RESOLVING POWER OF SPECTROGRAPHS: IMPACT OF THE SPECTRAL LINE SPREAD FUNCTION

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Abstract

When passing the spectrograph, an observed spectrum is broadened due to the limited resolving power R of the apparatus (i.e., $\Delta\lambda_{\mathrm{FWHM},R} = \lambda/R$). Theoretically, R is given by the instrument components, e.g., in the case of a diffraction grating, by the number of illuminated slits. In practice, however, the exact spectral Line Spread Function (LSF), which describes the shape of an infinitely sharp absorption (or emission) line on the spectrograph, is highly dependent on the instrument and is therefore not trivial to determine. By evaluating hundreds of absorption lines in the space telescope imaging spectrograph (STIS) ultraviolet (uv) spectrum of the hot subdwarf star Feige110, it could be shown that, in this case, the convolution with a corresponding Gaussian ($\Delta\lambda_{\mathrm{FWHM},R} = \Delta\lambda_{\mathrm{FWHM,GAUSS}}$) on average results in too-small line widths. To obtain a consistent treatment of different spectrographs' R, a correction factor can be applied to better match the respective LSF.

Introduction

Hot subdwarf stars populate the extreme part of the horizontal branch and are hot, evolved, low-mass stars which operate core-helium burning, having a hydrogen envelope too thin to fuel shell burning. Due to diffusion effects, some hot subdwarfs are chemically peculiar. Feige110 is a hot subdwarf star exhibiting extreme iron-group (IG) element (i.e., Ca – Ni) overabundances, making it an ideal laboratory to investigate absorption-line properties of these elements. However, for a precise investigation of even weak absorption lines, a high-resolution (R) and high signal-to-noise ratio (S/N) spectrum is needed. Besides, detailed knowledge about line-broadening mechanisms is crucial for proper absorption-line modeling.

With a high R and high S/N uv spectrum taken by STIS, we were able to quantitatively analyze more than 390 isolated IG-element absorption lines in Feige110 and compare line properties between the model and the observation. The impact of a consistent treatment of the LSF and possible implications on spectral analysis parameters will be shown on this poster.

Methodology, Results

First, an NLTE spectral analysis of the Feige110 STIS spectrum was performed using the Tübingen NLTE Model-Atmosphere Package [1]. Afterwards, isolated IG-element absorption lines were fitted with Gaussians to analyze their line properties. Although the actual line shape corresponds to a Voigt profile, which is the convolution of a Lorentzian and a Gaussian profile, the properties of the Lorentzian profile show mainly in the line wings. As these are, however, quite narrow in the case of the IG-elements, a Gaussian fit is appropriate. Besides allowing to compare the theoretical and observed line strengths (which was the initial aim of the analysis), the Gaussian fit also provided information about line broadening.

