NATIONAL OBSERVATORY OF ATHENS

Institute for Astronomy, Astrophysics,
Space Applications and Remote Sensing

HELMOS OBSERVATORY

COOKBOOK

for

Aristarchos Transient Spectrometer

(ATS)

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Contents

1. 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. 1). 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. 2)

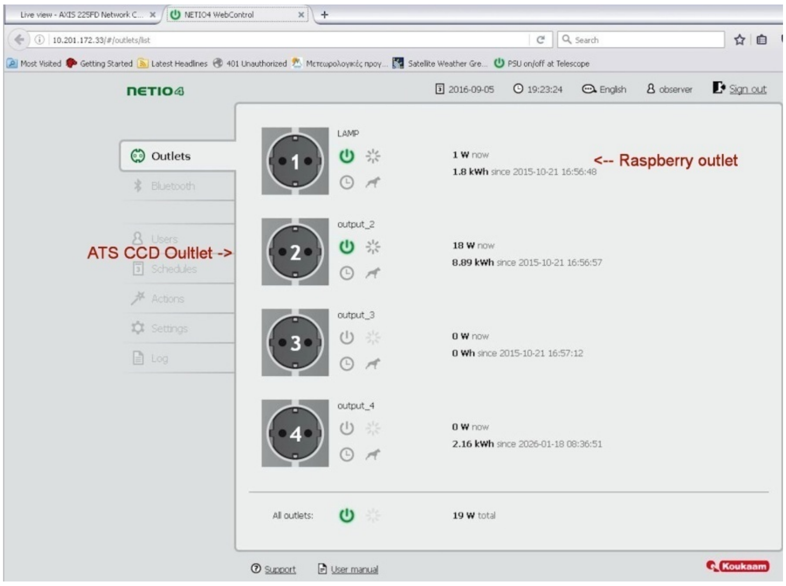


Fig. 1 The Network-multi plug software on the monitor pc

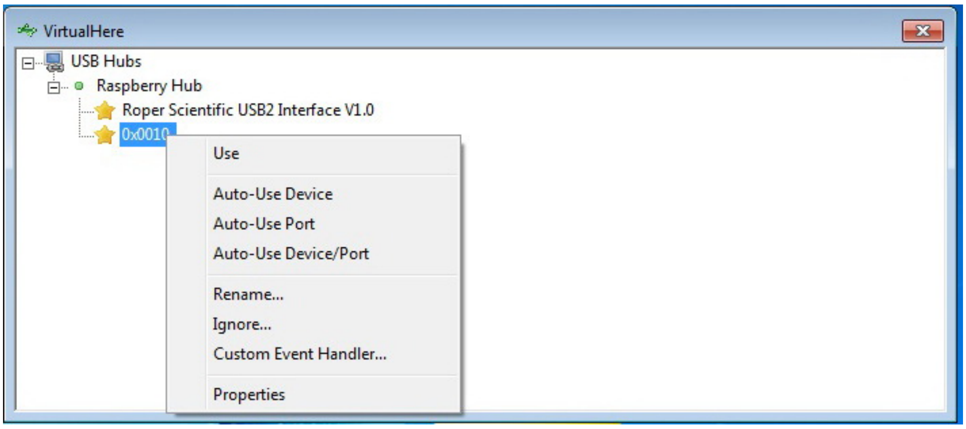


Fig. 2 The raspberry vhui software and the ATS CCD selection

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

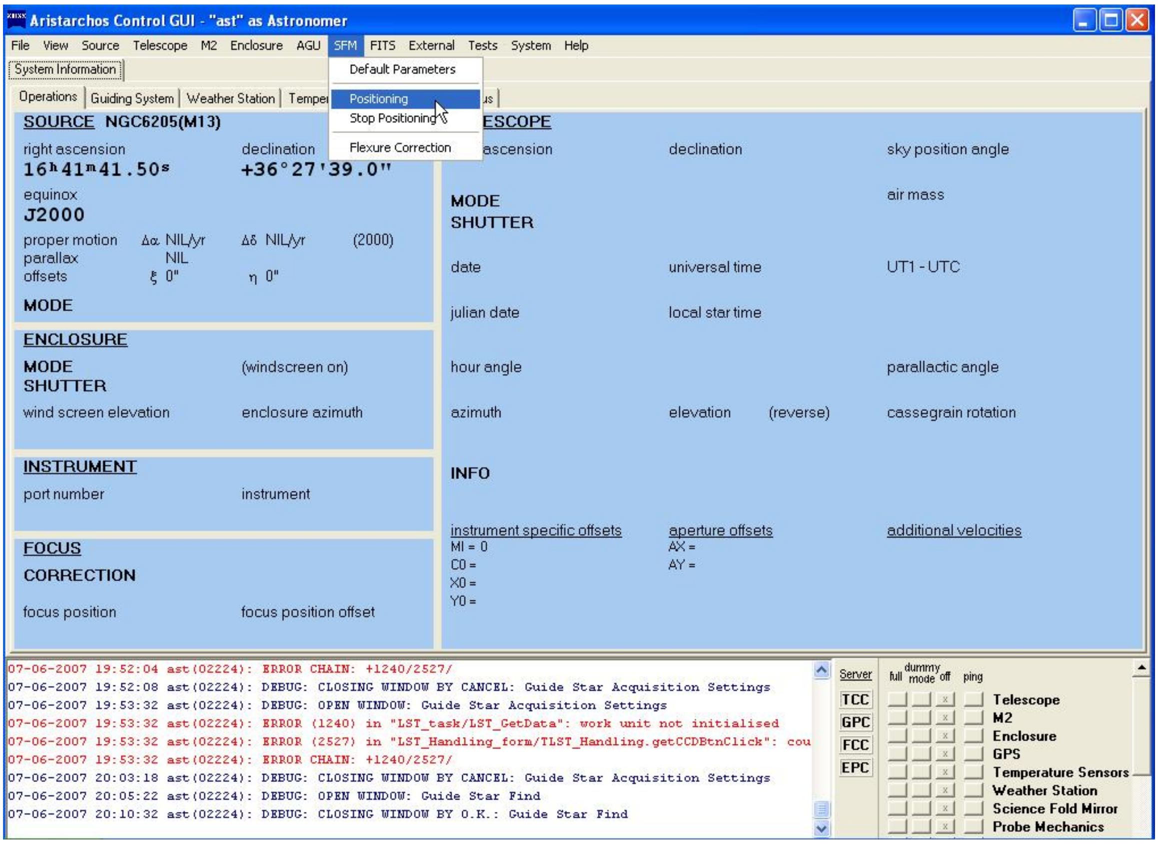


Fig. 3. The telescope operation menu for SFM positioning

Select the **"ATS"** instrument position (Fig.4)

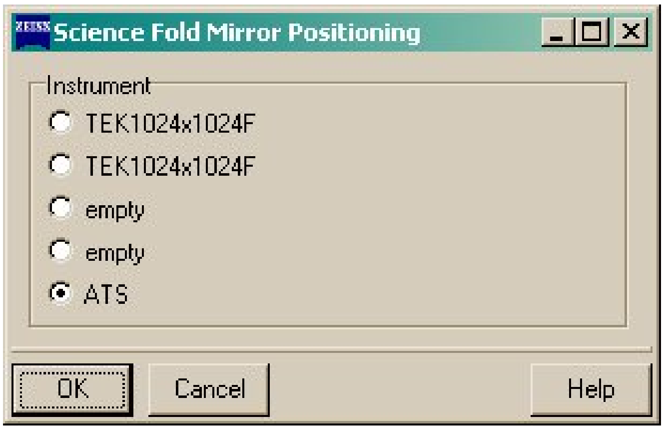


Fig. 4. The SFM positioning of ATS

2. Grating Operation

The systems that are needed in order to operate ATS in full are: (a) the mechanical console, (b) the graphical user interface and (c) the CCD software.

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

2.1 Computer control

All positions are fixed so the user only needs to move to a specific position (grating). 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 the mechanical console to the computer control option (Fig. 5).
3. Turn on the mechanical console (Fig. 5).
4. Open the graphical user interface (grating) by double clicking (Fig. 6).
5. Depending on the grating (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 always that position and the movement. During the movement there is an indication which shows if the movement is forward or reverse (the black circle becomes red).
6. When the led 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.

Fig. 5. The mechanical console of ATS

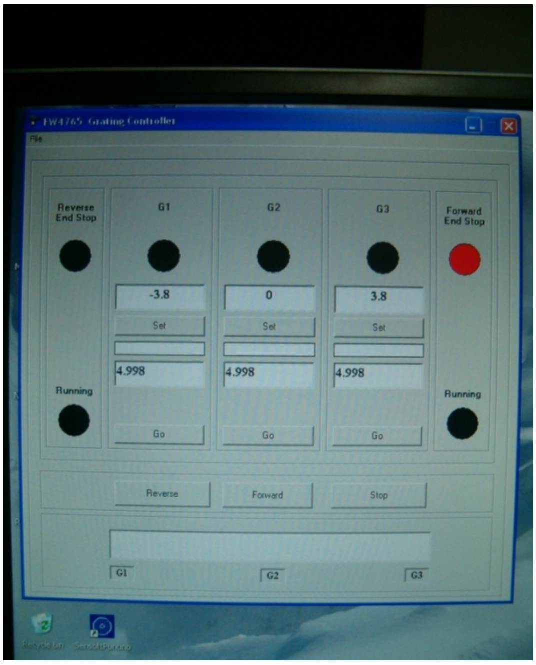


Fig. 6. Graphical user interface to operate ATS

2.2 Manual control

In case of a computer failure, the gratings can be moved and positioned by using the mechanical console (Fig. 7). To do that the user must follow the steps below:

1. Switch to the handset control option on the mechanical console (Fig. 5).
2. Turn on the mechanical console (Fig. 5).
3. Depending on the grating (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 goes to the appropriate position. Then stop pushing 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 at the appropriate position and the instrument is ready for use.

