The instrumental line-profile of TIGRE/HEROS

Stefan Czesla

Updated: March 5, 2014

I used ThAr spectra to analyze the instrumental line-profile of the TIGRE/HEROS system and provide an analytical approximation of the profile as a function of wavelength. In a first step, the line-profile is approximated by a Gaussian, whose width is derived as a function of wavelength. In a second step, I present a modified Gaussian profile, which accounts for the remaining deviations. The mean resolution of the TIGRE/HEROS system is 20 400.

1 Input data

I used the following ThAr spectra for the analysis in the blue arm

- ThAr_ThAr_B_2014_01_19_18_01_30.thar_ech.fits
- ThAr_ThAr_B_2014_01_19_18_01_48.thar_ech.fits
- ThAr_ThAr_B_2014_01_19_18_02_05.thar_ech.fits
- ThAr_ThAr_B_2014_01_19_18_02_22.thar_ech.fits

and in the red arm

- ThAr_ThAr_R_2014_01_19_18_02_05.thar_ech.fits
- ThAr_ThAr_R_2014_01_19_18_01_30.thar_ech.fits
- ThAr_ThAr_R_2014_01_19_18_01_48.thar_ech.fits
- ThAr_ThAr_R_2014_01_19_18_02_22.thar_ech.fits .

Further, I used the wavelength solution available from the files

- Sci_WASP_33_B_2014_01_19_20_39_17.sp_ech_main.fits
- Sci_WASP_33_R_2014_01_19_21_51_22.sp_ech_main.fits

for the blue and red arm.

2 Spectral line shape and width

I obtained wavelength-calibrated ThAr spectra by "re-applying" the wavelength solution stored in the science frames to the individual ThAr spectra; note that I relied on the individual orders instead of the merged spectrum (see Sect. 1). In the resulting ThAr spectrum, I searched for sufficiently isolated lines, which show the instrumental line profile unaffected by line blends.

Based on the selection of lines, I cut out the fraction of the ThAr spectrum containing the respective line; in particular, I used a half-width of 0.5 Å for the blue arm and 0.65 Å for the red arm. In this limited spectral range, I fitted a Gaussian profile of the form

$$f(\Delta\lambda) = \frac{A}{\sqrt{2\pi\sigma^2}} e^{-\frac{(\Delta\lambda-\mu)^2}{2\sigma^2}} + off \;, \qquad (1)$$

where off denotes an offset, accounting for background. Figures 1 and 2 show the average line profile as a function of wavelength for the blue and red arm along with the best-fit Gaussian. Note that the individual line profiles were normalized by the area of the best-fit Gaussian prior to averaging, which prevents that the profile of weaker lines is overwhelmed by the strongest line(s). However, the result also benefits less from the better noise properties of strong lines.

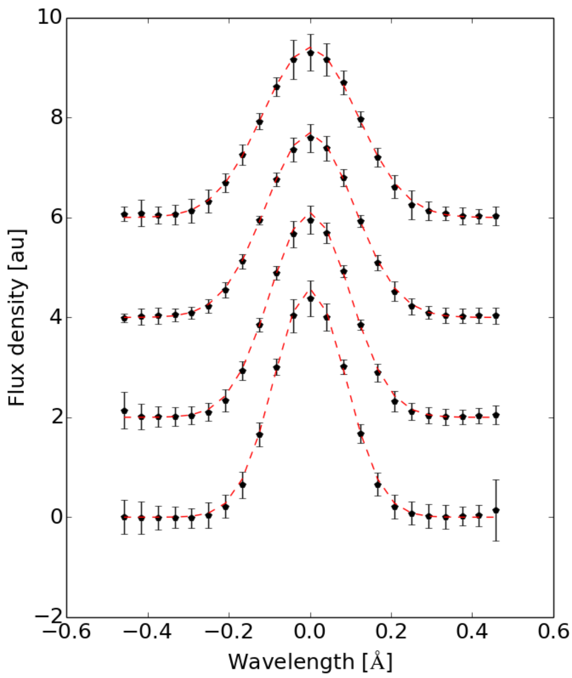

Figure 1: Mean line profile (black dots) observed in the wavelength ranges 3800 – 4300 Å, 4300 – 4800 Å, 4800 – 5300 Å, and 5300 – 5800 Å (from bottom to top).

Clearly, the Gaussian provides a good approximation to the line profile. Its width depends on the wavelength with a tendency for larger widths at longer wavelengths. In Fig. 3, the distribution of line widths is shown as a function of wavelength along with the best-fit linear relation. For the individual arms, the dependence of σ on wavelength reads

$$\sigma_B(\lambda) = 1.132 \times 10^{-2} + 1.8589 \times 10^{-5} \times \lambda \quad (2)$$
$$\sigma_R(\lambda) = 7.074 \times 10^{-3} + 1.9708 \times 10^{-5} \times \lambda \;, \quad (3)$$

where λ and σ are given in units of $\mathring{A}$.

