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Geo Vibert Douglas

Salve frater carissime sapientissimeque.
A.V.D.

THE CYANOGEN BAND NEAR λ 4200 IN THE SPECTRA OF THREE CEPHEID VARIABLES.

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THE CYANOGEN BAND NEAR λ 4200 IN THE SPECTRA OF THREE CEPHEID VARIABLES.

(Plates 15, 16.)

BY

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The Cyanogen Band near λ 4200 *in the Spectra of Three Cepheid Variables.* By A. Vibert Douglas, M.B.E., Ph.D. (Plates 15, 16.)

(*Communicated by the Secretaries.*)

1. Cyanogen has two well-known bands at λ 4216 and λ 4197. In stellar spectra a wide absorption band extending from about 10 A to as much as 40 A on either side of λ 4200 has been recorded by various writers during the past six or seven years. The attribution of this band to cyanogen molecules in the stellar atmospheres has been made by several astrophysicists at one time or another and appears to be a justifiable assumption at the present time.

The presence of this band in the spectra of A-type stars had been noted by the writer, who tried in 1925, but without success, to make it the basis of a method of estimating absolute magnitudes, since Lindblad had successfully used the cyanogen bands in region $\lambda\lambda$3883–3935 for this purpose. Subsequently the band was studied in some F and G stars of the Cepheid variable type, and a cyclical variation in intensity was discovered.

Interest has been stimulated in the band by papers by Shapley *

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* *Harvard Circ.*, 317, May 1928. *Harvard Bul.*, 862, Dec. 1928 ; 864, Feb. 1929.

