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სიმეიზი—აბასთუმანი
ოქტომბერი, 1942.

აბასთუმნის ასტროფიზიკური ობსერვატორიის ბიულეტენი № 7. 1943
БЮЛЛЕТЕНЬ АБАСТУМАНСКОЙ АСТРОФИЗИЧЕСКОЙ ОБСЕРВАТОРИИ № 7. 1943
BULLETIN OF THE ABASTUMANI ASTROPHYSICAL OBSERVATORY No. 7. 1943

SOME PHYSICAL CHARACTERISTICS OF THE ATMOSPHERES OF SUPERGIANTS cB5—cA3

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It is worthy of attention that at certain stages the spectra of Novae manifest a striking resemblance to those of Wolf-Rayet, P Cygni and c-stars. Since long time the study of new stars led to the conclusion that there undoubtedly takes place an ejection of high speed atoms. Further in the last years the emission bands of W-R stars have been also successfully interpreted in terms of the continuous ejection of matter. The third type of objects where the ejection hypothesis found serious support are the P Cygni stars. But such evidences are lacking with regard to c-stars. As to the *Be* stars the observed facts are very difficult for interpretation, but in several cases there are indications on the formation of tenuous shells. The purpose of the present paper, which represents an account of a more detailed investigation, consists in the search for more direct evidences in favour of the hypothesis of outward streaming of matter in the atmospheres of supergiants of early type. The investigation was done on following lines: 1) The estimate of the effective gravity acceleration from the study of the Stark effect for hydrogen lines and of the relative intensities of spectral lines of neutral and ionized atoms. 2) The study of radial velocities of several individual lines showing systematic displacements. 3) The investigation of the systematic motion of c-stars having mainly in view the derivation of the constant term *K*.

1. Owing to the accurate computations by Verweij[1] bearing on Stark effect one can now derive with fair accuracy the effective gravity acceleration g_{eff} on the stellar surface from the measurements of profiles of hydrogen lines. The theoretical profiles for H_γ and H_δ for different values of g have been compared with those observed at Simeis (7 stars). Fig. 1 illustrates such a comparison for β Orionis (H_δ). For the central portion of the line the theory is not accurate. The microphotometer tracings (Fig. 2) give a representation of the difference in the profiles of hydrogen lines between a supergiant and an usual star of the same type A2. For the seven supergiants studied the observed values of $\log g_{eff}$ are within 1.0—1.4. On the other hand, the mean computed value from the formula

$$g = G\frac{M}{R^2}$$

turns out to be about 10^3. Still earlier Schalen found $\log g_{eff}=1.2$ for α Cygni[2] and the author $\log g_{eff}=1.0$ for β Orionis[3]. Pannekoek emphasized the importance of the discrepancy between g and g_{eff} for α Cygni and Cepheids[4]. The question may arise whether this discrepancy is real. First, a doubt may be expressed with regard to the applicability of the mass-luminosity relation when computing the masses of stars of such high luminosity. But this doubt is removed by the fact that the mass of Pearce's star (a binary *cB9*) derived immediately is of the order given by the mass-luminosity relation. But perhaps the weakness of the wings of hydrogen lines in the supergiants is due to the relative scarcity of hydrogen atoms and not to the small pressure effect? However the few known observations show that the jump at the edge of the Balmer series 3646 does not bring out some anomaly in the spectra of supergiants and therefore the above objection is also untenable. For this reason the large discrepancy between the observed effective gravity acceleration g_{eff} and the dynamical one g seems to indicate that in the atmospheres of supergiants in addition to the gas pressure there are operative some other forces acting against gravitation.

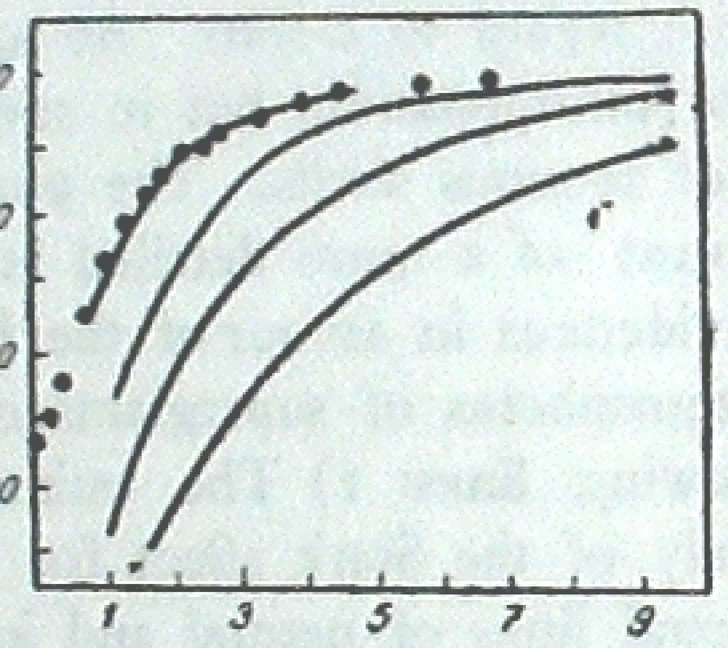

Fig. 1 636.
The theoretical profiles of Hδ for different values of the gravity acceleration $\log g=1$, 2, 3 and 4. The dots are the observations for Hδ in the spectrum of Rigel. The abscissae are the distances from the line centre, the ordinates are the intensities

2. A mere comparison of the spectra of *cA2* and *A2* reveals at once a striking difference. Though the spectra of supergiants leave an impression of a fairly large amount of turbulence, the curve of growth does not manifest this (Struve and Elvey)[5] and therefore we have at present no reason to interpret the spectral characteristics of c-stars in terms of this hypothesis. The apparent constancy of the spectrum of α Cygni except the changes in the Hα emission, the shape of hydrogen absorption lines and the general uniform character of other spectral lines suggest that we are not concerned here with permanent or temporary tenuous shells like those observed in several Be stars. Notwithstanding the probability of an extended atmosphere it appears that no much

room remains at present for the discussion of the dilution effect, except, may be, for few individual lines. There is no doubt that the main cause of the difference in spectral characteristics between *cA2* and *A2* lies in the difference in models of atmospheres of supergiants and usual stars. Without appealing to the detailed theory one may suggest on the basis of the working hypothesis that the high discrepancy between g and g_{eff} plays an important role in producing the difference in the models in question and in the general characteristics of spectra. Not refusing the possible influence of some other factors we should like to emphasize here the importance of the gravity or luminosity effect. The stars *cA2* and *A2* do not differ properly too much in the gravity acceleration (nearly 10^3 and 10^4 respectively). For the sake of illustration one may mention that the observed difference between the spectra of a giant and dwarf of type *Go* in spite of the greater difference in g (nearly 10^3 and $10^{4.4}$) is incomparably smaller than the difference between *cA2* and *A2*. But the observed striking difference between *cA2* and *A2* can by no means be explained by the ten-fold decrease of g. However matters will differ if the effective value of g in supergiants is of the order of 10 cm/sec^2 instead of 10^3 as this is suggested by the working hypothesis. Before to interpret the spectroscopic peculiarities of c-stars we shall indicate the main of them.

