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DETECTION OF FLARE LIKE EVENTS AND THEIR RELATIONSHIP TO PRESUMED SPOT REGIONS ON V471 TAU: A SOLAR-STELLAR CONNECTION

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ABSTRACT

High speed photometric observations of the eclipsing binary V471 Tau were made with the intent of detecting flares similar to those which have been reported in the literature by various observers over several years. Two such flare events were observed at a 3 σ detection level. A search of the literature uncovered five other reliably reported events (many more are mentioned but not documented for analysis). A study of the occurrence times of these events in terms of the ephemeris of the photometric wave that is known to migrate through the light curve of V471 Tau reveals a strong correlation, suggesting that the flares occur near regions of the K dwarf where spot groups are inferred. The evidence suggests that active regions similar to those observed on the Sun occur on V471 Tau but with considerably greater magnitude.

A new period study strongly implies that the system is subject to abrupt period changes interspersing long intervals of period constancy. A new linear ephemeris is derived. New X-ray observations of the coronal radiation from the dwarf K star are also reported and discussed.

Subject headings: stars: eclipsing binaries — stars: flare — stars: individual

I. INTRODUCTION

Ever since its discovery as an eclipsing binary with a white dwarf companion by Nelson and Young (1970), and the subsequent description of its properties by Young and Nelson (1972), V471 Tau (BD +16°516) has been an object of considerable importance, rewarding its observers with new and unexpected properties. Interest at first was directed to the white dwarf because its total eclipse every 12.5 hours yields information about its dimensions and thermal properties. More recently, however, the K dwarf companion has been the subject of intensive studies because it demonstrates many of the properties normally attributed to classical RS CVn stars. In the present study we shall demonstrate that it also exhibits flaring properties which characterize the BY Dra stars (see Bopp and Espenak 1977, and Bopp *et al.* 1981). In a sense, V471 Tau may be the critical link serving to inform us that the distinctions between RS CVn phenomena and BY Dra phenomena are artificial and misleading, arising entirely from the historical processes which gave rise to their discovery, description, and classification. From the more meaningful point of view of the physics of stellar phenomena, it appears that in both the RS CVn and BY Dra stars we are witnessing the effects of the complex processes which occur in rapidly rotating convection zones. From the RS CVn stars to the BY Dra stars we encounter rotating convection zones spanning a vast range of stellar structure, from K giants to M dwarfs. It is hardly surprising that the phenomena which we observe exhibit considerable diversity in their details. Tidal coupling in binary stars, such as V471 Tau, is a further complication which

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affects the behavior of a rotating convection zone, and the details of such effects are not well understood (see Scharleman 1982).

Interest in V471 Tau heightened when Young and Capps (1971) demonstrated that it is almost certainly a member of the Hyades, from which an upper limit to its age could be inferred. Unfortunately, confusion arose over the temperature of the white dwarf which led to confusion in theories of cooling times for white dwarfs. Young and Nelson (1972) used the $U-B$ color extracted from eclipse data to infer a temperature of 32,000 K with considerable uncertainty since the flux from such an object in those wavelength bands is on the Rayleigh-Jeans portion of the energy distribution. Hills (1971) gave a temperature of 64,000 K based upon the assumption that the peculiar morphology of the light curve resulted from heating of the hemisphere of the K dwarf which is irradiated by the white dwarf. The assumption used by Hills is incorrect, since the light curve is dominated by ellipsoidal variability and a migrating wave of the RS CVn variety, and hence his temperature is also incorrect. Recently, Guinan and Sion (1981) have given a definitive temperature of 34,000 K$\pm$3000 based upon *IUE* observations.

Variability of the light curve, excluding the eclipse, was demonstrated by Young and Nelson (1972), and investigated more carefully by Cester and Pucillo (1976). The latter authors suggested that the changes in the light curve's appearance were only in the overall amount of light, and attributed them to ejected material which dissipates and is then replenished. Because of the restricted phase coverage of their observations, they failed to see the pattern in the variations of the light curve, and there is no basis for accepting the notion that material in any significant amounts is present between the two stars, or surrounding them. Credit for discovering the RS CVn type migrating wave in the light curve should go to Ibanoglu (1978) who showed that it had a period of 191 days in the retrograde (decreasing orbital phase) sense. A more recent study by Guinan and Sion (1982) shows that the migrating wave has a period of 247 ± 4 days between 1976 and 1980, but a different period prior to 1976 (undetermined). The discrepancy between the results of Ibanoglu and of Guinan and Sion seems to arise from the fact that Guinan and Sion subtracted out the expected variations due to the tidally distorted K dwarf before deriving times of wave minimum. A survey of published light curves shows a marked tendency for the observed minima to be near phases 0.0, and 0.5, suggesting that the modulation produced by the geometrical distortion of the star predominates over that produced by the migrating wave. Thus, for all calculations in this study we have adopted the wave ephemeris given by Guinan and Sion (1982), because their procedure seems to be necessary, and their ephemeris gives an excellent representation of the wave data over the time interval for which they assert that it applies.

