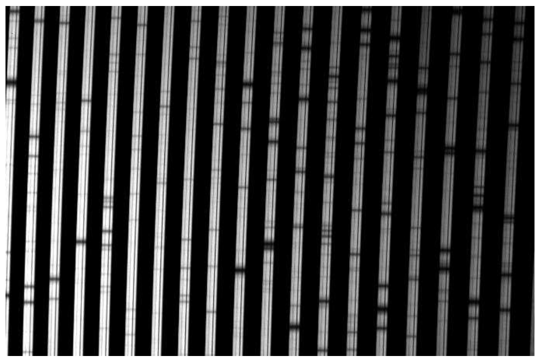
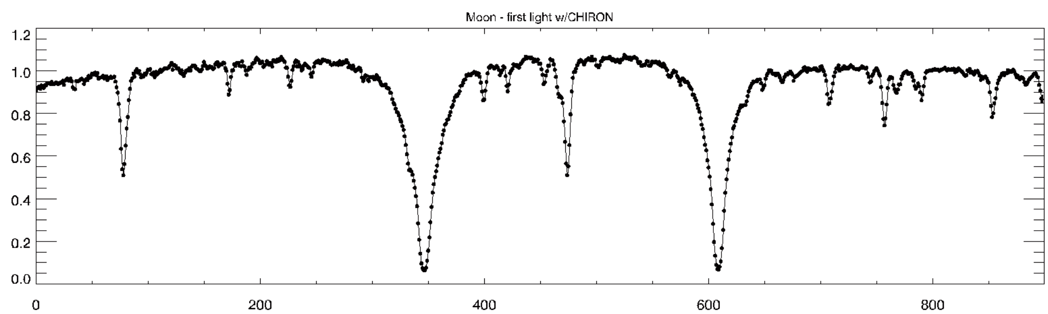
Cerro Tololo Inter-American Observatory

CHIRON manual





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1 Overview

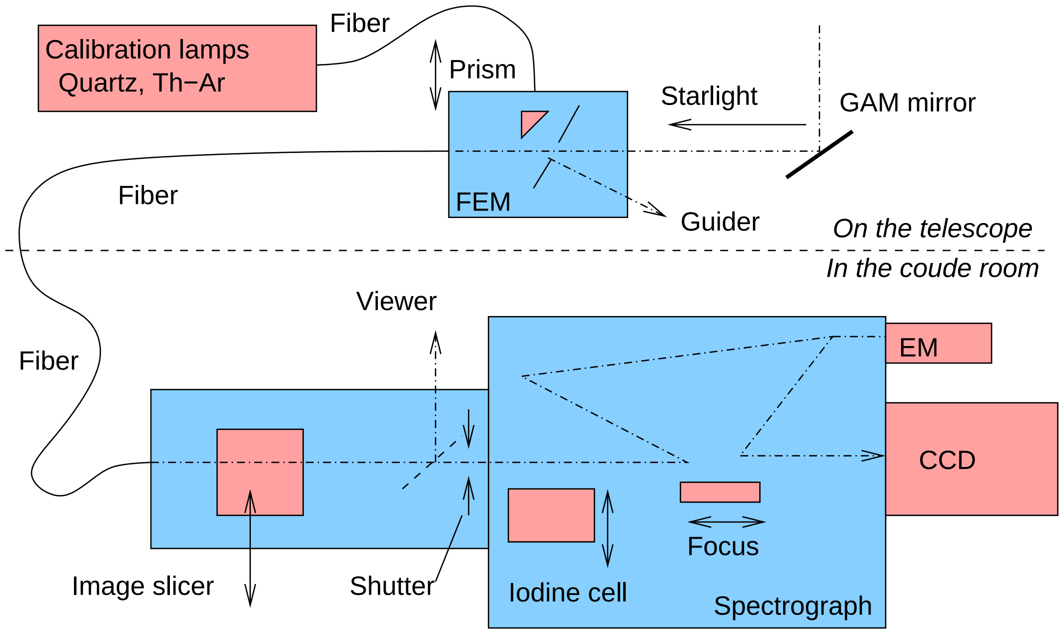

Figure 1: Light path in CHIRON, from the telescope to the CCD. Elements under user control are pink-colored.

