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The Spectroscopic System  
Beta Canis Majoris

BY

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## THE SPECTROSCOPIC SYSTEM BETA CANIS MAJORIS

BY F. HENROTEAU, PH.D.

The present study is a continuation of the work done by the writer on  $\beta$  Canis Majoris at the Lick Observatory in 1917-18.\* The principal results of this former study were:—

- (1) *A radial velocity oscillation of very short duration (about six hours) a result that was already arrived at by Dr. Albrecht in 1908.*
- (2) *A considerable variation of the amplitude of the velocity curve.*
- (3) *The fact that the maxima of the different velocity curves could not be connected by a period.*
- (4) *A short periodic variation of the widths of the spectral lines  $O^{\lambda}25130$ .*

It was thought at the time, the star having been observed on only a few nights, that the variation of amplitude was rather erratic, not simple-periodic. It was thought also that a period of radial velocity variation existed in such a way that it sometimes furnished a maximum, sometimes a minimum, of the velocity curve.

The present research, in which the coöperation of Messrs. J. F. Frédette, mainly in observing, and W. A. Thorn, in measuring, is acknowledged, shows that the variation of amplitude is probably periodical, while the radial velocity variation must follow a more complicated law than was at first imagined. For a long time it was thought by the writer that the study of  $\beta$  Canis Majoris with the 15-inch telescope and one prism spectrograph would be almost impossible. Since the star is bright, however, it was decided to use very fine grained plates, and it was found that Seed Process 0 plates furnished splendid spectrograms with an exposure of about thirty minutes. Most of the spectrograms were taken on these plates and  $\beta$  Canis Majoris was observed from the end of December, 1921, continuously through January and February, 1922. Weather conditions were favourable, providing whole weeks of clear and exceedingly transparent skies. While a few of the spectrograms are poor and the measures they furnish unreliable the majority give very accurate velocities. All the spectrograms were measured directly on an ordinary micrometric measuring engine and some have been remeasured on a Hartmann spectro-comparator.

The list of radial velocities obtained in 1921 and 1922 follows:—

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\*L.O.B., Vol. IX, No. 311, p. 155.

RADIAL VELOCITIES OF  $\beta$  CANIS MAJORIS

Date	Julian Day G.M.T.	Velocity km.	Probable error km.	Measure on Spectro- comparator, km.	Quality of spectrogram
1921					
December 21.....	2423045.783	+35.8	$\pm 1.5$	.....	coarse grain
	.792	+36.1	$\pm 2.8$	.....	coarse grain
	.803	+31.5	$\pm 2.0$	.....	coarse grain
	.824	+27.6	$\pm 4.6$	.....	coarse grain
	.837	+36.2	$\pm 3.9$	.....	coarse grain
	.853	+20.5	$\pm 7.3$	.....	coarse grain
December 27.....	051.627	+40.8	$\pm 3.6$	.....	poor
	.662	+35.2	$\pm 2.2$	.....	good
	.694	+34.2	$\pm 1.6$	.....	good
	.756	+24.6	$\pm 0.8$	.....	good
	.787	+27.3	$\pm 2.6$	.....	good
	.812	+21.9	$\pm 2.8$	.....	fair
	.839	+20.7	$\pm 3.4$	.....	poor
December 29.....	053.712	+23.4	$\pm 4.4$	.....	very poor
	.739	+30.5	$\pm 1.7$	.....	good
	.774	+29.5	$\pm 1.2$	.....	good
	.805	+21.6	$\pm 1.1$	.....	fair
1922					
January 1.....	056.615	+30.3	$\pm 2.0$	.....	fair
	.647	+39.8	$\pm 2.1$	.....	good
	.683	+28.4	$\pm 1.5$	.....	fair
	.715	+21.6	$\pm 3.8$	.....	poor
	.750	+22.7	$\pm 3.6$	.....	coarse grain
January 2.....	057.581	+24.4	$\pm 2.5$	.....	fair
	.603	+29.0	$\pm 2.4$	.....	fair
	.626	+31.2	$\pm 2.7$	.....	good
	.648	+35.7	$\pm 2.2$	.....	good
	.670	+38.0	$\pm 1.7$	.....	good
	.693	+39.2	$\pm 1.9$	.....	good
	.717	+29.3	$\pm 1.6$	.....	fair
	.747	+29.4	$\pm 2.4$	.....	fair
	.773	+23.3	$\pm 3.1$	.....	poor
January 6.....	061.651	+37.2	$\pm 1.4$	.....	fair
	.677	+42.4	$\pm 3.0$	.....	good
	.700	+36.2	$\pm 2.5$	.....	fair
	.726	+45.3	$\pm 2.5$	.....	fair
	.751	+18.8	$\pm 2.1$	.....	fair
	.779	+28.2	$\pm 2.8$	+22.1	poor
January 12.....	067.560	+20.8	$\pm 3.5$	.....	very poor
	.584	+23.5	$\pm 3.0$	.....	poor
	.606	+36.1	$\pm 2.2$	.....	poor
	.628	+38.7	$\pm 2.2$	.....	fair
	.651	+36.4	$\pm 2.2$	.....	fair
	.675	+39.8	$\pm 2.4$	.....	good
	.699	+41.9	$\pm 2.2$	.....	good
	.728	+29.0	$\pm 2.9$	.....	fair
January 15.....	070.607	+23.4	$\pm 3.0$	.....	very poor
	.631	+35.0	$\pm 3.0$	.....	poor
	.653	+30.0	$\pm 2.1$	.....	fair
	.676	+24.4	$\pm 2.6$	.....	fair



