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ORBIT OF THE SPECTROSCOPIC BINARY 29 CANIS MAJORIS

BY W. E. HARPER, M.A.

This star ($\alpha = 7^h\ 14^m$, $\delta = -24° 23'$, vis. mag. 4·77) was announced as a spectroscopic binary* by Professor Frost, director of the Yerkes Observatory, in March, 1906. His results depended chiefly upon $H\gamma$ and the helium line λ 4471, and the four observations gave a range in velocity from − 3 to − 243 km. per second.

In *Harvard Circulars* Nos. 16, 17 and 32, Professor E. C. Pickering called attention to the presence in the spectrum of the lines characteristic of the star ζ Puppis. Miss Cannon has made it the typical star of Class Oe, and a detailed description of its spectrum may be had in *Harvard Annals*, Vol. XXVIII, pages 148–150. It will suffice here to say that, in addition to the regular hydrogen and helium absorption lines and the additional ζ Puppis series of hydrogen absorption lines, there are also emission bands. These in general are not pronounced and, excepting that at λ 4688, would not arrest the attention in a casual glance at its spectrum. The emission line at λ 4633 does not show upon our plates, but there does seem to be an emission band stretching roughly from λ 4647 to λ 4669 and this band appears as though broken by absorption. The absorption line λ 4542 is flanked by emission not only on the red edge, as Miss Cannon states in her description, but on the violet edge as well. Owing to the low altitude of the star (meridional altitude 20°) the plates are not of the best, particularly in the violet region, and it would be worth while at some observatory in the southern hemisphere, where better plates can be secured, to redetermine its orbit. The elements given here are regarded as provisional only.

Observations were commenced on the star in November, 1915, as it was felt that its unfavourable southern declination and poor spectrum would be offset by the large range in velocity. The first plate increased the already large range by showing a velocity of recession of 119 km. per sec. and later plates have further increased the range, so that now this star, so far as the writer is aware, shows the largest range in velocity of any spectroscopic binary yet known.

In our latitude it is necessary that the star be photographed while near the meridian and although it has been kept well in mind during the two seasons since work was com-

*Astrophysical Journal, vol. xxiii, page 265.

menced, yet only 26 plates have been secured in that time. Many of these are not of the best quality, nevertheless, it is felt that a determination of the star's orbit from them will be at least a good approximation.

The lines used for velocity determination have been the absorption lines given in the accompanying table. It was seen from some of the early plates that the ordinary wave-lengths were not suitable, probably owing to their being flanked with emission, and arbitrary values were assumed so as to suit the first few plates measured. These values have been retained, though better values could have been secured by correcting for the residuals given in the table. These residuals are in the sense, mean velocity of plate minus line velocity. While the region around $H\delta$ is generally underexposed and not the most reliable, yet there seems evidence that the wave-length for $H\delta$ must be even greater than the increased value used in the work.

LINES USED IN 29 CANIS MAJORIS

—	No. of Times Used	Weight of Lines	Mean Numerical Residual	Mean Algebraic Residual
4861·527	21	7	22·7	+ 3·7
4713·597	4	1¾	13·3	−13·3
4543·600	25	10⅜	14·6	+ 2·9
4471·676	25	9¼	15·4	− 7·4
4340·634	26	10	18·2	+ 5·8
4201·787	3	1¼	14·8	− 1·9
4102·396	8	2	21·9	−12·6
4097·550	3	¾	22·3	− 0·7

