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COMMUNICATION FROM THE OBSERVATORY AT LEIDEN.

On the oscillating Ca^+ lines in O and B stars, by *B. J. Bok*.

1. *Introduction.*

It is a well known fact that the *H* and *K* lines in spectroscopic binaries of spectral type earlier than *B*5 do not as a rule take part in the orbital motion of the system. A review of the material bearing on this phenomenon has recently been given by O. STRUVE *). EDDINGTON **) has dealt with the theoretical side of the problem and has discussed the hypothesis that an interstellar cloud might be responsible for the appearance of the stationary *H* and *K* lines.

These lines are not always stationary; in many cases they follow the orbital displacements of the other lines, but with reduced amplitudes. It is clear that this may be explained by a blending of a stationary *Ca* line of the interstellar cloud with an oscillating line of the binary itself. O. STRUVE however met with some difficulties in following up this hypothesis in detail.

In the second section a statistical study is given of the *O* and *B* binaries showing variable *H* and *K* lines; in the third section a method is designed, by which a comparison between the stellar velocity curve and the curve obtained from the *Ca* velocities can easily be made, if the star shows a well measurable variation of the *H* and *K* lines. The fourth section gives a brief discussion of the blending hypothesis.

2. *Number of stars showing variable H and K.*

First of all it seemed interesting to get an idea of the ratio of the number of stars showing variable *H* and *K* to the number having stationary *Ca* lines. As the numerical results for *H* and *K* are rather scanty for a statistical discussion, it seemed better to collect all the material bearing on the *H* and *K* lines of early binaries, and to compute the percentage showing variable *H* and *K* as a function of the spectral type. Table 1 shows the stars having certainly variable *H*

TABLE 1.

certainly variable			possibly variable			possibly stationary			certainly stationary		
Boss Nr.	Name	Spectr.	Boss Nr.	Name	Spectr.	Boss Nr.	Name	Spectr.	Boss Nr.	Name	Spectr.
123	π And [2]	B 3	103	$\varkappa$ Cas	B 0	538	....	B	46	....	B 0
175	ν And [2]	B 3	384	φ Per	B 0 p.	....	D.M. 61°, 676 N	O	1365	θ_2 Ori	B 1
641	π Ari [2]	B 5	....	D.M. 58°, 467	Oe	....	D.M. 61°, 676 S	B 0	1366	ι Ori	Oe 5
844	o Per [1]	B 1	....	D.M. 56°, 693	Oe	....	H.D. 25833	B 3	....	D.M. 6°, 1309	B 0 p.
913	ξ Per	Oe 5	1370	ε Ori	B 0	1301	η Ori	B 1	4158	σ Sco	B 1
1139	9 Cam	B 0	....	D.M. 20°, 1284	Oe 5	1339	δ Ori	B 0	5070	....	B 2
1147	π_4 Ori	B 3	....	D.M. 5°, 1334	B 1	1357	....	Oe 5	5150	....	B 0
1159	π_5 Ori	B 3	2804	ρ Leo	B 0 p.	1363	....	Oe 5	....	Y Cyg	B 2
1314	ψ Ori	B 2	3281	? $\varkappa$ Dra?	B 5 p.	1388	125 Tau	B 3	....	H.D. 199.579	Oe 5
1333	χ Aur	B 1	....	D.M. 35°, 3949	Oe	1398	ζ Ori	B 0	5565	....	Oe 5
1349	VV Ori	B 2	....	D.M. 35°, 3952	B 1	....	D.M. 11°, 1204	B oe	....	H.D. 216.014	B 0
1353	φ_1 Ori	B 0	5918	....	B 3	....	D.M. 6°, 1351	B 2	5913	16 Lac.	B 3
1375	ζ Tau	B 3 p.				1730	42 Cam	B 3	6142	....	B 0
1525	ν Ori	B 2				1899	29 CMa	Oe			
1635	ν Gem	B 5				....	D.M. 35°, 3930 N	Oe			
1733	16 Mon	B 2				....	D.M. 35°, 3930 S	Oe			
3586	h Cen [2]	B 5				....	H.R. 8153	B 3			
4086	β Sco	B 1				....	H.R. 8427	B 3			
4794	δ_1 Lyr [2]	B 3				....	H.R. 8800	B 5			
5018	σ Aql [1]	B 3									
5236	....	B 3									
5856	12 Lac.	B 2									
....	H.R. 8803 [1]	B 3									

[1]) One or more stellar lines were measured in addition to the stationary line.
[2]) *K* measured together with the other lines.

