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Merging of Spectral Orders from Fiber Echelle Spectrographs

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Abstract. We review the data reduction of two fiber-based echelle spectrographs (HEROS and FEROS) with emphasis on the similarity of the inconsistencies between the overlap of spectral orders before merging.

The literature on echelle data reduction shows that such inconsistencies are commonly observed and usually handled by rather heuristic interactive procedures.

For both instruments it seems to be the calibration unit that introduces the bulk of the problem through errors in the flat field. We discuss strategies to treat the problem and to remove the inconsistencies before merging the spectral orders with minimal use of interactive, subjective algorithms.

1. Introduction

Merging spectral orders from echelle spectra is known to be non-trivial. Some manuals of echelle spectroscopy even advise against trying it. Authors who do the merging usually report problems and try to solve the order inconsistencies by some heuristic interactive method (Churchill 1994; Hall et al. 1994; Erspamer & North 2002). Recently, De Cuyper & Hensberge (2003) commented on a study of calibration flat-fields taken with the FEROS fiber-fed echelle spectrograph at ESO and pointed out several effects influencing the merging. In this contribution, we present the results of an extended analysis including special calibration flat-fields, dome flat-fields and science exposures of bright objects. The results obtained from FEROS were compared, where possible, to red-channel exposures made with HEROS at Ondřejov observatory.

2. Spectrographs

A detailed description of both instruments can be found on web pages of FEROS[1] and HEROS[2] respectively. FEROS is a 2-fiber spectrograph covering a wide spectral region (3600–9000 Å) in 39 spectral orders. It is particularly suited to distinguish effects that are related to blazed spectral orders from optical projection effects since the bluest spectral orders are much narrower than the size of the detector while the reddest orders are covered over a bit less than their free spectral range. FEROS operates in a temperature and humidity controlled room. HEROS is a one-fiber instrument developed earlier by the same team in Heidelberg, as a compact echelle spectrograph that has been used at several telescopes. Since August 2000 it has been connected for more than two years to the 2m telescope of Ondřejov observatory. The light from the telescope Cassegrain focus is fed by the 10m long fiber to the echelle grating and then, after the beam-splitter, it goes to two independent channels: blue (3600–5600 Å in 70 orders) and red (5800–8400 Å in 32 orders).

2.1. Experiences with FEROS

The projection of the spectral orders on the detector over an observing run of 4 nights was stable in the wavelength direction at the level of 0.1 pixel (except for an explained, and meanwhile removed oscillation, due to short-term temperature fluctuations of 1 K in the FEROS room) and in the spatial (cross-order) direction at the level of 0.5 pixel (Figure 1).

However, the position of the blaze profile in wavelength changed by of the order of 10 pixels (i.e., 10^{-4} of the wavelength) in a highly correlated way with the changes in spatial direction (Figure 1). These slow temporal changes apply as well to calibration unit flat-fields as to dome flat-fields or scientific exposures. Such changes, if not taken into account when flat-fielding a science frame, lead to inconsistencies at the level of several percent of the flux in the overlap of spectral orders. The data suggest a very similar shift of the blaze function over all orders in the case of FEROS, leading to larger overlap mismatch in the narrower orders in the blue spectral region i.e., with larger gradients in the blaze function.

2.2. Experiences with HEROS

Temporal changes in the blaze profile are detected on shorter time-scales, which is presumably related to the fact that the spectrograph is operating in the dome and not in a controlled room. The changes vary smoothly over subsequent orders, but cannot be represented by a simple small shift in wavelength of the blaze function. This may be related to the fact that the blaze profiles produced by HEROS are not so near to the theoretical predictions than in the case of FEROS: the blaze profiles of different spectral orders are almost identical when expressed in the coordinate

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[1] `http://www.ls.eso.org/lasilla/Telescopes/2p2T/E1p5M/FEROS/index.html`

