CHIRON temperature control

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Abstract. This document describes temperature control of the CHIRON spectrograph with the Lakeshore controller and the stabilization of the air temperature in the surrounding warm room. Temperature stabilization of the iodine cell is covered as well.

1 Hardware and settings of CHIRON temperature control

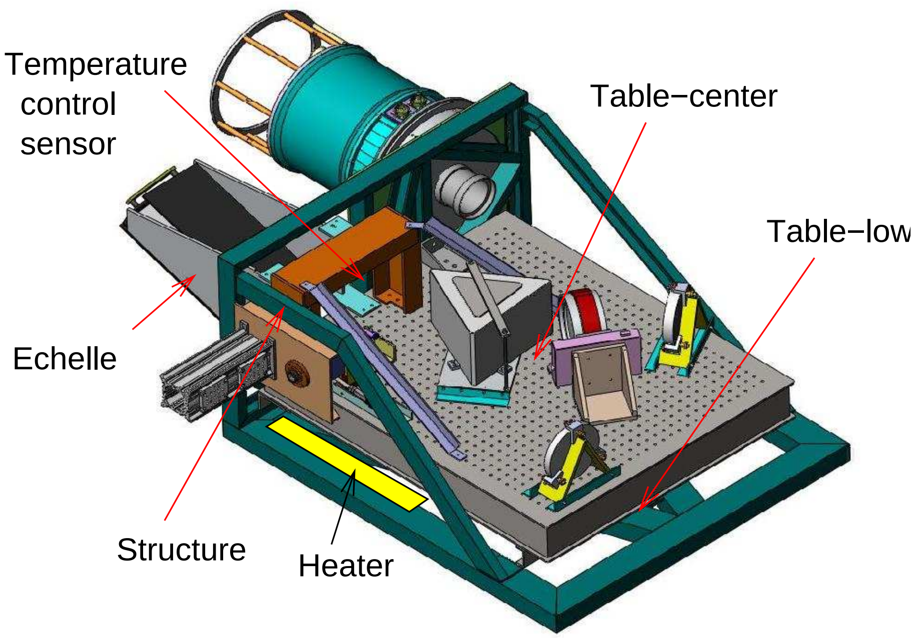

Figure 1: Locations of the temperature monitoring sensors and the temperature control sensor (red arrows) in CHIRON. One heater element out of three is also shown.

The temperature of the CHIRON is stabilized (nominally at +21°C) by a combination of heater, sensor, and controller. The heating elements are silicone rubber heating strips (110V/45W each, size 1"x18" - part 35765K154 from mcmaster.com). Three such strips are glued to the aluminum panel of the enclosure below the optical table. The resistance of the heater (all strips in parallel) is 98.9 Ω The space between the panel and the table is insulated by a 1-inch foam sheet to prevent table heating from below and bending. The heat produced by the strips is evenly distributed by the aluminum panel to other elements of the instrument support structure (ISS) and (passively) to the table and other elements. Four RTD-100 temperature sensors connected to the ADAM module are monitoring temperature at critical locations (Fig. 1). The zero-points of those sensors were equalized during initial tests of the system in 2011, but a systematic difference on the order of 0.1°C can remain.

Originally, CHIRON temperature was stabilized with the simple CNi8 controller from Omega (omega.com), driving the heater with 110V line (maximum power 120W). In December 2011, a more accurate controller Lakeshore Model 325 was configured for CHIRON. This unit was used previously for the temperature stabilization of the 2K CCD with the Monsoon Orange controller and fiber echelle. The Lakeshore Model 325 can provide up to 25W of power in a 50 Ω load. As the heater resistance is 100 Ω, the maximum heating power is 12.5W.

The sensing element is a 100 Ω RTD platinum sensor taped to the vertical bar of the ISS. This location is intentionally chosen to be relatively close to the heater, to reduce the reaction time and to facilitate the temperature control. The sensor is connected to Input A of the controller (Fig. 2). Inside the spectrograph, the connection between the pin G and the shield of the internal sensor cable was removed because the shield is connected to the RTD.

