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THE SEMI-REGULAR VARIABLE o^1 CENTAURI

by

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Summary

The supergiant star o^1 Centauri is show to be a semi-regular variable. Cycles of about 700 days can be seen in the light curve reproduced here, based on 1175 measures on photographic plates taken between 1934 and 1952.

The variable star o^1 Centauri was discovered by the writer in 1937 with a blink comparator on plates taken at Riverview Observatory, but the type of variation was not detected at the time and nothing was published. It was discovered independently by COUSINS[1] at the Cape Observatory when measuring the magnitudes of bright southern stars by the Fabry method.

The star is so bright that estimates on the Riverview plates are very difficult, owing partly to the large distances of most of the comparison stars from the variable and partly to the fact that, on most of the plates, the variable and comparison stars are close to the edge and are considerably distorted. As it seemed that the variable might prove to be an interesting one, it was decided to measure the plates on the HAFFNER-SARTORIUS photometer of the Vatican Observatory.

Comparison Stars

The comparison stars are listed in Table 1, with the HD number and spectrum, Lick spectrum[2], Cape photographic magnitude (SPg scale)[3], Cape colour index (SCI)[3], and, in the last column, the photographic magnitude on the Cape BPg scale[4]. The magnitude of star *d* was determined from comparison with a sequence of ten nearby stars chosen from Cape Annals 20. This sequence, together with star *d*, was measured with the photometer on 14 Riverview plates on which the sequence was not far from the centre. It was found that the colour equation of the Riverview plates differs appreciably from that of the Cape SPg scale, but that it is close to the BPg scale of magnitudes observed with the Fabry photometer at the Cape Observatory[4]. The magnitudes of the comparison stars were reduced to the BPg scale by means of the relations given in Cape Mimeogram 1.

TABLE 1

Comparison Stars

Designation	HD	Spectrum		Cape An. 20		BPg
		HD	Lick	SPg	SCI	
				m	m	m
a = o² Cen	100262	A2p		5.37	+.20	5.49
b	101570	G0	cG6	5.90	+.99	6.16
c	101021	K0	K2	6.10	+.98	6.36
c′	100773	F0		6.70	+.08	6.80
d	100380	A2		—	—	6.93
o¹ Cen	100261	F8p	cG4		+.95	var.

I suspected that the comparison star *b* is variable. The probable error of one measure of *b*, obtained from the root mean square of the deviations from the mean of the measures on 55 plates taken at random, is $\pm 0^{m}.038$. This is greater than the probable error of one measure of the variable (see below, p. 355) and indicates that star *b* (HD 101570) is indeed slightly variable, the extreme magnitudes measured on these plates being $5^{m}.99$ and $6^{m}.23$. The radial velocity of HD 101570 is also variable, from —4.4 to +23 km/sec.[5,6].

Stars *c* and *c′* are rather far from the variable, and the distortions of the images due to distance from the plate centre are different from those of the variable. Furthermore the corrections due to distance from the plate centre are different for the two main series of plates. On account of the additional sources of error due to these factors it was thought better to use only the two comparison stars, *a* and *d*, that are close to the variable, in spite of the considerable difference in brightness between these two stars.

The Measures

Measures were made on 1175 Riverview plates taken between 1934 and 1952. On 510 plates centred on α Crucis, and on 555 centred on η Carinae, all taken with the R and P ZEISS Astrotriplet cameras, the variable is near the edge of the plate. On the remaining 110 plates, 65 taken with the R and P cameras and 45 with the G camera (Ross-Grubb-Parsons triplet), the variable is nearer to the centre. There are systematic differences between the measures on the various plate series. From comparisons between measures of the variable on plates of different series taken on the same night, it was possible to reduce all the measures to a common scale, that of the plates centred on α Crucis.

On various occasions plates of the different series were taken throughout the night. Seventy-five plates, taken on five nights, were used to determine the error of a measure. The light of the variable did not vary appreciably during any one night, the maximum range being $0^{m}_{.}14$. From the sum of the squares of the deviations of the measures from the mean for each night the probable error of one measure was found to be $\pm 0^{m}_{.}027$. Another estimate of the error was obtained from the differences between the measures on plates of the series centred on α Crucis and η Carinae and taken on the same night within a short time of each other. The average difference between the measures on 362 such pairs of plates is $\pm 0^{m}_{.}052$ (after the measures on the η Carinae plates had been reduced to the α Crucis scale). The resulting probable error of one measure is $\pm 0^{m}_{.}031$. The errors are reasonably small, in spite of the fact that the images, being near the edge of the plates, are very distorted, which makes the measures more difficult than usual.

