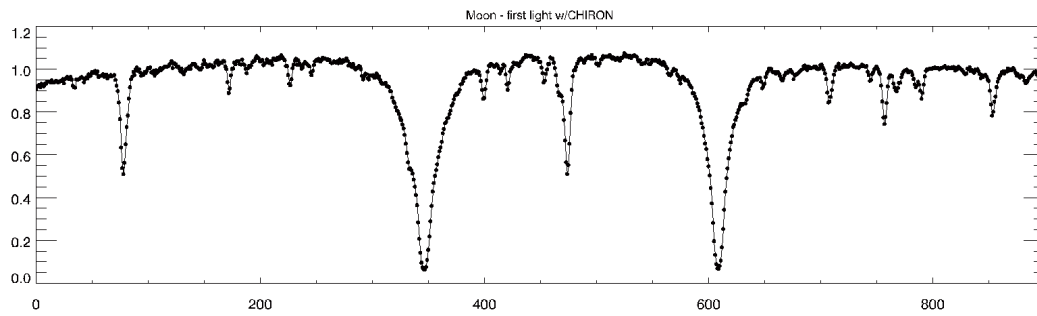
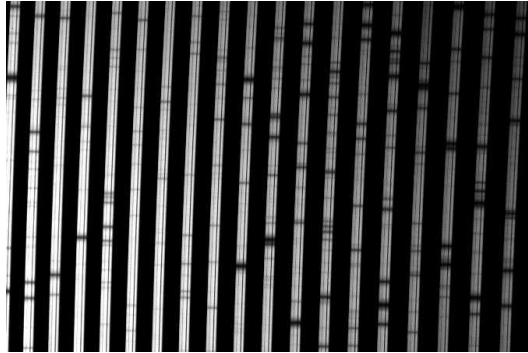


# CHIRON manual



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# 1 Overview

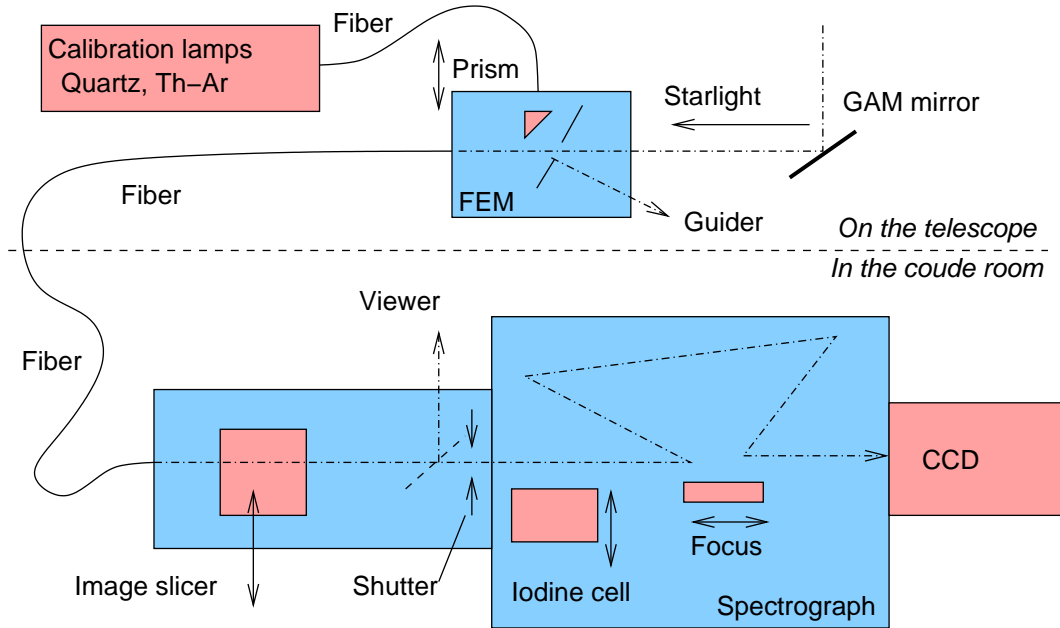


Figure 1: Light path in CHIRON, from the telescope to the CCD. Elements under user control are pink-colored.