CHIRON is a high-resolution fiber-fed echelle spectrometer installed at the CTIO 1.5-m telescope. It can record multi-order echelle spectra of single objects (stars) with spectral resolution up to $R = 80\,000$, 3 pixels per resolution element. The spectral format on the detector is fixed, covering the wavelength range from 4150Å to 8800Å without gaps.

Figure 1 shows main elements of CHIRON from the user perspective. We follow the path of starlight, directed towards the fiber module (FEM) by a diagonal mirror located in the telescope GAM (at certain position of the pickup arm). The star image is focused on a mirror with a hole; most of the light goes into the fiber, the remaining halo is reflected towards the acquisition/guiding camera. A small prism can be placed behind the mirror to feed calibration light (quartz or Th-Ar lamps) to the spectrometer.

The spectrometer is located in the coude room. The light beam emerging from the fiber can be re-shaped into a slit-like image by the *image slicer*, to increase spectral resolution without light loss. The slicer can be moved out of the way to work with bare fiber image (with spectral resolution decreased to $R \approx 30\,000$) or to mask the fiber by slits (increase the resolution at the expense of light loss). A viewer with manually-activated mirror is used only for troubleshooting, to see the sliced image. Other user-controlled elements are the shutter, iodine cell which can be placed in or out of the beam, and the focusing stage. The CCD is operated by a GUI-driven data-acquisition program. About 1% of light is sent to the exposute-meter (EM).

CHIRON is designed to be very stable, its internal environment is maintained at constant temperature. Opening the spectrometer, any other intervention or manipulation are **strictly prohibited.**

Table 1: CHIRON parameters

Slicer	**Iodine cell**	**CCD**
Slicer ($R = 80\,000$)	IN	Normal/Fast readout
Fiber ($R = 30\,000$)	OUT	Binning HxV
Slits (wide, narrow)		

To specify observations, astronomer needs to decide whether the image slicer is needed, whether the iodine cell should be used, and what detector parameters are best suited for the program. Although these choices can be made in any combination, only a subset of all combinations makes sense. Two observing modes suitable for typical science applications are defined in Table 2. Each program must also specify required calibration data (Th-Ar and quartz spectra, bias frames, etc.).

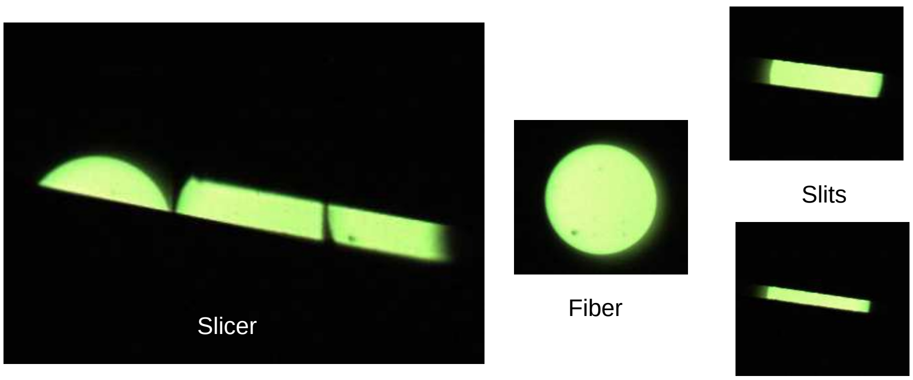

Figure 2: Images of the “slit” as seen through the viewer, with fiber illuminated by the quartz lamp. The position of the translation stage defines whether the fiber image is “sliced”, transmitted unchanged or masked by the slits. The slits are not normally used for observations, unless the star is very bright; $R = 120\,000$ can be reached with the narrow slit.

