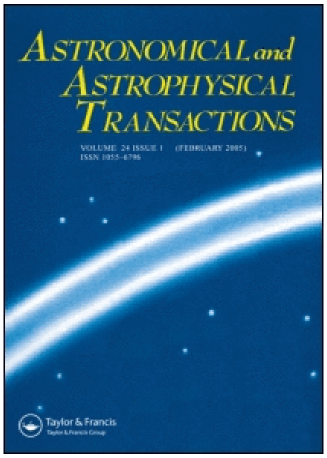

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DETECTION OF BINARY SYSTEMS FROM THEIR ULTRAVIOLET SPECTRA

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A method for detection of binary systems using their ultraviolet spectra is proposed. The method allows determination of stellar parameters such as effective temperatures, radii, luminosities.

KEY WORDS Binary systems, spectra

Is it possible to define the binary nature of either star analyzing its continuous spectrum, while traditional methods are not suitable for that; when, for example, the orbital planes of the system components are almost perpendicular to the line-of-sight beam and hence there are no eclipse signs? In principle—yes, if the wavelength range of the observed spectrum is large enough. One may accomplish this, with high efficiency, combining optical region spectrograms (ground-based observations) with ultraviolet ones (space observations). In this case it will be possible to define not only the stars' duality, but the physical and geometrical parameters of the system components too.

If we have a summary spectrum of a binary system, not resolved into components, then, properly choosing the main physical parameters of the components—effective temperatures and ratio of their radii, we can achieve practically full coincidence of the synthetic spectrum constructed on the basis of model calculations with an observed summary spectrum.

We have developed a binary star detection technique based on such analysis of their summary continuous specta, which have been applied to 14 stars of O–F classes [1].

This article had already been sent to the press when there appeared another report [2], dealing with the same problem—comparison of observed binary star spectra in the ultraviolet and visible regions with theoretical models. However that comparison is of purely qualitative nature.

We suggest a quantitative procedure allowing to find parameters of the system components, in particular, effective temperatures (spectral classes), radii ratios, absolute values of radii themselves and luminosity classes of the components.

There will be presented results obtained for the version where from the observations it is known:

a) summary ultraviolet spectrum of the system
b) summary long-wave spectrum of the system
c) summary stellar brightness.

However there are cases when one does not succeed in obtaining spectra of both A and B components separately, but their visible stellar magnitudes, namely V_A and V_B, are known. In this case the energy distribution of the observed total spectrum—the dependence of total flux F_λ on the wavelength—will be

$$F_\lambda = C[R_A^2 E_\lambda(T_A) + R_B^2 E_\lambda(T_B)] \tag{1}$$

where R_A, R_B and T_A, T_B are radii and effective temperatures of the system components, and C is a constant. Having written (1) for two spectrum points λ_i and λ_0, we shall get for the flux relation:

$$\frac{F_{\lambda i}}{F_{\lambda 0}} = \frac{E_{\lambda i}(T_B)}{E_{\lambda 0}(T_B)} \cdot \frac{E_{\lambda i}(T_A)/E_{\lambda i}(T_B) + (R_B/R_A)^2}{E_{\lambda 0}(T_A)/E_{\lambda 0}(T_B) + (R_B/R_A)^2}, \tag{2}$$

where

$$(R_B/R_A)^2 = \frac{E_{\lambda v}(T_A)}{E_{\lambda v}(T_B)} \cdot 10^{0.4(V_A - V_B)} \tag{3}$$

where $E_V(T_A)$ and $E_V(T_B)$ are flux values from models in V-rays ($\lambda_v = 5500$ Å). Combining (2) and (3) we get

$$\frac{F_{\lambda i}}{F_{\lambda 0}} = \frac{E_{\lambda i}(T_B)}{E_{\lambda 0}(T_B)} \cdot \frac{E_{\lambda i}(T_A)/E_{\lambda i}(T_B) + [E_{\lambda v}(T_A)/E_{\lambda v}(T_B)] \cdot 10^{0.4(V_A - V_B)}}{E_{\lambda 0}(T_A)/E_{\lambda 0}(T_B) + [E_{\lambda v}(T_A)/E_{\lambda v}(T_B)] \cdot 10^{0.4(V_A - V_B)}} \tag{4}$$

where the numerical value of $F_{\lambda i}/F_{\lambda 0}$ is taken from observation. If V_A and V_B are known, the relation in (4) gives us an equation with two unknowns, T_A and T_B.

