THE SPECTRUM OF NU ERIDANI*

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ABSTRACT

Observations in 1953–1954 confirm de Jager's and our own interpretation of our previous velocity-curves The new results show that the absorption lines tend to be sharpest on the ascending branch near minimum and broadest on the descending branch near maximum. Three cycles show pronounced departures from the velocity-curves predicted on the basis of two interfering harmonic oscillations. There are some indications that, in addition to $P_1 = 0$ 1779 day and $P_2 = 0$ 1735 day, there is a third period, $P_3 = 0$ 064 day and $K_3 = 5$ km/sec.

In a previous paper Struve *et al.* (1952) discussed the radial-velocity observations of ν Eridani over a period of about fifty years. A beat phenomenon was detected, and a beat period of 6.9808 days was found to represent the observations fairly well. However, it was difficult to ascertain the exact beat period because of irregular variations in the smaller amplitude, K_1. The following periods and amplitudes were obtained:

$$P_1 = 0.1779 \text{ day}, \qquad K_1 = <8\text{–}15 \text{ km/sec},$$

$$P_2 = 0.1735089 \text{ day}, \qquad K_2 = 24.5 \text{ km/sec}.$$

C. de Jager (1953) tried to separate the dominant variation by constructing a mean curve for the period $P_2 = 0.1735089$ day. The residuals could then be combined to form a mean curve with period $P_1 = 0.1779$ day. These two periods represented the variation of radial velocity as well as of magnitude. They confirmed the previous value of the beat period, viz., 6.9808 days. The mean values of K_1 and K_2 were 10.6 and 20.2 km/sec, respectively.

The present observations confirm these results. But the radial velocity-curves show more complicated shapes, perhaps because of the greater dispersion used in the current work. It seems that the observations cannot be interpreted as a combination of two pure sine-curves.

All the measured spectrograms were obtained during 1953–1954 by Struve (on five nights) with the 100-inch coudé spectrograph of the Mount Wilson Observatory (designated "Cd") and by McNamara (on two nights) with the Mills three-prism spectrograph and the three-prism combination spectrograph with the 12-inch camera of the Lick Observatory (designated "LS"). The coudé plates taken on October 24, 1953, September 19, 1954, and November 18, 1954, have a dispersion of 4.5 A/mm, and the Lick plates taken on October 14, 1954, have a dispersion of 25 A/mm. The rest of the plates have a dispersion of 10 A/mm. The lines which were measured are listed in Table 1.

The observed radial velocities and phases, calculated from maximum radial velocity, are given in Table 2 and are plotted in Figure 1. The observed and calculated minima and maxima, and the differences (O − C) are given in Table 3. They were obtained from:

$$\text{Minimum} = 2423709.816 + 0.1735089E;$$

$$\text{Maximum} = 2433965.857 + 0.1735089E.$$

The differences (O − C) for the minima are small (except for October 14, 1954) and show that the period $P_2 = 0.1735089$ is correct. The differences (O − C) for the maxima

* The observational material used in this paper was obtained at Mount Wilson and Lick Observatories by O. Struve and D. H. McNamara, respectively.

are systematically negative except for October 21, 1954. In order to see whether this was due to the beat phenomenon, theoretical differences (O − C) were calculated for the three pairs of values of K_1 and K_2, already given, by means of the formula (Struve 1950):

$$\phi = \tan^{-1}\left\{\frac{K_1 \sin \phi}{K_2 + K_1 \cos \phi}\right\}.$$

Upon fitting these curves with the differences (O − C) for the present observations, as well as the observations of 1951–1952, it seems that the epoch of the maximum can be changed by 8×10^{-3} days to 2433965.849 (Fig. 2). But even after making this change, many of the points lie considerably off any of the curves.

In order to verify the beat period, the observed values $2K$, given in Table 4, were plotted against the phases of the beat period. Figure 3, which contains these points, as well as three theoretical curves, shows that the estimated period of 6.9808 days is fairly accurate. But it appears that K_1 and to some extent K_2 are irregularly variable. This and the scatter of points in Figure 2 indicate that the oscillations involved are not simple harmonic. Also the radial velocity-curves are complicated, particularly when $2K$ is small.

