The reliability of echelle spectroscopy in the hot rotating star research

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Abstract

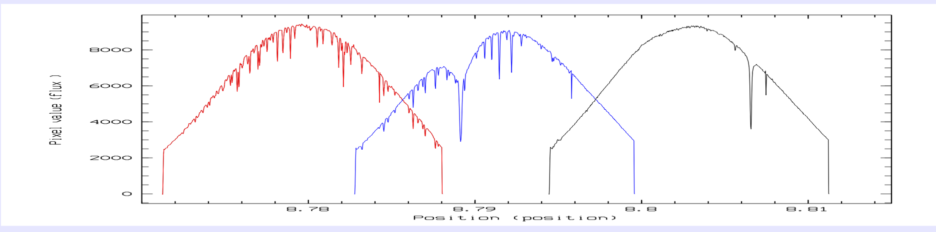
The great importance for the study of variable hot stars have the hydrogen and helium line profiles. As the detailed study of profile changes requires the spectra with very high dispersion and wide spectral range, the most common instrument chosen for the observation is the echelle spectrograph. For hot and rapidly rotating stars, the considerably wide line profile is spread over several echelle orders and thus a precise data reduction before merging several spectral orders together is required to obtain reliable results.

We show on examples of several Be stars observed by the fiber-fed echelle spectrograph HEROS in Ondřejov that the correct data processing requires the detailed understanding of the instrument (mainly calibration unit) behaviour during the observation. Our experience proves the necessity of an individual handling of each spectrum to get reliable continuum (mainly in wings of wide shallow lines) and thus obtain correct equivalent widths.

On the other hand, the usage of automatic pipelines or wrong application of general reduction procedures may result in periodic ripple disturbances in the shape of the apparent stellar continuum and by this way introduce considerable errors in the equivalent widths measurement leading to incorrect determination of fundamental quantities as gravity and mass of the stars.

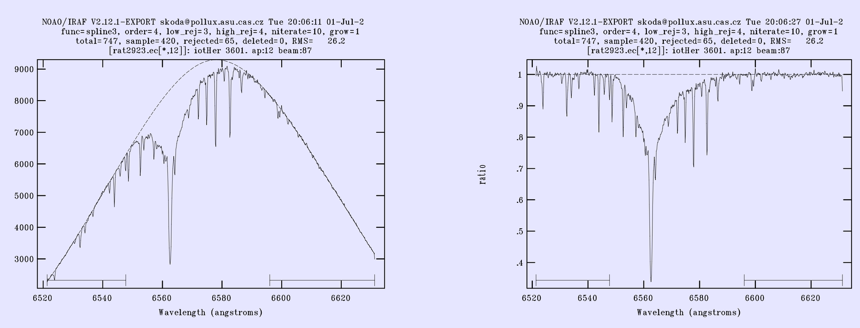
Echelle spectra processing

Both basic principles and detailed cookbooks for reduction are described in a number of places (Hall et al. 1994; Hinkle et al. 2000; Churchill 1994; Erspamer & North 2002). Although quite complicated, the main part of echelle reduction is quite straightforward and the automatic pipelines can be used to reduce the data until the stage of individual extracted echelle orders with associated wavelength scale.
Such data are very useful for measurement of radial velocities of many lines on late-type stars or for study of abundances using the equivalent width of metallic lines (Skuljan et al. 2000).

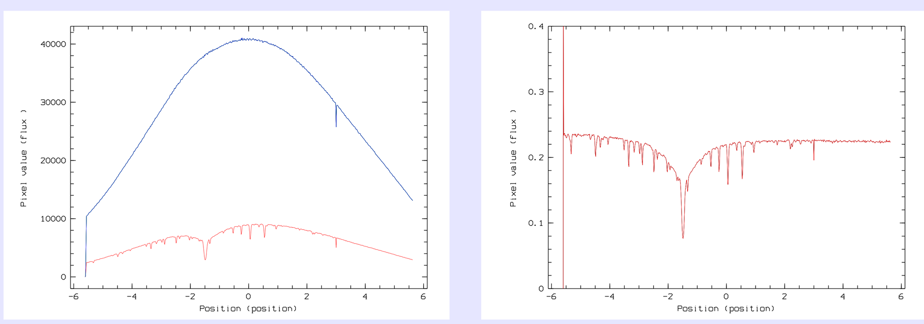


Blaze function removal

One of the possible methods of blaze removal is the fitting the low order polynomial through the (apparent) continuum windows in each order. This method, however, fails for the orders containing wide lines.



The widely used method 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.



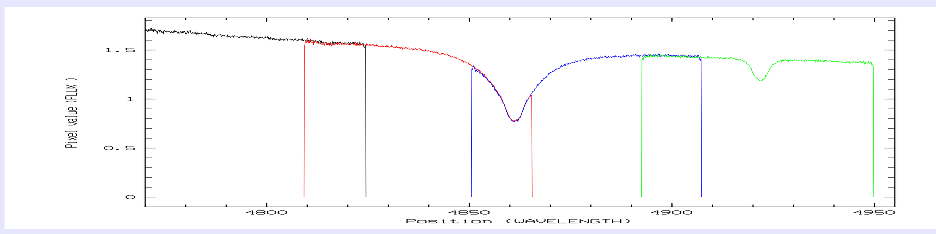
In practice, however, this is not the case, and the blaze function shows small temporal variations of still unknown origin. There is the suspicion of the influence of flat-field calibration units and the influence of fiber itself. Moreover, the blaze profiles are still modulated by the slowly changing spectral sensitivity curve of flat field and stellar extinction.
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.