Table 2: Basic observing modes

Mode	Slicer	Binning HxV, speed
Normal	Slicer	3x1, normal
Fiber	Fiber	4x4, normal

2 How to use CHIRON

2.1 CCD parameters

The CCD detector is a e2v device with 4096(H)x4112(V) square pixels of 15-micron size, with graded coating. It lives in a dewar cooled by liquid nitrogen, with the Torrent controller. Four quadrants of the detector are read with different amplifiers. The gain and readout noise in normal readout mode are listed in Table 3. Part of the readout noise is a quasi-periodic pick-up sugnal that causes characteristic "fringes" in the bias and dark frames.

Table 3: Readout modes and detector parameters

Mode, binning	Readout time, s	Lower-left (0)		Lower-right (1)		Upper-left (2)		Upper-right (3)	
		RON, el	Gain el/ADU	RON el	Gain el/ADU	RON, el	Gain el/ADU	RON el	Gain el/ADU
Normal, 1x1	38	5.4	1.30	5.5	1.250	5.4	1.264	5.7	1.257
Fast, 1x1	18	12.8	5.684	19.0	5.454	11.3	5.520	12.2	5.470

In CHIRON, most observations are done with 3x1 and 4x4 binning in the full-frame normal mode, with readout time of 18 s and 5 s respectively. The fast readout mode is not used so far.

The detector response in normal readout mode is linear to better than 0.5% in the full 16-bit dynamic range (65535 ADU). In the fast mode, the linearity extends to 15 000 ADU.

Echelle dispersion is directed along the columns (vertically), cross-dispersion along the lines. The charge transfer efficiency is very good, better than $1 - 1.1 \cdot 10^{-5}$ per pixel in the line and column directions. The CCD has minor cosmetic defects. In the left side, there is a charge trap at X=566,567 and Y=3414 (pixel count in the trimmed image), making for two bad columns. In the right half, the most prominent defect is a charge trap at X=2305,2306 and Y=2460 which leaves a dark tail in those two columns below the trap. The tail extends for about 1000 pixels, then disappears. There are few localized detector blemishes and/or dust particles.

2.2 Exposure-time calculator

Calculation of the sigmal-to-noise ratio per pixel is based on the following formula:

$$S/N = N_{ph}/\sqrt{N_{ph} + KR^2} \tag{1}$$

where N_{ph} is the number of stellar photons per spectral pixel collected during the exposure time, $R = 5.5$ is the CCD readout noise in electrons, K is the number of binned pixels across the order. In the 3x1 slicer mode $K = 9$, pixel size is 0.0202Å. In the fiber mode with 4x4 binning $K = 2.5$ and the spectral pixel is 4 times larger. The number of photons received during exposure time t is calculated as

$$N_{ph} = F_0 \, \epsilon \, t \, 10^{-0.4V} \quad \text{[el/pixel]} \tag{2}$$

where $F_0 = 3.4E5$ photons/s/pixel is the flux of $V = 0^m$ star outside atmosphere per 0.0202Å, $\epsilon = 0.05$ is the total system efficiency (conservative estimate), V is source magnitude. These parameters are valid around 500 nm near the center of order in the normal mode. The plots in Fig. 3 were produced using these data.

2.3 Acquisition and guiding

The guiding camera is connected to the guiding PC, `ctioxb`. Use VNC connection to 139.229.12.62:1. In the VNC screen, open the PCguider program from a menu activated by the left mouse button

