The flat bottomed lines of Vega (A0V)

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Introduction and context

Vega, the bright A0V standard star, is actually a very fast rotator seen nearly pole-on. It is one of the northern slowly rotating early A stars we are currently monitoring (see Royer et al. 2014) . Because of the large rotation, there is a large gradient in temperature and gravity between the poles and the equator across the stellar disk, the pole being hotter and having a higher gravity than the equator. Temperature sensitive lines are accordingly distorted and their profiles have flat cores. Gulliver et al. (1994) first reported on the occurence of several flat-bottomed lines in the high dispersion very high signal-to-noise DAO Reticon spectra of Vega. They found that weak lines have flat-bottomed profiles in contrast to strong lines which display classical rotationaly broadened profiles. Their modeling of the photosphere of Vega with model atmospheres of different effective temperatures and surface gravities revealed that, in order to reproduce the flat-bottomed profile of Fe I 4528 Å and Ti II 4529 Å, the temperature and surface gravity near the pole need to be respectively: $T_{pole} = 9695 \pm 25$ K and $\log(g_{pole}) = 3.75 \pm 0.02$ dex. In this model, Vega has a linear equatorial velocity of $V_{eq} = 245 \pm 15$ km.s^{-1} and is seen with a very low inclination angle of the rotation axis (respect to the line of sight) of $i = 5.1 \pm 0.3$ degrees. At that time, Gulliver et al. (1994) did not however publish a complete list of the flat-bottomed lines in the optical spectrum of Vega. The purpose of this work is to present a complete list of the 198 lines we find to be flat bottomed in a high resolution high signal-to-noise spectrum of Vega obtained with SOPHIE at OHP.

Observations and Reduction

Vega has been observed 78 times at Observatoire de Haute Provence using the High Resolution (R =75000) mode of SOPHIE in 2006 and 2007.

We have analysed one 25 seconds well exposed spectrum whose $\frac{S}{N}$ ratio is 583 at 5000 Å.

Conclusions

The flat-bottomed lines of Vega appear to be weak lines absorbing less than 3% of the continuum due to C I, O I, Mg I, Al I, Ca I, Sc II, Ti II, V II, Cr I and Cr II, Mn I, Fe I and Fe II, Sr II, Zr II and Ba II.

References

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Identification table for the flat bottomed lines in Vega

A list of all flat bottomed lines in the spectrum of Vega from 4400 Å up to 4600 Å appears in Table 1 with the observed wavelengths of the centroids of the lines, the laboratory wavelength of the responsible specie, the specie, the lograithm of the oscillator strength and the lower excitation energy of the transition.

Laboratory Wavelength (Å)	Observed Wavelength	Identification	log(gf)	E_{low} cm^{-1}	Comment
4400.40	4400.379	Sc II	-0.510	4883.570	
4411.10	4411.074	Ti II	-1.060	24561.031	
4417.80	4417.719	Ti II	-1.430	9395.710	
4418.40	4418.330	Ti II	-2.460	9975.920	
4450.60	4450.482	Ti II	-1.450	8744.250	
4451.60	4451.551	Fe II	-1.840	49506.995	
4454.90	4455.027	Fe I	-1.090	31307.244	
4464.50	4464.450	Ti II	-2.080	9363.620	
4466.65	4466.551	Fe I	-0.590	22856.320	
4473.00	4472.929	Fe II	-3.430	22939.357	
4476.10	4476.019	Fe I	-0.570	22946.815	
	4476.076	Fe I	-0.290	29732.735	
4488.40	4488.331	Ti II	-0.820	25192.791	
4494.65	4494.563	Fe I	-1.140	17726.928	
4528.70	4528.614	Fe I	-0.820	17550.180	
4529.60	4529.569	Fe II	-3.190	44929.549	
4541.60	4541.524	Fe II	-3.050	23031.299	
4554.20	4554.033	Ba II		0.000	15 hfs iso
4582.85	4582.835	Fe II	-3.100	22939.357	
4590.0	4589.958	Ti II	-1.790	9975.920	
	4589.967	O I	-2.390	86631.153	
4592.10	4592.049	Cr II	-1.220	32854.949	

Table 1: The flat bottomed lines in the SOPHIE spectrum of Vega from 4400 to 4600 Å

