

VARIATIONS OF THE EMISSION LINE PROFILES IN THE O6ef STAR LAMBDA CEPHEI

PETER S. CONTI*† AND STEWART A. FROST

Joint Institute for Laboratory Astrophysics, University of Colorado and National Bureau of Standards; and
 Department of Physics and Astrophysics, University of Colorado, Boulder, Colorado 80302

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ABSTRACT

Dramatic variations in the emission line profiles of $H\alpha$ and $\lambda 4686$ He II from eight consecutive nights of observations are reported. Other absorption lines appear to be constant during this time. Also described is an innovative computer method for obtaining line profiles from spectrograms.

Subject headings: emission-line stars — spectrum variables — rotation

I. INTRODUCTION

Oef stars are those early O-type stars that show double emission lines in $\lambda 4686$ He II (Conti and Leep 1974). They have the additional characteristics of more rapid rotation and luminosities nearer to the main sequence than the brighter Of stars. Although it is not proved, we believe that the rapid rotation of the star fundamentally influences the envelope producing the emission lines. Lambda Cep is one of the brightest members of this newly identified class (a recent spectrum is given in Walborn 1973). From spectra already available to us, it appeared that the $\lambda 4686$ line profile changed drastically between different observing seasons. We have thus begun an intensive observational program for this star.

II. OBSERVATIONS

Spectroscopic observations were obtained for this star on eight consecutive nights on the 84-inch (210 cm) telescope at Kitt Peak, 1973 September. These were taken at the coudé focus, with the number 2 camera and the new large-size B grating giving dispersions of $17 \text{ \AA mm}^{-1}$ in the blue on baked IIa-O emulsion and $25 \text{ \AA mm}^{-1}$ in the red on 098-02 emulsion. The spectra were invariably widened to about 1 mm; the exposure times were typically 5–10 min for each wavelength region and were taken sequentially.

We have obtained normalized and smoothed tracings of these spectra by the following innovative computer reduction procedures. The plates were traced on the Boller and Chivens microphotometer at the High Altitude Observatory and the data put directly onto magnetic tape. The sampling slit was about 18μ wide, similar to the grain size. Readings were taken every 18μ , giving us about 4000 bits of information per spectrum. The density information was then filtered by a fast Fourier transform method similar to that outlined by Brault and White (1971) using the University of Colorado CDC 6400 computer. The choice of filter size

was made primarily by trial and error; our optimum filter for work on O-type stars with broad lines was basically a low-pass filter with a cutoff at 32 percent of the Nyquist frequency. This degraded the resolution slightly but had very little effect on the stellar lines.

The result of filtering was to remove most of the noise introduced by finite grain size on the spectrograms. After filtering, the density values were transformed to an intensity scale by using a fourth-order polynomial fit to the calibration curve. This was obtained by tracing a spot sensitometer plate which was developed with the stellar spectrogram(s). (These calibration plates were not filtered.) After obtaining the intensity values, the numbers were normalized by choosing continuum points *a priori*. This step required judicious choice of points but was possible to do accurately in stars without many lines. It would probably not be prudent to make this step this way in F- or G-type stars.

Finally, selected lines were normalized to a velocity coordinate by choosing a number of stellar lines to have "zero" velocity. This sets the velocity scale but is only accurate to 20–30 km s^{-1} , given the "X" accuracy of the microphotometer. Problems of "paper stretching" normally associated with microphotometer output are avoided since no data are plotted until this final step. Certain selected lines were transferred to microfilm by the computer and a photoenlargement made of the desired lines.

To illustrate what smoothing has accomplished, we show in figure 1 both an unfiltered profile (*top*) and filtered profile (*bottom*) of the $\lambda 4541$ He II line in λ Cep. The individual sampling points are shown in the unfiltered profile where the grain noise is clearly present. (The continuum points were picked outside the range of this particular figure.) There is still low-frequency noise present in the smoothed profile, which can only be reduced if a number of plates are averaged.

In figure 2 we show a plot of individual smoothed spectra of the $\lambda 4541$ line taken on eight consecutive nights. To within a few percent accuracy, the profile is constant over this time. The fluctuations shown are undoubtedly due to low-frequency random noise present in the spectrograms that is not removed by this par-

* Also Department of Astrophysics, University of Colorado.

