# A NEW ECLIPSING BINARY CONTAINING A VERY HOT WHITE DWARF

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A new eclipsing binary has been discovered in which one of the stars is shown to be a hot white dwarf. The eclipse is total, and considerable fundamental information about white dwarfs appears to be obtainable.

The star BD $+16°516$ ($\alpha = 3^h44^m\!.5$, $\delta = +16°57'$ (1900), $V = 9.6$) is noted as a spectroscopic binary by Wilson (1963) in the *General Catalogue of Stellar Radial Velocities* (No. 2196). This conclusion is based upon five spectrograms obtained at the Mount Wilson Observatory between 1942 and 1945, at a reciprocal dispersion of 80 Å/mm. The listed range of observed velocities for these spectrograms is 242 km/sec. Spectrograms of this star obtained at the Kitt Peak National Observatory at 39 Å/mm show single, rotationally broadened lines of a K0 V star with strong emission lines of singly ionized calcium, and an unusually strong ultraviolet continuum. In Figure 1 a portion of an intensity tracing of one of these spectrograms is reproduced, showing the strength of the Ca II emission. Five spectrograms have been obtained so far, all of which show positive radial velocities, and with a maximum recorded radial velocity of +180 km/sec.

In order to test for eclipses, photometric observations were begun on December 19, 1969 (U.T.) at the Mount Laguna Observatory. The observations were made with a 16-inch reflecting telescope and

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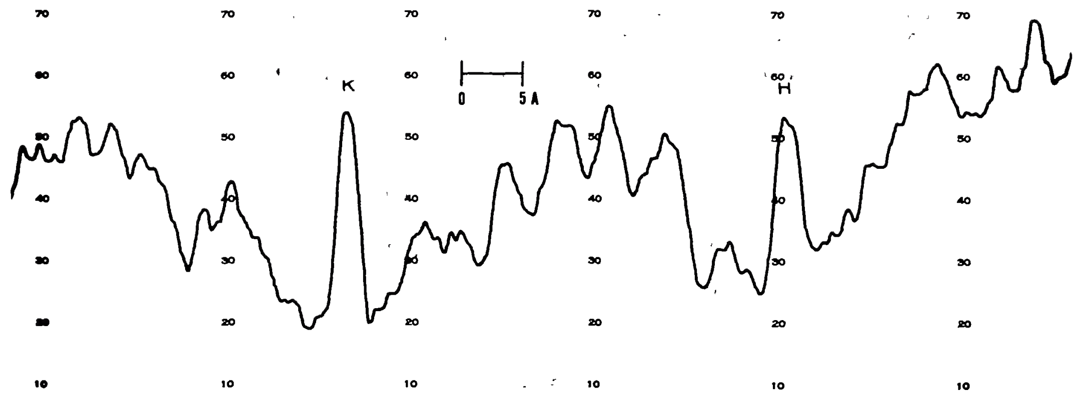


FIG. 1 — A portion of an intensity tracing of a spectrogram of BD +16° 516 showing the emission lines of singly ionized calcium.

a refrigerated 1P21 photomultiplier. A Schott GG-7 yellow filter, a Schott BG-1 and a Corning 3060 blue filter, and a Corning 9863 ultraviolet filter were used to approximate the *UBV* system. Nearly continuous variation was found in all three bands when the star was compared to HD 24040. The constancy of this comparison star was assured by observations of the check star HD 24620.

Continued observations on the nights of December 27, 29, 30, 31, 1969, and January 5 and 14, 1970 (all dates U.T.) led to a provisional determination of the period and epoch of primary minimum, and produced the light curves which are reproduced in Figures 2, 3, and 4. The differential magnitudes reported here are on the instrumental system.

We believe that most of the variability depicted by these light curves can be ascribed to the variation in aspect of a rotating, tidally distorted, K0 V star with a heated zone facing the hot companion. The only discernible eclipse phenomenon appears to be the occultation of this hot companion which produces the primary minimum. In the yellow this eclipse is only barely detectable, being of the order of $0^m.04$. In the blue it is approximately $0^m.09$, while in the ultraviolet it is $0^m.36$. These values represent the depth of total eclipse, which lasts 47 minutes, and is unquestionably due to the occultation of the hot star. The overall variation from maximum to minimum light is greater than these values in all three bands. It is also to be noted that these eclipse depths do not always repeat from cycle to cycle, suggesting variability of the K0 V star.