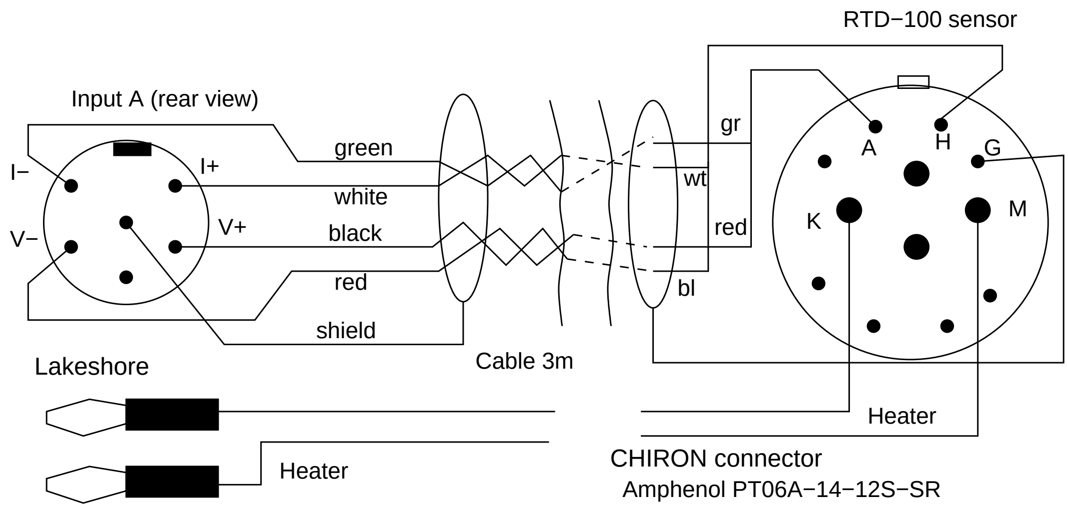

Figure 2: Connection between Lakeshore controller and CHIRON.

The Lakeshore settings were initially practiced on a physical model consisting of a 100 Ω heater, sensor, and thermal mass. The controller was then installed at CHIRON on December 22, 2011. It is connected to the RS232 line through the Lantronix terminal. The CHIRON instrument was not in use, the room heater was off, and the CCD dewar was removed. The tests were conducted in this quiet or basic state of CHIRON. At the moment of installation the instrument temperature was 16.2°C.

The settings of Lakeshore are kept in its memory, they are listed in Table 1.

Table 1: Settings of Lakeshore Model 325 controller

Sensor parameters	Control loop: 1
Input A: P100 Ω Plat/250	SPunit: temp C
Curve: 06	Control mode: closed
Reversal: on	Power up: enable
Filter: on, 8pts	Heater output: power
Tem. limit: 0 K	Setpoint ramp: off
	Heater load: 50 Ohm
	Control mode: manual PI
	Proportional: P=750
	Integral: I=0.2

2 Tuning and tests of CHIRON temperature control

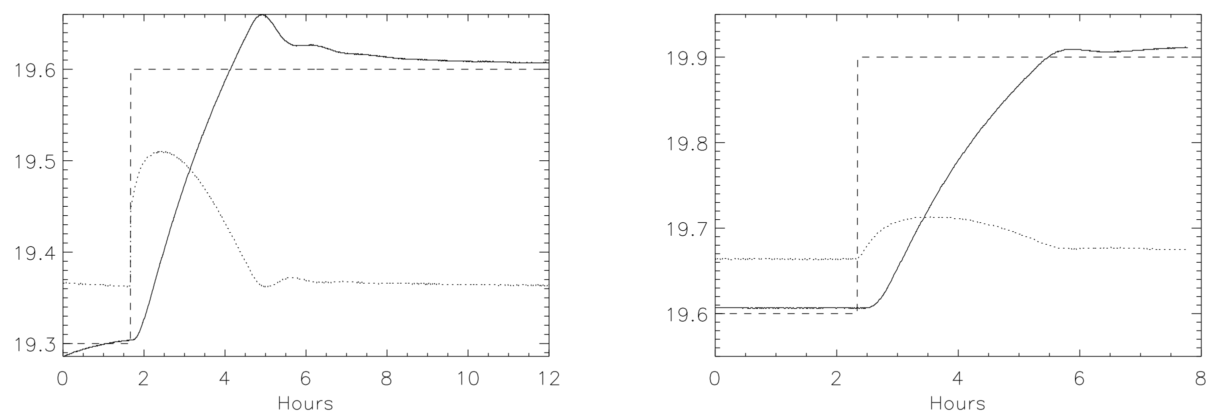

Figure 3: Sensor temperature vs. time. Reaction of the system to a 0.3°C increment of the temperature setpoint. Left: $P = 750$, right: $P = 500$. In both cases $I = 0.2$. Full line: sensor temperature, dashed line: setpoint, dotted line: heater power scaled to the setpoint (100% equals the step).

The behavior of the system was monitored remotely from La Serena by VNC connection to `ctioe1`. The GUI to change controller parameters is evoked by the command `>CHRTEMP TCTRL CCDTEMP opengui`.

First tests have shown that the reaction of the system is very slow. Even with the maximum setting of the proportional control parameter $P = 1000$ there were no temperature oscillations. A typical reaction time of the system (presumed oscillation period) was crudely evaluated to be $T_0 = 5$h. Therefore the recommended integral parameter would be $I = 1000s/T_0[s] \sim 0.05$. The minimum setting of I allowed by the controller is 0.1.

