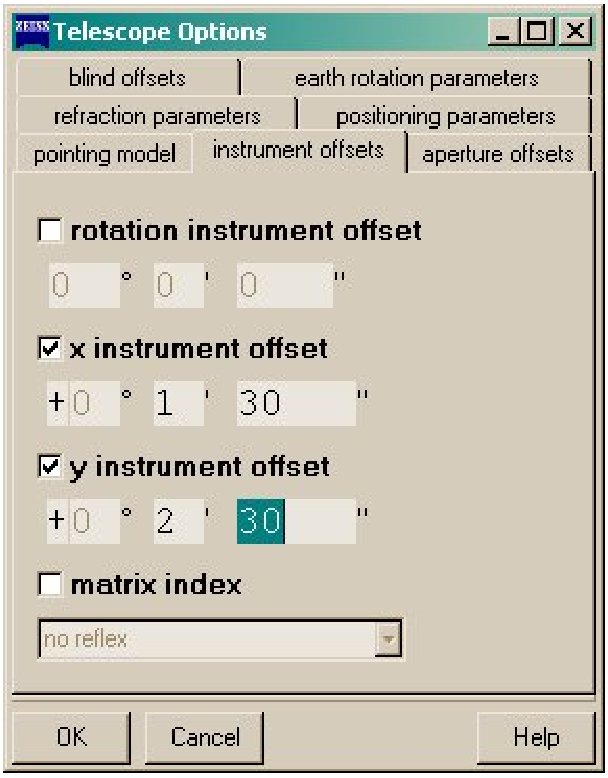
We changed only one of the coordinates X0 or Y0 by:
Telescope => Options (see the next screenshot):



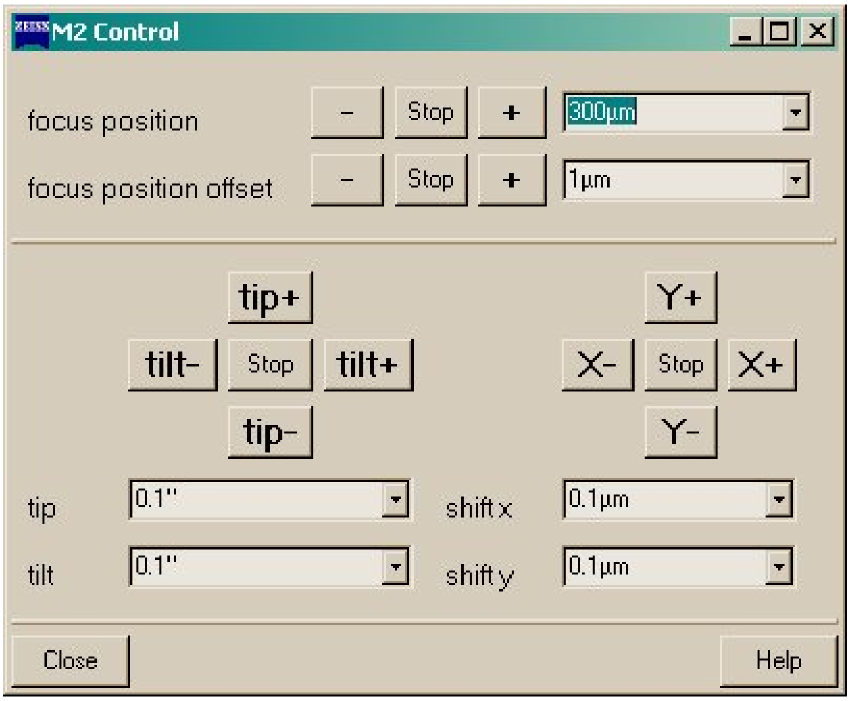
First we kept the X0 constant at 1´30˝ and then Y0 at 2´15˝. The next diagram shows the signal of both scans (Y0 scan is presented with negative signal for better representation). The double peaked structure is clear. This means the image of the star is strongly defocused and created a ring structure with central vignetting by M2. The local minima of the double peaks give us the co-ordinates of the object in the X0,Y0 plane. The values were 1´30˝ and 2´30˝.



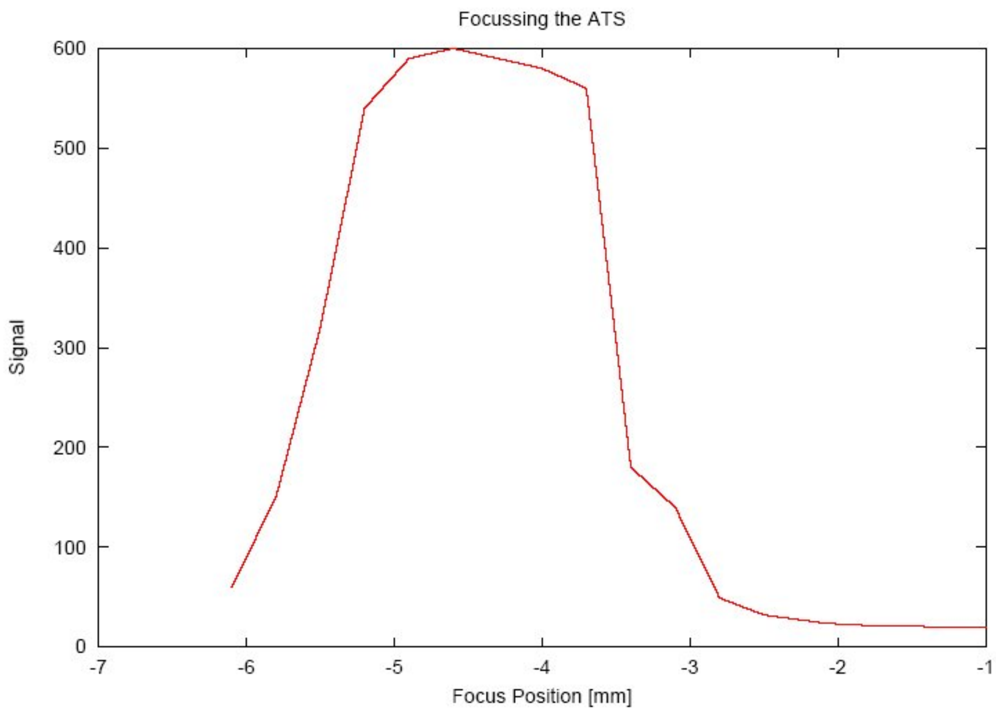
Next, we entered the centre co-ordinates to the control system (see the next screenshot):
Telescope => Options



In order to find the focus we changed the focus by using:
M2 => Control Panel

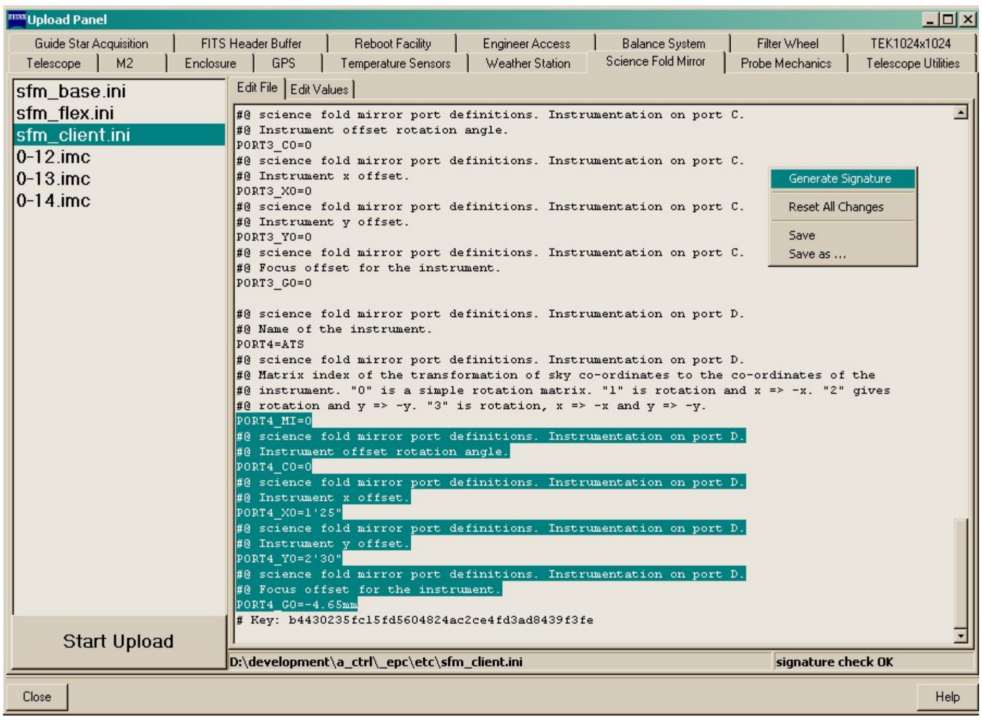


By pressing the + und – buttons we changed the focus and noted the signal. The results are presented in the next diagram. The function shows a maximum signal at –4.5mm.



The focus offset was –0.15mm (for TEK1024x1024), therefore, we determined a new focus offset for the ATS as –4.65mm.

Results:
X0 = 1’30”
Y0 = 2’30”
GO = -4.65mm
All these values were entered in the sfm_client.ini initialisation file by:
Work Unit Panel Popup Menu => Upload Panels
select “Science Fold Mirror” tab sheet and sfm_client.ini file



Enter the values as presented in the screen shot. Then open the popup menu and press “Generate Signature” and then “Save”. The changes will be activated after the next start of the graphical user interface software.

