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THE OCCURRENCE OF CARBON ISOTOPES IN THE SPECTRA OF N TYPE STARS

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Introduction. The problem of isotopes is of considerable interest for astronomy. Thus the relative abundance of several isotopes may be predicted by the theory, since in the statistical equilibrium the concentration of each nucleus in the known cyclical reaction is proportional to its lifetime [1]. For instance, C^{13} captures slow protons about 70 times as easily as C^{12}, therefore C^{12} should be 70 times as abundant. This must hold at least in the interior of stars.

If the relative abundance of isotopes does not depend on the nuclear reactions mentioned above, the general presumption that the isotopes of carbon will be found everywhere in the same proportion (nearly 70 : 1) can hardly be applied to stars of type N and R, the relative abundance of elements, at least of carbon and oxygen, being quite unusual in these stars.

Further, it is brought out from the few laboratory experiments by King [2] that the intensity ratio of the band $C^{12}C^{12}$ to $C^{13}C^{13}$ for the transition (1,0) depends on the conditions of excitation. If this is really so, an information may be obtained with respect to the physical conditions within N and R stars. In any case it is highly desirable to test this unexpected and mysterious result by means of astronomical data.

Carbon generally deserves great attention owing to its peculiar role in the stars. The carbon branch of late type stars characterized by the relative excess of carbon as compared to oxygen was discovered long ago. More recently Beals [3] manifested the existence of two parallel sequences in Wolf Rayet stars designated as the carbon and nitrogen sequence respectively. For some reasons it is more difficult to judge about any branching with respect to the carbon in the intermediate classes, but it may be mentioned that L. Berman [4] was able to discover a carbon star of type Go (R Cor. Bor.).

The isotopic effect for atoms (except hydrogen) is so feeble that it cannot be detected in stellar spectra. But in the case of molecules, when we are dealing with motion of heavy nuclei, the isotopic shift reaches often several tens of angström. As a result we shall have the shift of bands as a whole and of the lines of bands which shall be in each case in first approximation proportional to the distance from the band (0,0) and the line (0,0) respectively.

About 20 years ago Shane [5] pointed out that in the spectrum of 19 Piscium (N_0) there is near the Swan band 4737 an apparent head at 4745 and in that of 152 Schjel. (N_3) one at 4753. A common origin was suggested for these three bands. On the other hand, Rufus[6] in his study of the spectra of class—R stars also noticed the peculiar bands at 4745 and 4753. In 1929 King discovered in the laboratory a faint unknown band 4744 developing with the well known Swan band at 4737, which Birge and King[7] were able to identify as belonging to the heavy molecule $C^{13}C^{12}$, Sanford[8] and Menzel[9] pointed out that the three bands under consideration observed in spectra of N and R type stars belong to the molecules $C^{12}C^{12}$, $C^{13}C^{12}$ and $C^{13}C^{13}$. Sanford,[10] found also in the R class the secondary bands of the same heavy molecules. Another point of interest is the conclusion on the large abundance of C^{13} drawn by Menzel[11] from the relative intensities of these bands.

However, the evidences in favour of the above results were too meagre, and serious doubt was expressed in this respect by Wurm[12]. In fact, the more or less satisfactory agreement of the laboratory or theoretical wave-lengths of the bands with those observed in late type spectra does not afford a convincing evidence in favour of correct identification. The accuracy of measurements of bands is low (of the order of 0.5 A and more), and in addition at the moderate dispersion used the effect of blends is generally great in these spectra. At last, when measuring the heads, a systematic error is mostly inevitable.

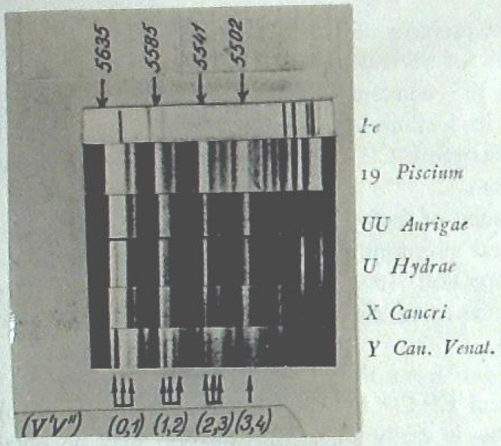

Photo 1.—The spectra of N type stars in the region of the Swan bands of sequence—1. The arrows show the position of the $C^{12}C^{12}$, $C^{13}C^{12}$ and $C^{13}C^{13}$ bands.

In this investigation I tried to find new isotope bands and, on the other hand, to pay attention to the photometric side of this problem. In this way, as appears to me, I was able to find more convincing evidences as compared with those found hitherto.

The $C^{13}C^{12}$ bands of the sequences +1 and—1. Previously the investigation of isotope bands $C^{13}C^{12}$ was properly confined to the transition (1,0) in N and R stars and in addition to (2,1) in R type ones. The evidence for the occurrence of still heavier molecules $C^{13}C^{13}$ seems to be more doubtful. Basing on Hutchisson's theory of vibrational transition probabilities[13] and Maxwell-Boltzmann distribution of molecules in different vibrational levels one may expect a very considerable strength of bands of the sequence +1. In fact, the bands 4737, 4715, 4698..... overlap each other to such extent, as to cause within the region in question the well-known gap in the continuous spectrum of type N. Therefore, the blue sequence except the first band is generally not suitable for the study of isotopes. This holds still more for the sequence O (moreover the isotopic shift for these bands is too small).

In this respect the yellow sequence—1 appears to some extent more appropriate for testing the presence of isotope C^{13}. In fact, the theoretical intensities of Swan bands (0,1), (1,2).... are sensibly lower than those of the sequence (1,0), (2,1)..., and in the stellar spectra the gap in the region 5635—5500 is much fainter than that in the blue one 4737—4680. Further, it may be mentioned that it is incomparably easier to get the yellow portion of spectrum of type N than the blue one. However, it appears that most valuable information may be obtained from the comparison of both sequences.

It is to be emphasized that a sure identification in the late type spectra may be made only with respect to the stronger bands, especially if the latter are not wide. The general impression is of importance in the question of the identification. In our case we may judge of the degree of certainty from the inspection of Photo 1 representing a series of spectra of N type stars (yellow region). The arrows mark the position of Swan bands. It is evident that at least the first two Swan bands consist of two and sometimes of three close components.