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  $4200\text{\AA}$  to  $8800\text{\AA}$  without gaps [TBC].

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.

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**.

To specify observations, astronomer needs to decide whether the image slicer is needed, whether the

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)		Region-of-interest

iodine cell should be used, and what detector parameters are best suited for the program. Although these choices can be made in any combinations, 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.).

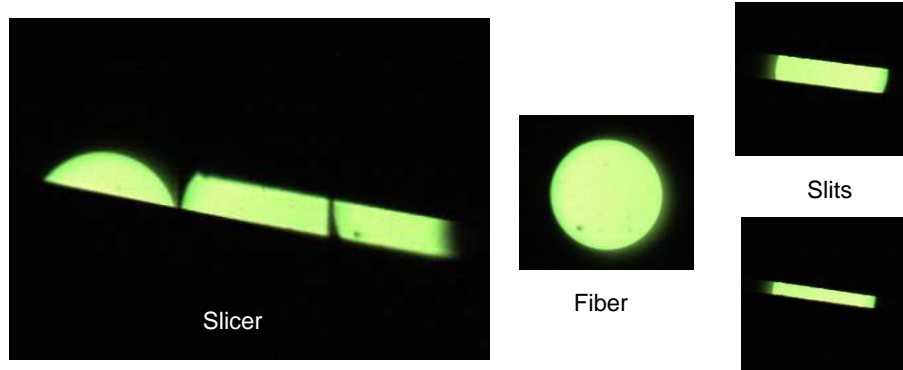


Figure 2: Images of the “slit” as seen through the viewer, with fiber illuminated by the quartz lamp. The position of the translation stage defines whether the fiber image is “sliced”, transmitted unchanged or masked by the slits. The slits are not normally used for observations, unless the star is very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

Table 2: Basic observing modes

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

## 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 Monsoon-Orange controller. Left and

right parts of the detector are read with different amplifiers. The gain and readout noise in fast and slow readout modes are listed in Table 3.

Table 3: Readout modes of the CCD

Mode	Readout time s	Upper-left		Upper-right	
		RON, el	Gain el/ADU	RON el	Gain el/ADU
Normal 1x1	37	4.5	2.39	4.2	2.05
Normal 2x2	14	4.3	2.23	4.1	1.92
Fast 1x1	22	9.6	2.59	7.4	2.19
Fast 2x2	10	7.5	2.53	6.1	2.10

The detector response is slightly non-linear. A formula to linearize the measured signal  $S$  (in ADU)

$$S_{corr} = S (1 - kS) \quad (1)$$

leads to the resulting linearity of about 1% at signal level up to  $10^4$  ADU, using the *non-linearity coefficients*  $k$  of  $[4.5, 4.0] \times 10^{-6}$  in the normal mode and  $[5.0, 4.3] \times 10^{-6}$  in the fast mode for the [left,right] amplifiers. **It is not recommended to exceed the signal level of 10 000 counts.**

Echelle dispersion is directed along the columns (vertically), cross-dispersion along the lines. The charge transfer efficiency is very good, about 0.999986 per pixel in the line direction and even better in the column direction. The CCD has minor cosmetic defects. In the left amplifier, 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 two localized detector blemishes at X,Y=(2347, 2526) and (2399, 2516).

## 2.2 Exposure-time calculator

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

$$S/N = N_{ph} / \sqrt{N_{ph} + KR^2} \quad (2)$$

where  $N_{ph}$  is the number of stellar photons per spectral pixel collected during the exposure time,  $R$  is the CCD readout noise in electrons,  $K$  is the number of binned pixels across the order. In the normal mode  $R = 8$ ,  $K = 9$ , pixel size is  $0.0202\text{\AA}$ . In the fiber mode with 4x4 binning and slow readout,  $R = 4.3$ ,  $K = 2.5$  and the spectral pixel is 4 times larger. The number of photons received during exposure time  $t$  is calculated as

$$N_{ph} = F_0 \epsilon t 10^{-0.4V} \quad [\text{el/pixel}] \quad (3)$$

where  $F_0 = 3.4E5$  photons/s/pixel is the flux of  $V = 0^m$  star outside atmosphere per  $0.0202\text{\AA}$ ,  $\epsilon = 0.04$  is the total system efficiency,  $V$  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.