Notes:

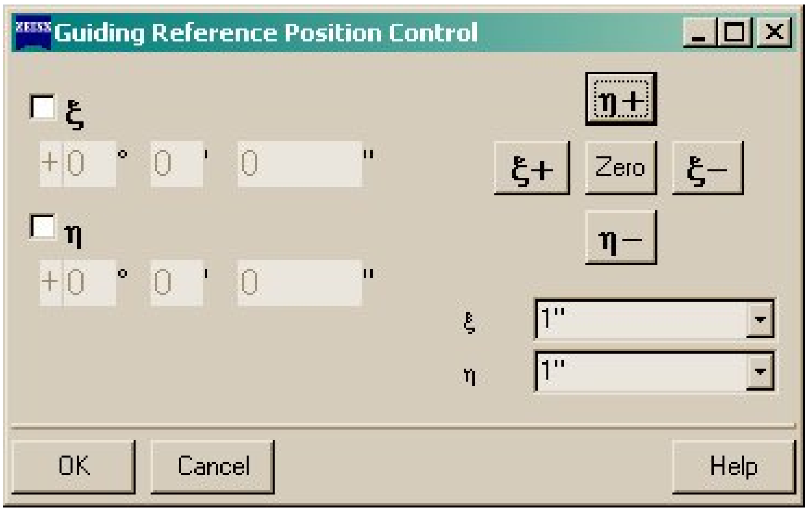
- The stepping by 15” gives only a coarse instrument offset determination. After focussing it should be repeated with step sizes of 2” or less. If the star is focussed well, the signal diagram should give steep slopes when the star comes in and goes out of the fibre.
- The M2 focus offset of –4.65mm is too big to be able to adapt the guiding probe camera foci accordingly. This means, in this situation guiding cannot be applied together with the ATS.
- Dismounting/mounting all instruments requires a redetermination of its instrument and focus offsets.

Proposal to refine the instrument offset determination

The instrument offsets we determined are only coarse results and need a refinement. The approach described above is affected by:

- bad focus
- large step size (larger than the diameter of the aperture)
- tracking drifts

Scanning must be repeated with smaller step sizes at a focus position nearby the optimum and with guiding active (this requires to adapt the optics to the telescope’s optimum focal plane). When guiding the instrument, offsets of the telescope cannot be changed. There is another way to change the telescope pointing by changing the guiding reference position:
AGU => CCDs => Adjust Reference Position
(see the next screen shot)



Because we used instrument offset parameters MI=0 and C0=0 the X0 and Y0 are aligned along XI and ETA. Note that for shifting the guiding reference, the region of interest (ROI) for the guiding process must be set large enough. The standard ROI is 5 times 32 pixels which corresponds to 17.7”. to have 10" in both directions the ROI value should be set to at least 10 (see AGU => CCDs => CCD and Guiding Options).

7. Wavelength Calibration

The calibration of the three gratings was made in the Optical Laboratory using a CuAr arc lamp. The arc produced for each grating can be seen below. The coefficients of each polynomic order used for the wavelength calibration for each grating are given in Table 2.

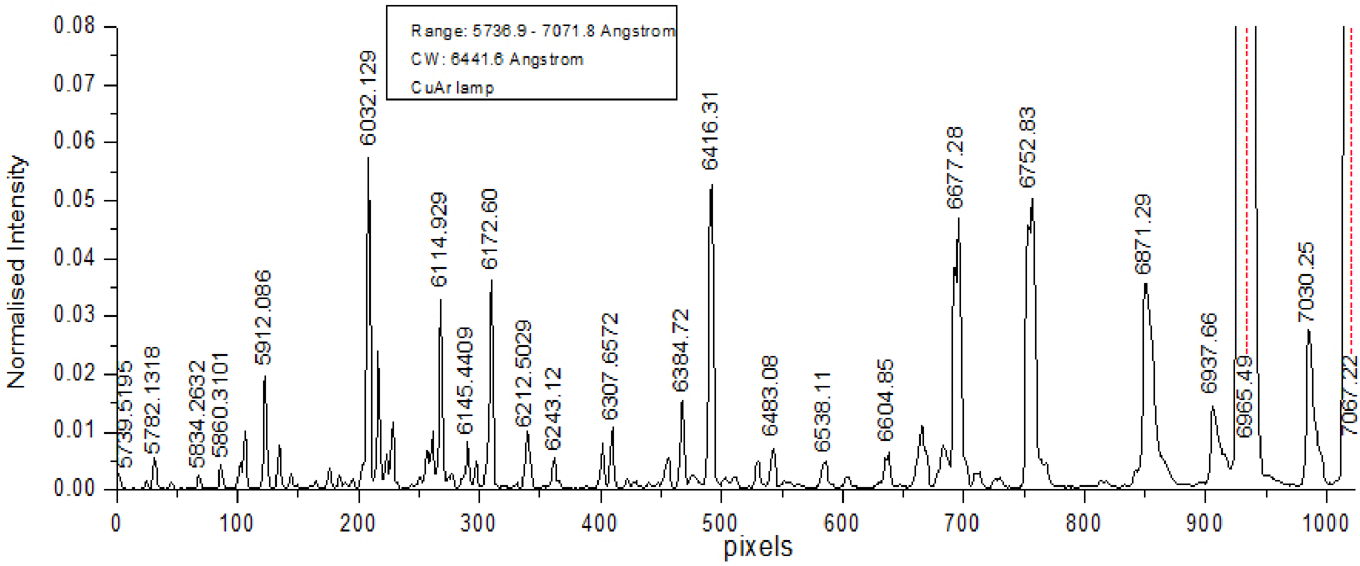


Fig. 23. Arc for the Red 1200 groove/mm grating centered on 6441.6 Å.

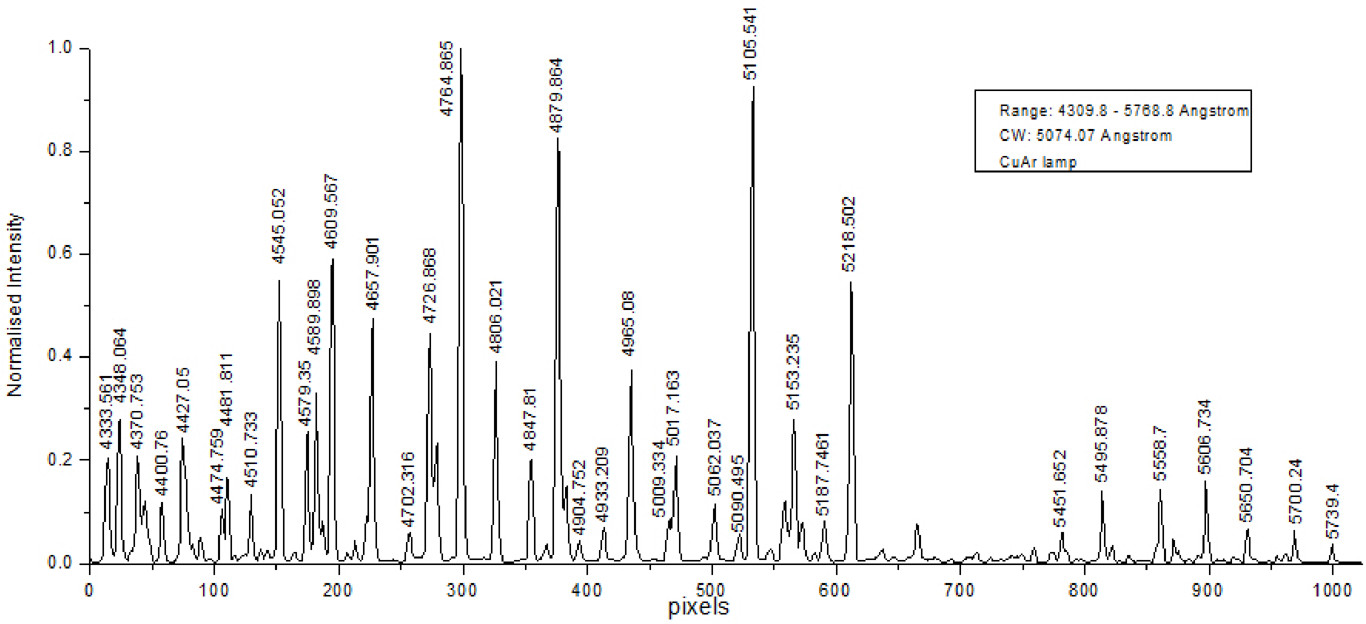


Fig. 24. Arc for the Blue 1200 groove/mm grating centered on 5074.1 Å.

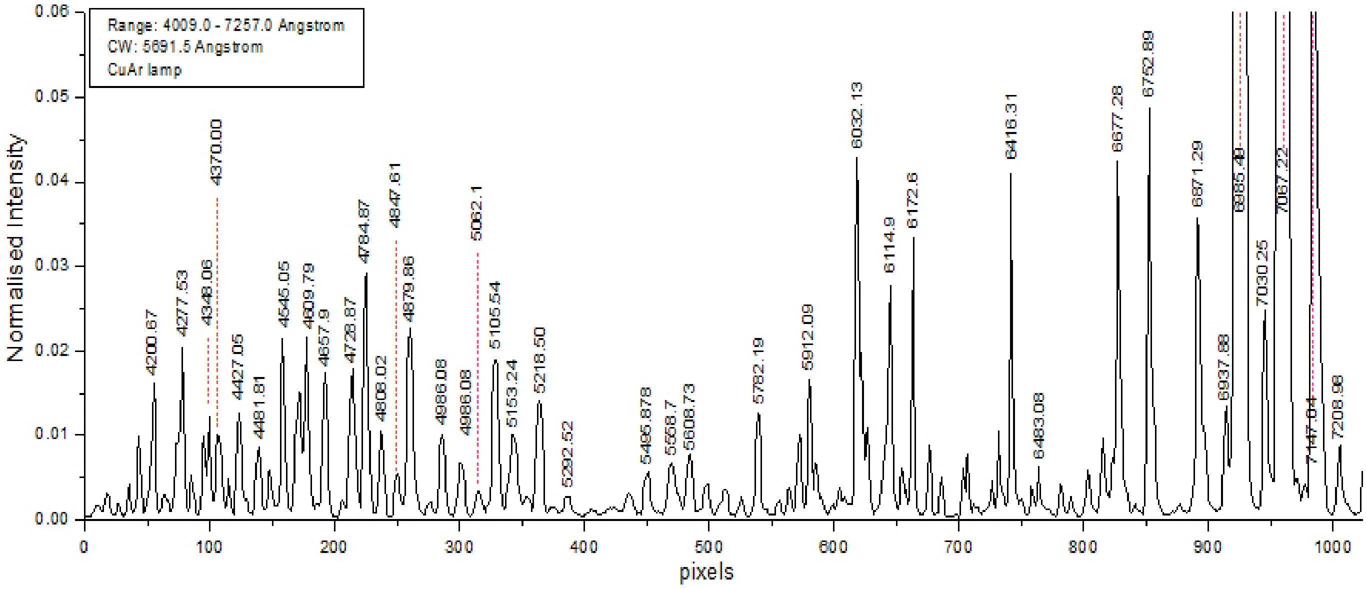


Fig. 25. Arc for the 600 g/mm grating centered on 5691.5 Å.