Having written (4) for boundary wavelengths in our spectrogram we shall have a system of two equations with regard to the unknowns T_A and T_B. Since the intensity has a nonlinear dependence on the effective temperature, the values T_A and T_B can be found by the method of successive approximations and then the components' radii relations may easily be found from (3).

Thus obtained effective temperatures give spectral classes of components, and their radii relations yield the luminosity relation. In most cases the distances of binary systems are known. Combining them with absolute luminosities one may find absolute values of radial components and hence their luminosity classes [1].

If only total stellar brightness is known the number of unknowns will be one parameter larger. Apparently, now the main relation should be written not for two, but for three, four or more spectrum points. In this case an operating relation will have the form:

$$\frac{F_{\lambda i}}{F_{\lambda 0}} = \frac{E_{\lambda i}(T_B)}{E_{\lambda 0}(T_B)} \cdot \frac{\dfrac{E_{\lambda i}(T_A)}{E_{\lambda i}(T_B)} + \dfrac{\dfrac{E_{\lambda j}(T_A)}{E_{\lambda j}(T_B)} - \dfrac{\Delta F_{\lambda j}}{E_{\lambda j}(T_B)/E_{\lambda 0}(T_B)} \cdot \dfrac{E_{\lambda 0}(T_A)}{E_{\lambda 0}(T_B)}}{\dfrac{\Delta F_{\lambda j}}{E_{\lambda j}(T_B)/(E_{\lambda 0}(T_B)} - 1}}{\dfrac{E_{\lambda 0}(T_A)}{E_{\lambda 0}(T_B)} + \dfrac{\dfrac{E_{\lambda j}(T_A)}{E_{\lambda j}(T_B)} - \dfrac{\Delta F_{\lambda j}}{E_{\lambda j}(T_B)/E_{\lambda 0}(T_B)} \cdot \dfrac{E_{\lambda 0}(T_A)}{E_{\lambda 0}(T_B)}}{\dfrac{\Delta F_{\lambda j}}{E_{\lambda j}(T_B)/(E_{\lambda 0}(T_B)} - 1}} \tag{5}$$

In such a scheme the presented method will be applied to the star HD 5015A (type F8) for which there are ultraviolet spectrograms obtained with 'Orion-2' and spectrograms in the optical range obtained on the 70 cm meniscus telescope of Abastumany Observatory.

The energy distribution observed in the range 2300–4800 Å differs from the model curve, corresponding to the star F8 IV, i.e. $T_{eff} = 6200$ K at $\lg g = 4$, this discrepancy increasing while approaching the far ultraviolet. Furthermore, none of the theoretical models in its pure form within temperature from 7500 K to 5500 K [3]—as is shown in Figure 1—is in satisfactory agreement with observations: when we match the model at $T_{eff} = 7500$ K (solid line) with the short-wave part ($\lambda = 2300$ Å) of the observed spectrum the long-wave part of it ($\lambda = 4800$ Å) turns out to be considerably lower than the observed level, and similarly, in matching the long-wave model end at $T_{eff} = 5500$ K (dashed line) with the