RADIAL VELOCITIES OF  $\beta$  CANIS MAJORIS—Continued

Date	Julian Day G.M.T.	Velocity km.	Probable error km.	Measure of Spectro-com- parator, km.	Quality of Spectrogram
1922					
January 15 .....	2423070.699	+27.1	$\pm 4.2$	.....	poor
	.722	+32.3	$\pm 2.0$	.....	good
	.745	+17.2	$\pm 4.4$	.....	poor
	.772	+ 8.2	$\pm 3.9$	.....	poor
January 17 .....	072.566	+ 9.8	$\pm 2.4$	.....	poor
	.612	+25.1	$\pm 3.2$	.....	poor
	.658	+ 5.3	$\pm 4.2$	.....	poor
January 22 .....	077.535	+20.6	$\pm 2.1$	.....	poor
	.559	+21.4	$\pm 1.8$	.....	weak
	.582	+16.4	$\pm 2.6$	.....	poor
	.608	+24.1	$\pm 2.8$	.....	poor
	.637	+24.1	$\pm 2.1$	.....	fair
	.665	+34.6	$\pm 2.6$	.....	fair
	.694	+30.1	$\pm 2.0$	.....	fair
January 23 .....	078.569	+13.2	$\pm 3.2$	.....	good
	.594	+21.0	$\pm 2.1$	.....	good
	.618	+25.0	$\pm 2.6$	.....	good
	.642	+18.9	$\pm 2.6$	.....	fair
	.669	+29.1	$\pm 2.3$	.....	good
	.699	+30.9	$\pm 2.6$	.....	good
	.733	+30.9	$\pm 4.2$	.....	fair
January 24 .....	079.542	+24.9	$\pm 2.6$	.....	fair
	.568	+13.1	$\pm 1.8$	.....	good
	.591	+20.8	$\pm 2.8$	.....	good
	.614	+19.9	$\pm 1.3$	.....	poor
	.637	+24.1	$\pm 2.6$	.....	good
	.661	+31.6	$\pm 2.2$	.....	good
	.686	+25.9	$\pm 2.6$	.....	good
	.715	+23.4	$\pm 2.6$	.....	good
	.747	+26.0	$\pm 3.0$	.....	poor
January 25 .....	080.535	+32.8	$\pm 1.7$	+28.1	good
	.567	+15.5	$\pm 2.6$	+19.4	fair
	.590	+11.8	$\pm 1.6$	+11.9	good
	.614	+18.1	$\pm 1.9$	+18.0	good
	.637	+24.3	$\pm 1.5$	+19.4	good
	.660	+34.2	$\pm 1.3$	+27.9	good
	.684	+32.8	$\pm 1.7$	+31.9	good
	.708	+16.8	$\pm 4.0$	+ 7.4	poor, very weak
January 26 .....	081.525	+36.9	$\pm 3.2$	+31.3	poor
	.549	+30.9	$\pm 2.1$	+30.2	fair
	.573	+20.6	$\pm 1.5$	+20.6	good
	.597	+25.2	$\pm 1.8$	+21.2	good
	.620	+20.0	$\pm 1.4$	.....	fair
	.644	+21.6	$\pm 2.0$	+19.4	fair
	.723	+28.3	$\pm 2.2$	+28.0	poor
January 27 .....	082.531	+26.0	$\pm 1.8$	.....	poor
	.560	+19.1	$\pm 1.5$	.....	fair
	.585	+24.0	$\pm 1.6$	.....	good
	.608	+29.1	$\pm 2.0$	.....	good
	.632	+20.3	+1.1	.....	good
	.676	+15.2	$\pm 3.2$	.....	poor
	.699	+22.2	$\pm 3.5$	.....	poor