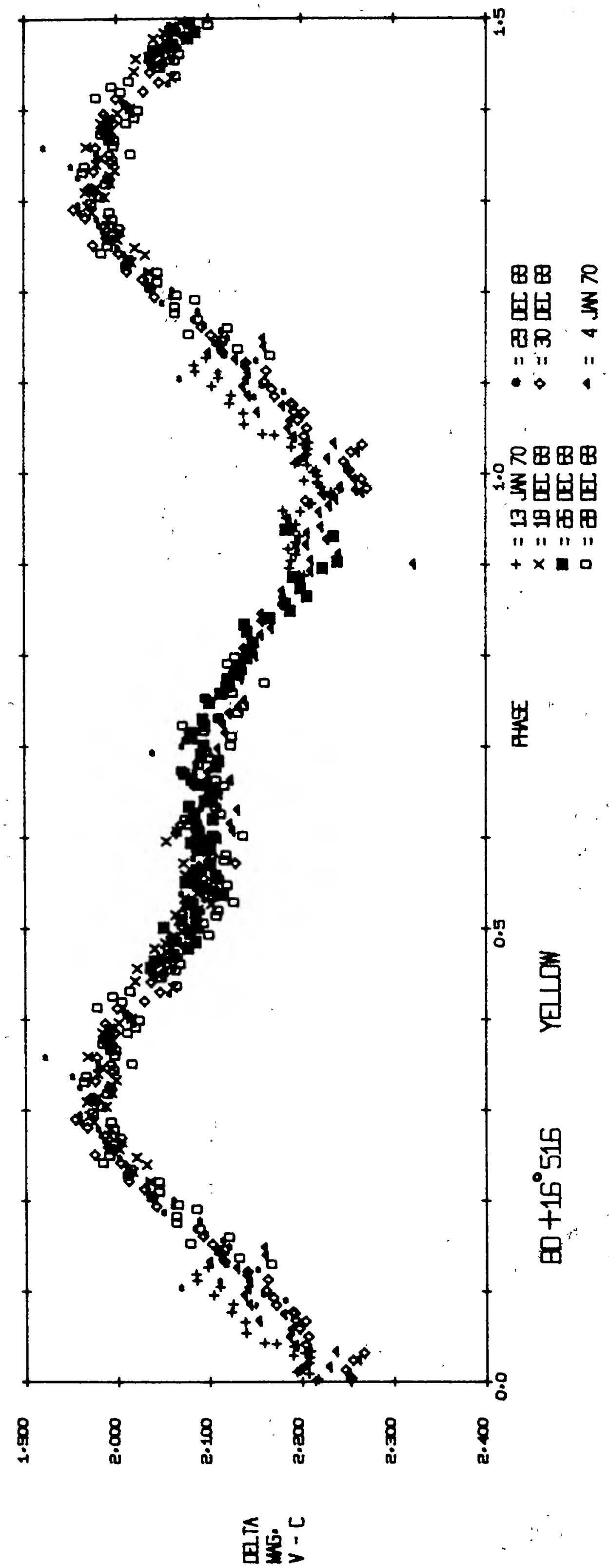


FIG. 2 — The light curve in the yellow band.