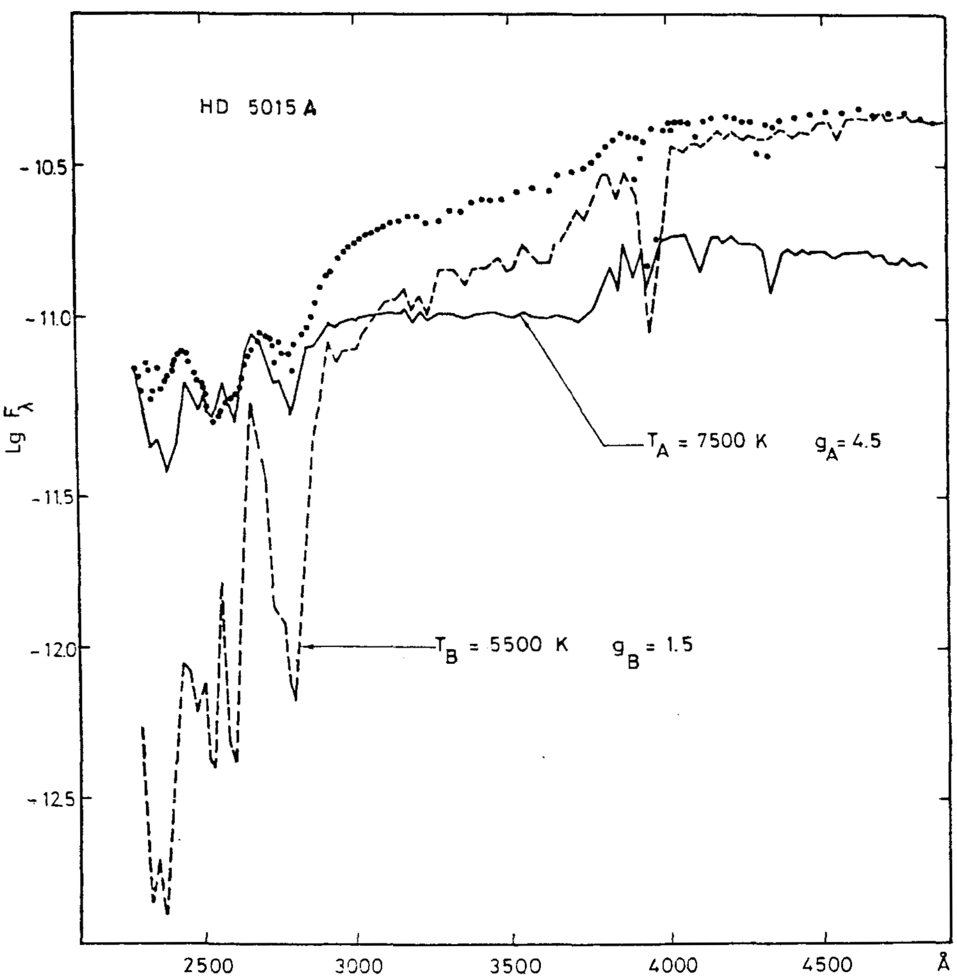

Figure 1 Comparison of the observed energy distribution of the continuous spectrum of the star HD 5015A in the range 2300–5000 Å (dots) with theoretical models of single stars at $T_{eff} = 7500$ K, $\lg g = 4.5$, and $T_{eff} = 5500$ K, $\lg g = 1.5$ (solid and dashed lines).

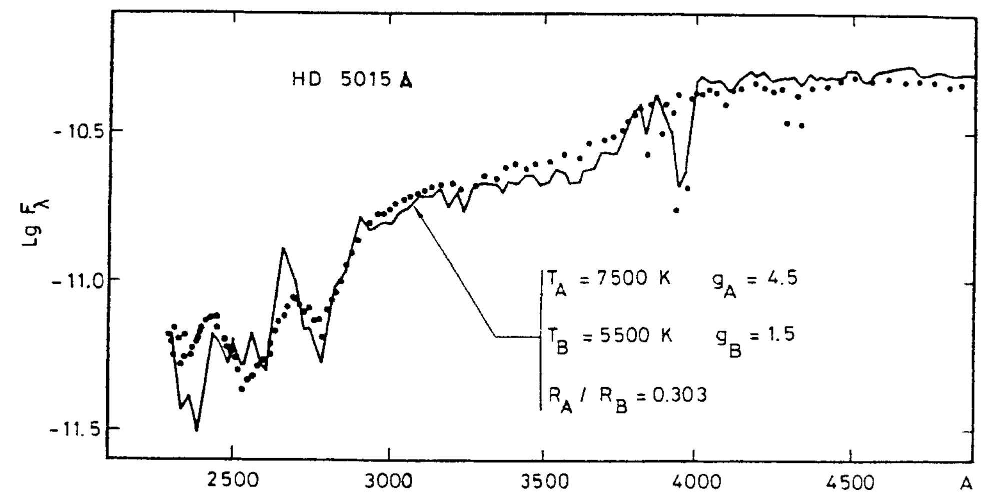

Figure 2 Synthetic spectrum (solid line) calculated for the system HD 5015 A at parameters of components given in Fig. 1; dots—observations; the interstellar extinction is absent.

observed spectrum the short-wave end of it appears to be much above the model.