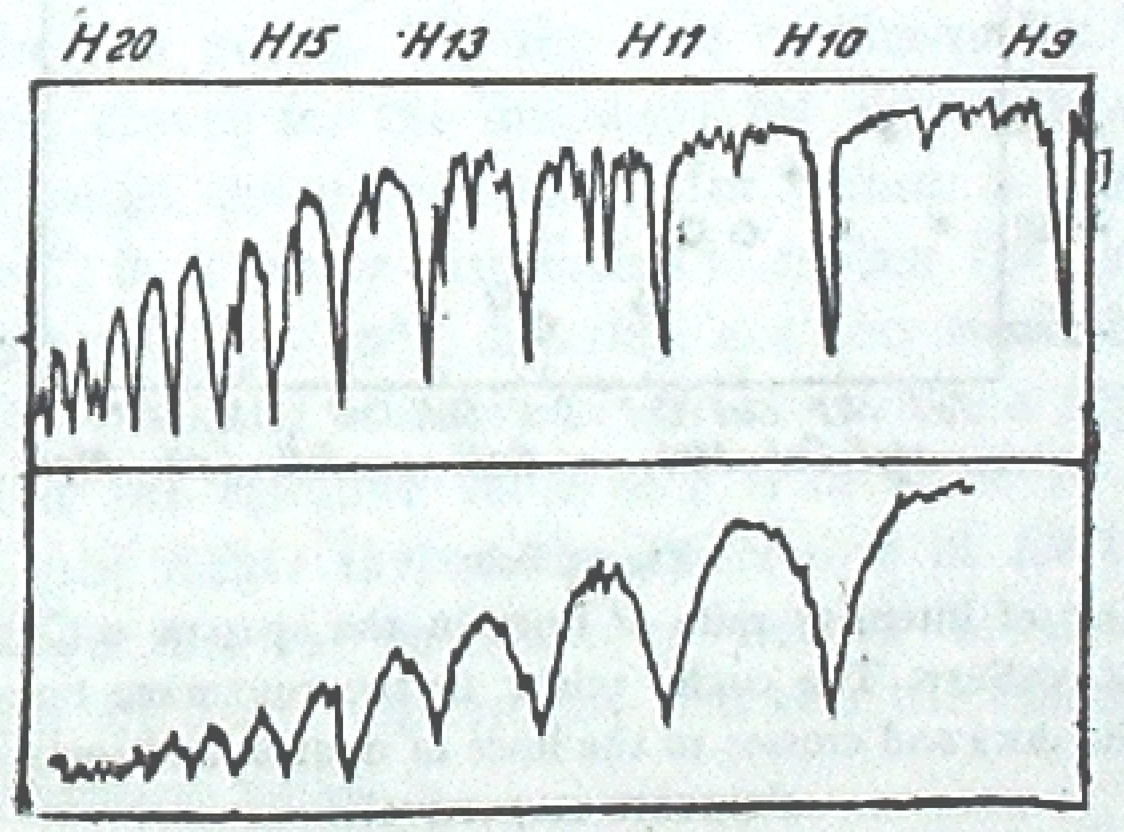

Fig. 2 636.
Microphotometric tracings of the hydrogen lines of Balmer series in the spectrum of a supergiant *A2* (top) and an usual star *A2* (bottom).

The observed data were taken from our measurements of total absorptions of some tens of stronger lines belonging to several multiplets of different elements. As main basis of comparison served the well expressed supergiant α Cygni (*A2*) and the typical dwarf of the same class ε Serp. The measurements were partly checked by the estimates of line intensities in the spectra of other stars. The main results of comparison are as follows: 1) The intensities of the considered lines due to neutral atoms *Fe* I, *Mg* I, *Cr* I, *Ni* I, *Co* I, *Ca* I in the dwarfs are stronger than in the supergiants. 2) On the contrary, the spectral lines due to the ions *Fe* II, *Si* II, *Ti* II, *Cr* II, *Ni* II and *Mg* II, are much or fairly stronger in the supergiants. 3) The few observed resonance lines due to the atoms and ions *Sr* II, *Ba* II, *Ca* I, *Cr* I, *Mn* I are much stronger in the dwarfs (the effect is probably very small for *Ca* II and *Al* I, if existing at all). 4) Several helium lines are still fairly strong in the supergiants even of type *A2*. The results are represented in Fig. 3, the ordinates being the mean intensity ratio α Gygni : ε Serp.

3. We shall now compare some details in the spectra of α Cygni and Nova Herculis in the stage of α Cygni. It is of importance to know whether the likeness of spectra is based only on the presence of a great number of enhanced lines or this concerns also the intensity relations of lines. The latter point is not quite clear. For the stage under consideration even rough photometric data are absent. Our own collection of spectrograms of Nova Herculis begins on Dec. 22, two days after the α Cygni stage (13—20 Dec.). But in December we have had several obser-

