The limitations of precise echelle data reduction

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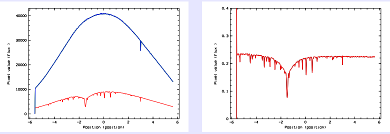
Abstract

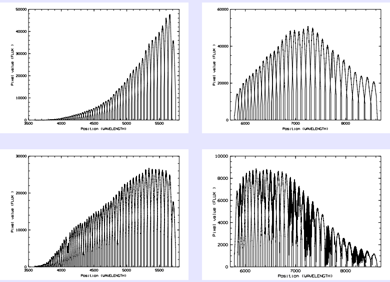
The most complicated task in echelle data reduction is the removal of the blaze function. The usual way of doing this is the division by the extracted profile of flat field, other star or the theoretical model. Such unblazing, however, is good only as a first approximation. There still remain residual structures giving after merging of orders wavy patterns in continuum shape. Their size - up to the 5% of continuum level - prevents the detailed study of line profile changes and can introduce considerable errors into equivalent width measurement, especially on shallow wide lines or on resonance lines with wide wings spread over several echelle orders. The inconsistencies seem to be dependent on the physical state of the instrument (fiber bending, temperature) and on the observing environment, but due to their random behaviour a time consuming individual treatment of each spectrum is required to achieve reliable results. We give examples of such perturbed data from HEROS spectrograph obtained by an automatic pipeline as well as the overview of our attempts to improve the merging of orders.

Sensitivity modulated blaze function

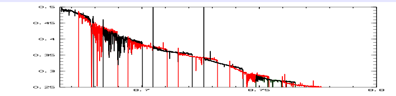
The widely used method of blaze function removal at most modern spectrographs is the division by the extracted flat field spectrum. This can help remove the fringing patterns and main part of blaze function. For fiber-fed spectrographs, where the cross-order profile of the star and flat is (almost) identical, the continuum should be very flat.



But the blaze profiles are still modulated by the slowly changing spectral sensitivity curve of flat field and stellar spectral intensity (including extinction). Following pictures show the typical HEROS blaze profiles modulated by the spectral intensity of the flat field (upper panels) and star η UMa (lower panels) in blue (left) and red channel (right).

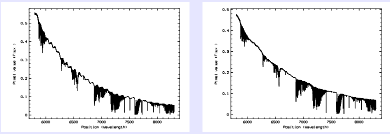


Even a very small discrepancy in the blaze function of flat field and star then causes the tilt of individual flat-fielded orders and introduces intensity gaps between the overlapping edges of successive orders.



The problem of merging of extracted echelle orders

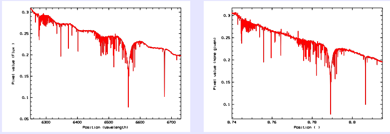
For early type stars, where hydrogen and helium lines are of great interest, the considerably wide line profile is spread over several echelle orders. Therefore the merging of orders together is required to see the whole profile with the surrounding pseudo-continuum. The merged spectra produced by standard HEROS pipeline show sometimes strange ripples on the continuum. Their occurence seems not to be correlated with the position of the telescope, spectral type of the star or the exposure intensity. As their presence is a serious problem for the study of line profiles and measuring equivalent widths we began the study of conditions under which they can show themselves. Following figures show the same star η UMa exposed several days apart under simmilar conditions.



Correction of orders before merging

The solution of the problem of order overlap inconsistency seems to be only a carefull handling of each observation individually. Following method was devised and succesfully applied by Škoda & Hensberge (2003):

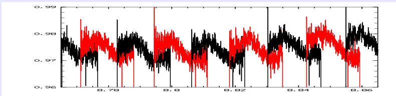
We can study diffential changes in extracted orders only after removing the global spectral sensitivity of flat and stellar spectrum. This requires fitting of this large-scale structure in both stellar and flat-field spectrum by the smooth spline as the "envelope" of all individual modulated blaze functions. It is very complicated for the star as the orders contaminated by wide deep lines have to be eliminated. After removing the global sensitivity the differential correction function estimated from order overlap region may be constructed. It will remove the inconsistencies. At the same time the already continuum normalized spectra are obtained. Although the method works well (see figure before and after correction) it is a subjective and very time consuming method that may not yet be used in automatic pipeline.



