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Test of the relation between wave-like disturbance of the quasi-continuum and physical conditions of the optical fiber

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The reduction of echelle data (and fiber-fed echelle data especially) is a quite complicated process since there are many unpredictable effects; they may evoke some instabilities in exposed spectra. As consequence of these, there are problems with merging spectral orders – merged continuum exhibits characteristic wave-like patterns. Of course, these structures complicate broad lines measurement (H_α etc.) – thus it is advisable to describe all complications and effects and minimise them, if possible. We have put main accent to the temperature and torsion influences.
We will continue with experiments described in this paper; final results and some summary will be published in future.

Keywords: Astrophysical Data – Echelle Spectrographs

1 Introduction

The continuum (or better "quasi-continuum" of the stellar spectra exposed in fiber-fed echelle spectrograph HEROS very often presents a wave-like disturbance, but, unfortunately, this behaviour is quite chaotic. The presence of wave-like patterns and their intensity[1] do not depend on the spectral type of the star, intensity of the spectrum etc. – see Fig. 1. One can find (weak) relation between wave-like structure and the exposure time but, nevertheless it is not unambiguously predictable: nobody can say that extremely long exposure time will lead to the strong wave-like patterns.

The existence of the perturbation is really serious problem as it makes study of wide lines (as H_α) complicated, or even impossible – see Fig. 1.

We put effort to description of this behaviour. Some experiments we have made are described in this paper. Therefore we divided this paper to several parts: in the sections 2.1 and 3 we present the influence of the optical fiber (the temperature and deformation); next, we switched on/off mirrors for flat field and comparison light exposures (called foldable mirror herein) and look for the stability of the system – see the section 4. It is found that the optical fiber play fundamental role (first suspicion about the influence of fiber on the quality of echelle spectra was articulated by Baudrand and Walker (2001) and confirmed by Rivinius (2002)), while switching of the mirrors has no influence (i.e. the system is stable).

In the section 5 we describe the experiment with dome temperature. All results are summarized in the section 6.

2 Tests of the position of the optical fiber

2.1 Description of the experiment

We have tested some effects which could perhaps increase the perturbation. The position and physical condition of the fiber was supposed to be one of the strongest influences.

We realised these experiments on Friday, May 31th, 2002. The Dewar's bottles, both in red and blue channel, were re-filled 1.5 hours (18:00UT) before experiments in order to reach stable state.

In the beginning we have exposed some offsets (i.e.