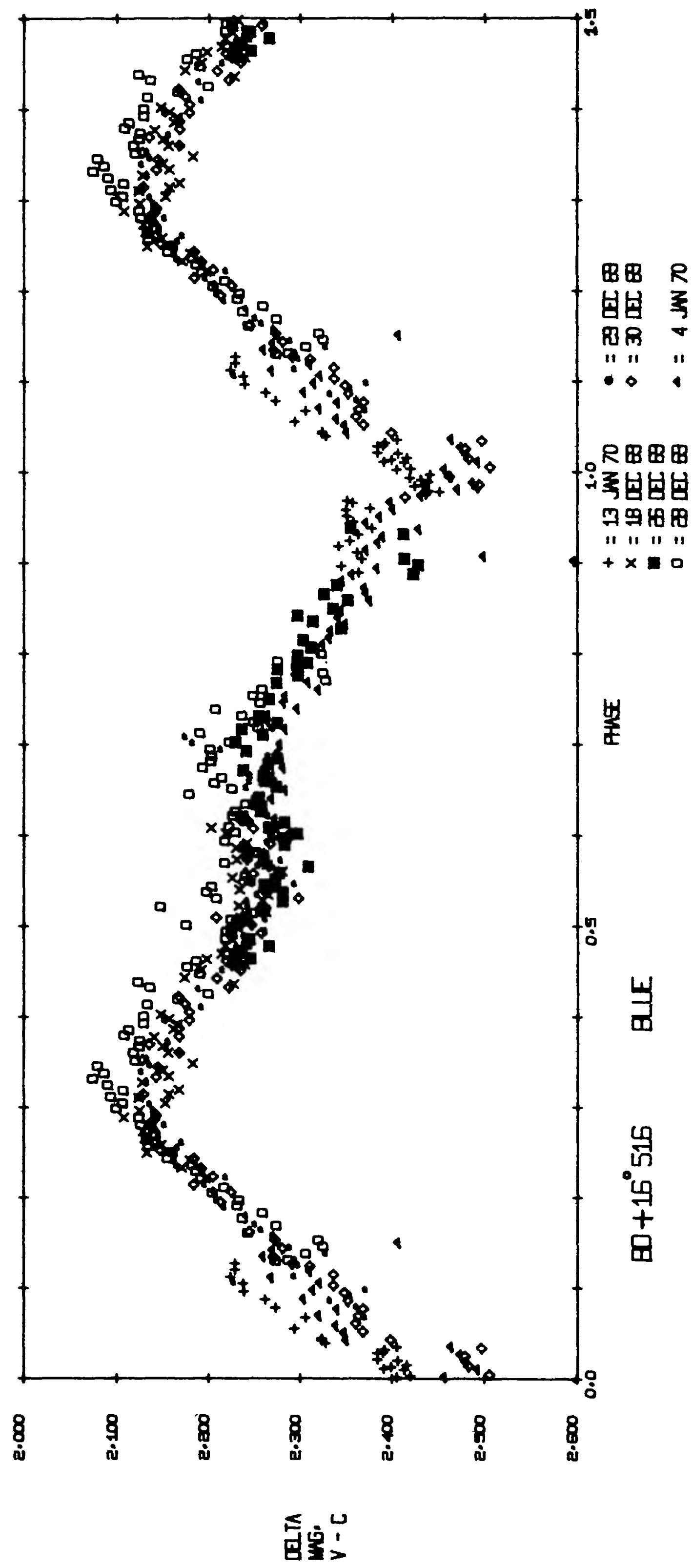


Fig. 3 — The light curve in the blue band.