This discrepancy itself solves our first problem: detection of binary system. Then we can start finding the component parameters with the above described procedure. As a result we find (Figure 2):

FOV	$T_A = 7500$ K	$V_A = 6^m20$	$R_A = 1.3R_\odot$
GOIII	$T_B = 5500$ K	$V_B = 5^m11$	$R_B = 4.4R_\odot$

The duality of the HD 30739 star has been found in the same way. Space (1300–2740 Å) observations were carried out with the help of S2/68 [4], and data for the long-wave region (3225–7500 Å) were taken from [5]. For the system we have (Figure 3):

A1V	$T_A = 9300$ K	$V_A = 4^m42$	$R_A = 2R_\odot$
K5V	$T_B = 4000$ K	$V_B = 7^m5$	$R_B = 3R_\odot$

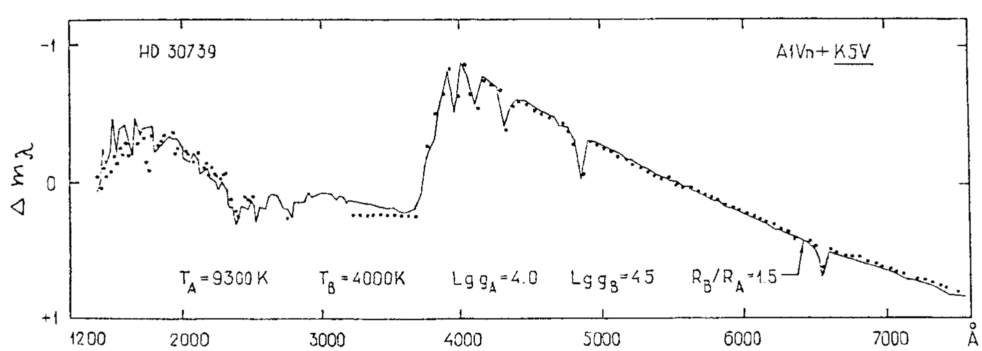

Figure 3 The same as in Figure 2 for the system HD 30739.

The HD 149499 binary system is another subject of our discussion. It was observed by Skylab in the range of 2000–4100 Å [6]. In the Buscombe Catalogue [7] it is KO V + WD. The system visible brightness is 8^m8. The observed energy distribution had already been described by synthetic model 22,500 K [3] + 5000 K (since there is no theoretical Kurucz model for temperatures below 5500 K observations for single stars were used):

$$V_A = 9^m94 \qquad V_B = 9^m25 \qquad R_A = 0.07R_\odot \qquad R_B = 0.7R_\odot$$

$$R_B/R_A = 10$$

There had been reports about theoretical models for white dwarfs from 12,000 K to 21,000 K [8]. For the summary (total) spectrum with temperatures of 21,000 K (WD) + 5000 K the agreement is much better. In this case:

$$V_A = 9^m46 \qquad V_B = 9^m63 \qquad R_A = 0.08R_\odot \qquad R_B = 0.6R_\odot$$

$$R_B/R_A = 7.5$$

In both cases M_A is $+7^m$, i.e. it is rather an ultraviolet dwarf than a white one.

The present method's possibilities for decoding stellar pairs were revealed by us a little earlier for a group of stars with known V_A and V_B [1]. In decoding either pair analysis and comparison of the results obtained were carried out. Here we want to emphasize the following circumstance: in principle, there is a possibility of presenting the total spectrum by only one model of single star. This occurs when spectral classes of components are the same or almost the same. In this case resolving such a pair into components is impossible.

The conclusion is clear: the rated content of binary stars should be much more than is generally accepted. In any random sample there may always be binary systems that do not submit to decoding. Apparently, the establishment of possible combinations among components' parameters, for which the summary (total) spectrum of a pair could be described by only one model, will help to clarify a real ratio of binary systems. Further improvement of the method and extention of its application field must comprise a solution of this problem.

2800 MgII DOUBLET METHOD

The behaviour of the 2800 MgII ultraviolet doublet in the stellar spectra of middle and late classes is still largely incomprehensible and even mysterious. The supergiant HD 135345 of G5 Ia spectral class presents a striking example. In 1989 G. A. Gurzadyan received its IUE recording in the wavelength range of 2000–3000 Å [9], which is shown in Figure 4. In this recording the continuous spectrum as well as the structure of the ultraviolet doublet k + h MgII at 2800 Å are anomalous in essence. The main observed level of the continuous spectrum increases on the short wavelength side, up to the recording limit of 2000 Å, which is evidence that this supergiant is a binary system with a hot companion. For comparison in Figure 5 there is shown a recording of another supergiant HD 206859 of the same spectral type G5 Ib [10].