Before to discuss the possible isotopic effect it is necessary to prove that the doubling of bands as brought out in Photo 1 and Fig. 2 is not due to the rotational structure. In fact, it is known that the Swan bands consist of the branches P and R and at the absence of the null-line a gap may be expected at the distance about 8 A from the head. But we have convincing evidences that the observed doubling is not due to the effect of rotational structure. In fact, the intensities of individual lines of the band may be computed. On the other hand, the rotational structure of any band (say 0,1) is known from the laboratory study by Johnson[11] performed with very high dispersion. Basing on these data one may compute the integral intensity of small separate sections of a band and therefore to obtain a representation on the profile of a band in emission as it must appear in the case of small or moderate dispersion when the rotational structure cannot be properly discerned. The results depend also to some extent on the temperature. The dots (Fig. 1) are the integral intensities for sections of the profile for every 0.5 A. Some fluctuations in the intensities as brought out by individual dots depend on the arbitrary selected limits of integration. There remains no doubt that the computations represent the profile at least qualitatively rather well.

It is clear that the computed profile shows no trace of a doubling contrary to the observed one in the band 5635 and others (Photo 1). Properly speaking this was to be expected since at the distance about 8—9 A from the head the individual lines became rare. Fig. 1 characterizes the theoretical intensity distribution in the band 5635 in emission. However, it may be shown that in the case of an absorption band the effect of overlapping of the branches P and R will also not give any sensible doubling. A still more convincing evidence in favour of the not structural origin of the observed doubling of the band 5635 is found in the following. The bands 5635 (0,1) and 4737 (1,0) must be similar in the rotational structure. But 4737 in the spectra of N type stars shows no trace of doubling towards the shorter wave-lengths. On the contrary, one observes for the band 4737 a component towards the longer wave-lengths. The observed components of the main bands of the molecule $C^{12}C^{12}$ 5635 (0,1) and 4737 (1,0) are displaced in opposite sides by—9.7 and 7.4 A in good agreement with isotopic shift as given by the theory for the heavy molecule $C^{13}C^{12}$. It may be added that on our spectrograms the profiles of main and isotope bands 4737, 4745 and 5635, 5626 seem to be similar.

The results of our measurements of wave-lengths of heads are given in Table 1. The main portion of isotopic shift (the vibrational one) can be computed with desired accuracy from the equation

$$\nu_2-\nu_1=(\rho-1)\,(\omega'_e\,u'-\omega''_e\,u'')-(\rho^2-1)\,(\omega'_e\,x'_e\,u'^2-\omega''_e\,x''_e\,u''^2)$$

In this equation ρ is the square root from the ratio of assumed reduced masses of the two molecules, ω'_e, ω''_e, $\omega'_e x'_e$ and $\omega''_e x''_e$ the vibrational constants known from the work of Johnson and $u'=v'+1/2$ and $u''=v''+1/2$ the „effective“ vibrational quantum numbers. The isotopic rotational shift which reaches a few tenths of angström was also accounted for.

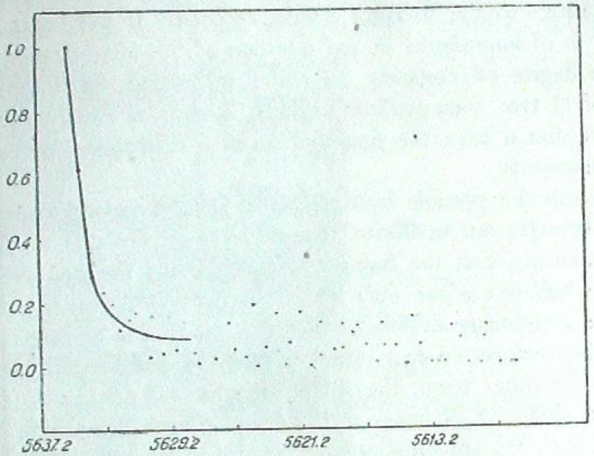

Fig. 1.—The theoretical intensity distribution in the Swan band 5635.

TABLE 1

Bands of Carbon molecules

(v′ v″)	(1,0)	(2,1)	(0,1)	(1,2)	(2,3)	(0,2)	(1,3)	(2,4)
$C^{12}C^{12}$	4737.1	4715.2	5635.5	5585.5	5540.7	6191.2	6122.1	6059.7[15]
Observed	4737.5	4715.8	5636.0	5585.9	5540.8	6193.7*	6122.6	6060.9
O—C	+0.4	+0.6	+0.5	+0.4	+0.1	+2.5	+0.5	+1.2
$C^{13}C^{12}$ (Theory)	4744.7	4722.9	5625.9	5577.1	5533.2	6168.1	6101.1	6040.4
Observed	4744.9	4724.3	5626.3	5577.4	5533.3	6168.1	6101.5	6042.7***
O—C	+0.2	+1.4	+0.4	+0.3	+0.1	0.0	+0.4	+2.3
$C^{13}C^{13}$ (Theory)	4752.3		5616.1	5568.5	5525.6			
Observed	4752.9		5615.2**	5568.7	5525.5***			
	+0.6		—0.9	+0.2	—0.1			

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* A blend with the band of CN 6193.9.

** Y Can. Ven. For 4 other stars of type N we have 5612.4.

*** The identification is doubtful.

Accounting for the mean error in the measurements of wave-lengths of the heads and also for the systematic error as brought out by the residuals for Swan bands (line 4), we must consider the agreement between the observed and the theoretical wave-lengths for the suggested isotopic bands (line 7 and 10) as quite satisfactory. The few larger residuals may be explained mainly by the effect of blends. However, the agreement would seem to be not so convincing were it not supported by the general impression received from the inspection of Photo 1 and 2. We had to our disposal no apparatus for the widening of spectrograms and for this reason a part of the spectra reproduced on Photo 1 are taken from Publ. Yerk. Obs. 11 1903.

We must now consider the individual bands in detail. As we have already mentioned above rather convincing evidences were found in favour of the isotopic origin of the bands 5626 (0,1) and 4745 (0,1). As to the isotope band 5577 it is especially notable in the spectra of type N_3 and later. In the earlier subclasses of N stars this band is often not surely seen. The corresponding band for the transition (2,1) was also measured, the residual being rather large. This band was already found in R type stars by Sanford. But in N type stars the overlapping of the main Swan bands is so strong that this isotope band is brought out only with difficulty. There remains still less hope to discover the isotope band (3,2). On the other hand, we have found in the green-yellow sequence the band (2,3). This band is mostly very faint, and it is difficult to judge by its aspect whether we are dealing with a band or blend or even a line. The same relates also to some extent to the bands (1, 2) and (2,1). The identification for the latter bands has a smaller weight.