Table 2. The coefficients of the polynomials used for the wavelength calibration

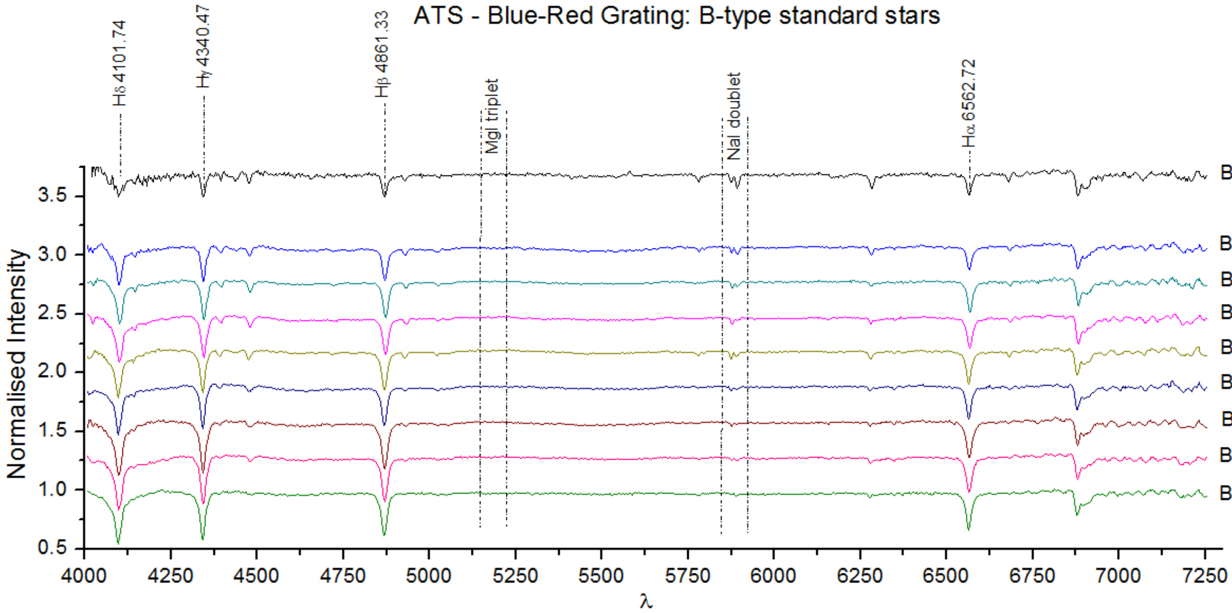
$$\lambda = \lambda_0 + A*px + B*px^2 + C*px^3 + D*px^4 + E*px^5$$

where px = pixel value (0-1023) and λ = wavelength

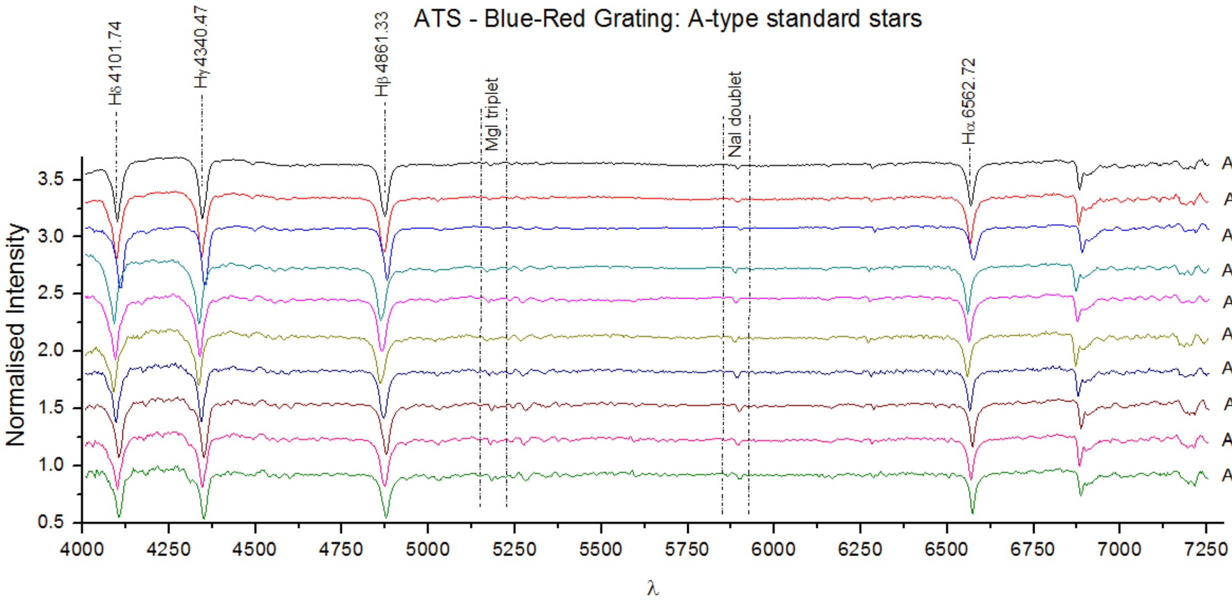
	Red grating		Blue grating		Blue-red grating	
	Value	error	Value	error	Value	error
λ_0	5736.877	0.87784	4309.794	0.47064	4008.963	11.76908
A	1.43924	0.01373	1.55323	0.0045	3.42126	0.19224
B	-1.05E-04	5.81E-05	-1.07E-04	1.13E-05	-9.69E-05	0.00104
C	-3.27E-08	8.74E-08	-1.71E-08	7.63E-09	-7.99E-07	2.39E-06
D	7.18E-12	4.27E-11	0	0	1.25E-09	2.45E-09
E	0	0	0	0	-5.93E-13	9.24E-13

8. Standard stars

In the following plots are shown the spectra of standard stars (luminosity class – V) taken with the ATS using all gratings. A few famous stellar spectral lines (e.g. Balmer lines, MgI, NaI) are also indicated.



(a)



(b)

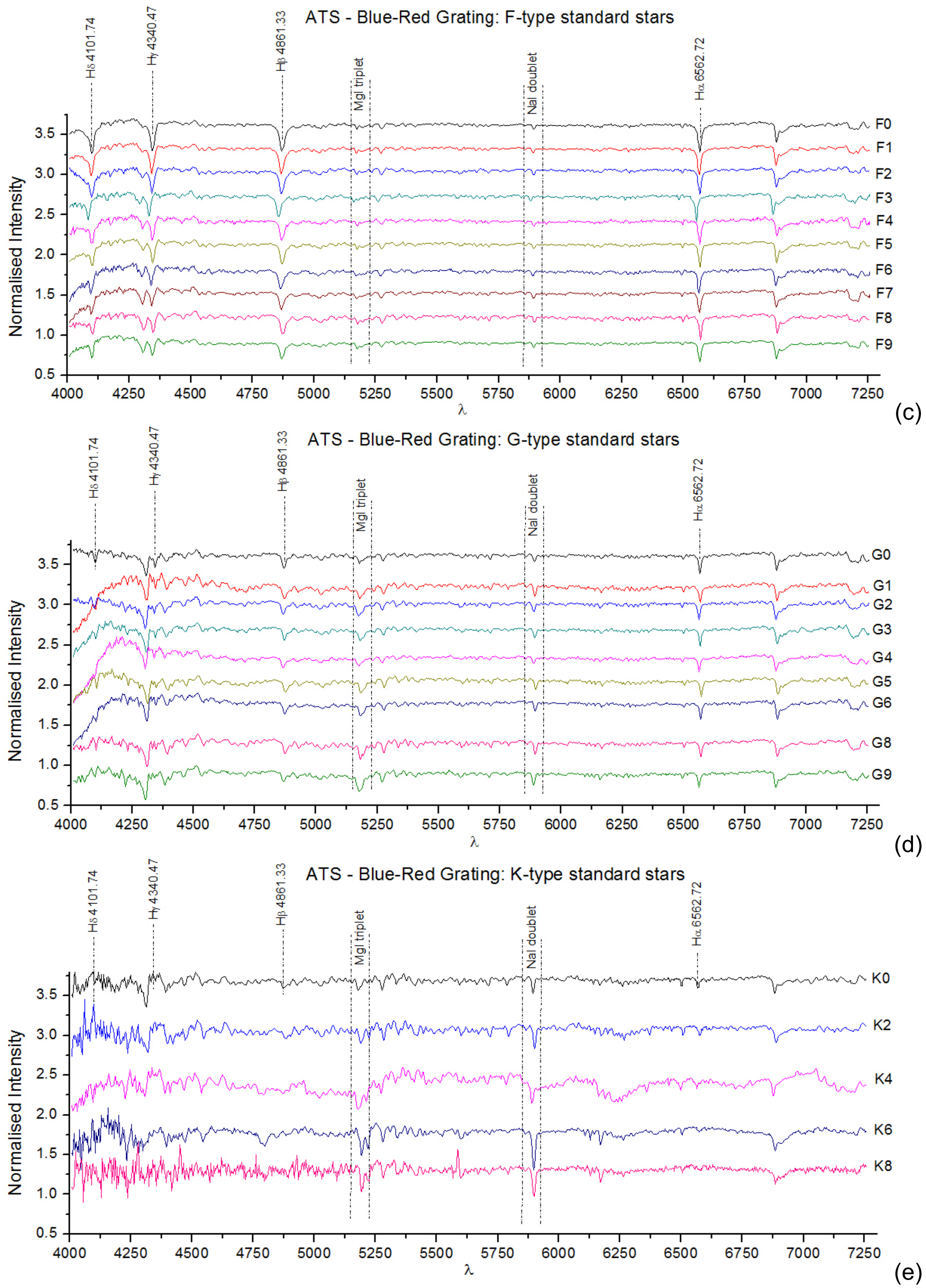
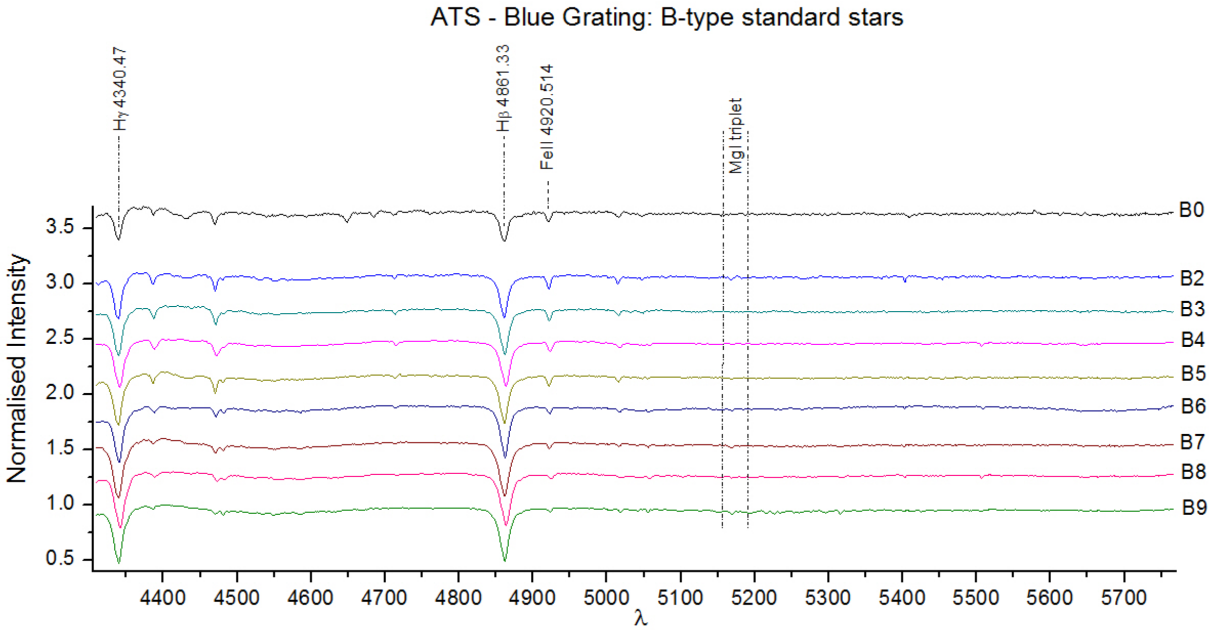
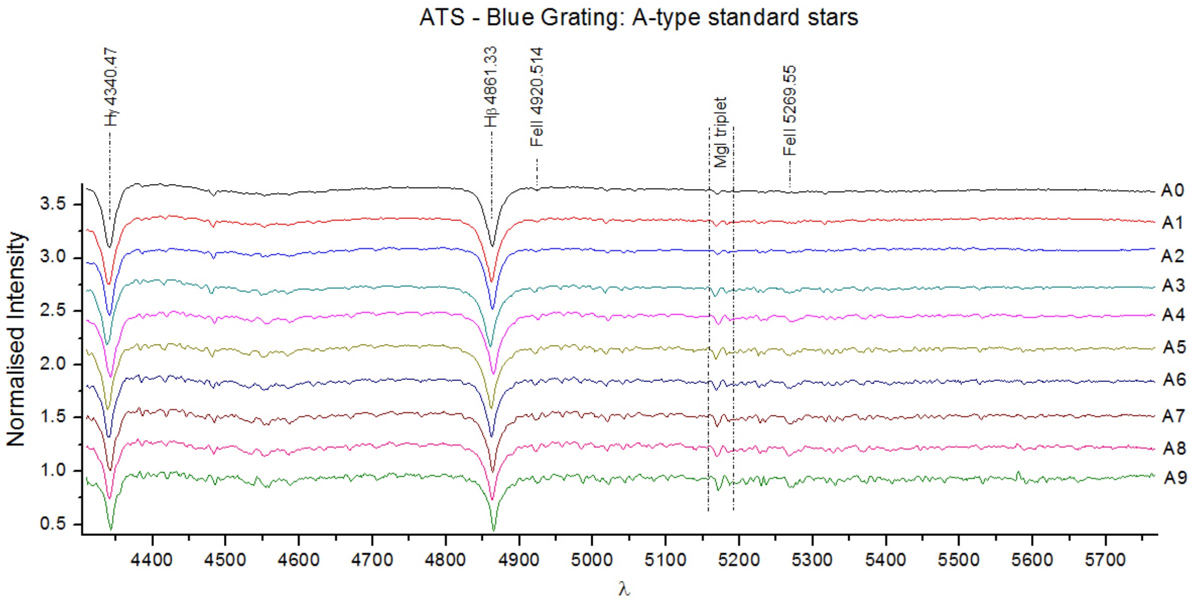


