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MEMORANDUM

Test results on HARPS iodine cell #1

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Date: 14 Feb 2002

Subject: Test results on HARPS iodine cell #1

Summary:

This memorandum summarizes measurements made at La Silla of the first (#1) manufactured iodine cell for HARPS. All measurements were made with the CES at a resolving power of $R = 205,000$, but the subsequent analysis was performed on the spectra convolved in the subsequent analysis to $R = 100,000$.

The HARPS iodine cell #1 has very good transmission, but iodine absorption line depths are somewhat lower than expected (i.e. compared to the iodine cell in use with UVES). The temperature stability of the line depths falls short of expectations by over an order of magnitude. Possible reasons are (a) a too low iodine content or (b) strong condensation inside the sideward connector tube complicating temperature control.

Some general properties of iodine cells

Wavelength range

Molecular iodine produces absorption lines redward of ≈ 5000 Å. The higher the gas temperature and the iodine vapour content of an iodine cell the further the absorption spectrum extends towards the red. Typical iodine cells for astronomical applications are operated at temperatures of ≈ 50 – 70°C and produce iodine absorption lines roughly between 5000 Å and somewhat beyond 6000 Å. As an example, and our major comparison, the UVES iodine cell, operated at 70°C, still has useful lines (at the several percent line depth level) at H_α, i.e. at 6563 Å. Iodine cells used in the laboratory at several 100°C can produce absorption lines to beyond 8000 Å.

For HARPS we aim at an operating temperature of no more than 70°C as the cell is located in front of the HARPS fibre in the Cassegrain adapter. At the same time, useful lines at H_α (6563 Å) are desired as they have possible astronomical applications, e.g. high precision RV work for pulsations of white dwarfs that show only this Balmer line within the useful range of the iodine cell.

Line depth

The observed depths of the iodine absorption lines depend on the vacuum in the cell, the operating temperature, and saturation. High pressure broadens the lines, high temperature makes them stronger and increases the evaporation of iodine cristals to a saturation level.

Deeper lines are more useful for precise wavelength (radial velocity) calibrations as the error propagation of the photon noise error to the velocity error goes with the inverse gradient of the spectral flux.

Transmission

The overall transmission through the cell decreases with increasing strength of the observed absorption lines usually accompanied by some reduction of the level of the quasi-continuum.

Therefore, in order to obtain deeper lines some loss in photon statistics is unavoidable.

Requirements given to manufacturer

The cuvettes of the HARPS iodine cells were produced by HELLMA, Müllheim/Baden, Germany, and filled with iodine by Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany. At present the first of (three) cuvettes has been filled and delivered to La Silla for testing.

Of the requirements given to PTB the following two concern us here:

Requirement #1:

Properties of the iodine spectrum: Iodine line depth and transmission through the iodine cell heated to 70°C as measured at a resolving power of $R = 100,000$ as a function of wavelength:

Wavelength [nm]	500	510	530	560	600	630	650	660
Line depth [%]								
strongest lines	23	63	85	71	51	29	9	6
average line	12	32	43	36	26	15	5	3
Transmission [%]:								
in quasi-continuum	18	41	62	71	72	70	70	70
total	15	28	41	49	62	69	70	70

Note: These value have a tolerance of about ±10%. The transmission will be lower, if the lines are stronger.

Requirement #2:

Around an operating temperature of $70 \pm 1°C$ the change of the iodine line depth should be $< 0.2\%$ per degree over the wavelength range $5000 - 6000$ Å.

As PTB could not provide us in advance with clear characteristics of the iodine cells (whose physical dimensions are tailored for the HAPRS Cassegrain fibre adapter and non-standard for them) and could not evaluate our requirements (which were based on measurements of the UVES iodine cell), it was decided that PTB would send us one cell after filling and await our feedback before proceeding with filling the remaining two. Eventually, the best-quality cell will be selected for use in the HARPS Cassegrain fibre adapter.

Measurements made

The CES sepctrograph was used at a resolving power of $R = 205,000$ together with its white-light flatfield lamp to obtain iodine absorption spectra for the characterization of HARPS iodine cell #1. In the later analysis the spectra were convolved (with a Gaussian) to $R = 100,000$, i.e. the value for which our requirements had been established based on the comparison with our data of the UVES iodine cell (taken at this value of R), and also a value closer to the resolving power HARPS will have ($R \approx 90,000$).

The following measurements of the HARPS iodine cell #1 were made: Iodine absorption line depth and transmission through the cell at the foreseen operating temperature of 70°C as well as measurements of the dependancy of transmission and line depth on temperature.

These measurements were made at the following wavelengths:

- 5000 ± 17 Å: this is the (most blueward) region were iodine absorption lines begin to appear.
- 5395 ± 18 Å: this is a representative wavelength for the region of the strongest iodine lines (and well-known as we use it with the CES).
- 6000 ± 19 Å: near this wavelength the iodine lines in several iodine cells in use for astronomical applications become weak.
- 6563 ± 23 Å: this region is centered on H_α and of astronomical interest.