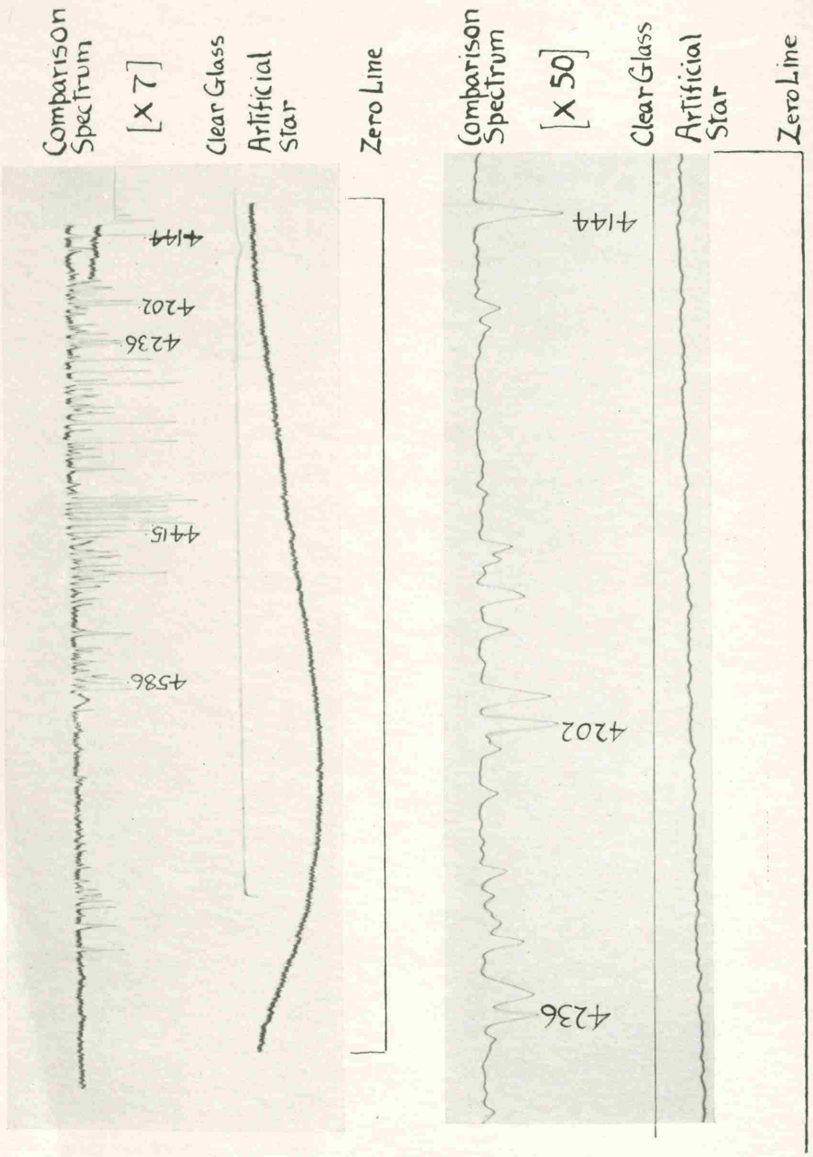

Fig. 1.—Transmission of light by optical system of 15-inch refractor of the Dominion Observatory.

and by Elvey.* The latter in his paper refers to what has been previously reported in regard to this band, and goes on to show that as it appears on the spectrograms of the Yerkes Observatory (Bruce spectrograph and 40-inch refractor) the band can be fully accounted for by selective absorption in the glass of the optical system. It is therefore desirable that any data tending to re-establish or confirm the true stellar origin of the band should be recorded.

2. Since all the spectrograms which formed the basis of this study of the behaviour of the λ 4200 band were obtained from the Dominion Observatory, Ottawa, it was essential that the selective absorption, if any, of the optical system of the spectrograph and 15-inch refractor of that institution should be determined.

By the courtesy of the Director and with the kind assistance of Miss M. S. Burland of the Dominion Observatory, the writer was able to test the system in the following manner. A 1000-watt Mazda lamp was attached to the dome and exposures were made of various durations up to five minutes. The plates were developed and subsequently put through the microphotometer in exactly the same manner as for the stellar spectrograms. The resulting microphotometer tracings show no sign of selective absorption in the region about λ 4200, and indeed the transmission throughout the range λ 4100 to λ 4800 is remarkably smooth.

In fig. 1 two tracings are reproduced, one having a linear magnification of × 7, the other × 50, the comparison spectrum in each case being iron and vanadium. The other exposures yielded equally smooth tracings, so that it can confidently be asserted that the absorption in the neighbourhood of λ 4200 on Dominion Observatory spectrograms is not an instrumental effect but an example of true stellar absorption.

3. The assignation of this stellar band to the molecule *CN* is less certain though not improbable. The question of its being due to some molecule other than cyanogen does not appear to require discussion at the present time.† It might be objected, however, that it was in reality merely a spurious band due to the overlapping of the wings of closely adjacent arc or spark lines, or a mixture of the two. This possibility requires careful consideration.

As will be seen in the three sections following, the intensity of this band in the spectra of three Cepheids varies with the phase of the star in each case. This cyclic variation, moreover, is found to be very nearly in phase with the periodic variation in intensity of a large number of typical enhanced lines and of the Balmer lines of hydrogen; and distinctly out of phase with the variations in intensity of the well-known Fraunhofer G band near λ 4300, whose identification with the hydrocarbon molecule *CH* seems to be fairly certain.‡ This would seem to point to the possibility that the λ 4200 band was an ionization effect. A glance, however, at Table I. will show that the central region of the band, λλ 4198–4202, is by no means rich in strong arc lines of stellar

* *Ap. J.*, **70**, 243, 1929.
† *Int. Crit. Tables*, **5**, 412, 1929.
‡ *Ibid.*

importance and completely devoid of intense spark lines. The data here given are taken from Kayser's *Tabelle der Hauptlinien der Linienspektra.*

TABLE I.

Spectrum Lines near λ 4200.