The Light Curve

The light curve is shown in the figure, where large dots denote the mean of two, and small dots single, measures. Dr. Cousins[7] kindly sent me his unpublished observations of o^1 Centauri, made with a Fabry photometer at the Cape Observatory. They are on the same BPg system as my comparison star sequence, and are shown as open circles in the figure.

The extreme range of variation is from about $5^{m}_{.}75$ to $6^{m}_{.}55$. The variable is semi-regular. At times there are cycles of about 200 days, with an amplitude of five or six tenths of a magnitude. At other times the range is smaller, and sometimes only small irregular fluctuations can be seen, as for instance from J.D. 2434087 to 34211. The scattering of the observations, apparent over most of the light curve, shows clearly that more rapid fluctuations are superimposed on the long period variation. The scattering is at times, in fact, several times as large as the probable error of a single measure ($\pm 0^{m}_{.}03$). Moreover, the points in the figure represent, for the most part, the mean of two measures, with a probable error of $\pm 0^{m}_{.}02$. Occasionally the brightness changes appreciably within a few days, e.g. from $6^{\rm m}.32$ on J.D. 2428956 to $6^{\rm m}.07$ on J.D. 28965; or the drop from $6^{\rm m}.14$ on J.D. 2429302 to $6^{\rm m}.33$ on J.D. 29311, followed by a rise to $6^{\rm m}.18$ in the next five days. The most marked of these rapid changes is the rise from $6^{\rm m}.27$ on J.D. 2432273 to $5^{\rm m}.74$ on J.D. 32285, followed by a drop from $5^{\rm m}.80$ on J.D. 32300 to $6^{\rm m}.41$ on J.D. 32301. There is no reason to doubt the correctness of the observations last mentioned; the plates are good, and I have checked the measures carefully.

It should perhaps be mentioned that on each of the nights of J.D. 2428549, 32618, 32628, 32652 and 34212 many plates were taken. The dots in the figure, representing each the mean of two plates, are very crowded and in consequence some of them are slightly displaced from the true date.

TABLE 2

Maxima and Minima of o^1 Centauri

Maxima		Minima	
J. D.	m_{pg}	J. D.	m_{po}
2400000+		2400000+	
		27810	6.3
27892	6.03		
		28250:	6.35
		28525	6.4
28590	5.85	28710	6.37
		28920	6.40
29000	5.98	29102	6.43
		29310	6.27
29365	5.90	29465	6.28
29845	6.0		
30065	5.95		
32290	5.75	32310	6.4:
32400	5.75		
32610	5.9	32715	6.5
		33000:	6.35:
33110:	6.05		
		33350	6.4
33440:	6.1		
		33740	6.5
33845	6.0		

In Table 2 are listed the maxima and minima determined from the light curve; colons denote determinations of lower weight. The sequence of eight minima from J.D. 2427810 to 29465 seems well established, the average length of cycle being 207 days. There are seven cycles between the maximum of J.D. 2428590 and that of 30065, giving an average length of 211 days. Other cycles of about 200 days can be