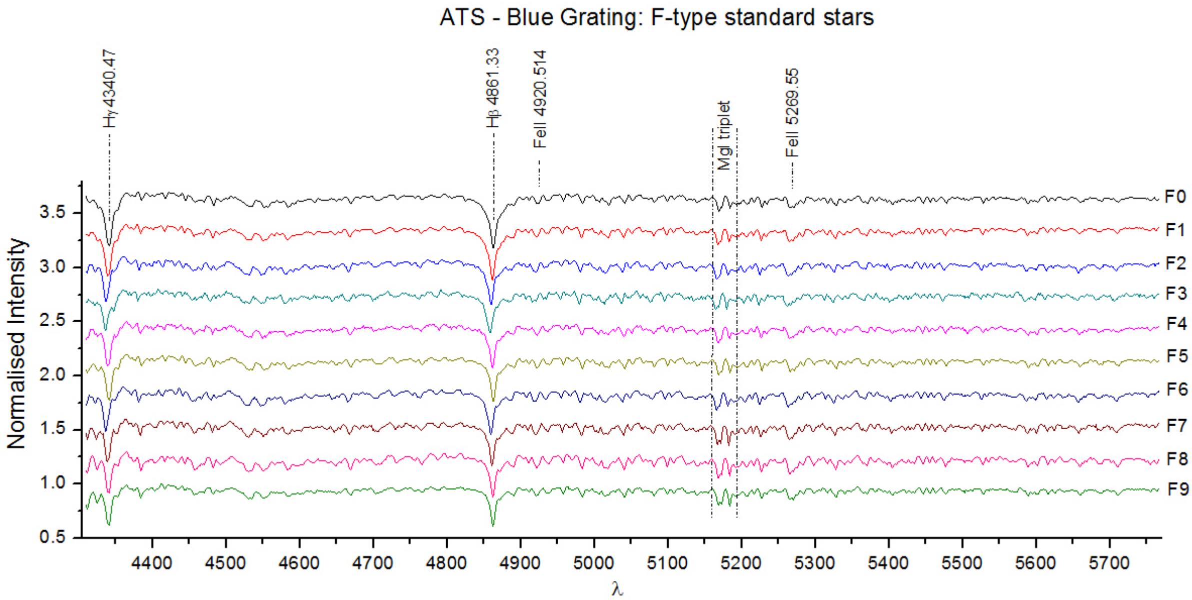
Fig. 26. Spectra of standard stars of: (a) B-type, (b) A-type, (c) F-type, (d) G-type, and (e) K-type obtained with the ATS using the Blue-Red Grating.


ATS - Blue Grating: B-type standard stars
Hγ 4340.47
Hβ 4861.33
FeII 4920.514
MgI triplet
Normalised Intensity
λ
B0
B2
B3
B4
B5
B6
B7
B8
B9
3.5
3.0
2.5
2.0
1.5
1.0
0.5
4400 4500 4600 4700 4800 4900 5000 5100 5200 5300 5400 5500 5600 5700

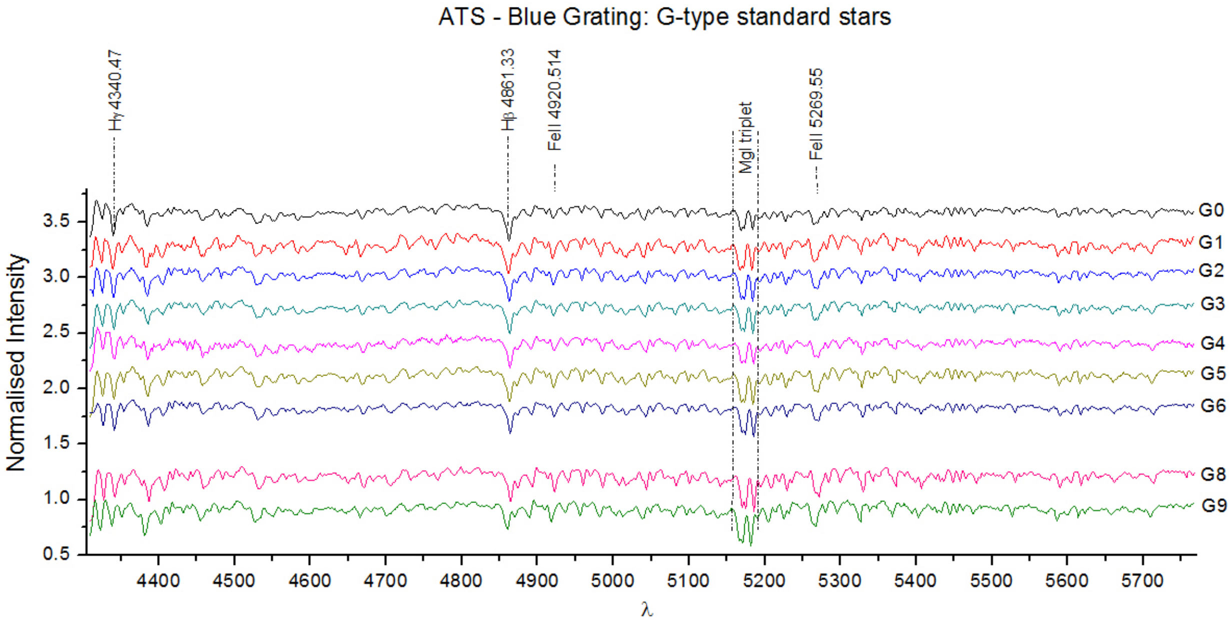
(a)


ATS - Blue Grating: A-type standard stars
Hγ 4340.47
Hβ 4861.33
FeII 4920.514
MgI triplet
FeII 5269.55
Normalised Intensity
λ
A0
A1
A2
A3
A4
A5
A6
A7
A8
A9
3.5
3.0
2.5
2.0
1.5
1.0
0.5
4400 4500 4600 4700 4800 4900 5000 5100 5200 5300 5400 5500 5600 5700