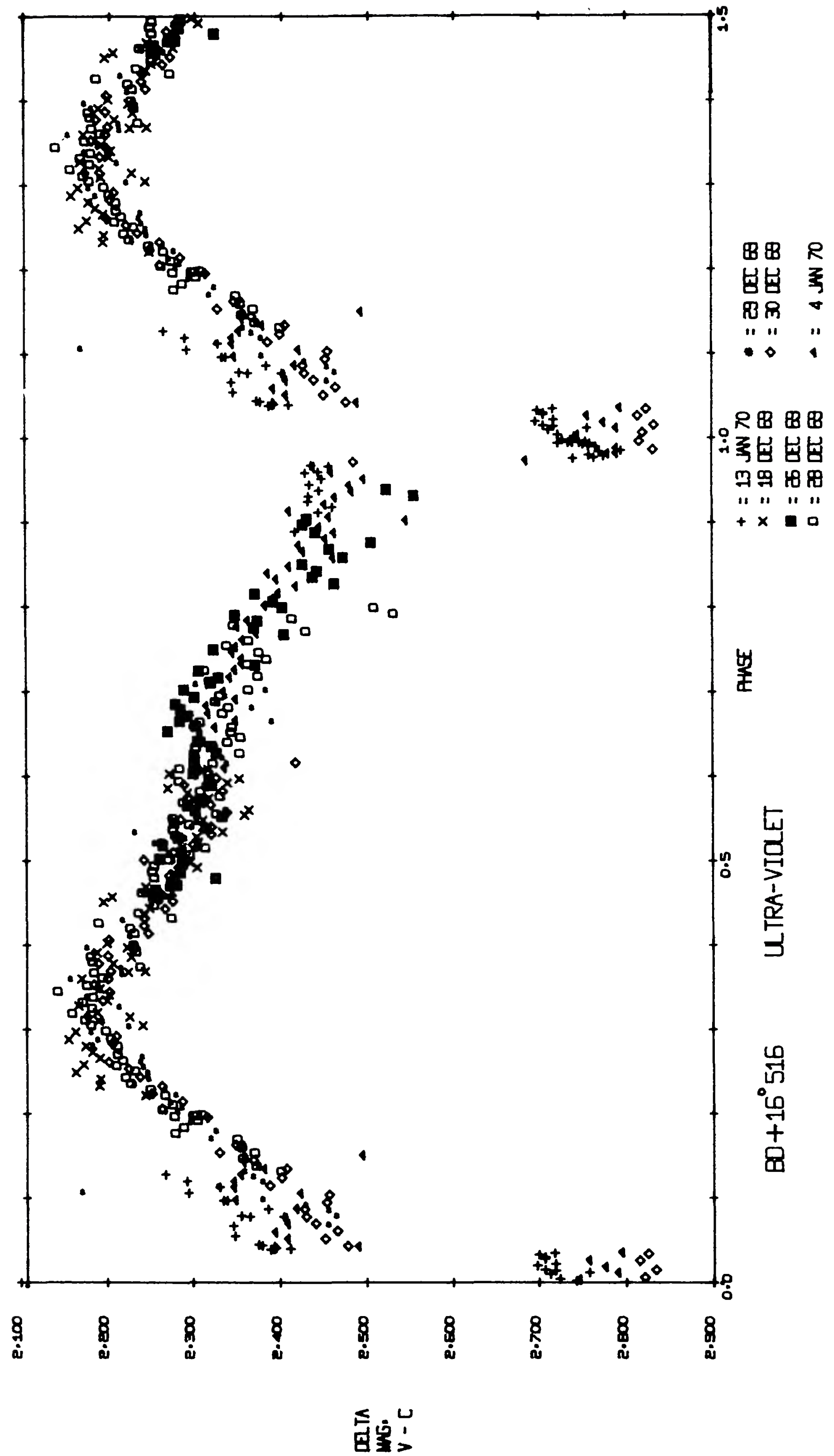


FIG. 4 — The light curve in the ultraviolet band.

A steady brightening after primary eclipse is apparent in all three bands, reaching a maximum at approximately phase 0.3. Thereafter, a steady decline to phase 0.5 is observed, but it will be shown later that this cannot be a secondary eclipse phenomenon. Following phase 0.5 there is a conspicuous extended interval (~0.2 phase) of essentially constant light, followed by a steady decline which precedes the primary eclipse.

Ingress into primary eclipse is most striking in the *U* filter. The interval from first to second contact, and from third to fourth contact is so short that direct mode photometry was necessary to time it. In Figure 5 a small portion of one of the strip chart recordings of the continuous photomultiplier output covering first to second contact in the *U* filter is reproduced. Observations such as this give a mean value of 58 seconds for that interval. The duration of primary minimum is 47.2 minutes, leaving no doubt of a nearly central occultation eclipse. These timing observations have also yielded an improved period and heliocentric epoch of primary minimum = JD 2440574.62473 + $0^{d}.521180$ E. The uncertainty of the period is now thought to be $\pm 2 \times 10^{-6}$ days since the contacts can be estimated to ±5 seconds, and our observations for precise timing currently extend over 26 cycles.

