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A COMPLETE OPTICAL LIGHT CURVE OF THE HYADES ECLIPSING BINARY V471 TAURI WITH THE IUE SATELLITE

V 471 Tauri (BD $+16^{\circ}516$) is a $\sim 12\overset{h}{.}5$ eclipsing binary member of the Hyades cluster, consisting of a K0(2) V star and a hot white dwarf component (Nelson and Young 1970; Young and Nelson 1972). The system has been extensively studied and a review of its physical properties is given by Nelson and Young (1976). Although initially much attention was given to determining the properties of the white dwarf component and the system's evolutionary history from its Hyades membership, it has become apparent that the cool component is also important because it displays many properties in common with the chromospherically active components of RS Canum Venaticorum binaries (Hall 1976). Like RS CVn stars, the cool component has strong variable Ca II H and K emission lines (Oswalt 1979), as well as strong Mg II λ2800 h and k emission (Guinan and Sion 1979). In addition, the light curve of V471 Tauri is abnormal and displays a variable wave-like disturbance similar to the photometric waves found in RS CVn-type variables. Ibanoǧlu (1978) reports, furthermore, that the photometric wave in V471 Tau migrates toward decreasing orbital phase with a period of about 191 days. In RS CVn systems the photometric wave has been attributed to the rotational modulation of optically darker starspots through the observers's field of view.

On 14 August 1980 UT, V471 Tau was observed continuously for about 14 hours with the International Ultraviolet Explorer (IUE) Satellite in order to obtain ultraviolet spectra (λλ1150-3200) over the entire orbit. A comprehensive description of the IUE satellite and its scientific instrumentation is given by Boggess et al. (1978). In the course of observing the star, the Fine Error Sensor (FES) on board the satellite was used as a photometer to obtain the first complete light curve of V471 Tau. The $12^{h}.5$ orbital period of the system hitherto has not permitted a complete light curve to be obtained in one continuous observing session from ground-based stations.

The FES is an unfiltered image dissector tube with an S-20 photocatode which has a broad wavelength response from about 4000Å to 7000Å with a broad maximum sensitivity centered near 5000Å. The incident photons to the FES reflected from the satellite's 45 cm, f/15 Cassegrain telescopic system. The FES is normally used to provide an image of the star field at which the telescope is pointed or in a track mode. In the track mode of operation the FES gives a count rate which is related to the brightness of the object. The brightness of the star is obtained by averaging the count rate from multiple scans of the image dissector with an effective integration time of about 2.5 seconds. The source plus background is actually measured, but for bright stars ($m \leq +11$ mag) the contribution of the background is insignificant. Holm and Crabb (1979) and Stickland (1980) have independently calibrated the FES in terms of V of the UBV system. We have used the calibration of Holm and Crabb given below in reducing our data since it appears to yield better results with our standard stars:

$$V(FES) = +16^{m}.58 - 2.50 \log C_f - 0.24\ (B-V) \qquad (1)$$

where C_f is the FES count rate from the fast track. The above calibration was derived from 120 observations of 60 stars in the overlap fast track mode and has an accuracy of about $\pm 0^{m}.06$.

In order to increase the precision of the FES measures, the star was observed for 15 seconds except during the first 90 minutes where the observing interval was 5 seconds. The observations were made as frequently as possible between the exposures of the UV cameras and a total of 71 FES measures were obtained. Judging from the repeatability of successive measures, the relative magnitude measures have an uncertainty of less than $\pm 0^{m}.01$. The FES measures were transformed to V magnitudes using the value of B-V= +0.92 for inside primary eclipse and B-V=+0.86 elsewhere. These B-V values were obtained from the photometric studies of Young and Nelson (1972) and from Ibanoǵlu (1978).

The times at which the observations were made were converted from Universal Time to heliocentric Julian Date and the orbital phases were computed with the ephemeris of Oliver and Rućinski (1978):

$$\mathrm{MIN\ I} = \mathrm{HJD}\ 2440610.06642 + 0\overset{d}{.}52118294\cdot E \qquad (2)$$

where zero phase corresponds to mid-eclipse of the white dwarf by the K-component (i.e. primary eclipse). As shown by Oliver and Rućinski, the period of V471 Tau is variable and equation (2) corresponds to the range in epoch of 3000-4800 and was taken from Table II of their paper. The data are plotted against orbital phase and Universal Time in Figure 1. The eclipse limits (first contact to fourth contact) are shown in the figure and correspond to 0.967 to 0.033 phase for primary minimum and 0.467 to 0.533 phase for secondary eclipse. These limits were obtained from the study of Beavers, Oesper and Pierce (1979) where the average time interval between first contact and fourth contact is 49^m24^s and