λ in I.A.	Element.	Intensity.	
		Arc.	Spark.
4198·313	*Fe* I	6	3
98·52	*Cr*	3	2
98·72	*Ce*	5	6
98·88	*Ru*	4	3
99·09	*Zr*	6	3
99·10	*Fe*	6	5
99·29	*Y* II.	3	3
99·91	*Ru*	10	10
4201·73	*Ni*	5	..
01·81	*Rb* I.	8	7
02·03	*Fe* I.	7	6
02·44	*V*	1	8

In marked contrast to this portion of the spectrum is the region λλ 4446–4476, where a spurious band is actually produced as a result of the confluence of the wings of more than thirty strong arc lines which are very closely crowded in this region. The variations in intensity of this spurious band, discussed in § 5 below, make it apparent that the λ 4200 band is unlikely to be due to any such cause.

In the absence of any evidence to the contrary, therefore, the band will be regarded as due to stellar cyanogen.

4. *η Aquilæ.*—This star has a period of $7^{d}·176$; a light variation from $3^{m}·7$ to $4^{m}·5$; and a range in spectral class from F2 to G9, the average spectrum being given in the Henry Draper Catalogue as G0p. The variations in intensity with phase, of the Balmer lines and a score of typical enhanced lines as well as of the G band, were determined * recently as far as it is possible to do this from unstandardized plates. The hydrogen and enhanced lines are most intense near the phase of maximum light, whereas the G band is increasing in intensity at minimum light when ionization is less pronounced. This is in full accord with theoretical expectation, conditions favourable to increased ionization being favourable also to dissociation of a molecule, and conversely.

It soon became apparent that the cyanogen band, clearly defined on the majority of the microphotometer tracings of some sixty spectrograms and extending in general from λ 4194 to λ 4212, undergoes a similar variation in intensity, but out of phase relative to the variation of the G band.

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* Henroteau and Douglas, *Pub. Dom. Obs.*, ix., 7, p. 163, 1929.

Fig. 2 shows this very clearly. Absolute measures of intensity were obviously impossible, but relative intensities throughout the period were considered to have been obtained by measuring on each tracing the depth of the band below the smooth curve representing the continuous background, and also the depth of an insensitive, closely adjacent line, and then taking the ratio of the two. The G band curve is thus determined by the mean values of the ratio G/λ 4289 plotted against phase, and the *CN* curve likewise for the ratio *CN*/λ 4213. That the resulting curves represent the variations of the numerators rather than the denominators of the ratios is tested by trying out various other lines as the basis of comparison from one tracing to another. Thus in fig. 4 the line λ 4198 is used in addition to λ 4213, and the essential features of the *CN* curve, namely, its phases at maximum and minimum, are practically unaltered. (λ 4289 is an ultimate line of chromium with arc lines of calcium and titanium closely adjacent; λ 4213 is a very weak line of uncertain origin, possibly due to terbium; λ 4198 is an arc line of iron.)

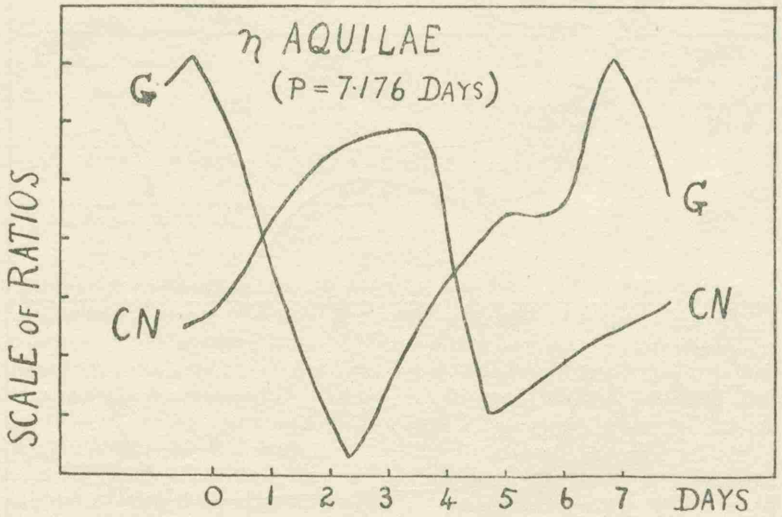

FIG. 2.

