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THE MOTIONS OF THE B STARS[1]

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THE radial motions of the B type stars have been discussed by Frost and Adams, Campbell, Kapteyn, von Pahlen and Freundlich and by many others. Frost and Adams, from the radial velocities of twenty B type stars, were the first to direct attention to and Campbell, from much greater observational material, to confirm the results of these early observations, that the peculiar radial velocities, the velocities remaining after the component of the solar motion was removed or the actual velocities with respect to the stellar system, were much smaller for the B stars than any other spectral class, and further, that there was a large excess of velocities of recession, positive velocities, on the average nearly 5 km per sec., as if the system of B stars was expanding with respect to the sun.

This K term, as Campbell called it, which in his final determination had a value of +4.9 km per sec. and which was practically non-existent in other spectral types than B, caused considerable speculation. Attempts to explain it as due to a personal equation in the measurement of the broad-lined B type spectra, to errors in wave-length or to a red displacement of the effective center of absorption produced by some physical cause could not be made to account for more than a small part of the 5 km observed. The Einstein redward shift of the spectral lines of massive stars was later brought forward as a cause of this mysterious effect but on no probable assumption of mass and density could the displacement thus produced exceed a fraction of a kilometer.

A new departure in the explanation of this mysterious K term appeared a few months ago in the *Potsdam Publications* in a paper by von Pahlen and Freundlich who claim that it represents a real motion

[1] Address of the retiring vice-president for Section D—Astronomy, American Association for the Advancement of Science, Des Moines, Iowa, December 31, 1929.

of the B stars and is produced by an orbital motion of the stars around a very massive center, the center of the stellar system. On their hypothesis these orbits are very eccentric, $e = 0.9$ or so, and the sun and the cluster of B stars have just passed the apogalactic point, the point most distant from the center. As the orbital velocity will increase as the stars approach the center of the galaxy, the B stars preceding the sun will be moving faster and those following slower than the sun, thus giving an apparent expansion, a K term. They were thus able to explain not only the distribution of the then known residual velocities of the B stars but also other systematic motions of the stars in general, but this could be done only by rather special and somewhat artificial assumptions.

Objections may be urged to several of the hypotheses and methods used by von Pahlen and Freundlich, but this is scarcely necessary as the introduction of additional material, the radial velocities of about 450 fainter B stars obtained at the Victoria Observatory, so changes the nature of the observational data on which their investigation was based as to require a complete revision of the theory. As will be seen later, the motions of the B stars are well and simply explained by a general rotation of the stellar system around a massive and distant center, the orbits of the individual stars being nearly circular instead of highly eccentric as in von Pahlen and Freundlich's investigation.

The material for the present discussion of the motions of the B0 to B5 stars, to which it has been limited, as the classes B8 and B9 are generally taken as belonging to A type stars, has been gradually accumulating at Victoria since 1924 in the determination of the radial velocities of all B0 to B5 stars brighter than 7.5 visual magnitude and north of $-11°$ declination, by Mr. J. A. Pearce and the writer. There were about 450 stars in this program, which with those previously determined gave the radial velocities of 815 B0 to B5 stars, nearly 500 more than were available to Campbell or von Pahlen and Freundlich. These 815 radial velocities or rather the 815 residual velocities, the velocities after removal of the component of the solar motion, the velocities with respect to the stellar system, were analyzed with particular reference to the theory of a rotation of the galactic system as introduced by Lindblad and further developed by Oort and the writer.

This theory assumes that the great galactic system is in practically circular rotation around a very distant and massive center supposed to coincide with the center of the globular cluster system at galactic longitude 325°. If, as seems likely from analogy with the spiral nebula, there is a condensation of the matter or stars towards the center, the law of force will approach that of the inverse square, the stars nearer the center will revolve more quickly than those farther out, somewhat similar to the solar system where the inner planets move much more quickly than the outer. In such a case, it is obvious there would be a relative motion of the stars nearer to or farther from the center with respect to the sun, or a rotation of the galaxy could be measured.

Oort analyzed the consequences of such a rotation and showed that the residual velocities were proportional to the distance from the sun and varied with the sine of twice the angle between the star and the direction to the center. Expressed mathematically, all positions being referred to galactic coordinates:

$\bar{\varrho} = K + \bar{r}A \sin 2(\bar{l}-l_0) \cos^2 \bar{b}$, where

ϱ = Mean residual velocity, the velocity with solar motion removed

$\bar{l}$ = Mean galactic longitude

$\bar{b}$ = Mean galactic latitude. All these barred terms refer to the average of a small group of stars, this grouping being necessary on account of the peculiar or random motions of individual stars.