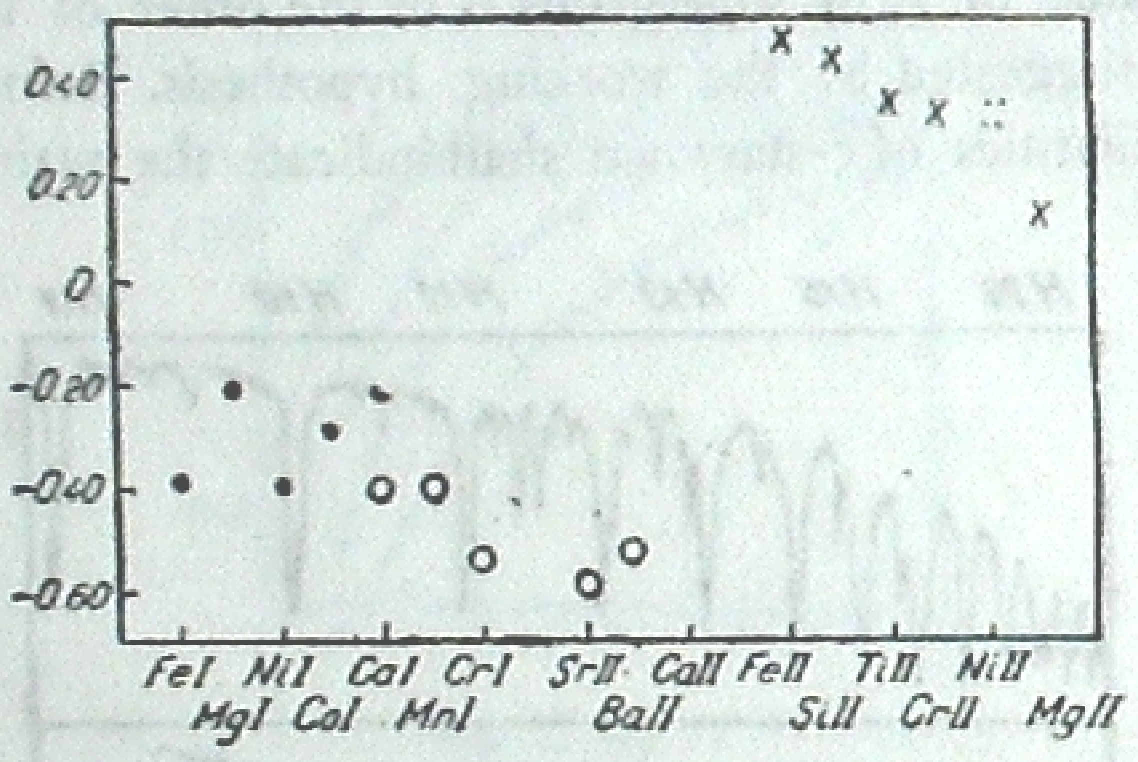

Fig. 3 бзб.
Log of intensity ratio of lines in the spectra α Cygni : ε Serp. The circles relate to the resonance lines, the dots and crosses to the lines of neutral and ionized elements respectively.

vational dates in common with McLaughlin, and this allowed to reduce his scale to ours[6]. Then, using McLaughlin's estimates relating to Dec. 17 we were able to express in an homogeneous scale the intensities of the same lines in the spectra of the Nova at the α Cygni stage, α Cygni itself and ε Serp.—our standard dwarf *A2*. Though this procedure can give certainly only a low accuracy, we hope that the following results are as yet trustworthy: 1) The lines due to neutral atoms *Fe* I, *Mg* I, *Co* I, *Ni* I in the Nova are fainter than in an usual *A2* star. 2) The lines due to the ions *Fe* II, *Ti* II, *Si* II, *Mn* II, *Cr* II, *Mg* II, *Sc* II, *Co* II are much stronger in the spectrum of the Nova. There are possibly few exceptions (V II a. o.) 3) The few resonance lines due to atoms or ions *Sr* II, *Ca* I, *Mn* I, *Cr* I, *Ba* II, *Al* I are much fainter in the spectrum of the Nova or even absent. 4) Probably the helium line 5876 was present in the spectrum of the Nova at the α Cygni stage. One cannot assert that there are no differences between the spectra of α Cygni and the Nova (for instance, in the latter *O* I was present) but all these four peculiarities are in a striking manner paralleled with the results of comparison of α Cygni with the same standard (ε Serp.). Such a likeness of spectra of the Nova at this stage, when g_{eff} is zero or even negative, and α Cygni is probably caused by the likeness of physical conditions in their atmospheres. Keeping also in mind that the absolute magnitude at least of several c-stars is near to that of a Nova at maximum brightness, one must conclude that the above considerations bring an additional argument in favour of a very small value of effective gravity acceleration in α Cygni stars.

4. Now we turn to the interpretation of some observed spectral peculiarities of c-stars. In the recent years progress was reached in the computation of theoretical curves connecting the variations of the intensity of lines with temperature and gravity (Russell, Pannekoek, Unsöld). When comparing our observations with theory we used partly Pannekoek's curves, partly those computed by ourselves following his method[7].

Let us take helium, the presence of which in the spectra of supergiants c*A2* has always been a puzzle. For the sake of illustration in Fig. 4 are given the theoretical curves for the line 4471 for different values of *g* from $10^{0.4}$ to $10^{4.4}$. Though the gravity effect for helium is sensible at temperature of about 9000°, it is surely insufficient to explain the appearance of helium lines in supergiants c*A2* ($g=10^3$), differing not too much in *g* from the usual stars ($g=10^4$). The observed strength of *He* lines in the supergiants c*A2* may be accounted for if the effective value of *g* is of order 10 or somewhat more. The Stark effect may rather favour the appearance of *He* in *A2*. The conclusion may be drawn that the behaviour of helium lines in the supergiants c*A2* also points on the large discrepancy between the effective gravity acceleration and its dynamical value.

From many details of spectra of supergiants we compare with theory for the sake of illustration only two typical iron lines *Fe* II 4233 and *Fe* I 4383. As it was mentioned earlier, the characteristic feature of spectra of supergiants as compared with those of usual stars is the considerable increase of the intensities of lines due to the ions and the decrease of those of neutral atoms. In fact the theoretical curves (Fig. 4) show that the change of the intensity of the lines in question when passing from low to high luminosity is of opposite character and this is in agreement with the observations. But again, as in the case of helium, the observed relative intensity *Fe* II: *Fe* I in ε Serp. as compared with that in α Cygni will be probably accounted for not by passing from $g=10^4$ to $g=10^3$ but to a much lower value (may be to $g=10^1—10^2$).

Nearly the same holds with some variations if taking another pair of lines due to iron or another element under consideration. The discrepancy in question seems to be in agreement with that found when discussing the hydrogen and helium.

It remains to mention that the resonance lines of ions and neutral atoms are weakened in the supergiants, the effect being strong for *Sr* II, *Mn* I, *Cr* I, *Ca* I, *Ba* II and small for *Ca* II, if existing at all. The computed theoretical curves predict a moderate gravity effect for these lines at temperature of about 9000°, and in order to explain the considerable weakening of the lines under consideration in α Cygni relatively to ε Serp. an extremely low value of g is required, much smaller than the dynamical one. This is also in agreement