The significance of the curves in fig. 2 can best be appreciated in conjunction with the physical picture of the pulsating star. For brevity the main facts are set out in tabular form (p. 803), the references to radial velocity being taken from a recent paper by Henroteau.*

5. *RT Aurigæ.*—The period of this variable star is $3^{d}·724$; its magnitude changes from $5^{m}·0$ to $5^{m}·9$; its usual spectral classification is F8 with a range from F1 to G5.†

In fig. 3 four curves are given based upon measurements from the

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* *Pub. Dom. Obs.*, ix., 5, pp. 136, 142, 1928.

† Cannon, *Harv. Bul.*, 1930 March 1.

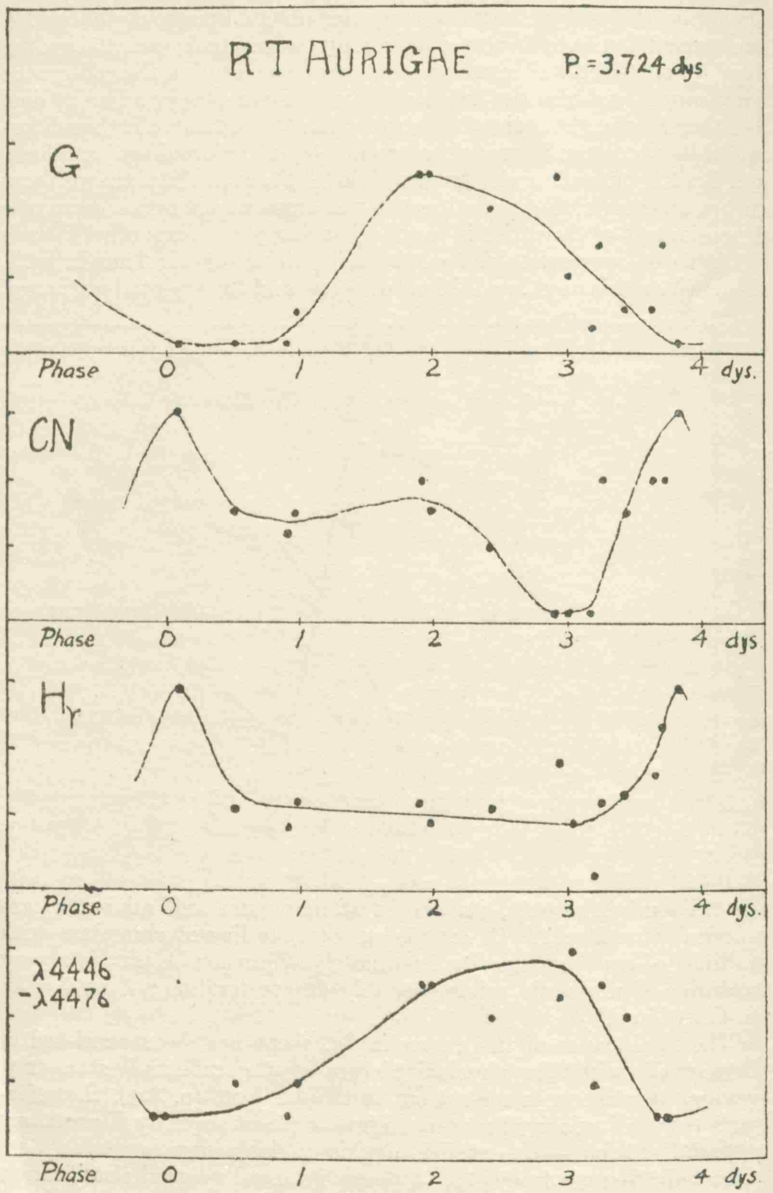

Fig. 3.
(Ordinates represent scales of intensity.)

tracings of fifteen spectrograms. Again the contrast between the G band and the *CN* band is very striking, as also is the similarity between the behaviour of the hydrogen line *H*γ and *CN*.

Table II.

η Aquilæ.