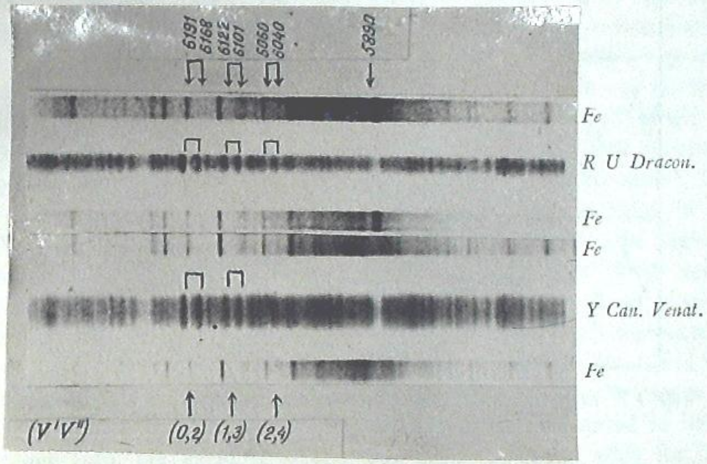

Photo 2.—The spectra of N type stars. The arrows show the position of $C^{12}C^{12}$ and $C^{13}C^{12}$ bands of sequence—2.

Now we turn to the photometric side of the problem in question. Unfortunately accurate photometric measurements cannot be made since the wide strong bands overlap each other and this fact combined with the crowding of many atomic lines does not allow properly to draw a continuous background. The microphotometric tracings of several stars are represented in Fig. 2. For most stars of our small list of 8 stars mere estimates of intensities have been made. The relative intensities of bands 4737 (1,0) : 4745 (1,0) and 5635 (0,1) : 5626 (1,0) vary sensibly from one star to another. But when estimating the intensity ratio 5635 : 5626, a difficulty arises since as seen on our spectrograms and microphotograms closely to the band 5626 towards the shorter wave-lengths there is a blend or unknown band not always separable from the band under consideration. For this reason the band 5626 appears probably stronger and wider.

As a result of our estimates and partly of measurements we have found that the intensity ratio for 4737 (1,0) : 4745 (1,0) varies nearly from 5 : 1.7 to 5 : 5 and from 5 : 2.5 to 4 : 5 for 5635 (0,1) : 5626 (0,1). Though the accuracy is low here it is worthy to note that in the mean the intensity ratio 4737 : 4745 and 5635 : 5626 is nearly equal. This also seems to be an argument in favour of the common origin of the four bands under consideration.

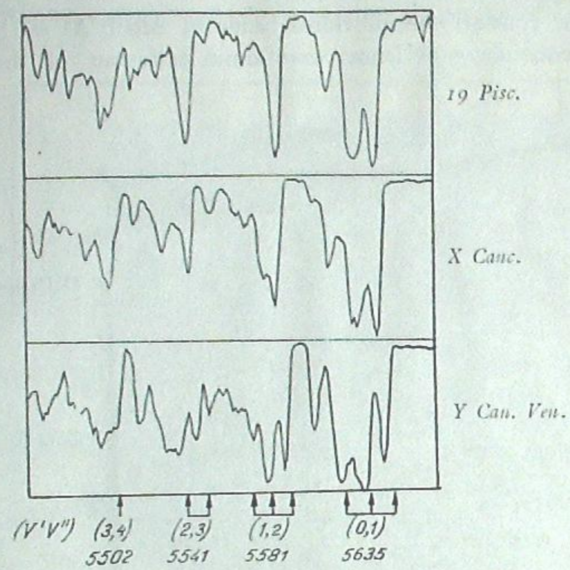

Fig. 2.—Spectrophotometric tracings of the region 5480—5660. The arrows show the position of the $C^{12}C^{12}$, $C^{13}C^{12}$ and $C^{13}C^{13}$ bands of the sequence—1.

Further, the larger deviations from the mean value of intensity ratio of 4737 : 4745 and 5635 : 5626 for the individual stars show some tendency to occur simultaneously in both pairs. For instance, in the spectrum of WZ Cassiop. the suggested isotope bands 4745 and 5626 seem to be as strong as the corresponding main bands 4737 and 5635 respectively. This adds further evidences in favour of intimate relationship of these four bands.

When turning to the relative intensities of main and isotope bands for the transitions (1,2), (2,3) and (2,1), the thing is less distinct. At first sight it is to be expected that the intensity ratio for the pairs in question will be the same for all bands of a given sequence or even for all bands of different sequences. We think, that in reality the expected constancy does not hold even within the transitions (0,1), (1,2), (2,3) and (1,0), (2,1). Especially in the stars of early subdivisions of type N the isotope bands (1,2) (2,3) seem to be fainter than they should be. But in the spectrum of Y Can. Ven. and others the intensity ratio seems to be nearly constant. However, it is to be mentioned that it is difficult to obtain a true representation of the intensity of bands when the latter overlap each other and moreover when the region in question is highly rich in atomic lines. Particularly we must remind here that 5626 and probably other bands are blended.

The isotope bands of the sequences +2 and —2. We have tried also to find the isotope bands of the sequence —2. As it is known the main bands of this sequence are rather well represented in the spectra of N type stars. However, the identification here is more difficult owing to the considerable decrease of the dispersion and to the increasing effect of blends. Keeping all this in mind, we must be especially cautious when searching the isotopic effect for the sequence —2.

The intensity of the main Swan bands in the spectra of type N varies considerably in different stars. We were able to measure the main and isotope bands of the sequence under consideration only in 6 stars (Table 1). The satisfactory agreement with theory seems to be, however, but little convincing since the bands are mostly not outstanding. But in several stars, where the sequences +1 and —1 are especially strong, the main and the suggested isotope bands are so prominent that the first glance reveals them to be intimately related. This is well seen in the spectrum of RY Drac. and Y Can. Ven. (Photo 2). On the effect of blends in these stars we can approximately judge in the following manner. When comparing the spectra of type N and M within the region 4300—4450, we recognized that the atomic lines of Fe, V, Cr, a. o. do not differ sensibly in both classes. Assuming this to be true also for the red region, we could obtain from the comparison of spectra of type N and early subclasses of M a rough representation of the blending effect for the individual bands of the sequence—2. We found in this way that at least in the case of N type stars with strong Swan bands the suggested isotope bands 6168 (0,2), 6101 (1,3) and partly 6041 (2,4) can be considered as being to a considerable extent free from the blending effect. The latter is strong only for the first main band 6191, overlapping with the cyanogen band 6194 (3,0) of the red sequence.

I think that Photo 2 does not leave any doubt that we are dealing here with isotopic duplicity of bands. In some respect the sequence—2 is even more suitable for the study of isotopic effect than the sequences—1 and+1: this is due to the absence of overlapping of bands owing to the greater value of isotopic shift (Table 1). A safe conclusion may be derived that the yellow-red sequence—2 contributes no less serious evidences in favour of the presence of isotope bands than the two other sequences+1 and—1 in the green-yellow and blue region of spectrum. But considering all three sequences together we obtain quite convincing proofs of the abundant presence of the heavy molecules $C^{13}C^{12}$.