2.3 Explanation of Grating operation

Some explanations concerning the operation of the ATS gratings are given below. 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 front the gratings support on the trail
Stop: Stops the movement of the gratings support on the trail

3. CCD operation (Maxim DL software)

3.1 Exposure

Start Maxim DL and open the Camera Control window by clicking on the  toolbar button (Fig. 7).

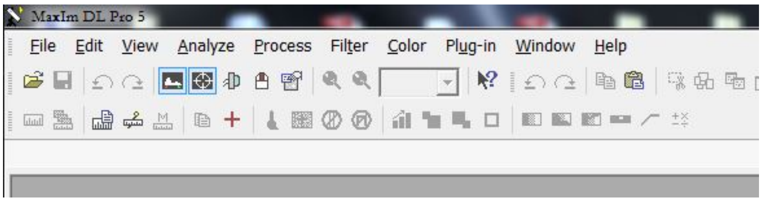


Fig. 7. Start up window of Maxim DL

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. 8).

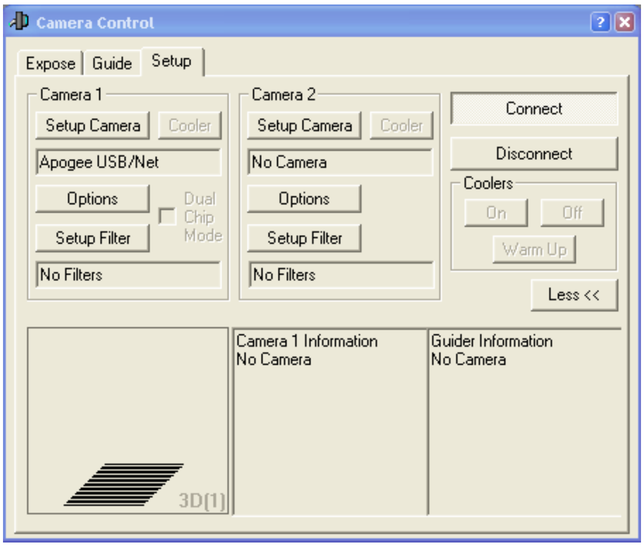


Fig. 8. Camera Control window

Set the Coolers **On** from the respective submenu (Fig. 8 - right side & Fig. 9) to activate the cooling system, and then click the associated **Cooler** button (Fig. 8 - 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. 9. Coolers buttons

Select **Expose** tab (Fig. 10). 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.

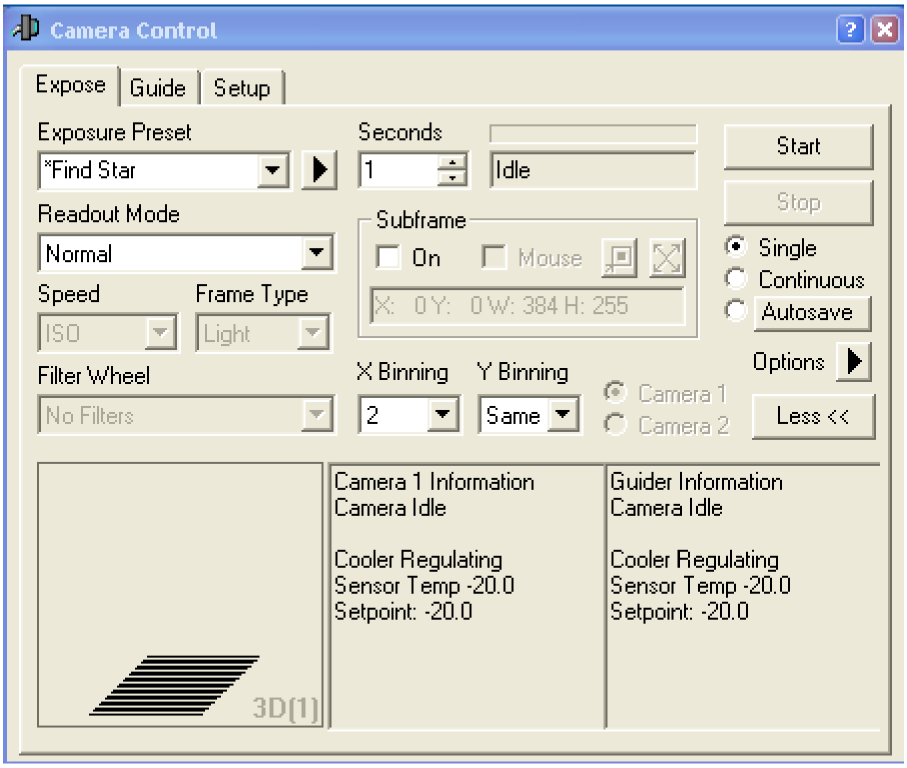


Fig. 10. Expose tab on Camera Control

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. 11). 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. 11). 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.

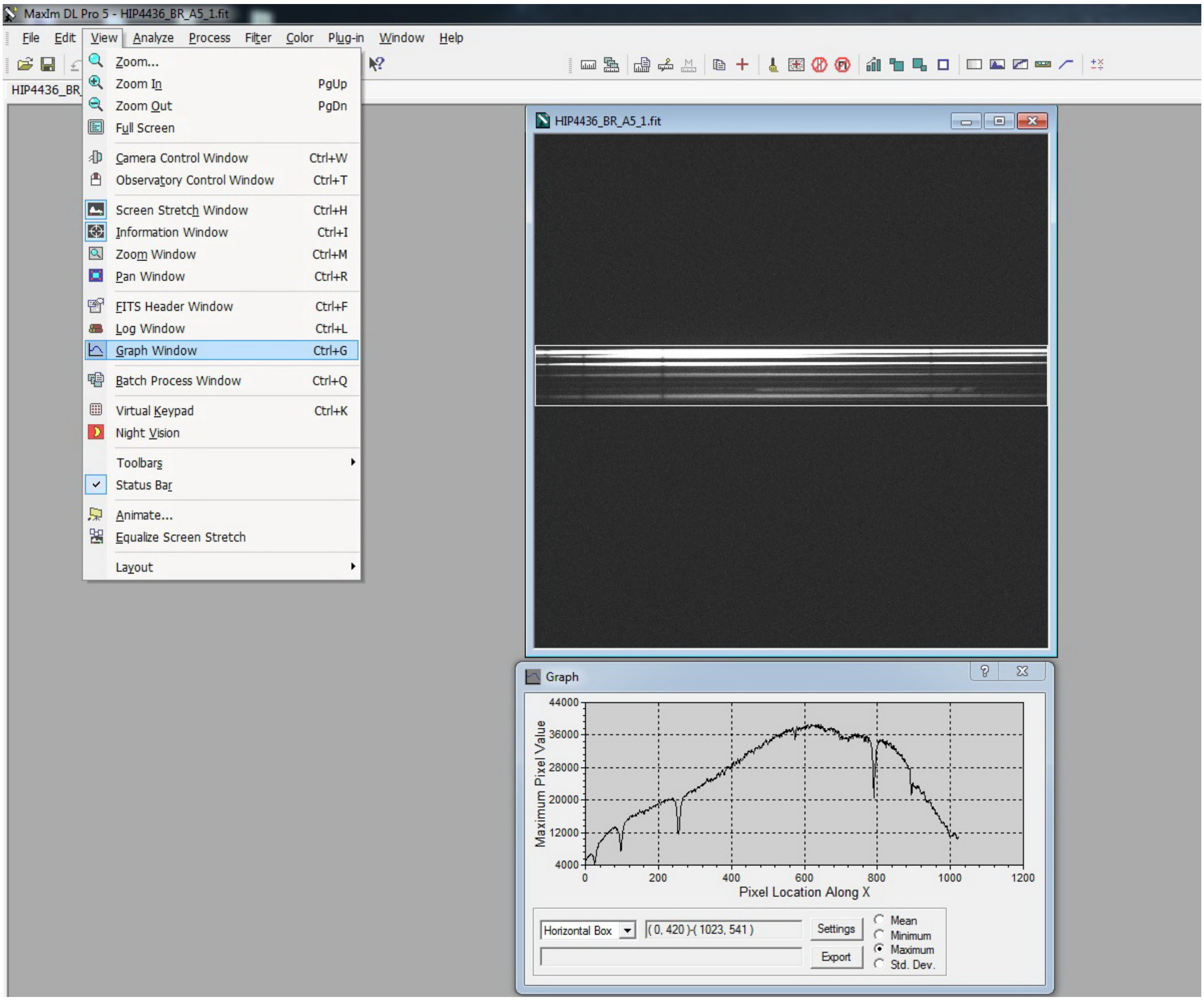


Fig. 11. CCD spectrum image and the graph window

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** (Fig. 9 & Fig. 12). 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.