Fortuitously a spectrogram was taken very near to primary minimum, and another very nearly at the maximum positive velocity phase, before the epoch and period of the system were known. This circumstance has permitted an estimate of +50 km/sec for the $\gamma$ velocity, and 130 km/sec for the orbital velocity of the K0 star relative to the center of mass of the system. From these values and an assumed mass of 0.8 $\mathfrak{M}_{\odot}$ for the K0 star, the following characteristics of the system are derived assuming that the orbital inclination is 90°.

| | |
|---|---|
| K0 star: | $R = 0.6\ R_{\odot}$ (lower limit) |
| | $\mathfrak{M} = 0.8\ \mathfrak{M}_{\odot}$ (assumed) |
| | $(U-B) = +0.9$ |
| | $(B-V) = +0.5$ |
| Hot companion star: | $R = 1.3\ R_{\oplus}$ |
| | $\mathfrak{M} = 0.6\ \mathfrak{M}_{\odot}$ |
| | $(U-B) = -1.2$ |
| | $(B-V) = -0.2$ |
| Center-to-center separation: | $3.0\ R_{\odot}$ |

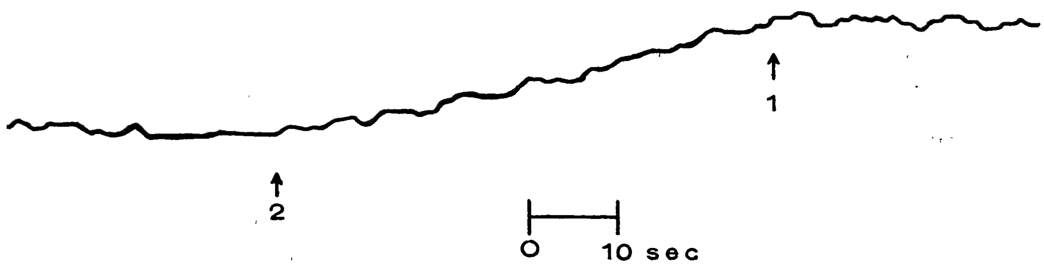


FIG. 5 — A photomultiplier output record of ingress into primary eclipse. The arrows indicate the first and second contacts.

The color indices have been transformed to the *UBV* system by observation of standard stars. The mass and radius derived for the hot star are characteristic of a white dwarf. The cross section area of this minuscule white dwarf is not capable of attenuating the light from the K0 V star by more than $0\overset{m}{.}004$! Hence we have concluded that the light loss into phase 0.5 exhibited by the light curves is not due to a secondary eclipse.

Preliminary calculations suggest that the effective temperature of the white dwarf is not less than 25,000° K, but better data and more refined calculations are needed before a reliable temperature can be derived. The $(U-B)$ and $(B-V)$ color indices are consistent with a blackbody of that temperature as computed by Arp (1961). The star may be a member of the class known as ultraviolet dwarfs whose properties are given by Stothers (1966).

The observations during primary minimum, most notably in the *U* filter, suggest that the intrinsic luminosity of the K0 star is not constant. Specifically the observations plotted for January 13, 1970 (PST) are systematically brighter than those for December 30, 1969 (PST). Furthermore on January 13 the K0 star appeared to be brightening measurably during the 47-minute totality, a trend which the data indicate continued after fourth contact. Spurious momentary brightenings of up to $0\overset{m}{.}2$ have also been noted in all three bands at various times, and there is little justification for questioning the reality of these occurrences since the sky and both comparison stars were assiduously monitored.

In many ways the properties of this system are reminiscent of those of U Geminorum stars, except for certain noteworthy differences. It is tempting to speculate that this system may be a progenitor of the U Gem class. The emission lines which characterize the U Gem stars are conspicuously absent from this system, suggesting that the K0 star is indeed a dwarf which has not yet filled its Roche lobe and hence has not produced a ring of luminous gas about the white dwarf. The strong Ca II emission lines exhibit the same radial velocity and phase as do the absorption lines, suggesting that they have their origin in a (tidally) extended chromosphere about the K0 star.

Although not yet transformed accurately to the *UBV* system, the mean blue magnitude of this object is approximately 10.5 and is therefore a difficult object for a 16-inch telescope. More observations with larger telescopes are planned for the next observing season for this interesting star. We expect to greatly improve both the spectroscopic and photometric results.

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