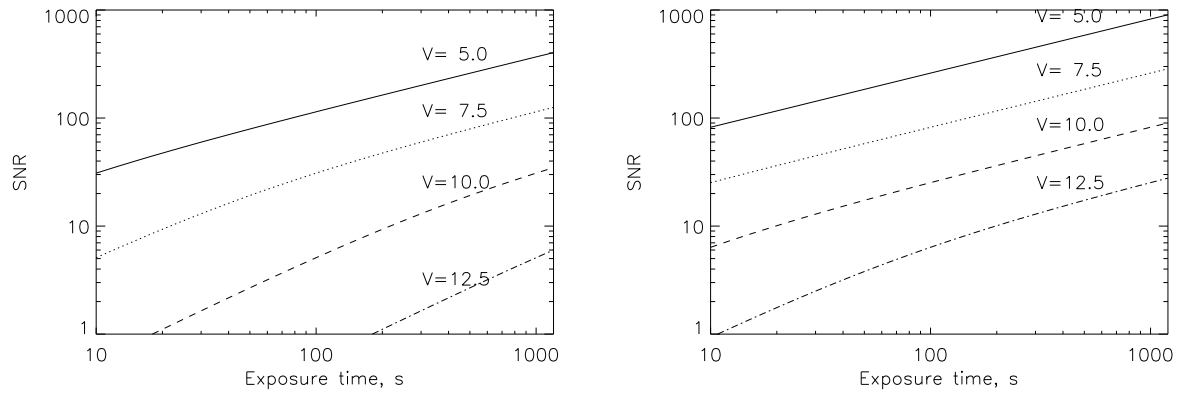


Figure 3: Estimated signal-to-noise ratio at 500 nm vs. exposure time in normal mode with slicer (left) and in the fiber mode (right). The numbers near curves indicate  $V$ -magnitude of the source.