The first indication of variability of the orbital period was given by Anderson and Seeds (1972), and followed by Lohsen (1974). The latter author suggested that abrupt period changes might be occurring. Young and Lanning (1975) published a complete analysis of period variations, finding evidence for both increases and decreases in the period. Controversy over the nature of the period variability began with the analysis by Oliver and Rucinski (1978) wherein it was shown that the best representation to the $O-C$ residuals was obtained by three straight line-segments, suggesting at least two abrupt period changes interspersing intervals of period constancy. However, Tunca *et al.* (1979) combined the same $O-C$ data into seasonal normal points and showed that a single quadratic ephemeris best represented the data. They derived a period variation of -2.2×10^{-7} yr^{-1}, and they used the model of Biermann and Hall (1973) to derive a mass loss rate. We hasten to point out that regardless of which representation of the data is correct (linear segments, or quadratic), the use of the Biermann and Hall (1973) model is inappropriate for V471 Tau because the white dwarf cannot be tidally locked to the K dwarf, and the latter is a fundamental prerequisite for the Biermann-Hall mechanism.

The first mention of what we now suspect to be flare events was made in the discovery paper by Nelson and Young (1970), but dates and times were not recorded. Spurious momentary brightenings are also mentioned by Cester and Pucillo (1978) and Ibanoglu (1979). Lanning and Etzel (1976) reported a single incidence of Hα emission in one spectrogram, and they interpreted it as being due to recombination radiation from gas between the stars. We suspect that what they observed was actually a flare event on the K dwarf, but the observation is ambiguous since it was made at phase 0.5 where a radial velocity measurement cannot distinguish the two possibilities. The more reliable flare reports, along with our own will be discussed in § 3.

II. OBSERVATIONS

a) *Optical Wavelength Region*

Observations reported here were made at the Cloudcroft Observatory with a photometer described by Schneeberger *et al.* (1980). The observations consist of sequences of 0.1 s integrations through a Johnson *U* filter, but the reduced data have been rebinned into 1 s intervals to improve the signal-to-noise ratio. One set of observations was made at the McDonald Observatory using the 96 cm telescope with an Amperex 56 DVP photomultiplier. Table 1 lists the observed epochs and eclipse durations. Figures 1 and 2 exhibit the portions of the observations in which the two flarelike events were detected. The sky was clear, and the light curve was flat immediately before and after the flare events.

TABLE 1

OBSERVED EPOCHS

UT Date	Cycle[a]	t_{mid} [b] (JD − 2,440,000)	t_i [c] (s)	t_e [d] (s)	t_{min} [e] (minutes)	$O-C$ [a] (s)
1979 Dec 10 ...	6922	4217.69483	61	57	48:06	−171
1980 Feb 8	7037	4277.63087	60	57	47:09	−175
1980 Oct 4	7496	4516.85391	51	55	47:12	−191
1980 Oct 5	7498	4517.89650	55	42	47:36	−171
1980 Oct 16 ...	7519	4528.84111	56	62	48:05	−192[f]
1980 Oct 19 ...	7525	4531.96811	72	34	47:09	−201
1980 Oct 31 ...	7548	4543.95542	58	60	47:07	−194
1980 Nov 6	7559	4549.68849	47	60	47:16	−188
1980 Dec 2	7609	4575.74784	60	75	47:13	−174
1980 Dec 4	7613	4577.83238	60	63	47:15	−190
1980 Dec 11 ...	7626	4584.60777	59	45	47:23	−190
1980 Dec 15 ...	7634	4588.77687	62	55	48:08	−221

[a] Calculated from JD = 2,440,610.0649 + $0^{d}.52118346E$ (Young and Lanning 1975)
[b] Heliocentric time of mid-eclipse.
[c] Time from first to second contact.
[d] Time from third to fourth contact.
[e] Duration of eclipse.
[f] Observed at McDonald Observatory.