The anomalous nature of the structure of the magnesium doublet k + h MgII is in complete absence of the emission profile of chromospheric origin as well as of

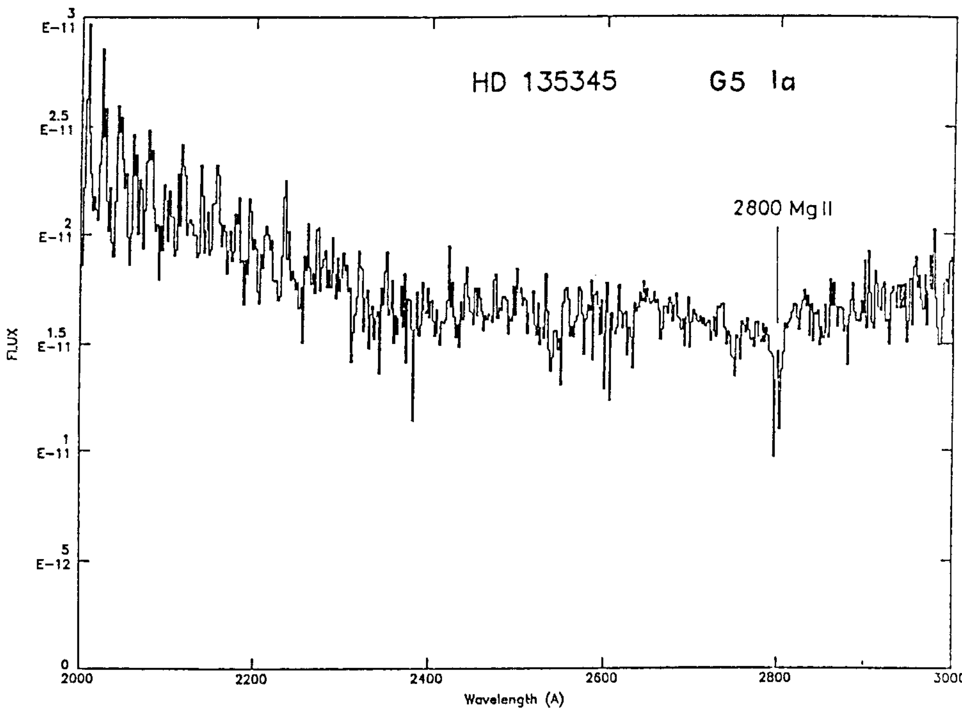

Figure 4 IUE spectral recordings for the supergiant G5 Ia, HD 135345, in the wavelength interval of 2000–3000 Å. The mean level of continuous spectrum increases beginning from 2800 Å, to the short wavelength region.

very small magnitude of the equivalent width of this doublet in absorption: it is equal to 4 Å, that is 7.5 times smaller than we usually have for a G5 type star. This fact also explains the binary nature of this supergiant.

If this supergiant has a hot companion, then the continuous spectra of this companion being superposed on the common spectra of the G5 I star, may raise strongly the local level of continuous spectra everywhere including also the region near 2800 Å. Of course, a rise of the level of continuous spectra must bring about a decrease of absolute magnitude of equivalent width, W(MgII); only the equivalent width, but not the real intensity of this doublet. We can obtain the part, p, of continuous spectra of the hot companion in the total spectra in the region of the doublet, that is, at $\lambda_0 = 2800$ Å. It is given by the relationship:

$$p = \frac{4\pi R_G^2 E_{\lambda 0}(T_G) + 4\pi R_B^2 E_{\lambda 0}(T_B)}{4\pi R_G^2 E_{\lambda 0}(T_G)} \tag{6}$$

from which we obtain

$$\left(\frac{R_B}{R_G}\right)^2 = (p-1)\frac{E_{\lambda 0}(T_G)}{E_{\lambda 0}(T_B)} \tag{7}$$

where $p = 7.5$ for our system.