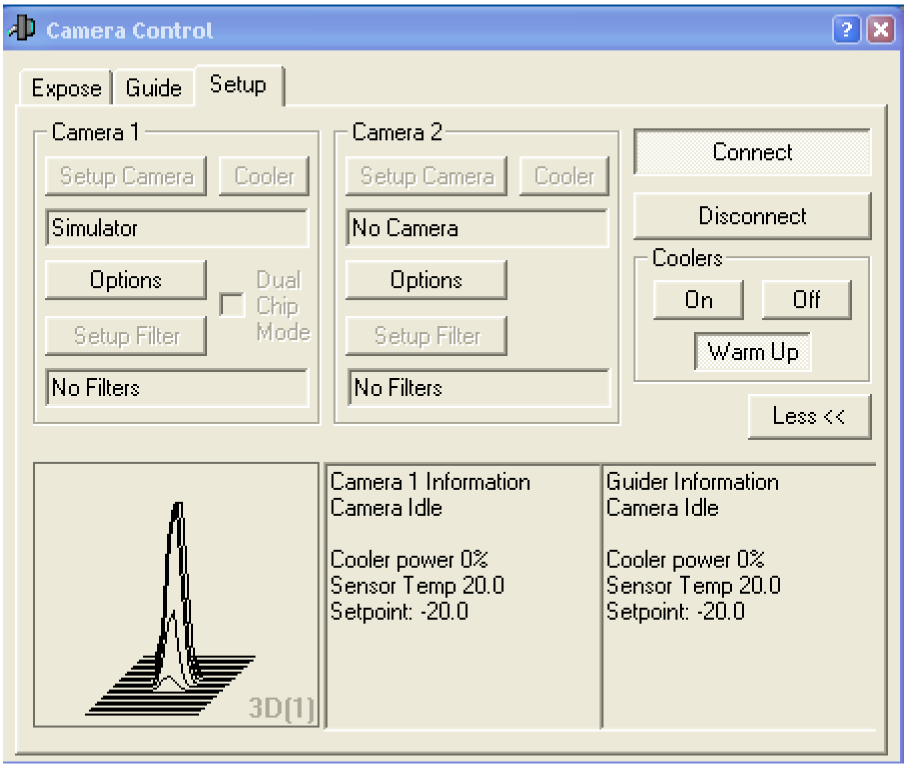


Fig. 12. Warm Up the CCD

3. In the raspberry vhui software, right click on the "0x0010" and select "stop using this device" (Fig. 2).
4. In the monitor pc, and in the IP-multi plug software turn off the outlet number 2 (Fig. 1).

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:

4.1 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. 13)

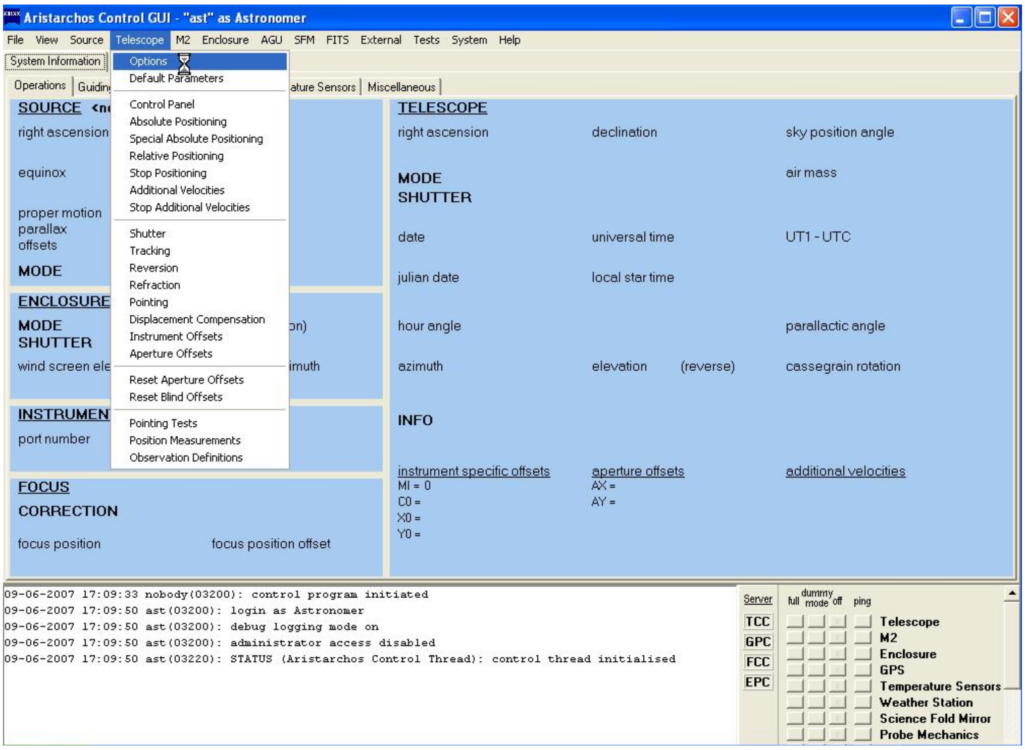


Fig. 13. The telescope operation menu for telescope options

2. Select the **"instrument offsets"** menu (Fig. 14).
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).

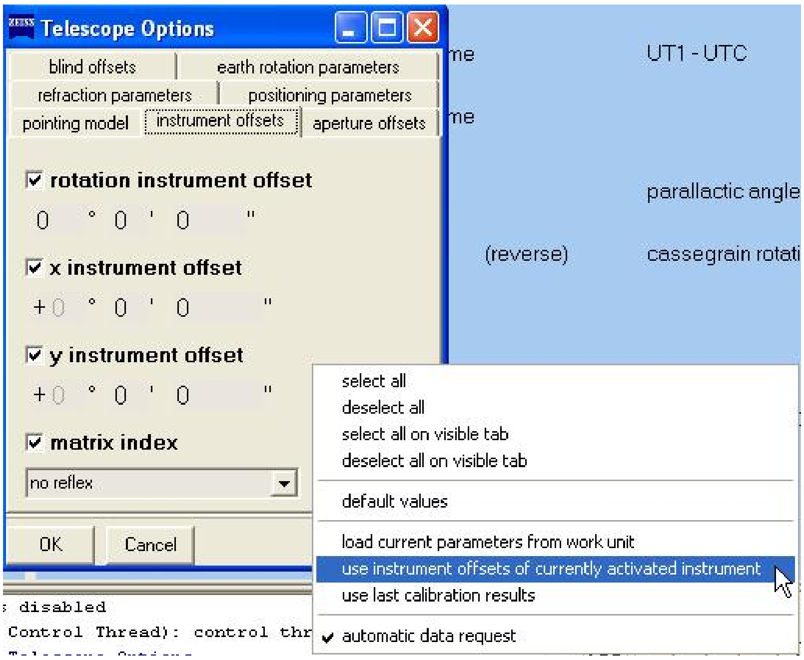


Fig. 14. The instrument offsets menu

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

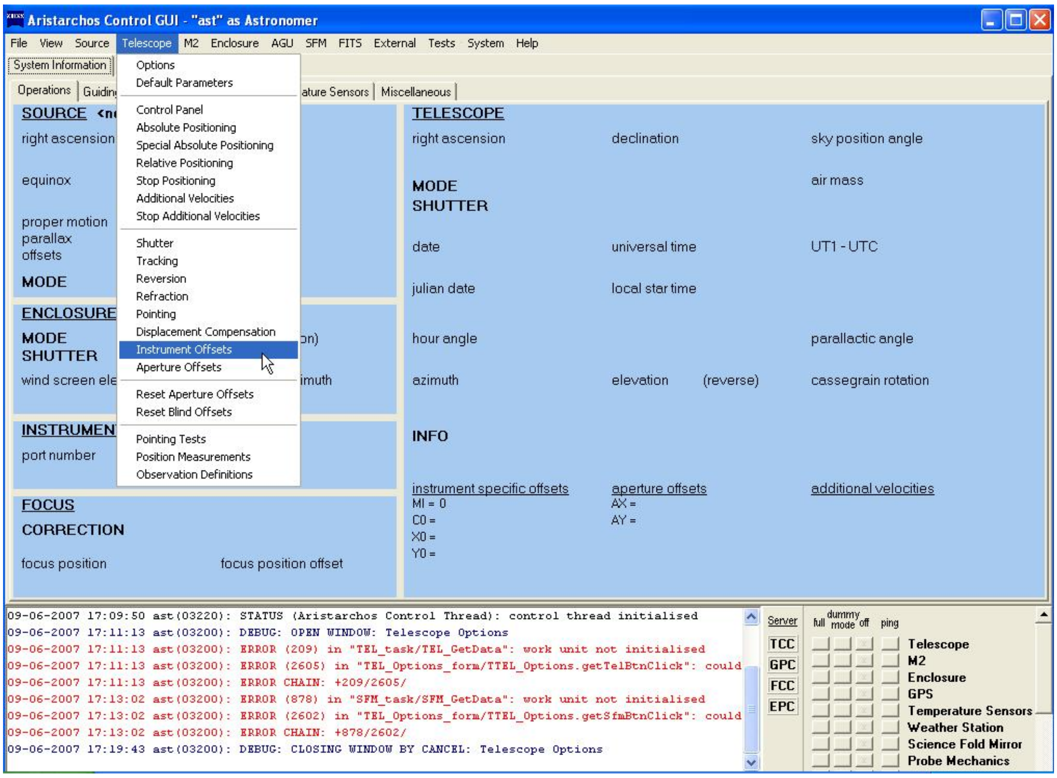


Fig. 15. The telescope operation menu for instrument offsets

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

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. 10), 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 4.1.

