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MODELS FOR VEGA

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ABSTRACT By using the ATLAS9 code which requires the new opacity data from Kurucz (1992), we derived a new atmospheric model for Vega with parameters T_{eff}=9500 K, log g=3.95, [M/H]=-0.5, ξ=2 km s^{-1}. The model was fixed by comparing observed and computed energy distributions and Balmer profiles.

INTRODUCTION

Vega (α Lyrae=HR 7001 = HD172167) is a Pop. I star of spectral type A0 V with a projected rotational velocity $v sini$=23 km s^{-1} (Gray, 1980). The importance of computing a very accurate model atmosphere for Vega is mostly related with the use of its colours as zero point for the theoretical photometric grids and the need of a reliable theoretical flux distribution for Vega is therefore evident. This choice of Vega as reference star is due to its role of primary and secondary spectrophotometric standard in the visual (Hayes, 1985) and in the ultraviolet (Bohlin et al., 1990) respectively.

OBSERVATIONS

In the visual, from 330 to 1050 nm, we have used the mean energy distribution published by Hayes (1985), who estimates the accuracy to be 1.0 to 1.5 %. In the ultraviolet from 130 to 330 nm we have used the observations both from TD-1, S2/68 experiment (Jamar et al., 1976) and from IUE as determined by Bohlin et al. (1990). The last ones are affected by a noisy bump of 5%-10% in the 200-210 nm region and are of moderate quality below 230 nm owing to the presence of artifacts which were, however, removed from the individual spectra (see Bohlin et al., 1990). As flux distributions we adopted either the magnitude M_ν=-2.5$\log_{10}F_\nu$, normalized to 0.000 at 555.6 nm or the absolute flux at the star surface $F_\lambda=4\pi H_\nu c/\lambda^2$ in ergs cm^{-2} s^{-1} nm^{-1}. We have assumed that the

