Investigation of Residual Blaze Functions in Slit-Based Echelle Spectrograph

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Abstract

We have studied the Residual Blaze Functions (RBF) resulting from division of individual echelle orders by extracted flat-field in spectra obtained by slit-fed OES spectrograph of 2m telescope of Ondřejov observatory, Czech Republic. We have eliminated the dependence on target and observation conditions by semiautomatic fitting of global response function, thus getting the instrument-only dependent part, which may be easily incorporated into data reduction pipeline. The improvement of reliability of estimation of continuum on spectra of targets with wide and shallow lines is noticeable and the merging of all orders into the one long spectrum gives much more reliable results.

1 Introduction

The most serious problem in the reduction of echelle spectra is the removal of the grating blaze function. The blaze function changes the intensity of the spectrum inside each order and thus modulates strongly the shape of the stellar continuum. The widely used method is the division of extracted stellar spectrum by the extracted flat field spectrum in every order separately. The illumination pattern of the flat is, however, generally different from the stellar one, the discrepancies being larger at slit-fed spectrographs. The understanding of their blaze function behaviour is therefore important for the succes of its correct removal.

2 Ondřejov Echelle Spectrograph

OES is the slit-fed prism cross-dispersed echelle spectrograph developed at the Stellar department of the Astronomical Institute of the Academy of Sciences of the Czech Republic and installed at the coudè focus of 2m telescope of the Ondřejov observatory. In its current setup it can cover spectral range from 3750Å–9500Å in 62 orders. Due to various construction limitations there is a lack of order overlap at wavelengths longer than about 6000 Å. This together with strongly curved orders, tilted spectral lines and high level of inter-order scattered light makes reduction extremely complicated. Moreover, there is some vignettation seen at the edges of the orders. The example of the echellegram is given on the Fig. 1.

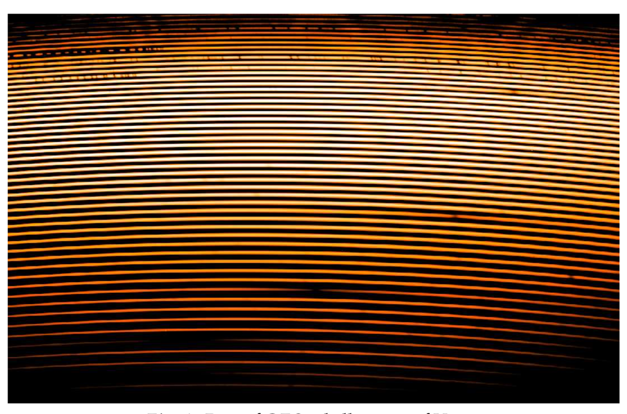

Fig. 1: Part of OES echelle-gram of Vega.

Conclusions

We have shown a one possible way how to tackle the problem of precise unblazing of echelle spectra using the separation of correction function to instrument-only dependent part (IRBF) changing on the scale of one echelle order and observation-dependent part (GSF) smoothly changing over the whole observed spectrum.
Our method is just a first simple approximation of the general correction procedure, it may be instrument dependent (better suited to slit-fed spectrographs) and so the future investigation of the problem is still highly desirable.

Acknowledgements

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References

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[2] Hinkle, K., Wallace, L., Valenti, J., and Harmer, D., [*Visible and Near Infrared Atlas of the Arcturus Spectrum 3727-9300 A*] (2000).

[3] Takeda, Y., Kawanomoto, S., and Ohishi, N., "High-Resolution and High-S/N Spectrum Atlas of Vega," *PASJ* **59**, 245–261 (Feb. 2007).

3 Residual Blaze Function

In general the blaze function of stellar exposures on slit-fed echelle spectrographs is quite different from blaze function of the flat field spectrum due to different character of slit illumination. So the unblazing by direct division of the extracted stellar continuum by the extracted flat field does not remove the shape of blaze function completely and some residual structure remains superimposed on the stellar continuum. For such a curve we are using the term Residual Blaze Function (RBF). In the ideal case it should be the line of constant value corresponding to the ratio of intensity of stellar and flat field exposures. This is better fulfilled by fiber-fed spectrographs as the illumination of flat and star is almost the same due to the same size of fiber entrance with a micro-lens. The example of the behavior of one spectral order on fiber spectrograph HEROS is given on Fig. 2.