K = Mean residual velocity with regard to sign

$\bar{r}$ = Average distance of the whole group of stars

A = Rotational term, about 1 km per sec. for stars about 60 parsecs, 200 light years away

l_0 = Direction to the center of rotation, generally taken as galactic longitude 325°, the direction of the center of the system of globular clusters.

Using this relation and the method of least squares, Oort showed that the motions of the more distant stars were very similar to those that would be produced by such a rotation of the galaxy. This was further confirmed by an analysis of the motions of part of the B stars discussed in the present paper which was presented by the writer to the Royal Astronomical Society two years ago. The galactic rotation is still more strongly confirmed by the investigations of the radial motions of the 815 B0 to B5 stars used in this paper, and is specially marked in the most distant stars of the list where, as will be seen later, the K term disappears and the motions follow almost exactly the double wave swing produced by a galactic rotation. In a paper shortly to appear in *Monthly Notices,* the velocities of the most distant stars, and particularly the velocities of the intervening diffuse matter in the stellar system, as determined from the "interstellar" H and K lines in the spectra of these stars, show this rotational effect so distinctly and certainly as to leave no doubt of its objective reality.

The presence of this systematic effect in the radial motions of the B type stars makes it necessary, before we can speak intelligently about a residual velocity, a K term, to remove this double wave rotational term from the radial velocities in addition to the usual single wave solar motion which was the only one known and allowed for by Campbell. It is only when all known systematic motions of the stars are removed from the radial velocities that the true residual velocity, the real K term, can be obtained, and that any explanation of this mysterious effect can be final. Consequently, in order to find the real K term for the B type stars, the 815 observed radial velocities may be either analyzed simultaneously for the solar motion, the galactic rotation and the K term or preferably, as the stars are unsuitably distributed for the accurate determination of the solar motion, the component of the usual solar motion may first be removed and then the remaining 815 residual velocities analyzed for the galactic rotation and the K term.

It seems evident, however, before proceeding with the solution, as the rotational term is directly proportional to the distance from the sun and varies with the direction or longitude, that it will be necessary to divide the stars into groups at different distances and then further subdivide into smaller groups in galactic longitude. It has long been known that the B0 to B2 stars are considerably more luminous and hence more distant than the B3 and B5 stars, thus making two main distance divisions, containing 185 B0 to B2 and 630 B3 to B5 stars respectively, which should be separately considered. Each of these divisions was arranged in three groups according to apparent magnitude and hence, assuming small dispersion in absolute magnitude, according to distance. The first group contains all stars, 390 in number, brighter than 5.5 visual magnitude, and includes practically all those available to earlier investigators. The second contains 196 stars between 5.5 and 6.5 and the third 229 stars between 6.5 and 7.5 or fainter magnitudes. Each of these six groups was subdivided into a number of subgroups, in longitude, varying from 7 to 18, as shown in Tables I, II and III, and the mean longitude and mean residual velocity were obtained for each subdivision. It is desirable to use small groups rather than individual stars in the solutions, as thereby some of the irregularities caused by the peculiar or random motions of the stars are avoided.

These six separate main groups were solved by the least squares, using the equation given above, with l_0 taken as 325°, and yielded the following values of $\bar{r}A$ and K.

TABLE I

SOLUTIONS FOR $\bar{r}A$ AND K

Mag. Intervals	Types	No. Stars	Mean Mag.	No. Long. Div.	$\bar{r}A$	K
0 to 5.5	BO to B2	93	3.95	13	+ 2.1 ± 1.6	+ 5.8 ± 1.0
	B3, B5	297	4.65	18	− 0.4 ± 0.9	+ 4.8 ± 0.6
5.5 to 6.5	BO to B2	39	6.04	7	+ 16.3 ± 1.8	+ 0.2 ± 1.2
	B3, B5	157	6.07	10	+ 2.8 ± 1.2	+ 1.4 ± 0.8
6.5 to 7.5	BO to B2	53	7.15	9	+ 13.2 ± 2.0	− 0.5 ± 1.4
	B3, B5	176	7.01	10	+ 3.6 ± 0.8	− 0.5 ± 0.6

The first five columns of Table I are self-explanatory and show graphically how the 815 stars are arranged into distance and longitude groups. The sixth column containing the values of the rotational term from the six main groups may preferably be first discussed. The $\bar{r}A$ for the two groups of brighter stars is small and practically indeterminate, owing partly to the brightness and hence the relative nearness of the stars but mainly, as will be seen later, to irregular systematic motions of certain groups of these stars. For the fainter stars, especially those of types B0 to B2, the rotational term is well defined, from 7 to 9 times the probable error, and corresponds, by the relation given previously of 1 km per sec. for stars 200 light years away, to average distances of the groups of about 3,000 light years, although for the B3, B5 stars fainter than 5.5 magnitude, the average distance is less than 1,000 light years. The smaller value of the rotational term for the faintest group of B0 to B2 stars may be ascribed partly to possible large random motions of single stars in the small groups but mainly to large dispersion in absolute magnitude so that apparent magnitudes do not necessarily represent relative distances.