† Visiting astronomer, Kitt Peak National Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract to the National Science Foundation.

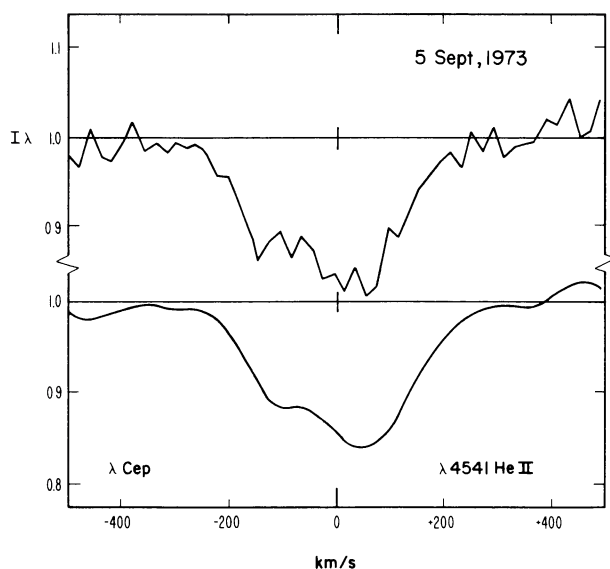


FIG. 1.—Individual point-by-point representation of the $\lambda 4541$ He II line profile in λ Cep is shown in the upper portion. The individual points are spaced about 18μ apart (similar to the grain size of the spectrograms). The smoothed profile is shown in the lower part of the figure. This was obtained by using an inverse Fourier transform method similar to that of Brault and White (1971) operating on the entire spectrum.

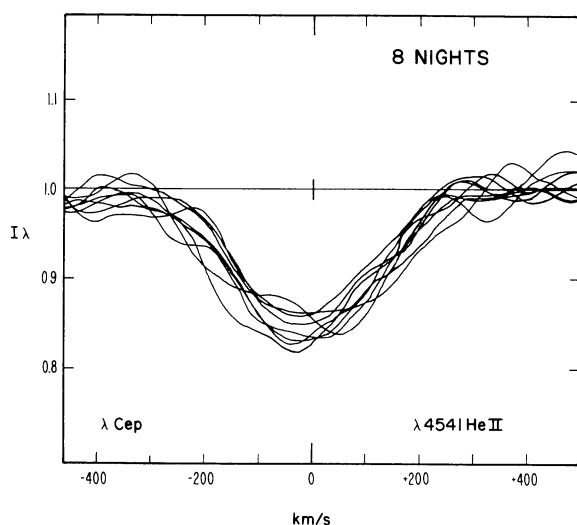


FIG. 2.—Smoothed line profiles of $\lambda 4541$ He II for eight consecutive nights of observations of λ Cep. The differences among the individual profiles are probably due to low-frequency noise not removed by the filtering technique. This line is probably constant, and the variations shown may be regarded as a measure of the scatter in the data. This line is one of several assumed to have "zero" velocity with respect to the stellar photosphere.

ticular filter. The figure can be used as a standard comparison for a nonvarying line in the following. It should be noted that this particular line appears to be symmetrical and rotationally broadened. Other absorption lines we have looked at do not appear to vary.

Slettebak (1956) did not include λ Cep among the O stars for which he listed rotational velocities from tracings of spectra, but he did give a visual estimate of V^* of 150 km s^{-1} . According to his discussion, V^* , which represents an estimate of the turbulent velocity, is about 25 percent smaller than $V \sin i$. The latter term is used if the profile is ascribed wholly to rotation. This description is now commonly used in the literature, but we should remember that the importance of turbulence in early-type stars is not resolved. From eye estimates of our spectra and comparisons of intensity tracings, we estimate that $V \sin i$ for λ Cep is practically identical to ξ Per, for which Slettebak (1956) estimated $V \sin i$ as 210 km s^{-1} . (This is also consistent with his estimate of V^* .)