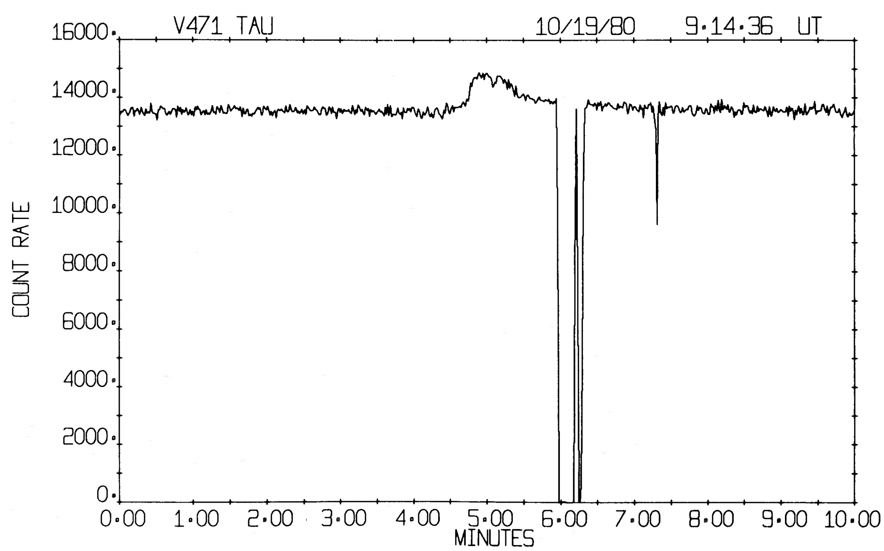

FIG. 1.—Photometric record of the flarelike event which occurred on 1980 October 19 UT. The sky background has been subtracted. The time resolution is 1 s, and 0.0 minutes corresponds to the (geocentric) UT at the top of the figure. The interruption was caused by a measurement of sky brightness.

b) *X-Ray Wavelength Region*

We obtained two observations of V471 Tau with the *Einstein* IPC instrument in February of 1981. The essential results of those observations are given in Table 2 which lists the times, the orbital phases, the observed fluxes, and the results of fitting a model to the spectrum in the 0.2–4.0 keV energy band. Figure 3*a* and 3*b* display the actual time sequence of observed flux with photon arrival times grouped into 100 s bins. We note that there is a statistically significant difference in the mean flux level of the two observations, with the flux on 1981 February 16 being 35% lower than that of 1981 February 10. However, the spectra of the two observations were not significantly different, and so they have been combined with appropriate corrections for gain fluctuations in the detector. In Figure 4 we display the resulting spectrum as a histogram, with a Raymond thermal spectrum (Raymond and Smith 1977) obtained by a least χ^2 fitting procedure. The observations of

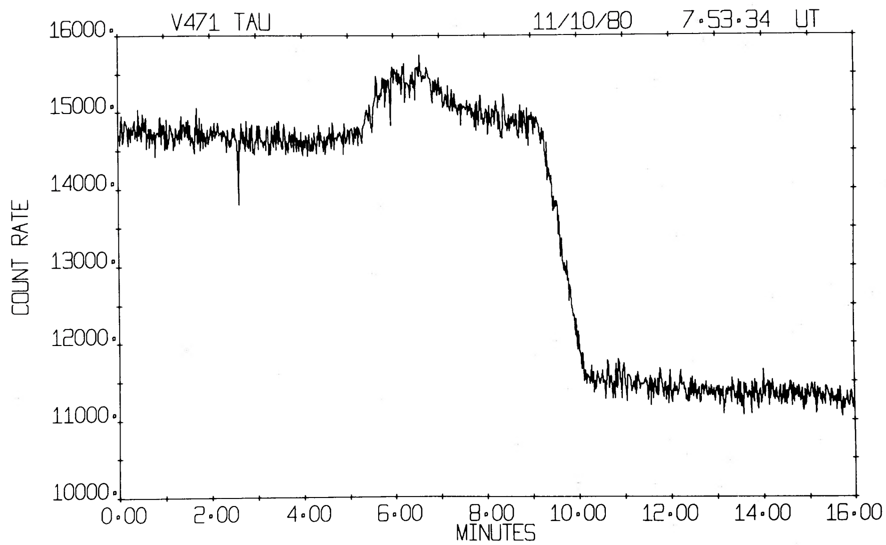

FIG. 2.—Photometric record of the flarelike event which occurred on 1980 November 10 UT. The sky background has been removed. Note the expanded vertical scale. An ingress is seen just after the flare event. Downward spikes in the light curves of Figs. 1 and 2 are caused by rebinning errors which do not affect the overall results.