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 4.1). 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).

4.3 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 4.2. If not, you can skip this section. If this is the case, then use the offsets you found in the step 2 of section 4.2 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 4.2) and the target. Once the telescope reaches the target:

1. In the MaximDL (Fig. 10), 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 4.2. 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. 10). 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 3.2,
2. Turn off the mechanical console,
3. Close down the graphical user interface,
4. Turn off the ATS computer.

6. 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.

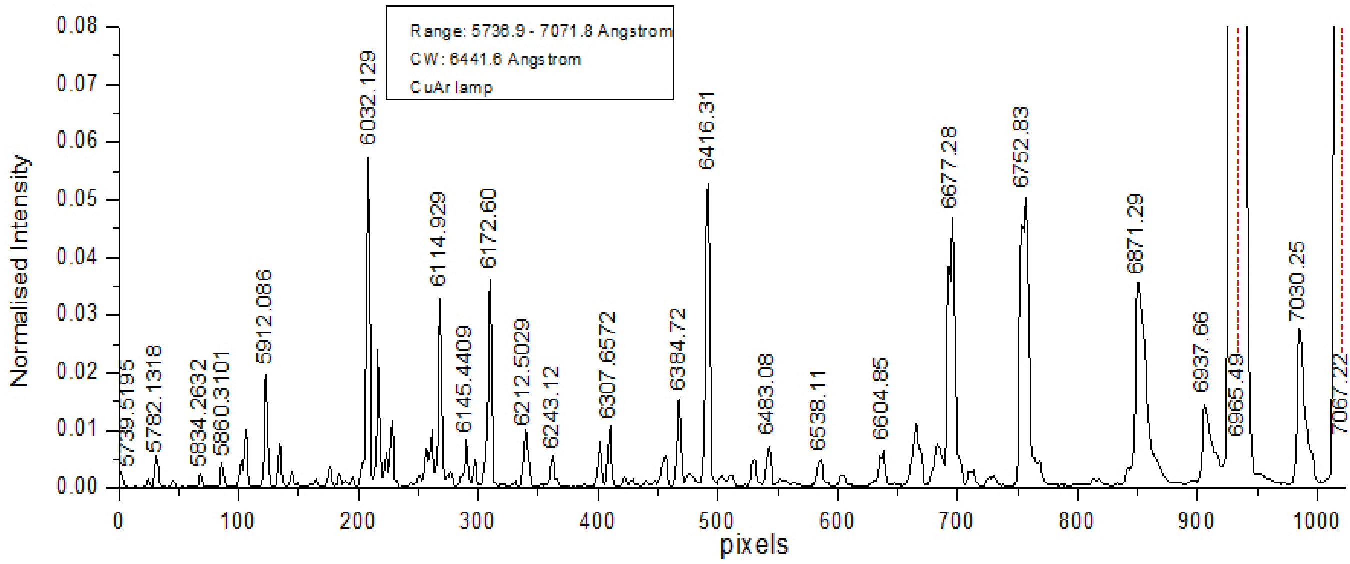


Fig. 16. Arc for the Red 1200 groove/mm grating centered on 6441.6 Å.

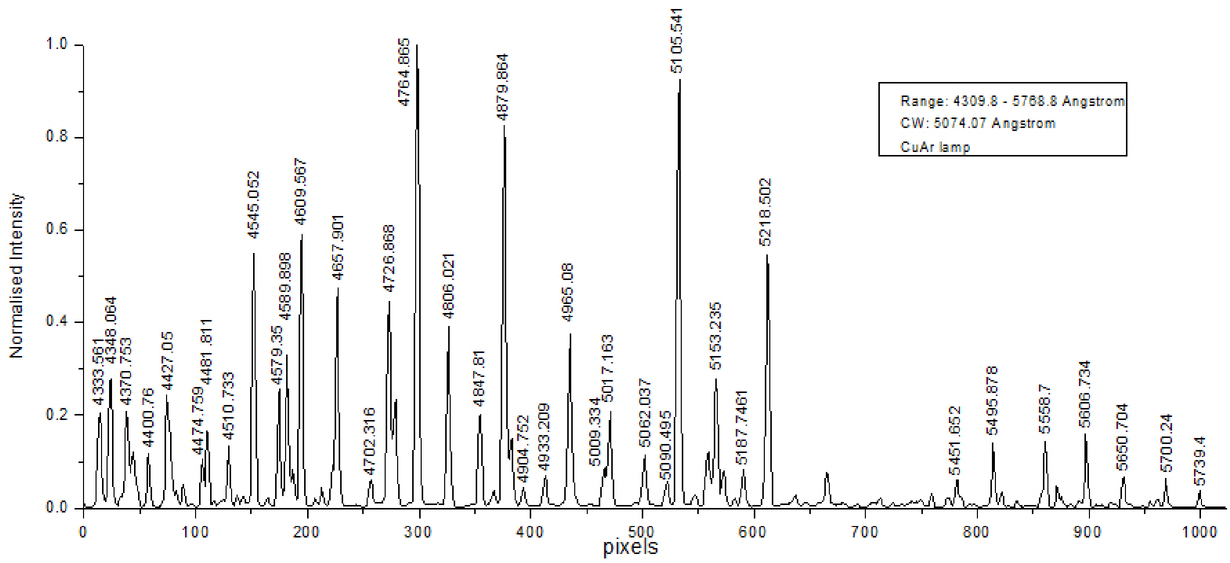


Fig. 17. Arc for the Blue 1200 groove/mm grating centered on 5074.1 Å.

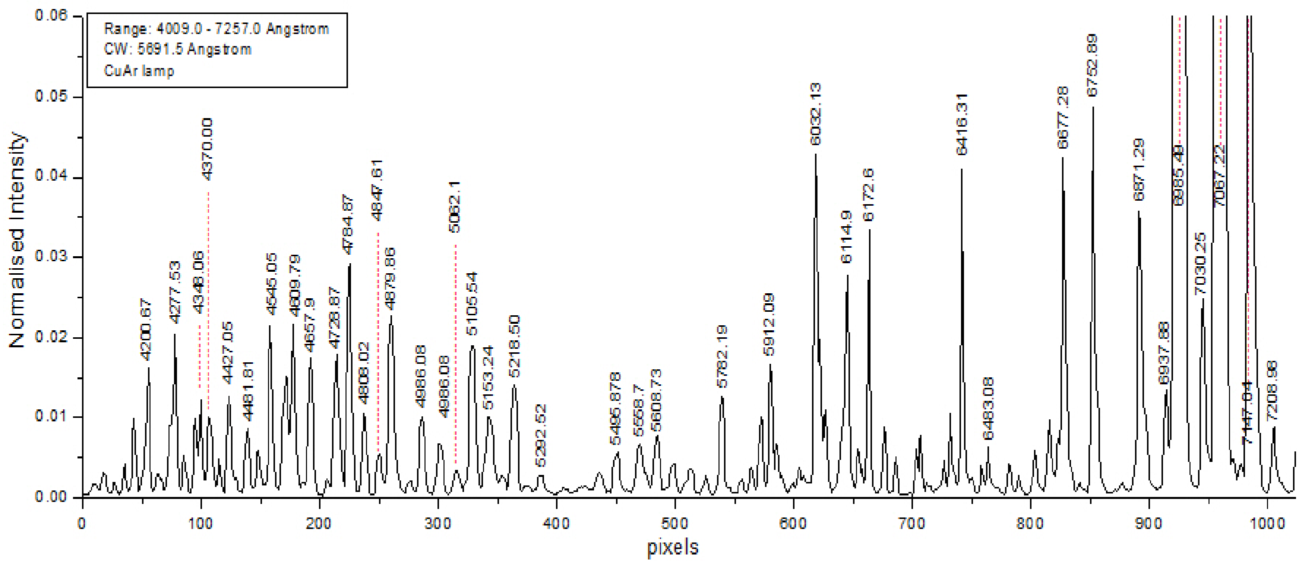


Fig. 18. Arc for the 600 g/mm grating centered on 5691.5 Å.