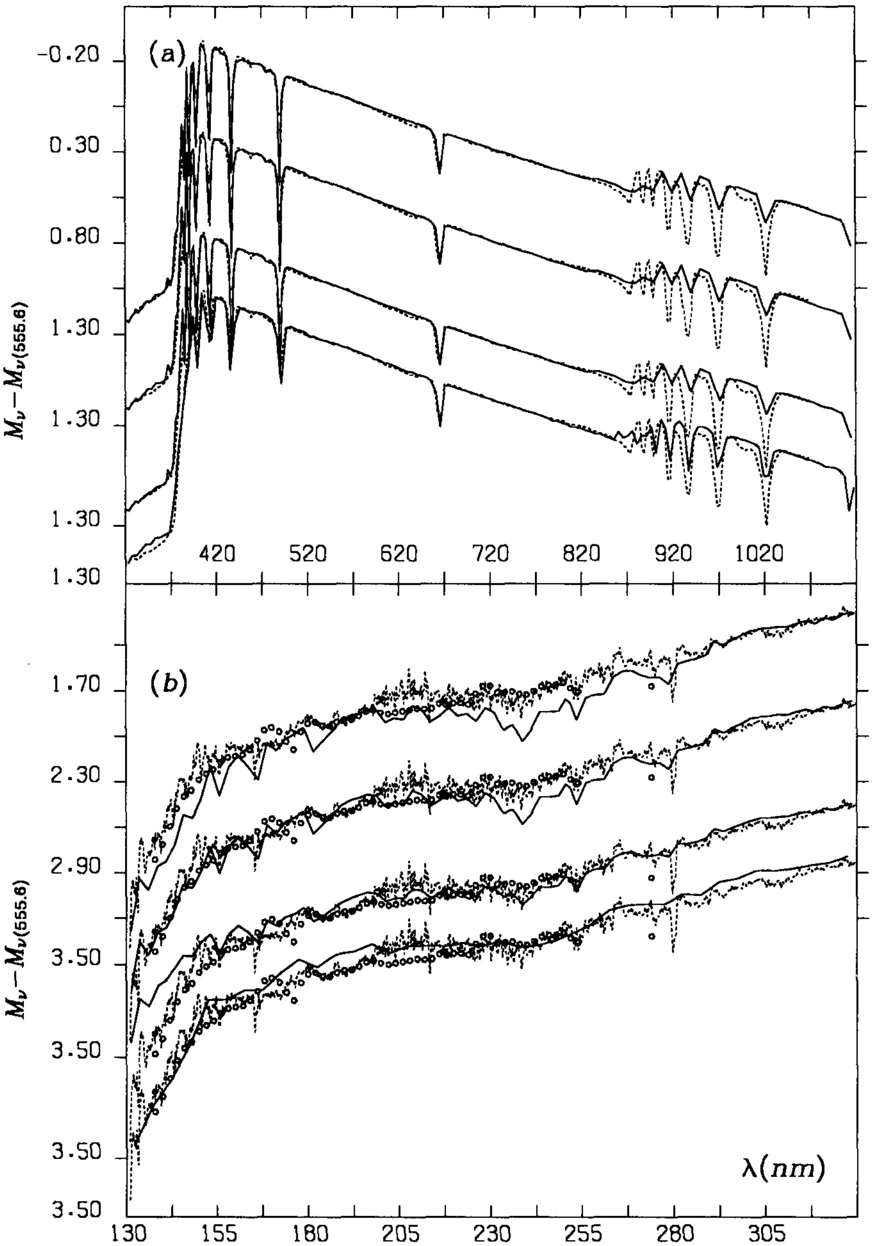

Fig.1. Comparison between observed and computed energy distributions: (a)visual (b) ultraviolet. In the visual, observations are from Hayes (1985) (dashed line), in UV are from IUE (Bohlin et al., 1990) (dashed line) and from S2/68 TD1 (Jamar et al., 1976) (points). Computations (full lines) are from top to bottom from Kurucz (1979), Lane and Lester(1984), Gigas (1986), and Dreiling and Bell (1980).

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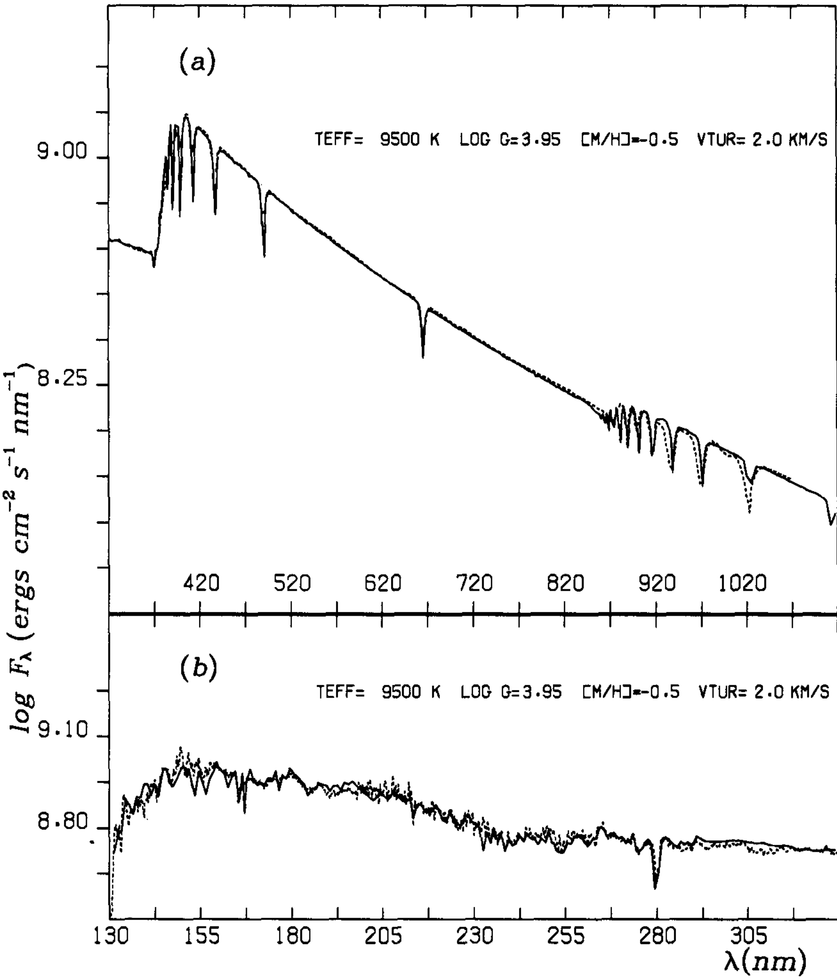

Fig.2. Comparison between observed (dashed lines) and computed (full lines) absolute fluxes at the star surface:(a)visual (b) ultraviolet. Observations are from Hayes (1985) in the visual and from IUE (Bohlin et al., 1990) in the ultraviolet.

absolute flux at earth at 555.6 nm is F_ν=3.50x10^{-20} ergs cm^{-2} s^{-1} Hz^{-1} (Hayes and Latham, 1975) and that (d/R)^2 is (1.62±0.03) 10^{16} (Dreiling and Bell, 1980).

OLD VEGA MODELS

Vega models most widely used up to now are based on the model atmospheres computed either by using the ATLAS code of Kurucz (1979) or by using the MARCS code of Gustaffson et al. (1975). Table I lists the model parameters

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adopted by Kurucz (1979), Lane and Lester (1984), and Gigas (1986), who used the ATLAS code, and by Dreiling and Bell (1980), who used the MARCS code.

TABLE I Model Parameters for Vega

Author	T_{eff} (K)	log g	[M/H]	ξ(km s^{-1}) in ODF
Kurucz (1979)	9400	3.95	0	2
Lane and Lester (1984)	9500	3.90	0	2
Gigas (1986)	9500	3.90	-0.5	2 (2.5 km s^{-1} in P_{turb})
Dreiling and Bell (1980)	9650	3.90	0.0	3 (Doppler width)

Figure 1, upper panel, shows that the visual energy distributions from the different models (full lines) do not differ very much each from the other. All the models fairly well reproduce the observed energy distribution (dashed line) between the Balmer and Paschen discontinuities. All the models do not predict correctly the Paschen discontinuity and the hydrogen Paschen lines, which are computed too weak. The best agreement shortward the Balmer discontinuity is given by the Kurucz and by the Gigas models (first and third tracings respectively). Figure 1, lower panel, shows that the ultraviolet energy distributions from the different models (full lines) differ from one model to another and that none of the models reproduces correctly the ultraviolet flux. The Gigas model, which differs from the other models mainly in metallicity, gives the best agreement over the largest spectral range from about 160 nm to 800 nm.