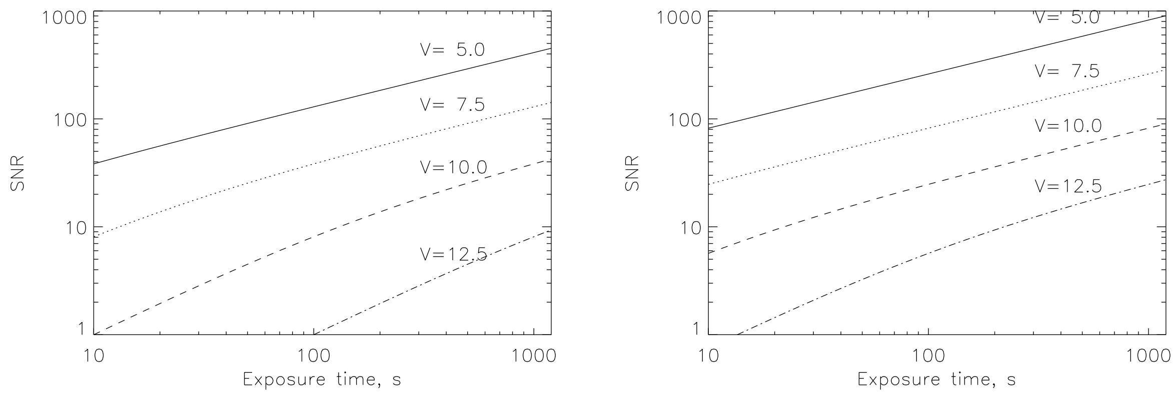

Figure 3: Estimated signal-to-noise ratio at 500 nm vs. exposure time in normal mode with slicer (left) and in the fiber mode (right). The numbers near curves indicate V-magnitude of the source.

(Fig. 4). In order to see better the star images, use automatic intensity scaling. To do so, use menu in PCguider: `Options` → `Parameters` → `olut = off` (the default is `sigma`).

When the field is illuminated by sky or dome light, dark images of the two holes are seen. The guiding box should be centered on the small hole, normally at X=289, Y=255. You may want to shift the box by ±1 pixel to achieve better centering of the star in the hole. The normal box size is 29 pixels. The North-South direction coincides with Y.

After pointing the telescope, the object should be seen on the screen. Adjust camera integration time to avoid saturation (max. counts < 4096). In the PCguider menu, use `Windows` → `Camera Control` → `Integration Time`, set the new value, press `Enter`. The effect is immediate. In Fig. 4, the integration time is 100 ms.

Using hand paddle, move the telescope to bring the star into the box. Most of the image disappears in the hole, and we see a ring (donut), as shown in Fig. 4. The guiding loop can now be closed. To view the image better, adjust the display using its control panel (display menu: `Options` → `Control panel`). It is helpful to adjust the contrast and brightness and to use zoom for a larger view of star image in the hole.

Sometimes the PCguider program looks functional, but does not keep the star centered because the telescope does not make the corrections. Always check that the guider works! Before closing the loop, put the star in one corner of the box and see how it is centered automatically after closing the loop.**The star must look like a symmetric ring** as shown in Fig. 4 when the guider works properly.

For focusing the telescope, move the star away from the hole, make sure that the image is not saturated in the camera (max. count < 4096) and in the display. With bad settings of brightness/contrast, the central part of the image looks "flat", with right settings it is peaked.

The position of the guider arm must be checked because the GAM control software systematically goes wrong, so the displayed coordinates of the guide arm do not match its actual position. The correct position should be $X = -268, Y = +259, Z = -41$. Put a bright star away from the hole, defocus the telescope, and verify that the image is donut-like, not cut on one side. If the image is

