Part 11

Data analysis and reduction techniques

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The reliability of echelle spectroscopy in hot rotating star research

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Abstract. 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. As we show, 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 into the determination of fundamental astrophysical quantities as gravity and mass of the stars.

1. Introduction

Of great importance in the study of variable hot stars are the hydrogen and helium line profiles. As the detailed study of profile changes requires spectra with very high dispersion and wide spectral range, the most common instrument chosen for the observation is the echelle spectrograph. Although quite complicated, the main part of the reduction of echelle spectra 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. (Churchill 1994, Hall et al. 1994; Hinkle et al. 2000; Erspamer & North 2002)

For early type (especially rapidly rotating) stars, the considerably wide hydrogen and helium lines profiles are spread over several echelle orders. Therefore the merging of orders together is required to see the whole profile with the surrounding pseudo-continuum (Fig. 1).

Although the merging can be done quite easily after rebinning of orders to the same wavelength grid, this step requires extremely precise handling of data to get reliable results. The problem is caused by the behaviour of the echelle blaze function, which changes the intensity of the spectrum inside each order and thus modulates strongly the shape of the stellar continuum.

2. Blaze function removal

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 (Fig. 2.).

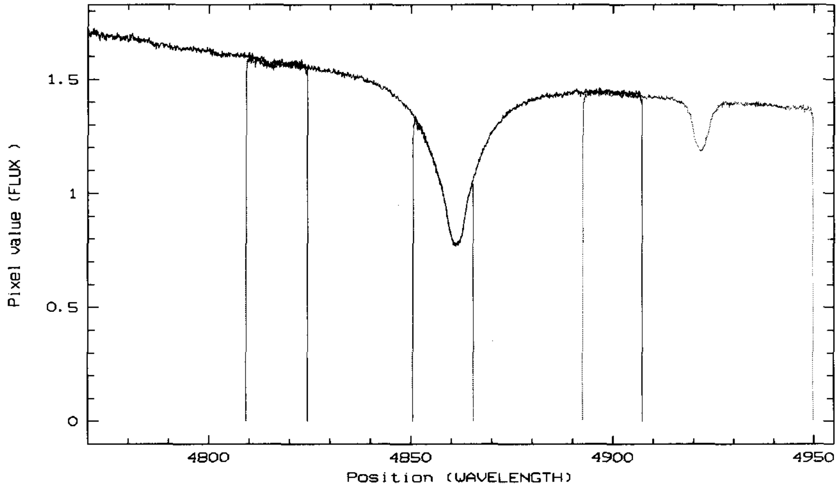

Figure 1. Profile of H_β composed from three flat-fielded orders.

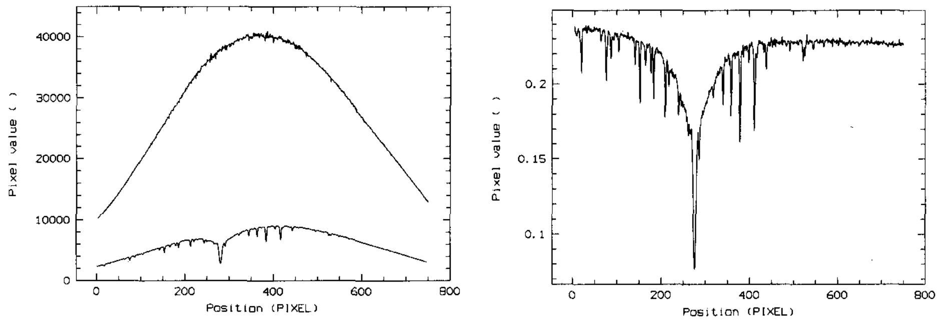

Figure 2. Removal of the blaze function by the extracted flat field.

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 the fiber itself. Moreover, the blaze profiles are still modulated by the slowly changing spectral sensitivity curve of the flat field and by 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 (Fig. 3).

3. Continuum normalization

If flat-fielded orders with offsets are blindly merged uncorrected (as in the automatic pipeline), strong ripple-shaped periodic disturbances occur on the apparent stellar continuum (Fig. 4).

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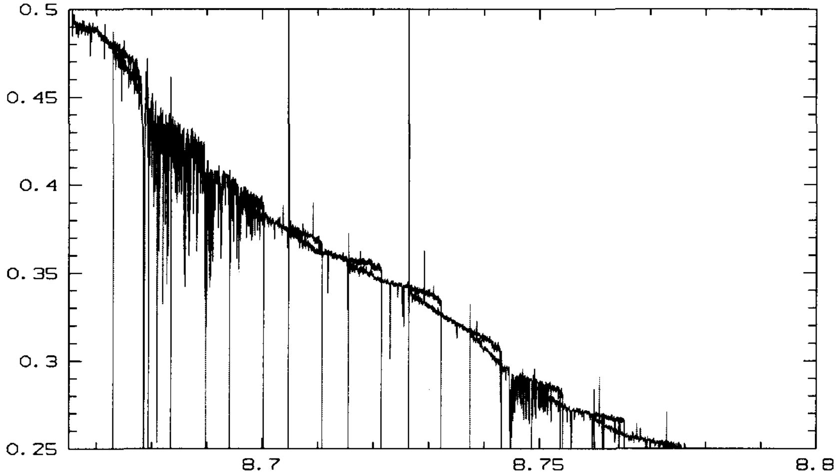

Figure 3. The discontinuity of echelle orders before merging.

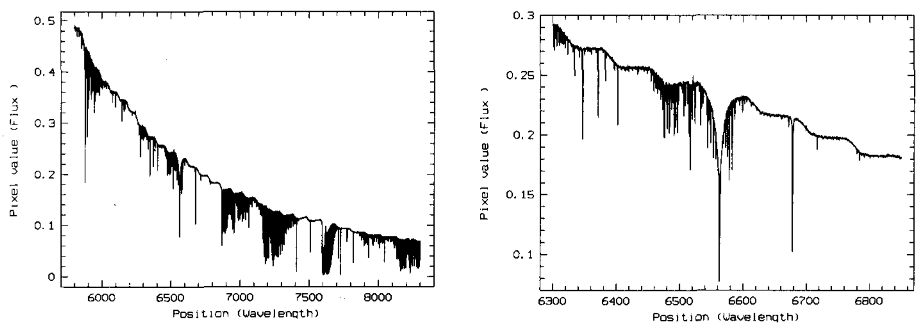

Figure 4. Ripples on the merged spectrum.

An obvious 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, however, very difficult (or almost impossible) to interpolate the rippled continuum well 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 to this problem seems to be only a careful handling of each observation individually as was shown by Škoda & Hensberge (2003). Their method is, however, subjective and very time consuming and thus may not be used in an automatic pipeline.

4. 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

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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 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 ripples are present.

Synthetic profiles fitting High-dispersion echelle spectra allow 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 the continuum on normalized spectra.

Fourier disentangling One recent method for analysis of spectroscopic binaries and improving the radial velocity measurement is 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. The method is, however, very sensitive to the precise placement of the continuum as was shown by Ilijic et al. (2002) and neglecting instrumental systematic errors may lead to wrong disentangled spectra and thus to wrong physical parameters when comparing to synthetic spectra.

5. Conclusions

The study of early type rapidly rotating stars using an 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.

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