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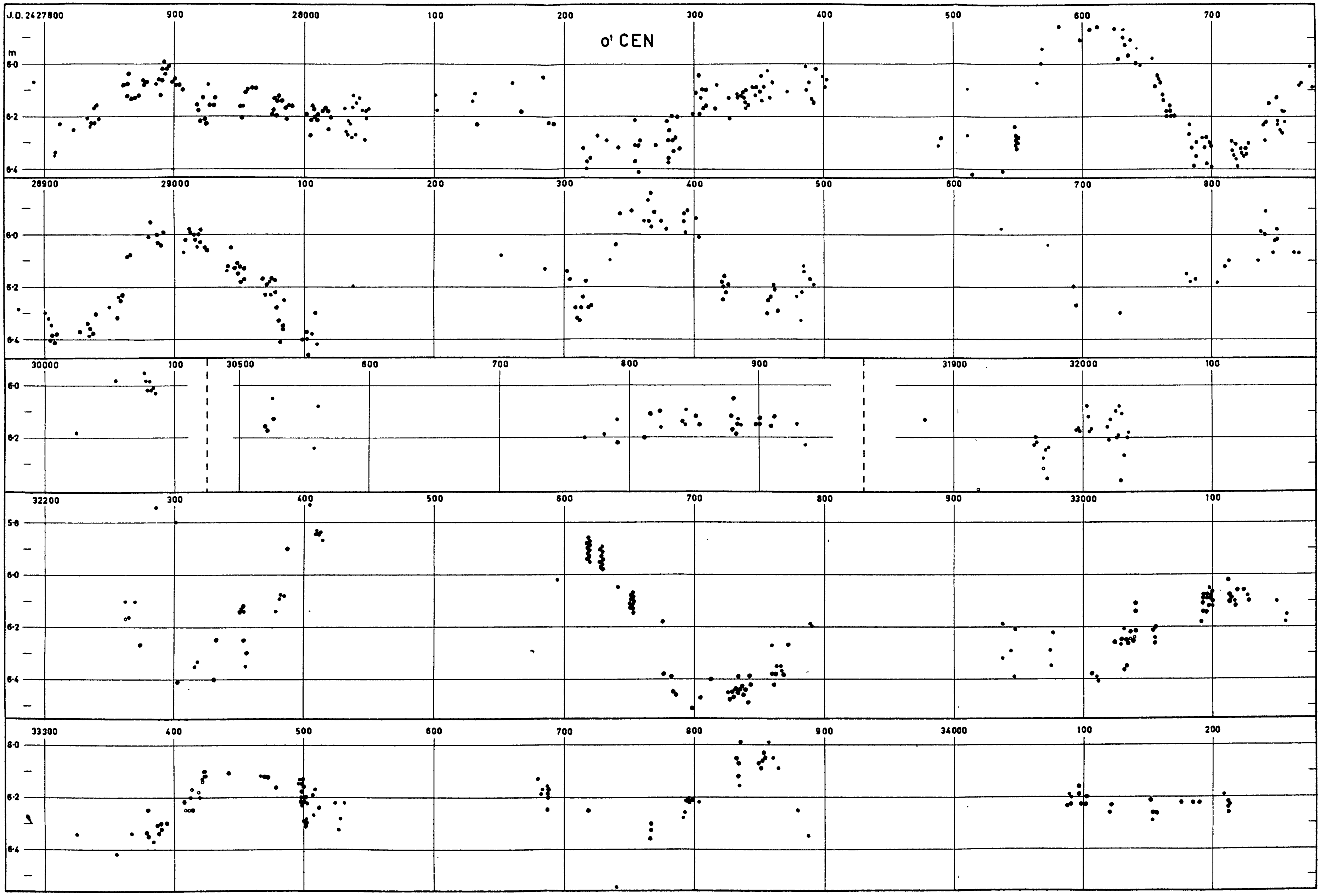

Light Curve of o¹ Centauri

Abscissae are Julian Days, ordinates photographic magnitudes. Large dots represent the mean of two, and small dots single, measures on Riverview plates; open circles, Cape Observatory measures by Cousins. The broken lines indicate an interruption in the sequence of Julian Days.

traced in the light curve, although there are times when the variation almost subsides. In general one may conclude that the characteristic cycle of variation is about 200 days, or a little more. This is appreciably longer than the periods of any of the eleven semi-regular yellow variables studied by ROSINO[8]. ROSINO's list includes spectral types F, G and K, and the periods range from 64 to 116 days (excluding the doubtful period, 138 days, for TX Ophiuchi). The 1958 edition of the Russian Variable Star Catalogue lists the semi-regular giants and supergiants of spectral types F to K under the heading SRd. The longest period I have found among the variables in this list is that of DE Herculis (171 days, spectrum K0); the periods of the rest are mostly less than 100 days.

JOY[9], from his detailed study of the spectra of 38 semi-regular variables (including RV Tauri stars) of types F to K, concludes that they are clearly separable into two groups, of high- and low-velocity stars respectively. o[1] Centauri, whose observed radial velocity ranges from —12 to —25 km/sec,[10] belongs to the low-velocity group. It is much brighter than any of the stars in JOY's list and is worth intensive study.