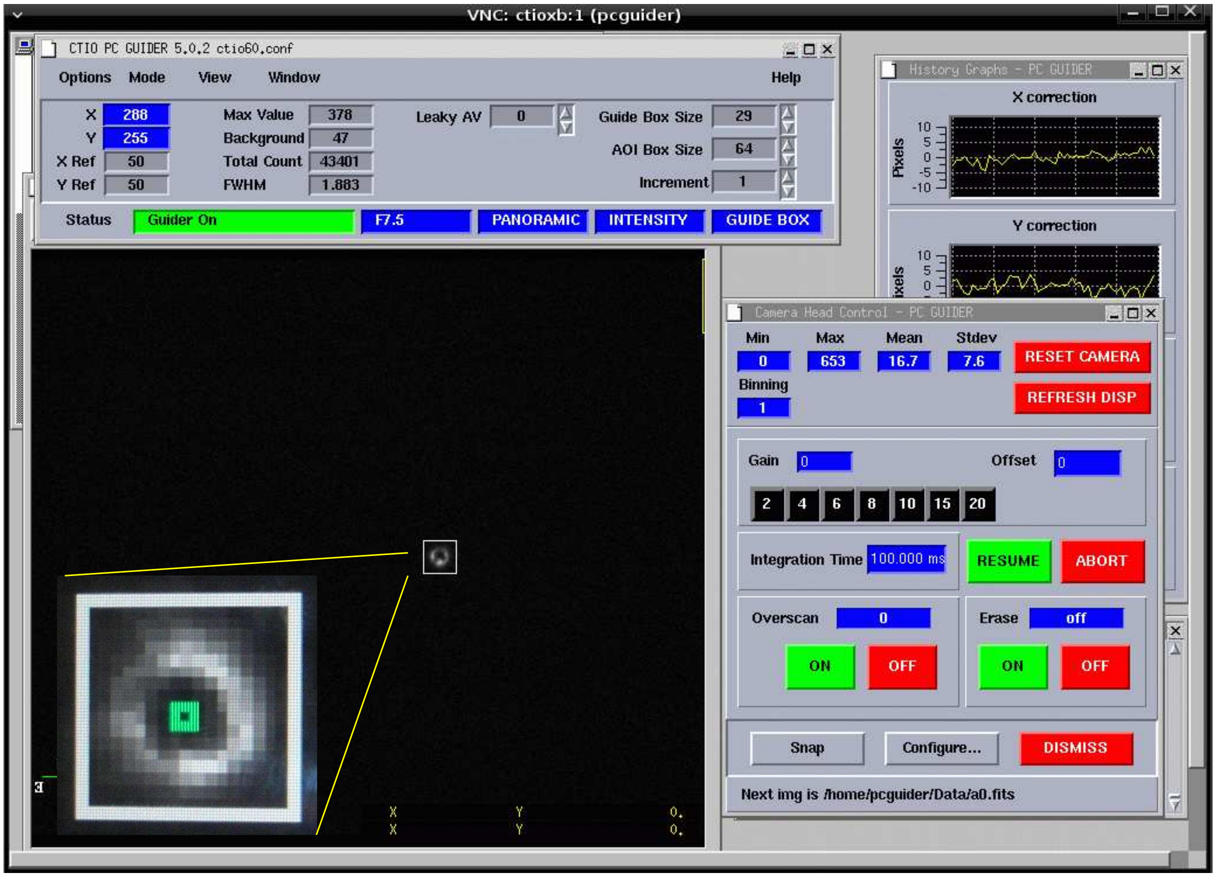

Figure 4: Snapshot of the PCguider screen during guiding. The insert in the lower-left shows how the star must look when the guider is working properly.

vignetted, re-initialize the GAM control program.

2.4 Spectral format

The spectral formal is fixed. It covers the wavelength range from 415 nm (center of the bluest order 136) to 884 hm (center of the reddest order 64). Figure 5 shows the spectrum of a G0V star with order numbers and approximate central wavelengths. Central wavelength of each order m in Åis $\lambda_m = 565754/m$. The sodium D-lines are located near the center of order 96. Note that the order 110 (514 nm) is right at the center, it is split between amplifiers.

2.5 Taking spectra

CHIRON and its CCD are controlled by the `ctioe1` computer. Use VNC connection to 139.229.12.29:9. Read the GUI user manual[1] to find out how to operate it. The program controls all CHIRON motors (prism, slicer, iodine cell and focus), calibration lamps, and CCD.