In addition the transmission and line depth at 70°C were measured at the wavelengths

- 3994 Å: CaII K line; this major indicator of stellar activity provides useful ancilliary information in precise radial velocity studies.
- 4340 Å: H_γ.
- 4861 Å: H_β.
- 6708 Å: LiI line useful for estimating stellar ages.

Bluewards of ≈ 5000 Å the iodine cell should become transparent and produce no absorption lines. At the wavelength of the LiI region iodine lines are expected to be very weak.

Results

The results of these measurements are be summarized by the following table. Line depth measurements (after convolution of the spectra to $R = 100,000$) are corrected for a 7% flux offset corresponding to a diffuse background known to be present in CES spectra.

Wavelength [nm]	399.4	434.0	486.1	500.0	539.5	600.0	656.3	670.8
Line depth [%] at 70°C:								
strongest lines	0.0	0.0	0.0	11.7	66.7	40.0	4.1	1.9
average line	0.0	0.0	0.0	6.4	42.6	22.4	2.2	0.9
Transmission [%] at 70°C:								
in quasi-continuum	83.1	82.8	52.3	43.3	75.8	81.5	81.6	84.1
total	83.1	82.8	52.3	40.8	56.6	69.7	80.3	83.5
Temperature stability at 70°C:								
Transmission change per degree [%] (total transmission)				−3.1	−1.2	−0.75	−0.23	
Line strength change per degree[%] (relativ to quasi-continuum)				2.9	1.4	2.0	4.5	

The variation with temperature of the transmission through the cell and of the absorption line depth is shown in Figs. 1 and 2, respectively, for the tested wavelengths which are labelled on the plots.

Conclusion

While the transmission through HARPS iodine cell #1 is better than expected, the line depth is somewhat less than envisaged especially in the extremes of the useful range. (The line depth is, however, strong enough to contaminate the LiI region; if the iodine lines present are regarded as "noise", i.e. their detailed structure is ignored, the limiting achievable signal-to-noise ratio is $S/N = 260$.) The most important observed effect is, however, that the temperature stability of the line depth exceeds the requirement by a factor $7 - 14.5$ (depending on wavelength). It falls short of the line depth stability of both the UVES and CES iodine cells by more than a factor 20.

It appears that the delivered iodine cell is not producing saturated iodine lines at $T = 70°$C and that the temperature-related changes of the iodine partial pressure are larger than desired for high spectral stability in a future application where the windows of the cell will be exposed to an open environment with strong fluctuations of outside temperature (Cassegrain adapter of the ESO 3.6m telescope).

A proposed alternative for the use of the HARPS iodine cell #1 is in the calibration unit, where an iodine cell is also foreseen for test purposes. Thus it will which will be located in a climatized environment in the Coudé room. The temperature of can be controlled to 0.1°C thereby ensuring sufficiently stable spectra for test applications.

A probable reason for the temperature sensitivity of the iodine absorption lines is too strong condensation of iodine in the tube that, in the manufacturing process, connected the iodine cell with the vacuum pump and was then sealed off by melting; this tube is a narrow appendage sticking out at a right angle from the mantle of the cylindrical cuvette (the main cell). This appendage is longer than in other iodine cells used for astronomical purposes (e.g. with UVES, CES) and makes temperature control and equilibration difficult. Another possibility is that the amount of iodine inserted during the filling was not large enough to ensure saturation.

I am asking our contact at PTB, Dr. Uwe Sterr, to comment on this conclusion and to consider adequate improvements (if any) during the filling of the remaining two cells. La Silla should also consider whether further improvements are possible in the currently used heating mechanism.