TABLE 1

LIST OF MEASURED LINES

Wave Length	Identification	Plate*	Wave Length	Identification	Plate*
3964 73	*He* I	Cd	4349 43	*O* II	Cd, LS_2
3973 26	*O* II	Cd	4387 93	*He* I	Cd, LS_2
4026 19	*He* I	Cd	4414 91	*O* II	Cd, LS_2
4072 16	*O* II	Cd	4416 98	*O* II	Cd, LS_2
4075 87	*O* II	Cd	4471 48	*He* I	Cd, LS_2, LS_1
4101 74	$H\delta$	Cd	4481 23	*Mg* II	Cd, LS_2, LS_1
4119.22	*O* II	Cd	4552 65	*Si* III	Cd, LS_2, LS_1
4120 81	*He* I	Cd	4567 87	*Si* III	Cd, LS_2, LS_1
4143 76	*He* I	Cd	4574 78	*Si* III	Cd, LS_2, LS_1
4340 47	$H\gamma$	Cd, LS_2	4590 97	*O* II	Cd, LS_1
4345 56	*O* II	Cd, LS_2	4596 17	*O* II	Cd, LS_1
4347 42	*O* II	Cd, LS_2			

* CD = Mount Wilson coudé; LS_1 = Lick 10 A/mm; LS_2 = Lick 25 A/mm

Unlike DD Lacertae, BW Vulpeculae, and σ Scorpii, no doubling of spectral lines was observed on any of the plates. But the lines showed broadening near the maximum, on the descending branch of the velocity-curve. The plates on which the lines were sharpest are marked by *s*, and those on which the lines were broadest are marked by *b* in Figure 1. We note that on all curves the sharpest lines occur on the ascending branch near the minimum and the broadest lines are found on the descending branch near the maximum. This agrees with the previous result that the line broadening is associated with period P_2.

In the curve for December 8, 1954, we find two distinct maxima. In this case the lines are sharpest on the main ascending branch at the point marked *ss*. They become broad on the descending portion after the first maximum. The lines become sharp again on the ascending portion of the second maximum, but they are not so sharp as in the first case. Hence this point is marked by a single *s*. Finally, the lines again become broad on the main descending branch of the curve. It is interesting to note that a similar sharpening and broadening of the lines has been observed in the case of BW Vulpeculae (McNamara *et al.* 1955).

At first sight it is tempting to interpret the flat portion of the velocity-curve on December 8, 1954, between 0.790 and 0.825 as a "stillstand" of the kind observed pre-