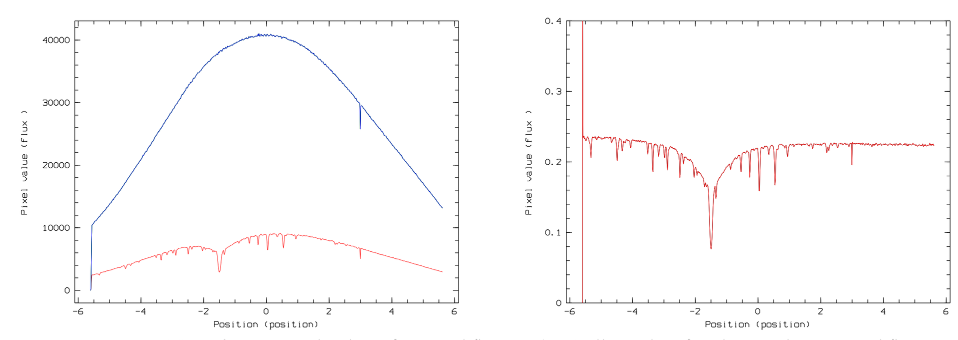

*Fig. 2: HEROS: **Left:** Extracted orders of star and flat. **Right:** Stellar order after division by extracted flat.*

However, the shape of such orders in case of OES is more complicated mainly influenced by vignettation due to incompatibility of illumination structure. Examples of orders containing line H_γ and ones with obvious continuum for case of Vega and Arcturus are given on Fig. 3 and Fig. 4.

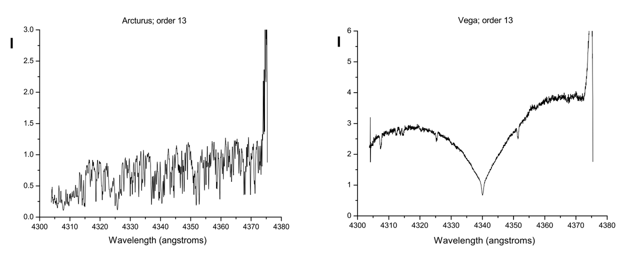

*Fig. 3: OES: unblazed order 13 with line H_γ. **Left:** Arcturus. **Right:** Vega*

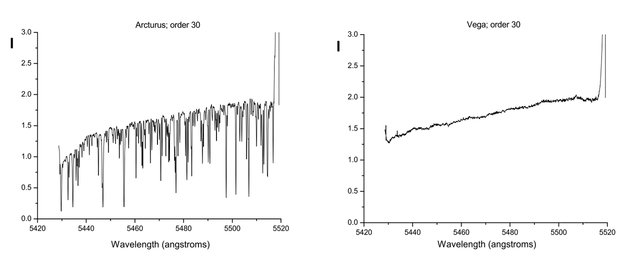

*Fig. 4: OES: unblazed order 30 with continuum. **Left:** Arcturus **Right:** Vega*

As the true RBF is unknown (we do not see the true continuum due to wide lines and blends), we have to estimate its shape using comparison with other spectrum with already known RBF. The best case is the spectrum of the same target with approximately same resolution that is already continuum normalized (the continuum reference spectrum).
Sources of normalized merged spectra are web archives (e.g. ELODIE archive(1)) or published spectral atlases (in our case atlas of Arcturus by Hinkle et al.(2) and Vega atlas of Takeda et al. (3)).
We also tried to rectify the spectra of Vega and Arcturus order by order comparing visually the merged rectified spectrum with the synthetic spectrum. of Arcturus (Teff=4300 K, $v \sin i$=2 km/s) and Vega (Teff=9300 K, $v \sin i$=25 km/s).
After dividing non-rectified spectrum (individual orders) of Arcturus and Vega by rectified ones (continuum master reference), we get the shape of residual blaze function for each order. Following figures show comparison of shape of residual blaze functions in two different orders (containing Balmer lines H_γ and H_β) of Arcturus and Vega (Fig. 5.). The global view of RBFs in all orders can be seen on Fig. 6.