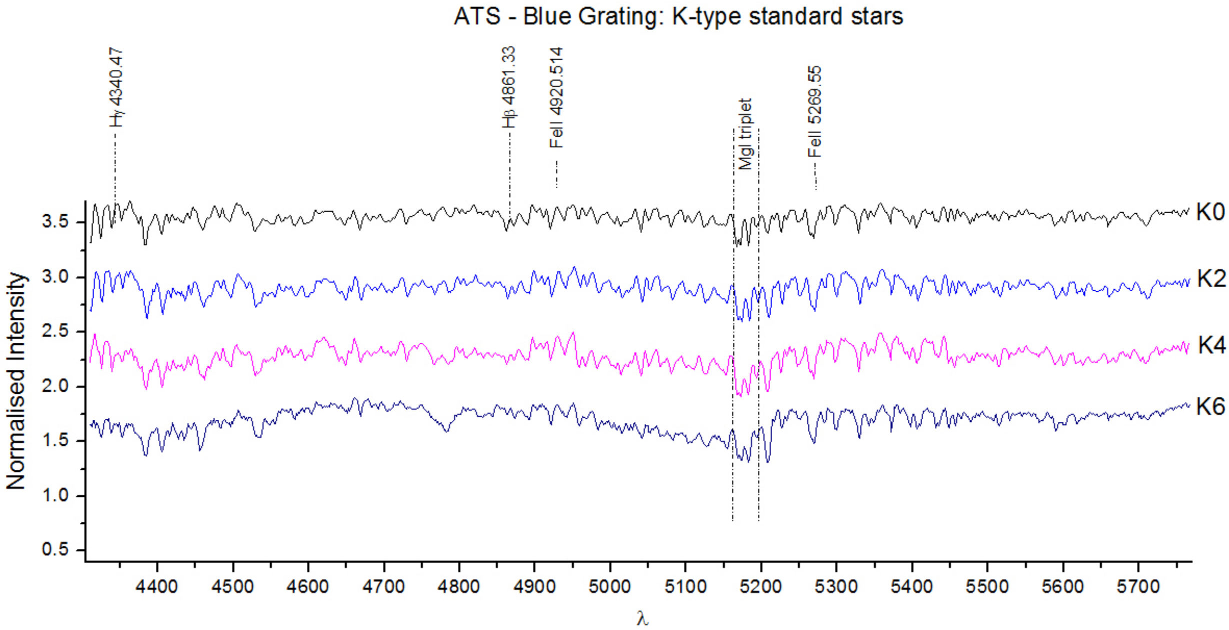
(b)


ATS - Blue Grating: F-type standard stars
Hγ 4340.47
Hβ 4861.33
FeII 4920.514
MgI triplet
FeII 5269.55
Normalised Intensity
λ
F0
F1
F2
F3
F4
F5
F6
F7
F8
F9
3.5
3.0
2.5
2.0
1.5
1.0
0.5
4400 4500 4600 4700 4800 4900 5000 5100 5200 5300 5400 5500 5600 5700

(c)

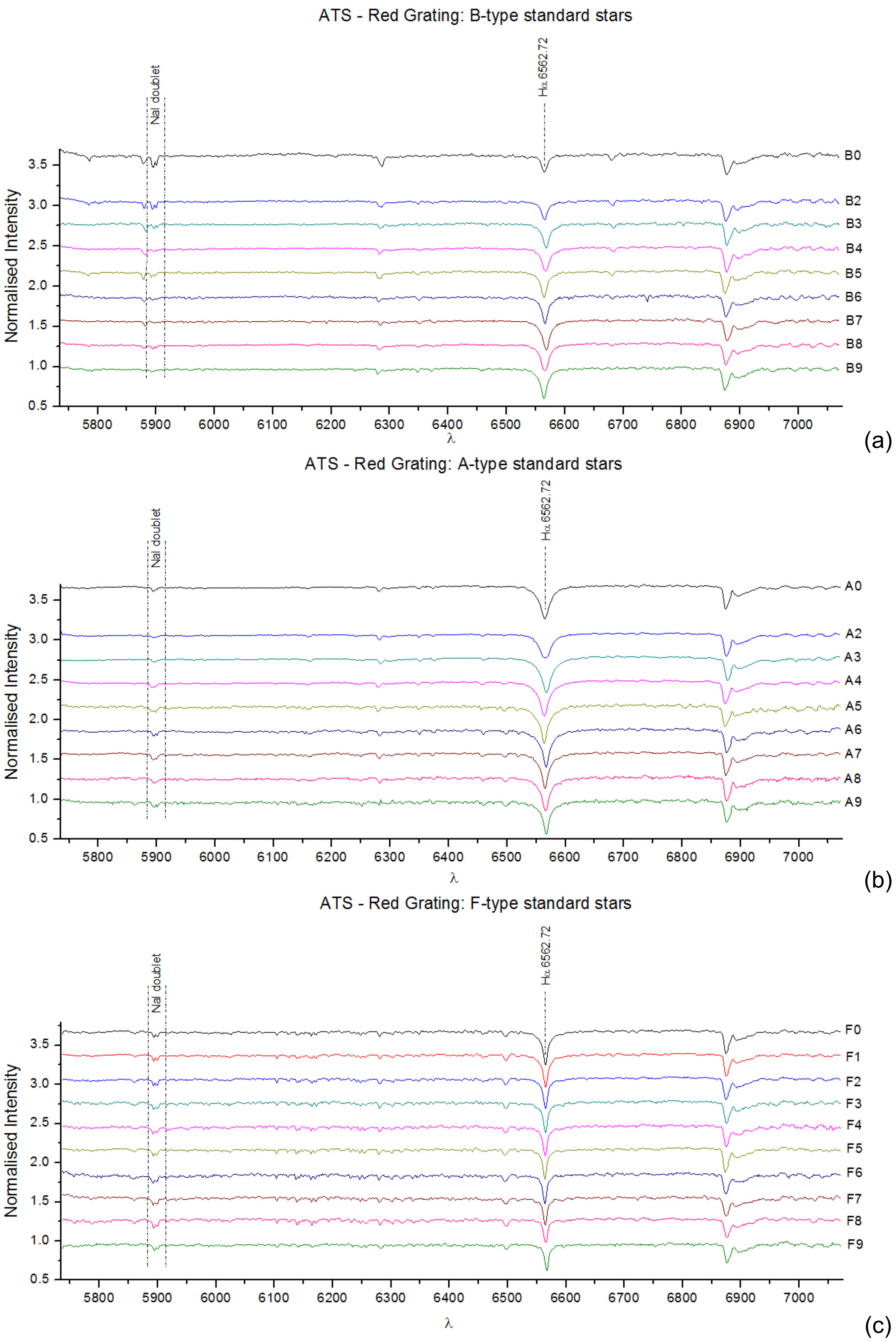


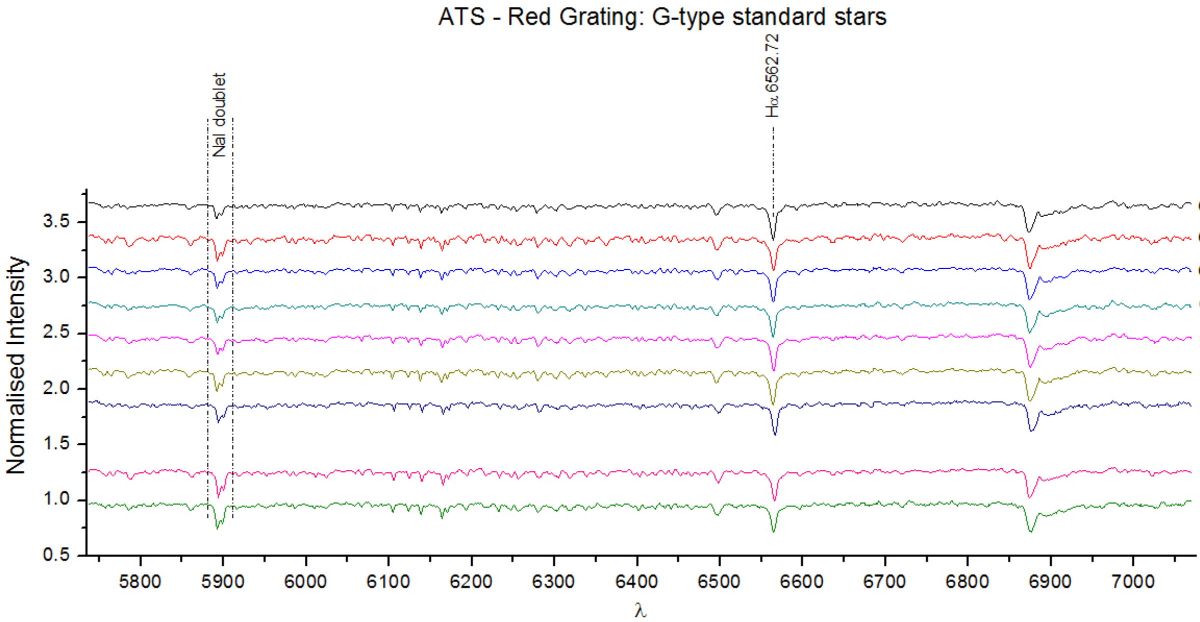
(d)



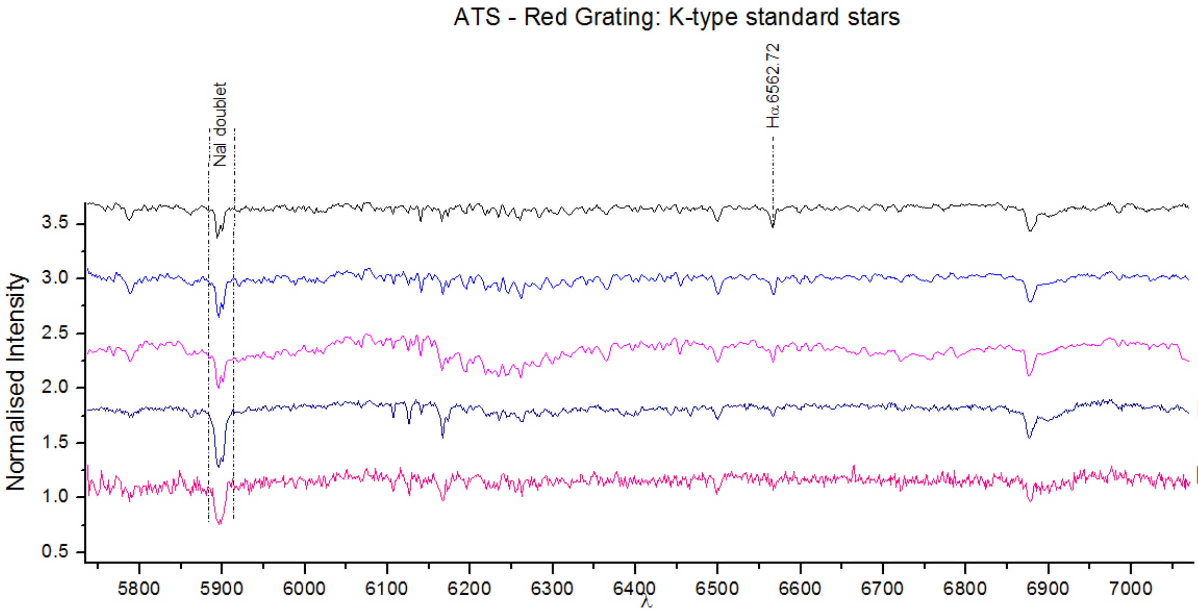
(e)

Fig. 27. Spectra of standard stars of: (a) B-type, (b) A-type, (c) F-type, (d) G-type, and (e) K-type obtained with the ATS using the Blue Grating.