That all these fainter stars show distinctly and certainly the presence of the rotational effect is at once evident when the mean observed residual velocities of the various longitude groups are compared, as in Table II, with the velocities computed from those values of $\bar{r}A$ and K obtained in the solutions and given in Table I, and below the columns in Table II. It is scarcely conceivable, especially when the possible disturbing effects of large peculiar or

TABLE II

COMPARISON OF OBSERVED AND COMPUTED VELOCITIES

B0 to B2 Stars

5.5 to 6.5 Mag.				6.5 to 7.5 Mag.			
No.	$\bar{l}$	$\bar{\rho}$(Obs.)	$\bar{\rho}'$(Comp.)	No.	$\bar{l}$	$\bar{\rho}$(Obs.)	$\bar{\rho}'$(Comp.)
1	338°	+ 7.3	+ 7.1	1	359°	+ 36.3	+ 11.7
6	32	+ 15.2	+ 11.7	6	40	+ 11.7	+ 6.2
5	48	+ 9.1	+ 3.9	6	50	+ 2.1	+ 1.9
7	77	− 12.8	− 10.0	9	69	− 5.6	− 6.6
3	134	+ 1.2	− 2.5	4	91	− 19.8	− 12.8
6	160	+ 6.6	+ 8.2	8	109	− 12.3	− 12.8
11	180	+ 12.6	+ 15.2	6	148	+ 5.5	+ 0.9
				6	168	+ 2.6	+ 8.7
				7	179	+ 6.3	+ 11.4
	$\bar{r}A = +16.3$; $K = +0.2$				$\bar{r}A = +13.2$; $K = -0.5$		
B3, B5 Stars							
15	359	+ 5.4	+ 4.0	7	55	+ 5.9	+ 3.0
24	29	+ 0.9	+ 3.6	27	22	+ 3.5	+ 2.8
25	56	− 1.8	+ 1.4	20	37	+ 2.4	+ 1.6
15	76	− 3.5	− 0.4	18	56	+ 1.9	− 0.6
16	120	+ 1.0	− 0.7	26	76	− 4.0	− 3.0
23	164	+ 6.2	+ 3.2	19	93	− 5.7	− 4.1
21	177	+ 3.1	+ 3.9	16	126	+ 0.6	− 2.8
11	208	+ 3.8	+ 3.7	13	148	− 0.8	− 0.2
5	245	+ 11.9	+ 0.5	20	167	− 2.2	+ 2.0
2	307	+ 5.1	− 0.2	10	182	+ 2.8	+ 3.0
	$\bar{r}A = +2.8$; $K = +1.4$				$\bar{r}A = +3.6$; $K = -0.5$		

random velocities on the mean residual velocities of groups with few stars is considered, that such a close agreement between observed and computed velocities can be accidental. If the double wave swing of the observed velocities from positive to negative and back again to positive is not produced by a galactic rotation it must be due to some cause which gives a systematic trend of the velocities almost exactly similar to a galactic rotation.

It is evident, therefore, that these rotational effects should be removed from the observed radial velocities in addition to the solar motion. Obviously this has been done in the solutions, and the remaining residual velocity, the true K term, is shown in the last column of Table I. Its value for the 93 B0 to B2 stars brighter than 5.5 magnitude is +5.8 km and for the corresponding 297 B3, B5 stars is +4.8 km per sec. It is therefore little different from Campbell's value of +4.9 km per sec., obtained from practically the same stars. It has, however, completely vanished, at least well within the probable errors of the determinations, for the stars fainter than 5.5 magnitude. That is to say, while the application of the galactic rotation to the residual velocities of the B stars has completely eliminated the mysterious K term from the 425 B stars fainter than 5.5 magnitude, this K term of about 5 km per sec. still persists for the 390 B stars brighter than 5.5 magnitude.