RADIAL VELOCITIES OF  $\beta$  CANIS MAJORIS—*Continued*

Date	Julian Day G.M.T.	Velocity km.	Probable error km.	Measure on Spectro-com- parator, km.	Quality of Spectrogram
1922					
January 29.....	2423084.531	+31.3	$\pm 1.3$		good
	.556	+32.2	$\pm 1.6$		good
	.579	+28.1	$\pm 2.0$		good
	.602	+22.6	$\pm 1.8$		good
	.625	+21.7	$\pm 1.1$		good
	.649	+25.5	$\pm 1.7$		good
	.704	+23.8	$\pm 2.8$		poor
January 30.....	085.521	+27.8	$\pm 1.7$		good
	.546	+31.6	$\pm 1.5$		good
	.569	+27.4	$\pm 1.7$		good
	.592	+26.7	$\pm 1.2$		good
	.615	+27.0	$\pm 1.8$		fair
January 31.....	086.538	+57.2	$\pm 2.6$	+58.4	good
	.562	+19.6	$\pm 1.3$		good
	.585	+19.6	$\pm 1.3$		good
	.609	+ 0.3	$\pm 2.2$		poor
	.632	+26.7	$\pm 3.3$		poor
February 7.....	093.501	+28.2	$\pm 2.1$		fair
	.529	+35.3	$\pm 2.3$		good
	.555	+36.2	$\pm 2.2$		good
	.578	+30.5	$\pm 1.9$		good
	.601	+23.1	$\pm 1.8$		good
	.625	+22.6	$\pm 2.2$		good
	.648	$\pm 24.4$	$\pm 2.4$		good
	.674	+42.8	$\pm 3.1$		very poor
February 13.....	099.488	+32.2	$\pm 1.8$	+32.4	poor
	.513	+29.9	$\pm 2.9$	+23.8	very poor
	.536	+25.5	$\pm 2.3$	+29.3	fair
	.559	+28.0	$\pm 2.1$	+30.9	fair
	.583	+32.8	$\pm 2.0$	+26.8	good
	.606	+25.4	$\pm 2.2$	+30.2	poor
	.628	+28.1	$\pm 2.9$	+26.6	poor
	.654	+17.5	$\pm 3.2$	+30.3	very poor
February 16.....	102.476	+30.9	$\pm 1.3$		fair
	.500	+30.4	$\pm 1.3$		good
	.523	+29.7	$\pm 1.5$		good
	.546	+27.7	$\pm 1.5$		good
	.569	+24.4	$\pm 1.3$		good
	.591	+33.0	$\pm 2.1$		fair
	.613	+31.0	$\pm 1.7$		good
	.636	+38.4	$\pm 1.8$		good
February 20.....	106.487	+24.2	$\pm 1.6$		good
	.510	+23.0	$\pm 2.0$		good
	.556	+19.8	$\pm 2.7$		good
	.579	+15.0	$\pm 1.3$		good
	.602	+ 7.1	$\pm 2.0$		poor
	.627	+23.7	$\pm 2.0$		poor
February 28.....	114.487	+37.1	$\pm 4.2$		poor
	.510	+19.7	$\pm 1.8$		good
	.533	+20.7	$\pm 2.6$		fair
	.557	+ 9.7	$\pm 1.7$		good

Among the different velocity curves that the above results furnish, those shown in Figs. 1 and 2 are among the most interesting; in tracing these curves account was taken of the probable errors of the different observations.