It seems to be desirable to consider other sequences besides those mentioned above. The sole sequence which at first sight appears to be suitable for this purpose is+2. Theoretically the bands of this sequence at T=1300° must be nearly as strong as those of the sequence—1. However, these bands in reality seem to be fainter. On the other hand, we have in this region numerous strong atomic lines blending with the bands. Moreover, it is highly difficult to obtain at the dispersion about 30—40 A per mm this region of spectrum even for the brightest N type stars. Therefore the sequence in question is hardly suitable for the study of isotopic effect.

In order to get a rough representation of the blending effect we have again compared the violet portion of the spectrum of 19 Piscium and ο Ceti. The temperatures of these stars do not differ probably too much, and in addition ο Ceti is but little affected here by TiO. In this way it was found that the metallic lines do not differ too much in the spectra of stars. In the light of this result it seems rather strange that even the blend 4383 (mostly Fe in ο Ceti and Fe+Swan band (2,0) in 19 Pisc.) is more or less of the same strength in these stars. Basing on this comparison one cannot affirm the presence of any strong molecular band at 4383 in the spectrum of 19 Pisc. The second Swan band 4371 (3,1) must be blended with the low temperature line of Cr 4371.3. Notwithstanding this we have here a rather faint line or blend which is, however, still fainter in the spectrum of ο Ceti. It may be suggested that the bands of sequence+2 are at least not much stronger than those of the sequence−2 and one may conclude that the main bands of this sequence are not prominent. In such a case we can hardly hope to find the corresponding isotope bands, especially when the blending is rather strong. For instance, the first isotope band 4395 (2,0) must coincide with the rather strong low temperature line of V 4395.3. This blend or line is nearly of the same strength in the spectra of 19 Pisc. and ο Ceti, and we are not able to judge, whether the isotope band (2,0) is present in the spectrum of 19 Pisc. or not. Still more hopeless is to search the second isotope band 4384 (3,1) which must be blended with the first Swan band (2,0) and the very strong iron line 4383.5. All this shows that the sequence +2 is really not suitable for the discovery of isotope C^{13}. In any case one may say that the data concerning this sequence do not bring any evidences against the hypothesis of the abundant presence of isotope C^{13}.

The isotope C^{13} and the bands of cyanogen. If the relative concentration of heavy molecules $C^{13}C^{12}$ in N type stars is really so high as it follows from the observed intensity of the bands of the three sequences +1, −1 and −2, one must expect to find besides the usual molecules $C^{12}N^{14}$ also the heavy molecules $C^{13}N^{14}$. Unfortunately, the violet system of CN is not suitable for the study of isotope effect in N type stars. Thus, the sequence O lies almost in the inaccessible region for N stars, and moreover the effect in question is very small here. As to the following sequence−1, things are as follows. The first main band 4217.2 (red edge) must be blended with the very strong resonance line Sr II 4215.5 which itself lies on the wing of the still stronger resonance line of CaI 4226. Therefore, it seems to be impossible to judge which share of the observed intensity falls on Sr II and CN (0,1). In the spectra of M type stars the resonance lines Sr II 4215 and Sr II 4077 (belonging to the same multiplet) differ probably but little in intensity. The same holds approximately for the spectrum of 19 Pisc. and therefore 4215 is probably but little affected by the presence of $C^{12}N^{14}$. It might be supposed that in the spectrum of 19 Pisc. are present the second 4198 (1,2) and the third 4182 (2,3) band of CN since here are really seen rather appreciable lines or sharp bands. But when comparing the spectrum of 19 Pisc. with that of α Orionis we find also in the latter corresponding lines or blends of moderate intensity. All this is in agreement with the current opinion that in the spectra of N type stars the violet bands of CN are at least not outstanding. According to Shane[16] and others the sequence−2 behaves in a different manner. This seems to be strange. But independently on this or another point of view with respect to this difference, we must consider this sequence also as but little suitable for our purpose: by chance almost all main bands of $C^{12}N^{14}$ are blended with strong low temperature lines. Thus the first band 4607.4 (0,2) must be blended with the very strong resonance line of Sr 4607.3, the second band 4579.3 (1,3) with low temperature lines 4577.2 (V), 4580.1 (Cr), 4580.4 (V), and the third one 4554 (2,4) with the strong resonance line 4554.0 (Ba II) and some lines of known multiplets of Ti. In fact, in the spectra of M type stars, we find corresponding lines not too much differing in intensity from those in the spectrum of 19 Pisc. Under these circumstances it is hardly reasonable to search the bands due to heavy molecules, especially having in view the high richness of this region of the spectrum by atomic lines.

As concerns the red system of cyanogen we have more trustworthy data with respect to the presence of $C^{12}N^{14}$. Merrill[17], when comparing the spectra of Y Can. Ven. and U Hydrae with that of the carbon-tube furnace obtained by King[18], found a considerable number of coincidences of details ascribed by King to cyanogen. The identifications are generally difficult, but series of triple bands may be indicated in the red and infra-red region. Asundy and Ryde[19] gave the following vibrational formula:

$$\nu\ (\text{head}) = 10937 + (1782\,n' - 13.5\,n'^2) - (2055\,n'' - 13.3\,n''^2)$$

It is not certain whether the band at 9143 is the (0,0) band. The latter may be higher up in the infra-red beyond the range of sensitivity of the photographic plates now available, and therefore the computed isotopic shift for all bands is to some extent conjectural. Further, there is a disagreement between the data of King and Merill, amounting to few angströms, and on the other hand, the computed wave-lengths sensibly differ from the observed ones. At last, the formula relates to single bands and the observations to the triple ones. Therefore the difficulties for the discovery of isotope bands are great. For the study of the isotopic effect we have obtained the spectrum of Y Can. Ven. in the near infra-red with neon as comparison spectrum. Certainly at the small dispersion used (about 180 A per mm at 7100) no much hope remains for correct identification. On our plates we have only the bands (2,0), (3,1) and (4,2) and for them the computed shift is nearly 33, 30.5 and 28 A respectively. The examination of the spectrograms leads to the conclusion, that though on the places predicted by theory we have something that can be perhaps identified with the bands of the heavy molecule $C^{13}N^{14}$, but because of the small dispersion used and the blending effect (partly due to telluric bands B and a) the identification seems to be rather uncertain. Both systems of cyanogen, the violet and the far red one give no evidences neither for nor against the theory of isotopic effect, so clearly demonstrated by the molecules of carbon. One may say even more: the bands of the heavy molecule $C^{13}N^{14}$ can not be surely discovered at the dispersion used, if even they would exist. Were the isotopic bands of cyanogen even not found at all, this should not be considered yet as a disproof of the existence of isotope C^{13}. In fact, as we shall see later, the intensity of isotope bands shows often sensible deviations from that predicted by theory. It may be also mentioned that in the spectra of comets there is manifested in emission the $C^{13}C^{12}$ band 4745 (sometimes not too faint) and perhaps even the $C^{13}C^{13}$ band (1,0)[20]. However, the revision of wave-lengths in cometary spectra did not allow to identify the isotope bands $C^{13}N^{14}$ (0,1) and (0,2).

