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C.P.D.—41°·4511

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VARIATION OF THE STAR C.P.D. - $41^{\circ}4511$.

By A. W. ROBERTS, D.Sc.

(Read October 2, 1901.)

The star C.P.D. - $41^{\circ}4511$

R.A. 10h. 16m. 44s. (1875)

Dec. $41^{\circ}43'8$

has recently been discovered, through the assiduous and fruitful industry of Mr. R. T. A. Innes, of the Royal Observatory, to be an Algol variable of a very interesting type.

I purpose in the present paper stating very briefly what this type of variation is, and indicating the physical conditions of orbital movement that have produced the light changes observed.

The star came under observation at Lovedale in July of this year. A few nights' observation was sufficient to establish the fact that the star was an Algol variable.

By the end of the month sufficient measures had been secured to yield a full light curve.

It was matter of some regret that the western position of the star in the evening sky prevented an extended series of observations from being taken every evening. Still, as stated, enough observations were obtained to indicate unmistakably the complete form of the light curve.

Mr. Innes was good enough to send me some of his earlier measures, and these, combined with my own, yield as the full period of variation—

1d. 20h. 30m. 3s.

With this period all the observations made were reduced to the

mean light curve of 1901, July 1 and 2. These reduced observations are as follows :—

Reduced Date.			Mag.	Reduced Date.			Mag.	Reduced Date.			Mag.		
1901. d.	h.	m.	m.	1901. d.	h.	m.	m.	1901. d.	h.	m.	m.		
1. July 1	1	12	10·00	33. July 1	20	50	10·00	64. July 2	13	45	10·00		
2.	2	3	10·00	34.	21	14	9·90	65.	13	48	10·05		
3.	2	15	10·00	35.	22	10	9·90	66.	14	50	10·25		
4.	2	33	10·00	36.	22	57	10·00	67.	15	5	10·35		
5.	2	45	10·00	37.	23	10	10·00	68.	15	5	10·40		
6.	2	45	9·90	38.	1	23	20	10·00	69.	15	12	10·45	
7.	4	6	10·00	39.	2	1	0	10·00	70.	15	15	10·40	
8.	5	25	10·00	40.	1	50	9·90	71.	15	20	10·55		
9.	5	55	10·00	41.	2	45	10·00	72.	15	25	10·60		
10.	6	25	10·00	42.	3	0	10·00	73.	15	35	10·60		
11.	6	30	10·00	43.	4	15	10·00	74.	15	35	10·75		
12.	7	0	10·00	44.	4	52	10·00	75.	15	40	10·60		
13.	7	44	10·00	45.	5	25	10·00	76.	15	50	10·70		
14.	9	36	10·00	46.	6	25	10·00	77.	15	50	10·85		
15.	9	45	10·00	47.	6	30	10·00	78.	15	55	10·75		
16.	10	0	10·10	48.	7	5	10·00	79.	16	0	10·85		
17.	10	0	10·00	49.	7	26	10·00	80.	16	5	10·75		
18.	10	58	10·00	50.	7	30	10·00	81.	16	15	10·95		
19.	13	30	10·00	51.	8	15	10·00	82.	16	30	10·90		
20.	13	45	10·00	52.	8	42	10·05	83.	16	30	10·85		
21.	14	30	10·10	53.	9	15	10·05	84.	16	45	10·80		
22.	15	0	10·00	54.	9	30	9·90	85.	16	48	10·95		
23.	15	58	10·00	55.	10	15	10·00	86.	17	0	10·65		
24.	16	0	10·00	56.	10	30	10·00	87.	17	0	10·60		
25.	17	0	10·15	57.	11	30	10·00	88.	17	15	10·45		
26.	18	0	10·15	58.	11	42	9·90	89.	17	15	10·68		
27.	18	30	10·00	59.	12	15	10·00	90.	17	30	10·30		
28.	19	0	10·05	60.	12	48	10·10	91.	17	45	10·25		
29.	19	0	10·00	61.	13	10	9·90	92.	18	0	10·15		
30.	20	0	10·00	62.	13	20	10·20	93.	18	15	10·15		
31.	20	0	10·10	63.	2	13	40	10·10	94.	2	19	30	10·05
32.	1	20	44	10·00									

From these observations the following elements of light variation can be readily determined :—

Full period of variation	1d. 20h. 30m. 3s.
Epoch of prin. min.	1901. July 2d. 16h. 17m.
Epoch of second. min.	July 1d. 17h. 30m.
Magnitude at max.	10·00m.
Magnitude at prin. min.	10·90m.
Magnitude at second. min.	10·15m.
Duration of prin. mid.	4h. 30m.
Duration of increasing phase...	2h. 15m.
Duration of decreasing phase...	2h. 15m.

The explanation of Algol variation which has commended itself to astronomers generally, is that every Algol variable is a binary star,

the components of which move in an orbit almost coincident with the line of sight. In the case of three Algol stars this theory is supported by spectroscopic evidence. It may be remarked that these three cases are the only ones where such confirmation is possible, at least in the present limitations of spectroscopic research.

Now in a binary system whose orbit is situated in the plane of sight, it is evident that eclipse, partial or total, will take place every revolution. The amount, duration, and chief features of this eclipse will depend upon the form and position of the orbit in which the stars move, as well as on their relative size and brightness. Further, it is possible to express in set terms and definite relations the connection which exists between the elements of light variation and the orbital elements on which the elements of light variation depend.

It is beyond the purpose of this paper to deal with these relations. Sufficient to say that the variation of C.P.D. - 41°4511, was rigorously subjected to analysis in order to ascertain the form and dimensions of the orbit in which it moved.