MEASURES OF 29 CANIS MAJORIS

λ	7418 Vel.	7418 Wt.	7483 Vel.	7483 Wt.	7505 Vel.	7505 Wt.	7513 Vel.	7513 Wt.	7518 Vel.	7518 Wt.	7540 Vel.	7540 Wt.	7543 Vel.	7543 Wt.
4861	…	…	+3·2	½	…	…	…	…	+181·6	½	−134·6	¼	+221·5	¼
4713	…	…	33·8	¼	…	…	…	…	…	…	…	…	…	…
4543	+82·2	¼	5·2	¼	+126·4	¼	−191·8	⅛	190·8	½	149·5	½	233·0	½
4471	106·9	¼	52·0	¼	93·3	¼	167·7	⅛	214·4	½	120·8	½	234·5	¼
4340	87·3	¼	40·6	½	+51·2	¼	−187·7	⅛	188·8	½	−169·5	½	+163·3	¼
4202	+128·5	¼	32·7	½	…	…	…	…	168·6	½	…	…	…	…
4097	…	…	+9·8	¼	…	…	…	…	+165·4	½	…	…	…	…
Weighted mean	+101·22		+25·36		+90·30		−182·40		+184·93		−144·86		+217·04	
V_a	+17·95		+0·95		−9·92		−12·05		−12·90		−15·72		−17·00	
V_d	+·04		+·04		−·10		·00		−·03		−·04		+·03	
Curv.	−·28		−·28		−·28		−·28		−·28		−·28		−·28	
Radial Velocity	+118·9		+26·1		+80·0		−194·7		+171·7		−160·9		+199·8	

MEASURES OF 29 CANIS MAJORIS—*Continued*

λ	7548		7569		7584		7593		7598		7913		7914	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4861	−165·2	½	− 33·4	¼	−126·5	½	+187·9	¼	+ 14·7	¼	+179·8	¼	+222·4	¼
4713	172·4	¼	......	......	......	......	......	......	......	......	......	......	......	......
4543	225·8	½	32·2	½	110·9	½	258·9	¾	51·4	¼	187·9	½	178·8	¼
4471	......	......	54·4	½	38·8	½	247·9	½	33·5	⅛	183·4	¼	199·0	½
4340	173·8	¼	71·6	¾	52·5	½	223·4	¾	+ 8·6	⅛	+223·4	½	143·8	¼
4101	126·8	¼	− 52·3	¼	− 57·9	¼	......	......	......	......	......	......	+186·7	¼
4097	−152·3	¼	......	......	......	......	+244·3	¼	......	......	......	......	......	......
Weighted mean	−175·90		− 52·63		− 79·20		+237·56		+ 29·05		+197·67		+188·27	
V_a	− 18·11		− 19·01		− 19·80		− 20·04		− 20·12		+ 17·04		+ 17·04	
V_d	− ·02		− ·02		− ·06		− ·09		− ·08		+ ·09		− ·04	
Curv.	− ·28		− ·28		− ·28		− ·28		− ·28		− ·28		− ·28	
Radial Velocity	−194·3		− 71·8		− 99·3		+217·2		+ 8·6		+214·5		+205·0	

MEASURES OF 29 CANIS MAJORIS—*Continued*

λ	7926		7927		7935		7957		7964		7970		7979	
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4861	...	...	−252·0	¼	− 86·9	¼	−205·5	¼	+ 12·0	½	...	...	−174·1	¼
4713	...	...	...	...	...	...	...	...	55·8	¾	...	...	178·1	½
4543	−151·5	¼	271·9	¼	122·9	¼	204·2	½	28·7	¼	− 68·4	¼	181·2	½
4471	181·1	½	230·3	¼	137·9	¼	196·0	¾	29·4	¾	101·6	½	180·1	½
4340	−176·3	¼	−227·1	¼	−119·8	¼	202·3	½	+ 31·2	½	− 58·6	½	−230·4	¼
4101	...	...	...	...	...	...	174·4	¼	...	...	...	...	...	...
4097	...	...	...	...	...	...	−151·9	¼	...	...	...	...	...	...
Weighted mean	−169·63		−245·33		−116·63		−193·28		+ 33·67		− 77·76		−185·35	
V_a	+ 12·24		+ 12·24		+ 11·03		+ 9·45		+ 7·44		+ 6·05		+ 1·75	
V_d	+ ·06		− ·07		·00		+ ·05		·00		+ ·04		− ·04	
Curv.	− ·28		− ·28		− ·28		− ·28		− ·28		− ·28		− ·28	
Radial Velocity	−157·6		−233·4		−106·1		−184·1		+ 40·8		− 72·0		−183·9	