Several experiments (small setpoint increments) have shown that $I = 0.2$ is a better choice (with low $I = 0.1$ the response has long settling period). The final tuning consisted in reducing the P from

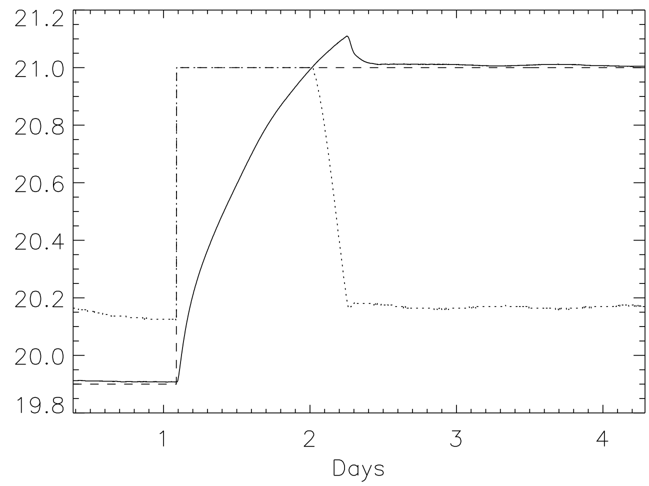

Figure 4: Evolution of sensor temperature and heating power after changing the setpoint from 19.9 to 21.0 on Dec. 27, 2011. Controller parameters $P = 500$, $I = 0.2$. The stationary heating power is 24%, room temperature around 18.9°C.

its maximum value to get smaller "overshoots". Figure 3 shows system reaction to a stepwise increase in the setpoint with $P = 750$ (moderate overshoot and some oscillation of the heating power) and $P = 500$ (less overshoot). In both tests the maximum heating did not reach 100%, so the system remained in the linear regime. It took about 4h to adjust the temperature to its new value. In the stationary state, the heating power was between 20% and 25%. Therefore, few Watts were sufficient to maintain CHIRON (without dewar) slightly above ambient temperature.

On December 26, 2011 the full temperature monitoring was started. Figure 1 shows the location of the monitoring points. I found that the room temperature has increased to 17.9°C and continued to rise (the weather at Tololo became warmer). At 9h Dec. 27 I increased the setpoint to 21.0°C. After 24h of 100% heating the sensor reached the setpoint and started to overshoot, but the system was not yet stationary (table at 20.97°C). After reaching the equilibrium, the sensor temperature remained very stable (Fig. 4), its rms variation during 26h (starting at day 3) was only 0.002°C.

Around January 1, 2012 the weather at Tololo became cooler and the temperature in the coude room started to drop. In response, the controller increased the heating power, but not fast enough. The sensor temperature dropped by 0.07°C before the heating reached 100% and continued to drop further afterwards (Fig. 5). Attempting to get a better (faster) reaction, I set the integral constant to $I = 1$ on January 3, but it caused instability (oscillation of the heating power). Reducing to $I = 0.5$ did not help. Attempt to use $P = 1000$ and $I = 0.2$ also lead to oscillations. Finally I adopted $P = 750$ and $I = 0.2$ as a compromise between reaction speed and overshoots.

Figure 6 shows the evolution of temperature at 4 monitoring points inside CHIRON during 8 days: the stationary period, cooling, re-tuning, and final setpoint at 20.2°C. Diurnal cycles in the room temperature are apparent. The stationary heating power is 25.5% for a room temperature 2.3°C below the setpoint. The heat loss of CHIRON without CCD is therefore 1.4W per 1°C of temperature

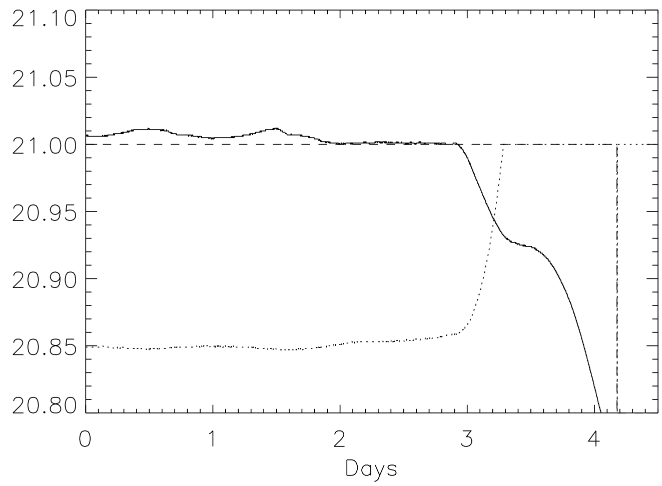

Figure 5: Reaction of sensor temperature (full line) to a fast cooling of the ambient air. The heating power (dotted line) increased to 100%, but was still insufficient to compensate the cooling.