The $C^{13}C^{13}$ bands. On the basis of elementary statistics it is easy to show, that if we have two isotopes A and B, the relative concentration of possible molecules AA, AB and BB (in our case $C^{12}C^{12}$, $C^{13}C^{12}$ and $C^{13}C^{13}$) will be in the ratio $r^2 : 2r : 1$, where $r = C^{12}/C^{13}$. For instance $C^{12}C^{12} : C^{13}C^{12} : C^{13}C^{13} = 10 : 20 : 10$ when $r = 1$ and

10 : 2 : 0.1, when r = 10. At the moderate dispersion used in stellar spectroscopy, when the individual lines of a band are not resolved, these numbers must represent with some approximation the intensities of heads of the bands in emission. However, the picture must be much more complicated in stellar atmospheres for the bands in absorption. We may, perhaps, apply to the individual lines the known function characterizing the change of intensity of the line with the increasing number of atoms («the curve of growth»). For the strong lines of the head the total absorption may be assumed to be proportional to $\sqrt{Nf}$. It may be also thought that at the very high clustering of lines at the edge of the band the same relation holds for the band as a whole. In order to test this the following observation was secured. A large series of the spectrum of the Sun was obtained within very wide limits of zenith distance (28°—75°), and for them the total absorption for the head of the telluric band B was measured. Since the optical depth is proportional to sec*z*, we could obtain from these measurements a fair representation of the correlation between the total absorption for the head of the band B and the relative number of oxygen molecules $O^{16}O^{16}$. We have recognized in such a manner, that with some approximation one may assume a proportionality to the square root of the number of molecules (in reality somewhat slower). Since there is an analogy between the molecules of $O^{16}O^{16}$ and $C^{12}C^{12}$, one may probably apply this correlation also to the Swan bands. At last it is of interest to know this correlation even with very rough approximation.

As it was already emphasized it is very difficult, if possible at all, to measure the total absorption of the bands in question. But from approximate measurements of the pairs 4745/4737, 5626/5635 and partly of other ones (Table 1) we have found that the intensity ratio for the few stars of our list varies nearly within the limits from 1.0 to 0.3. It follows then from the above considerations that in different stars the relative abundance of heavy molecules $C^{13}C^{12}$ varies from 1.0 to 0.1, and the relative abundance of isotope C^{13} from $^1/_2$ to 1/20. This result is hardly more incorrect than by the factor 2.

It is evident that the intensity of the bands due to the molecule $C^{13}C^{13}$ is a very sensitive criterion of the relative abundance of isotope C^{13}. However, the usual faintness of the isotope bands $C^{13}C^{13}$, especially if they are overlapped by other bands, highly hinders the study of the isotopic effect. The band $C^{13}C^{13}$ 4752 (1,0), which is situated outside the band $C^{12}C^{12}$ 4737 (1,0) and $C^{13}C^{12}$ 4745 (1,0) is an exception. For the majority of stars this third component is generally faint and in addition in some stars closely to it a line or blend is observed. Out of the few stars of our list the band 4752 may be surely identified with $C^{13}C^{13}$ only for Y Can. Ven. and perhaps for WZ Cassiop. Just for these two stars the component 4745 ($C^{13}C^{12}$) is nearly as strong as the main band 4737. This seems to be an argument in favour of their common origin. However, in the spectra of UU Aurigae and U Hydrae the band 4745 is also relatively strong but 4752 remains faint. For the majority of stars the measured position 4752 is in good agreement with the computed wave-length for $C^{13}C^{13}$ (Table 1), but the intensity relation seems to be anomalous. Having in view the faintness of this band and the possible effect of blends, the identification with $C^{13}C^{13}$ for the majority of stars is not certain. Evidently it is almost hopeless in this respect to identify the second and the third band (2,1) and (3,2) as they can hardly be discerned on the very faint background due to the overlapping of more strong Swan bands (1,0), (2,1), (3,2).

In Table 1 are given the wave-lengths of the isotope bands (0,1), (1,2) and (2,3) of the yellow sequence due to $C^{13}C^{13}$. For the majority of stars of our list the band $C^{13}C^{13}$ (0,1) is not brought out. It is true that for these stars at the distance about—4 A from the theoretical position there is observed a band or blend 5612.4. This divergence cannot be ascribed to the effect of blends or any photographic effect. With some confidence the isotope band (0,1) due to $C^{13}C^{13}$ is observed in the spectrum of Y Can. Ven. and may be in 155 b Schjel. and U Hydrae. The former is just the star in whose spectrum the band (1,0) $C^{13}C^{13}$ of the blue sequence, as we have seen above, is very strong. We may also mention that in the list of wave—lengths by Hale, Ellerman and Parkhurst[21] there are measured details in the spectrum of Y Can. Ven. and U Hydrae which can be identified with the theoretical wave-lengths for $C^{13}C^{13}$ (0,1).

It is of importance also to note that in the spectrum of Y Can. Ven. and may be of some other stars are also observed three components $C^{12}C^{12}$, $C^{13}C^{12}$ and $C^{13}C^{13}$ for the transition (1,2) in good argeement with theory (Table 1). The intensity ratio of the components for the transitions (1,2) and (0,1) is nearly the same, and we think that these six bands are intimately connected. As to the third group of bands (2,3) we may note a detail near to the theoretical wave-length for $C^{13}C^{13}$. But having in view the faintness of this band and the blending effect it is hardly possible to identify it surely with $C^{13}C^{13}$ even for Y Can. Ven.

The following summary may be made with regard to the difficult question on the presence of the molecule $C^{13}C^{13}$. For Y Can. Ven. and probably 155 b Schjel. we have serious arguments in favour of the presence of bands (0,1), (1,2) and (1,0). For other transitions the bands could not be manifested if even they would exist in view of their faintness and blending-overlapping effect. In other stars of our list we find at the distance about—4 A from the computed position for (0,1) a blend or a band which cannot, however, be identified with $C^{13}C^{13}$. As to the sequence+1 we find in many stars a faint blend or band 4752.9 nearly coinciding with the theoretical wave-length. It is strong only in Y Can. Ven. and can be more surely identified there.