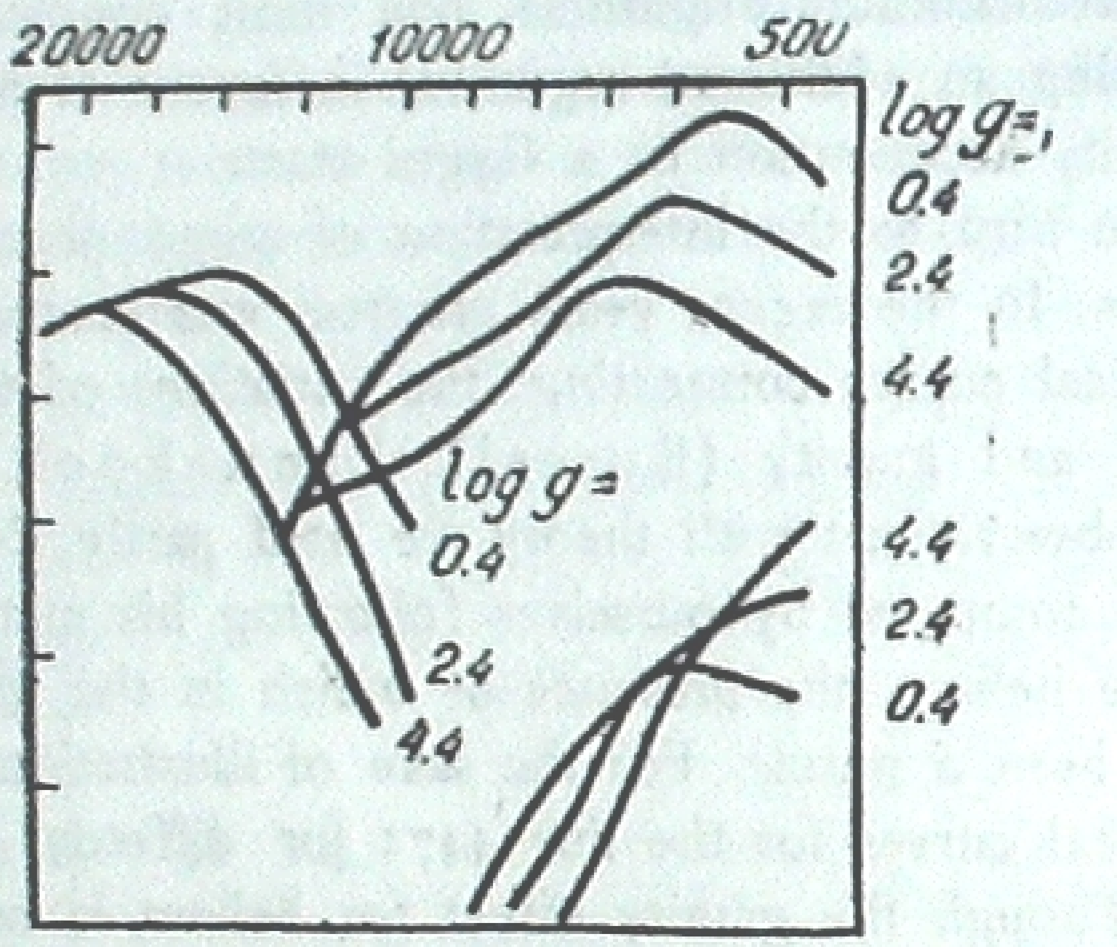

Fig. 4 бзб.

Variations of line intensity for *He* I, *Fe* II and *Fe* I with temperature and gravity. For abscissae (temperature) and ordinates a logarithmic scale has been chosen. The zero point of the vertical scale is arbitrary for different lines (one division corresponds to a factor 10).

with all preceding results. But the lines *K* and *H* behave probably in a different manner, the effect becoming reverse in *cB8* stars, even after account for the interstellar lines. One may guess that the behaviour of resonance lines is governed by some additional factor.

We have considered in this work a number of characteristics in the spectra of supergiants (but by far not all) and found that the main peculiarities may be accounted for if the effective gravity acceleration is much lower than the dynamical value 10^3. It would be premature to derive the ratio g/g_{eff}. The numerical result may be properly derived from hydrogen and it turns out to be about 50—100. Confronting now all the observed facts, it is difficult to escape the conclusion that in the atmospheres of supergiants in addition to the gas pressure there are any other forces acting against gravity and causing the observed large discrepancy between g and g_{eff}.

It is of importance to note that in the spectra of supergiants not all lines are strengthened. The neutral lines in general and the resonance ones are weakened.

5. Now we shall indicate some consequences of dynamical character, which follow from the hypothesis under consideration. Let us suppose that the cause of the high discrepancy between g and g_{eff} is the radiation pressure. As it is known, the residual intensity of the net stream, properly determining the radial outward pressure, is a function of the height in the atmosphere. For this reason, if the observed value of g_{eff} makes up a very small fraction of g one may imagine that in several layers g_{eff} is negative and that the matter moves there outward.

Another complication is connected with the effect of ionization. If many atoms, whose ultimate lines are in the visible region of the spectrum, under the action of radiation pressure are moving outward, they will become successively ionized before being gone very far from the surface, and their lines will be generally far in the ultraviolet, where the effect of radiation pressure is negligible. Then under the force of gravity the ions at last will fall back to the surface until again a recombination will occur. This represents a sort of cyclical process suggested by Gurney and Lyman Spitzer[8], the neutral or singly ionized atoms rising, the ionized (singly or doubly) returning. However there are several restrictions for this process connected with the amount of ionizing radiation and the electron density. At last we must keep in mind the effect of diffusion drag suggested by McCrea (§ 6). Therefore the problem of the radiation pressure in its application to stellar atmospheres is highly complicate.

Following the ideas of Milne, Chandrasekhar and especially of McCrea[9] we are able as yet to estimate roughly without appealing to the detailed theoretical model of the atmosphere at least that fraction of radiation pressure which is due to the continuous absorption and to the effect of the integral equivalent width of absorption lines. The total force in question per unit area is

$$p = \left(\frac{1}{3}\eta + \frac{1}{4}\tau_0\right) a T^4 \qquad (1)$$

where $a = \frac{4\sigma}{c}$ is an universal constant, η—the total equivalent width of lines supposed for simplicity to be uniformly distributed over the spectrum (in our case $\eta < 0.1$), τ_0—the total optical thickness in the continuous spectrum (it may be assumed to be equal to 0.5). The significance of (1) is best seen by evaluating the mass m', which this force will support against gravity at the stars surface per unit area

$$m' = \frac{a T^4 R^2 \left(\frac{1}{3}\eta + \frac{1}{4}\tau_0\right)}{G\, M} \qquad (2)$$