*) *Pop. Astr.* 33, 639, 1925, 34, 1, 1926. **) *Bakerian Lecture, Proc. Roy. Soc* 111A, 424, 1926.

and K, those having probably variable H and K and on the other side those with probably stationary lines, followed by the ones with certainly stationary H and K lines.

For most stars contained in this list it is not possible to give even a rough estimate of the ratio f of the intensities of the stellar K line and the K line of the interstellar cloud. For that reason the stars are only separated in variable and stationary stars. This division is of course rather arbitrary, but I do not think we can do any better at present. In order to make the result as homogeneous as possible, some stars with a very small f, such as VV Orionis and β Scorpii have been treated as though they had stationary H and K lines. $\varkappa$ Draconis was excluded because the period of variability of the *Ca* lines is 4 years, against a period of 9 days for the variation of velocity of the star.

The percentages of stars of a given spectral type showing variable H and K are shown graphically in fig. 1. Of course this result has only a statistical value. It is impossible to predict the value of f for a star of a given spectral type. This is evident from a comparison of χ Aurigae ($B1$; $f = 1.0$) and φ_1 Orionis ($B0$; $f = 1.2$) on one side, with H.R. 8800 ($B5$) or Y Cygni ($B2$), which have stationary lines, on the other side.

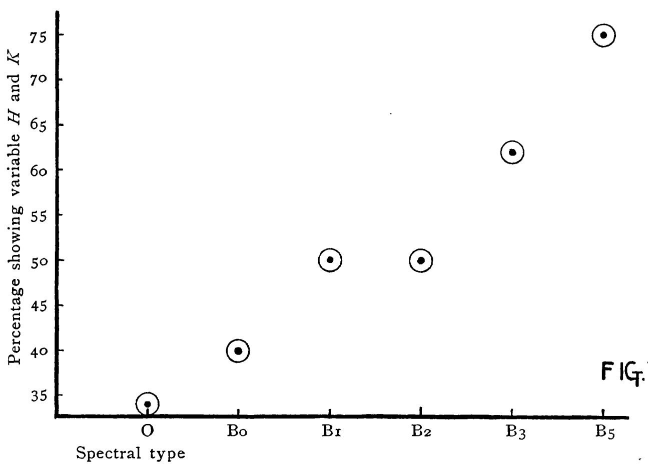

FIG. I

3. *Tangent method.*

In some cases there is a definite velocity curve for the displacements of H and K. Combining this with the stellar velocity curve, we can obtain the value of f, which is the intensity of the stellar K line divided by the intensity of the cloud line. If we assume that the observer measured the weighted mean of the blend, we have:

$$f = \frac{K^{ca}}{K^* - K^{ca}},$$

K^* being the amplitude of the stellar lines and K^{ca} the observed amplitude of the *Ca* lines.

f being known, it is easy to obtain the velocity of the absorbing part of the interstellar cloud from the velocity of the system and the observed mean velocity of the K line.