A NEW MODEL FOR VEGA

We have assumed Gigas parameters T_{eff}=9500 K, log g=3.90, [M/H]=-0.5, and ODF's for ξ=2 km s^{-1} as starting point for computing a model for Vega by using the ATLAS9 code (Kurucz, 1992). The version 9 of ATLAS has, as regards to the version 8, improved continuum opacities, increased line opacity, and yields higher resolution computed fluxes, owing to the 1212 wavelenght intervals for the tabulated opacity distribution functions for computing fluxes, instead of the 342 of the old models.

We have determined the value of log g by comparing the Balmer profiles computed with log g=3.90, 3.95, and 4.00 with the profiles observed by Peterson (1969). The BALMER code was used for computing hydrogen lines. The gravity log g=3.95 well reproduces the Hγ profile, but log g=4.00 fits better the wings of Hα and Hβ. By giving more weight to Hγ, we have assumed log g=3.95 as the final gravity.

The metallicity [M/H]=-0.5 of the Gigas model agrees with the results of Adelman and Gulliver (1990) and Venn and Lambert (1990), who, from the equivalent widths measured in high resolution visual spectra, derived abundances lower than the solar ones from about 0.0 dex to -0.9 dex for the different elements. The comparison of ultraviolet Copernicus high-resolution spectra with computed spectra for the whole regions 130-135 nm and 200-318 nm has confirmed the mild-underabundance of metals in Vega (Castelli,1992). The microturbulent velocity ξ derived from the visual and ultraviolet high resolution spectra was found to be of the order of 2±0.5 km s^{-1} (Dreiling and Bell,1980; Gigas, 1986; Venn and Lambert, 1990, Castelli, 1992). The computed and observed absolute fluxes $\log F_\lambda$ at the star surface are compared in figure 2 both for the ultraviolet and visual regions. Longward of the Balmer discontinuity the model flux is 1.0 to 2.5% lower, but shortward of the Balmer discontinuity it matches the observations or it is even somewhat higher. A slight reddening E(B-V)=0.01 would reduce the overall agreement. An higher effective temperature T_{eff}=9550 K, improves the fit in the visual range, but worsens it in the ultraviolet, where the computed flux becomes higher than the observed one. In particular, absolute model fluxes at 555.0, 555.6, and 1040.0 nm are lower than the observed fluxes by about 2%, but they are within the error limits estimated by Dreiling and Bell (1980) from the combined errors on the observations and on the angular diameter.

We have therefore assumed as final model that with parameters T_{eff}=9500 K, log g=3.95, [M/H]=-0.5, and ODF's for ξ=2 km s^{-1}, because it well reproduces the observed ultraviolet and visual energy distributions, the Balmer profiles, and it is consistent with the metallicity and the microturbulent velocity derived for Vega from the high resolution spectra.

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DISCUSSION (Castelli and Kurucz)

ADELMAN: Did you include turbulent pressure from the 2 km s^{-1} microturbulent velocity used in your ODF's ? Gulliver showed that helium was underabundant. Have you experimented with models less than solar He/H ratios or with 0 or 1 km s^{-1} in the ODF's ? If so, what model parameters are found ?
CASTELLI: For computing the model we assumed zero turbulent pressure in the hydrostatic equilibrium equation. Turbulent pressure is caused by random motions of small gas elements and we assumed that the mean value of this random velocity is zero. In any case, the inclusion of a turbulent pressure corresponding to a microturbulent velocity ξ=2 km s^{-1} has negligible effect on the model structure. The meaning of ξ in the ODF's is that of an additional broadening parameter for the line profiles. The value of ξ=2 km s^{-1} was derived from the analysis of high resolution Copernicus spectra both by using the synthetic spectrum method and, for unblended Fe II lines, the relation equivalent widths versus abundances. Microturbulent velocities of 0 or 1 km s^{-1} are not appropriate for Vega. We have experimented with the He/H ratio of 0.0677 from Gulliver et al. (ApJ, 380, 223, 1991) for models computed with solar metallicity The energy distribution does not differ from that computed with the solar ratio He/H=0.0977, so that the effective temperature does not change; the Balmer profiles are slightly weaker, so that the gravity should be increased by 0.05 dex to fit the observed Balmer lines.
HOUZIAUX: Do you have an explanation for the fact that the fit for the higher Paschen line profiles seems rather poor ?
CASTELLI: No, I do not have any explanation at the moment. High-resolution spectra in that region could solve the problem. Hayes (1985, Proc. IAU Symp. No. 111, p. 225) recommends caution in the use of the mean energy distribution at wavelengths near strong lines and in the Balmer and Paschen confluences. In fact, the accuracy here is low owing to the difficulty in combining data obtained with different wavelength accuracy and different bandpasses.