TABLE 2

EINSTEIN IPC OBSERVATIONS OF V471 TAURI

UT Date (1981 Feb)	Orbital Phases	0.1–4.0 keV Flux (ergs cm^{-2} s^{-1})	Log N_x	T_R (K)
10.1854–10.2159 ...	0.191–0.249	$1.87^{+0.05}_{-0.16} \times 10^{-12}$	$19.2^{+0.5}$ [a]	$(2.8 \pm 0.3) \times 10^6$
16.2069–16.2381 ...	0.744–0.804	$1.21^{+0.04}_{-0.12} \times 10^{-12}$		

[a] No lower limit.

February 10 show no evidence for variability on time scales of several hundred to several thousands of seconds. However, the observations of 16 February suggest a flarelike event at the 4600 s mark. We call attention to the fact that the event is less than a 2 σ detection and is therefore not necessarily real. Since it has the morphological signature of a flare, we performed a statistical test by fitting the data to a four-parameter model of an exponentially decaying flare. The model parameters corresponding to the best fit are a steady state background count of 0.25 s^{-1}; a flare onset time of 4600 s into the observation; a maximum flare count rate of 0.16 s^{-1}; and a flare decay timescale of 130 s. We caution again that at the 2 σ level the observations are also consistent with the hypothesis that the X-ray flux was constant. X-ray flares have also been observed to occur on the Sun, presumably as a result of coronal disturbances above optical flare sites. The literature about such flares is very extensive, but a good illustration is given by Kahler, Petrasso, and Kane (1976). They find characteristic decay time scales ranging from 3 to 10 minutes, using the full width at half-maximum of the flare profile to measure the lifetime.

III. DISCUSSION

In Table 3 we list the seven most reliable flarelike events, including the two observed by us, and references. Some authors give only a phase and date from which we inferred the UT, and others give the date and UT from which we inferred the phase. Along with those data are the computed phases of wave minimum based upon the ephemeris given by Guinan and Sion (1982). For each event we also give the angular extent corresponding to the difference between the two quoted phases, and the elapsed number of wave periods from the epoch given by Guinan and Sion (1982).

Since an observed flare can, in principle, occur anywhere on the hemisphere that faces us, the phases and the angular differences are not directly interpretable. However, if the photometric wave is assumed to be caused by a reasonably localized region of dark spots, as proposed by Hall (1972), and if the flarelike events are similar to solar flares and are hence strongly spatially correlated with the spot regions (see Severny 1964), then we would expect the two sets of phases to be well correlated. Figure 5 displays the relation between the

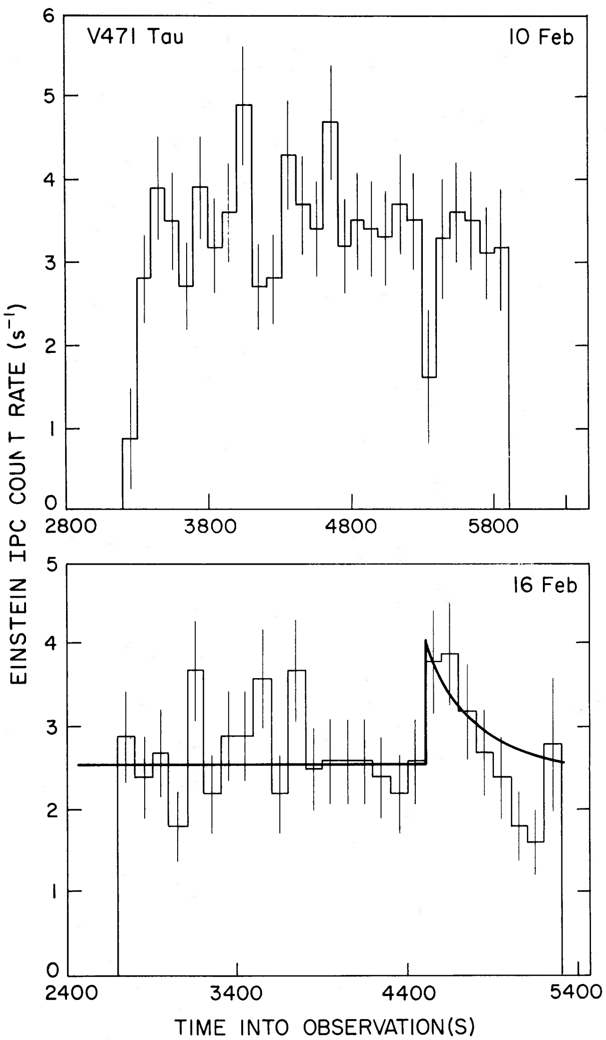

FIG. 3.—Time series of the two X-ray observations: (*a*) 1981 February 10 and (*b*) 1981 February 16 in which a possible flare is indicated.