The Spectrum

The spectrum of o[1] Centauri is given as F8p in the Henry Draper Catalogue; Miss CANNON notes that the lines are narrow and that the spectrum resembles that of δ Canis Majoris. The Lick spectrum[2] is cG4. BIDELMAN's classification[11] is G0Ia. At my request Dr. BIDELMAN has examined all the available Lick plates (listed in Lick Publications 16[12]), taken between 1908 and 1917, and has found no significant variations in the spectrum on these plates.[13] It is of course possible that they were taken at the same phase of the light variation, but there are no contemporary photometric observations to check this point.

o[1] Centauri is clearly a supergiant star of very high luminosity. Not a great deal is known about the yellow supergiants, which occupy an interesting region in the HR diagram. ABT[14] has studied a number of *early-type* supergiants, ranging in spectrum from B8 to A5, and found that all are variable in radial velocity. Some of them have also been found to vary in light. ABT discusses the nature of the variability, in particular whether it is due to pulsation or to turbulence, prominences or other types of mass motion. He puts forward various lines of evidence which go to indicate that the variability is due to pulsation, in which case these stars would evidently have affinity with Cepheids and other pulsating variable stars. ABT indeed suggests that all the stars in the HR diagram above $M_V = +1$, and to the right of the main sequence, are variable in light and radial velocity.

Since o¹ Centauri is comparable in luminosity with the stars studied by ABT, and is not much later in spectral type, one might expect that its behaviour would also be similar. W. W. CAMPBELL[10] found the radial velocity variable, from —12 to —25 km/sec. This variation was found from only six spectra, and the range is probably greater. The amplitude of the light variation is greater than that of any of the stars studied by ABT. It is not, however, as great as that of ϱ Cassiopeiae, which has a spectrum rather similar to that of o¹ Centauri. ϱ Cas has been known for many years to vary irregularly (or semi-regularly) with a range of about one magnitude, until a few years ago when a remarkable eclipse-like minimum, more than one magnitude deep, was observed by S. GAPOSCHKIN.[15,16] The spectrum of ϱ Cas has been studied in detail by BIDELMAN and MCKELLAR[17] and found to be very peculiar and showing marked changes. Particularly remarkable were the changes during and after the deep light minimum. During the minimum TiO bands appeared and the spectrum was exceedingly complex. After the minimum the spectrum was markedly different from what it had been previously, many of the lines appearing double. BIDELMAN and MCKELLAR considered the possibility that the observed peculiarities might be due to an expanding shell, but they found reasons for rejecting this interpretation. They suggest tentatively that we are dealing with an unusual manifestation of turbulent motion in a stellar atmosphere. They point out that UNSÖLD and STRUVE showed that the line profiles in the spectrum of the F8Ia supergiant δ Canis Majoris indicated with great probability large-scale turbulent motions in the atmosphere.

BIDELMAN[13] thinks that o¹ Centauri is not quite so bright as ϱ Cassiopeiae and that the spectrum does not vary as much. In any case, further spectroscopic observations of o¹ Centauri are much to be desired. Since the light changes are not regular (whether they be termed semi-regular or irregular is a matter of choice), the phases of the light curve are not predictable and it is obviously desirable that the light curve be observed as continuously as possible. This could well be done by visual observers.

Many more observations will be needed before it becomes clear whether such changes as those shown by o¹ Centauri are due to pulsation or to turbulent motions in the atmosphere. The two modes are in any case not mutually exclusive, although their co-existence would make it much more difficult to interpret the observations.

In this connection it would be worth while examining other supergiant stars with spectra resembling that of o^1 Centauri. Miss CANNON[19] found the following stars to have spectra of somewhat similar character to that of o^1 Centauri: δ Canis Majoris (F8p, F8Ia), x Carinae (F8p), y Carinae (F5p), i^1 Scorpii (F5p, F2Ia), b Velorum (F5p, F2Ia). In brackets are given Miss CANNON's spectra, followed in some case by revised spectra taken from Cape Observatory Mimeogram 1.[4] To these may be added ε Aurigae (cF5, revised spectrum FoepIa). All these stars, except y Carinae, are known to vary in radial velocity. Epsilon Aurigae, apart from the light variation due to eclipse, shows a persistent "quasi-regular" variation of brightness.[20] Light variations have not yet been observed in the other stars, but they are all so bright that small variations might easily escape detection and it would seem desirable to check them for possible light changes. I intend to investigate three of these stars, x Carinae, y Carinae and i^1 Scorpii, on plates which I have on loan from Riverview Observatory.

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