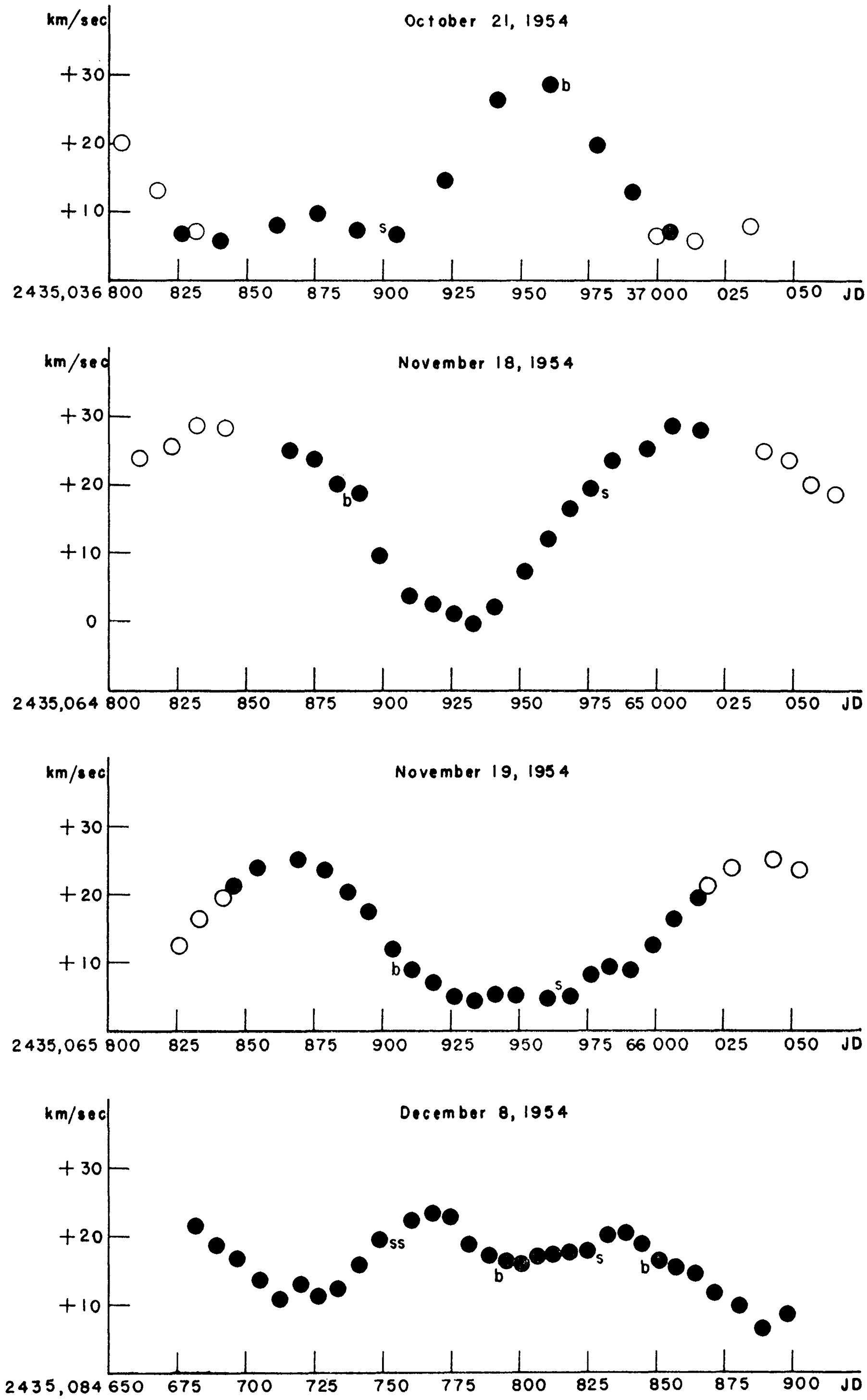

FIG. 1*a*—Individual radial velocities of ν Eridani

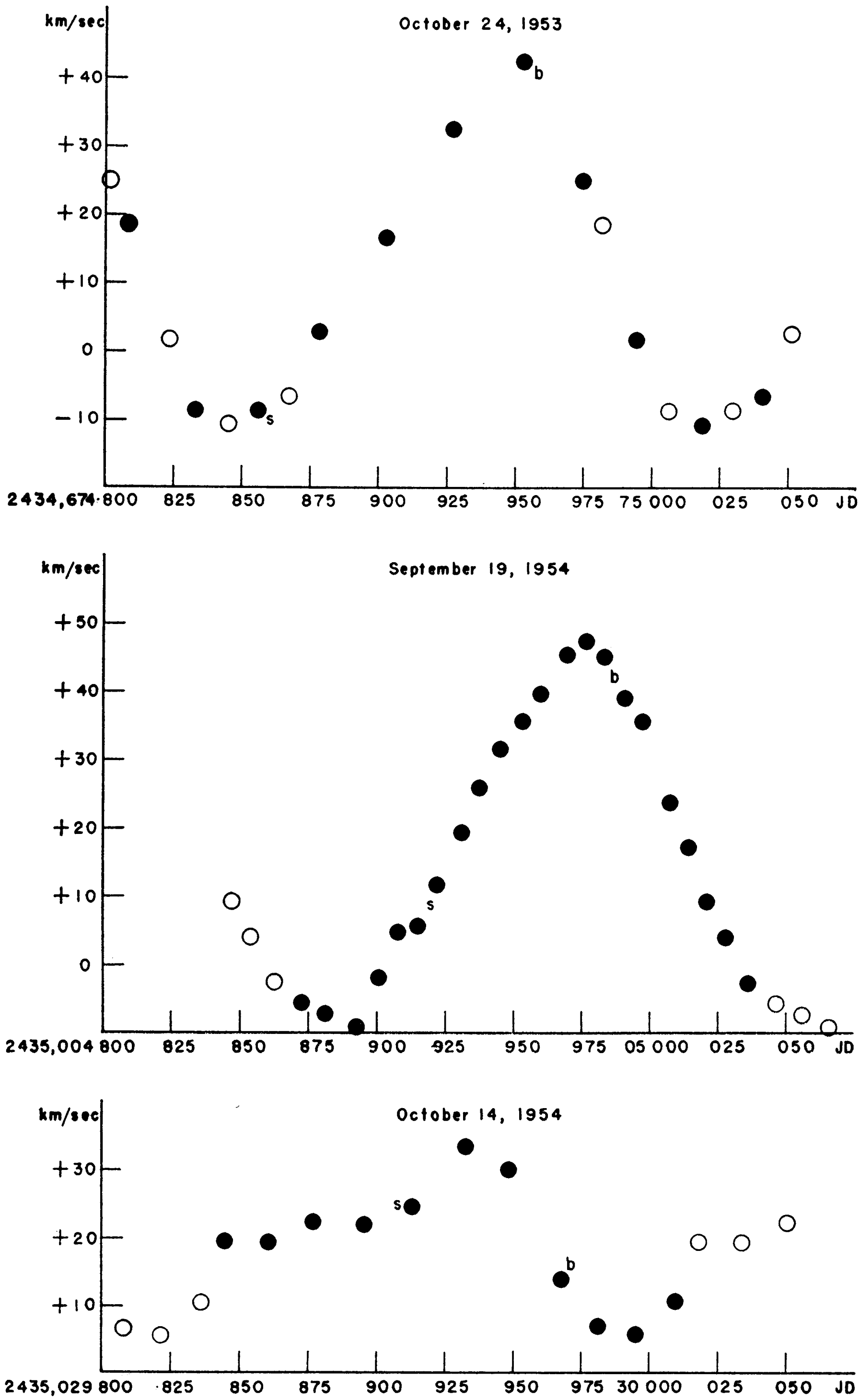

FIG. 1*b* —Individual radial velocities of ν Eridani

TABLE 2

OBSERVED RADIAL VELOCITIES

Plate	JD 243+	Phase (Days)	Velocity (Km/Sec)
Cd	4674 808	0 035	+18 5
	833	060	− 8 7
	856	083	− 8 7
	878	106	+ 2 7
	903	130	+16 7
	927	154	+32 3
	953	006	+42 4
	975	028	+25 0
	997	050	+ 1 6
	4675 019	072	−10 8
	041	094	− 6 5
	5004 873	069	− 5 6
	882	078	− 7 2
	892	089	− 9 1
	901	097	− 2 0
	908	105	+ 4 6
	915	112	+ 5 5
	922	119	+11 6
	931	128	+19 3
	938	134	+25 7
	945	141	+31 5
	953	149	+35 6
	960	156	+39 7
	969	166	+45 3
	976	173	+47 4
	983	006	+45 2
	990	013	+39 1
	997	020	+35 6
	5005 008	031	+23 8
	015	038	+17.1
	021	044	+ 9 2
	028	051	+ 3 9
	036	059	− 2 8
LS_2	5029 845	082	+19 3
	860	097	+19 2
	877	114	+22 2
	896	133	+21 8
	913	150	+24 5
	933	170	+33 2
	949	012	+29 9
	967	030	+13 8
	981	044	+ 6 8
	995	058	+ 5 7
	5030 010	073	+10 3
LS_1	5036 826	046	+ 6 7
	840	060	+ 5 8
	861	081	+ 8 0
	876	096	+ 9 7
	890	110	+ 7 3
	905	125	+ 6 8
	922	142	+14 7
	942	162	+26 4
	960	006	+28 7
	978	024	+20 0