Figure 3 shows that smoothed line profiles of the $\lambda 4686$ He II line for the eight consecutive nights demonstrate an unmistakable variability from night to night. The profile is basically a double emission one, characteristic of Oef stars (Conti and Leep 1974), which we believe is a result of a combination of absorption and emission. The total emission-line width is somewhat wider than that shown for $\lambda 4541$; the absorption width is similar or broader and is slightly violet displaced. (The velocity zero point is determined from other absorption lines.)

Figure 4 shows the line profiles of $H\alpha$ for five of the eight nights $\lambda 4686$ was observed. These were obtained a few minutes before or after the blue spectrograms. There is also an indication of double emission in this profile, but the line shape is not identical to that of $\lambda 4686$. The $H\alpha$ line is broader and the absorption component tends to be stronger and is more violet displaced. These observations suggest that the region of line formation of $H\alpha$ is slightly more extended than that for $\lambda 4686$, which is consistent with the source function for each line and the observed behavior in O stars (Conti and Leep 1974).

According to the radial-velocity catalog of Abt and Biggs (1972), no velocity variation has been noted in λ Cep in three separate investigations involving 22 spectrograms. The weighted average of -74 km s^{-1} is similar to that obtained on a Lick Observatory coude spectrogram for which a velocity -79 km s^{-1} was found using a Grant machine. Although we have not yet measured the Kitt Peak spectrograms, a study using a Boller and Chivens microcomparator revealed no velocity differences larger than 10 km s^{-1} from plate to plate. We conclude that λ Cep is a single star.

III. DISCUSSION

One important datum that we do not have is the time scale of the variations. The peculiar emission line profile at $\lambda 4686$ and its variability have previously been noted by Slettebak (1969), who found changes on the time scales of hours. Brucato (1971) finds that the $\lambda 4686$ line strength varies in the time scale of *minutes* in ζ Pup. There is a similarity in the $\lambda 4686$ profiles between λ Cep and ζ Pup since both stars have a central absorption component superposed on a broad emission feature, although the absorption is considerably weaker in the

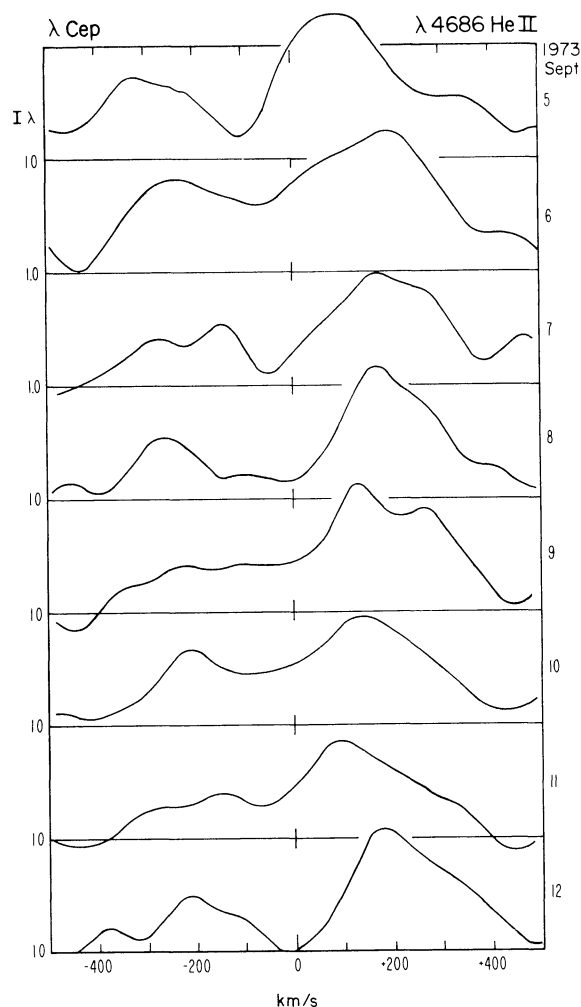


FIG. 3.—Smoothed line profiles of $\lambda 4686$ He II for eight consecutive nights of observations of λ Cep. The velocity axis is determined from other absorption lines assumed to have “zero” velocity with respect to the stellar photosphere. The intensity scale is 1.3 to 1.0 (from one night to the next). The profile is basically a double emission peaked one which is believed due to a combination of more or less central absorption and emission. The emission width is considerably wider than other absorption lines in the spectrum and appears to vary. The absorption width in this line is equal to or broader than the width of other absorption lines and also varies. The changes from night to night are pronounced.

latter star. Zeta Pup is also classified Oef by Conti and Leep (1974) and has a relatively large rotational velocity. The similarity of these features of the spectra in the two stars may be more than coincidental.

