Comets, 7th edition, and Remarkable Eclipses, 4th edition, presented by the author; L. Weinek, Photographischer Mond-Atlas, Heft 4–6, presented by Professor Weinek; E. T. Whittaker, Report on the progress of the solution of the problem of three bodies, presented by the author; Bronze copy of the Stokes Jubilee Medal, presented by the University of Cambridge.

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## *On the Binary System of Capella.* By H. F. Newall.

A very brief announcement of the discovery of the binary character of *Capella* was made in a note communicated to the Society in 1899 November (*ante*, p. 2). A similar announcement was made by Professor Campbell, of the Lick Observatory, in the October number of the *Astrophysical Journal* (vol. x, p. 177). Two brief communications have been made to the Observatory (1900 February, pp. 92, 93). The object of the present note is to lay before the Society the result of a preliminary investigation of the photographs of the spectrum of *Capella* which have been obtained at Cambridge.

A new four-prism spectroscope was attached to the 25-inch equatorial in 1899 July. Some of the earliest photographs obtained with it were spectra of *Capella*; and it was at once noticed that the definition appeared poor and unsatisfactory. From night to night it varied in a curious manner; and it became clear that the peculiarities were real, and not due to instrumental defects, for excellent photographs were obtained of the spectra of other stars—notably of *Procyon* and *Sirius*.

After a preliminary study of ten or twelve photographs of the spectrum of *Capella*, it seemed clear that the spectrum was composite, and lines were picked out as belonging to one component, which we will call the solar component, and other lines as belonging to another component, which in the short range of spectrum dealt with has the characteristics of the spectrum of *Procyon* and $\gamma$ *Cygni* and $\alpha$ *Persei*; it will be convenient to refer to it in what follows as the *Procyon* component. It is difficult to make out the spectrum; and I think it not unlikely that this choice of name may require revision.

Measurements were then made in the short range of spectrum $\lambda\lambda$ 4250–4325; and the results in the case of the solar component are given in the following table, and are plotted in the accompanying plate; ordinates representing the velocity of that component relative to the Sun, with time as abscissa. The curve drawn through the observations is a sine curve, to which further reference will be made below. In the table the first column contains the plate number, the second the date, the third the duration of exposure, the fourth the velocity deduced from the photograph (*i.e.* the velocity relative to Earth), the fifth the correction for orbital motion of the Earth, and the last column the velocity relative to the Sun.

*Velocity of Solar Component of α Aurigæ.*

| | 1899. | G.M.T. | Exp. | Vel. rel. to ⊕ | Corr. to ☉ | Vel. rel. to ☉ |
|---|---|---|---|---|---|---|
| F. 21 | Sept. 28 | 12.20 | 60 | −23·5 | +26·3 | + 2·8 |
| F. 22 | Oct. 2 | 12.19 | 60 | −18·2 | +25·7 | + 7·5 |
| F. 32 | 16 | 10.58 | 75 | + 8·3 | +22·8 | +31·1 |
| F. 33 | 17 | 10.30 | 75 | + 3·2 | +22·6 | +25·8 |
| F. 34 | 18 | 10.54 | 75 | +12·4 | +22·3 | +34·7 |
| F. 38 | Nov. 1 | 9.55 | 62 | +33·2 | +17·9 | +51·1 |
| F. 39 | 6 | 9.12 | 75 | +34·4 | +16·0 | +50·4 |
| F. 40 | 6 | 10.43 | 63 | +37·3 | +16·0 | +53·3 |
| F. 44 | 8 | 9·56 | 62 | +37·9 | +15·2 | +53·1 |
| F. 46 | 10 | 9.17 | 70 | +41·1 | +14·4 | +55·5 |
| F. 48 | 11 | 10.15 | 60 | +41·8 | +14·0 | +55·8 |
| F. 49 | 17 | 9.16 | 60 | +39·6 | +11·4 | +51·0 |
| F. 50 | 20 | 9.40 | 60 | +39·6 | +10·1 | +49·7 |
| F. 54 | 23 | 9.16 | 70 | +37·8 | + 8·8 | +46·6 |
| F. 56 | 28 | 8.45 | 70 | +32·3 | + 6·5 | +38·8 |
| F. 58 | Dec. 1 | 8.47 | 70 | +27·8 | + 5·1 | +32·9 |
| F. 62 | 2 | 9.6 | 60 | +28·3 | + 4·6 | +32·9 |
| F. 64 | 11 | 6.40 | 50 | +22·7 | + 0·3 | +23·0 |
| | 1900. | | | | | |
| F. 67 | Jan. 9 | 5.57 | 62 | | | |
| F. 71 | 17 | 12.6 | 60 | +26·6 | −16·9 | + 9·5 |
| F. 72 | 18 | 12.34 | 63 | +30·1 | −17·3 | +12·8 |
| F. 73 | 20 | 12.22 | 70 | +38·1 | −17·8 | +20·3 |
| F. 76 | 24 | 12.30 | 70 | +42·8 | −19·3 | +23·5 |
| F. 79 | 27 | 11.10 | 70 | +48·4 | −20·3 | +28·1 |