It is obvious that all the early explanations of this K term as caused by errors of measurement, errors of wave-length, displacements due to physical causes or to the Einstein shift, or the later explanation provided by the hypothesis of von Pahlen and Freundlich must fall to the ground, as it is inconceivable that these causes should not operate in exactly the same way and to the same degree for faint as for bright stars. To imagine any physical property of this uniform class of B stars which depends only on the apparent brightness or, in other words, on the distance from the sun, an insignificant member of the stellar system only about one thousandth as luminous as the B stars, is to carry anthropocentric prejudices to an absurd degree.

The explanation of the K term, therefore, must be sought in some peculiar or systematic motion of these brighter B stars, or of certain groups of these stars. It is well known that the B stars show marked clustering into groups in position and it is not unreasonable to suppose there might also be some systematic trend in the motions of these same groups. In the subdivision of the stars brighter than 5.5 magnitude into longitude groups, advantage was taken of natural separations so that these subgroups may be assumed to correspond approximately to the natural clustering of the B stars. Some information in regard to such group motions may therefore be obtained by a comparison of the observed residual velocity $\bar{\varrho}$, with the computed, ϱ', of the two groups of stars brighter than 5.5 magnitude, which is given in Table III. This comparison shows first of all no indication of the agreement so conspicuous in the fainter stars. This

stars, that rA for the bright B0 to B2 stars should be about + 6 km and for the B3, B5 about + 3 km. Further assuming the K term as half the computed values or + 3 and + 2 km respectively and again computing velocities we get the columns ϱ''. Although without objective reality, they are still useful in indicating a possible representation of the velocities and showing that the groups mainly responsible for the high K term are those between 240° and 290° longitude.

Thus the low and uncertain values of the rotational term and the high values of the K term for these brighter stars are probably due to the high systematic

TABLE III

COMPARISON OF OBSERVED AND COMPUTED VELOCITIES

Stars brighter than 5.5 Mag.

B0 to B2 Stars					B3, B5 Stars				
No.	$\bar{l}$	$\bar{\varrho}$	ϱ'	ϱ''	No.	$\bar{l}$	$\bar{\varrho}$	ϱ'	ϱ''
3	33°	+ 18.3	+ 7.0	+ 6.3	9	355°	+ 1.6	+ 4.5	+ 4.3
5	64	+ 3.3	+ 5.2	+ 1.6	7	12	0.0	+ 4.5	+ 4.4
7	87	+ 1.8	+ 4.1	− 1.9	19	32	+ 2.4	+ 4.6	+ 3.8
6	133	− 0.3	+ 5.0	+ 0.7	15	49	+ 2.0	+ 4.8	+ 2.5
7	162	+ 2.5	+ 6.9	+ 6.2	11	68	− 1.6	+ 5.0	+ 0.8
14	177	+ 6.7	+ 7.6	+ 8.2	11	93	− 0.3	+ 5.2	− 0.6
8	203	+ 11.2	+ 7.0	+ 7.8	16	117	− 1.1	+ 5.2	− 0.4
10	230	+ 9.3	+ 6.2	+ 4.1	15	136	+ 0.7	+ 4.9	+ 1.2
5	268	+ 12.3	+ 3.9	− 2.3	18	156	+ 7.2	+ 4.7	+ 2.9
10	291	+ 7.6	+ 4.0	− 2.0	20	175	+ 4.1	+ 4.5	+ 4.4
4	309	− 9.0	+ 4.7	− 0.2	12	195	+ 8.5	+ 4.5	+ 4.6
11	320	+ 5.6	+ 5.4	+ 3.0	22	212	+ 7.6	+ 4.6	+ 4.0
13	344	+ 1.3	+ 7.0	+ 6.3	21	230	+ 5.3	+ 4.5	+ 2.5
					24	249	+ 6.3	+ 5.0	+ 0.7
					25	271	+ 10.2	+ 5.2	− 0.8
					24	293	+ 7.8	+ 5.2	− 0.5
					19	315	+ 7.8	+ 5.0	+ 1.1
					9	329	+ 5.0	+ 4.8	+ 2.3
$\bar{r}A = + 2.1$; $K = + 5.8$					$\bar{r}A = - 0.4$; $K = + 4.8$				

is partly due to the relative nearness of the stars to the sun thus making the rotational term small and indeterminate, but mainly to group or cluster motions of recession of some of the southern stars.

The great preponderance of relatively large positive observed velocities beyond longitude 200°, in the southern sky, provides an obvious reason not only for the low values of $\bar{r}A$ but for the high values of K. It can be safely assumed from the agreement between observed and computed velocities for the fainter stars in Table II that there are positive rotational terms for these two groups of brighter stars also, which are masked by the distribution of the velocities. It may be assumed from the relative brightness and distance as compared with the fainter recessional velocities, probably group or cluster motions, of limited groups of the southern stars, mainly between galactic longitudes 240° and 290°. This is made more probable by the relative brightness and nearness of these stars, the B0 to B2 stars in the above longitude limits being more than a magnitude brighter than the average, with a similar though smaller difference for the B3, B5 stars.