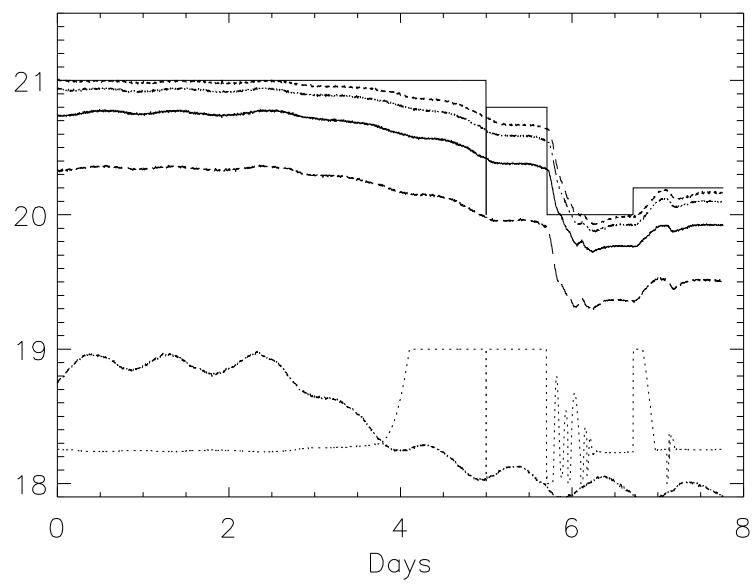

Figure 6: Temperature evolution of CHIRON monitoring points during one week of tests and tuning. The curves from top down are: TABCENT, TABLOW, GRATING, STRUCT, ROOM. The step-wise line shows the setpoint, the dotted line – heater power.

difference.

Temperature at the TABCENT is closest to the setpoint, the TABLOW follows closely behind,

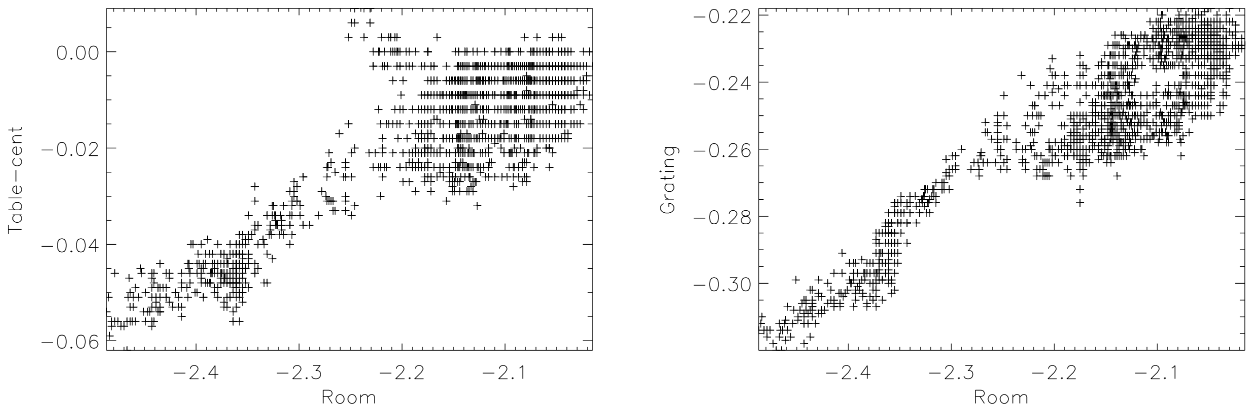

Figure 7: Correlation of the temperature deviation from the setpoint with the difference with ambient temperature (room − setpoint). Left: table center, slope 0.112; right: grating, slope 0.187. Data collected during 3.5 days.

while GRATING and STRUCT are progressively colder. The grating enclosure E2 is not heated, it gets calories from inside CHIRON[1]. There may remain small (0.1°C?) systematic offsets between the sensors, despite their calibration (known offsets are taken into account). Note also that room temperature was measured above CHIRON, the actual temperature may be lower due to air stratification.

Figure 7 shows the correlation between monitoring points and temperature difference. The data were collected during first 3.5 days plotted in Fig. 6 (stable control and initial part of the cooling). As the response to changing conditions is dynamic, there is no 1:1 correspondence, but the slopes are well defined: 0.112 for the table and 0.187 for the grating (determined by simple linear fits). In other words, the temperature control reduces fluctuations of ambient temperature by a factor 10 at the table, by a factor 5 at the grating, and by a very large factor at the sensor. The degree of stabilization can be increased by re-distributing the heating power (add a small heater in the grating enclosure) and by better thermal insulation around CHIRON.