Although the Gaussian approximation works reasonably well, the fits show systematic deviations from the Gaussian profile. This is demonstrated for the blue arm in Fig. 4, which shows the mean residuals for the Gaussian fits in a number of spectral bands; in the red arm, the result is qualitatively the same. There is a clear wave-like structure dominating the residuals, indicating a shortcoming of the Gaussian profile.

To account for this structure, I used the following modified Gaussian profile to approximate the line profile of the TIGRE-HEROS system:

$$g(\Delta\lambda) = \frac{A}{\sqrt{2\pi\sigma^2}} e^{-\frac{(\Delta\lambda-\mu)^2}{2\sigma^2}} \times \left(1 - c \cos\left(\frac{\pi}{2\pi\, d\, \sigma}\Delta\lambda\right)\right) + off \;. \quad (4)$$

Here, the wave-like structure is accounted for by the cosine term, whose characteristics are determined by the additional parameters c and d. In the fits of the line profile, I found that a value of $d = 0.6$ provides good fit results and, therefore, fixed the parameter. The strength of the cosine term is controlled via c, which is left as a free parameter in the fits. The result for the blue and red arm reads:

$$\sigma_B(\lambda) = 5.985 \times 10^{-3} + 1.9 \times 10^{-5}\,\lambda$$
$$c_B(\lambda) = 1.462 \times 10^{-1} - 1.9589 \times 10^{-5}\,\lambda$$

$$\sigma_R(\lambda) = 1.919 \times 10^{-2} + 1.7261 \times 10^{-6}\,\lambda$$
$$c_R(\lambda) = 2.269 \times 10^{-2} + 3.8373 \times 10^{-6}\,\lambda \;. \quad (5)$$

Figure 5 shows the residuals of the fit using the modified profile for a number of bands in the blue arm.

3 Spectral resolution

Using the results of the Gaussian fits given in Eq. 5, the spectral resolution can be obtained as the ratio of wavelength and the FWHM of the Gaussian. In Fig. 6, the resulting spectral resolution is shown as a function of wavelength. The mean resolution is a little over 20 000 and shows only a weak dependence on wavelength.

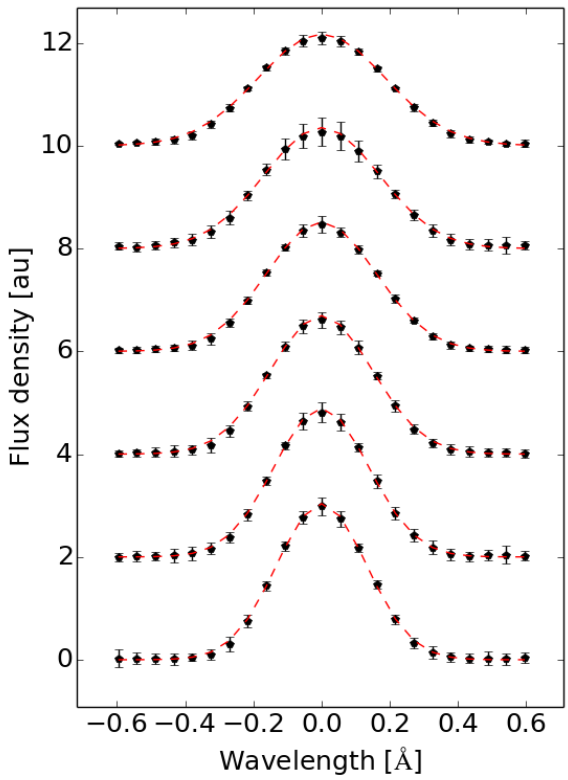

Figure 2: Mean line profile (black dots) observed in the wavelength ranges 5800 – 6300 Å, 6300 – 6800 Å, 6800 – 7300 Å, 7300 – 7800 Å, 7800 – 8300 Å, and 8300 – 8800 Å (from bottom to top). The dashed (red) line represents the best-fit Gaussian.

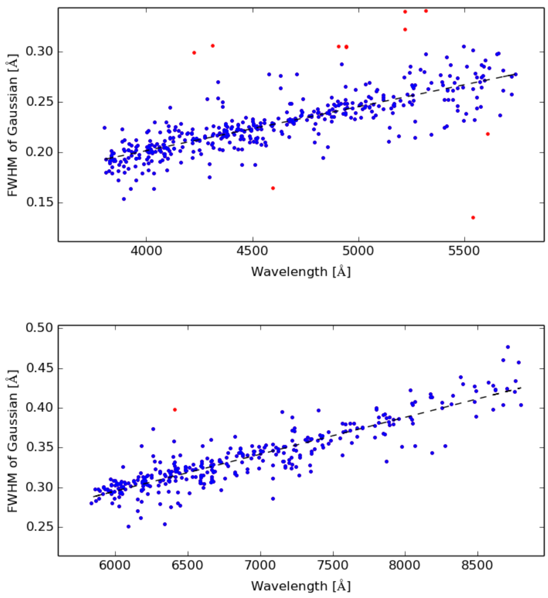

Figure 3: Distribution of line widths as a function of wavelength for the blue (top) and red (bottom) arm. Red points are disregarded as outliers. The dashed black line shows the best-fit linear relation.