	991	037	+13 0
	5037 005	051	+ 7 1
Cd	5064 866	023	+25 0
	875	032	+23 6
	883	040	+20 1
	892	049	+18 7
	899	056	+ 9 6
	910	067	+ 3 7
	918	0 075	+ 2 5
Cd	5064 926	0 083	+ 1 0
	933	090	− 0 4
	941	098	+ 2 1
	952	109	+ 7 2
	960	117	+12 1
	968	125	+16 6
	976	133	+19 6
	984	141	+23 7
	996	154	+25 3
	5065 006	163	+28 7
	016	173	+28 2
	846	156	+21 2
	854	164	+23.8
	869	005	+25 0
	879	015	+23 5
	888	024	+20 2
	895	031	+17 4
	904	040	+11 9
	911	047	+ 8 9
	919	055	+ 6 9
	926	062	+ 5 1
	934	070	+ 4 4
	942	078	+ 5 2
	949	085	+ 5 2
	960	096	+ 4 7
	969	105	+ 5 0
	976	112	+ 8 2
	983	119	+ 9 3
	991	127	+ 8 9
	999	135	+12 5
	5066 007	143	+16 2
	015	151	+19 5
	5084 682	088	+21 4
	690	096	+18 6
	697	103	+16 8
	705	111	+13 5
	712	118	+10 8
	720	126	+12 9
	727	133	+11 1
	734	140	+12 2
	742	148	+15 8
	749	155	+19 4
	760	166	+22 2
	768	000	+23 2
	775	007	+22 7
	782	014	+18 6
	789	021	+17 0
	795	027	+16 2
	801	033	+15 8
	807	039	+17 0
	812	044	+17 2
	818	050	+17 5
	825	057	+17 8
	833	065	+20 1
	839	071	+20 3
	845	077	+18 8
	851	083	+16 3
	858	090	+15 2
	865	097	+14 4
	872	103	+11 7
	881	113	+ 9 6
	890	122	+ 6 2
	899	0 131	+ 8 4