It is worth to stress the large time constant of the system. A temperature increment of 0.3°C can be compensated in 4 hours, but it takes one full day to stabilize the whole spectrograph after a major change or opening. For the same reason the system cannot react adequately on fast changes of the ambient temperature. The air around CHIRON should be maintained at stable temperature some 1° below the setpoint.

3 Warm-room temperature control

The new warm room around CHIRON was assembled in January 2012 using 80/20 aluminum bars. Originally it was planned to make the walls and ceiling of 5-cm styrofoam panels. These panels, however, produce particle contamination and are not flexible. They are used on the ceiling as an extra

[1]An attempt to add a small heater element inside E2 was made in May 2011. It resulted in grating being over-heated, so the element was disconnected.

(outer) insulation layer, wrapped in a stretchable film to trap the particles.

A better material was identified by D. Fischer, *protex* from `http://www.insulation4less.com`. This is a foil-covered bubble wrap with $R = 15.67$, stretchable and flexible. The room walls and ceiling were made of this material in February 2012.

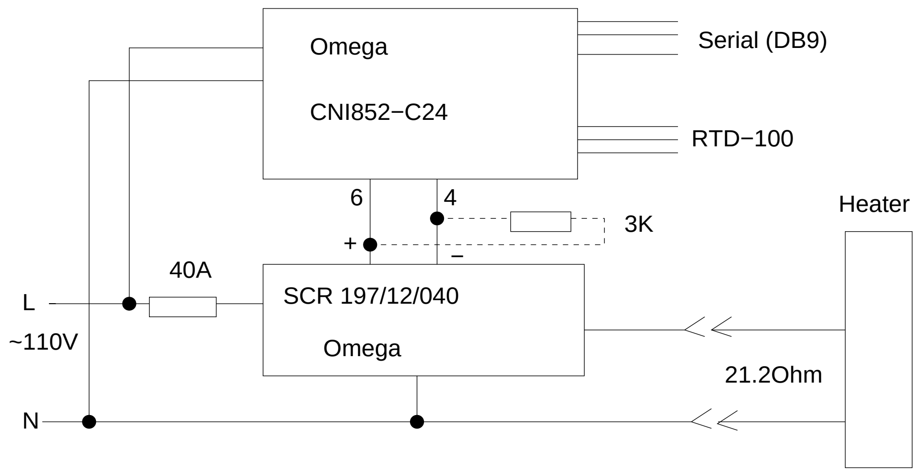

Figure 8: Schematics of the room temperature controller.

The temperature controller for the warm room was assembled by A. Szymkowiak at Yale from the Omega components: the digital controller and the SCR power amplifier (Fig. 8). The amplifier switches the load during transitions of the line voltage through zero to avoid producing EM noise. It supports only pure resistive loads and requires a special fast 40A fuse. The SCR unit is controlled by the 4-20 mA current loop provided by Omega. This Omega model has serial connection. The settings of the Omega controller determined by A. Szymkowiak on March 15, 2012, are: `PROP=12, RESET=50, CYCLE=010, DPNG=0003`.

Originally it was planned to use the De Longhi oil heater for the room. This black heater has resistance of 21.2, 19.4, 10.3 Ω in the min, med, max settings respectively. The minimum nominal power is therefore 570 W. However, we found that the controller never switched the heater off completely and the SCR unit was "on" for short periods of time even when it should be off completely. This caused over-heating of the warm room during summer months (January-March). The instrument was operated without any room heating for a while, then two improvised heaters were used in March. The first was made of a 45 W strip (as in CHIRON) and failed quickly. The second was improvised from a silicone tape (Cole-Parmer heating tape 03110-20, 104W/110V, $R = 127\Omega$) used previously for heating the iodine cell. As the weather became colder in April, the small heater proved to be insufficient and the De Longhi oil heater was plugged again, at minimum power. This time the over-heating was not a problem. Finally, on May 28, 2012, I shortened the pins 6,4 of Omega with a 3 kΩ resistor, as suggested by the manufacturer. The voltage on these pins is about 9 V, the resistor takes 3 mA current and prevents unwanted heater operation. Even a larger 10-kΩ resistor could be used. This configuration should be adequate for all seasons.