Fig. 1.

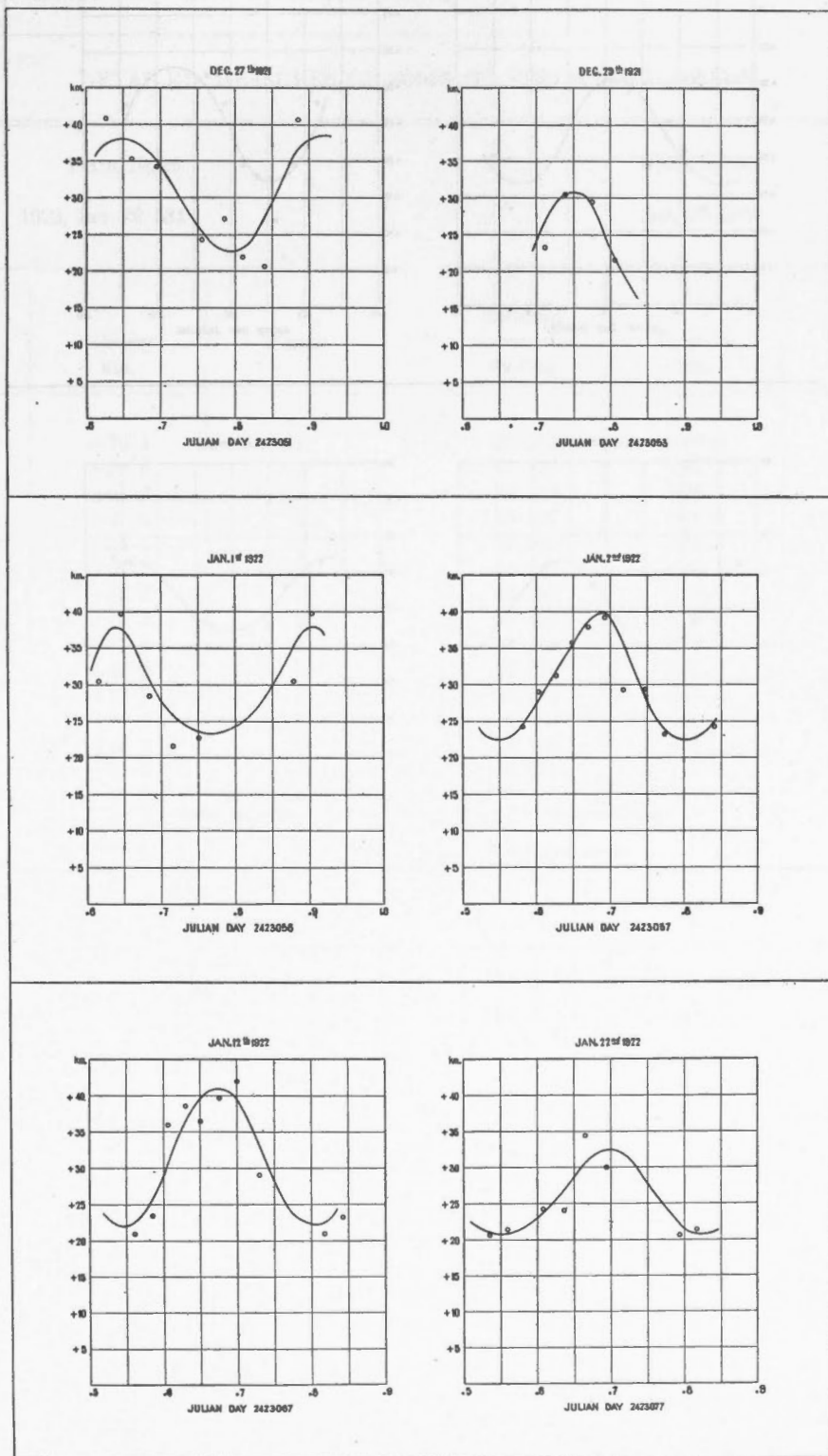