TABLE 3

THE OBSERVED AND CALCULATED MAXIMA AND MINIMA

(Minimum = 2423709.816 + 0.1735089E; Maximum = 2433965.857 + 0 1735089E)

DATE	E	OBSERVED JD	CALCULATED JD	DIF
		Minimum		
Oct. 24, 1953	63196	2434674 846	2434674 884	-38×10^{-3}
	63197	2434675 020	2434675 058	−38
Sept 19, 1954	65098	2435004 888	2435004 898	−10
	65099	2435005 061	2435005 072	−11
Oct. 14, 1954	65242	2435029 815	2435029 884	−69
	65243	2435029 991	2435030 057	−66
Oct 21, 1954	65282	2435036 840	2435036 824	+16
	65283	2435037 015	2435036 998	+17
Nov. 18, 1954	65444	2435064 929	2435064 932	− 3
Nov. 19, 1954	65450	2435065 949	2435065 974	−25
Dec. 8, 1954	65558	2435084 720	2435084 712	+ 8
	65559	2435084 893	2435084 886	+ 7
		Maximum		
Oct. 24, 1953	4087	2434674 947	2434674 988	−41
Sept 19, 1954	5989	2435004 977	2435005 002	−25
Oct. 14, 1954	6133	2435029 937	2435029 987	−50
Oct. 21, 1954	6173	2435036 954	2435036 927	+27
Nov 18, 1954	6334	2435064 843	2435064 862	−19
	6335	2435065 015	2435065 036	−21
Nov. 19, 1954	6340	2435065 864	2435065 903	−39
	6341	2435066 040	2435066 077	−37
Dec. 8, 1954	6449	2435084 768	2435084 816	−48

TABLE 4

OBSERVED 2K

Date	Observed 2K (Km/Sec)	(O−C) (Maximum) (Days)	Phase (Days)	Date	Observed 2K (Km/Sec)	(O−C) (Maximum) (Days)	Phase (Days)
Oct. 24, 1953	54 5	-41×10^{-3}	4 7	Nov 18, 1954	29 7	-20×10^{-3}	3 7
Sept. 19, 1954	57 0	−25	6 6	Nov. 19, 1954	21 4	−38	4 8
Oct 14, 1954	29 2	−50	3 7	Dec 8, 1954	14 6	−48	2 6
Oct. 21, 1954	24 0	+27	3 7				