[1] http://www.ctio.noao.edu/~atokovin/echelle/CHI60S-1.2_chiron_User_Manual.pdf

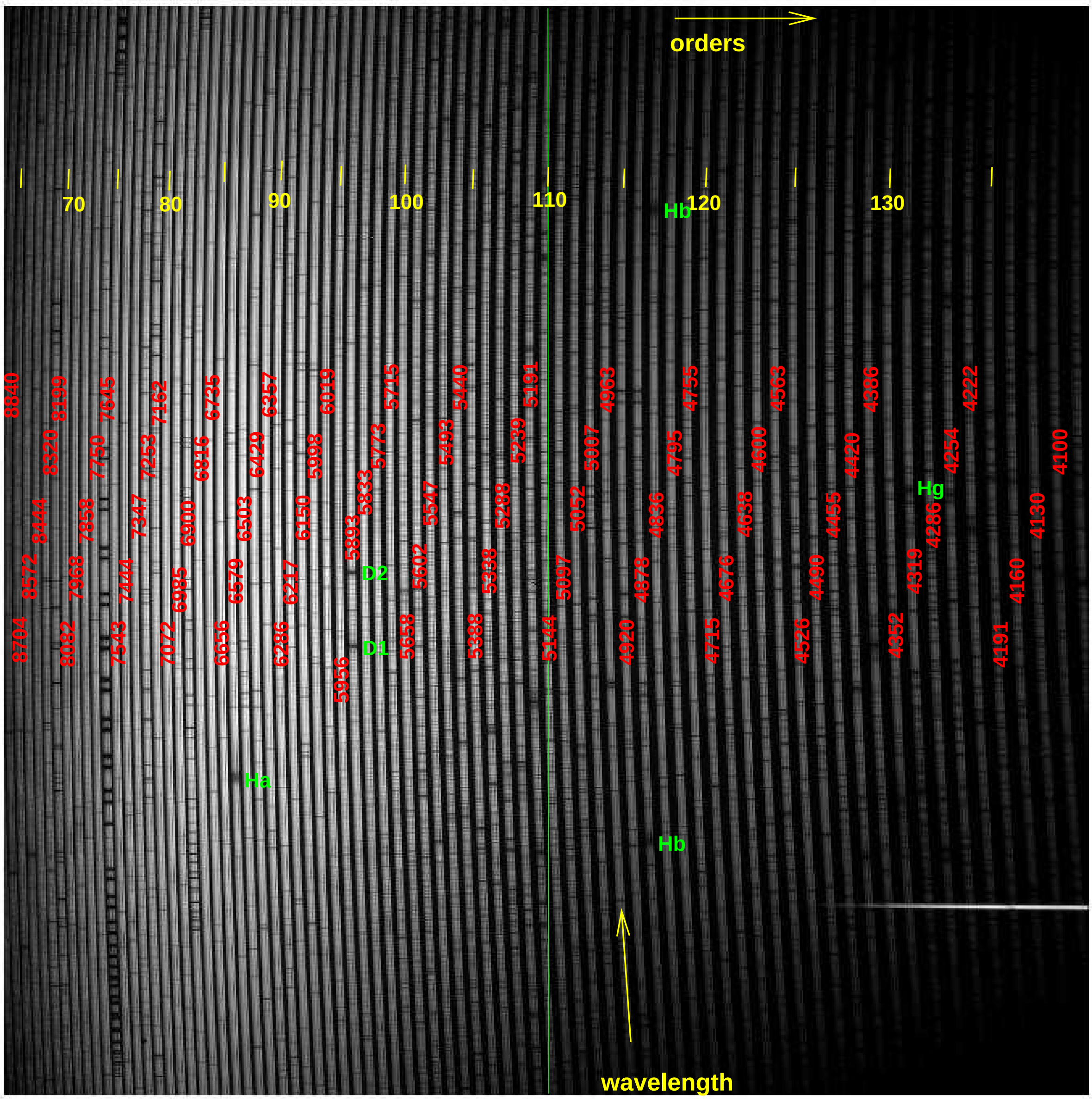

Figure 5: Spectral format of CHIRON covering the range 415–880 nm. Spectrum of α Cen in normal mode with iodine cell is displayed in the background (bias-subtracted and trimmed, 4096x4112 pixels). Order numbers are indicated in yellow, some stellar lines in green, approximate central wavelengths of the orders in red. The vertical green line indicates the division between left and right halves of the CCD. Horizontal line in the lower-right is a reflex from the window of echelle vacuum enclosure.