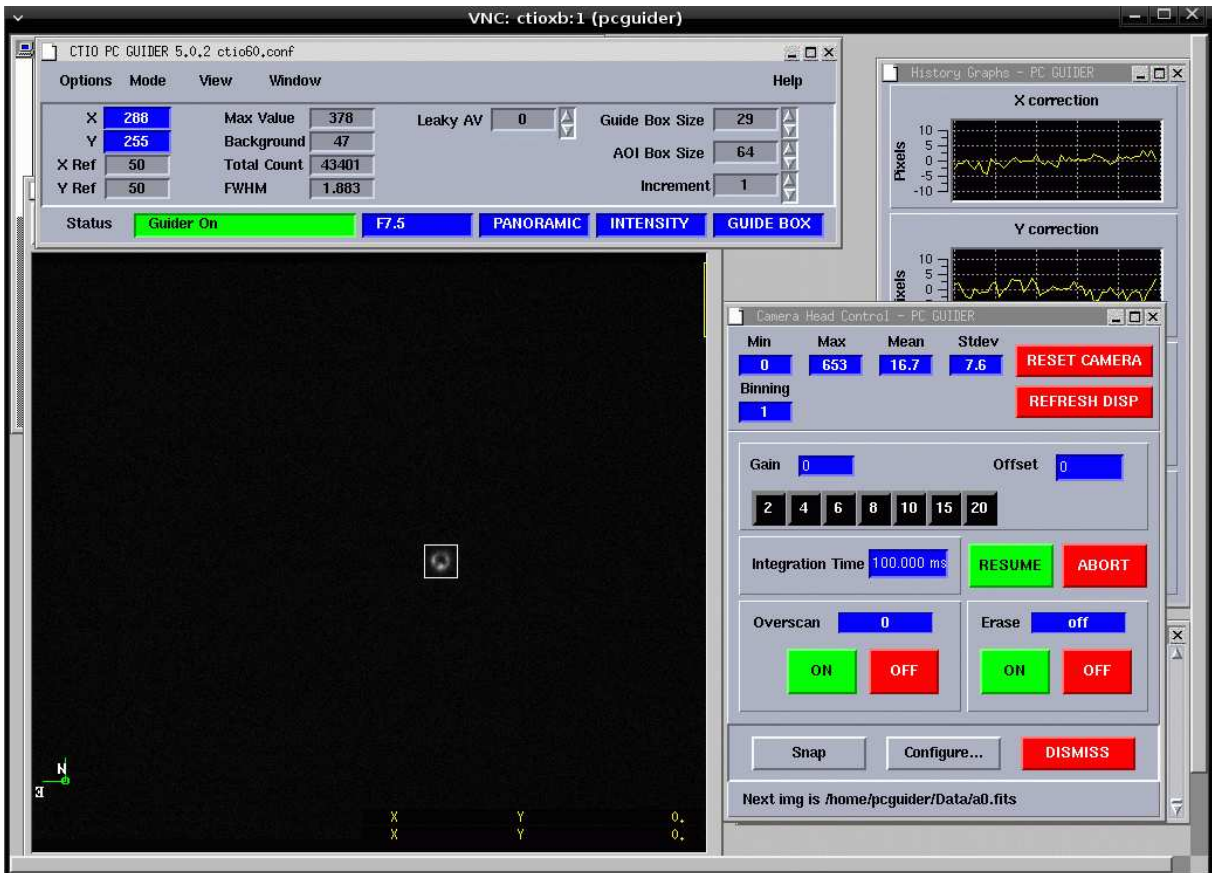


Figure 4: Snapshot of the PCguider screen during guiding.

## 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 (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  $\pm 1$  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.

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 this is not the case, re-initialize the GAM control program.

## 2.4 Spectral format

The spectral format is fixed. It covers the wavelength range from 410 nm (start of the bluest order 137) to 874 nm (end of the reddest order 65). Figure 5 shows the spectrum of a F0II star (Canopus) with order numbers and approximate central wavelengths. The order table is listed in the Appendix. Note that the order 109 (517 nm) is right at the center, it is split between two 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<sup>1</sup> to find out how to operate it. The program controls all CHIRON motors (prism, slicer, iodine cell and focus), calibration lamps, and CCD. The nominal (best) focus setting is 10.24 [TBC].

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<sup>1</sup>[http://www.ctio.noao.edu/~atokovin/echelle/CHI60S-1.2\\_chiron\\_User\\_Manual.pdf](http://www.ctio.noao.edu/~atokovin/echelle/CHI60S-1.2_chiron_User_Manual.pdf)