[2] `http://www.lsw.uni-heidelberg.de/projects/instrumentation/Heros`

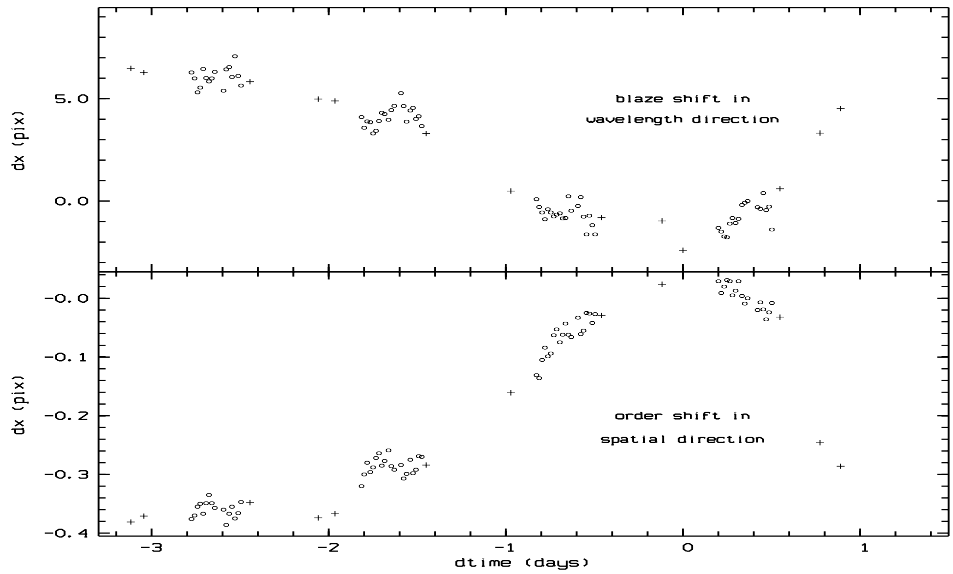


Figure 1. FEROS — time evolution of the position of the spectral orders in cross-order direction (lower part) and the shift of the blaze function along the spectral order (upper part) during an observing run. Flat-field images (+) and science frames (o) are indicated with different symbols.

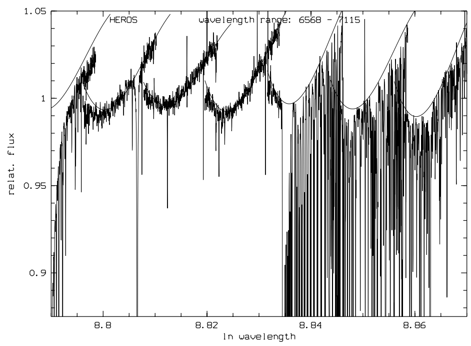
$$\frac{\nu}{2\pi} = \frac{m}{2}\left(\frac{\lambda_b(m)}{\lambda} - 1\right)$$

where m refers to the spectral order, λ to the wavelength and $\lambda_b(m)$ to λ in order m at the peak of the blaze intensity. De Cuyper & Hensberge (2003) discuss the similar case for FEROS, but the shape and the width do not scale accurately in the same way for HEROS.

Since flat-fields are commonly taken with each science exposure at Ondřejov (because of the fast low-frequency temporal changes of the calibration images), efforts to address the order merging problems were directed to the study of the unblazed science frames rather than considering the calibration images and the science frames separately, as in the FEROS case.

In order to visualize the lack of consistency in the order overlap regions more clearly, we present figures where the global wavelength dependency of instrument and object is removed from the separate orders. This step, the normalization of the merged spectrum, comes last in a real data reduction chain.

Figure 2 shows the separate spectral orders and the level of inconsistency in the regions of spectral order overlap. Overplotted is a correction function with identical shape (in pixel space) in all 32 spectral orders, but smoothly varying amplitude. Dividing by this function reduces the inconsistencies in the overlap of spectral orders to well below the 1% level.



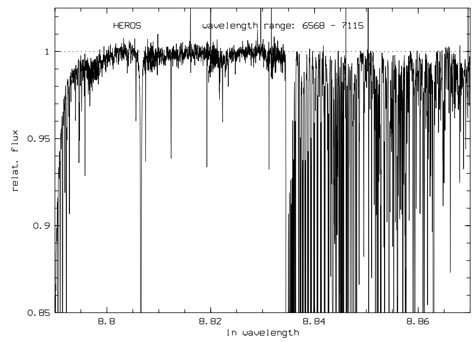


Figure 2. HEROS — seven spectral orders starting from the longward wing of Hα before (left panel) and after (right panel) correction

3. Conclusion

Analysis of data obtained by the fiber echelle spectrographs FEROS at ESO, La Silla, Chile and HEROS at Ondřejov, Czech Republic, identifies the high sensitivity of the shape and position of the blaze function as the primary source of order overlap inconsistencies. Since changes in the blaze function are very consistent over many spectral orders, and highly correlated with positional changes in the projection of orders on the detector, a robust empirical model can be developed. However, on a longer term, the origin of these effects should be understood such that action can be taken to stabilize the blaze function sufficiently.

If sufficient attention is paid to understand the calibration unit, in order not to introduce spurious low-frequency patterns in the flat-fielded science data, merging spectral orders becomes a trivial exercise.

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