Conclusions

The study of early type rapidly rotating stars using echelle spectrograph requires extremely precise data reduction as well as detailed knowledge of the instrument construction and behaviour. Neglecting these requirements may lead to incorrect results of further astrophysical analysis.

The merging of echelle orders

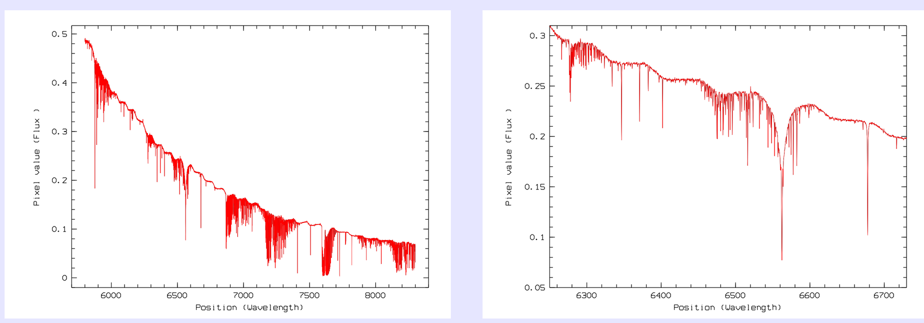
For early type stars, where hydrogen and helium lines are of great interest, the considerably wide line profile is spread over several echelle orders. Therefore the merging of orders together is required to see the whole profile with the surrounding pseudo-continuum.



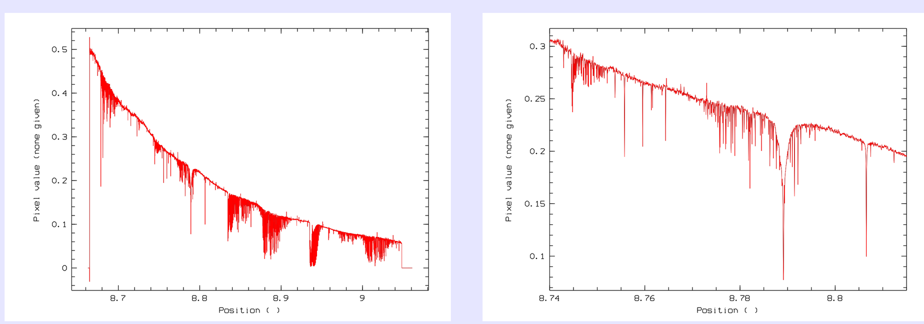
Although the merging can be done quite easily after rebinning of orders to the same wavelength grid (preferably in $\log\lambda$), by weighted averaging of the overlapping regions (and cutting the very edges where the high noise is present), this step requires extremely precise handling of data to get reliable results. The problem is caused by the behaviour of the echelle blaze function.
The blaze function changes the intensity of the spectrum inside each order and thus modulates strongly the shape of the stellar continuum. In each order, the intensity of signal steeply rises from one edge to the center of frame and falls down to the other edge.

Continuum normalization

If flat-fielded orders with offsets are blindly merged uncorrected (as in the automatic pipeline), the strong ripple-shaped periodic disturbances occur on the apparent stellar continuum.



A one way to remove them is the manual fitting of a sufficiently smooth spline function through the parts of the merged spectrum where the continuum seems to be present. It is very difficult (or almost impossible) well interpolate the rippled continuum inside the wings of wide line. Using this approach may introduce considerable errors in the line profile shape leading to incorrect determination of fundamental stellar quantities. The solution of this problem seems to be only a careful handling of each observation individually (removing the global spectral sensitivity of flat and stellar spectrum and applying to each extracted order the differential correction function estimated from order overlap region) as was shown by Škoda & Hensberge (2003). 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 importance of precise continuum

The processing of every observation should strive to give the most precise results from the principle. It is, however, not the case always and good science may be done even on briefly prereduced data (e.g. radial velocity measurement). But there are fields of astrophysical analysis requiring extremely precise knowledge of the continuum position and shape. Here are the examples of best known:

Equivalent width measurement

The direct measurement of equivalent widths is influenced by the level of the fitted pseudo-continuum. For the wide lines with large wings it is very difficult to do the normalization by spline interpolation between neighbouring continuum windows if the ripples are present.

Synthetic profiles fitting

The high-dispersion echelle spectra allow the quite precise abundance analysis by comparison with the grid of synthetic spectra models. The important condition of the good result is, however, very precise placement of continuum on normalized spectra.

Fourier disentangling

One of the recent method for analysis of the spectroscopic binaries and improving the radial velocity measurement is the Fourier disentangling devised by Hadrava (1995) and successfully applied many times in obtaining the separate spectra of each binary component as well as its orbital solution It has lead to the most precise determination of mass, radius, rotational velocity and other fundamental stellar parameters in well detached binaries (Fitzpatrick et al. 2002; Hensberge et al. 2000)
The method is, however, very sensitive to the precise placement of the continuum as was shown by Ilijic et al. (2002) and neglecting of instrumental systematic errors may lead to wrong disentangled spectra and thus to wrong physical parameters when comparing to synthetic spectra.

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 – 8400Å in 32 orders). For details see `http://www.lsw.uni-heidelberg.de/projects/instrumentation/Heros`.

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