It is of interest to express m' in units of mass m of the column of atmosphere per unit area. This may be computed only with very low accuracy. One may assume in the first although rough approximation $\left(\frac{1}{3}\eta + \frac{1}{4}\tau_0\right)$ to be constant for all stars within $A-G$. The difficulty is in the derivation of the mass of the reversing layer m. We may appeal to the value of m for the Sun (10^{-2} and 7×10^{-2}gr/cm², if basing on Russell's and Unsöld's composition of the atmosphere). For different stars m may be derived from Fig. 83 and 84 of Unsöld's book[10]. We have adopted for all stars and the Sun $m = 3 \times 10^{-2}$gr/cm². This is certainly a very crude treatment. Whence it follows that for the Sun only about 0.001 of m may be supported by the radiation pressure under consideration. For usual stars $A2$ and $B8$ m'/m reaches few hundreths and for the supergiants $cA2$ and $cB8$ even few tenths. One may select another way to estimate the effect in question. The latter consists in the computation of the ratio $\frac{g_r}{g}$ where $g_r = \frac{1.23}{\theta^4} \bar{k}$ is the acceleration due to the radiation pressure ($\bar{k}$ is Rosseland's mean coefficient of absorption[11]). The computed ratio for cB8 (also a very crude approximation) amounts very few tenths. The accuracy of the above results is very low and it is perhaps not excluded that these figures may be diminished or increased even 5 times. Particularly the results depend on the dispersion in absolute magnitude of early supergiants (probably between—3.0 and—7.0). Therefore even confining ourselves to the portion of the radiation pressure as expressed by (1), we find that the atmospheres of several supergiants may be supported at least partially.

However, the selective radiation pressure can by no means be neglected here, its rôle in the supergiants of early type is probably more important than of that expressed by (1). Since the pioneer work of Milne on the equilibrium of the solar chromosphere we know that this effect is important for *Ca* II. For the supergiants at temperatures of 10000—15000° the computed acceleration due to the radiation pressure for hydrogen atoms is of the same order as the gravity acceleration, or even may be exceeds it (McCrea a. o.[12]). This holds at least for several layers of the atmosphere. The question on the initial velocities of atoms is also of importance in this problem. However the complexity of the phenomenon, primarily its cyclical character, and several restrictions involved there, make the numerical results without appealing to a detailed model of the atmosphere not quite definite.

It is possible that the radiation pressure is the sole agency responsible for the observed discrepancy between g and g_{eff}. However we are not able to decide whether there are not other additional agencies causing the strong decrease of g or even the expulsion of matter. In any case, such forces are effective for example in the solar chromosphere, though their origin remains unknown. For instance, some kind of systematic motions may much help in supporting the atoms against gravity. The above theoretical considerations lead to the conlusion that the atmospheres of several supergiants $cB5-cA3$ are probably supported against gravity at least partially—a result, in favour of which we brought forward earlier a number of spectroscopic evidences.

6. In the light of the above discussion concerning the c-stars of type $B5-A3$ one may expect perhaps an outward motion of the reversing layer as a whole and of atoms of given species particularly strongly subject to selective radiation pressure. This suggests the necessity to study the systematic motion of supergiants having mainly in view the discovery of the K-term and the systematic differences in the radial velocities for individual lines. It is remarkable that the observed facts (Novae, prominences) mostly speak in favour of the common motion of different elements in spite of the great difference in selective radiation pressure. In such exceptional cases as P Cygni, where the various atoms and ions bring out a very sensible difference in velocities (Beals, Struve, Kharadse), the matter concerns properly the difference in motion in dependence on height in the atmosphere[13]. If the atoms of an abundant element, say hydrogen, come in motion under the influence of any force, the diffusion drag will cause a redistribution of the acquired momenta amongst the various atoms, so that the layer as a whole will move outward. But if only the atoms of very small partial abundance come in motion, the diffusion drag will lead evidently to a considerable decrease of the velocities of the atoms under consideration, the layer as a whole remaining but little affected, if at all. In the light of this effect a sensible difference in the velocities of different elements is not to be expected. But in supergiants, where the density is low, the effect of diffusion drag is smaller and the difference in velocities for individual lines seems to be perhaps more probable than in the usual stars.

Starting from these considerations we have obtained 106 spectrograms for seven supergiants (Table 1). To eliminate the possible variations in the radial velocity of a star as a whole and also the error of the plate we determined from the measurements only the difference: line in question minus average velocity based on hydrogen and helium lines. We are briefly considering here only the *Ca* II lines K and H, leaving the detailed discussion for these and all other lines for another paper. It is to be remembered that Adams and McCormack found a systematic negative displacement for K and H in the spectra of β Orionis and α Cygni[14]. I confirmed their result for β Orionis (3). But the radial velocity of the lines K and H in the distant supergiants must be influenced by the interstellar calcium and therefore the stellar origin of the observed displacement for two stars cannot be considered as proved. Now we have seven supergiants. Using the statitistical data (Merrill, Sanford and Burwell) concerning the intensities of interstellar calcium lines[15] we were able to estimate in a rough manner the term due to galactic rotation for the interstellar line and its influence on the observed radial velocity of K and H for each star. To do this even roughly it was necessary to measure the equivalent width of the lines K and H. The observed values of relative velocities of the *Ca* II lines and the ones corrected for the interstellar lines are given in Table I. It is to be emphasized that the accuracy of the correction is very low since it depends on the assumed values for the distance and the intensity ratio - K stellar : K interstellar, on the assumption that the peculiar motion of interstellar calcium is zero and that no abnormally dense clouds occur in the direction of the star. But we hope that this correction gives as yet some improvement.

TABLE I

	R. V. (uncorr.)	R. V. (corr.)
β Orion	−5.4±0.8	−4.6
67 Oph.	−5.0±1.1	+0.2
4 Lac.	+2.2±0.8	−4.5
2 Hev.	−4.6±1.1	−5.0
σ Cygni	−0.6±0.8	+2.9
α Cygni	−2.5±0.5	−1.5
η Leonis	+1.0±0.9	+0.2

The main result is that out of seven stars four ones (β Orion., 2 Hev., α Cygni, 4 Lac.) show a systematic negative displacement nearly four times as large as the probable error. For two stars (67 Oph. and η Leon.) the displacement is negligible and for σ Cygni one may suggest a positive displacement. At least for several supergiants $cB7$—$cA2$ systematic negative displacements for K and H may be considered as highly probable, as well as the absence of this effect in other ones. In view of the very rough estimate of the influence of interstellar lines, the latter may be overestimated or underestimated for the individual stars, but the result in whole is probably correct.

It is worthy of attention that the negative displacement does not surpass 6 km. Let us try to consider these results in the light of the idea of McCrea on the motion of one gas through another[16]. Using equations (7), (11), (19), (23) of McCrea's paper we can derive the limiting velocity of *Ca* II relatively to H. Suppose tentatively that the atmosphere consists of an excess of hydrogen at 10000° for which the force of gravitation is almost balanced by some other force, say $g_{eff}=0.01\ g$. We suppose further that the ions *Ca* II are subject to selective radiation pressure. The solution is given for two cases when the relative velocity of two elements is small (U_0) and large (U'_0) as compared with the thermal velocities. The result depends essentially on the density ν'. If $\nu'=10^9$ atoms/cm³, we find $U_0\sim 0.2$ km/sec and $U'_0\sim 2$ km./sec.