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

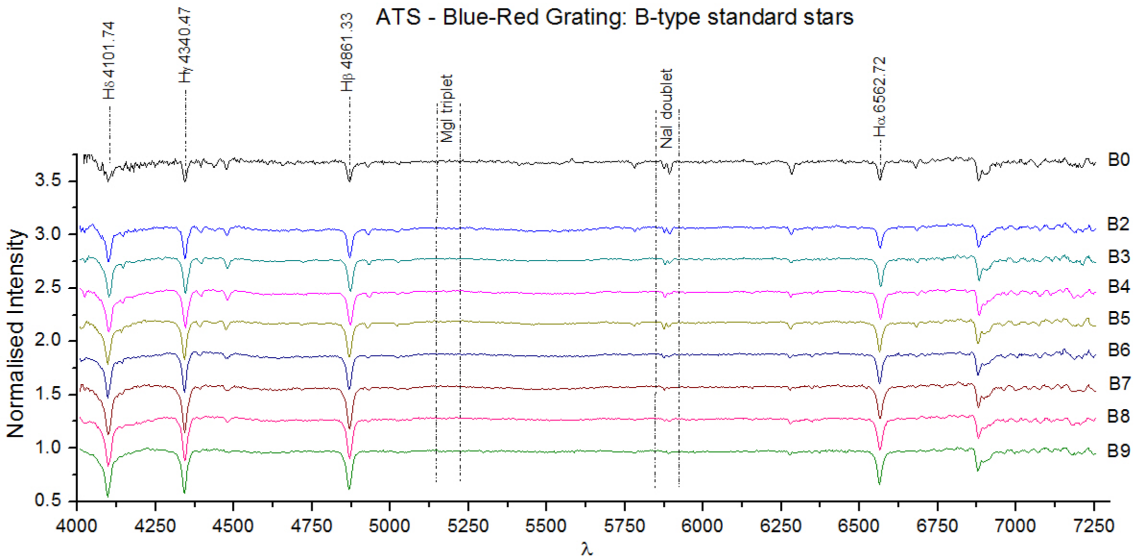
$\lambda = \lambda_0 + A*px + B*px^2 + C*px^3 + D*px^4 + E*px^5$

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

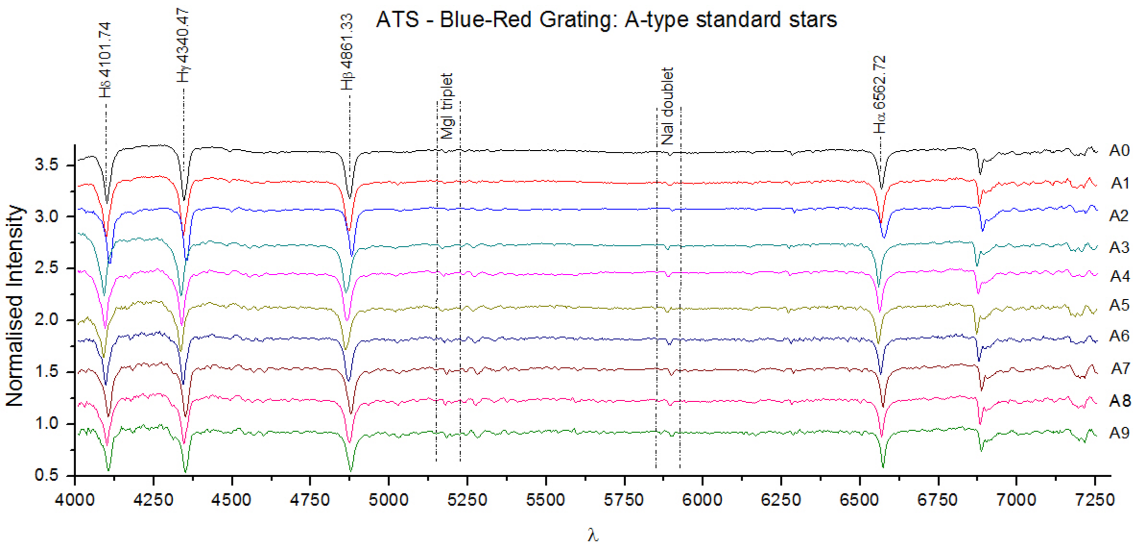
	Red grating		Blue grating		Blue-red grating	
	Value	error	Value	error	Value	error
λ_0	5736.877	0.87784	4309.794	0.47064	4008.963	11.76908
A	1.43924	0.01373	1.55323	0.0045	3.42126	0.19224
B	-1.05E-04	5.81E-05	-1.07E-04	1.13E-05	-9.69E-05	0.00104
C	-3.27E-08	8.74E-08	-1.71E-08	7.63E-09	-7.99E-07	2.39E-06
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

7. Standard stars

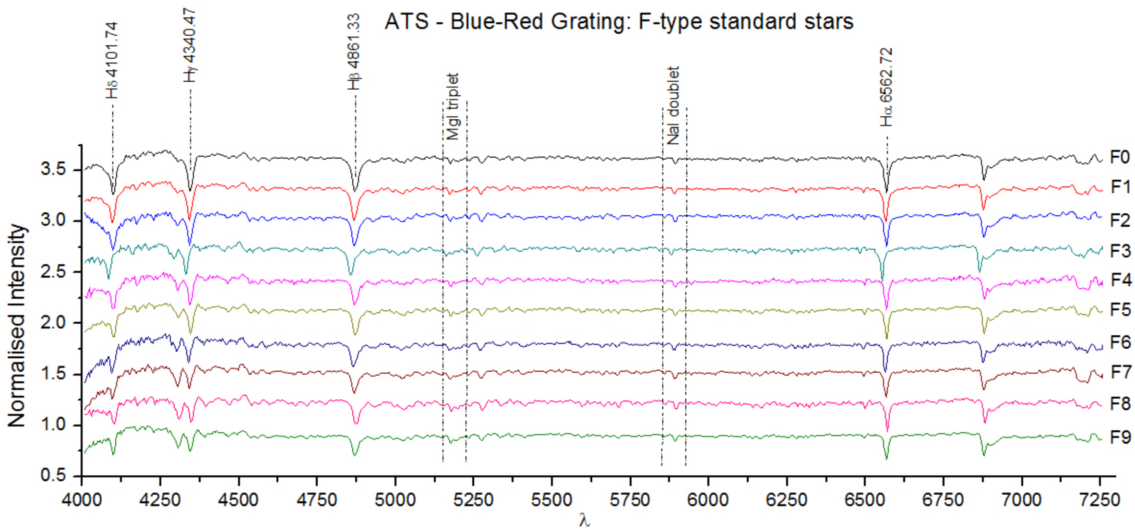
In the following plots are shown the spectra of standard stars (luminosity class – V) taken with the ATS using all gratings. A few famous stellar spectral lines (e.g. Balmer lines, MgI, NaI) are also indicated.



(a)



(b)



(c)