phases, and it appears that six of the seven do conform to the expected correlation. The dashed line boundaries represent the phase limits for the observable limb of the star (± one-quarter phase); however, we do not know if the angular extent in longitude of a spotted region might be larger than 180°. Nevertheless, it seems that the deviant flarelike event observed by Rucinski (1981) is probably not directly associated with the major spot grouping and may be an event beyond the limb. Studies of active regions on the Sun reviewed by Sawyer (1968) indicate that active regions which can generate large flares can and do grow in advance of the formation of spot groups.

Not all of the flares have the same character. Ours show very rapid rise time (1 minute for November 10, and 10 s for October 19), as do those of Beavers, Oesper, and Pierce (1979). Those of Patterson and Rucinski (1981) have characteristic durations of 20 to 30 minutes (with unknown rise times). While most solar flares typically enhance emission lines rather than continuum, and the less common white-light flares do enhance the ultraviolet, flares such as those reported by Moffett and Bopp (1976) on M dwarf stars generate extreme enhancement of the ultraviolet continuum. Therefore, although we cannot claim with certitude that we have observed flares which are specifically solar-like, nor that they occur near the regions where dark spots may be located, our evidence is highly suggestive that these assertions might be correct. Obviously, the energy released by these events is much larger than that of solar flares in order to be so readily detected in the integrated hemispheric radiation. Assuming that the K dwarf is a normal star, we estimate that its luminosity in the U band is 2.6×10^{32} ergs s^{-1}. Correcting for the contribution from the white dwarf, and integrating under the flare profiles, we find that the total energy (in U band radiation *only*) liberated by the flare of 1980 October 19 was 1.3×10^{33} ergs, and by the flare of 1980 November 10, 2.4×10^{33} ergs. These are, of course, lower limits, but they exceed typical white light solar flares by three or more orders of magnitude. The frequency of occurrence of such large flares must also be quite high for so many to have been caught by random and infrequent observations. We plan, therefore, to initiate a synoptic observing program to obtain reliable statistical information

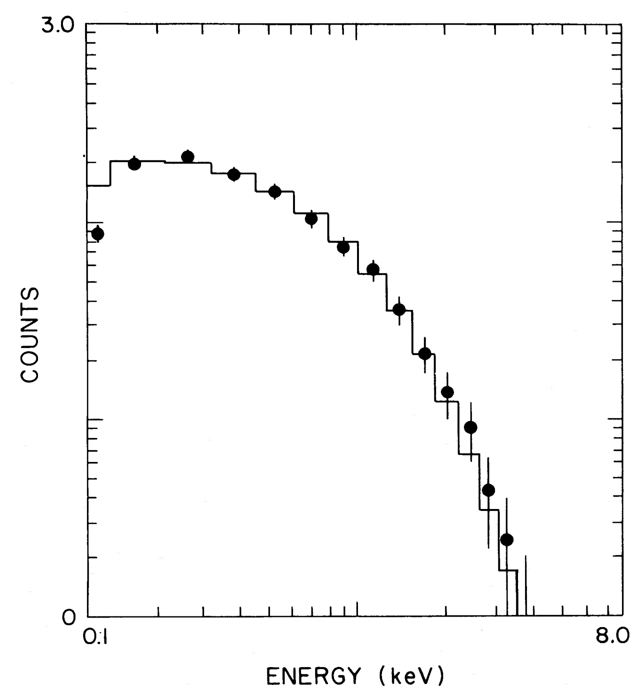

FIG. 4.—The X-ray spectrum shown as a histogram, fitted with a Raymond thermal spectrum corresponding to a temperature of 2.8×10^6 K.