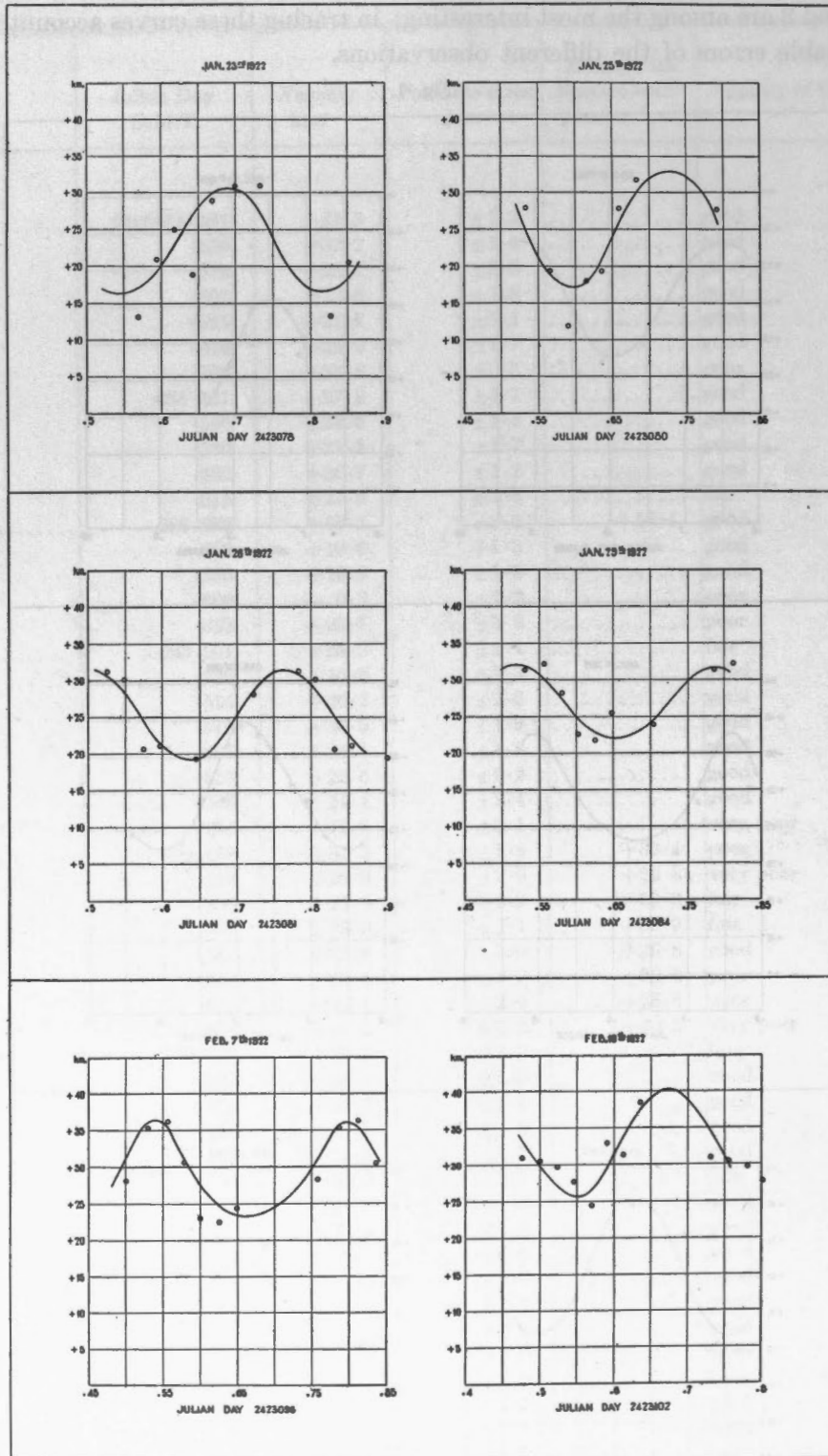