[1] The dispersion scale of the structure is equal to one spectral order

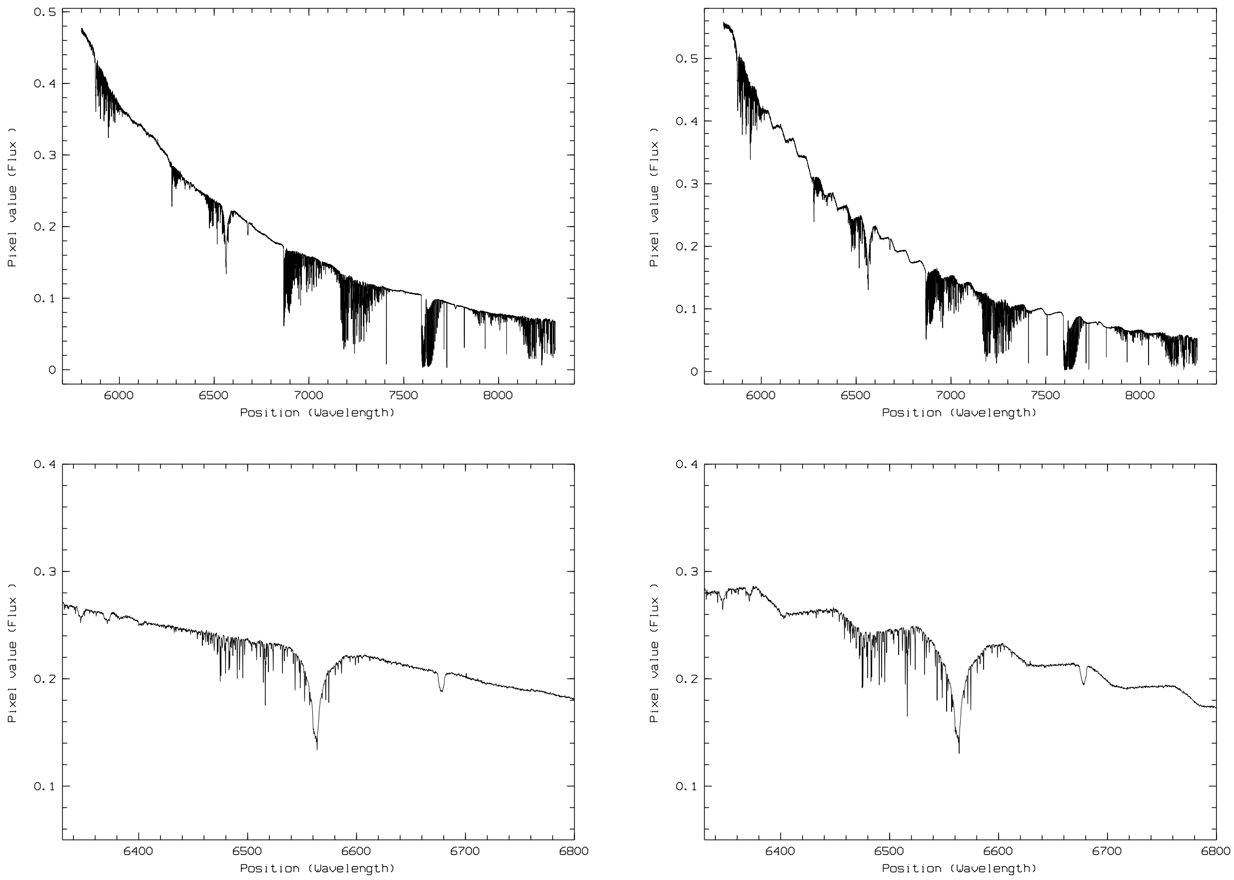

Fig. 1: The existence/non-existence of wave-like patterns in spectrum of η UMA. It is not possible to predict (until reduction process is finished) whether quasi-continuum will be flat or perturbed. Unperturbed spectrum is on top left and detail of H_α region on left bottom; perturbed spectrum is on top right. It is almost impossible to define continuum (and normalise it) in perturbed H_α region (right bottom).

we have exposed dark with zero exposure time) although usually offsets are not exposed (the background is determined in inter-orders space[2] separately in each frame). Then the telescope was fixed in the vertical position.

Next, we have put the optical fiber in certain fixed position and exposed a set of four flats. Afterwards we changed the position of the fiber and exposed another set of four flats. This process was repeated in five different positions. The flat field lamp was switched on all the time. Then we have taken a 1 hour pause to cool the lamp.

Finally, we exposed five groups of comparison ThAr spectra (three in each of groups) to compare shifts (if they are present) along dispersion.

2.2 Experiment: realisation

Position A: Files `9003-9006`
Optical fiber is in arbitrary position on the floor; we did not put it to any specific position.

Position B: Files `9007-9010`
Optical fiber is coiled up to a narrow spiral (large curvature of the fiber) laying on the floor.

Position C: Files `9011-9016` (file `ra9013.at1` is missing due to error in the exposure).
The fiber is coiled to a narrow spiral hanging down from a chair (vertical spiral).

Position D: Files `9017-9020`
The fiber is hanging down from the Cassegrain focus to the floor, then it is elevated up to 2 meters and hanging again down to the spectrograph.

Position E: Files `9021-9024`; file `ra9022.at1` is quite weak, maybe due to some random error in shutter; we did not use this file (but it is depicted in Fig. 2).
The fiber is in the same position (in order to test repeatability) as in the **Position A**.

[2] The inter-order space is an area between orders where no light (or only scattered light) is supposed

We have checked several points (on the CCD chips) to test of shifts along the cross-order profile – see. Table 1

Camera	
Red (x, y)	**Blue** (x, y)
Cross-order shifts	
376, 1101	*409, 1901*
320, 775	409, 1808
330, 693	419, 1358
364, 655	*409, 785*
368, 221	
362,59	
Along-dispersion shifts	
322, 1049	651, 1949
196, 689	39, 1850
197, 467	*309, 1901*
328, 57	331, 1511
100, 29	403, 731
376, 35	415, 290
	325, 395
	491, 392

Table 1: List of points used to tests of cross-order shifts. Slanted letters denote points where we printed shifts to the graph Fig. 2

Shifts along cross-order profile and also along dispersion are shown in Fig. 2; the numbering of panels in the figure follows the scheme in the Table 2:

Fig.	
1	2
3	4
5	6
7	8

Table 2: Configuration (numbering) of the Fig. 2.

3 Testing of the temperature influence of the optical fiber

In the following experiment we have tested the dependence of shifts (shifts across the order and along columns of pixels) on the temperature in the fiber.

3.1 Description of the experiment

We have put the telescope in the fixed position (same position as in the previous sections 2.1 and 2.2). Then we wrapped the optical fiber round the metal pot and fixed it in that position.

Next, we exposed a sets of flats under different (but controlled) physical conditions.

3.2 Experiment: realisation

Stabilisation of the fiber: Files `0001-0004`
We waited for about 10min in order to stabilize the physical condition of the fiber. Then we exposed the first set of 4 flats.

Heating 1: Files `0005-0008`
We filled the pot with 1 liter of the boiling water, waited for some time and exposed the following set of flats.

Heating 2: Files `0009-0013`
We poured on the 1l of the boiling water again, waited and exposed the following set of flats.

Drying: Files `0014-0016`
We dried the pot (files `0014-0015`) and exposed 3 flats while the pot was still hot.
Next flat we exposed with the pot warm (not hot) - file `0016`.

Cooling: Files `0017-0020`
We filled the pot with a small amount of liquid nitrogen and exposed file `0017`.
The nitrogen evaporated, nevertheless the pot was very cold, with hoarfrost on the bottom (exposed files `0018-0020`).

Test flat: Files `0021-0023`
We waited in order to balance the temperature of the fiber, put the fiber on the floor and (after some minutes) exposed test flats.

