Comparisons between Observed and Computed Visible and Near-UV Spectra of Vega

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Abstract. We use newly compiled atomic data to address the long-standing controversy over the possible missing opacity in calculations of ultraviolet spectra of late-type stars. The spectrum that would be observed from Earth for different atmospheric models of Alpha Lyrae (Vega, spectral type A0V) is computed taking into account the angular diameter from interferometric measurements. These synthetic spectra are compared with ultraviolet spectra from the IUE satellite and optical ground-based observations.

1. Introduction

The UV region of the spectrum of late-type stars contains a very large number of atomic lines. Some of those lines are produced by chemical elements whose abundances are not accessible from other spectral ranges. A possible missing opacity source in the models was first invoked by Holweger (1970) to explain the failure of calculations to match the observed solar spectrum. Kurucz (1992) claimed line opacity was responsible for the mismatch. However, Bell, Paltoglou, & Tripicco (1994) suggested that improvements in the continuous absorption coefficients for neutral metals could solve the problem better. Recent comparisons for other stars (Allende Prieto & Lambert 2000, Fitzpatrick & Massa 1999) have not found inconsistencies between Kurucz’s models and the observations. Here we address the controversy taking advantage of recently compiled atomic data and revised observations of the standard star Vega. The significant difference between the effective temperature of Vega and the Sun should help to disentangle the effects of line and continuous opacity.
2. Atomic models and important ions for the continuum opacity of Vega

The atomic models used in our calculations employ Resonance Averaged Photoionization (RAP) cross sections from TOPBASE (Cunto et al. 1993) and line transition probabilities and observed energy levels from the Atomic Spectroscopic Database at NIST (US National Institute of Standards and Technology). For some important species not included in the new library, the MODION model atoms were used (see http://tlusty.gsfc.nasa.gov/ for more details).

The computations are based on a Kurucz model atmosphere for a star like Vega. We employed Synp1ot (Hubeny & Lanz 2000) to calculate the emitted flux. We found that the most relevant ions shaping the continuum were H\textsuperscript{+}, H\textsuperscript{-}, He\textsuperscript{+}, C\textsuperscript{i} and Si\textsuperscript{ii}. He bound-free opacity is only important at very short wavelengths ($\lambda$ < 1300 Å), but it affects indirectly at longer wavelengths. Hydrogen opacity utterly dominates the shape of the spectrum. After hydrogen, C\textsuperscript{i} was the most important absorber below 1450 Å and H\textsuperscript{-} at longer wavelengths. We determined He, C, Si and Fe abundances, and compared them with those available in the literature from the analysis of spectral lines.

3. Instruments and calibrations

There is a large number of UV spectra available for Vega. In the visible range, we used the spectrum of Hayes (1985). Its uncertainty is 1-2\% (Bohlin 1996; Hayes 1985). In the UV region, we compiled low resolution (large aperture) spectra from the International Ultraviolet Explorer (IUE) satellite. We worked with three spectrophotometric calibrations: INES (IUE Newly Extracted Spectra; see González-Riestra, Cassatella, & Wamsteker 2001 and references therein), CALSPEC (Bohlin 1996), and the Massa & Fitzpatrick calibration (M&F, Massa & Fitzpatrick 2000). We used the mean of CALSPEC and M&F (both in the flux scale of FOS, Faint Object Spectrograph, onboard HST), with uncertainties in the absolute flux of 3-4\% (Bohlin 1996; M&F).

As a nearby star, the Hipparcos parallax of Vega provides an accurate distance (7.76 ± 0.03 pc) and surface gravity (log $g$ = 3.98 ± 0.02 dex, Allende Prieto & Lambert 1999), which we used in our calculations. In addition, a recent interferometric determination of its angular diameter ($\theta = 3.28 \pm 0.01$ mas at 2.2 μm, Ciardi et al. 2001) was adopted. With these data, it is possible to transform an observed spectrum to that emitted at the stellar surface, or vice versa. Fig. 1 compares the different UV spectra of Vega.

4. Comparison between observed and computed spectra of Vega

We interpolated in a grid of spectra computed with Kurucz's model atmospheres. The grid considered the effect of the most relevant parameters ($T_{\text{eff}}$, $\theta$, the metallicity M and the chemical abundances) on the shape of the spectrum. We started with two wavelength regions: 5000 to 8500 Å and 2350 to 2750 Å, adopting M = −0.7 and chemical abundances from Qiu et al. (2001).

We analyzed the region from 1270 to 2130 Å, excluding some segments that could not be fit well. The resolution of the observed spectrum was taken as a
Figure 1. Comparison of observed UV fluxes obtained by different instruments and/or with different calibrations. Note the lower flux of INES (about 8%) compared to those of CALSPEC and M&F.

Figure 2. Computed fluxes using different line lists and the parameters of the best fit. A slightly modified version of the line list distributed with Synplot is labeled as 'Synplot'. 'Kurucz' represents the most recent line list distributed by R. L. Kurucz. The 'VALD' line list was extracted from the Vienna Atomic Line Database. The observed flux is the mean of CALSPEC and M&F.

free parameter (FWHM of a Gaussian instrumental profile). The C abundance is relevant for λ < 1480 Å, Si for λ < 1550 Å, and He and Fe in all the region considered. The best fit provides: [He/H] = −0.06 dex, $T_{\text{eff}} = 9640$ K, [C/H] = 0.05 dex, $M = -0.7$, [Si/H] = −0.85 dex, and FWHM = 13.5 Å. Fig. 2 confronts spectra computed with different line lists against observations. The synthetic and observed spectra differ especially in regions with strong lines (where NLTE effects could be important), in the near-UV (where the quality of the observed spectrum is not very high) and in some other regions (from 1375 to 1460 Å, with a possible Si IV stellar wind feature, or from 2000 to 2250 Å). The fitting improves by changing the Stark damping parameters for some lines of Si II, but it is still poor for other lines of Fe II and C I, and possibly Al II.

The parameter uncertainties are: ± 0.033 mas for $\theta$, ± 38 K for $T_{\text{eff}}$, ± 0.11 dex for [He/H], ± 0.04 dex for [C/H], ± 0.29 dex for [Si/H] and ± 0.10 for M.
5. Conclusions

When comparing computed and observed spectra from two calibrations of IUE, we obtain reasonable agreement adopting $T_{\text{eff}} = 9640$ K, log $g = 3.98$, M = $-0.7$, $\theta = 3.28$ mas, [He/H] = $-0.06$ dex, [Si/H] = $-0.85$ dex and [C/H] = $0.05$ dex. Hydrogen plays a dominant role shaping the spectrum, but H$^-$, He, and Fe opacities are important in the visible and UV ranges, and C I and Si II in the UV below 1480 and 1550 Å, respectively. The 3% correction to the UV fluxes suggested by some authors (e.g. Gulliver, Hill, & Adelman 1994) seems unnecessary, although the agreement is not good at all wavelengths. For example, some strong lines of Fe II, Al II and C I are not well reproduced. Vega is a rapidly rotating pole-on star, which may affect our results slightly (Gulliver et al. 1994).

Work is in progress to improve the determination of chemical abundances in the atmosphere of Vega from high-dispersion optical spectra. We will also improve the atomic models and compare synthetic and observed spectra for other nearby stars. Our main goals are a better understanding of the formation of the UV spectrum, and to check the different sources of UV spectra.

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References

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