Intensity of isotope bands and the relative abundance of C^{12} and C^{13}. The question on the intensities of the isotope bands was partly considered in this paper. Here is given the further discussion. It was already mentioned that the relative intensity of the bands of the heavy molecule $C^{13}C^{12}$ seems to be anomalous in some cases. Partly this may be due to the blending or overlapping effect. The anomaly seems to be still more pronounced in the bands due to $C^{13}C^{13}$. Disregarding some peculiar anomalies in individual stars (for instance in WZ Cassiop.) we must indicate that the bands due to the heavy molecule $C^{13}C^{13}$ (0,1) and (1,0) seem to be distinctly fainter than this follows from the elementary statistics. It cannot be properly discerned, whether the corresponding bands due to $C^{13}C^{12}$ are anomalously strong or those due to $C^{13}C^{13}$ are anomalously faint. Out of the few stars of our list the agreement with the theoretical intensity ratio is observed only in the spectrum of Y Can. Ven. and may be in that of 155 b Schjel. However, there is no disharmony in the behaviour of (0,1) and (1,0) when comparing the bands between them. Namely the faintness of (1,0) and the probable absence of (0,1) in the majority of the stars does not seem to be an evident contradiction since theoretically the Swan band (0,1) must be sensibly stronger than (0,1). Unfortunately in view of the difficulty of measurements we cannot give here the intensities themselves.

Perhaps the suggested anomaly may be interpreted in the terms of the «curve of growth». If the different bands consist of lines which fall on different branches of the «curve of growth» we may obtain a sensible apparent anomaly: so the difference between faint and moderate or strong bands will be strengthened as compared with that given by elementary statistics. On the contrary, the difference between two moderate or strong bands will be smoothed. However, this idea cannot be now really applied to the observations.

On the other hand, we may remember here the results of laboratory experiments by King [22] on the dependence of intensity ratio 4745 ($C^{13}C^{12}$) to 4737 ($C^{12}C^{12}$) upon the conditions of excitation: «the relative intensity of the isotope band in emission increases enormously in passing from arc to furnace or vacuum tube», the arc electrodes and furnace tube being made of the same material. This result seems to be highly surprising. But if really the relative intensity of the bands $C^{13}C^{12}$ depends on the conditions of excitation, the more this must hold probably for the still heavier molecules $C^{13}C^{13}$. In the light of these results it is not to be expected, perhaps, that the relative intensities of the bands $C^{12}C^{12}$, $C^{13}C^{12}$ and $C^{13}C^{13}$ will be in agreement with the data of elementary statistics. Evidently, further laboratory experiments in this direction are highly desirable both from the theoretical and practical point of view. In the terms of King's results the study of relative intensities of main and isotopic bands of carbon molecules will, perhaps, give a sensitive criterion for the study of the conditions of excitation in the atmospheres of N type stars. There is no doubt that the relative and absolute strength of isotope bands varies considerably from star to star (compare, for instance, the spectra of 19 Pisc. and Y Can. Ven.). But the observed data are too meagre to confront them with physical characteristics of the stars. There is only a slight indication that the relative intensity of the isotope bands is stronger in the later subclasses of N stars. At present we cannot decide whether the variation of relative intensity is due to the difference in the abundance of isotope C^{13} or to the difference in physical conditions. Having, however, in view that the physical conditions within N type stars seem to vary considerably, we cannot reject at all the second alternative, although it appears unexpected and striking. Unfortunately we are not able now to say more about this point, deserving in the light of King's laboratory results great attention.

The great strength of the Swan bands is a remarkable feature of the spectra of the N type stars. This is connected mainly with the peculiar chemical composition of the atmosphere (excess of carbon over oxygen), but there is nothing new on principle. However, the most remarkable anomaly in these stars is the great relative strength of the isotope bands, especially those due to $C^{13}C^{12}$. As we have seen above (p. 10) the relative abundance of the heavy molecules $C^{13}C^{12}$ varies within the limits from 1.0 to 0.1 in different stars. When applying here the elementary statistics, we find a very high value for the relative abundance of the isotope C^{13} (within the limits from $^1/_2$ to 1/20). This result is so surprising and mysterious, that it is necessary to examine it more in detail and to consider all possible objections, particularly those of Wurm [23]. K. Wurm suggested that the observed intensities of the bands 4737 ($C^{12}C^{12}$), 4745 ($C^{13}C^{12}$) and 4752 ($C^{13}C^{13}$) may be brought in agreement with the relative concentration $C^{13} : C^{12} = 1/400$ or at least 1/200, i. e. with a value of the same order as that observed on the earth, and therefore there is no peculiar isotope problem at all. This suggestion has so important consequences, that it is necessary to examine it in detail. Basing on Hutchisson's theory of probabilities of transitions (A), Wurm finds the intensities: ($I = c\nu^4 A^2 e^{-E_{v''}/kT}$) of the bands (1,0), (0,1) and (0,2) as follows: I = 574 for 4737, I = 87 for 5635 and I = 1 for 6191. Further, assuming $r = C^{12}/C^{13} = 5$, Wurm from the above formula $C^{12}C^{12} : C^{13}C^{12} : C^{13}C^{13} = r^2 : 2r : 1$ computes I = 230 for 4745 ($C^{13}C^{12}$) and I = 23 for 4752 ($C^{13}C^{13}$). Therefore he concludes that 4745 must be three times as strong as 5635, and 4752 must be much stronger than 6191. This conclusion, especially the last one, contradicts to the observations (at least for 19 Pisc.), and Wurm considers the value r = 5 as unreliable. On the other hand, taking King's rough laboratory estimate r = 400 Wurm finds I = 3 for 4745 and I = 3/800 for 4752. He had to his disposal no original spectra but only their reproductions in Publ. Yerkes Observatory 11, 1903. Considering that in the spectrum of 19 Pics. the band 6191 (0,2) is well visible (theoretical intensity I = 1), 4752 ($C^{13}C^{13}$) not perceptible at all and 4745 ($C^{13}C^{12}$) is sensibly stronger than 6191, Wurm thinks that these observed facts may be generally conciliated even with r = 400.