MEASURES OF 29 CANIS MAJORIS—*Concluded*

λ	7984		8006		8019		8024		8058					
	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.	Vel.	Wt.
4861	− 78·1	¼	− 56·6	½	+282·5	¼	−233·5	½	−140·0	¼	...	...	...	...
4543	121·0	¾	...	...	247·1	¾	191·7	¾	210·0	¼	...	...	...	...
4471	135·3	½	72·6	½	230·9	½	159·3	¾	171·8	¼	...	...	...	...
4340	93·2	½	− 88·8	½	+229·0	½	213·4	¼	180·2	¼	...	...	...	...
4101	−152·2	¼	...	...	...	...	−165·5	¼	−145·2	¼	...	...	...	...
Weighted mean	−116·62		− 72·67		+242·95		−189·96		−169·44	...	...	...	...	...
V_a	+ 1·39		− 1·89		− 5·64		− 6·16		− 10·76	...	...	...	...	...
V_d	·00		− ·04		− ·10		− ·02		+ ·02	...	...	...	...	...
Curv.	− ·28		− ·28		− ·28		− ·28		− ·28	...	...	...	...	...
Radial Velocity	−115·5		− 74·9		+236·9		−196·4		−180·5	...	...	...	...	...

YERKES OBSERVATORY MEASURES

Date	Julian Date	Phase	Velocity	Lines	O-C
1906					
Jan. 26	2,417,237·742	1·887	−164	2	+28
Jan. 29	240·744	0·496	− 3	3	− 9
Feb. 12	254·653	1·224	−243	4	−61
Feb. 16	258·622	0·800	− 92	4	+ 3

OTTAWA MEASURES

Plate	Date	Julian Date 2,420,000 +	Phase	Absorption Vel.	Absorption Wt.	Absorption O-C	Emission Vel.	Emission O-C	Character of
	1915								
7418	Nov. 17	0,819·835	3·360	+119	3	+ 9			
	1916								
7483	Jan. 13	0,876·676	3·086	+ 26	4	− 8	+ 62	+28	faint
7505	Feb. 13	0,907·674	3·330	+ 80	2	−20	+102	+ 2	poor
7513	Feb. 20	0,914·645	1·515	−195	3	+ 8	−243	−40	faint
7518	Feb. 23	0,917·604	0·080	+172	6	+ 9			
7540	Mar. 5	0,928·583	2·273	−161	4	−15	−202	−56	
7543	Mar. 11	0,934·509	3·805	+200	4	−12	+169	−43	poor
7548	Mar. 17	0,940·550	1·059	−194	4	−36			
7569	Mar. 23	0,946·524	2·640	− 72	4	+ 4			
7584	Mar. 30	0,953·524	0·853	− 99	3	+11	− 48	+62	pronounced
7593	April 2	0,956·524	3·853	+217	5	− 2	+200	−19	
7598	April 3	0,957·519	0·455	+ 9	3	−16			
7913	Nov. 21	1,189·803	4·282	+214	3	+ 3			
7914	Nov. 21	1,189·869	4·348	+205	4	+ 8	+207	+10	poor
7926	Dec. 10	1,208·763	1·275	−158	2	+30	−153	+35	fair
7927	Dec. 10	1,208·826	1·338	−233	3	−39	−192	+ 2	fair
7935	Dec. 14	1,212·774	0·892	−106	3	+15	− 27	+94	pronounced
7957	Dec. 19	1,217·739	1·464	−184	3	+17	−230	−29	poor
7964	Dec. 25	1,223·741	3·073	+ 41	6	− 9	− 2	−48	good
7970	Dec. 29	1,227·713	2·651	− 72	3	+ 3			
	1917								
7979	Jan. 10	1,239·723	1·481	−184	4	+18			
7984	Jan. 11	1,240·702	2·460	−116	5	− 2			
8006	Jan. 20	1,249·696	2·667	− 75	3	− 5			
8019	Jan. 30	1,259·704	3·888	+237	4	− 5	+255	+23	fair
8024	Feb. 1	1,261·656	1·447	−196	4	+ 5	−206	− 5	
8058	Feb. 15	1,275·596	2·207	−180	3	+ 5	−235	−78	no contrast