TABLE 3

FLARELIKE EVENTS

HJD (JD − 2,440,000)	UT	ϕ_{orb}	ϕ_{Wave}	$\Delta\theta$ (degrees)	N_w	Reference
3083.86	0838	0.46	0.90	158	−3.3	1
3777.7992...........	0710:53	0.96	0.09	47	−0.5	2
3777.8295...........	0754:33	0.02	0.09	25	−0.5	2
3863.69	0433	0.77	0.75	7	−0.2	3
4531.8851...........	0914:36	0.84	0.04	72	+2.6	4
4554.8289...........	0753:34	0.95	0.95	0	+2.7	4
4586.5417...........	0100	0.70	0.82	43	+2.8	5

REFERENCES.—(1) Rucinski 1981. (2) Beavers, Oesper, and Pierce 1979. (3) Tunca *et al.* 1979. (4) This paper. (5) J. Patterson 1981, private communication.

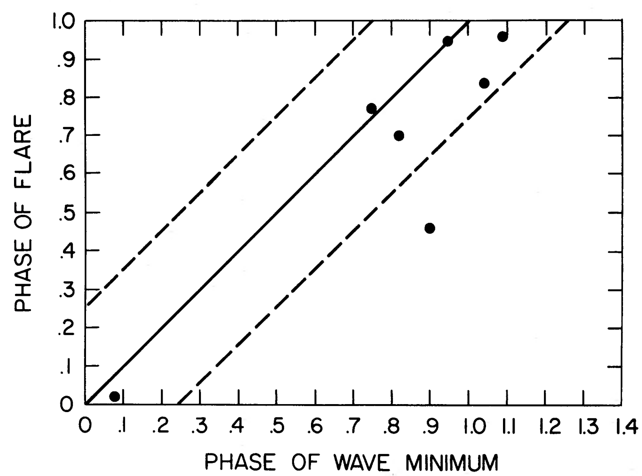

FIG. 5.—Plot of the orbital phase at which a flarelike event was reported against the predicted orbital phase of the minimum of the migrating wave.

about the frequency and phase distribution of such events, and to establish the behavior of the migrating wave.

Table 4 is a compilation of previously determined epochs of mid-primary eclipse along with their sources. Using the ephemeris given by Young and Lanning (1975) we have computed and tabulated the residuals for all of those observations. The recent residuals are given in Table 1. In Figure 6 we display all residuals as a function of cycle number, without grouping them into seasonal means. While there appears to be a curvature between cycles 500 and 3000, the interval from 3000 to 7500 appears to be well represented by a straight line. Thus, we have adopted the three piece linear interpretation given by Oliver and Rucinski (1978), and have redetermined a new linear ephemeris for the interval between 3000 and 7500 cycles. A least squares adjustment (rejecting the deviant observation of JD 2,442,723.4638) leads to the new ephemeris given by

$$\mathrm{JD} = 2{,}441{,}913.02368 + 0.521182993E,$$

wherein we have advanced the epoch to signify that this ephemeris should not be used for dates earlier than that.

Since Tunca *et al.* (1979) claim that the residuals from their quadratic ephemeris show an oscillatory pattern with a period of about 3.5 years, we have examined ours for a similar effect. In Figure 7 we plot the residuals from the new linear ephemeris over the interval for which it is valid (cycle numbers are now counted from the new epoch). There is some suggestion of oscillation, but it is not well represented by a simple sinusoidal curve, and the dispersions obtained by grouping into seasonal means are large enough to cast doubt on the reality of the oscillation. We conclude from the analysis of the timing residuals that V471 Tau is characterized by