Martin Kürster

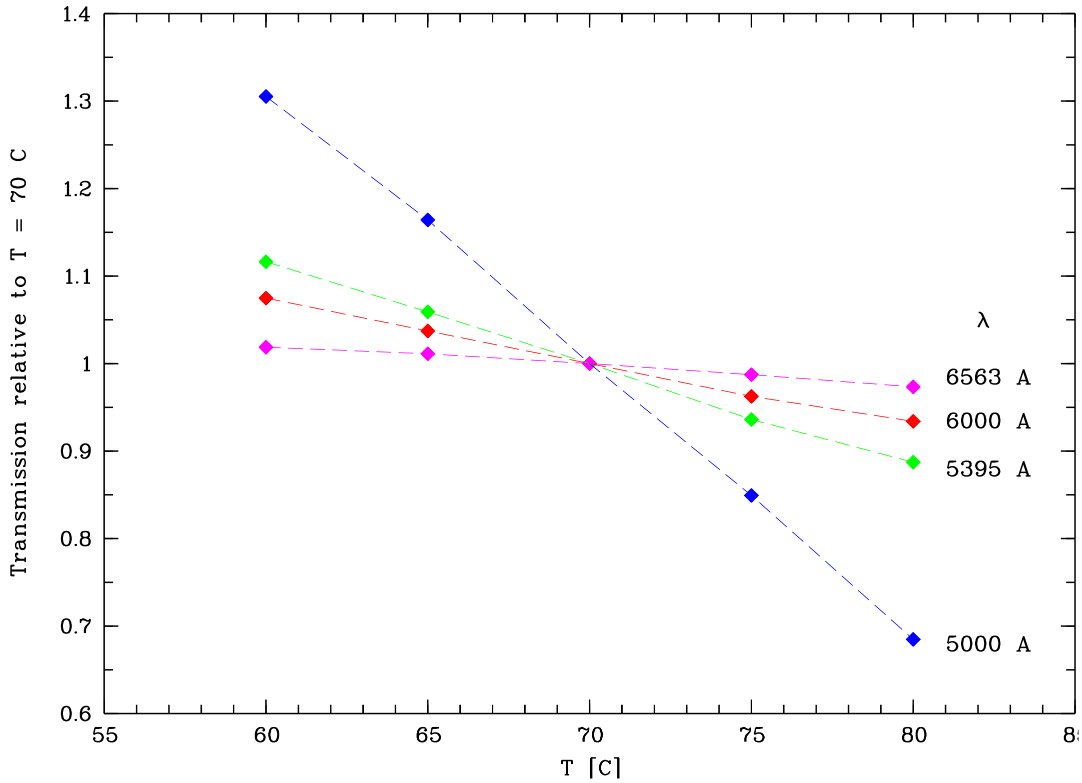

Fig. 1: Variation of the transmission through HARPS iodine cell #1 (relative to the transmission at 70°C) as a function of temperature for the tested wavelengths.

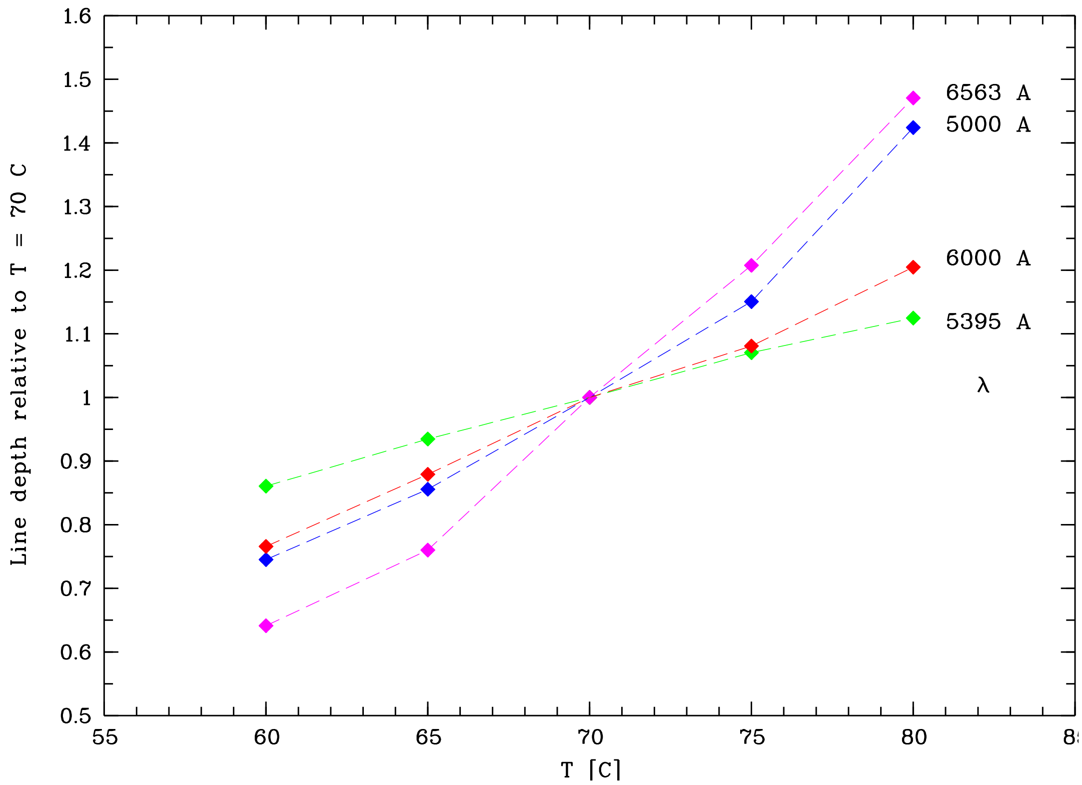

Fig. 2: Variation of the absorption line depth produced by HARPS iodine cell #1 (relative to the line depth at 70°C) as a function of temperature for the tested wavelengths.