Phase.	Physical State of Star.	Characteristics of Spectrum.
0^d–1^d	Minimum radial velocity; most rapid expansion; maximum light.	Ionization strong or rising; *CN* rising; G falling.
2^d–3^d	Expanding.	*CN* rising; G at minimum.
Approx. $3^d.5$	Maximum volume.	Ionization falling; *CN* near maximum.
4^d–5^d	Contracting; minimum light.	Ionization minimum; *CN* minimum; G strong and rising.
Approx. 6^d	Maximum radial velocity; most rapid contraction.	..
Approx. $6^d.6$	Minimum volume.	G maximum; *CN* weak but rising.

In order to test how the periodic changes in the intensities of spectral lines would affect a region of the spectrum where the close proximity of strong overlapping lines produces a band-like appearance, measurements were made of the region near λ 4460, where some thirty strong arc lines are closely assembled. This spurious band behaves much as does the G band, as might be anticipated, and in marked contrast to the *CN* band and to enhanced lines.

6. *α Ursæ Minoris.*—This star is recognised as a Cepheid variable having a period of $3^d.968$; its range in magnitude is very slight, being $0^m.171$ as determined photographically, and less visually. Notwithstanding this small range in light, there are appreciable variations in the spectrum.

Fig. 5 is a reproduction of tracings of four spectrograms representing two distinctly different phases. The G band and the *CN* band are indicated. There is no doubt, as Mr. C. T. Elvey has pointed out, that the better resolution of 3-prism spectrograms greatly reduces the depth of the band, but it does not remove all traces of band absorption, and even if the band does appear somewhat exaggerated on the 1-prism spectrograms, all the measurements being relative, the resulting variations with phase cannot be entirely without value, though lack of standardization of the plates makes certainty obviously impossible.

The G band curve in fig. 4 is based on measurements of ninety-two spectrograms. The *CN* band was measured relative to λ 4198 on seventy-seven spectrograms (*a*), and relative to λ 4213 on thirty-eight (*b*). While the two *CN* curves reflect to some extent the differences in behaviour of these two lines, the main variation represents the changes in the band and the phases of maximum and minimum are seen to oppose almost exactly those of the G band.

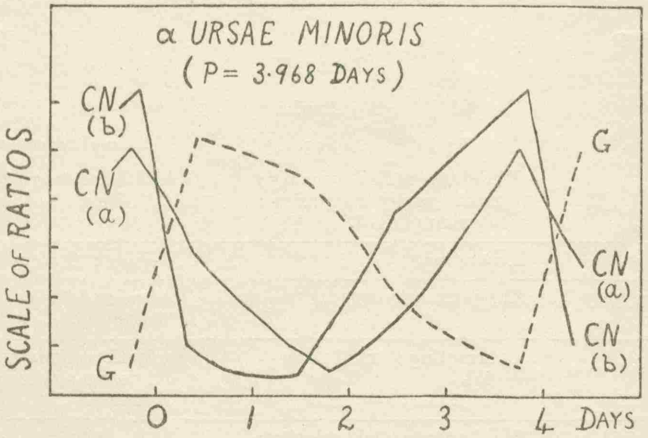

FIG. 4.

(*a*) Relative to λ 4198.
(*b*) Relative to λ 4213.

Considering these curves in conjunction with the curves of radial velocity * and light variation, we may tabulate the phenomena as follows :—

TABLE III.

a Ursæ Minoris.

Phase.	Physical State of Star.	Characteristics of Spectrum.
Approx. $0^{d}\cdot5$	Minimum radial velocity; most rapid expansion; maximum light.	Ionization maximum; *CN* falling; G maximum.
$0^{d}\cdot5$–$1^{d}\cdot5$	Expanding to maximum volume.	Ionization falling to minimum; *CN* near minimum; G strong but falling.
Approx. 2^{d}	Contracting; minimum light.	Ionization weak; *CN* weak but rising; G strong but falling.
Approx. $3^{d}\cdot5$	Minimum volume.	Ionization rising; *CN* rising to maximum; G falling to minimum.