If we ascribe the 210 km s^{-1} as entirely due to $V \sin i$, then a maximum rotational period of λ Cep is about 2.4 days (R is about $10 R_{\odot}$ for an O6 star according to Panagia 1973). The nightly changes we see in the spectrum could be a result of the rotational effects, but short-period changes can only be due to variations in the envelope in which $\lambda 4686$ and $H\alpha$ are formed.

That the absorption width at $\lambda 4686$ is similar to that

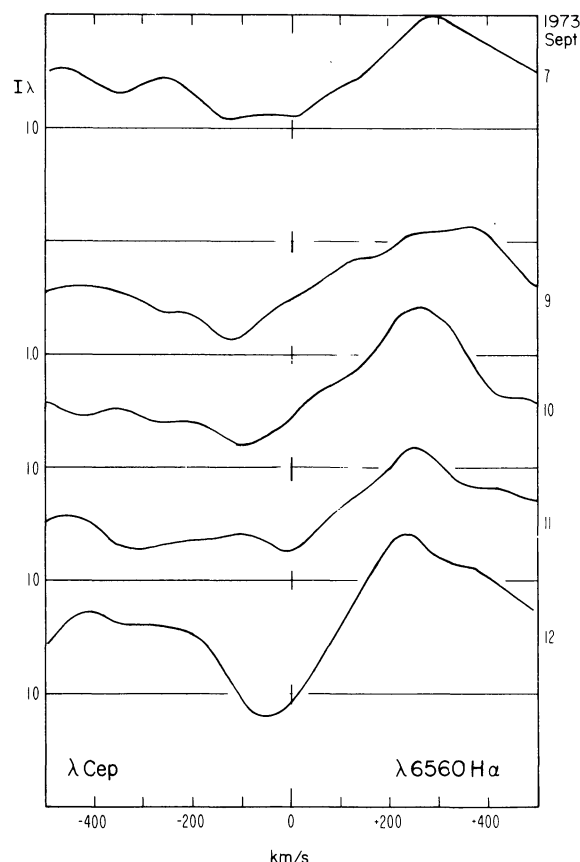


FIG. 4.—Smoothed line profiles of $H\alpha$ for five of the nights for which observations of $\lambda 4686$ were obtained. The velocity axis is determined from other absorption lines assumed to have “zero” velocity with respect to the stellar photosphere. The intensity scale is 1.3 to 1.0 (from one night to the next). The profile is similar to that observed at $\lambda 4686$ except that the emission is appreciably wider and the absorption is stronger and displaced more toward the violet.

observed in other lines suggests that this feature is seen projected against the stellar photosphere. The small violet displacement, somewhat larger in $H\alpha$, suggests that only a small net outward flow of material is present at this optical depth. We suggest that the emission width must come from an extended envelope with appreciable rotation, or possibly large-scale motions induced by the interaction with the rapidly rotating star.¹ Possible explanations involving phenomena other than rotation cannot be excluded.

The observed changes in these lines strongly suggest that the flow is variable in velocity, density, or symmetry, or in all three simultaneously. Conti and Leep (1974) have noted the similarity of these double emission profiles to the Be stars whose rotation probably has a fundamental influence in creating an emitting

¹ We are indebted to Dr. D. G. Hummer for suggesting this latter possibility to us.

envelope. Although radiation pressure and outward flow are also of crucial importance, we believe that the large rotational velocities observed for the Oef stars may be a similar manifestation of the same phenomenon.

We predict that other early-type stars with relatively large rotational velocities will show emission of this character. We want to emphasize that this emission manifests itself most readily in the $\lambda 4686$ He II and in the $H\alpha$ lines. It may be that some rapidly rotating

stars will show emission only at $H\alpha$ and not in the other Balmer lines, as for example in ζ Oph (Niemela and Mendez 1974). A relatively high-dispersion spectroscopic survey of $H\alpha$ in early type stars has not yet been undertaken and might lead to exciting results.

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