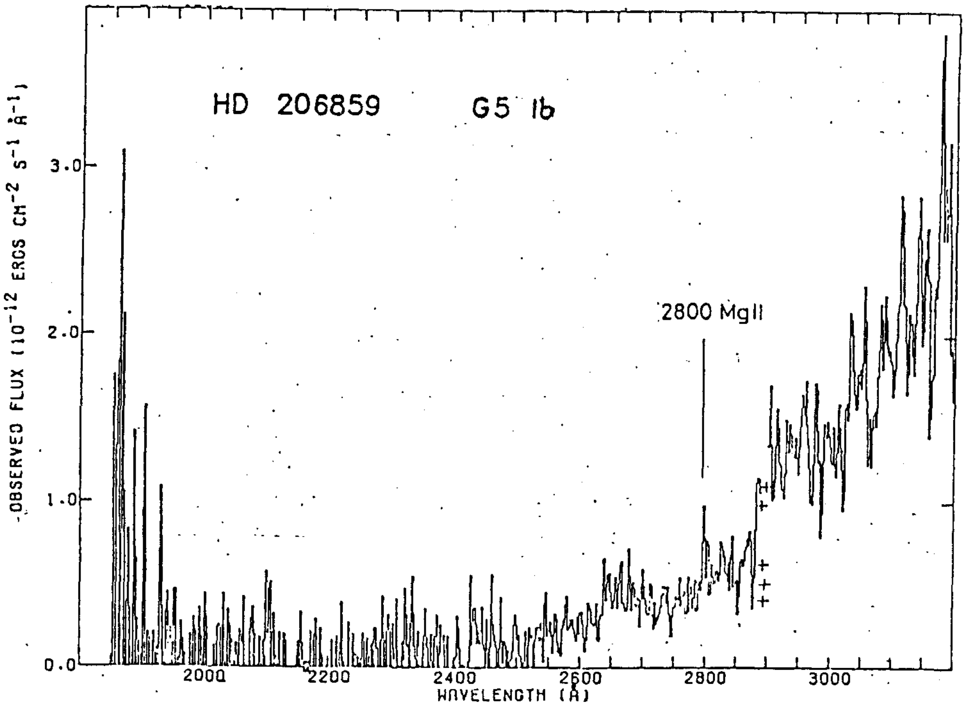

Figure 5 IUE spectral recording of the supergiant HD 206859 of G5 Ib type. The mean level of the continuous spectrum decreases contrary to the supergiant HD 135345, in the short wavelength region.

Putting (7) into (2) we obtain:

$$\frac{F_{\lambda 1}}{F_{\lambda 2}} = \frac{E_{\lambda 1}(T_{\mathrm{G}}) + (p-1)\dfrac{E_{\lambda 0}(T_{\mathrm{G}})}{E_{\lambda 0}(T_{\mathrm{B}})} E_{\lambda 1}(T_{\mathrm{B}})}{E_{\lambda 2}(T_{\mathrm{G}}) + (p-1)\dfrac{E_{\lambda 0}(T_{\mathrm{G}})}{E_{\lambda 0}(T_{\mathrm{B}})} E_{\lambda 2}(T_{\mathrm{B}})} \tag{8}$$

This supergiant is above the Galactic plane: $b = 12°$; the effective path of interstellar extinction is taken to correspond to the distance of 300 pc. The continuum corrected for this distance is shown in Figure 6 (open circles), model calculations (solid line), synthetic spectrum for the following parameters of system at $p = 7.5$: $T_{\mathrm{B}} = 20{,}000$ K, $\lg g = 3.8$, $T_{\mathrm{G}} = 5500$ K, $\lg g = 1.5$, and $R_{\mathrm{G}}/R_{\mathrm{B}} = 10$.

Here we would like to note that such parameters as effective temperatures, luminosity ratios, radii ratios and absolute radius values [9], obtained by this method, completely coincide with the data obtained by the continuous-spectrum method discussed in the previous section.