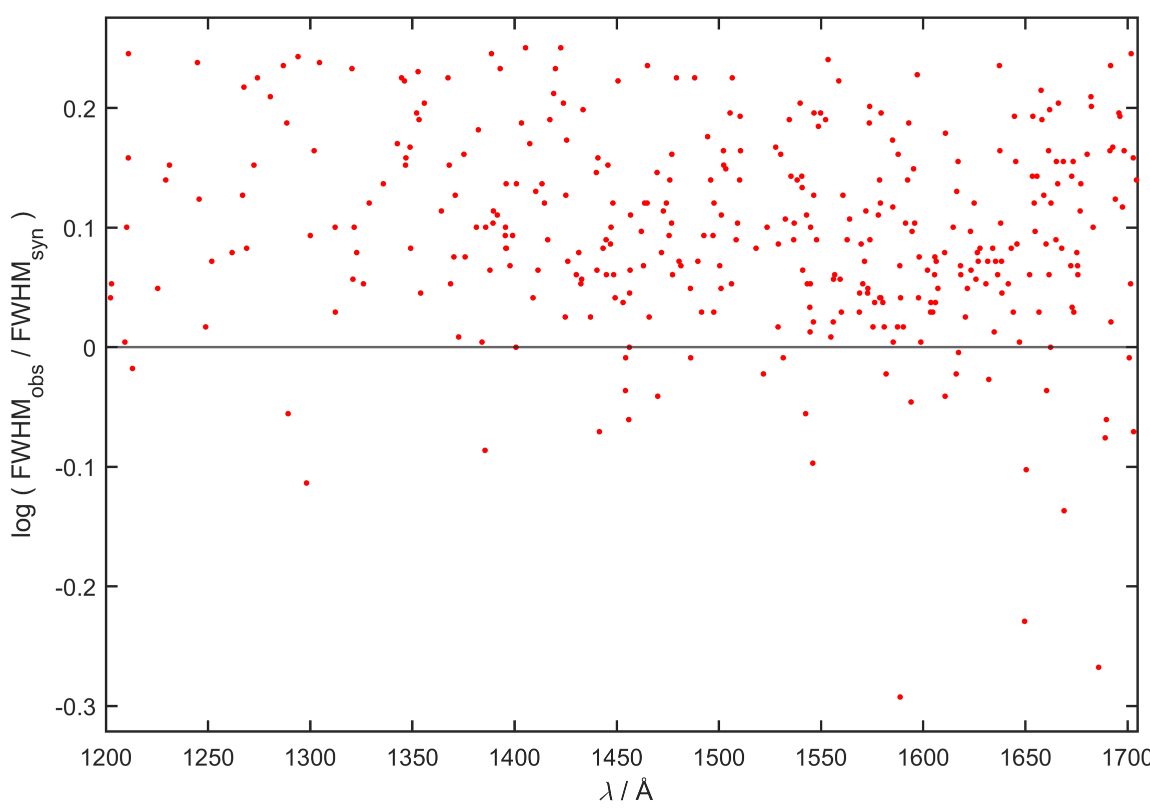

Fig. 1: Plot of the ratio of observed and modeled (labeled "syn" for synthetic) line widths of isolated absorption lines in Feige110 against the wavelength λ, with a mean systematic deviation of +25% (expressed as a non-logarithmic value) towards the observation.

From the Gaussian fits, the line widths (hereinafter the full width at half maximum, FWHM) of 392 isolated IG-element absorption lines were determined for the model and the observation. Here, a comparison showed that these are shifted by 25% towards the observed line widths (Fig. 1), which is partly because a seemingly isolated absorption line in the observed spectrum can be a composition of elements or lines that have not been considered in the model. However, also a more detailed investigation of the STIS LSF helped improving this issue. Usually, the limited R of spectrographs is treated in the model by a convolution of the whole spectrum with a corresponding profile function.

Table 1: Correction factor for the treatment of different spectrographs' LSF shapes, from Robertson [2].

LSF shape	β
sinc^2	1.129
Gaussian	1.127
Lorentzian	1.605
Semi-ellipse	0.943

If it is wanted to convolve the spectrum with a Gaussian profile (which is simpler to implement numerically), conventionally $\Delta\lambda_{\mathrm{FWHM,GAUSS}} = \lambda/R$ is used. This convention, however, can lead to inconsistencies between different spectrographs, as their PSF shapes may differ significantly. On the other hand, depending on the PSF shape, it is not given that a correspondence between the spectral resolution and the numerical convolution exists, hence $\Delta\lambda_{\mathrm{FWHM},R} = \Delta\lambda_{\mathrm{FWHM,GAUSS}}$ might not be applicable. It has been shown by Robertson (2013, [2]) that a correction factor β must be applied to the LSF in order to achieve a consistent treatment of different spectrographs' limited R (Table 1). We could additionally show that the application of β reduces the deviation of the observed and modeled line widths in our analysis significantly. As the STIS LSF takes more likely the shape of a Lorentzian profile (Fig. 2), a correction factor of

$$\beta \approx \frac{\beta_{\mathrm{Lorentz}}}{\beta_{\mathrm{Gauss}}} = 1.424$$

has to be applied to consistently treat R. Hence it is, in the case of STIS,

$$\Delta\lambda_{\mathrm{FWHM,GAUSS}} \approx 1.424\, \Delta\lambda_{\mathrm{FWHM},R} \quad .$$

This is also shown with Fig. 2, where the Gaussian approximation of the LSF without correction overestimates the line center clearly while underestimating the line wings. With correction, the line widths are on average well approximated, while the line wings are still underestimated a little, and even the Lorentzian profile can only approximate the LSF to a certain extent.

Besides, the inclusion of β significantly reduces the mean systematic deviation of the analyzed lines' widths (Fig. 1) from +25% to +11%, which provides an empirical confirmation of the statement.