Shifts along cross-order profiles are depicted in the Fig. 3

4 Influence of switching the foldable mirror on/off on the stability of the optical path

Another question which had to be solved was the stability of the optical path inside the HEROS spectrograph. We tested whether movable optical elements perturb output signals. The FF and ThAr light is thrown to the optical fiber by foldable mirror; there is a question whether the position of the mirror is repeatable, i.e. whether the final picture on the CCD chip is stable.

4.1 Description of the experiment

We fixed the telescope and even the optical fiber in arbitrary (but stable) position. Then we exposed sets of flats while moving the mirror and switching on/off the FF lamp.

Remark: In the following text we abbreviate the *star* position of mirror to the symbol *
Numbering files follow previous temperature experiments.

4.2 Experiment: realisation

Set A: Files `0024-0026`
We exposed file `0024`, toggled the mirror five times and then exposed files `0025-0026`.

Set B: Files `0027-0029`
We switched the FF-lamp off, toggled the mirror 5 times $\star \leftrightarrow$ FF, switched the FF-lamp on and exposed files.

Set C: Files `0030-0031`
We re-filled the Dewar bottle with nitrogen, waited for 20min (in order to stabilize the spectrograph) and exposed two files.

Set D: Files `0032-0033`
We moved the mirror 5 times again $\star \leftrightarrow$ FF (with FF-lamp switching on) and exposed files.

Set E: Files `0034-0035`
We switched the FF-lamp off, toggled the foldable mirror 5 times $\star \leftrightarrow$ FF, switched the FF-lamp on and exposed files.

Shifts along cross-order profiles are depicted in the Fig. 4

5 Temperature variability in the dome

It is not sufficient to look for the temperature variability in the fiber since the whole spectrograph HEROS is situated in the dome; as a consequence it is not possible to keep the spectrograph under the fixed temperature. Therefore we have realised the second temperature experiment, simulating a realistic observation.

The telescope was kept in the fixed position, Dewar bottles of both HEROS cameras were re-filled 1.5 hours before our experiments.

The dome was opened and flat fields were exposed immediately in a long sequence.

The variability of blaze functions and cross-order profiles were studied as a possible source of wave-like disturbances – see Fig. 7.

6 Main results: cross-order profiles and profile along columns of pixels

Shifts in cross-order profiles and shifts along columns do not play a fundamental role in the creation of wave-like patterns. They may be just a consequence of a influence of the local noise on the centering algorithm (the typical width of the order is several pixels).

There is another effect which should be much more interesting (and important) in the presented problem: the variability of profiles along columns and cross-order profiles.

6.1 Experiment with the position of the optical fiber

In this section we present (see Fig. 5) the variability of the cross-order profile and the column-wise profile as a consequence of a deformation of the optical fiber. We have averaged flats exposed in one configuration of the fiber:

$$\begin{array}{rcl}
\mathrm{ba9003, ba9004, ba9005, ba9006} & \longrightarrow & \mathrm{c9003} \\
\mathrm{ba9007, ba9008, ba9009, ba9010} & \longrightarrow & \mathrm{c9007} \\
\mathrm{ba9011, ba9012, ba9013, ba9014} & & \\
\mathrm{ba9015, ba9016} & \longrightarrow & \mathrm{c9011} \\
& \vdots &
\end{array}$$

and the same for the red channel. Here `c****` is the averaged picture; its number follows the number of the first averaged raw `ba****` file.

It is possible to summarize that the effect of the deformation the optical fiber play a considerable role mainly in the red channel: the cross-order profile is different from file to file (cf. `c9011`×`c9021` – Fig. 5 lower row left).

6.2 Temperature experiment

First of all we averaged files exposed in one set of flat and in one fiber configuration (and/or physical conditions):

$$\begin{array}{rcl}
\mathrm{ba0001, ba0002, ba0003, ba0004} & \rightarrow & \mathrm{c0001} \\
\mathrm{ba0005, ba0006, ba0007, ba0008} & \rightarrow & \mathrm{c0005} \\
\mathrm{ba0009, ba0010, ba0011, ba0012} & & \\
\mathrm{ba0013} & \rightarrow & \mathrm{c0009} \\
\mathrm{ba0014, ba0015, ba0016} & \rightarrow & \mathrm{c0014} \\
\mathrm{ba0017, ba0018, ba0019, ba0020} & \rightarrow & \mathrm{c0017} \\
& \vdots &
\end{array}$$

and the same for the red channel. Here `c****` is the averaged picture; its number follows the number of the first averaged raw `ba****` file. Results are depicted in the Fig. 6. As one can see, cross-order profiles are (relatively) reproducible, except for file `c0017` which corresponds to the "frozen" fiber. The intensity of the flat is considerably lower.

Moreover, it is important to point out the fact that the red cross-order profile of the "frozen" fiber is quite different (even in the shape) as one can see on the Fig. 6, second row left.

6.3 "Toggling mirror" experiment

Next, we toggled the foldable mirror in the Cassegrain focus (just in front of the the optical fiber) and studied the stability (or variability) of the cross-order profile and column-wise profile. The result of the experiment is presented in the Fig. 6 below (third and fourth row).

As one can easily see, the reproducibility of files is very good; foldable mirror does not contribute to the cross-order profile and column-wise profile variabilities.

