Stellar Spectroscopy

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Abstract

The aims of the project were to calibrate a high resolution spectrometer containing a diffraction grating, in order to investigate the spectral lines of chosen targets. More specifically, the investigation was performed to identify the mechanisms responsible for the broadening of lines in the spectra of halogen lamps and in Vega. Thermal broadening was identified in the halogen lamps whilst pressure broadening was the cause of the widths of the lines in Vega.

Introduction

Thermal broadening is caused by the Doppler shift of emitting photons, and follows a Gaussian distribution

$$\mathrm{G(x)} = \frac{1}{\sqrt{2\pi\sigma^2}}\exp\left[\frac{-(\mathrm{x}-\mathrm{x_0})^2}{2\sigma^2}\right] + \mathrm{B}\,,$$

where x_0 is the position of the peak and σ is the width of the peak.

Pressure broadening is caused by collisions between the emitting atoms [1], and follows a Cauchy-Lorentz profile

$$\mathrm{L(x)} = \frac{\mathrm{a}}{\pi\gamma}\frac{\gamma^2}{(\mathrm{x}-\mathrm{x_0})^2+\gamma^2} + \mathrm{B}\,,$$

where γ is the width of the peak. The parameter B in both cases represents a polynomial which is used to fit the background. For the Gaussian function this was first order, for the Lorentzian it was third order.

Calibration using Halogen Lamps

During observations the fibre optic cable is mounted onto the back of the telescope, transmitting light from the target into the spectrometer which diffracts it onto the CCD chip in the camera.

After focusing the camera the 5 halogen lamps were used as reference spectra in a conversion between a micrometer-pixel position and wavelength. This involved fitting all lines in the lamp spectra with a Gaussian convoluted with a semicircle representing the instrumental line shape of the spectrometer, in order to find the precise pixel position of the peak.

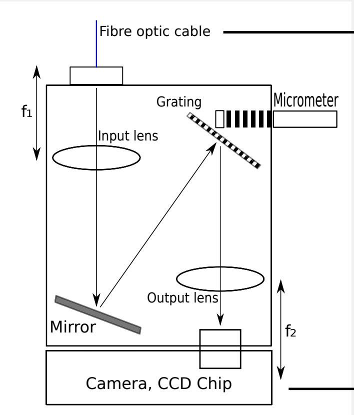


Diagram shows the layout of the inside of the spectrometer.

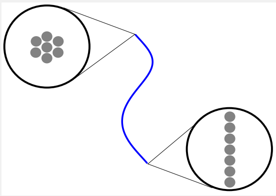
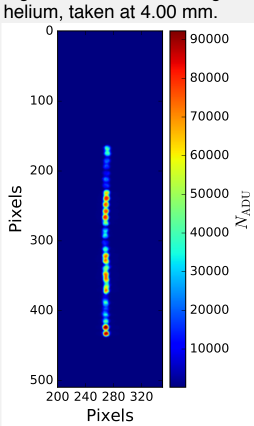


Diagram shows the structure of the round-to-linear fibre optic bundle.

Figure shows a raw image of helium, taken at 4.00 mm.



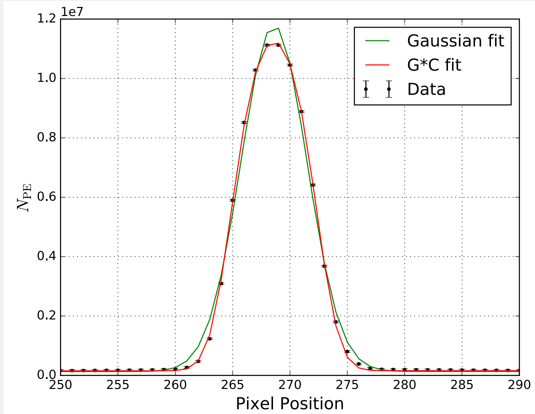


Figure shows the Gaussian and (G * C) convolution fits to the profile of a line in helium, taken at 4.00 mm.

Broadening Mechanisms in Vega

The independent spectral lines in Vega were identified (from [2]) as hydrogen Balmer lines and oxygen lines.

The best fit to lines in Vega was a Gaussian * Lorentzian convolution, known as a Voigt profile.

The average value of the Gaussian σ contribution to the width of the hydrogen lines was

$$\bar{\sigma} = (0.206 \pm 0.089)\,\mathrm{nm}.$$

The average value of the Lorentzian γ contribution to the width was

$$\bar{\gamma} = (1.092 \pm 0.108)\,\mathrm{nm}.$$

This shows that while there is both thermal and pressure broadening, it is pressure broadening that dominates.

The position of the H_β line (shown to the right) was measured to be

$$x_0 = (4860 \pm 56)\,\text{Å}\,,$$

while the given value was

$$\mathrm{H}_\beta = 4861\,\text{Å}\,.$$

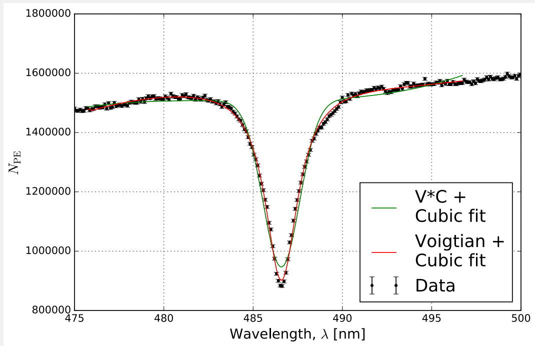
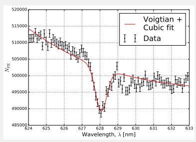
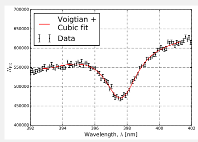


Figure shows the Voigtian and (V * C) fits to the H_β line in Vega.





Figures show the Voigtian fits to the aO_2 (left) and H_ϵ (right) lines in Vega.

References

[1] G Peach, *Theory of the pressure broadening and shift of spectral lines*, Advances in Physics, **30**, (1981).

[2] Hannu Karttunen *et al.*, *Fundamental Astronomy*, (4th edition, Springer, Helsinki, 2003), 202-204.