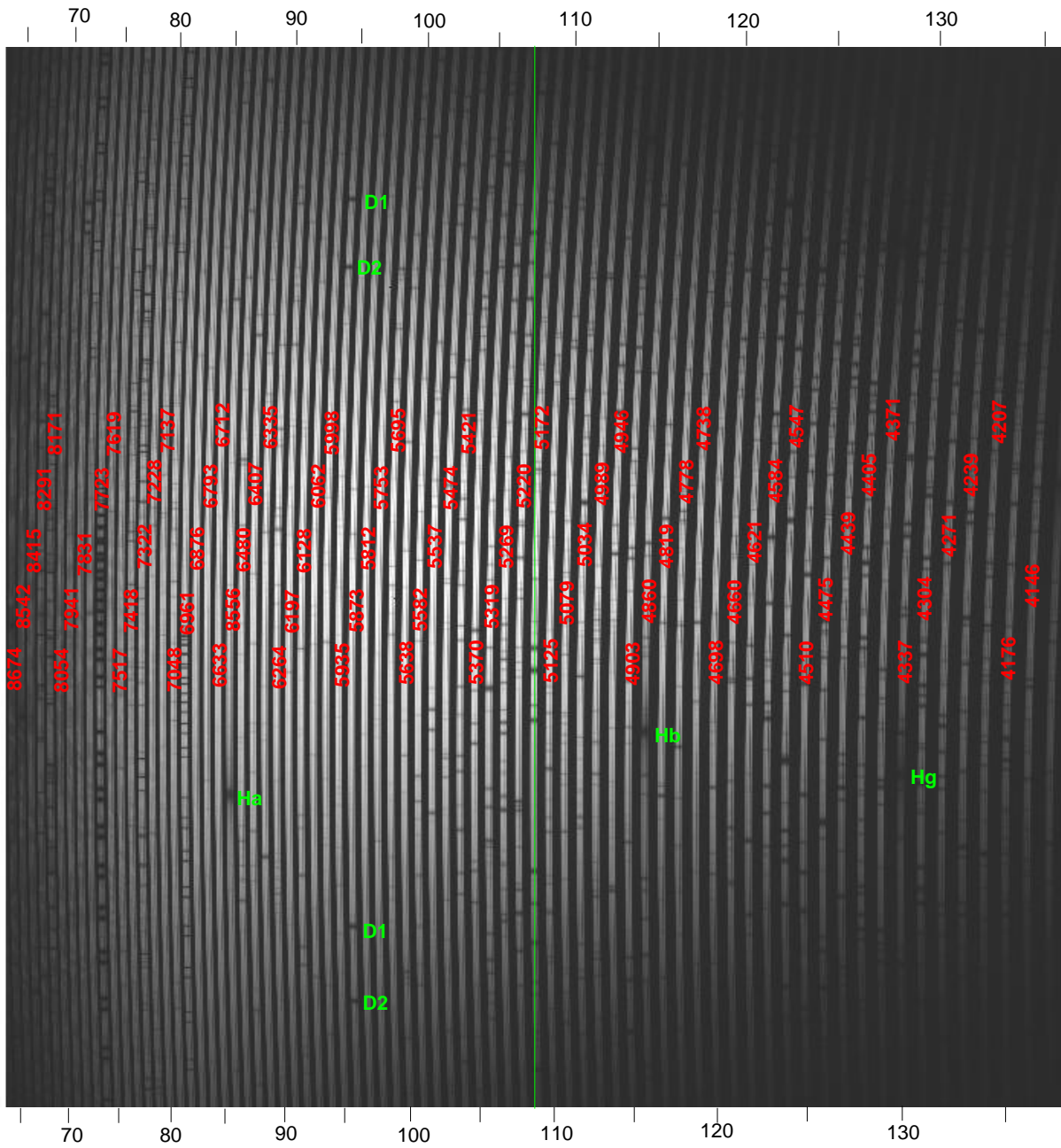


Figure 5: Spectral format of CHIRON covering the range 410–874 nm. Spectrum of Canopus (F0II) in normal mode is displayed in the background (bias-subtracted and trimmed, 4096x4112 pixels). Order numbers are indicated by the scales above and below, some stellar lines in green, approximate central wavelengths of the orders in red. The vertical green line indicates the division between upper-left and lower-right amplifiers.

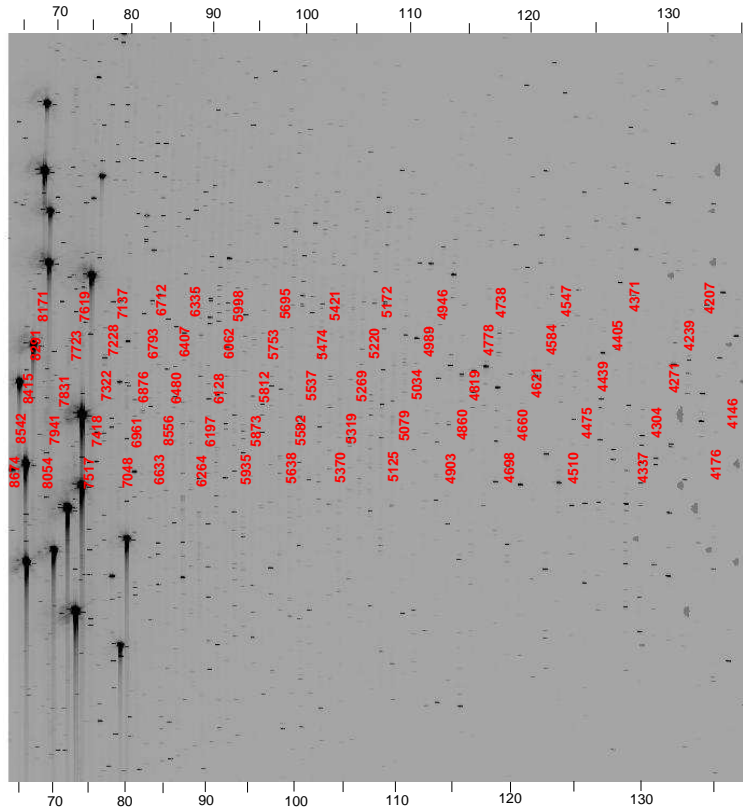


Figure 6: Spectrum of the Th-Ar comparison lamp.