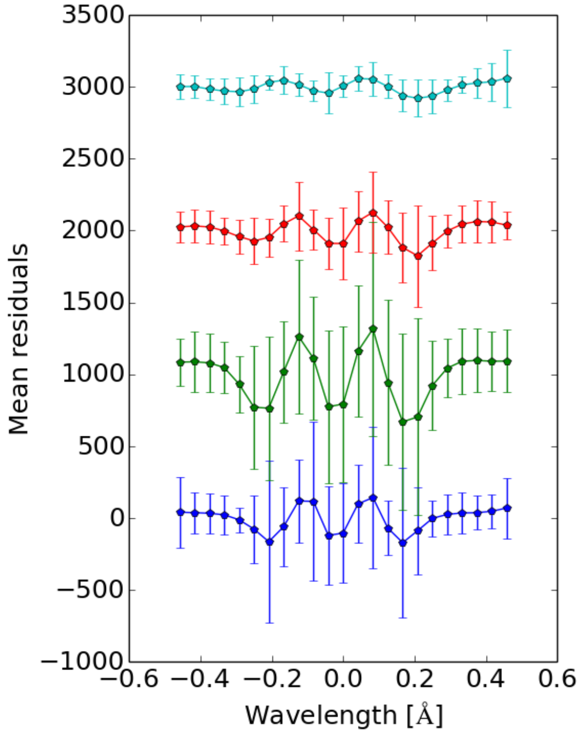

Figure 4: Mean residual of the Gaussian fits. From bottom to top the spectral bands are 3800 – 4300 Å, 4300 – 4800 Å, 4800 – 5300 Å, and 5300 – 5800 Å (from bottom to top).

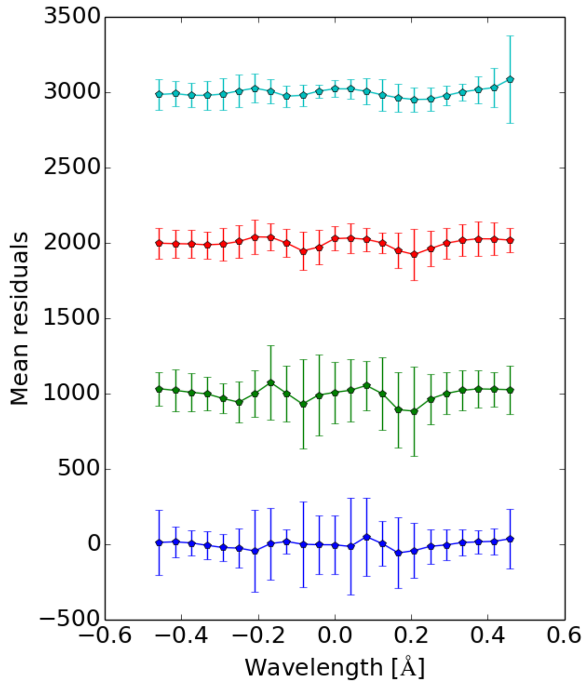

Figure 5: Mean residual of the modified Gaussian fit. From bottom to top the spectral bands are 3800 – 4300 Å, 4300 – 4800 Å, 4800 – 5300 Å, and 5300 – 5800 Å (from bottom to top).

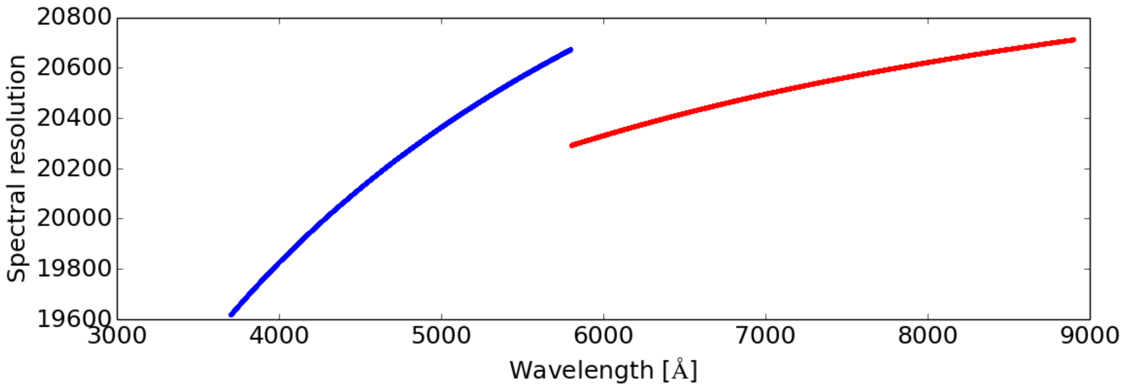

Figure 6: Spectral resolution of the TIGRE/HEROS system as a function of wavelength.