On the other hand, in [2] comparison of the observed spectrum of our binary system HD 135345 in the ultraviolet (2275–2650 Å) with UBVRIJKL combination of ground-based photometry available in the literature and with theoretical models [3] had a pure qualitative character and yielded: $T_{\mathrm{eff}} = 6500$ K; $\lg g = 1$ for

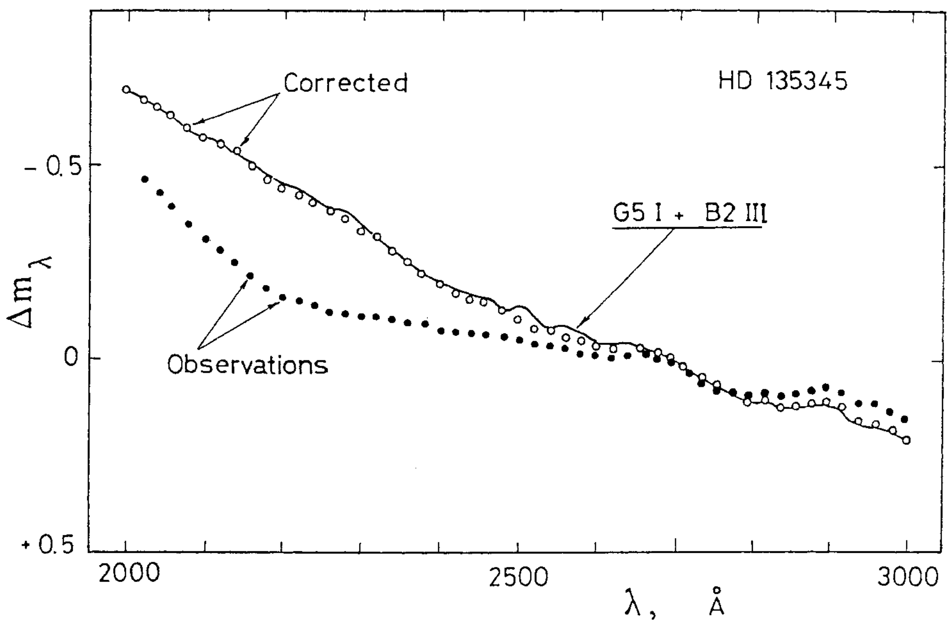

Figure 6 The continuous spectrum of the supergiant HD 135345 in the ultraviolet: direct observations (dots) corrected for the interstellar extinction (open circles) and model calculations (solid line), synthetic spectrum of the system at parameters: $T_B = 20{,}000$ K, $\lg g = 3.8$, $T_G = 5500$ K, $\lg g = 1.5$ and $R_G/R_B = 10$.

the cool component, and $T_{eff} = 18{,}000$ K, $\lg g = 4$ for the hot component. The authors themselves have mentioned a large discrepancy in the spectral class of the main component: F7 instead of G5.

Thus we have a principally new method used for binary system detection, which may be formulated as follows: any discrepancy in W(MgII) values, from the standpoint of deviation from the normal value, for a star of the given spectral type can be interpreted as a sign of the binary nature of the star.

References

1. Rustambekyan, S. S. *Comm. Byurakan Obs.*, **60,** 75, 1988.
2. Ferro, A. A., Madore, B. F. *Ap. J.*, **302,** 767, 1986.
3. Kurucz, R. L. *Ap. J. Suppl.*, **40,** N1, 1979.
4. Jammar, C., Macau-Hercot, D., Monfils, A., Thompson, G. I., Hoziaux, L., Wilson, R. *Ultraviolet Bright-Star Spectrophotometric Catalogue,* ESA SR-27, 1976.
5. Kharitonov, A. V., Tereschenko, V. M., Knyazeva, L. N. *Summary Spectrophotometric Catalogue of Stars,* Alma-Ata, Science, 1978.
6. Henize, K. G., Wray, J. D., Parsons, S. B., Benedict, G. F. *Catalog of Far-Ultraviolet Objective-Prism Spectrophotometry*: NASA Reference Publ., 1031, 1979.
7. Buscombe, W. *MK Spectral Classification*, Fifth General Catalogue, Northwestern University, 1981.
8. Wegner, G., Nelan, E. P., *Ap. J.*, **319,** 916, 1987.
9. Gurzadyan, G. A., Kondo, Y., Rustambekyan, S. S., Terzian, Y. *Ap. J.*, 1991, in press.
10. Wu, C.-C., Ake, T. B., Boggess, A., Bohlin, R. C., *et al.*, *The IUE Ultraviolet Spectral Atlas, NASA Newsletter N22,* 1983.