The changes of blaze function caused by instrument instability

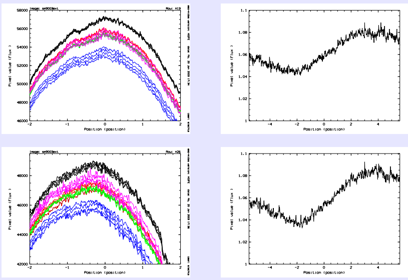
We studied the HEROS red channel as the ripples were more prominent. The ripples occured on the pipeline processed (and automatically merged) spectrum randomly, but were stronger if the flat field exposure was taken in different position of telescope than the stellar exposure. We tried to find the key mechanism having the strongest influence on their amplitude. As the stellar spectrum is influenced by the extinction and the spectral type of star, we began study of time dependent behaviour of flat fields obtained during the observation. One flat field was taken as a reference and was taken for the "flat fielding" of others. It was used as well for the definition of the centre of the extraction slit for order extraction. I an ideal case the result should be the flat line set to 1.0.

We have, however, obtained the ripple pattern as well:



As it was clear there is a time dependence ot the riples, we tested the stability of all instrument devices that were changed during the observation. In all experiments we have taken 5 flat field exposures under the same conditions. The spectra were extracted along the order traces of maximum light with background subtraction using the same MIDAS procedure written by H. Hensberge. The changes in the extracted blaze function and cross-order profile were studied. The following results were obtained:

- **flat field lamp** The lamp was fed by the stabilized current. No noticable changes in intensity or COP were found.
- **foldable mirror** The folding the mirror between 'FLAT' and 'STAR' position didn't show any changes.
- **Fiber bending** We changed the tension of the fiber by bending it to various shapes. Some influence was observed if extremely bent in a narrow coil. Small changes of the COP and blaze function observed. There were, however, very tiny to produce strong ripples.
- **Temperature inside the dome**. We have measured the strong changes in blaze function when the dome shutter was opened and the fresh air filled the dome interior. It is probable that the even tiny temperature changes have the strongest influence on the blaze function. The instrument is not placed in controlled environment (the wooden box is not air-tight) and so the temperature changes during the observation can cause the tiny shifts of positions of optical elements. *On the following pictures the enlarged part in the centre of blaze function is shown in two orders : 13-th (upper panel) and 26-th (lower panel). The various colours show groups of flat-fields taken in several intervals (5 min long) after the opening of dome shutter. The right panels show the ratio of two most distant flat fields - The origin of one type of ripples is obiously here.*



HEROS

HEROS is a one-fiber instrument developed at the Landessternwarte Heidelberg-Königstuhl, Germany, as a compact echelle spectrograph which has been used at several telescopes. Since Summer 2000 it has been installed at 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 goes to two independent channels : blue (3600 – 5600 Å in 70 orders) and red (5800 – 8400 Å in 32 orders). For details see `http://www.lsw.uni-heidelberg.de/projects/instrumentation/Heros`.

The instrument is freely laid on the floor inside the dome and protected from dust adn stray light from the dome instruments by the wooden box. At the Casegrain focus of the 2m telescope is hanged the calibration unit. It contains foldable mirror for feeding the ThAr lamp of flat field tungsten lamp light into the fiber entrance, the calibration lamps and the guiding camera with the intensifier.

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Conclusions

For precise and reliable reduction of echelle spectra the time and position dependent changes in the behaviour of the spectrograph should be known and removed from the calibration exposures. However, the most precise removal of the instrument artefacts is possible only using the individual approach to each observation - it is very time consumingand not yet automatizable.

References

Škoda, P. & Hensberge, H. 2003, in Astronomical Data Analysis Software and Systems XII ASP Conference Series, Vol. 295, 415

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