There can be no reasonable doubt, therefore, that the mysterious K term, this positive residual velocity of 5 km per second found by Campbell for the B0 to B5 stars brighter than 5.5 visual magnitude, is due mainly to the high velocity of recession of limited groups of the brightest B stars in the sky in galactic longitudes 240° to 290° in the Vela-Lupus region.

That this high excess positive velocity appears only in these particular southern groups and is absent in the northern groups of the brightest and nearest stars, and is also completely absent in all B stars fainter than 5.5 visual magnitude, shows conclusively that the mysterious K term has no particular relation to the B type stars, is not due to any physical displacement of the spectral lines or to erroneous wavelengths and does not require the elaborate explanation of von Pahlen and Freundlich, but is probably caused entirely by an unsymmetrical distribution of the residual velocities, by a preponderance of high recessional group velocities in the Vela-Lupus region.

The average peculiar motion of the B stars, the mean residual velocity without regard to sign, after the removal of the effects due to solar motion and galactic rotation, is found to be somewhat greater than that obtained by Campbell, and varies between 9 km per second for the bright B stars to about 12 km for those fainter than the seventh magnitude. It is still considerably less than the average peculiar velocity of stars of other spectral types, and the stars of the spectral class B0–B5 may be considered as relatively slow-moving stars, as having smaller peculiar or random velocities than any other spectral class.

In conclusion, this investigation of the motions of the B0 to B5 stars has shown that their general residual velocities, the velocities with respect to the stellar system, agree very closely with those that would be produced by a rotation of the galactic system around a very distant and massive center, thus increasing the probability of such a rotation. It has further shown that the excess positive residual of about 5 km per second found by Campbell and others has entirely disappeared, when the effects of the galactic rotation have been removed, for all the B0 to B5 stars fainter than 5.5 magnitude. Although the K term still remains for the stars brighter than 5.5 visual magnitude an analysis of the residual velocities shows conclusively that this final residual of 5 kms is mainly due to the high positive group or cluster motions of the brightest and nearest B type stars in the sky in the Vela-Lupus region and is no general characteristic of the B type stars as a class. Finally, the investigation has shown that the average residual random or peculiar motions of the B0 to B5 stars varies from about 9 km for the brighter to 12 km per sec. for the fainter stars. While considerably higher than values previously deduced, the peculiar velocities of the Bs are still less than those of any other spectral class.

It gives me pleasure to acknowledge the effective collaboration of Mr. J. A. Pearce with the writer in the observation and measurement of the spectrograms and in the calculation of the results.

ORGANIC EVOLUTION[1]

ITS PROBLEMS AND PERPLEXITIES

By Dr. ALEŠ HRDLIČKA

AFTER cosmogony, the greatest phenomenon in nature is organic evolution.

There is no need any more of attempting to substantiate this great process. Natural history teems with its evidence. And this evidence is so convincing that some scores of thousands of men of science, who represent the most critical minds of the present human society, are without exception deeply convinced of its reality.

This does not mean, however, that this most comprehensive and complex subject is as yet well known in all its details, or understood. What the workers in natural sciences are deeply conscious of is the substantiality of this all-pervading phenomenon. They further feel that gradually they are learning its accomplishments, and some of its principles. But they are also deeply aware that they are still far from knowing all its details or processes and especially far from comprehending its essential causes and significance.

Let us survey briefly some at least of the dark areas of the field and some of its perplexities.

We may as well begin by trying to define evolution —and we are at once in serious difficulties.

There have been many attempts at such a definition; they have all failed. How even now they fail may be appreciated from two of the latest attempts.

For H. S. Jennings (1928), "The doctrine of organic evolution is the doctrine that animals and plants are slowly transforming, producing new kinds"; while for David Starr Jordan (1928), evolution is merely "the universal process of orderly change." How inadequate are these expressions, how partial; yet it seems impossible for the present to do much better.

The fact is that the totality of the great subject is not yet graspable. Every worker sees it mainly from his angle, while the phenomenon as a whole is as comprehensive as that of life itself—the two may even be synonymous, or one the discharge of the other.

An approach towards the understanding of organic evolution lies necessarily in ever-progressing, intensive research and study; research and study of its

[1] Address of the retiring president of the Washington Academy of Sciences, Washington, January 14, 1930.