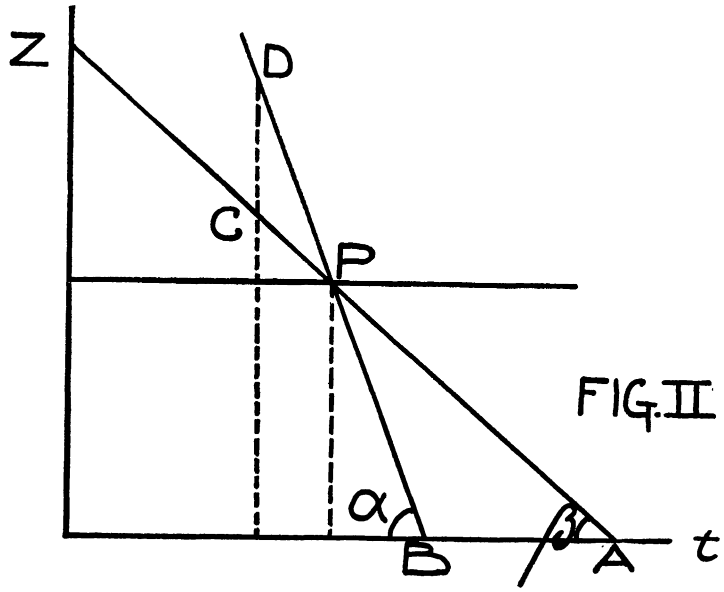

FIG. II

This method does not allow us to check the blending hypothesis, since a slight difference either in form or in phase between the two curves cannot be detected in this way. If the periods of the two curves correspond, the amplitudes are the main characteristics which we can use for comparing them. But in doing so a second characteristical feature of the curves is wholly disregarded. In general a velocity curve is determined rather well by giving the period and amplitude as well as the *positions* and *inclinations* of the tangents of the ascending and descending branches of this curve. The fact that these tangents can be used with advantage for the determination of an orbit of a spectroscopic binary was pointed out by Dr. WOLTJER.*) Since both tangents are as a rule determined with considerable accuracy, a comparison of the stellar tangent with the H and K tangent may give us a determination of f and of the real cloud velocity, V^{ca}.

In fig. 2 the abscissae are the times and the ordinates the measured velocities. If BPD is the tangent to the stellar velocity curve and APC the corresponding tangent for the *Ca* lines, it is clear that:

$$f = \frac{\tan \beta}{\tan \alpha - \tan \beta},$$

f being the ratio of the intensities.

The ordinate of P gives the real velocity of the *Ca* cloud, everything in the supposition that a blend was measured.

*) *B.A.N.* I, 18, p. 95, 1922.

The comparison of the two ascending branches, as well as of the descending ones, give us two values of f and V^{ca}. Together with the comparison of the amplitudes we thus get three values of f and three corresponding velocities of the interstellar cloud.

On the blending hypothesis these three values should be the same. Now suppose there is a slight *difference in shape* between the two curves. This would be seen immediately when comparing the values of f. In that case one might suspect that the value of f deduced from the comparison of the amplitudes should lie between the values deduced from the inclinations.

But a slight *difference in phase* can also be detected; for then the ordinates of the two points of intersection P will have different values. One will be larger than the cloud velocity, the other will have a smaller value. It is clear that in case of a difference in phase the value of V^{ca} deduced from the amplitudes should lie between the velocities obtained from the tangent method.

For some stars, for which two complete velocity curves were available, a solution was made in this way. The results are collected in Table 2. The first column contains the name of the star, the second gives the value of f from the comparison of the amplitudes, the third the corresponding cloud velocity. The four following columns show the values of f and of V^{ca} (cloud velocity) obtained from the application of the tangent method to the ascending and descending branches of the curves.

TABLE 2.

Star	amplitudes		descending branch		ascending branch	
	f	V^{ca}	f	V^{ca}	f	V^{ca}
χ Aurigae	1.05	+ 3.3 km/sec	0.80	+ 3.6 km/sec	1.26	+ 4.5 km/sec
VV Orionis	0.056	+ 14.0	0.065	+ 14.2	0.064	+ 16.0
φ_1 Orionis	1.3	— 5.8	0.95	+ 0.9	1.2	— 4.4
β Scorpii	0.086	— 8.3	0.038	— 8.5	0.078	— 3.0