The method adopted in deducing the velocity was as follows: The wave-lengths of the chosen lines in the spectrum of the star were determined with reference to the lines in the comparison spectrum of the iron spark, interpolation being performed by means of the relation $\lambda-\lambda_0=c/(R_0-R)$, to which Dr. Hartmann has called attention recently. The three constants, $\lambda_0$, $c$, $R_0$, are determined from three standard lines in the iron-spark spectrum.

The linear dispersion of the spectra obtained with the instrument is approximately six tenth-metres per millimetre, or 1·5 tenth-metres per revolution of the micrometer used for measuring the spectra. Wave-lengths of lines in the spectra can be determined with reference to the comparison spectra of the iron spark to within about 0·02 of a tenth-metre.

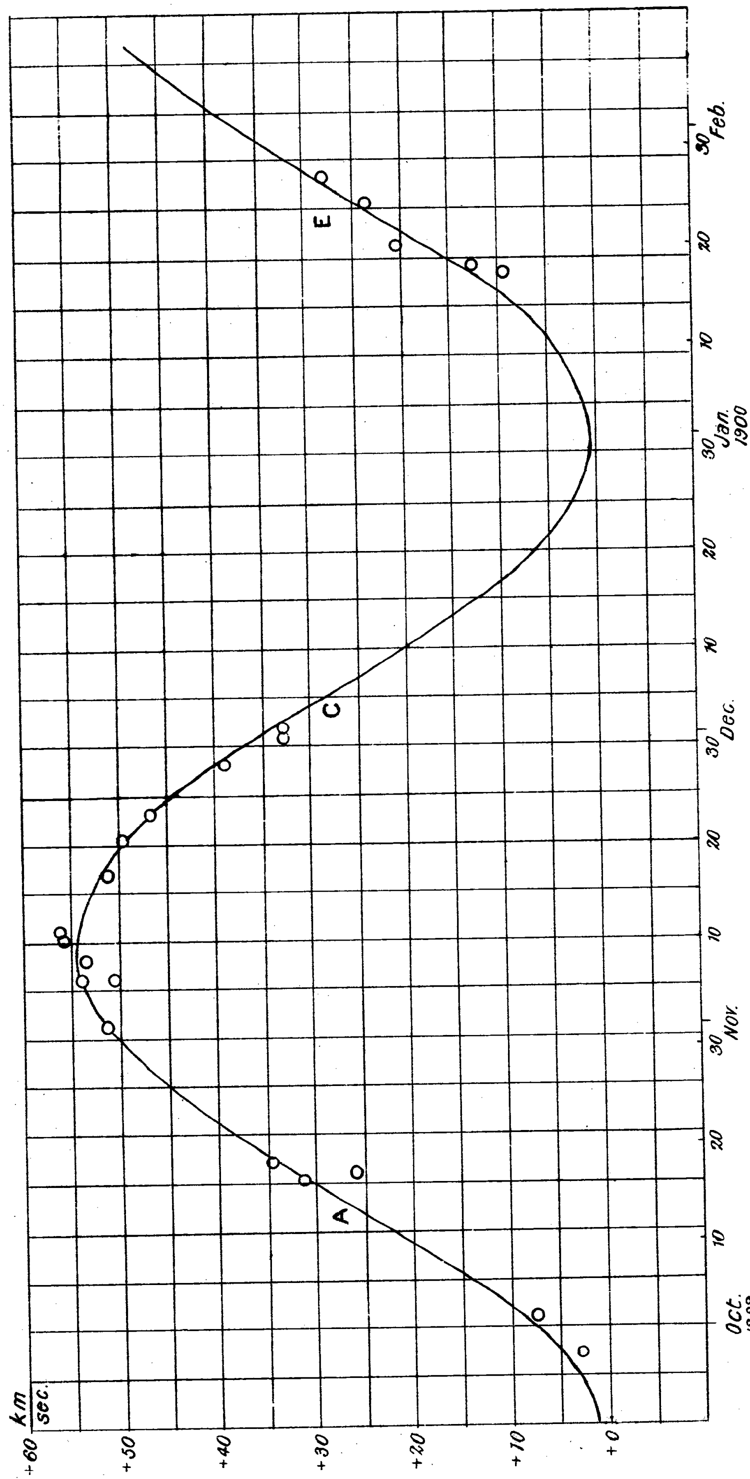
The same three standard lines in the iron-spark spectrum have been used in the reduction of all the plates; hence any error that may be introduced by assigning to them the wave-lengths given by Rowland for the corresponding lines in the solar spectrum instead of values of wave-lengths in which account is taken of the effects of pressure in the spark, affects all the plates approximately equally.