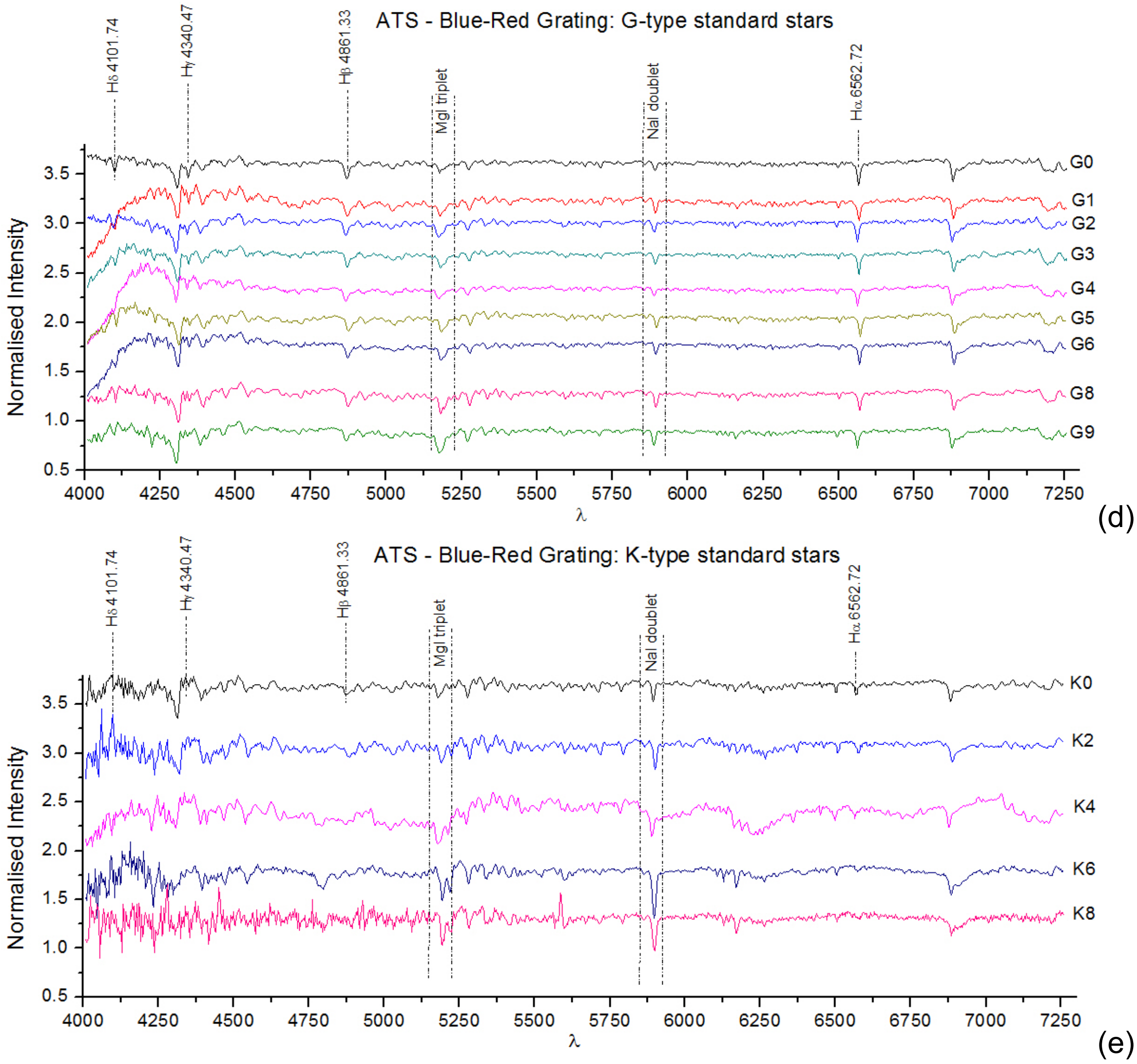
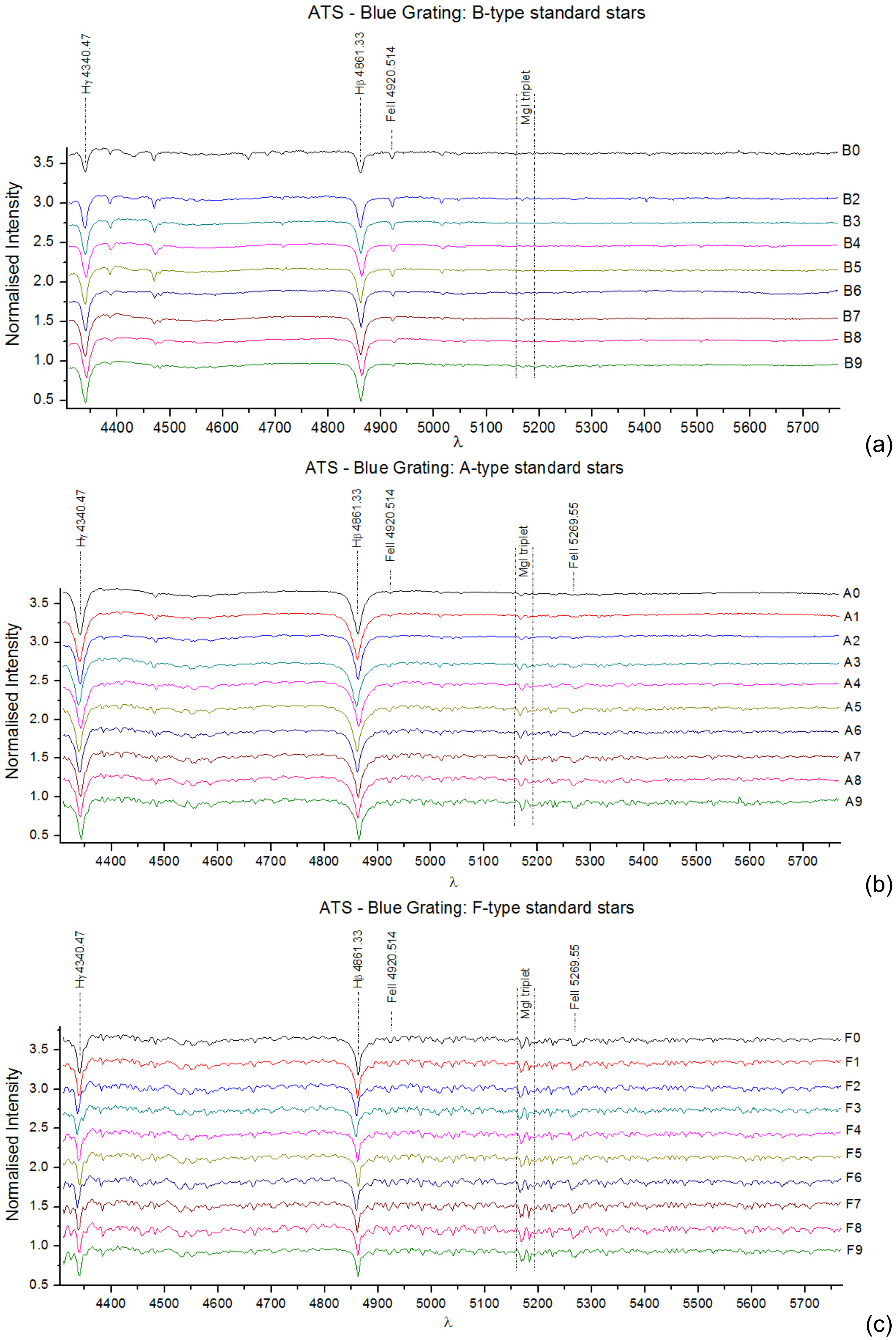
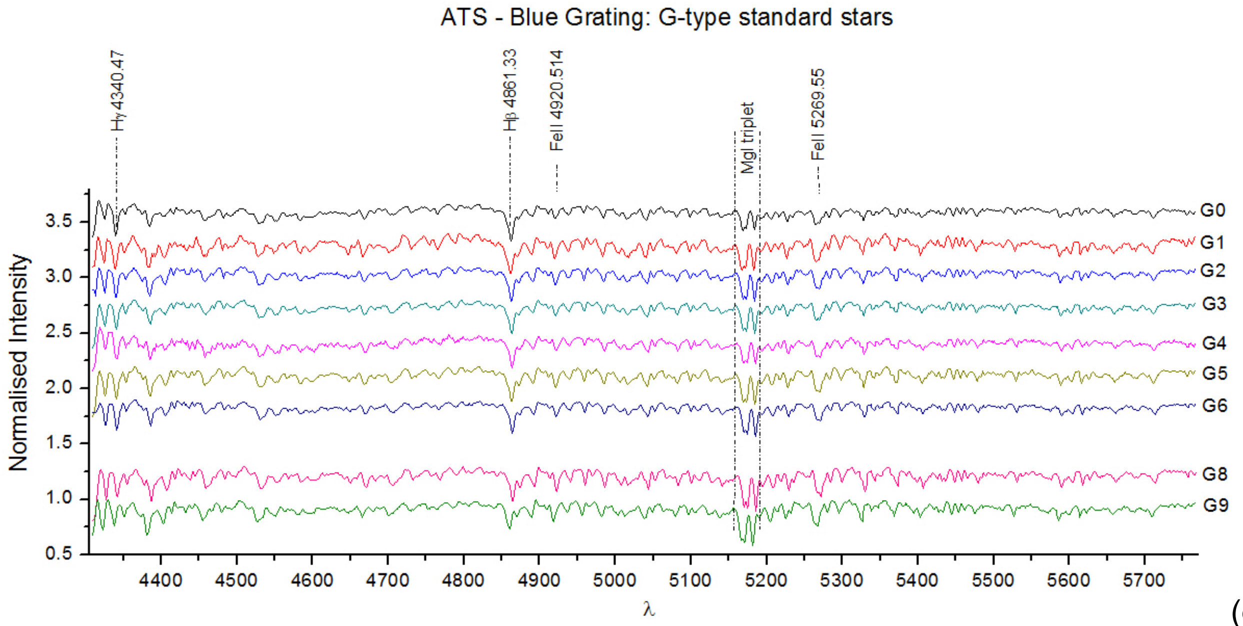
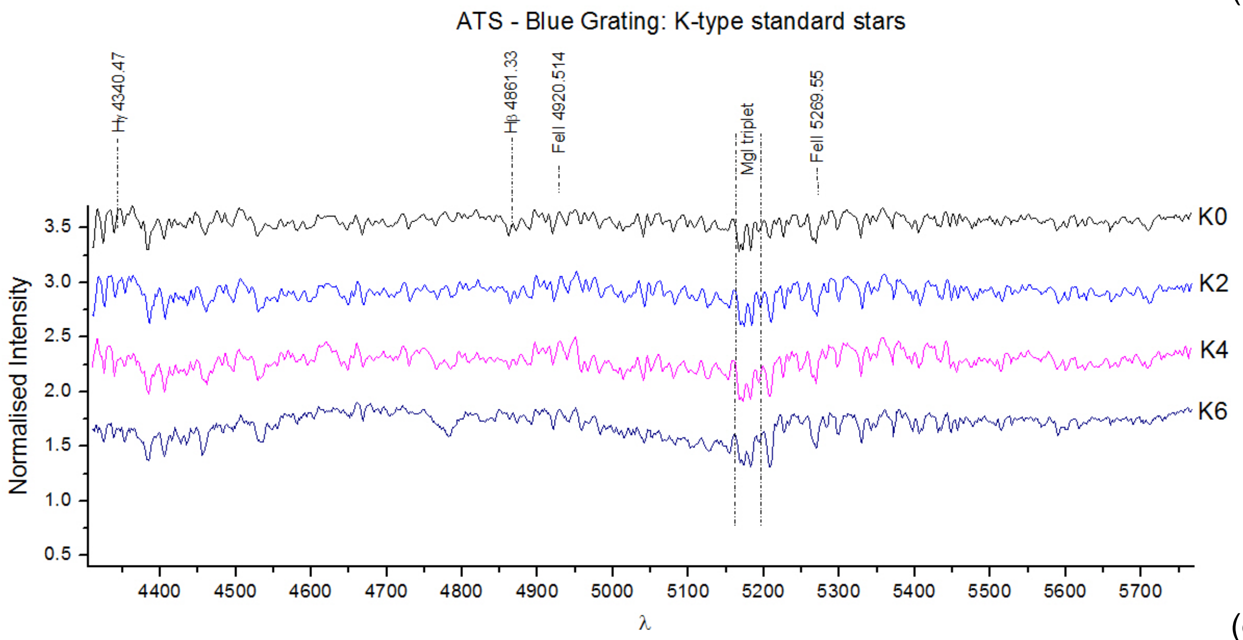


Fig. 19. Spectra of standard stars of: (a) B-type, (b) A-type, (c) F-type, (d) G-type, and (e) K-type obtained with the ATS using the Blue-Red Grating.