But these reasonings seem to me unsounded. 1) The theory perhaps succeeds more or less satisfactorily with the computation of intensities within one sequence, and even this is properly not proved. But it is quite unsafe to base on the computed intensities of the bands belonging to distant sequences. 2) Assuming together with Wurm I = 3 for 4745 and I = 574 for 4737 we encounter with a striking contradiction to the observed facts: in any star of type N and especially such as Y Can. Ven., WZ Cassiop., U Hydrae, UU Aurigae, the intensity of 4745 is not much lower than that of 4737 and in some cases is near to be equal. The same holds for the pairs 5635—5626 (0,1), 6191—6168 (0,2) and may be for other ones as it is clearly seen on Photo 1—2. For the four stars under consideration r must be less than 5 and even may be less than 3. 3) Instead of the complicated procedure for the comparison of the observed and theoretical intensities, selected by Wurm, a more direct way may be recommended, namely to use in each case the theoretical intensities only within one sequence. So we have from Wurm's paper for T = 1500° the theoretical intensities 574 : 339 : 193 for the main bands (1,0), (2,1), (3,2) of the sequence +1 and 86 : 32 : 8 for the main bands (0,1) (1,2) (2,3) of the sequence —1. It may be assumed that in emission these numbers within one sequence are proportional to the numbers of molecules participating in the corresponding transitions. In such case an interpolation within one sequence must give approximately the relative numbers of the heavy molecules responsible for the corresponding isotope band. The measurements are very difficult mainly because of the lowering of the continuous background in this region as a result of the overlapping of bands. The last effect is especially great for the sequence +1. But even for the sequence — 1 the gap in the continuous background is so considerable, that the measurements of intensities could be made only in a few cases. In this way we have found the intensity ratio 5626 : 5635 to be equal to 0.5, 0.7 and 0.7 for 19 Pisc., 318 Birm and RS Cygni respectively.

The measured total absorptions are corrected for the effect of the lowering of the continuous background. We used here the theory developed by Thackeray for the case of lines lying in the wings of another wide line [24]. There are several reasons diminishing the accuracy of the above results, one of which is the strong dependence of the relative intensities of the main bands serving as standards on the adopted temperature (1500°). A glance at Photo 1 and 2 shows that the intensity of the isotope bands (0,1), (0,2) and (1,0) due to $C^{13}C^{12}$ lies between that of the first and the second bands of the corresponding sequence and therefore the relative abundance of the heavy molecules $C^{13}C^{12}$ is of the order of 0.5, the unit being the abundance of the molecules $C^{12}C^{12}$.

There is some reason to suggest that the relative intensity of the isotope bands is greater in the later subclasses of type N, where the lowering of the continuous background is more considerable. Since these stars have not been measured, the above results do not characterize the maximum value of the ratio $C^{13}C^{12} : C^{12}C^{12}$. It is of interest to note that this method leads to the value $C^{13}C^{12} : C^{12}C^{12}$ of the same order as that found by another method (p. 12).

It may be thought that the great relative intensity of the isotope bands 4745 (1,0), 5626 (0,1), 6168 (0,2) a. o. is due to some kind of «saturation» effect as a result of great strength of the main bands. However, this is overthrown by the fact that in the spectra of several stars, for instance in WZ Cassiop., the main and isotope bands 4737—4745 and 5635—5626 are of moderate intensity, but yet the relative intensity of the secondaries is great. All this shows that the observed intensity of isotope bands due to $C^{13}C^{12}$ can by no means be reconciled with the value of the relative concentration 1/400 or even 1/70 for the isotope C^{13}.

If the great relative abundance of $C^{13}C^{12}$ is due to the high relative abundance of C^{13} (at present we have no reason to suppose another cause), it is impossible to escape the conclusion, however, bold and radical it might appear, that the relative concentration of the isotope C^{13} is of the order 0.05—0.5 in different stars, i. e. it is much higher as compared with that observed on the earth.

It might be also thought, that the excess of carbon over oxygen in N type stars favours in any way the formation of heavy molecules of carbon. From this point of view it is of interest to clear up whether in the uniquely known hot carbon star R Cor. Bor., containing according to Berman 67% of carbon, there are isotope bands in addition to the Swan main ones. The equivalent widths of bands 4737 and 4715 on our spectrograms of R Cor. Bor. are 0.40 A and 0.30 A respectively, and notwithstanding that there are found no traces of the isotope bands 4745 and 4723. The bands of the sequence −1 are too faint to be measured. Berman [25] gives for 4737 and 4715 the equivalent width 0.45 and 0.25 and also notes the absence of 4745. Therefore the cause of the phenomenon in question lies not in the great relative concentration of carbon, or at least not only in it. We do not know whether the low temperature of N type stars is a factor favouring in any way the formation of heavy molecules. In connection with this it may be mentioned that the temperature of several R type stars is probably higher and notwithstanding that the isotope bands are relatively strong.

It would be of interest to find from spectroscopic measurements the ratio C^{12}/C^{13} in stars of the main sequence, particulatly for the Sun. At $T = 6000^\circ$ the number of molecules $C^{12}C^{12}$ must be very small, and the intensity of the lines or bands even for the strongest band 5165 (0,0) are −2, −3 (in units of Rowland's scale). Having in view that the corresponding lines due to $C^{13}C^{12}$ must be probably much fainter and that the lines with intensity −2, −3 are in overwhelming majority unidentified, one cannot hope to manifest the isotope C^{13} in the Sun. We may try only to apply here the formulas of Russell and Bowen [25] for the computation of the number of chance coincidences $p = 1 - \left(1 - \frac{2x}{X}\right)^{M}$. Such an attempt was made by us without success with regard to the band 5165 (using the data of the Revision of Rowland's Preliminary Tables).

Perhaps, this problem appears not so hopeless with regard to the molecule CN. The main individual lines of bands have Rowland's intensity +2, +1. Were the corresponding lines of the heavy molecule $C^{13}N^{14}$ 5—10 times fainter, they might be brought out in the «Revision». A careful comparison of the laboratory data and those taken from the «Revision» leads to the conclusion that nearly for one half of the lines under consideration the isotopic components are not seen at all, and for the other half the suggested isotopic lines are mostly blended with more strong atomic lines. For this reason, if the molecules $C^{13}N^{14}$ are present, their concentration is much smaller than that of $C^{12}N^{14}$, in any case probably less than 0.1.

As it was recently brought out mainly thanks to Bethe's work [27], the cyclical reaction $C^{12}C^{13}N^{13}N^{14}N^{15}O^{15}$ is the most important source of energy in the main sequence of stars, the carbon and nytrogen serving merely as catalysts for the combination of four protons and two electrons into an α—particle. In this reaction in case of statistical equilibrium the concentration of each nucleus is proportional to its lifetime. Since C^{13} captures slow protons according to experimental data about 70 times as easily as C^{12}, the latter should be 70 times as abundant. The observed concentration of the terrestrial isotope C^{13} about 1/90, differing not too much from the theoretical value, seems to be therefore not accidental. In this connection the above mentioned high relative abundance of C^{13} in the stars of type N seems to test the impossibility here of the cyclical reaction in question, provided that the concentration $C^{13}C^{12}$ is the same in the inner and outer shells of the star. As it is known from other theoretical considerations the reaction in question cannot be a source of stellar energy in red giants. It is of interest to note here that at least with regard to N type stars we find spectroscopic evidence in favour of the fact that such a reaction is not realized here.