6.4 Blaze function variability in the red camera

As we could see (see Fig. 5 and 6), orders in the red camera are slanted and therefore it is not possible to watch deformations (if present) immediately on the profiles along the dispersion. Therefore we have extracted by the reduction pipeline the final order-by-order spectra (influenced mainly by the blaze function of the grating). We concentrated on the realistic dome temperature experiment to estimate the scale of the expected disturbances. Three interesting orders are shown on Fig. 7. The left panels show the enlarged central part of the blaze function (different grayness depicts the separate groups of flats) while the right ones demonstrate the origin of wave-like disturbances. We have just divided order by order the most different flat blaze functions representing the largest difference in dome temperature.

7 Conclusions

The observed wave-like deformations of the continuum in most of stellar spectra complicate the study of wide spectral lines (for example, H_α is spread over 3 spectral orders in HEROS). Therefore it is important to find the most considerable effects which lead to the deformation of the continuum and determine (if possible) the optimal observational routines which should minimize such effects.

We made a lot of experiments in order to get a quantitative estimation of such effects. We have found that the switching of the foldable mirror (situated in front of the optical fiber) does not play any observable role in the formation of wave-like patterns. On the other hand, deformation of the optical fiber and a temperature variability plays a considerable role.

It is important to point out that the HEROS was re-configured on June 3th, 2002, by Thomas Rivinius. This maintenance improved the PSF of the spectrograph and eliminated the cross-order asymmetry observed before. The wave-like patterns decreased since that time, nevertheless they were not fully eliminated. Therefore it will be necessary to repeat all experiments again with the new configuration. The main accent will be put to the quantitative description of all effects and, as we hope, we will be able to describe some other effects, not observed yet. The final effort should be given to the development of an algorithmic transformation eliminating the wave disturbances on all orders before the final (already simple) merging to one long spectrum.

Acknowledgement

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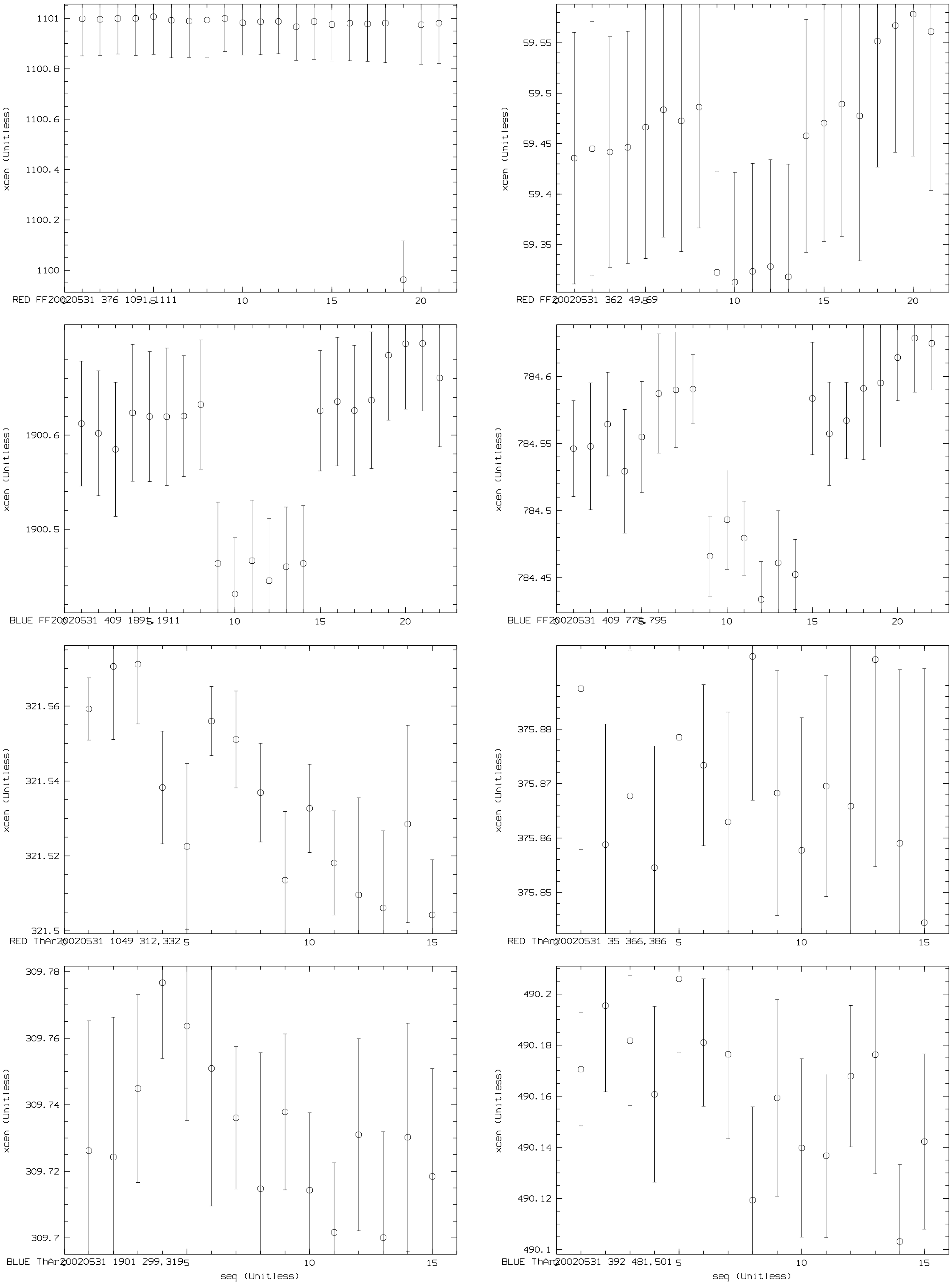