## 2.6 Checklist

- Open the telescope and place the GAM arm at X=-268, Y=+259.
- Switch on the FEM electronics on the telescope.
- Enter CHIRON GUI, verify that it is connected to the CCD controller, temperature monitor and TSC (green-colored boxes). Take ThAr spectrum.
- Check temperatures of the CCD and CHIRON. [Give right values]
- Enter the PCGuider program, verify that it acquires the guide-camera images.

## 2.7 Troubleshooting

To be written. Cite software troubleshooting by Marco.



## A Order table

Order numbers N are listed below, with wavelength limits (min,max) corresponding to the free spectral range and central wavelengths. These wavelengths are approximate.

#	N	Min	Cent	Max	N	Min	Cent	Max
	65	8607.5	8673.9	8740.4	101	5554.6	5582.2	5609.9
	66	8477.8	8542.5	8607.2	102	5500.4	5527.5	5554.6
	67	8352.2	8415.0	8477.8	103	5447.3	5473.8	5500.4
	68	8230.3	8291.3	8352.2	104	5395.2	5421.2	5447.3
	69	8111.9	8171.1	8230.3	105	5344.0	5369.6	5395.2
	70	7996.8	8054.4	8111.9	106	5293.8	5318.9	5344.0
	71	7885.0	7940.9	7996.9	107	5244.6	5269.2	5293.8
	72	7776.3	7830.6	7885.0	108	5196.3	5220.4	5244.6
	73	7670.5	7723.4	7776.3	109	5148.8	5172.5	5196.3
	74	7567.5	7619.0	7670.5	110	5102.2	5125.5	5148.8
	75	7467.3	7517.4	7567.5	111	5056.5	5079.3	5102.2
	76	7369.7	7418.5	7467.3	112	5011.5	5034.0	5056.5
	77	7274.6	7322.2	7369.7	113	4967.4	4989.4	5011.5
	78	7182.0	7228.3	7274.6	114	4924.0	4945.7	4967.4
	79	7091.6	7136.8	7182.0	115	4881.3	4902.7	4924.0
	80	7003.5	7047.6	7091.6	116	4839.5	4860.4	4881.4
	81	6917.6	6960.6	7003.5	117	4798.3	4818.9	4839.5
	82	6833.8	6875.7	6917.6	118	4757.8	4778.0	4798.3
	83	6751.9	6792.8	6833.8	119	4718.0	4737.9	4757.8
	84	6672.0	6712.0	6751.9	120	4678.8	4698.4	4718.0
	85	6594.0	6633.0	6672.0	121	4640.3	4659.6	4678.8
	86	6517.8	6555.9	6594.0	122	4602.4	4621.4	4640.3
	87	6443.3	6480.5	6517.8	123	4565.2	4583.8	4602.4
	88	6370.5	6406.9	6443.3	124	4528.5	4546.8	4565.2
	89	6299.3	6334.9	6370.5	125	4492.4	4510.5	4528.5
	90	6229.7	6264.5	6299.3	126	4456.9	4474.7	4492.4
	91	6161.6	6195.7	6229.7	127	4421.9	4439.4	4456.9
	92	6095.0	6128.3	6161.6	128	4387.5	4404.7	4421.9
	93	6029.8	6062.4	6095.0	129	4353.7	4370.6	4387.5
	94	5966.0	5997.9	6029.8	130	4320.3	4337.0	4353.7
	95	5903.6	5934.8	5966.0	131	4287.4	4303.9	4320.3
	96	5842.4	5873.0	5903.6	132	4255.1	4271.3	4287.4
	97	5782.5	5812.4	5842.4	133	4223.2	4239.1	4255.1
	98	5723.8	5753.1	5782.5	134	4191.8	4207.5	4223.2
	99	5666.3	5695.0	5723.8	135	4160.9	4176.3	4191.8
	100	5609.9	5638.1	5666.3	136	4130.4	4145.6	4160.9