Fig. 2.



In order to give an idea of the value of the radial velocities obtained, the detailed measures of a series of spectrograms are given here. Most of the lines in these measures can be identified by consulting the table of lines, elements, wave-lengths and micrometer readings published in "The Spectroscopic System Delta Ceti."\*

DETAILED MEASURES OF SOME OF THE SPECTROGRAMS

Plate 10225			Plate 10226		
1922, Jan. 29·531			Jan. 29·556		
Reduced micrometer reading	Velocity km.	Weight	Reduced micrometer reading	Velocity km.	Weight
28·238	+39·1	1	28·263	+60·9	1
31·863	+52·8	2	31·868	+57·3	2
32·091	+61·0	1	32·365	+39·1	1
32·352	+27·3	2	33·407	+39·6	1
33·423	+54·3	2	37·642	+45·6	3
34·429	+51·2	1	45·397	+44·5	3
35·893	+33·2	2	46·285	+36·4	3
37·637	+40·7	3	49·502	+52·2	2
45·399	+46·6	1	49·664	+59·9	2
46·292	+43·9	2	50·939	+45·2	3
49·489	+37·7	1	52·517	+31·0	1
49·647	+41·1	2	53·765	+36·3	4
50·940	+46·3	3	58·453	+37·2	4
52·536	+52·9	1	62·677	+57·6	2
53·771	+43·3	5			
55·313	+30·9	2			
58·461	+47·1	3			
62·672	+51·1	2			
Weighted mean.....	+43·8		Weighted mean.....	+44·8	
Va.....	-12·4		Va.....	-12·4	
Vd.....	+ 0·2		Vd.....	+ 0·1	
Curv.....	- 0·3		Curv.....	- 0·3	
Radial velocity.....	+31·3		Radial velocity.....	+32·2	

\*Pub. Dom. Obs. Vol. V, No. 11.

## DETAILED MEASURES OF SOME OF THE SPECTROGRAMS—Continued.

Plate 10227 1922, Jan. 29·579			Plate 10228 1922, Jan. 29·602		
Reduced micrometer reading	Velocity km.	Weight	Reduced micrometer reading	Velocity km.	Weight
28·241	+41·8	1	28·233	+34·8	1
31·873	+61·9	2	31·868	+57·3	2
32·050	+23·7	1	32·055	+28·2	1
32·367	+40·9	1	32·360	+34·6	1
33·432	+62·6	2	33·419	+50·6	2
34·404	+27·9	1	37·641	+44·6	3
37·635	+38·8	3	45·391	+38·2	3
45·395	+42·4	3	46·282	+33·2	3
46·296	+48·1	3	49·637	+30·0	2
49·496	+45·5	1	50·926	+30·5	2
50·926	+30·5	3	52·522	+36·8	2
52·528	+43·7	1	53·754	+23·4	5
53·754	+23·4	5	55·308	+25·0	1
55·328	+40·5	2	58·447	+29·8	4
58·460	+45·9	5	58·964	+23·7	2
62·666	+43·2	2	62·674	+53·7	2
Weighted mean.....	+40·7		Weighted mean.....	+35·3	
Va.....	-12·4		Va.....	-12·4	
Vd.....	+ 0·1		Vd.....	0·0	
Curv.....	- 0·3		Curv.....	- 0·3	
Radial velocity.....	+28·1		Radial velocity.....	+28·6	

Plate 10229 1922, Jan. 29·625			Plate 10230 1922, Jan. 29·649		
Reduced micrometer reading	Velocity km.	Weight	Reduced micrometer reading	Velocity km.	Weight
28·244	+44·4	1	28·240	+40·9	1
31·859	+49·1	2	31·860	+50·0	1
32·353	+28·2	2	32·052	+25·5	1
33·407	+39·6	2	32·363	+37·3	2
34·413	+36·3	1	33·388	+22·1	1
35·911	+50·3	1	35·894	+34·2	2
37·624	+28·1	3	37·641	+44·6	3
45·388	+35·0	3	45·409	+57·2	3
46·279	+30·0	3	46·280	+31·0	3
49·473	+20·0	2	49·479	+26·6	2
49·646	+40·0	2	49·649	+43·3	2
50·930	+35·0	4	50·933	+38·4	3
52·531	+47·1	1	53·759	+29·2	5
53·758	+28·1	6	58·457	+42·2	4
55·316	+34·5	2	62·672	+51·1	1
58·450	+33·5	5			
58·974	+36·2	3			
62·664	+40·6	2			
Weighted mean.....	+34·4		Weighted mean.....	+38·3	
Va.....	-12·4		Va.....	-12·4	
Vd.....	0·0		Vd.....	- 0·1	
Curv.....	- 0·3		Curv.....	- 0·3	
Radial velocity.....	+21·7		Radial velocity.....	+25·5	