ATS - Blue Grating: B-type standard stars
Hγ 4340.47
Hβ 4861.33
FeII 4920.514
MgI triplet
B0
B2
B3
B4
B5
B6
B7
B8
B9
Normalised Intensity
λ
(a)
ATS - Blue Grating: A-type standard stars
Hγ 4340.47
Hβ 4861.33
FeII 4920.514
MgI triplet
FeII 5269.55
A0
A1
A2
A3
A4
A5
A6
A7
A8
A9
Normalised Intensity
λ
(b)
ATS - Blue Grating: F-type standard stars
Hγ 4340.47
Hβ 4861.33
FeII 4920.514
MgI triplet
FeII 5269.55
F0
F1
F2
F3
F4
F5
F6
F7
F8
F9
Normalised Intensity
λ
(c)

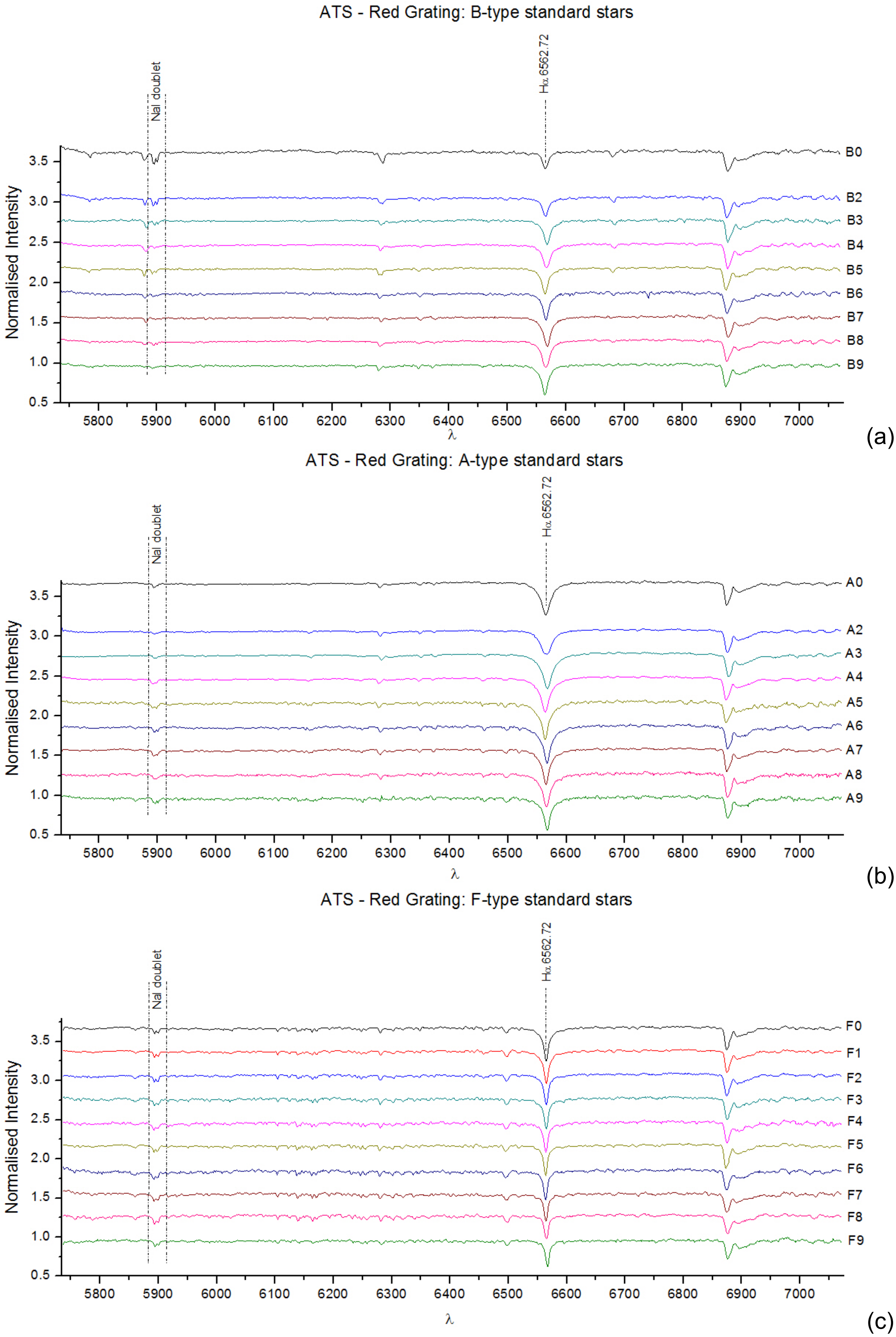


(d)



(e)

Fig. 20. 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)

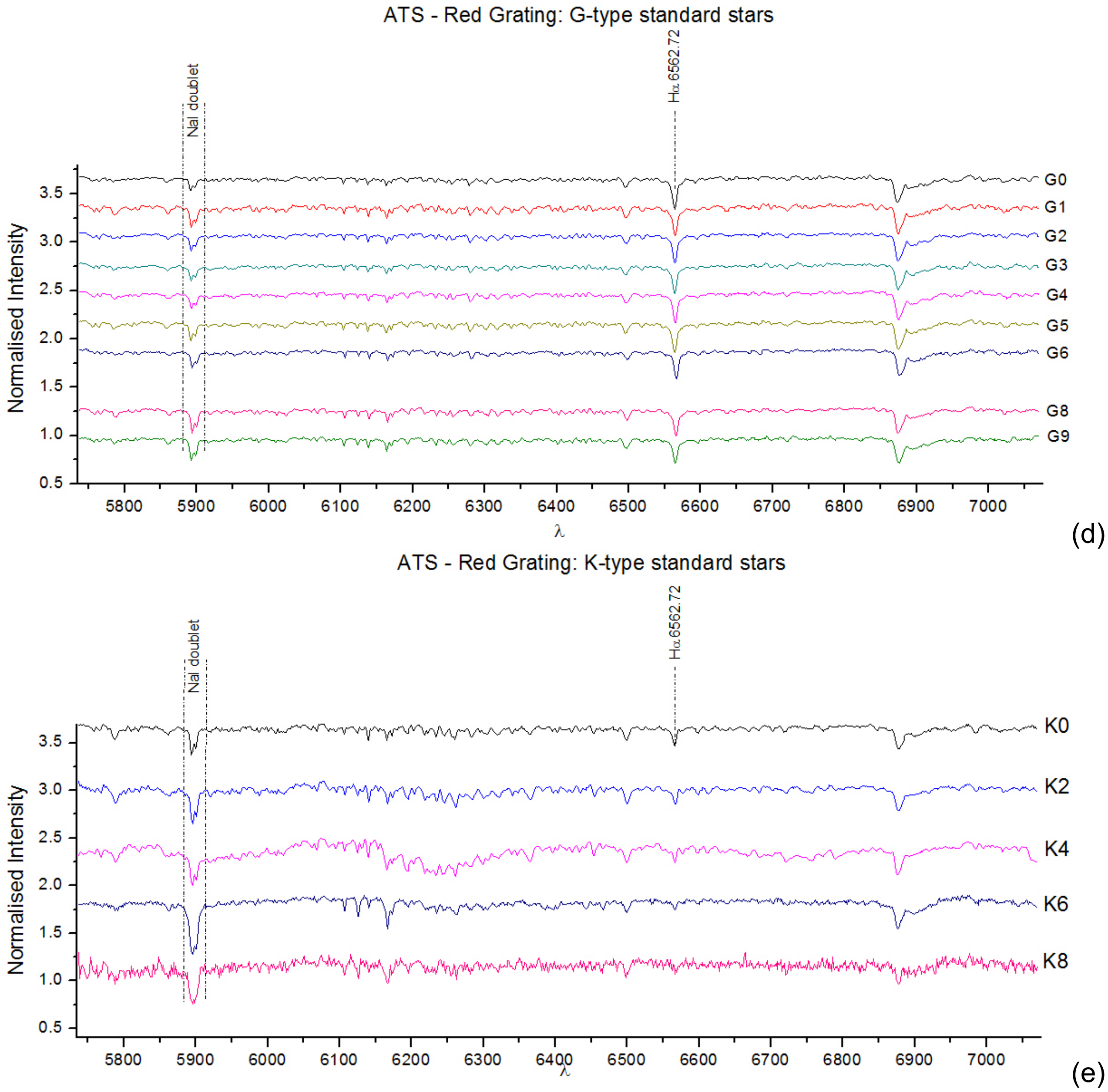


Fig. 21. Spectra of standard stars of: (a) B-type, (b) A-type, (c) F-type, (d) G-type, and (e) K-type obtained with the ATS using the Red Grating.