Figure 9 shows the location of this system. The controller is mounted on a metal plate and located on the floor outside the warm room. The heater is installed near the wall in front of a fan that blows

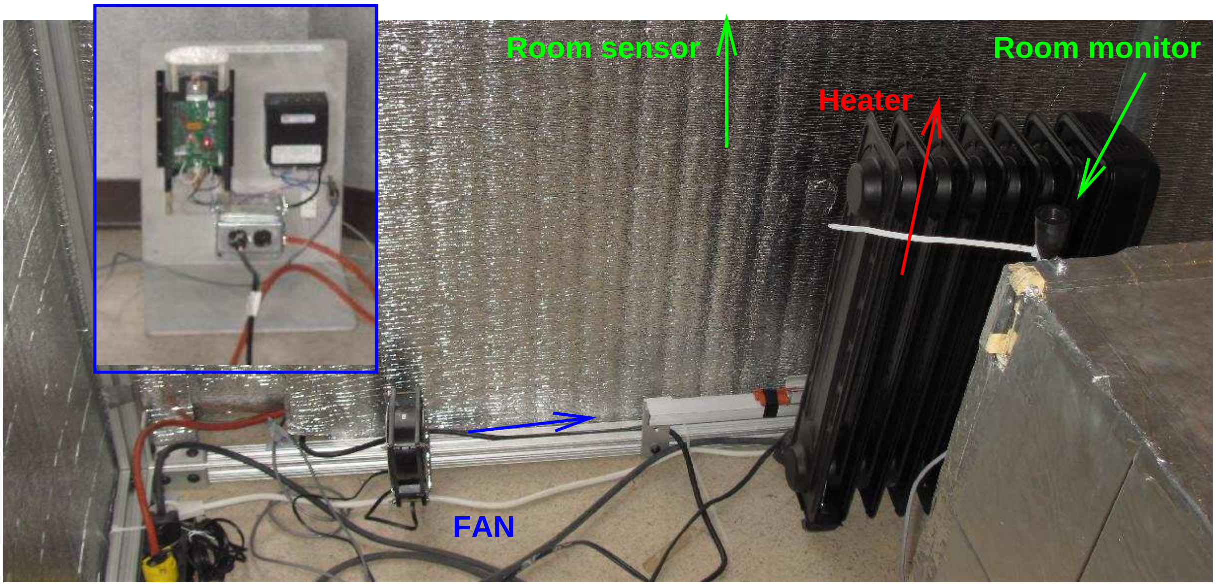

Figure 9: Location of heater inside the warm room. The insert shows the controller located outside the room.

air towards the heater. Another fan near the ceiling directs the warm air down, behind CHIRON, while the third fan below CHIRON blows towards the heater, too. In this way the fans create air circulation in the room and prevent stable stratification (accumulation of cold air near the floor). The sensor of the controller is suspended at $\sim$1 m above floor slightly in front of the heater (not visible in Fig. 9). Another RTD sensor, attached to the corner of CHIRON, monitors the room temperature independently of the controller.

4 Temperature stability of CHIRON

Unlike the tests described above, CHIRON is now working in nominal conditions, with the cold dewar attached and surrounding air stabilized. The grating was also replaced, and we added a small 20W heating strip to the ISS member above the grating window, to make its temperature a bit higher.

In March 2012, the control of the warm room was not yet working correctly. The air temperature varied, and the CHIRON temperature followed those variations with a reduced amplitude (Fig. 10, left). Selecting a period of March 3-8 when the room temperature changed and the CHIRON internal control was within the working range (enough heating power), we find a near-perfect correlation between CHIRON and room temperatures (Fig. 10, right). The slope is almost same at all points, e.g. 0.214 for TABCENT and 0.229 for GRATING.

Figure 11 shows temperature at monitoring points inside CHIRON logged during the last two months, as displayed at http://exoplanets.astro.yale.edu/~jspronck/chiron/CHIRTEMP.html. In the end of April the temperature dropped because the room controller lacked power. In the period May 28 to June 5 the instrument was opened and its control was not working. It stabillized again during the last week of June 6-13. During periods of stability we note tiny spikes in the STRUCT sensor,