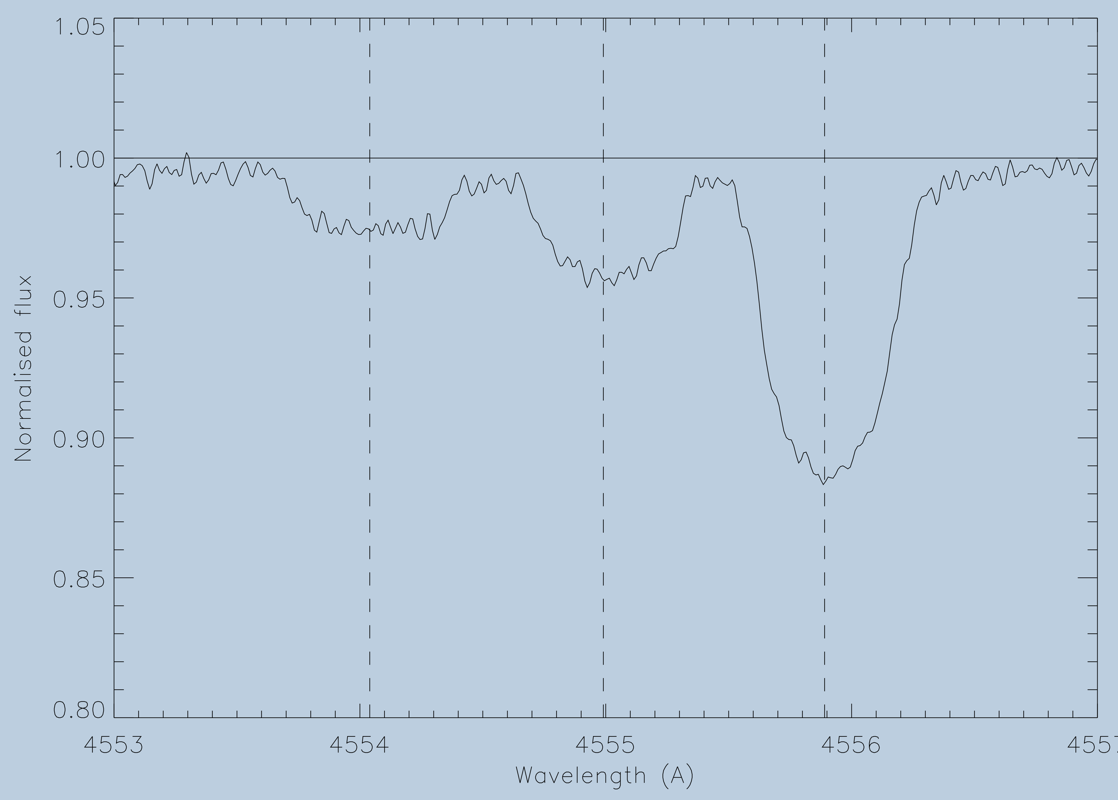

Figure 1: The flat bottomed line Ba II 4554.03 Å next to Cr II 4554.99 and Fe II 4555.89 Å

Model atmospheres and spectrum synthesis calculation

A grid of synthetic spectra was computed with SYNSPEC49 (Hubeny & Lanz, 1992) to model selected lines with good atomic data. A 72 layers plane parallel model atmosphere was computed assuming Local Thermodynamical Equilibrium, Radiative Equilibrium and Hydrostatic Equilibrium using ATLAS9 for an effective temperature of 9500 K and a surface gravity log(g) = 4.00 suitable for Vega (Castelli & Kurucz, 1994). The elemental abundances of Vega are also taken from Castelli & Kurucz. A microturbulent velocity of 1.7 km.s^{-1} was derived by minimising the iron abundances inferred from Fe II lines of various strengths. The output identification file from SYNSPEC49 was then used to identify the flat bottomed lines in Vega. In figure 1, the observed line profile of Ba II at 4554.03 Å is compared to that of the neighbor lines, Cr II at 4554.99 Å and Fe II at 4555.89 Å which have classical rotationaly broadened profiles. This comparison clearly illustrates the large deviations of the flat-bottomed Ba II 4554.03 Å line from a normal line profile.