It is also perhaps worthy to remember that the isotope C^{13} occurs in great relative concentration in the stars of type N and R, which are mostly variable in brightness.

Summary and conclusions. The paper is dealing with the problem of occurrence of isotopes of carbon in the spectra of N type stars. In order to strengthen the observational basis the search for the new isotope bands has been performed in different sequences of Swan and cyanogen bands.

The isotopic effect was manifested for the first time in the sequences −1 and −2: six new isotope bands (0,1), (1,2), (2,3), (0,2), (1,3), (2,4) due to the heavy molecule $C^{13}C^{12}$ have been found (Photo 1 and 2). The identification for (2,3) and (2,4) is more doubtful. In addition to the known isotope band (1,0) of the sequence +1 there was found a second one (2,1).

The observed doubling of the band (0,1) is not due to the effect of overlapping of the branches P and R (Fig. 1).

It is shown that the sequence +2 is not suitable for the discovery of isotope C^{13}: this is due to the great blending effect and partly to the fact that the bands themselves are not outstanding. The same relates generally to the sequences −1 and −2 of the violet system of cyanogen and to the sequence +2 of the red one. In the latter case the too small dispersion used and the composite character of bands hinders the sure identification. But these sequences at least do not bring out any evidences against the hypothesis of the abundant presence of the isotope C^{13}.

The intensity ratio of the pairs of bands $\frac{C^{12}C^{12}(1,0)}{C^{13}C^{12}(1,0)}, \frac{C^{12}C^{12}\ (0,1)}{C^{13}C^{12}\ (0,1)}, \frac{C^{12}C^{12}\ (0,2)}{C^{13}C^{12}\ (0,2)}$

and partly of other ones is nearly equal in the spectrum of a given star. For the few stars of our observing list the intensity ratio varies from star to star within the limits 0.9—2.5. The observed deviations of the intensity ratio from the mean value for individual stars manifest some tendency to occur simultaneously for all pairs. This seems to be an additional argument in favour of the common origin of the bands under consideration.

For the second and third pair $\frac{C^{12}C^{13}}{C^{13}C^{12}}$ of different sequences an anomaly is found: the isotope bands are fainter than it is predicted by the theory.

In view of the blending effect and the lowering of the continuous background the study of $C^{13}C^{13}$ bands is much more difficult. We have found arguments in favour of the presence of the isotope bands (0,1), (1,2), (1,0) due to $C^{13}C^{13}$ only for Y Can. Ven. and may be for one or two other stars. The former two bands are observed for the first time. For other stars of our list the observed position for (0,1) is too far from the theoretical one to be identified with $C^{13}C^{13}$. As to the sequence +1 there is observed a good agreement with theory for the $C^{13}C^{13}$ band (1,0), though the blending effect seems to be present. An anomaly may be indicated: the $C^{13}C^{13}$ bands (0,1) and (1,0) are clearly fainter than it follows from the elementary statistics (except Y Can. Ven.). But there is generally no evident disagreement between the intensity relation for the bands of the sequences +1 and −1.

It is noticed that the intensity anomalies observed in N type stars may be interpreted partly in terms of the «curve of growth» and partly in the light of King's laboratory results.

The observations give in my opinion convincing evidences in favour of the existence of heavy molecules $C^{13}C^{12}$ in great concentration. The relative abundance of heavy molecules $C^{13}C^{12}$ was found to vary from star to star within the limits 0.1—1.0; in the terms of elementary statistics this corresponds to the variation of the abundance of isotope C^{13} within limits 0.05—0.50.

It is shown that the criticism of the hypothesis of the high relative concentration of $C^{13}C^{12}$ and C^{13} rests upon unsounded observational and theoretical basis.

In the spectrum of the uniquely known hot carbon star (R Cor. Bor.) there is no trace of isotope bands. An attempt to find the isotopic effect in the solar spectrum also proved to be unsuccessful.

It is noticed that spectroscopic observations of red giants of type N testify that Bethe's cyclical reaction is not realized in these stars.

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КОЛОР-ИНДЕКСЫ 1758 ЗВЕЗД В ПЯТИ ПЛОЩАДКАХ КАРТЕYN'а, РАСПОЛОЖЕННЫХ В ГАЛАКТИЧЕСКОЙ ПЛОСКОСТИ

Е. К. ХАРАДЗЕ

Важность исследования вопроса о междузвездном поглощении света звезд с точки зрения современной звездной астрономии, а именно для уточнения наших представлений о форме и размерах Галактики, в настоящее время общепризнана. Этим обстоятельством объясняется тот факт, что усилия целого ряда обсерваторий и отдельных астрономов ныне направлены ко всестороннему исследованию космического поглощения; при этом астрономы привлекают для этой цели разнообразные методы, аппаратуру и средства, подходя к изучению вопроса с разных сторон.

В непосредственной связи с проблемой космического поглощения стоит и задача исследования селективного, т. е. избирательного поглощения света в разных направлениях.

Основа исследования селективного поглощения проста; как известно, если частицы космической пыли, производящие рассеяние света, имеют в диаметре менее 0.1 μ, поглощение зависит от длины волны, причем оно больше для более коротких длин волн, и потому звезды, находящиеся по ту сторону массы подобных частиц, будут казаться земному наблюдателю более красными, чем они есть в действительности. В связи с этим показатели цвета звезд, видимых сквозь такую среду, будут больше, чем это соответствует их спектральным классам. Избыток наблюдаемого колор-индекса по отношению к нормальному значению, т. е. колор-эксцесс, будет тем больше, чем интенсивнее поглощение или чем больше расстояние, проходимое лучом света в рассеивающей среде.

Следовательно, для оценки селективного поглощения необходимо определять показатели цвета звезд и сравнивать наблюдаемые значения с теми, которые соответствуют их спектральным классам, определяемым по интенсивности спектральных линий, т. е.—на основе спектральной классификации. Если, при этом, объекты, для которых определяются колор-эксцессы, будут расположены в разных участках неба, то, анализируя данные о колор-эксцессах принципиально не трудно построить заключения о форме, размерах и распределении поглощающей среды, распространенной в Галактике, а также и о свойствах частиц этой среды.

Насколько известно автору, подобные работы не предпринимались до сих пор систематически и планомерно и с охватом достаточно большого количества участков неба.