TABLE 4

ECLIPSE TIMINGS

HJD_{mid} (JD − 2,440,000)	Cycle (E)	$O - C$ (s)	References	HJD_{mid} (JD − 2,440,000)	Cycle (E)	$O - C$ (s)	References
574.62473	−67	26.8	1	1985.98931	2640	6.9	2
612.67079	5	−2.6	2	2006.31541	2679	1.7	6
612.67083	5	0.9	1	2007.35779	2681	2.6	1
625.70038	30	−1.7	2	2008.40018	2683	5.2	1
887.85561	533	−6.0	3	2015.696713	2697	1.7	5
896.71570	550	−8.6	1,3	2016.739071	2699	0.9	5
898.80038	554	−13.9	3	2016.73908	2699	1.7	7
898.80041	554	−11.2	1	2017.781452	2701	1.7	5
898.80042	554	−10.4	2	2025.599210	2716	2.6	5
898.80044	554	−8.6	2	2032.37464	2729	6.9	1
899.84279	556	−9.5	2	2046.44644	2756	6.9	1
899.84286	556	−3.5	2	2062.603171	2787	−2.6	5
907.66056	571	−8.6	1,3	2069.37850	2800	−7.8	1
911.82996	579	−13.8	1,3	2091.26836	2842	6.0	6
970.723705	692	−12.1	3,4	2341.95735	3323	−16.4	2
1015.54554	778	−7.8	1,3	2346.64794	3332	−21.6	7
1028.57523	803	0.9	1,3	2361.76233	3361	−15.6	2
1208.90483	1149	11.2	1,3	2362.80466	3363	−19.0	2
1218.80724	1168	5.2	1,2,3	2387.3003	3410	−17.3	6
1232.87919	1195	5.2	1,3	2723.4638	4055	−2.6	6
1255.81121	1239	0.0	1,3	2768.80621	4142	−50.1	7
1275.616250	1277	6.0	5	2788.61112	4180	−55.3	7
1281.87051	1289	11.2	2	2825.61509	4251	−60.5	7
1282.91283	1291	6.9	2	2849.58949	4297	−63.9	7
1288.64584	1302	6.9	1,3	3077.8678	4735	−67.4	7
1297.50580	1319	−6.9	1,3	3078.9100	4737	−82.1	7
1299.59076	1323	12.1	1,3	3079.9523	4739	−88.1	7
1322.52280	1367	9.5	1,3	3080.9948	4741	−76.0	7
1325.64990	1373	9.5	1,3	3460.4160	5469	−107.1	6
1326.69235	1375	16.4	2	3462.5008	5473	−102.1	6
1359.52685	1438	11.2	1,3	3463.5432	5475	−98.5	6
1665.46153	2025	10.4	1	3519.30975	5582	−105.4	6
1709.76210	2110	8.6	2	3789.80360	6101	−137.4	8
1712.36799	2115	6.0	1	3790.84590	6103	−143.4	8
1718.62228	2127	13.8	2	3811.69328	6143	−140.0	8
1981.81970	2632	−6.0	2	3813.77798	6147	−142.6	8
1982.86217	2634	3.5	2	3816.38402	6152	−132.2	9
1984.94693	2638	5.2	2	3817.42618	6154	−149.5	9

REFERENCES.—(1) Cester and Pucillo 1976. (2) Young and Lanning 1975. (3) Anderson and Seeds 1972. (4) Warner, Robinson, and Nather 1971. (5) Lohsen 1974. (6) Ibanoglu 1978. (7) Oliver and Rucinski 1978. (8) Beavers, Oesper, and Pierce 1979. (9) Tunca *et al.* 1979.

sudden discontinuous changes in its orbital period interspersing relatively long but unequal intervals of constant orbital period.

In discussing period changes for RS CVn binaries, Hall (1972) proposed an impulsive anisotropic mass ejection event (or series of events) associated with the spotted region, which would maintain a fixed phase relationship with the orbit during the ejection events. Arnold and Hall (1973) corrected a sign error in the effect discussed by Hall, and Catalano and Rodono (1974) challenged Hall's model on the grounds that the purported variations in orbital period may be chimerical because the migrating wave distorts the eclipse light curve and therefore affects the observed time of mid-primary eclipse. The unique structure of V471 Tau with its unambiguous eclipse of the white dwarf completely obviates the objections of Catalano and Rodono (1974).

The variations of the orbital period are unquestionably real. Unfortunately, the migrating wave has such a short period (247 days) that it has not been possible to unambiguously locate the phase of the presumed spotted region at the epoch when the last period change occurred, since that epoch is not defined with an uncertainty smaller than the wave period. The wave ephemeris of Guinan and Sion (1982) implies that the rotation period of the spotted region is $0^{d}.520086$ which is considerably shorter than the orbital period. Typically, RS CVn stars exhibit a rotation period shorter than their

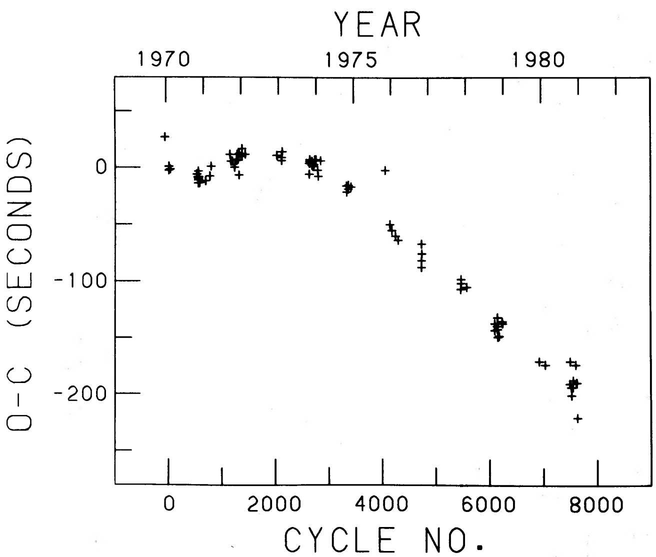

FIG. 6.—The $(O - C)$ diagram for all of the published data, including the new observations in this paper, with respect to the ephemeris given by Young and Lanning 1975.