ATS - Red Grating: B-type standard stars
NaI doublet
Hα 6562.72
Normalised Intensity
λ
B0
B2
B3
B4
B5
B6
B7
B8
B9
(a)
ATS - Red Grating: A-type standard stars
NaI doublet
Hα 6562.72
Normalised Intensity
λ
A0
A2
A3
A4
A5
A6
A7
A8
A9
(b)
ATS - Red Grating: F-type standard stars
NaI doublet
Hα 6562.72
Normalised Intensity
λ
F0
F1
F2
F3
F4
F5
F6
F7
F8
F9
(c)



(d)



(e)

Fig. 28. Spectra of standard stars of: (a) B-type, (b) A-type, (c) F-type, (d) G-type, and (e) K-type obtained with the ATS using the Red Grating.

9. Signal to Noise ratio

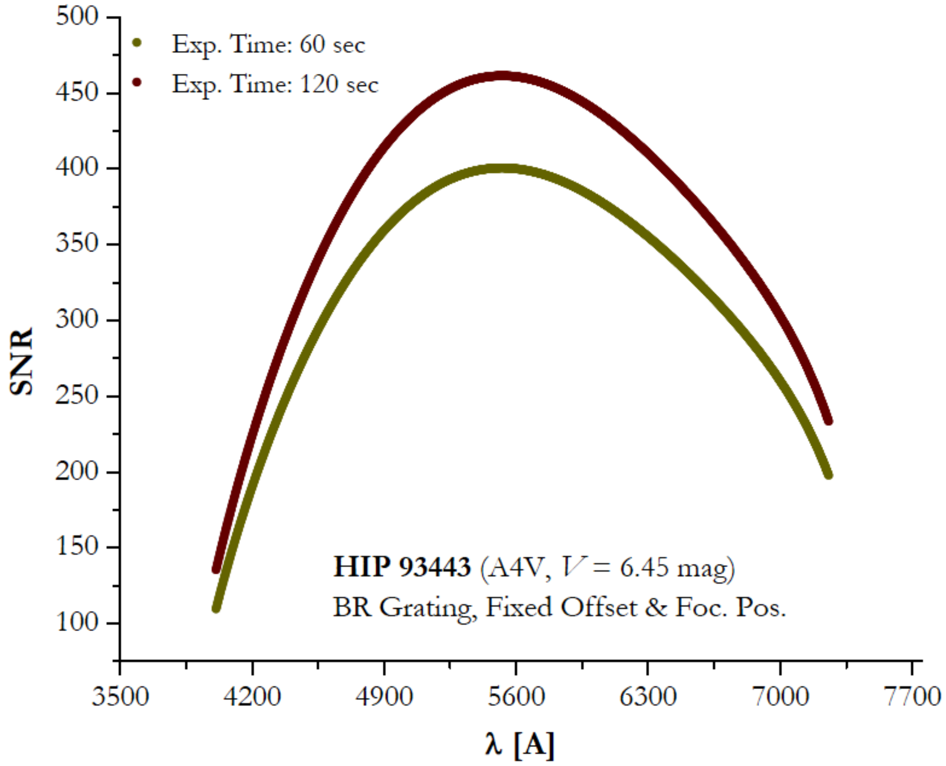
The signal-to-noise ratio (SNR) for ATS is estimated as a function of wavelength λ for a series of measurements of spectroscopic standard stars (with absorption only lines). The sample stars were collected from the *Gemini* observatory database; they were observed in the summer of 2015 and covered a wide range of spectral types. The sensitivity of SNR was then evaluated on the following four factors: (*a*) the spectral range, as provided in the three available gratings (BR, B, and R), (*b*) the exposure time for a specific star, (*c*) the focal position (the relative position of the secondary mirror with respect to the proper focus), and (*d*) the offset between the telescope optical axis and the spectrograph.

The reduction process was carried out through suitable IDL routines in a bias-corrected framework, including the following steps: (*i*) dark (and bias) subtraction from the raw images, (*ii*) bias subtraction from the dark images, (*iii*) outliers filtering (to deal with hot or damaged pixels), (*iv*) pixel integration in the space direction (direction perpendicular to dispersion), and (*v*) robust polynomial representation of the stellar (and the sky background) continuum. The SNR was then estimated via the formula:

$$SNR(\lambda) = \frac{N_{\text{cont}}(\lambda)}{\sqrt{N_{\text{cont}}(\lambda) + N_{\text{sky}}(\lambda) + N_{\text{dark}} + \frac{p}{f} m\sigma^2_{\text{read}}}},$$

where $N_{\text{cont}}(\lambda)$ and $N_{\text{sky}}(\lambda)$ are the integrated intensity in the space direction of the stellar continuum and the sky background, respectively, along the whole spectral range of each grating. N_{dark} is the dark noise accumulating intensity at the respective pixel series, while p is the number of the integrated pixels, f is the binning factor (here we worked with the highest pixel resolution, so f = 1), m is the number of stacked images (here we worked with a single only image, so m = 1) and σ_{read} is the readout noise of the CCD in the working mode. All values of the aforementioned quantities were transformed to the number of electrons recorded from the CCD through the gain conversion of each mode. Note that no attempt was made to remove the telluric lines by flat-fielding our raw measurements.

Typical SNR values range from 500 to 700 with 4 min exposures for our brighter program stars (V ~ 6 mag), while the same SNR remained with 5 min exposures for the fainter stars (V ~ 8 mag). The SNR performance for a 6 mag star is improved by about 20% when the exposures increase by 1 min (Fig. 29). The sky background contribution proved to be too low to affect the SNR values (less than 2%), suggesting that sky measurements could be discarded from an observing program of bright stellar targets (Fig. 29). The ATS performs better in the BR grating and closer to the maximum continuum of the program star. The spectral type is crucial for the ATS efficiency in the B and R gratings; as anticipated, the R mode behaves better than the B mode toward lower temperatures (Figs 30-31). The analysis, however, revealed that the focal position and, even more importantly, the offset of the spectrograph position with respect to the optical axis are factors that might affect the quality of observations in a critical way. A failure in the proper targeting procedure may reduce the SNR even by 50% (Fig. 32).



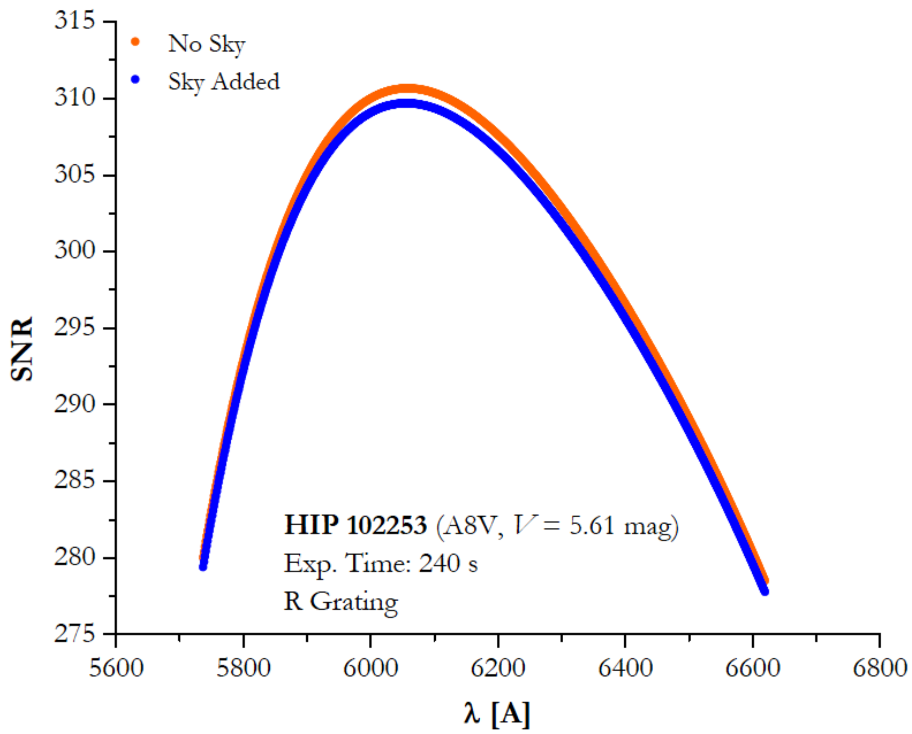
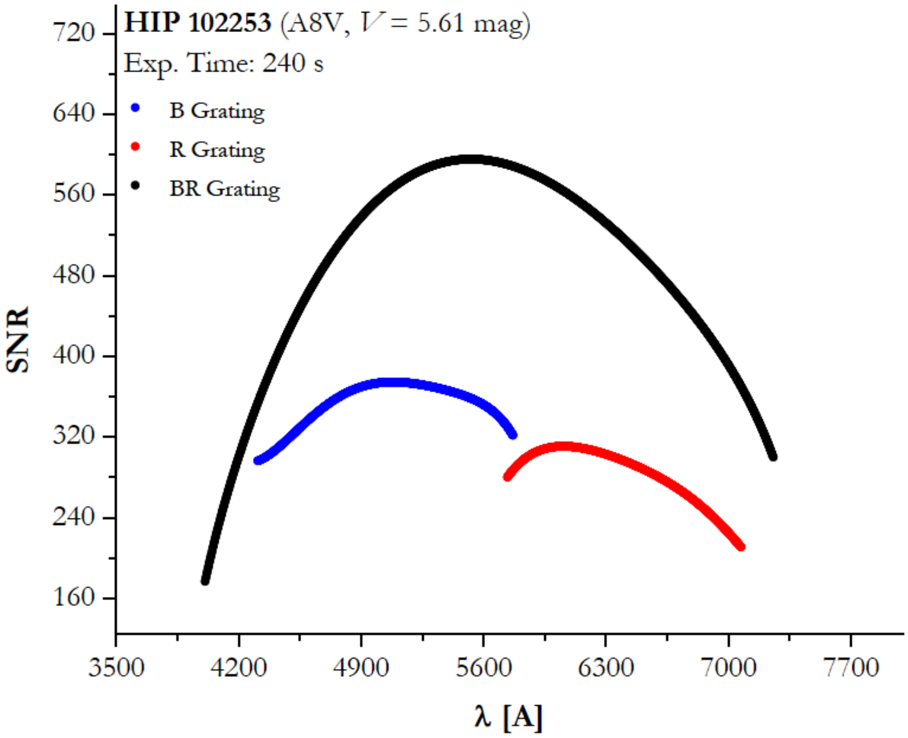


Fig. 29. SNR sensitivity on the time exposure (upper) and the sky background (lower).