Fig. 2: Shifts along cross-order profile due to a deformation of the optical fiber. 1: shifts in upper part of the red chip. 2: shifts in lower part of the red chip. 3: shifts in upper part of the blue chip. 4: shifts in lower part of the blue chip; Shifts along dispersion: 5: shifts in upper part of the red chip. 6: shifts in lower part of the red chip. 7: shifts in upper part of the blue chip. 8: shifts in lower part of the blue chip.

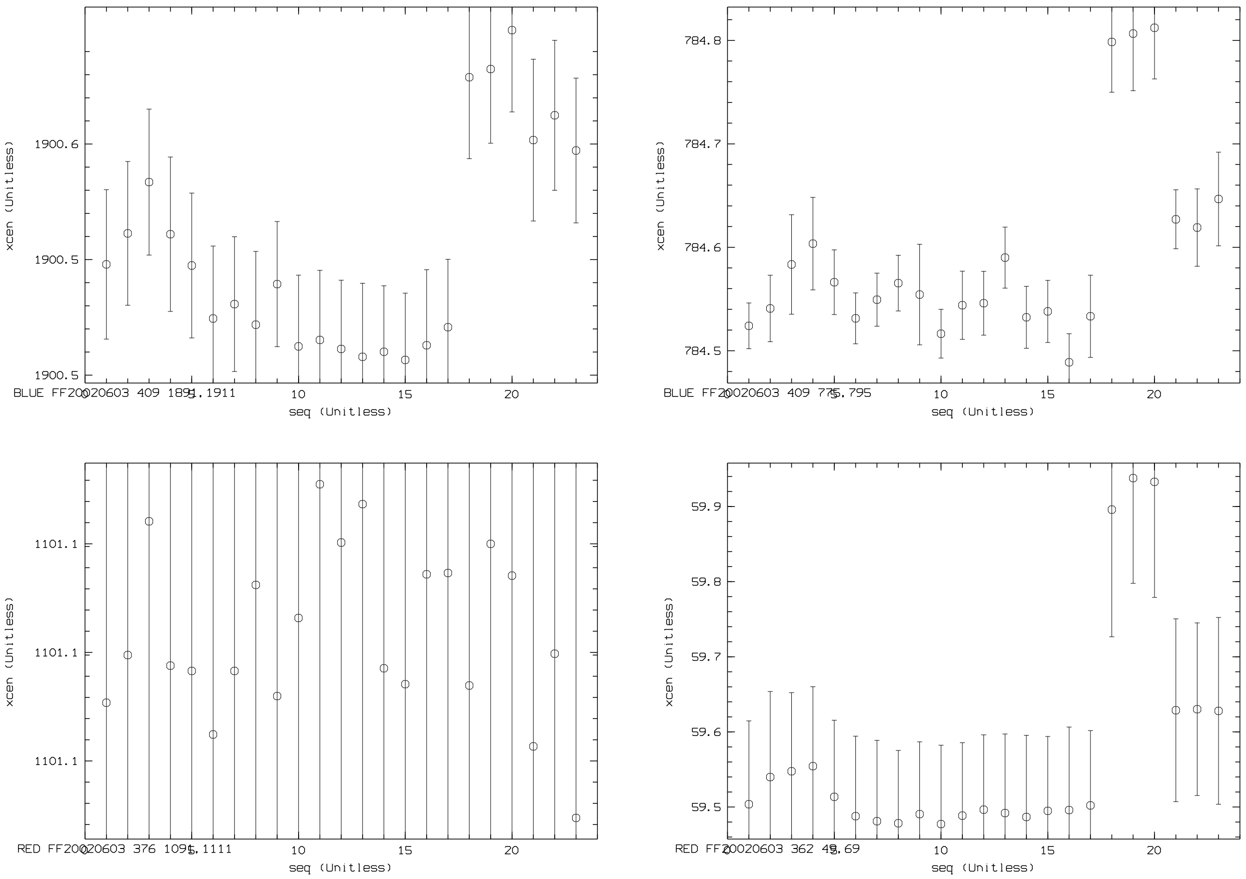

Fig. 3: Shifts along the cross-order profile due to the temperature variability. First row: the blue channel. The second row: red channel. The reference point (in which shifts were measured) in pictures 1÷4 correspond to the Table 1.