Thus, in the plate F. 39, taken 1899 November 6, the following wave-lengths were deduced for chosen lines in the star spectrum:

| Wave lengths (affected by velocity) of the Star-lines | Wave lengths in Rowland's Tables of Solar Spectrum. | Shift of Line $\delta\lambda$. | Corresponding Velocity. |
|---|---|---|---|
| 4275·47 | 4274·99 | +0·48 | +33·7 km/sec |
| 76·25 | 75·68 | 0·57 | 40·0 |
| 88·77 | 88·21 | 0·56 | 39·1 |
| 92·79 | 92·30 | 0·49 | 34·2 |
| 93·85 | 93·28 | 0·57 | 39·8 |
| 94·77 | 94·25 | 0·52 | 36·3 |
| 95·67 | 95·28 | 0·39 | 27·3 |
| 4302·13 | 4301·67* | 0·46 | 32·1 |
| 07·07 | 06·59* | 0·48 | 33·5 |
| 14·77 | 14·34 | 0·43 | 30·0 |
| 15·59 | 15·13 | +0·46 | +32·0 |
| | | Mean | +34·4 |
| | Correction for Earth's orbital velocity | | +16·0 |
| | Velocity relative to ☉ | ... ... | +50·4 km/sec. |

The velocities come out very consistently considering the difficulties in deciphering the superposed and shifted spectra of the two components. It will be realised that twice in each period the superposed spectra are coincident, line for line; the lines appear single and distinct, and the spectrum looks in nearly all respects like a well-defined solar spectrum. This occurs when the velocities of the two components are alike, namely, near the points marked A, C, E on Plate 11. At all other times the spectrum looks more or less ill-defined in a curious way; some lines look double, others are at first sight unexpectedly intensified, others apparently obliterated. Enlarged transparencies of well-defined single spectra have been made (i.) of the Sun, (ii.) of *Procyon*; when they are superposed on one another, the films being in contact, one spectrum can easily be shifted relatively to the other, and the resultant spectrum has been found to reproduce all the above-described effects in a very striking

* Bright spaces between absorption lines, wave-lengths determined in terms of Rowland from separate photographs.




*Velocity of Solar Component of the binary Capella.*

manner. A cursory inspection of the various combinations has been very helpful in guiding one to the choice of lines suitable for measurement. One of the most curious effects brought out is the apparent obliteration of certain groups of lines when the two spectra are appropriately shifted, relatively to one another.