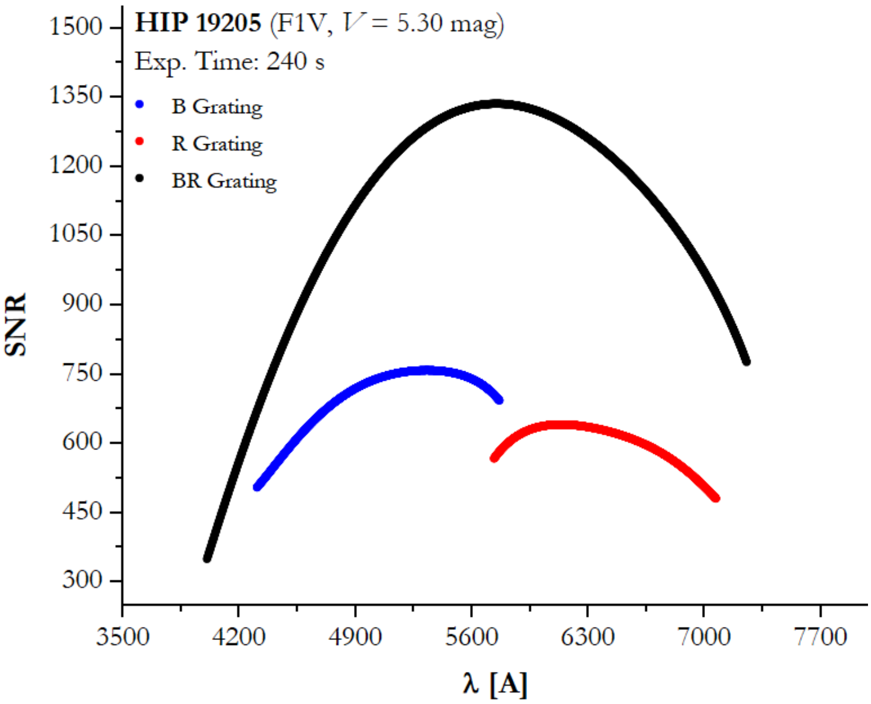
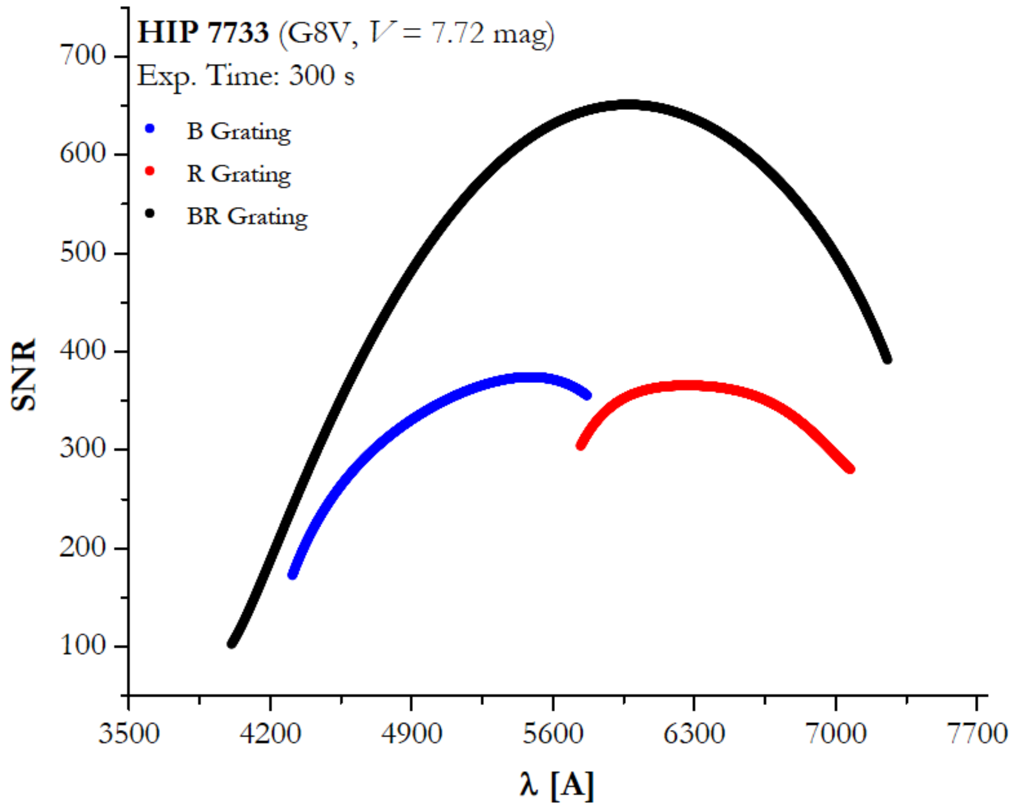


Fig. 30. SNR sensitivity on the spectral range (grating). SNR values are depicted for a A8V (upper), a F1V (lower) spectroscopic standard star.



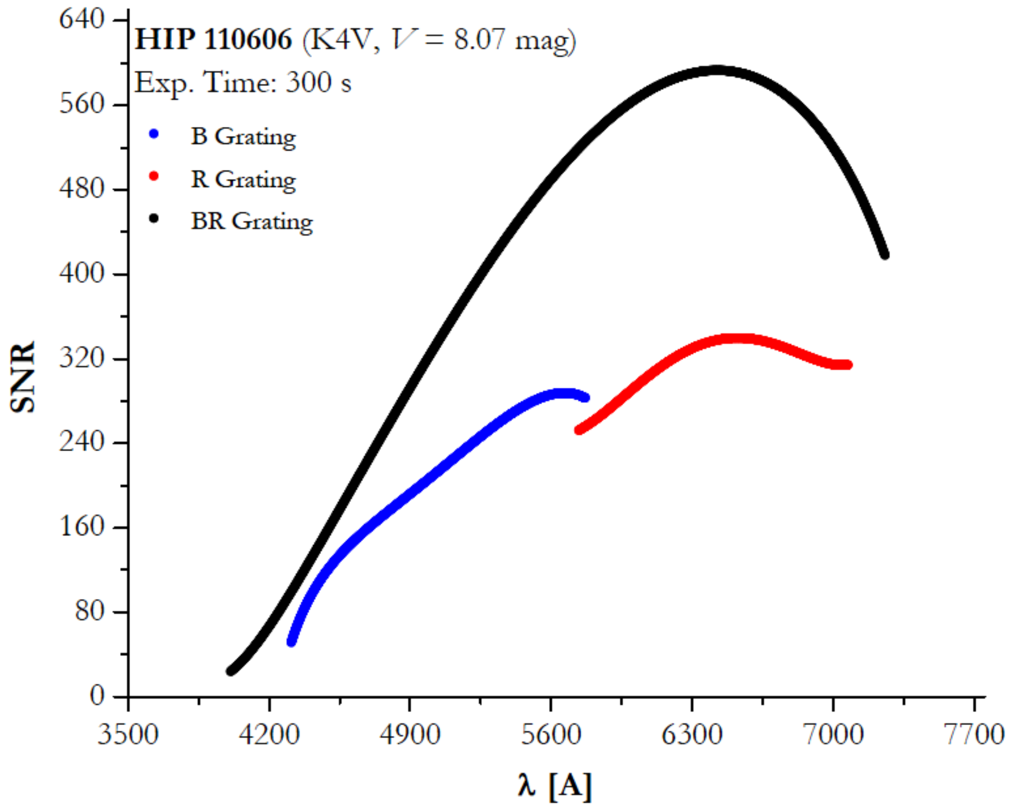


Fig. 31. SNR sensitivity on the spectral range (grating). SNR values are depicted for a G8V (upper), and a K4V (lower) spectroscopic standard star.