8. 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 three factors: (*a*) the spectral range, as provided in the three available gratings (BR, B, and R), (*b*) the exposure time, and (*c*) the apparent magnitude of a specific star.

▪ **Estimating the ATS performance among the three available gratings**

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:

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

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.

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. 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 (Fig. 22).

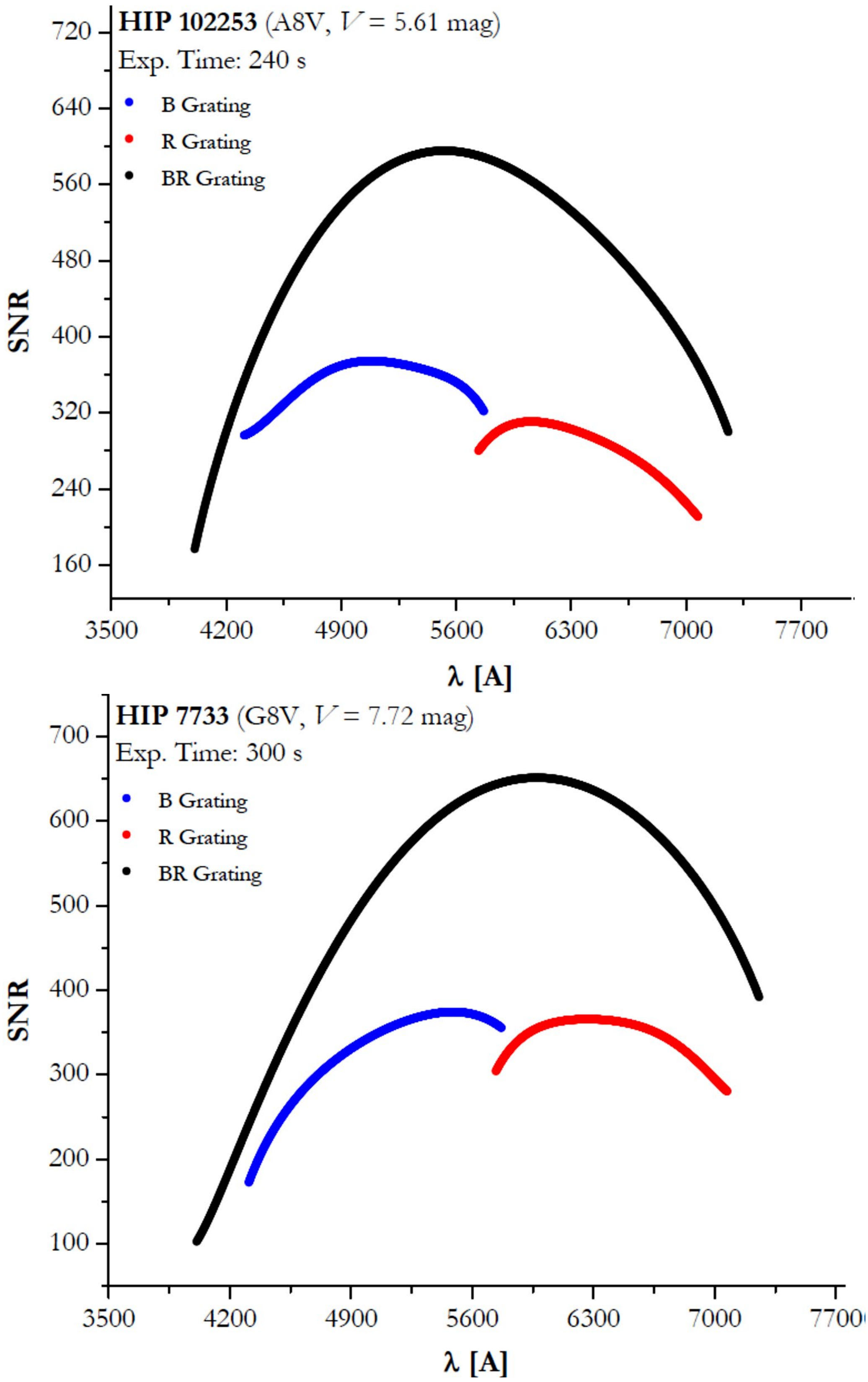


Fig. 22. SNR sensitivity on the spectral range. SNR values are depicted for a A8V (upper) and a G8V (lower) standard star.

▪ **Estimating the ATS performance among various exposure times and stellar magnitudes**

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:

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

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.

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 (Fig. 23). Note that the sky background was considered negligible and it was omitted from the overall procedure.

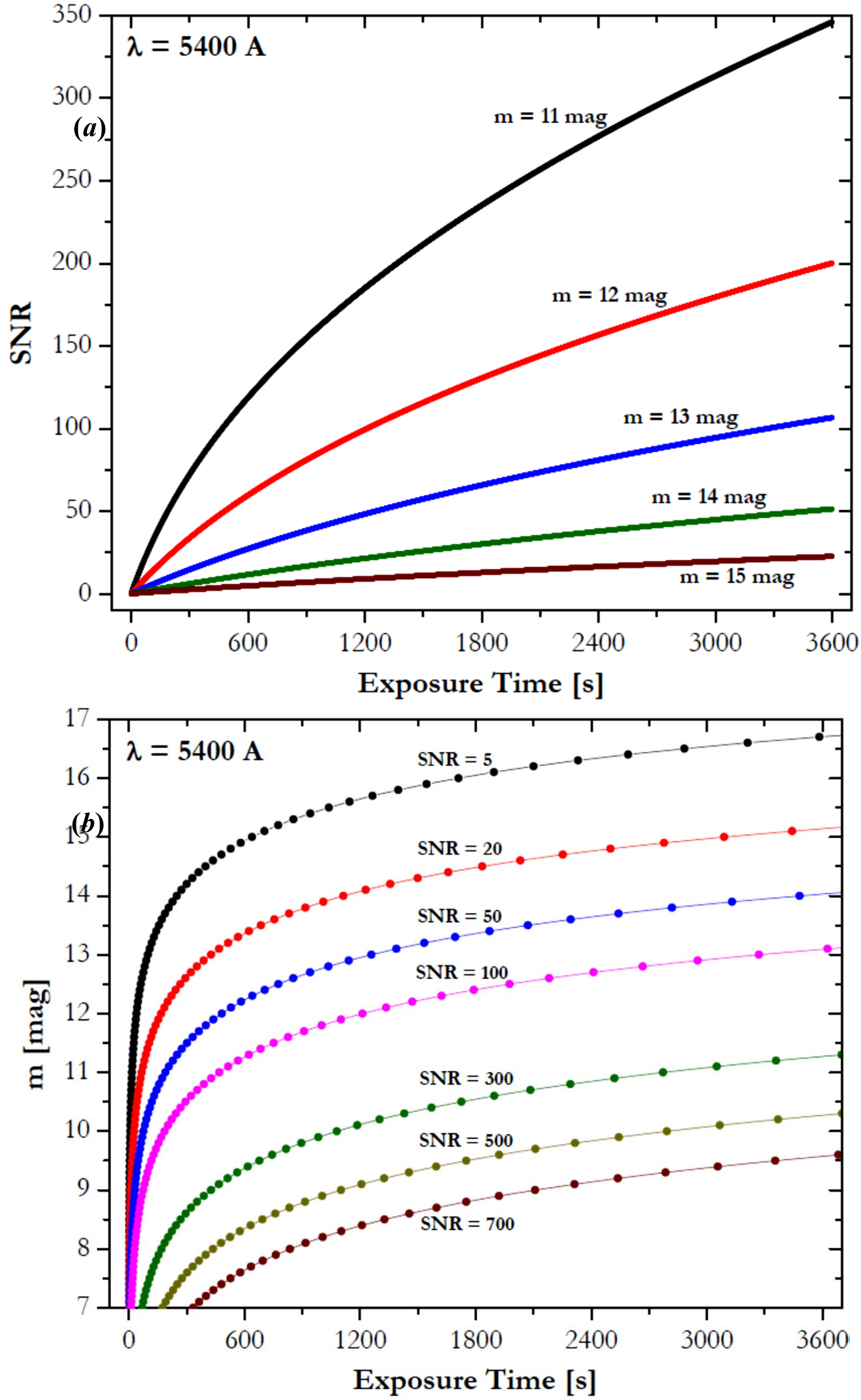


Fig. 23. SNR sensitivity on the stellar brightness and the exposure time (upper). SNR values are depicted for stars lying in the range 11-15 mag and various exposure times less than 1 hr. Magnitude-exposure time curves for a wide SNR range are also displayed (lower). ATS is inefficient to deal with stars fainter than m = 17 mag.