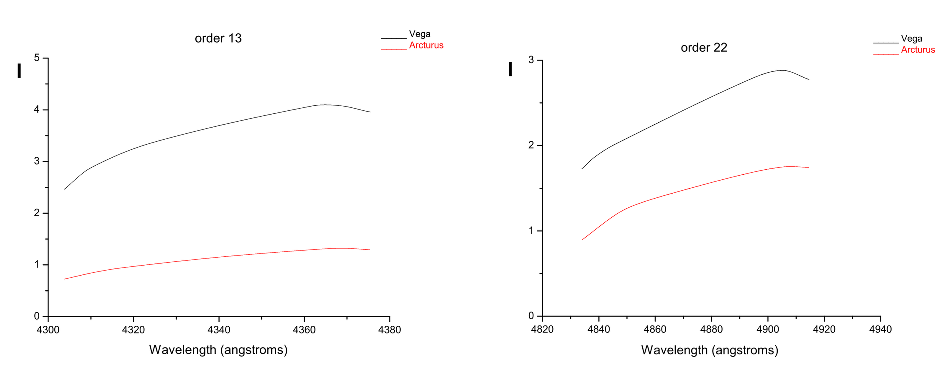

*Fig. 5: Comparison of RBFs in two orders of Arcturus and Vega. **Left:** Order 13. **Right:** Order 22.*

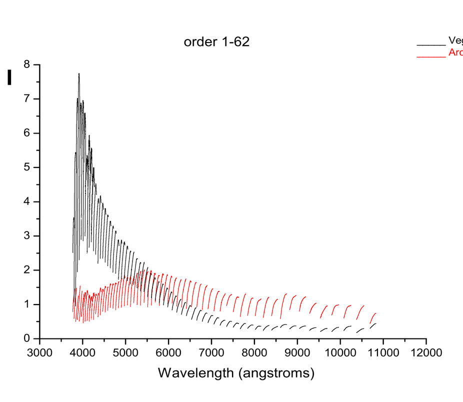

Fig. 6: Comparison of global shape of residual blaze functions for Arcturus and Vega.

4 Global Sensitivity Function

As is seen on Fig. 6, the RBFs are following some smooth curve different for Arcturus and the Vega. We suppose that this function, that we call the Global Sensitivity Function (GSF), depends on the ratio of energy distributions of the target and the flat field lamp and on the relative sensitivity of CCD detector in given spectral region.
Color changes are expected to be dependent on the extinction and hence the zenith distance of the target, as well as on seeing, atmospheric differential refraction and other observation-dependent parameters. That is the reason why we have chosen Vega and Arcturus as representants of two different SEDs (cold and hot star) and extinction (different zenith distance at the time of observation).
To find some representative point for fitting the GSF in every stellar order we have used the median of distribution of values of given order. The median better represents some "middle" point for case of strongly curved RBF.

5 Intrinsic Residual Blaze Function

Our order correction procedure is based on hypothesis supposing the RBF to be just product of some instrument-dependent part, called Intrinsic Residual Blaze Function (IRBF) and the GSF, which is observation dependent. We can get it from division of RBF by GSF. Example of IRBF for the two orders shown above (see Fig. 5) is given in Fig. 7.
Once known, the IRBF can be divided out from flat-fielded stellar orders (on extracted spectra) and the corrected orders should be matching better thus allowing easy merging of orders. Some examples of this procedure in global and detailed view is given on Fig. 8.

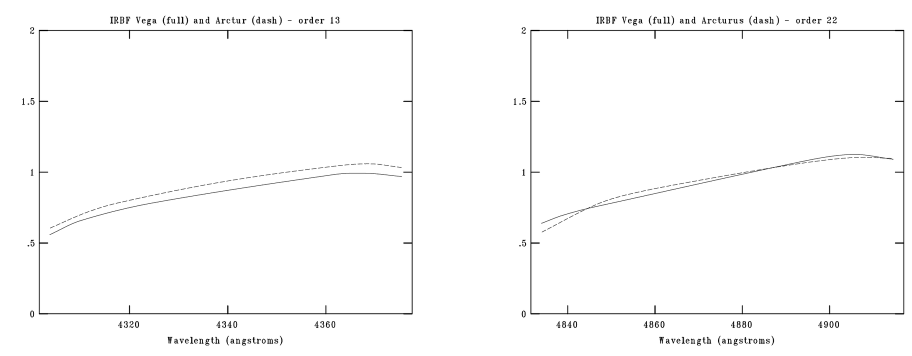

*Fig. 7: Comparison of IRBFs in two orders of Arcturus and Vega. **Left:** Order 13. **Right:** Order 22.*