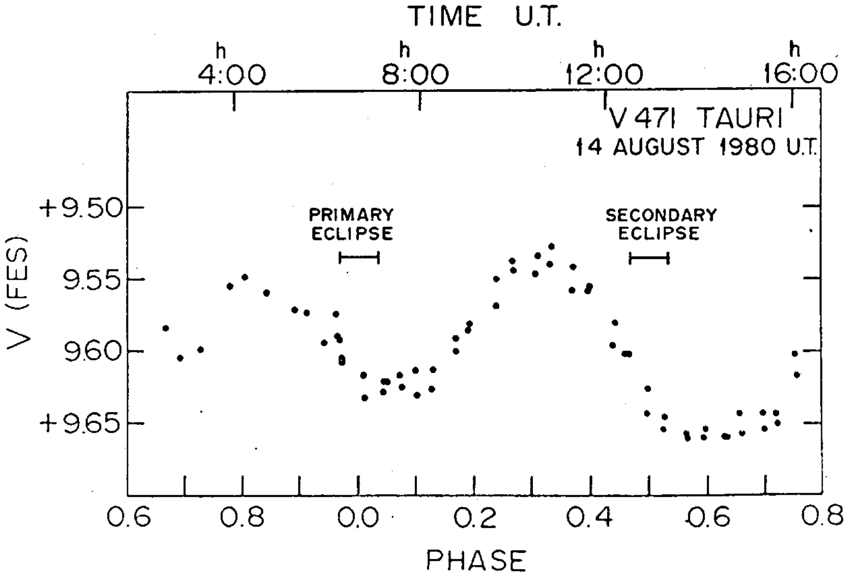

Figure 1: The FES light curve of V471 Tauri

where the duration of totality is about $47^{m}12^{s}$. As can be seen from the figure the light curve is well defined by the data and has a light amplitude of about $0^{m}.12$ with two maxima and two minima of different brightnesses occurring within an orbit. Although in the ultraviolet the depth of primary eclipse is large (about $0^{m}.32$ in the U-bandpass and $1^{m}.56$ at $\lambda 2700$), at the wavelength of the V bandpass, the contribution of the white dwarf to the total light of the system is very small where the depth of primary eclipse is less than $0^{m}.02$. No detectable decrease in brightness is expected at secondary eclipse because of small fractional size of the white dwarf relative to the cool star. No loss of light attributable to an eclipse is seen in the data at the time of secondary eclipse. Thus the light variation in the optical region arises almost entirely from the K-star. The mean value of two measures taken close to 0.0 phase of V(FES) = $+9^{m}.63$ is $0^{m}.08$ brighter than the value of V = $+9^{m}.71$ given by Young and Nelson for near 0.0 phase. (Using Stickland's calibration of the FES yields a value of V(FES) = $+9^{m}.512$ for the same data.) Since the primary eclipse is a total occultation, these measures correspond to the brightness of the facing hemisphere of the K component. With an uncertainty of $\pm 0^{m}.06$ in the calibration of FES to V magnitudes, it is difficult to determine whether the star is brighter or if the observed difference in brightness arises from the variations in the sensitivity of the FES.

Neglecting the minor loss of light during primary ecplipse, the light minima appear to occur at 0.07 phase and near 0.60 phase with V(FES) = $+9^{m}.63$ and V(FES) = $+9^{m}.66$, respectively. The brighter maximum occurs near 0.32 phase with V(FES) = $+9^{m}.54$ and the fainter maximum is near 0.80 phase with V(FES) = $+9^{m}.55$. The occurrence of the higher maximum near 0.32 phase is in good accord with the phase expected from the 191 day migration period suggested by Ibanoğlu (1978). The form of the light curve is unusual and does not correspond to the light variation theoretically expected from the tidal distortion of the K-star and from the irradiation of the inner hemisphere of the cooler star by the hotter white dwarf (the so-called reflection effect). The light curve is, however, similar to others obtained previously at optical wavelengths for V471 Tauri (see Ibanoğlu 1978 and Tunca et al. 1979). It also appears that the light curve does not repeat even over one orbital cycle. This can be seen in Figure 1 when the data covering the same phases are compared near the beginning and end of the observing interval. Some of these differences could, however, be caused by small drifts in the sensitivity of the FES over the observing interval.

A more thorough discussion and analysis of the optical light curve will be published elsewhere, together with the UV data. We have demostrated in this study, as in a few others (cf. Boggess et al. 1980; Guinan and Sion 1980; Rućinski et al. 1980) the importance and usefulness of the FES as a photometer. It is suggested, however, that the absolute sensitivity of the FES be monitored by observing standard stars during each observing run.

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