The foregoing tables give the data of the observations and are for the most part self-explanatory. The phases are reckoned from the periastron passage finally adopted, using the period 4·3934 days which was arrived at by a comparison of the early observations with our own. While the velocities were carried through to the first decimal place, they are here rounded off as the decimal place has no significance in measures of a spectrum of this type. The probable error of an average plate obtained from columns 6 and 7 of the table is ± 10·0 km. per sec. The probable errors of the elements are, happily, not of corresponding magnitude, thanks to the large range in velocity.

While the emission lines have not been used in the determination, they partake of periodic displacements due to the star's orbital motion just as do the absorption lines.

The velocities quoted are for the line at the assumed wave-length λ 4687·536. It would seem from an examination of the plates, that the centre of this emission band shifts somewhat to the red when the emission is more pronounced. On only one of our plates is the *K* line discernible, and its position would lead one to expect that it does not share the great range in velocity shown by the other lines.

The twenty-six observations were grouped into ten normal places and after preliminary elements were taken, a least-squares solution was carried through giving small corrections to these values and with a reduction of 11 per cent. in the value of Σpvv for the normal places.

These preliminary elements were:

$$
\begin{aligned}
P &= 4\cdot3934 \text{ days}\\
e &= \cdot16\\
\omega &= 40^\circ\\
K &= 218 \text{ km.}\\
\gamma &= -12\cdot2 \text{ km.}\\
T &= \text{J. D. } 2{,}417{,}240\cdot259
\end{aligned}
$$

NORMAL PLACES

	Mean Phase	Mean Velocity	Weight	O−C		Mean Phase	Mean Velocity	Weight	O−C
1	0·455	+ 8·6	·3	−15·9	6	2·651	− 71·2	1·0	+4·1
2	0·872	−102·7	·6	+13·0	7	3·078	+ 34·9	1·0	+5·2
3	1·200	−199·2	·9	−19·9	8	3·348	+103·3	·5	−1·2
4	1·474	−189·8	1·4	+11·5	9	3·849	+215·6	1·3	−2·9
5	2·332	−146·9	1·2	− 9·6	10	4·390	+191·8	1·3	+3·0

The Lehmann-Filhés formula was used and making the transformations,

$$x = \delta\gamma$$
$$y = \delta K$$
$$z = K.\delta e$$
$$u = K.\delta\omega$$
$$v = \frac{K}{(1-e^2)^{\frac{3}{2}}} \cdot \mu \cdot \delta T$$

the observation equations were:—

—	x	y	z	u	v	
1.	1·000	+ ·137	− ·867	−1·101	+1·219	+ 9·0=0
2.	1·000	− ·504	− ·836	− ·882	+ ·784	−19·5=0
3.	1·000	− ·778	− ·001	− ·529	+ ·371	+16·4=0
4.	1·000	− ·872	+ ·626	− ·204	+ ·080	−12·6=0
5.	1·000	− ·553	+ ·584	+ ·634	− ·520	+14·0=0
6.	1·000	− ·268	− ·031	+ ·817	− ·676	+ 0·5=0
7.	1·000	+ ·214	− ·835	+ ·893	− ·821	− 0·6=0
8.	1·000	+ ·549	− ·993	+ ·802	− ·832	+ 4·1=0
9.	1·000	+1·060	+ ·116	+ ·247	− ·408	+ 3·2=0
10.	1·000	+ ·908	+ ·807	− ·723	+ ·834	− 6·2=0

From these observation equations were derived the normal equations:

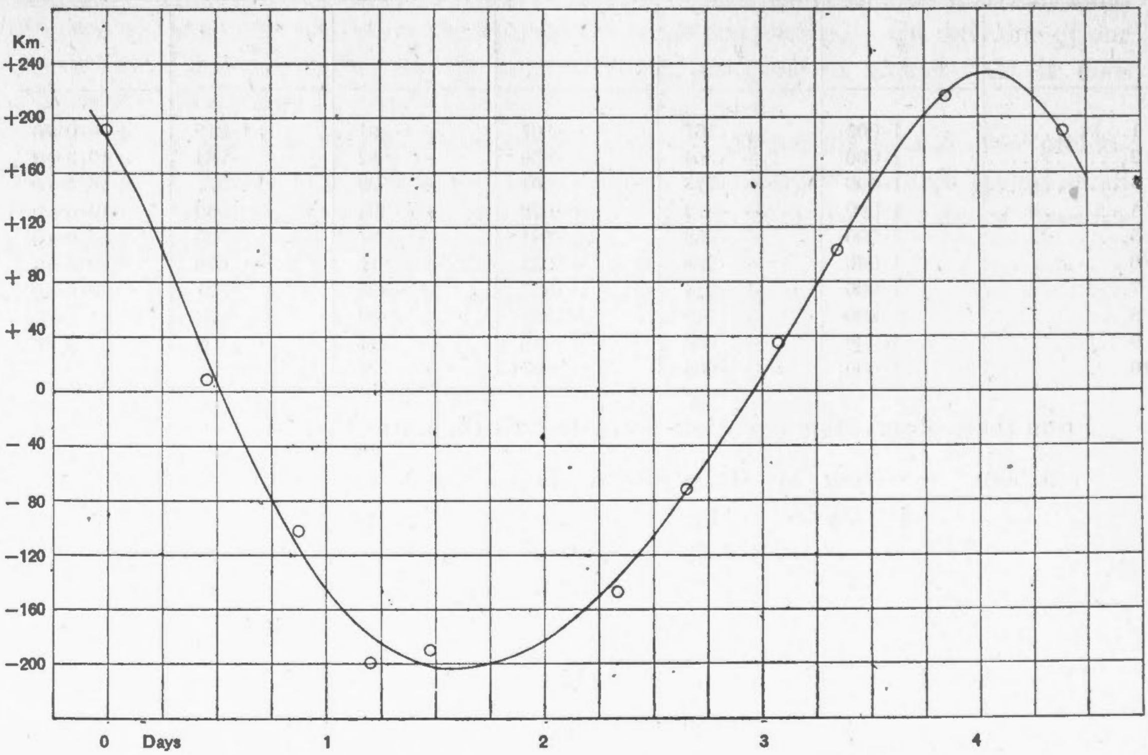
$$9{\cdot}500x - {\cdot}088y + {\cdot}652z + {\cdot}633u - {\cdot}702v + 2{\cdot}970 = 0$$
$$4{\cdot}925y - {\cdot}245z + {\cdot}122u - {\cdot}026v - 1{\cdot}383 = 0$$
$$3{\cdot}657z - {\cdot}898u + {\cdot}931v - 1{\cdot}360 = 0$$
$$4{\cdot}165u - 3{\cdot}946v + 22{\cdot}165 = 0$$
$$3{\cdot}868v - 20{\cdot}494 = 0$$

The corrected elements, with their probable errors, are then the following:—

$$P = 4{\cdot}3934 \text{ days}$$
$$e = {\cdot}156 \quad \pm {\cdot}017$$
$$\omega = 37^\circ{\cdot}64 \quad \pm 4^\circ{\cdot}95$$
$$K = 218{\cdot}44 \text{ km.} \quad \pm 3{\cdot}14 \text{ km.}$$
$$\gamma = -12{\cdot}12 \text{ km.} \quad \pm 2{\cdot}28 \text{ km.}$$
$$T = \text{J. D. } 2{,}417{,}240{\cdot}248 \quad \pm {\cdot}061$$
$$a \sin i = 13{,}035{,}000 \text{ km.}$$
$$\frac{m_1^3 \sin^3 i}{(m+m_1)^2} = 4{\cdot}58 \odot$$

The curve shown represents the final elements with the observations as grouped.

Dominion Observatory
Ottawa
May, 1917.



Velocity Curve of 29 Canis Majoris

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