4. *Blending hypothesis.*

In O. STRUVE's paper, cited above, it is intimated that the blending hypothesis leads to contradictory conclusions. If we assume that the measured K line is a blend of a stationary cloud line and a stellar line of variable position, we can get an idea of f by comparing the amplitudes (see section 3). But it is also possible to make an estimate of f by a quite different method. From the two velocity curves, we find the values of the velocity of the binary system and of the mean velocity of the blended K line. If it is possible to make an assumption as to the *real* cloud velocity, we can get a value of f by combining this velocity with the two measured velocities. O. STRUVE made a comparison between the values of f obtained from the amplitudes and those computed on the assumption of a zero cloud velocity (after correction for solar motion). Finding no agreement between the corresponding values of f, he rejected the blending hypothesis. He admitted, however, that in some cases a systematic motion of the cloud might have caused the disagreement. But he did not believe that the individual cloud velocities — which are invariably small — might cause such great differences between the two sets of corresponding f values. If we look at the residual velocities obtained in the first part of O. STRUVE's paper, it is clear that individual velocities of the order of 10 *km/sec* are not unusual. Therefore a discussion of the cloud velocities obtained from the two velocity curves might give a somewhat safer method to check the blending hypothesis.

Let us take χ Aurigae as an example. A comparison of the amplitudes gives $f = 1.0$, against $f = 4.8$ from the observed average velocities, assuming the cloud at rest. This looks very bad. But when we calculate the cloud velocity, with $f = 1.0$, we find + 3.3 *km/sec* (compare Table 2). Since the component of the solar motion is + 9.1 *km/sec*, the resulting individual cloud velocity appears to be quite allowable.

Applying this method for the other objects in O. STRUVE's paper (Table IX), there appear to be only two residual velocities larger than might be expected. φ_1 Orionis yields a cloud velocity some 20 *km/sec* smaller than the component of the solar motion, while the velocity turns out to be 30 *km/sec* too small in the case of π_4 Orionis. Considering the very preliminary character of the *Ca* velocity curve for this star, this result should not be given too much weight. The velocity of ψ Orionis is fairly small, while Boss 46 is no objection against the blending hypothesis, as it was recently shown by PEARCE *), that the H and K lines of this star do not fluctuate at all. This star has accordingly been transferred to the list of stars with absolutely stationary lines and large cloud

*) *D. A. O.* 3, 275, 1926.

velocities. No satisfactory explanation has as yet been given of the large relative velocities of some *Ca* clouds, but it does not appear advisible to abandon the blending hypothesis for that reason alone.

The results from the tangent method are still rather poor. When some new velocity curves for *H* and *K* have been determined, this method may give us a sharp test for the blending hypothesis. In Table 2 there is a slight indication that in some cases the curves for *H* and *K* differ in shape, especially for χ Aurigae. I think this is purely accidental. But we observe that there is *no systematic difference in phase* between the two curves, neither in the case of χ Aurigae and φ_1 Orionis, which have periods of 2 and 8 years respectively, nor for β Scorpii and VV Orionis having periods of 7^d and $1^d.5$. This is perhaps one of the strongest arguments in favour of the blending hypothesis.

The statistical result shown in fig. 1 cannot lead to very definite conclusions as to the blending hypothesis. Probably it represents the superposition of two effects: 1° the intensity of the Ca^+ lines in the stellar atmosphere is cut down if we proceed to the hotter stars, since the calcium will become more and more doubly ionized. 2° the intensity of the cloud line will be greater for the *O* stars than for the *B* stars, since the average distance of the *B* stars is certainly not as large as that of the *O* stars. Assuming a blending, one should expect a progression as indicated in fig. 1. But it must be remembered that other explanations are possible, which give an analogous relation.

A strong support to the blending hypothesis can be derived from the few cases in which an oscillating stellar line has been measured together with a stationary cloud line. The stars for which this has been observed are indicated by the footnote mark ([1]) in Table 1. In all cases the evidence for a stellar *K* line is rather strong, since the observed velocities of the second line agree with the values obtained from the stellar velocity curve.

The great intensity of the stellar *H* and *K* in cooler stars must be responsible for the non appearance of stationary lines in these classes.

5. *Conclusion.*

We conclude that the best explanation for the *K* lines, oscillating synchronously with the other lines of the binary spectrum in certain *O* and *B* stars, appears to be that it is a blend of a stationary line of an interstellar cloud, with an oscillating *K* line of the star itself.

I want to express my special thanks to Dr. OORT and Dr. WOLTJER, for the valuable advice they gave me during the preparation of this paper.