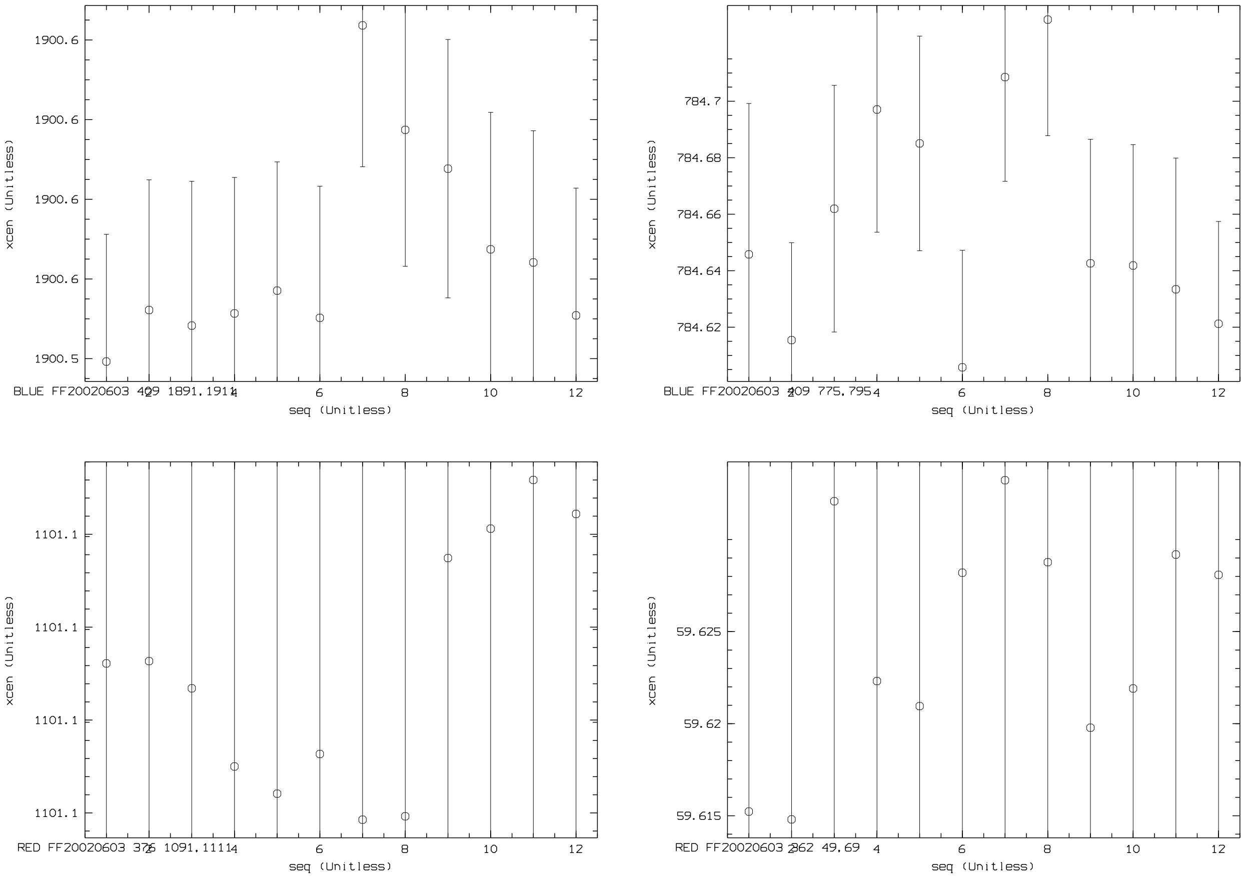

Fig. 4: Shifts along the cross-order profile due to the toggling the foldable mirror and switching the FF-lamp on/off. First row: the blue channel. The second row: red channel. The reference point (in which shifts were measured) in pictures 1÷4 correspond to the Table 1 and also to the Fig. 3.