If $\nu'=10^8$ $U'_0\sim 6$ km/sec. Here the ions of *Ca* II preceed in their motion the hydrogen atoms. The uncertainty of several parameters entering here is considerable and we must be cautious with regard to the numerical results. But it is of interest that the relative motion of the *Ca* II ions observed in the supergiants $cB7$—$cA2$ may be realized at the density about 10^8—10^9 particles/cm³, a value plausible for the reversing layer of supergiants under consideration. At greater pressure the diffusion drag will be sufficiently strong to reduce the limiting relative velocity to the value <1 km/sec. May be namely for this reason the differential displacement of K and H is not observed in usual spectra $B5$—$A2$, even apart from the fact that in these stars the probability for the balancing of hydrogen atoms is smaller. The conclusion may be drawn that the hypothesis of diffusion drag possibly not by chance correctly predicts for the stars the order of observed values of relative velocities of lines K and H.

One may also suggest the explanation of the phenomenon in question in terms of the hypothesis of accelerated outward motion in stratified layers so successfully applied at first by Bowen to planetary nebulae and afterwards by Beals and Struve to P Cygni and W—R stars. But such an application to c-stars is much more restricted. At last, one may imagine a tenuous shell of outward moving calcium ions in the upper layers in front of an underlying stationary reversing layer. The study of profiles of the lines K and H at high dispersion will be very useful to test this or another supposition.

7. If in c-stars is realized, as we have seen above, a systematic motion of the calcium ions, one may also suspect an outward motion at least for several atmospheric layers as a whole. From this point of view it would be of interest to analyse the radial velocities by means of the well known general relation

$$V=K+X\cos l\cos b+Y\sin l\cos b+Z\sin b+\bar{r}A\sin 2(l-l_0)\cos^2 b \qquad (3)$$

The notations are usual. When selecting the c-stars of type $B5$—$A3$ we were basing on the classification made only with slit spectrographs. The sources are as follows: 47 stars from a special list by Merrill[17], 4 stars observed by Harper[18] and one by Young[19]. It is to be emphasized that these stars are in overwhelming majority concentrated within a few degrees from the galactic plane. In addition, because of the lack of observations in the southern hemisphere, these stars are to some extent concentrated in the longitudes 50—210°. In view of such a distribution it would hardly be reasonable to expect that the solution would give even approximately the standard value for the direction of the solar apex, particularly the latitude of the apex remains practically indeterminable. Notwithstanding this and the small number of stars, the equations were solved at first in the form as given in (3). In order to assign not too much weight to the stars of the Perseus cluster (9 stars), we united them in three groups, so that we had only 46 equations of condition (the results are given in first column of Table II). For control another solution was made, assigning unity weight to all stars. A very poor determination of the solar apex is not surprising. The position of the galactic centre turned out to be in excellent agreement with the best modern results. The value $\bar{r}A$ gives the absolute magnitude which appears very probable for the c-stars. The most interesting result is a large negative value for the K-term. Further, adopting the standard position for the solar apex and the galactic centre, a second solution was made (second column). At last because of the impossibility to obtain practically the latitude of the solar apex we adopted in the third solution of (3) a standard value $+20°$ for the latitude (third column). In this solution in order to have a more homogeneous group with regard to the distance we excluded three brightest stars β Orion, (0.3), α Cyg. (1.3), η Ursae Maj. (2.4). We have here only 43 equations of condition (49 stars) with five unknowns since only the projected solar velocity $V_0 Cos b_a$ is determined. Again we have obtained the position of the galactic centre and the absolute magnitude from $\bar{r}A$ in good agreement with the best determinations.

TABLE II ცხრილი

	1	2	3	4
K	-6.8 ± 1.8	-5.3 ± 1.1	-5.8 ± 2.0	-4.9 ± 1.5
X	-16.2 ± 2.7		-13.6 ± 3.1	
Y	-4.7 ± 2.1		-5.8 ± 2.5	
Z	-30.4 ± 7.0			
$\bar{r}A\cos 2l_0$	$+8.2\pm3.0$		$+5.5\pm2.2$	
$\bar{r}A\sin 2l_0$	-21.5 ± 2.3		-20.8 ± 2.6	
l_a	$16°.3$		$23°.2$	
V_0		-18.5 ± 1.8		-19.5 ± 2.1
$V_0\cos b_a$			-15.8	
l_0	$325°.4$		$322°.4$	
$\bar{r}A$	$+23.0$	$+22.6\pm1.5$	$+21.5$	$+25.1\pm2.0$

All the three solutions give a large value for the constant term K. Having in view that the mean residual $\theta=11.9$ km/sec of these stars shows a small dispersion and that the probable error of K is nearly four times as small as its value, it is difficult to escape the conclusion that we are dealing here with a real phenomenon. This cannot be ascribed to the non-uniform distribution of c-stars in galactic longitude since the stars of type O and B_0–B_2 at nearly the same distribution give even a positive K-term. If account would be taken for the Einstein red shift for the c-stars, the values of K in Table II should be increased. The hypothesis of any peculiar stream motion for the supergiants is hardly tenable since the solar motion with regard to these stars does not probably display any anomaly. The negative K-term may be interpreted in terms either of the effect of spatial contraction of the system of c-stars or of the outward motion of gases in their atmospheres. But from the standpoint of stellar dynamics one must expect rather an expansion. Having also in view that in addition to the negative K-term there is observed also a relative negative shift for the *Ca* II lines, one must consider the hypothesis of outward motion of gases as much more plausible.