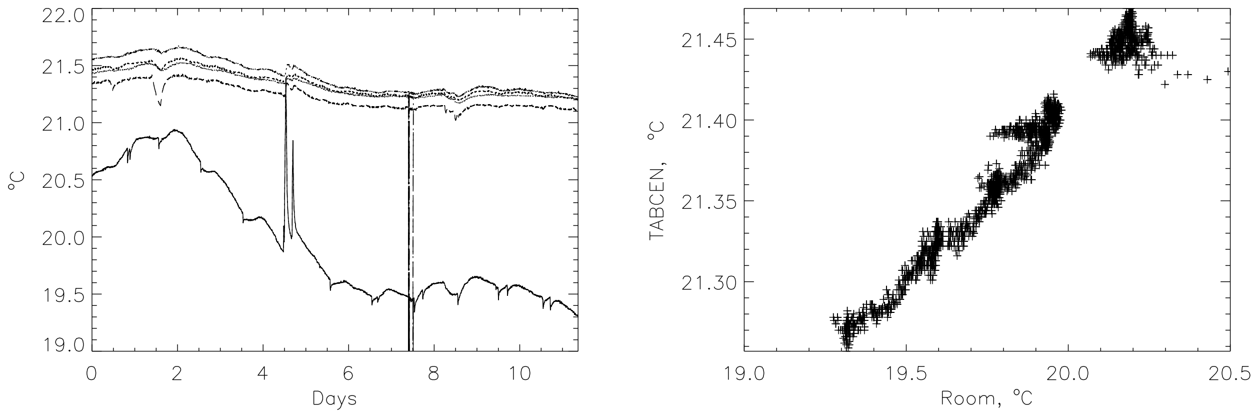

Figure 10: Left: temperature evolution in the period March 15 to 26, 2012. Right: correlation of TABCENT and room temperatures for March 3-8, 2012, slope 0.214.

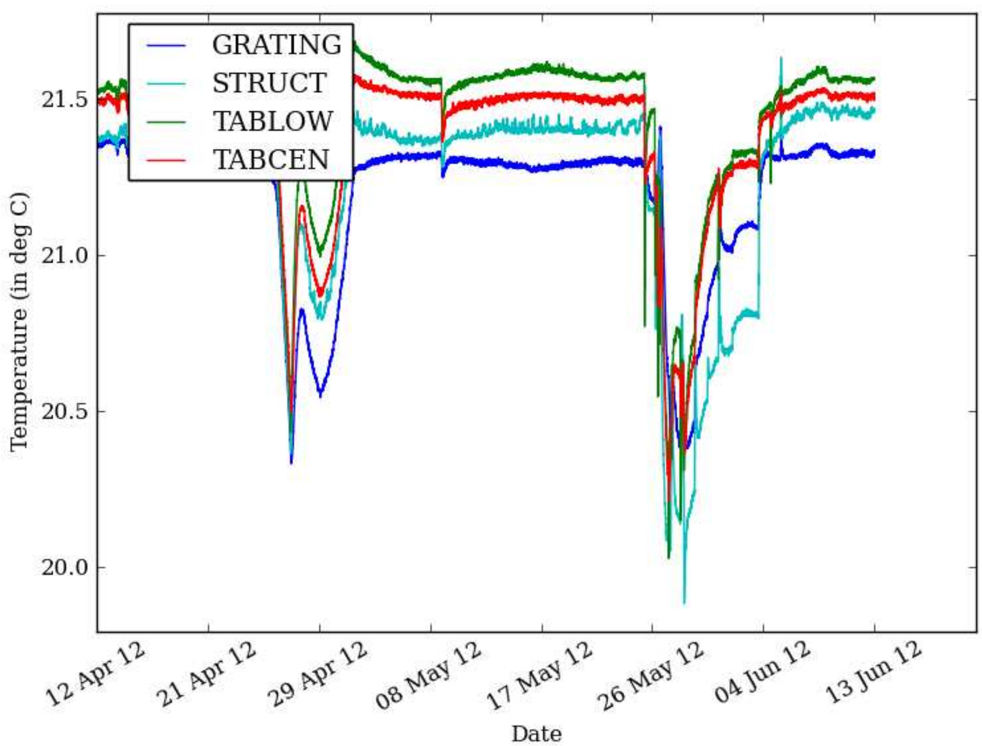

Figure 11: Temperature evolution of CHIRON in April-June 2012.

most likely caused by the in-out motion of the iodine cell (the sensor is above the cell container).

Figure 12 plots the temperatures during the stable period June 6−13. The warm-room controller

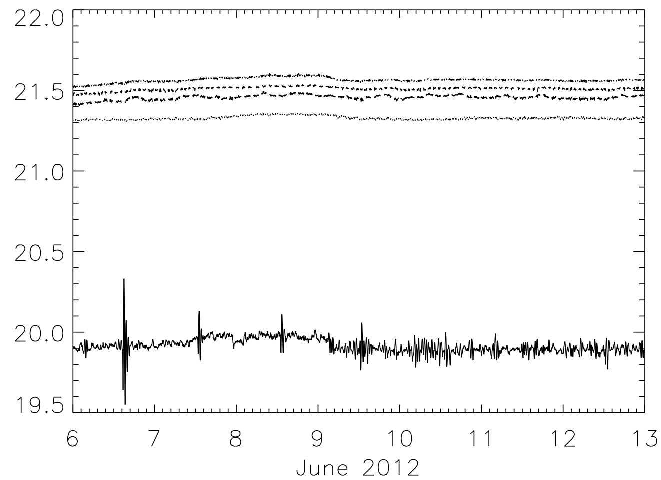

Figure 12: Data of temperature monitoring from June 6 to June 13, 2012. The instrument temperatures (top-down) are: TABLOW, TABCENT, STRUCT, GRATING. The lower line is the air temperature monitor in the warm room.

maintained the air around CHIRON close to the set-point of +20°C, despite large variations of air temperature at the observatory (total range from 5.1°C to 16.5°C, cooler by the end of the week). Spikes in the room temperature correspond to the daily dewar refills.