DETAILED MEASURES OF SOME OF THE SPECTROGRAMS—*Concluded*

Plate 10231  
1922, Jan. 29.704

Reduced micrometer reading	Velocity km.	Weight
31.859	+49.1	1
32.355	+30.0	1
34.430	+52.1	1
37.656	+59.2	2
45.388	+35.0	3
46.287	+38.5	3
49.463	+ 8.9	1
49.645	+38.9	2
50.924	+28.2	2
52.505	+17.3	2
53.763	+33.9	4
55.297	+11.9	1
58.472	+60.8	2
Weighted mean.....		+36.7
Va.....		-12.5
Vd.....		- 0.1
Curv.....		- 0.3
Radial velocity.....		+23.8

The last plate is very weak and difficult to measure, typical of some of the poor measures.

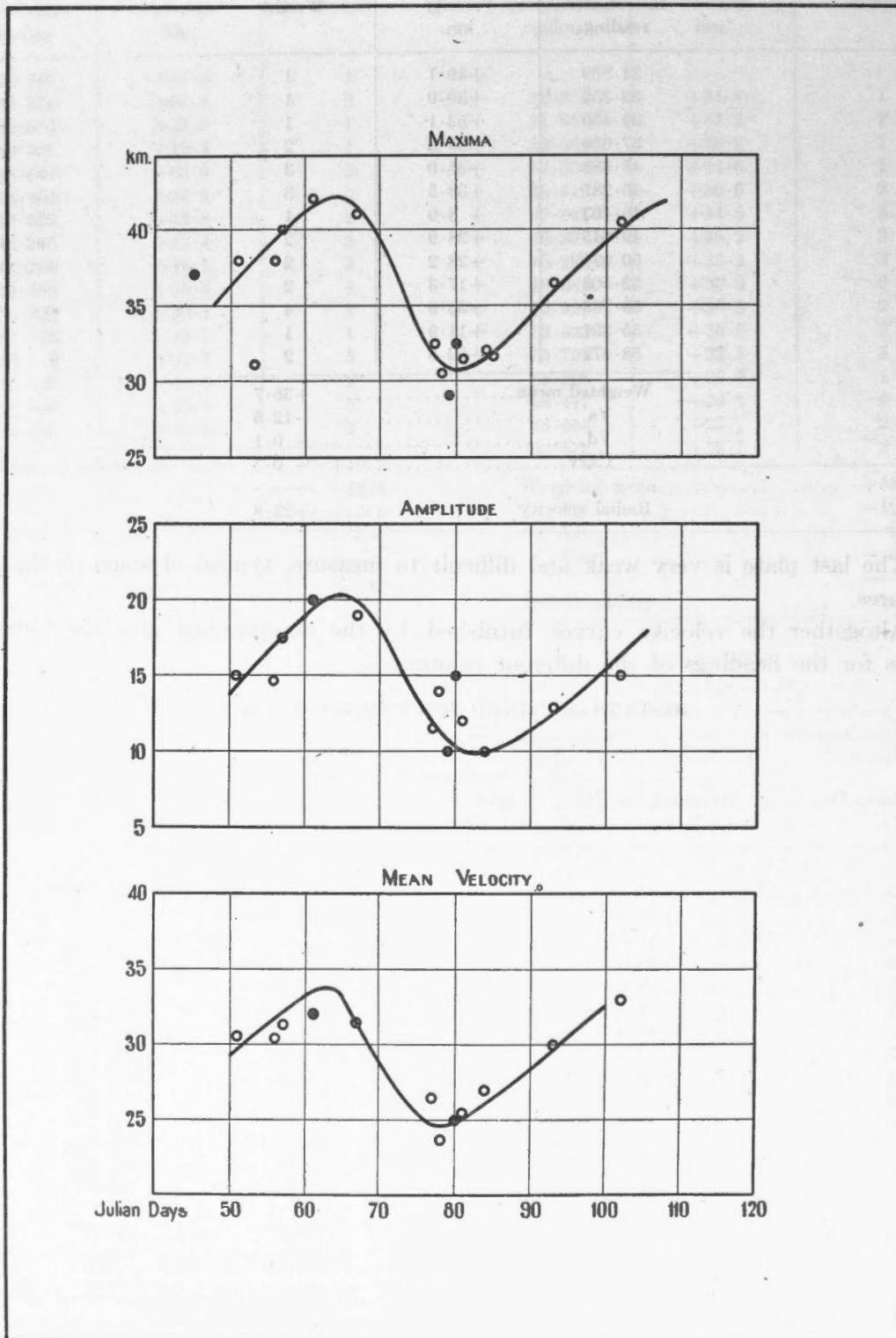
Altogether the velocity curves furnished by the observations give the following results for the headings of the different columns.