This conclusion is so important that it is of interest to consider the earlier work for c-stars in this direction. Until recently we find generally no available information in literature. But in 1940–41 appeared two papers concerning the motion of c-stars, which I was able to read because of the conditions of war time only when my work was completed. In the first paper by Greenstein[20], concerning the determination of the luminosity of c-stars from the galactic rotation, the K-term was assumed a priori to be zero. R. Wilson in another paper[21] solves the equations (3) for 205 stars *cB*–*cM* (not dividing them into spectral groups). The author obtained $K=-2.00\pm0.80$ but does not emphasize this. R. Wilson in the selection of c-stars was more liberal than myself, since he included in his list also the stars from Miss Payne's list, the spectra of which are described also from objective prism observations as having «very narrow» and «narrow» lines[22]. One may doubt whether all these stars without exception are really c-stars. Because of this difference and especially of the great difference in spectral classes our results are not comparable, but it is remarkable that in Wilson's solution we find a negative K-term, probably real, though sensibly smaller than those given in our Table. In order to control our results I took all the stars $B5$–$A7$ from Wilson's list and adding few stars omitted by him (the above mentioned Victoria and Dunlap observations) solved anew the equations (3) having now 66 stars instead of 52. All the stars in agreement with Wilson's procedure were entering in the solution with equal weight. As well as in our second solution we adopted for the solar apex and rotational centre the standard positions. The results, which do not differ much from our former computations, are represented in column 4 of Table II. Therefore one may speak with considerable probability on the reality of the negative K-term. When comparing this result for supergiants $B5$–$A7$ ($K=-4.9\pm1.5$) with Wilson's value $K=-2.0\pm0.8$ for the c-stars of all spectral classes taken together, the suggestion arises that the cause of this discrepancy, may be, lies in the small value of K for the supergiants of later classes. This will be tested elsewhere. In the meantime we will only indicate that in Wilson's solution of (3) concerning the Cepheids we find K to be equal -3.0 ± 1.0 [23]. This appears to be not accidental since the pulsation probably favours the great discrepancy between g and g_{eff}. Besides it is worthy of attention that α Cygni also displays some irregular oscillations in velocity and the variable character of *Hα* emission. The oscillations in velocity probably hold also for β Orionis.

The K-term may be also tested by the double stars in which one of the components is a supergiant of early type. It appears that Rigel is a good and probably a sole example for this purpose. The Simeis observations fail to manifest the negative excess in the radial velocity of Rigel with respect to the fainter component $B5$ (+21.0 and+16.9 respectively). However we must keep in mind that the accuracy of the derived velocity for the fainter component is low and in addition it is not excluded that the components are only optically connected.

Basing on the values of rA as given in Table II one may derive the mean absolute magnitide of the supergiants cB5—cA3 from the formula

$$M = m + 5 - 5\log r - 5C - \frac{ar}{1000} \tag{4}$$

The troublesome error C connected with the dispersion in distance is very small if using the data of our third solution and is neglected here. The coefficient of absorption for visual rays was obtained from $a=7E$, where E is the color-excess (for the majority of stars of our list E was taken from Stebbins, Huffer and Whitford's paper[24], for the remaining ones we have used an extrapolation). This turns out to be 0.90. As the mean apparent magnitude for the stars of our list (third solution) $m_{vis}=5.65$, one obtains, assuming for the galactic rotation constant $A=17.7$ km, $M=-5.9$. But the visual absorption $a=0.90$ may be is too high and if taking $a=0.65$ we shall obtain $M=-5.6$. The probable error of M may be roughly estimated as± 0.6. The derived values of M may be compared with recent determinations: Greenstein found from the galactic rotational term—6.3 for cB, cA and -5.4 for $cB8-cA5$[20], while Wilson derived from the rotational term, parallactic and peculiar motion—5.0 for $cB5-cA4$. The agreement seems to be quite satisfactory.

We have brought above a number of independent evidences of spectroscopic and dynamical character in favour of the hypothesis that in the atmospheres of supergiants $B5-A3$ there are operative in addition to the gas pressure also other forces acting against the gravitation. This leads to the very high discrepancy between the effective and dynamical value of gravity acceleration, and on the other hand, to the outward streaming of matter displaying itself in the existence of the negative K-term and the systematic displacement of Ca II lines.

Simeis—Abastumani
September, 1942.

Literature: ლიტერატურა:

1. Publ. Astr. Inst. Amsterdam No. 5, 1936.
2. Upsala Univ. Årsskr. No. 66, 1936.
3. Circ. Poulk. Obs. No. 26, 1939.
4. Bull. Astr. Inst. Netherlands No. 301, 1937.
5. Aph. J. 79, p. 409, 1934.
6. Publ. Michigan Obs. *VI*, No. 12.

7. Publ. Astr. Inst. Amsterdam No. 4, 1935.
8. M. N. 88, p. 377, 1928; Aph. J. 90, p. 537, 1939.
9. Zs. f. Aph. 14, S. 208, 1937. The Observatory p. 277, 1937.
10. A. Unsöld, Physik der Sternatmosphären, S. 263, 1938.
11. Loc. cit. p. 126.
12. M. N. 94, p. 737, 1934. The Observatory p. 277, 1937.
13. The Observatory, 319, 1934. Aph. J. *81*, p. 66, 1935, Zs. f. Aph. B. *11*, H. 4, S. 304, 1936.
14. Aph. J. 81, p. 119, 1935.
15. Aph. J. 86, p. 274, 1937.
16. M. N. 95, 509, 1935.
17. Aph. J. 81, p. 351, 1935.
18. Publ. Dom. A. O. *VII*, No. 1, 1937.
19. Publ. Dunlap Obs. *1*, No. 3, 1939.
20. Proc. Nat. Acad. Sc. 26, p. 263, 1940.
21. Aph. J. 93, p. 212, 1941.
22. Payne, The stars of high luminosity, 1939, Appendix A.
23. Aph. J. 89, p. 229, 1939.
24. Aph. J. 91, p. 20, 1940.

Note added in proof.

After the acquaintance with Trumpler's paper on the motion of galactic clusters (Aph. J. 91, 195, 1940) I think that the interpretation of the K-term in the light of the hypothesis of spatial contraction of stars has much more weight, as this was mentioned on p. 94 In any case the discovery of the large negative K-term for c-stars is of interest also from the point of view of this new suggested phenomenon. However the share of the outward motion may be is not small here, especially if account will be taken of the Einstein shift. Whether or not the K-term is entirely due to the spatial contraction, the main result of this paper on the large discrepancy between G and G_{eff} remains unaffected.

cB_5-cA_3—ზებუმბერაზ ვარსკვლავთა ატმოსფეროს ზოგიერთი ფიზიკური დამახასიათებელი

გ. შაინი

(რეზუმე)

ამ შრომაში მოყვანილია სპექტროსკოპული და დინამიკური ხასიათის რამდენიმე არგუმენტი cB_5-cA_3 ტიპის ზებუმბერაზთა ატმოსფეროში გაზების აღმავალი მოძრაობის ჰიპოთეზის სასარგებლოდ. წყალბადის ხაზების დაკვირვებით მიღებული პროფილების შედარება Stark-ის ეფექტზე დამყარებულ თეორიულად გამოთვლილ პროფილებთან საშუალებას გვაძლევს განვსაზღვროთ სიმძიმის ძალის აჩქარების ეფექტური მნიშვნელობა g_{eff} ვარსკვლავის ზედაპირზე (ნახ. 1, 2). შვიდი გამოკვლეული ზებუმბერაზისათვის იგი აღმოჩნდა 10—12 cm/sec²-ის ტოლი, რაც დაახლოებით 50—100-ჯერ ნაკლებია, ვიდრე დინამიკური მნიშვნელობა $g=G\frac{M}{R^2}$.