7. The behaviour of cyanogen as indicated by the foregoing results presents a problem of considerable interest.

The resemblance between its behaviour and that of the enhanced lines suggests at once that the molecule is in the ionized state. Two factors would then be working in opposite directions, the increasing

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* *Pub. Dom. Obs.*, ix., 1, p. 52, 1925.

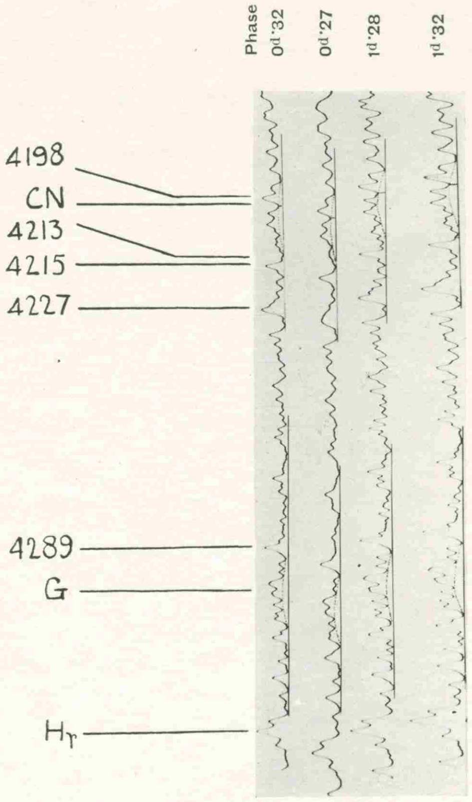

Fig. 5.—Alpha Ursæ Minoris.

temperature bringing about a dissociation of the molecule but producing a larger percentage of ionized molecules among those remaining, while fall in temperature would reverse the two tendencies. No physical data are at present available to disentangle these two effects, but the question is beside the point in any case if the spectroscopists are correct in asserting that the band is undoubtedly due to the neutral molecule.

In the regular sequence of spectral classes the G band reaches its maximum between G and K (according to C. H. Payne), and the *CN* bands near K2 (according to Lindblad). As no one of the above stars falls below class G9, it might be supposed that these two bands would react similarly to the changing physical conditions. The only explanation for the abnormal behaviour of *CN* that suggests itself at the present time is that, like the enhanced lines of iron, titanium, scandium, and so forth, this band has its origin at a very high level in the stellar atmosphere. Why the *CN* molecule should be lifted to a higher level than the *CH* molecule may rest upon the same line of argument as explains the altitude of the ionized calcium atoms in the solar chromosphere, since the *CN* molecule has strong absorption bands (λ 3883, etc.) near the H and K lines of calcium, whereas the *CH* molecule, having no strong absorption in this richest region of the continuous emission spectrum, might not be buoyed up to the high levels to which the *CN* molecule and calcium atoms are carried.

Observations by Shapley and Payne point to the abnormal behaviour of the H and K lines with regard to the periodic changes in spectral class of Cepheids, so that the one explanation may cover the two cases.

Atoms or molecules at high levels in the stellar atmosphere will absorb radiation in accordance with the temperature and pressure existing at that level at any given instant, but there will be a time lag relative to the deeper levels. Increase in interior temperature will precede increase in exterior temperature by a period of time to be measured in days.

This question of time lag plays a fundamental part in the pulsation theory of Cepheid variation, explaining why maximum light coincides with maximum rate of expansion rather than with maximum rate of contraction, this latter being the time when heat is being generated in the interior.

It may well be that consideration of the possibility of different atmospheric levels with consequent time lag provides the key to the problem presented by the apparent anomalies in the behaviour of the cyanogen band and perhaps other features of the spectra of these variable stars.

8. I am indebted to the Director of the Dominion Observatory and to Dr. F. Henroteau for the privilege of examining the spectrograms of that institution, and my thanks are due to them and to all those at the Yerkes, Harvard, and Cambridge Observatories, and at the Imperial College, London, who have at one time or another discussed some aspects of this problem with me.

To Dr. W. M. Smart, Cambridge Observatory, for his generously given assistance and advice, I am especially indebted and very grateful.