The measurements relating to the *Procyon* component are somewhat difficult, and unfortunately there was a spell of cloudy weather at an important phase of the observations, when the two spectra were shifted relatively to one another in such a way that it would probably have been least difficult to decipher the spectrum of that component. I therefore defer dealing with the motion of the *Procyon* component, and will here only state that it appears to be such as to lead me to think that the masses of the two components are not very different from one another. Furthermore, the relative distinctness of the two superposed spectra points to the probability that the two components do not differ much in brightness.

It is seen that the sine curve appears to satisfy the observations fairly well, but there is evidence that a better curve could be found. The orbit is consequently not quite circular, but nearly so.

A period of 104 days is deduced from the observations of the solar component. Passing the same curve through the velocities deduced by Professor Campbell from photographs taken in 1897, it is easy to pick out corresponding phases. A second approximation to the period is thus obtained, 104·0 days.

Here may be noted an interesting point connected with the Potsdam observations of *Capella* in 1888. It will be remembered that specially careful determinations were made of the velocity of this star, and the concordant results deduced may now clearly be taken as indicating the constancy of the motion of translation of the whole system of *Capella*. From twelve photographs taken between 1888 October 6 and 1889–September 15, Dr. Vogel made twenty-five determinations, and Dr. Scheiner fourteen determinations of the velocity with the definitive results :

| | | | |
|---|---|---|---|
| Vogel | ... | ... | +24·8 km/sec. |
| Scheiner | ... | ... | +24·1 km/sec. |

The velocity of the system at the present time is +27 or +28 km/sec.

It was the custom of the Potsdam observers to give a note of the general appearance of the photographs measured ; and some of the spectra obtained were described as good, and others as "verwaschen" or "unscharf," and in one case Dr. Vogel ascribes the want of definition to the faulty setting of the camera.

In determining the wave-lengths of the lines in *Capella* Professor Scheiner made use of two photographs, each of which he describes as "ganz ausgezeichnetes Spectrum" (*Potsdam Obs.*, vol. vii., page 257), one taken 1888 October 24 and the other 1888 December 13. It appears that photographs were also obtained on October 22 and on October 25, and that the photograph of October 24 may have been picked out as the best-defined spectrum. Possibly, then, October 24 was an epoch when the velocities of the two components were equal. If so, then the second photograph should correspond with an epoch 52 or 104 days later. The interval between October 24 and December 13 is 50 days, an agreement which may be taken as satisfactory, when it is borne in mind that at the epoch considered the width of the lines in the spectrum increases only at the rate of 0·02 tenth-metre per day.

Again, if the above inference is justifiable and the period 104 days is constant, then the interval between 1888 October 24 and 1899 December 6, which latter date is the epoch in my observations when the velocities were found to be equal and the definition of the spectrum at its best, should be either an exact number of periods or should differ from it by half a period. Now, the interval is 4060 days, or $39{\cdot}04 \times 104$ days. Hence we might arrive at another approximation to the period, viz. 104·1 days; but these are somewhat risky foundations, either for an accurate determination of the period of the system or in support of the view that the period has remained constant.

As to the system of *Capella*, one or two interesting points may be noted.*

The spectroscopic observations show

I. That the components are nearly equal in mass.

II. That the components are not very different in brightness.

III. That the radius of the relative orbit is at least 52,000,000 miles. This is the smallest orbit consistent with the spectroscopic observations; it corresponds to the case when the orbital plane is seen "edge on." Such an orbit would involve eclipses of one component by the other, and consequently also variability in brightness; but no sign of variability has been detected in *Capella*. If the orbit is inclined so that the angle between its normal and the line of vision is $i$, then the radius of the orbit is $52 \times 10^6/\sin i$ miles.