Subsequent observations may, to a very limited extent, modify the results thus determined, but the following conclusions will not be essentially altered by any new data :—

(1) The Algol variable C.P.D. - 41°4511 is an Algol close binary star, whose period of revolution is equal to its full light cycle, viz. :—

1d. 20h. 30m. 3s.

(2) The epoch when the two component stars move into the line of sight is—

1901, July 2d. 16h. 17m. (C.M.T.)

(3) The orbit is practically circular and inclined 6° to the plane of sight.

(4) The two stars are equal in size, the diameter of any one of them being equal to one-third the radius of the orbit.

(5) The two stars are unequal in brightness, one being 6.14 times brighter than the other.

(6) The density of the system is a little less than half that of the sun.

In order to test the dependence which can be placed on these results we invert the problem, and from the conditions of orbital movement and dimensions, compute a theoretical light curve.

Assuming that C.P.D. - 45°4511 moves in an orbit of which the foregoing is a numerical description, then three equations are sufficient to set forth the magnitude of the star at any instant.

These three equations are:—

$$(1) \quad \cos \phi = 3.077 \sqrt{1 - 0.991 \cos^2 (0.135T)^2}$$

$$(2) \quad L = 1 - 0.274 (2\phi - \sin 2\phi)$$

$$(3) \quad \text{Mag.} = 2.5 (10 - \log L) + 10.05m.$$

In Fig. (1) is given the light curve of C.P.D. - 45°4511 as determined from observation. The thick dotted line represents the mean *observed* light curve.

In the same Figure the *theoretical* light curve as determined from equations (1), (2), and (3), is indicated by a fine dotted line.

The two light curves are practically identical. This accordance between theory and observation is remarkable. It is testimony to the validity and accuracy of the conclusions come to as explanatory of the star's variation.

It is also, I think, strong presumptive evidence against the meteoric theory of stellar variation—at least as an explanation of the variation of C.P.D. - 41°4511.

The value of the density obtained also bears directly on this question.

It is true that the density of C.P.D. - 41°4511 is considerably greater than the mean density of stars of this type or class. In the *Astrophysical Journal*, vol. x., No. 5, I pointed out that the average density of close binary stars is—

$$0.13.$$

A more recent investigation (not yet quite completed) based on my own observations of eight southern Algol stars confirms this value.

In the case of C.P.D. - 41°4511 we have a value of the density equal to three times this mean value, and the pertinent question arises, Is it possible to have a globular mass of meteors, the density of which is—

$$0.4$$

or one-half that of the sun?

It is possible if the meteors be solid bodies, of the specific gravity of iron, and each meteor separated from its fellow by less than its own diameter; but under no other conditions. Against this assumption we postulate a luminous body revolving on its axis in less than two days, and consequently subjected to great tidal stress and strain.

In a boundless universe there are no doubt boundless possibilities of structural divergence; but in our explanation of such phenomena

Light curve of C.P.D. -41° 45II
1901 July 2.

as observation makes us acquainted with, we are limited in two directions.

(1) We must apply to all facts that come within the range of our knowledge only such explanations as are rational and intelligible, and which are warranted by our experience of that which is more immediate.

(2) The explanations preferred must be applicable to, and sufficient for, all the phenomena of a well-defined class or type.

If the theory fails in any one single instance it is inferior, as an explanation, to that which meets every case.

Judged by these criteria, the meteoric theory of stellar variation fails.

Far more sufficient, valid, and intelligible is the theory which regards variable stars as the first stage in that long spiral evolution of stellar systems which, starting with contiguous homogeneous gaseous bodies, ends in such binary systems as Alpha, Centauri, and Castor.

The successive stages of stellar development thus form a unified, orderly, related sequence.

In the early stages we have contiguous bodies of gaseous density and of apoidal figure revolving round one another in a few hours. When these contiguous stars move in orbits the plane of which passes through the earth, their movement is made evident as Algol variation. The orbits of stars in this stage of development are nearly all circular.

As the component stars move further and further apart, their orbits take to themselves a greater eccentricity; the influence of this eccentric motion is made evident as short period variation.

And then in the process of ages the star becomes a visual binary.

There is nothing in this statement of cosmic evolution to offend either our sense of the necessity to make observation and theory agree, or our appreciation of that unity and order which compasses the heavens as a garment.

Mr. R. T. A. Innes adds :—

This star was first suspected to be variable by Professor J. C. Kapteyn, of Groningen, from his examination of the plates taken for the Cape Photographic Divichmusterung. Four plates, covering the region of the sky where this star is situated, were sent him from the Royal Observatory; on three, the star appeared of the 9.6 magnitude, but on the fourth plate it was only of the 10.5 magnitude. Lest this might be due to some photographic defect, Professor Kapteyn

examined the image with a microscope; it was perfectly normal, making the variability of the star highly probable. Professor Kapteyn communicated these facts to Sir David Gill, who kindly gave me the matter for further investigation. As this star falls within the Cape zone of the *Carte du Ciel*, there were a number of plates available for a further examination without recourse to the sky. I examined these, twelve in number, but found no certain difference of magnitude. But my first telescopic observation on Feb. 20, 1899, caught the star at a low magnitude (10·5); this was fortunate, as I did not secure another minimum for sixteen months. Had my first observation not happened as it did, the confirmation of variability and Dr. Roberts's interesting paper might have been delayed many years, as both the *Carte du Ciel* plates and my other visual observations extending over sixteen months offered no evidence of change of magnitude.

At the Cape Observatory we have now secured in all nine observed minima covering 2,202 periods in 4,083 days, yielding a period of—

$$1\text{d. } 20\text{h. } 30\text{m. } 2\cdot9\text{s.},$$

a difference from Dr. Roberts's result of only one-tenth of a second—a quantity far smaller than the probable error to which such determinations are liable.