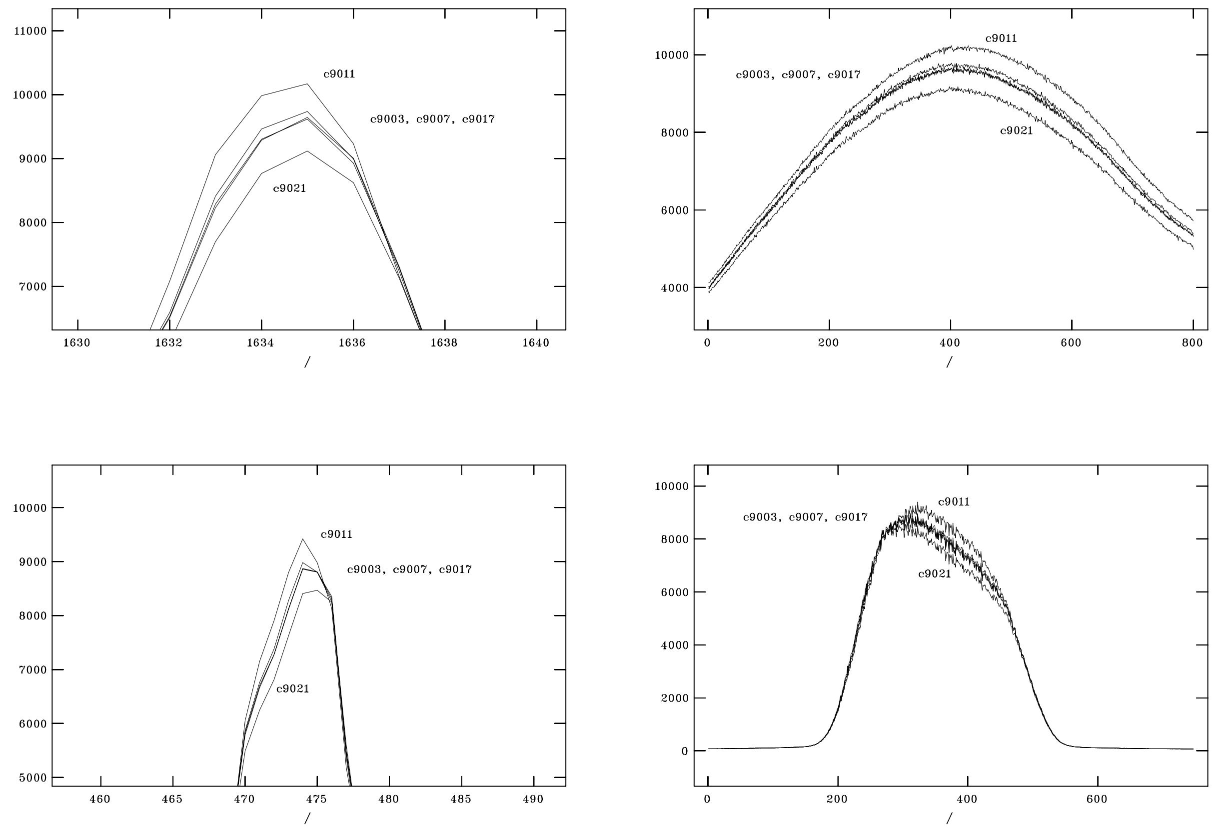

Fig. 5: Variability of the cross-order profile and column-wise profile (i.e. profile along columns of pixels) due to the deformation the optical fiber.
The column-wise profile in the red channel is deformed (apparently is not spread over full width) due to the considerably *slanted* spectral orders in the red camera.