RESULTS OBTAINED FOR  $\beta$  CANIS MAJORIS

Julian Day	Maximum velocity km.	Amplitude of velocity curve km.	Estimated mean velocity km.	Time of maximum (decimal fraction of a day)
243045.....	+37 *	.....	.....	.770*
051.....	+38.0	15.0	+30.5	.655
053.....	+31.0	.....	.....	.752
056.....	+38.0	14.7	+30.4	.640
057.....	+40.0	17.5	+31.2	.687
061.....	+42.0	20.0*	+32.0*	.700*
067.....	+41.0	19.0	+31.5	.675
077.....	+32.5	11.5	+26.5	.699
078.....	+30.5	14.0	+23.7	.690
079.....	+29.0*	10.0*	.....	.....
080.....	+32.5*	15.0*	+25.0*	.....
081.....	+31.5	12.0	+25.5	.766
084.....	+32.0	10.0	+27.0	.788
085.....	+31.6	.....	.....	.560
093.....	+36.5	13.0	+30.0	.540
102.....	+40.4	15.0	+33.0	.672

Some curves are too poorly determined to furnish results and give doubtful values, which are found in the table followed by an asterisk. The other results, especially in the third and fourth columns, are affected by a rather large degree of uncertainty. Columns 2, 3 and 4, combined with column 1, yield the curves shown in Fig. 3, where the doubtful

Fig. 3.





points are indicated by darkened circles. The three curves show unmistakably the same tendencies—probably passing from one maximum to the next in about 42 days—as if the center of mass of the short period system, if such it is, moved in a rather eccentric orbit, (the actual observations, however, do not justify calling this a period). If such an orbit exists it appears to be certain that the amplitude of the short period velocity variation is a function of the position of the center of mass of the system in this orbit.

It is possible that the amplitude of the mean velocity curve varies, as was found in the case of  $\sigma$  Scorpii, for, in 1917-18, hardly any variation of the mean velocity was found.

As to the times at which maxima occur it seems impossible to connect them by any period. Even the law proposed in 1918 connecting a series of maxima with a series of minima by a period, allowing for a reversal of the curve or interchange of maximum and minimum, does not seem to hold. No doubt two or several simple waves by their combination would produce a curve for which the several maxima could not be connected by a simple period—but the succession of maxima would, however, be brought about according to a definite law. Our spectra are too poor to measure the line widths; it seems probable, however, from the observations of 1918 that the variation of line-width is simple-periodic.

Granting the curve of variation of mean velocity to represent also the variation of the center-of-mass velocity of the short-period system, the following very approximate elements for a possible orbit of that center of mass are derived:—

$$\begin{aligned}
 k &= 4.75 \text{ km.} \\
 e &= 0.27 \\
 P &= 42^d \\
 \omega &= 90^\circ \\
 T &= 2423070 \text{ J.D.} \\
 \gamma &= +29.3 \text{ km.} \\
 a \sin i &= 2,633,000 \text{ km.} \\
 \frac{m_1^3 \sin^3 i}{(m+m_1)^3} &= 0.00041
 \end{aligned}$$

The eccentricity is not small. This suggests at once that the short-period velocity curve is possibly due to tidal action, showing variation of amplitude with the variation of position in the 42-day orbit. The variation of amplitude would be greatest for large eccentricity and small orbit, tidal action being approximately a function of the inverse cube of the distance.

DOMINION OBSERVATORY,

OTTAWA,

September, 1922.