Let $a$=actual radius of the relative orbit= $52 \times 10^6/\sin i$

$s$=maximum telescopic separation of the components expressed in seconds of arc (not yet observed)

D=distance of the system from the Sun

R=distance of the Earth from the Sun

$p$=parallax expressed in seconds of arc;

then we have $$\frac{a}{D} = s \,.\, \sin 1''$$

* In this connection reference should be made to an interesting note by Miss Clerke in *The Observatory*, 1900 March, p. 127.

and $$\frac{R}{D} = p \, . \sin 1'' ;$$

whence $$a = \frac{sR}{p} = \frac{52 \times 10^6}{\sin i}$$

or $$\frac{s \, . \sin i}{p} = \frac{52}{93} .$$

Now, Dr. Elkin gives for the parallax of *Capella* the value 0″·08. And *Capella* has not been observed telescopically as a double-star; its components are therefore presumably less than 0″·1 apart. Hence we infer that to make the spectroscopic observations fit with these data, we must have

$$\sin i > \frac{8 \times 52}{10 \times 93}, \text{ or } \cdot 447,$$
$$\text{or } i > 27^\circ .$$

Even when $i = 90°$, the maximum telescopic separation of the components, if Elkin's parallax be accepted, must be at least 0″·04.

With respect to the mass of the system, let

M = the mass of the solar component,
$n$M = the mass of the *Procyon* component,
U = the period of the binary system.

Then we have $$M = \frac{a^3(1+n)^2}{U^2} .$$

Since the solar component moves with an orbital velocity of $\frac{27}{\sin i}$ km/sec we deduce that the radius of its orbit (assumed circular), is

$$a = \frac{38 \cdot 6 \times 10^6}{\sin i} \text{ kilometres or } \frac{24 \times 10^6}{\sin i} \text{ miles.}$$

Hence the mass of the *Capella* system is

$$(1+n) \, M = \frac{24^3}{93^3} \cdot \frac{365^2}{104^2} \cdot \frac{(1+n)^3}{\sin^3 i} \times \text{Sun's mass}$$
$$= 0 \cdot 212 \times \frac{(1+n)^3}{\sin^3 i} \times \text{Sun's mass.}$$

And if, accepting I, we put $n = 1$, we have

$$\text{mass of } \textit{Capella} \text{ system} = \text{Sun's mass} \times \frac{1 \cdot 7}{\sin^3 i} ;$$

and, accepting Elkin's parallax, and assuming that the components are less than 0″·1 apart, we have

$$\text{mass of } \textit{Capella} \text{ system} < 19 \times \text{Sun's mass.}$$

With reference to the brightness of *Capella*, we have the following considerations:—If the Sun were removed to the distance of *Capella*, it would appear 32 magnitudes fainter than at its present distance. Taking the Sun's magnitude as $-25{\cdot}5$, and *Capella's* as $+0{\cdot}2$, we find

*Capella's* brightness=480 times the Sun's brightness.

If the components are equal and have the same intrinsic brightness of surface as the Sun, it would appear that each component must have a diameter about 15 times that of the Sun. In this case eclipses could only be avoided if the angle between the normal to the orbit and the line of sight is not greater than that value which satisfies the equation $\frac{15\times 8\times 10^5 \sin i}{52\times 10^6}=\cos i$, or $i=77°$.

These considerations are enough to show that we are nearly within reach of interesting *facts* relating to the evolution of stars. If telescopic observations show that *Capella* is a double star, we shall be in a position to deal with a known case of a star with a spectrum similar to that of the sun, though its mass and brightness may be very different. The complete investigation of the spectrum of the *Procyon* component is also likely to be of great interest in the same connexion.

I have great pleasure in taking this opportunity of saying that I owe much to the skill and care of my assistant, A. W. Goatcher. He has secured more than half of the photographs from which I have made the measurements contained in this note; and I am indebted to him in numberless ways for his unremitting patience and devotion.

*Note.*—The best chance of detecting doubleness in *Capella* by visual observations through a large telescope will first occur about April 13, or say between April 3 and April 23. The approximate equality in brightness of the components shows that a dark glass may be used at the eye-end.

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## *Photographic Observations of Hind's Variable Nebula in Taurus, made with the Crossley Reflector of the Lick Observatory.* By James E. Keeler, D.Sc.

The region of *T Tauri* and Hind's variable nebula has frequently been scrutinised by observers with visual telescopes, but I have been unable to find any record of photographic observations. In making out an observing list for the Crossley Reflector, this region was therefore noted as specially requiring attention.