ერთიდაიმავე სპექტრული კლასის ზებუმბერაზთა და ჩვეულებრივ ვარსკვლავთა სპექტრების დაწვრილებითი შედარება ამჟღავნებს დიდ სხვადასხვაობას მათ შორის: 1) ნეიტრალური ელემენტების ხაზები შესუსტებული არიან ზებუმბერაზთა სპექტრებში, ხოლო იონიზებული ელემენტების ხაზები, პირიქით, მნიშვნელოვნად გაძლიერებულნი; 2) ატომებისა და იონების რეზონანსული ხაზები მეტად შესუსტებული არიან; 3) *He*— ხაზები ძალიან შესამჩნევი არიან cA_2— ვარსკვლავებში, მაშინ, როდესაც A_2—ვარსკვლავების სპექტრში ისინი სრულიადაც არ მოჩანან (ნახ. 3). ზებუმბერაზთა ყველა ეს სპექტრული თავისებურება საოცრად მეორდება ახალი ვარსკვლავის სპექტრის საწყის სტადიაში, როცა მასში ნივთიერების გამოდინება იწყება.

ყველა ამ თვისებათა ინტერპრეტაციას იონიზაციის თეორიის თვალსაზრისით მივყავართ იმ დასკვნამდე, რომ ამ ვარსკვლავთა ზედაპირზე სიმძიმის ძალის აჩქარების მნიშვნელობა, რომელსაც დაკვირვება გვაძლევს, ალბათ, რამდენიმე ათეულჯერ ნაკლებია ვიდრე დინამიკური. ეს მნიშვნელობა კარგად ეთანხმება იმას, რაც წყალბადის ხაზების მიხედვით არის აღმოჩენილი. ეს ფაქტები გვაიძულებენ ვიფიქროთ, რომ ზებუმბერაზთა ატმოსფეროში ჩვეულებრივ გაზურ მოძრაობასთან ერთად მნიშვნელოვან როლს ასრულებენ სხვა ძალებიც, რომელნიც სიმძიმის ძალის საწინააღმდეგოდ მოქმედებენ.

გამოთვლა გვიჩვენებს, რომ სინათლის საერთო და სელექტური წნევით გამოწვეულ აჩქარებას შეუძლია ნაწილობრივ და ხანდახან მთლიანად გააწონასწოროს ამ ვარსკვლავთა ატმოსფერო და გამოიწვიოს კიდეც ზოგიერთ ფენებში გაზების აღმადენი მოძრაობა. ზებუმბერაზთა რადიალური საჩქარეების გაზომვამ ზოგიერთი მათგანისათვის გვიჩვენა იონიზებული კალციუმის ხაზების სისტემატური გადაადგილება სპექტრის იისფერ ბოლოსაკენ, რაც —5 km/sec-ს აღწევს. ეს შედეგი ინტერპრეტირებულია დიფუზური დამუხრუჭების ჰიპოთეზის თვალსაზრისით. ყველა ცნობილი ზებუმბერაზის სხივური სიჩქარეების სრულმა ანალიზმა საშუალება მოგვცა მიგვეღო, მზის მოძრაობისა და გალაქტიკური ბრუნვის ელემენტებთან ერთად, აგრეთვე მუდმივი წევრიც, რომელიც მნიშვნელოვან სიდიდეს აღწევს — 5 km/sec. ეს მიუთითებს ან ამ ვარსკვლავთა სისტემის სივრცით შეკუმშვაზე, ან მათ ატმოსფეროში გაზების აღმადენ მოძრაობაზე. მეორე ჰიპოთეზი, რომელიც სპექტროსკოპული და დინამიკური ხასიათის დაკვირვებით მოცემულ სხვა ფაქტებს შეიცავს, უფროა მისაღები.

სექტემბერი, 1942.

აბასთუმნის ასტროფიზიკური ობსერვატორიის ბიულეტენი № 7. 1943
БЮЛЛЕТЕНЬ АБАСТУМАНСКОЙ АСТРОФИЗИЧЕСКОЙ ОБСЕРВАТОРИИ № 7. 1943
BULLETIN OF THE ABASTUMANI ASTROPHYSICAL OBSERVATORY No. 7. 1943

КОЛОР-ИНДЕКСЫ 4535 ЗВЕЗД В ОДИННАДЦАТИ ПЛОЩАДКАХ KAPTEYN'а

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В нашей предыдущей статье—«Колор-индексы 1758 звезд в пяти площадках Kapteyn'а, расположенных в галактической плоскости» (Бюлл. Абаст. Обс. № 6, стр. 17, 1942)—мы сообщали о начатой нами работе по составлению Каталога колор-индексов звезд $11^m.0—13^m.5$ в избранных площадках Kapteyn'а. Статья освещала преимущественно методическую сторону работы и содержала вместе с тем список колор-индексов 1758 звезд в пяти KSA, расположенных в плоскости галактического экватора.

Настоящая статья, представляя собой по существу продолжение названной, содержит определение колор-индексов следующих 4535 звезд. Последние составят вместе с первым списком примерно одну третью часть планируемого нами на ближайшие годы Каталога. Одновременно, мы и в настоящей статье касаемся вопросов методики нашей работы и уделяем внимание тем данным, которые могут в той или иной степени характеризовать точность наших определений или показать согласие последних с современными аналогичными определениями. Попутно, пользуясь довольно значительным материалом (6293 звезды в шестнадцати KSA обоих списков) мы пытаемся получить некоторые звездно-статистические выводы относительно распределения и характера поглощающей среды в Галактике, которые однако пока могут иметь значение лишь предварительных заключений.

Выбор KSA, для включения в данную статью (табл. I), обусловлен тем, что KSA 18, 23, 25, 39, 41 в зоне $|b|=5°—10°$ являются следующими, после опубликованных в предыдущей статье KSA, в зоне $b=\pm 5°$, площадками, для которых определения ведутся согласно нашему плану последовательно, по мере удаления от галактической плоскости. Что же касается KSA 2, 3, 4, 5, 6, 7—то включение их в статью дает нам возможность сравнить наши данные с современными определениями B. J. Bok'a и W. F. Swann'a[1], на которые мы ссылались еще в предыдущей статье[2].

Негативный материал, послуживший для наших определений, описан в табл. II. Для каждой площадки использовано от 3 до 6 пар негативов, причем каждая пара промерялась на микрофотометре по крайней мере