Table 2 lists average temperature and its rms variation during selected periods. In March when the room temperature was variable, the CHIRON temperature also shows variability, but 5 times smaller. This matches the correlation with slope 0.2 mentioned above. During the stable period in June the rms fluctuations did not exceed 15 mK.

Table 2: Average and rms temperature inside CHIRON for selected time periods.

Period	GRATING	TABCENT	TABLOW	STRUCT	ROOM
March 3–8	21.294	21.380	21.439	21.227	19.860
	0.059	0.055	0.074	0.056	0.255
March 15-19	21.464	21.488	21.583	21.350	20.623
	0.040	0.045	0.056	0.049	0.242
June 6-13	21.328	21.511	21.565	21.458	19.914
	0.011	0.012	0.014	0.015	0.047

The temperature distribution inside CHIRON is influenced by the heat loss to the dewar. This is why the hottest point is below the table. The grating is at the largest distance from the heater and is the coldest. The temperature set-point of +21°C is maintained at the location of the controller sensor, obviously influenced by the cold dewar. For this reason all monitoring points are actually hotter than the set-point (see Fig. 1). As long as the heat flux remains constant, the temperature gradient inside CHIRON will remain constant, too. For the three test periods shown in Table 2, the temperature difference TABLOW-GRATING (i.e. the full range between all monitoring points) was 0.145, 0.119, and 0.237°C. Colder weather in June required more heating to compensate for the colder dewar. Unfortunately, we cannot improve thermal insulation between the dewar and CHIRON. A regulated heating of the dewar itself would eliminate this source of temperature variation.

5 Control of the iodine cell temperature

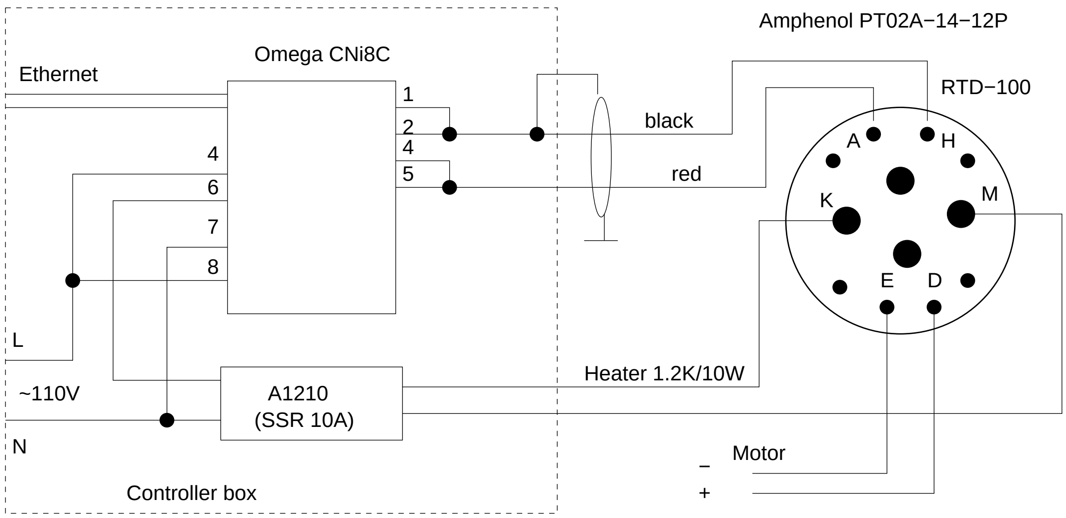

Figure 13: Schematics of the Omega controlled used for the iodine cell.

The iodine cell is located inside CHIRON in a thermo-insulated container. During first year of CHIRON operation it was controlled by the Cole-Parmer device with a thermo-couple as a sensor. In 2012 the cell was wired to the Omega controller used previously for CHIRON stabilization (Fig. 13). The 10A solid-state relay is no longer necessary (the Omega can control up to 1 A current while the heater uses only 0.1 A), but it is left in place. The thermo-couple is replaced by the RTD-100 sensor. The cable connecting controller to CHIRON also contains two wires for the linear actuator that moves the cell in and out. [**Settings of Omega?**]

The Omega controller is connected by Ethernet to monitor remotely the set-point and temperature. The cell is maintained at +40°C with fluctuations not exceeding ±0.2°C.