Combinations of slicer mode, detector mode, calibration lamps and iodine cell position are pre-defined as various *observing modes*. The operator selects one of those modes to set all instrument parameters at once. The duration of exposure is normally controlled by the exposure-meter than

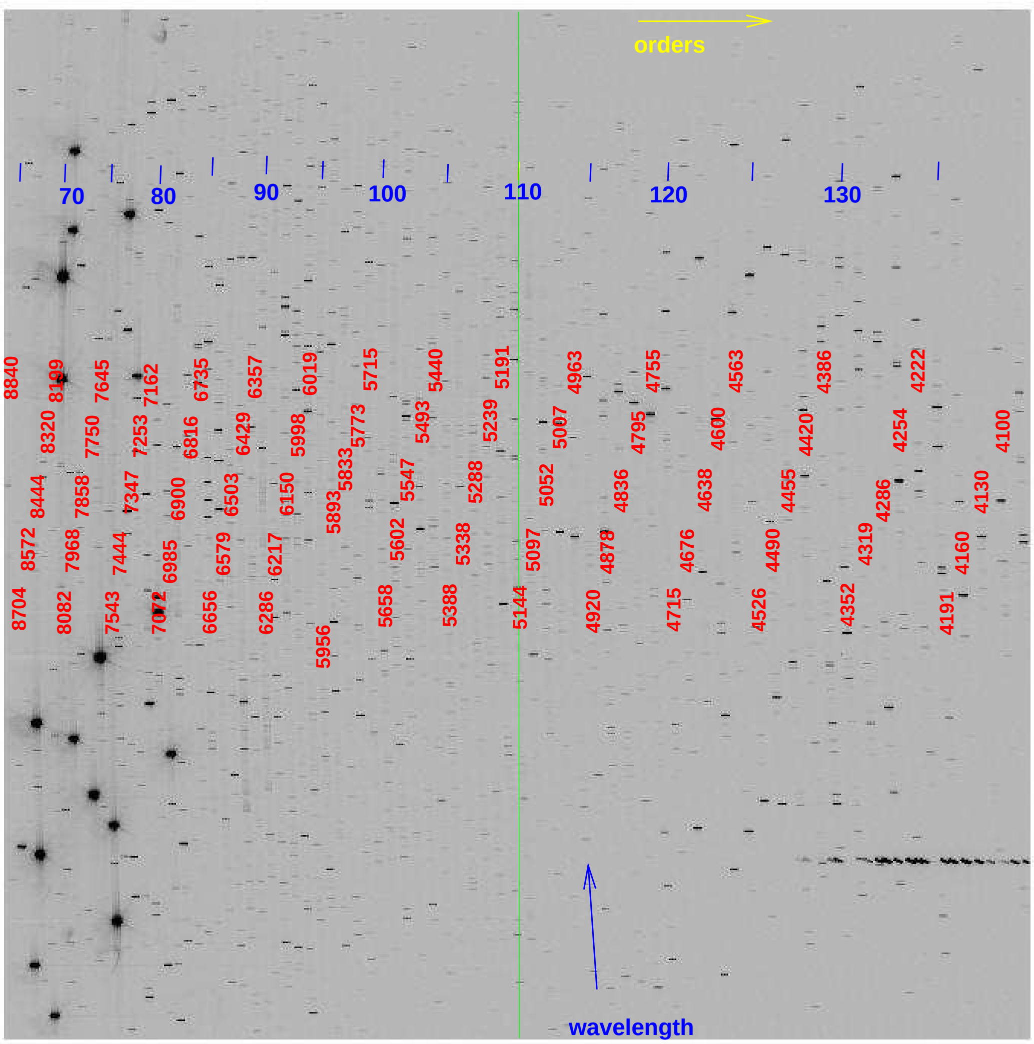

Figure 6: Spectrum of the Th-Ar comparison lamp.

accumulates requested number of counts. To disable the EM control, set this number to zero or negative in the EM plug-in window.

2.6 Checklist

- Open the telescope and place the GAM arm at X=-268, Y=+259.
- Enter CHIRON GUI, verify that it is connected to the CCD controller, temperature monitor and TCS (green-colored boxes). Take ThAr spectrum.
- Check temperatures of the CCD (-128C) and CHIRON ($+12$C) in the GUI.
- Enter the PCGuider program, verify that it the guider works.