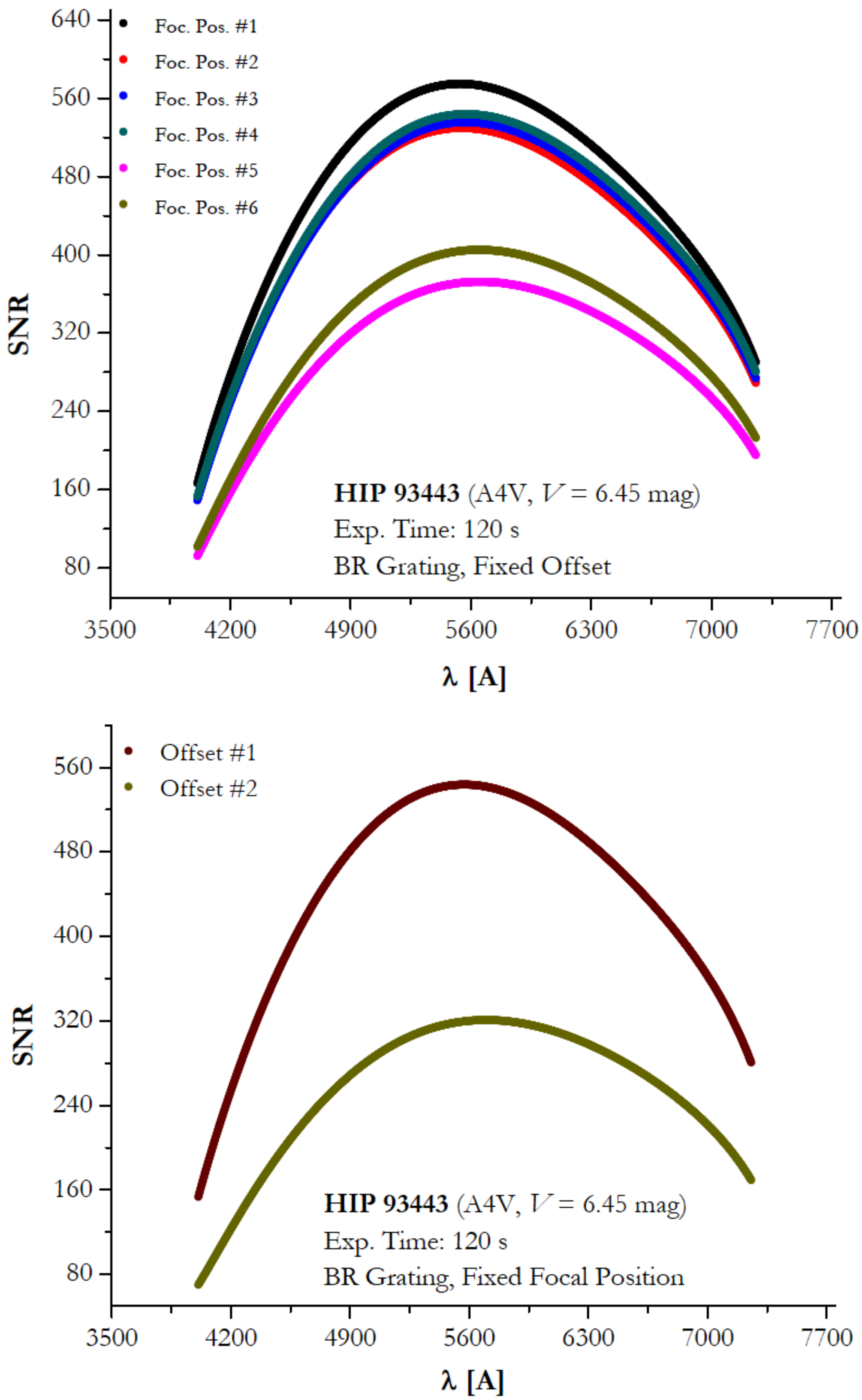


Fig. 32. SNR sensitivity on the focal position (upper) and the offset of the spectrograph position with respect to the optical axis (lower).

To estimate the SNR for a star with an apparent magnitude *m* and an exposure of time *t*, we extend the aforementioned analysis by employing the Pogson law (to deal with the brightness) and by taking advantage of the linear response of a CCD camera (to deal with the time) with respect to our instrumental values of a standard star with the same spectral type. To simplify the procedure, we restrict our computations to the central visual wavelength of 5400 A. Assuming that m_0 is the magnitude of the reference star, the SNR is then calculated according to the formula below:

$$SNR(t,m) = \frac{n_{\text{cont}} \cdot t \cdot 10^{0.4(m_0 - m)}}{\sqrt{n_{\text{cont}} \cdot t \cdot 10^{0.4(m_0 - m)} + n_{\text{dark}} \cdot t + \frac{p}{f} m \sigma^2_{\text{read}}}},$$

where n_{cont} is the integrated intensity in the space direction of the stellar continuum divided by the exposure time of the reference star, while n_{dark} is the corresponding rate of dark noise accumulating intensity at the respective pixel series.

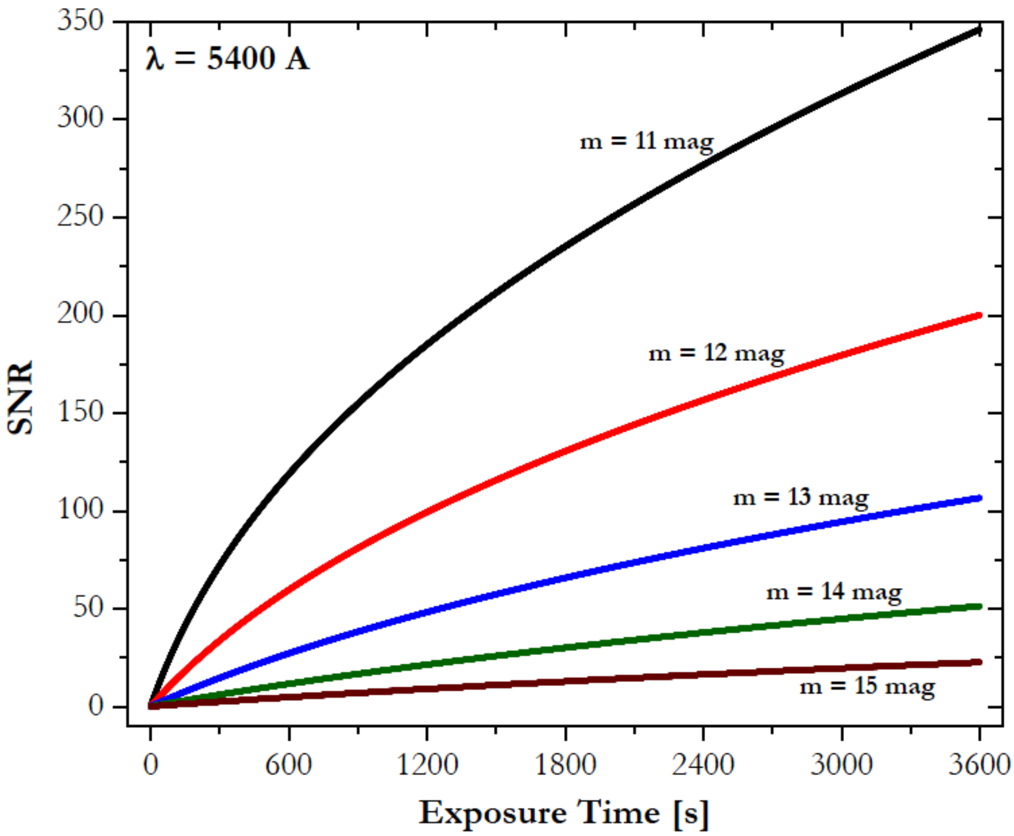


Fig. 33. SNR sensitivity on the brightness and the exposure time. SNR values are depicted for stars lying in the range 11-15 mag and various exposure times less than 1 hr.

HIP 93443 (A4V, m_0 = 6.45 mag) was selected as reference star and the BR grating was set as the working mode; many trial exposures were available at different focal positions and offsets giving the opportunity to choose the one of the highest SNR value. However, this does not exclude the possibility of an even more successful offset, and as a result, the inferred values should be considered as a lower limit of ATS efficiency. The analysis shown that ATS can provide hourly exposure spectra of high quality (SNR > 100) for stars brighter than *m* = 13 mag, while the range 13-15 mag is still considered admissible (SNR > 20). The performance of ATS hardly reaches the SNR = 5 for a star with *m* = 17 mag, suggesting that this magnitude refers to the ATS lower brightness limit (Figs 33 & 34). Note that the sky background was considered negligible and it was omitted from the overall procedure.

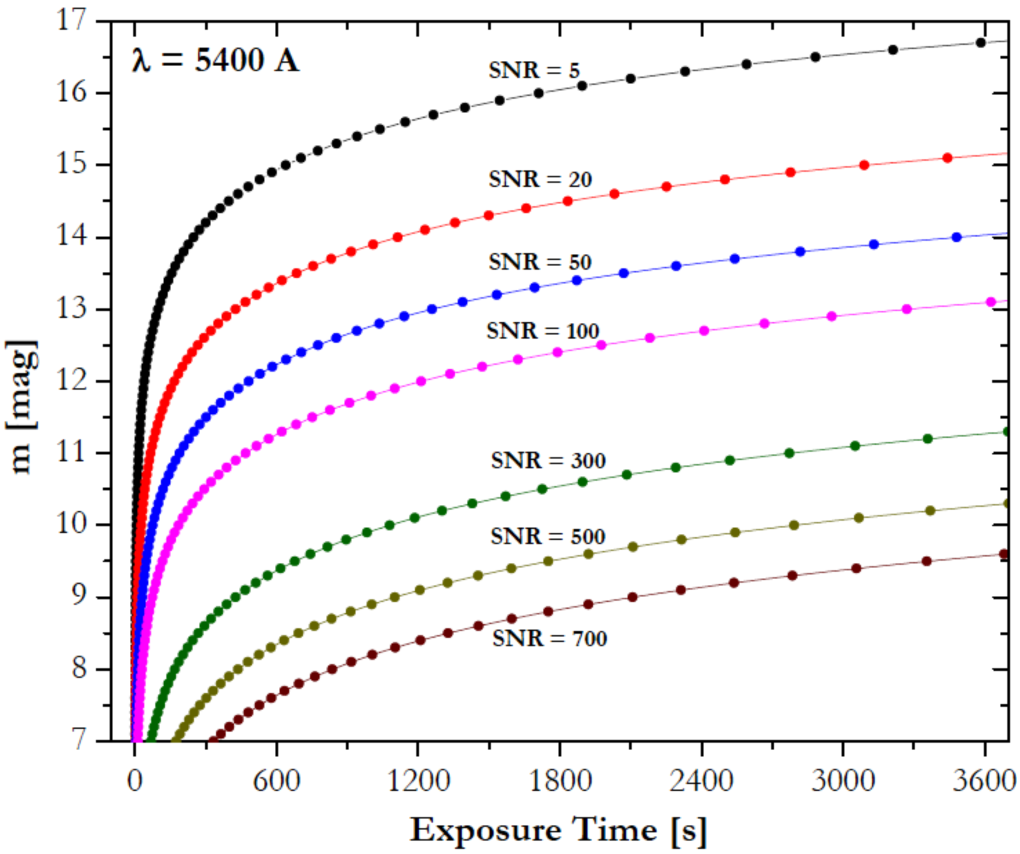


Fig. 34. Magnitude-exposure time curves for a wide SNR range. ATS is inefficient to deal with stars fainter than *m* = 17 mag.

10. Acknowledgements

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11. References

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