Conclusions

By a detailed analysis of more than 390 isolated IG-element absorption lines in the STIS uv spectrum of Feige110, it could be shown that the application of a correction factor β, as introduced by Robertson [2], is indeed a good treatment of the spectrograph's LSF. Although even with β the Gaussian profile cannot perfectly account for the STIS LSF, the exact handling of the line widths plays a negligible role for the evaluation of line strengths by measuring equivalent widths, as these are independent of $\Delta\lambda_{\mathrm{FWHM}}$. However, a correct adaptation of the line shape is important for determining atmospheric parameters. In this case, as shown, the line wings are still underestimated by the LSF adaption in the model. This in turn might lead, as the line wings are mainly affected by pressure broadening, to a slight overestimation of the star's surface gravity g (as an increase of g has to compensate the LSF adaption). A detailed investigation of the consequences on g is, however, yet to be performed.

References

[1] Werner, K., Dreizler, S., & Rauch, T. 2012, TMAP: Tübingen NLTE Model-Atmosphere Package, Astrophysics Source Code Library [record ascl:1212.015]

[2] Robertson, J. G. 2013, Publications of the Astronomical Society of Australia, 30, e048

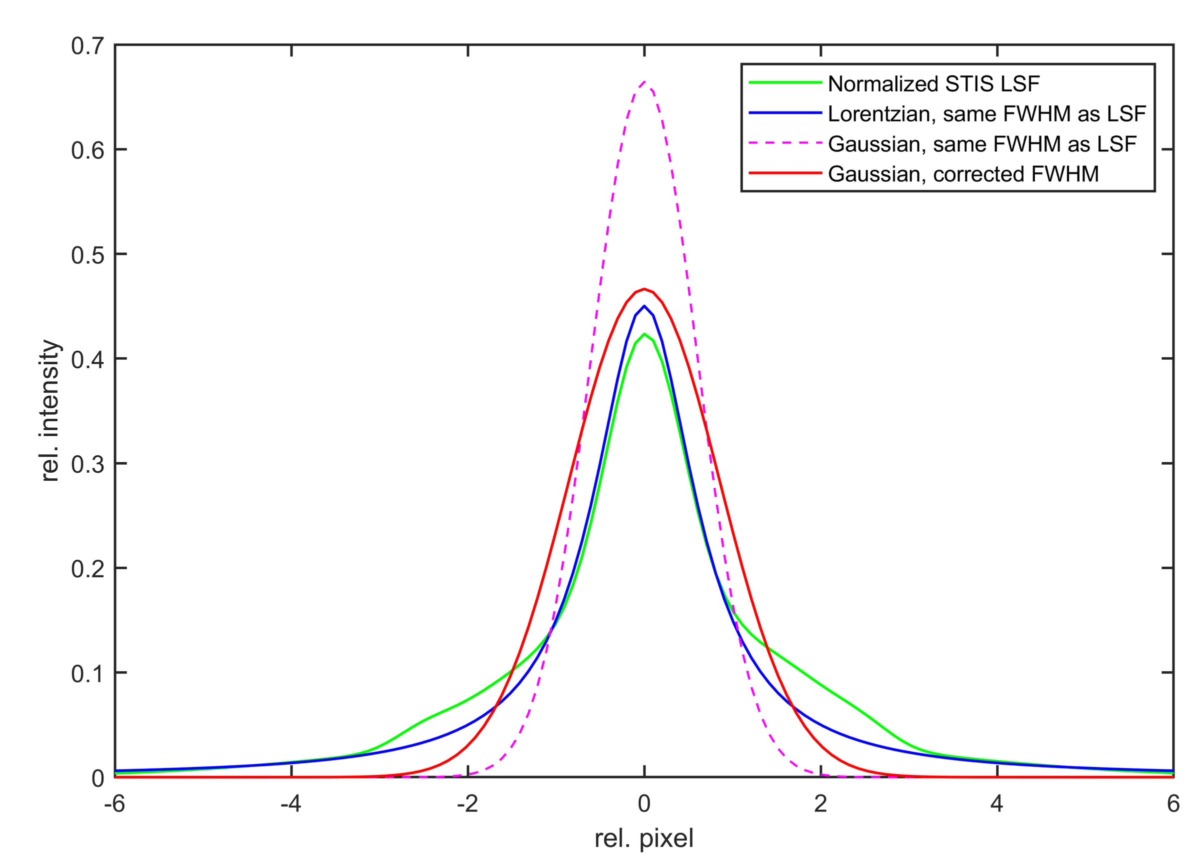

Fig. 2: Normalized STIS LSF (E140M grating, λ = 1 200 Å) compared with a Gaussian and a Lorentzian profile.