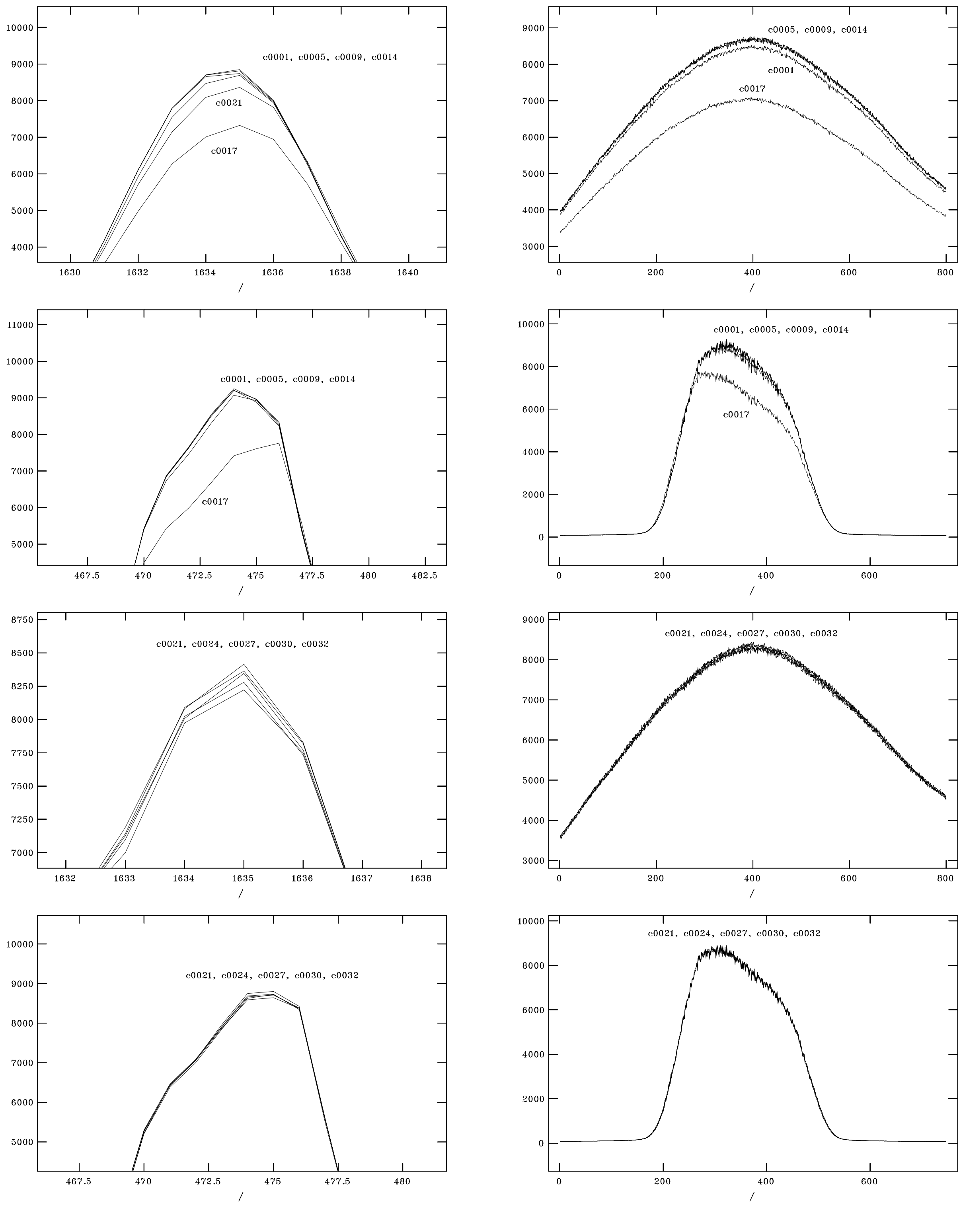

Fig. 6: Variability of the cross-order profile and the column-wise profile due to the temperature influence (averaged files – see text); cross-order profile is always on the left-hand side while column-wise profile is always on the right-hand side in the blue channel (first row) and the red channel (second row). The column-wise profile in the red channel is deformed (apparently is not spread over full width) due to the considerably *slanted* spectral orders in the red camera. The effect of the toggling the foldable mirror in the blue (third row) and red (fourth row) channel.

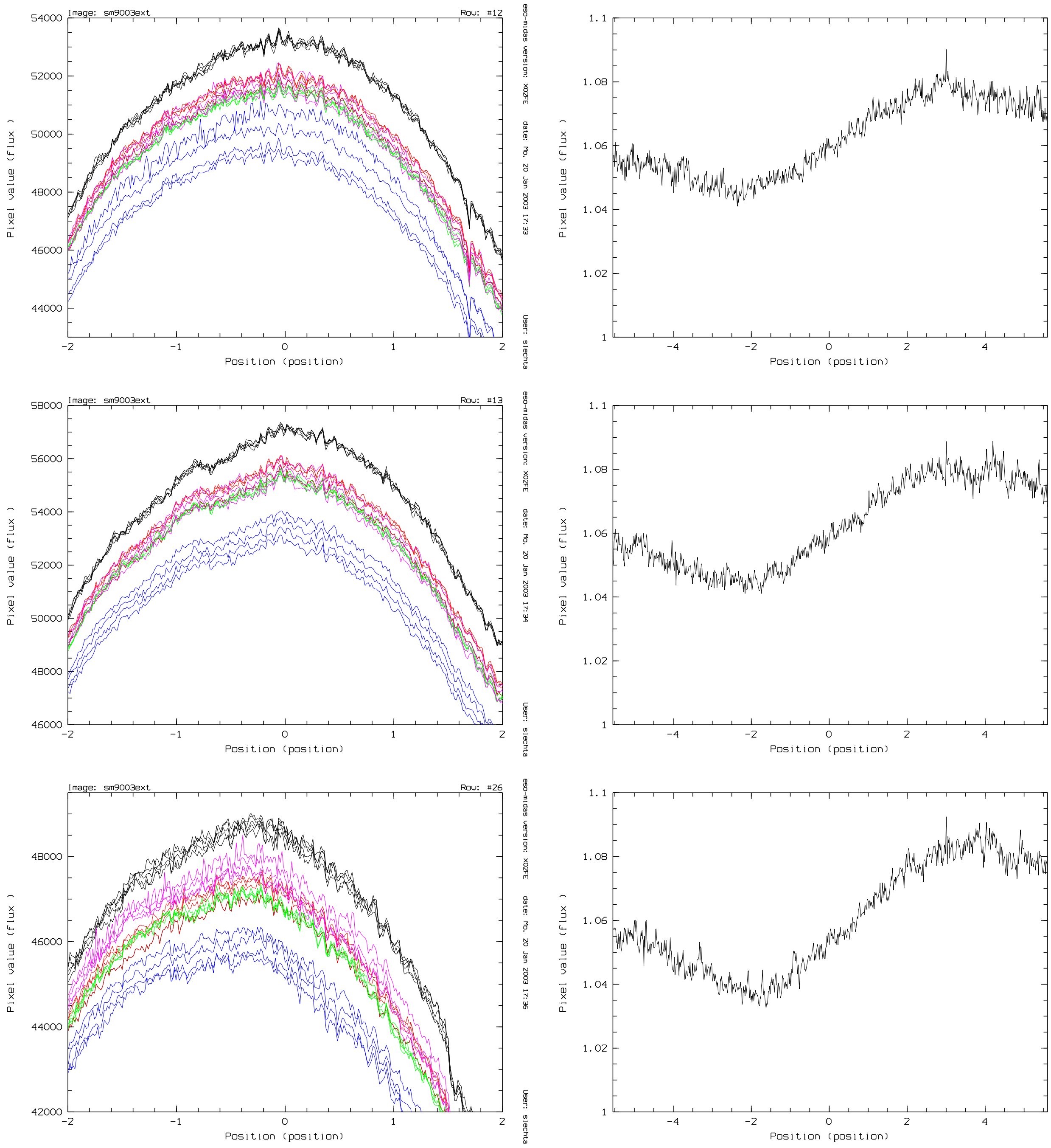

Fig. 7: The variability of the flat fields as a result of temperature experiments. Left panels: enlarged center of blaze function; right panels: division of two flats. Wave-like patterns are seen. First row: 12th order (neighbourhood of H_α); second row: 13th order (neighbourhood of He6678); third row: 26th order.