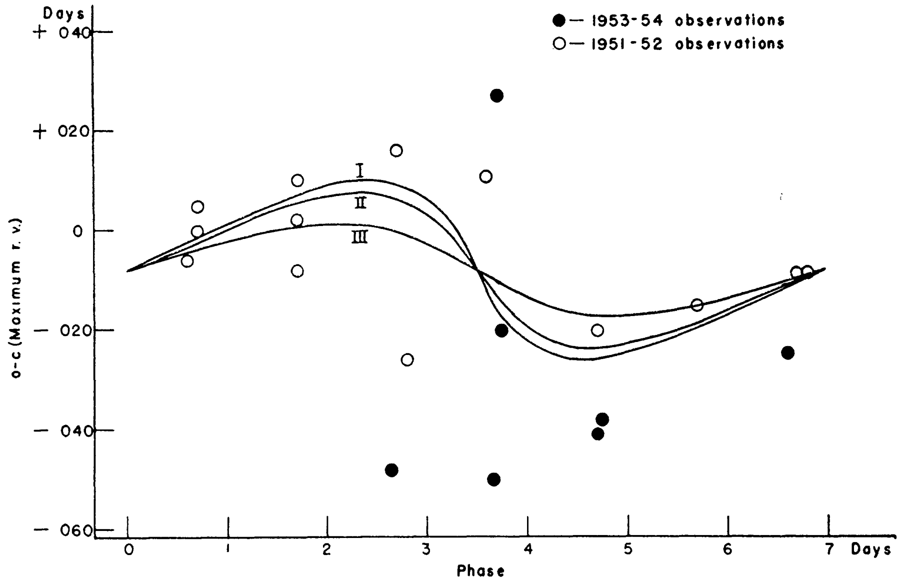

FIG 2 —Differences (O—C) for maximum radial velocity *I*, K_1 = 15.0 km/sec, K_2 = 24.5 km/sec; *II*, K_1 = 10 6 km/sec, K_2 = 20 2 km/sec; *III*, K_1 = 8 0 km/sec, K_2 = 24 5 km/sec.

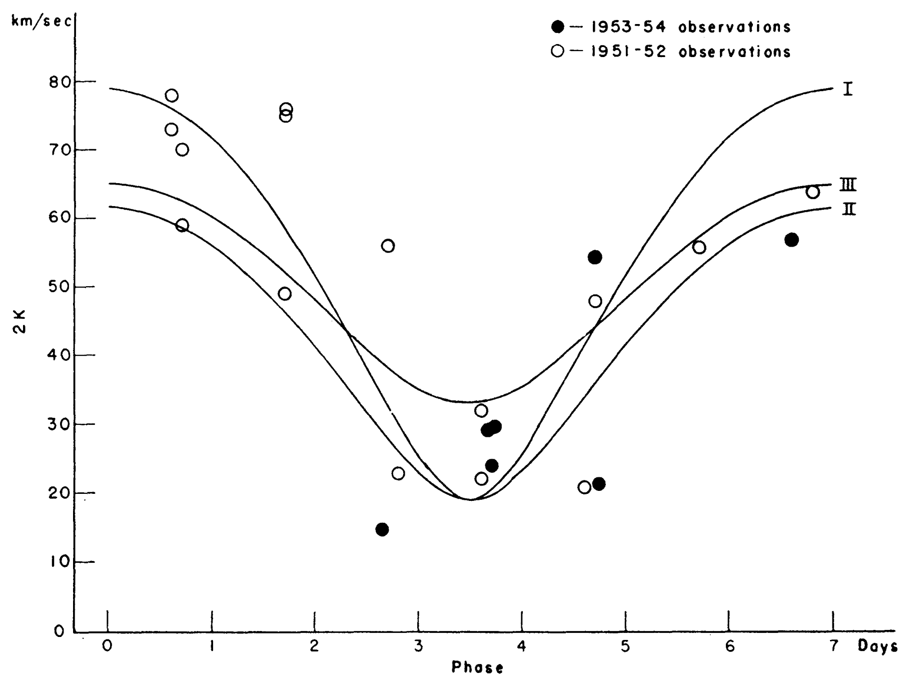

FIG. 3 —Observed and theoretical values of $2K$ *I*, K_1 = 15 0 km/sec, K_2 = 24 5 km/sec; *II*, K_1 = 10 6 km/sec, K_2 = 20.2 km/sec; *III*, K_1 = 8 0 km/sec, K_2 = 24.5 km/sec.

viously in BW Vulpeculae and σ Scorpii. But this is impossible for two reasons: (*a*) The computed maximum, uncorrected for the value of the initial epoch, is 0.816; after correction this becomes 0.808: both values fall upon the flat portion, while in BW Vulpeculae the computed maximum always *preceded* the "stillstand." (*b*) The phenomenon of double maxima and minima is pronounced only when the total range in velocity is small; in σ Scorpii the "stillstand" is most pronounced when the range is large.

We are undoubtedly concerned with another periodicity similar to those discovered by T. Walraven (1955) in AI Velorum. The present material is insufficient to examine this third period in detail. But on three nights we can estimate its value as follows: interval between two minima, October 14, 1954, 0.063 day; interval between two minima, October 21, 1954, 0.063 day; interval between two maxima, December 8, 1954, 0.067 day. We therefore suggest that there may be a period $P_3 = 0.064$ day, with an amplitude of $K_3 = 5$ km/sec.

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