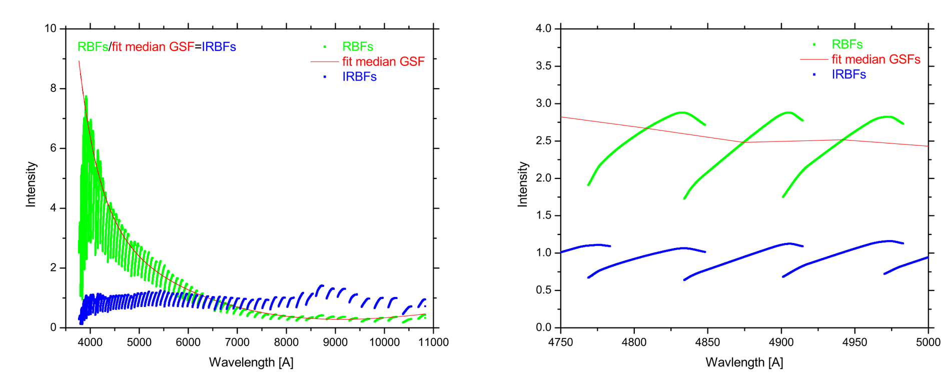

Fig. 8: RBF and IRBF of Vega with median fit of GSF in detailed and global view

6 Correction of Stellar Orders

The final goal of the reduction process is the continuum normalized (rectified) merged spectrum of a target. If the IRBF is really constant for given spectrograph, we can built it in an reduction pipeline, so every flat-fielded order is divided by it, before merging in one long spectrum (Fig. 9).

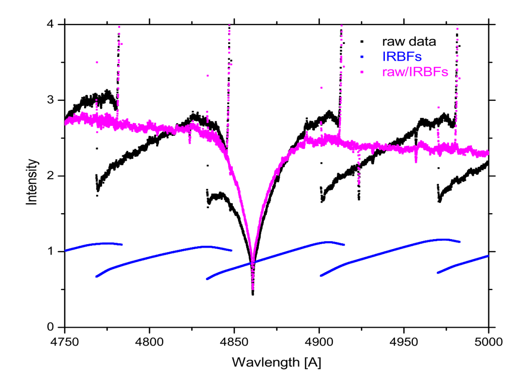

Fig. 9: Raw unblazed data after correction by IRBF. Merged profile of H_β

This correction assures the consistent behavior of order edges in the region of overlapping orders and thus smooth connection of neighboring orders. See Fig. 10 for example of merged Vega orders in different spectral regions.

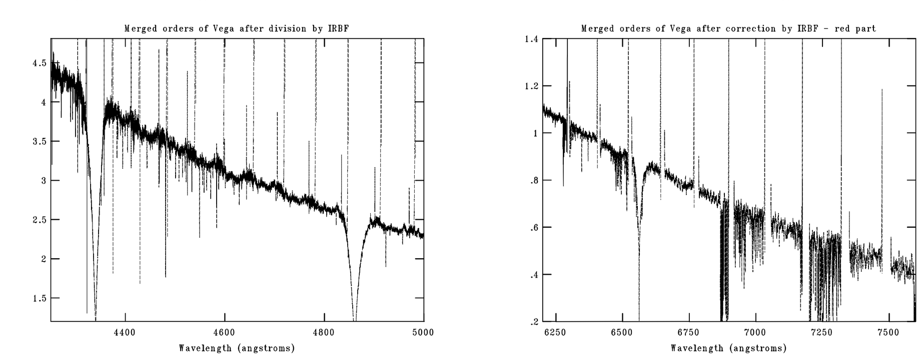

*Fig. 10: Merged orders of Vega in different spectral regions. The vertical lines mark the edges of individual orders. Note the gaps in red region. **Left:** Blue region. **Right:** Red region.*

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