orbital period, but not usually by that much; i.e. the beat period of the migrating wave is often many years instead of the 247 days reported by Guinan and Sion. De Campli and Baliunas (1979) discuss the physics of the impulsive ejection mechanism for RS CVn stars, but

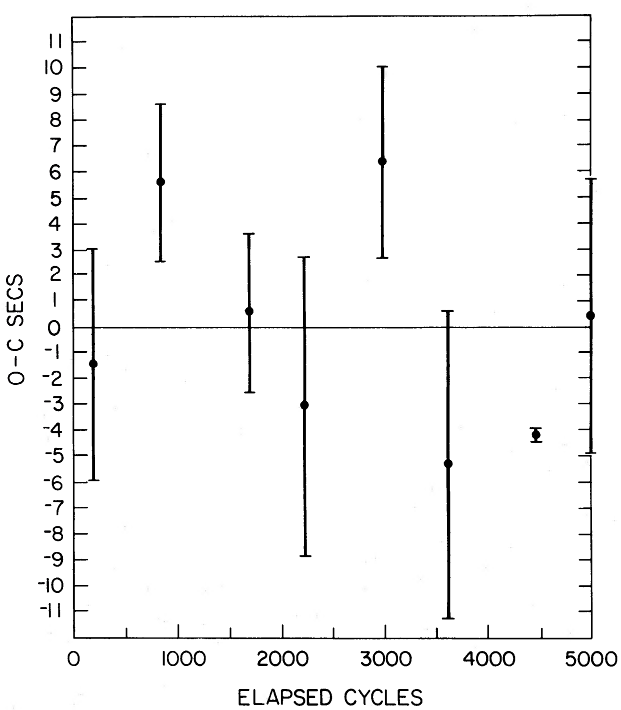

FIG. 7.—The $(O - C)$ diagram for the observations since 1975 with respect to the ephemeris given in this paper, grouped into seasonal means.

conclude that the implied mass loss rates are excessive. However, the flaring episodes in V471 Tau suggest that brief, but intense ejection events may be realistic. Using the formalism relating period variation with mass ejection flux given by De Campli and Baliunas, we find that an impulsive mass loss rate of 1.6×10^{-7} $M_{\odot}$ yr^{-1} would be required. That value is similar to values quoted by De Campli and Baliunas for typical RS CVn systems, and as they remark, it is very large. In view of the magnitude of the required impulsive mass loss necessary to account for the period variations (using the De Campli and Baliunas mechanism), and the absence of convincing evidence for such mass flux, we regard such a mechanism as highly unlikely to explain the observed variations of the orbital period. Nevertheless, the orbital period is unquestionably established to be variable. The significance of V471 Tau, therefore, lies in its demonstration of the reality of orbital period variation in at least one instance of a star which exhibits RS CVn properties. A plausible explanation is not yet known, but is clearly needed.

A potential diagnostic for ejection of material from the events of the K dwarf is the ingress-egress light curves of the white dwarf. The excellent photometry of these events reported by Warner, Robinson, and Nather (1971) shows that the eclipse ingress takes 68 ± 1 s, and so does the egress. However, other observers such as Young and Nelson (1972), Young and Lanning (1975), and Beavers, Oesper and Pierce (1979) have obtained different results, partly due to inadequate photon statistics, and partly to different operational definitions for the contact events. Our own data (Table 1) also exhibit some disparity from the aforementioned and, even more disturbingly, they exhibit large scatter. If opaque material were seen in projection above the limb of the K dwarf at ingress or egress, we would expect those durations to increase, and the light curve of the ingress or egress to be altered. However, we have no reasonable explanation for durations as small as 34 s, and therefore we presume that we are seeing observational error. However, contact timings done with good photon statistics could be analyzed with respect to the phase of wave minimum to search for ejected material such as quiescent limb prominences. We propose this for future work, since the published data seem to be inadequate to the task.

V471 Tau had been measured earlier as an X-ray source with $L_x = 5 \times 10^{30}$ ergs s^{-1} (Van Buren, Charles, and Mason 1980), and seems to fit with the general picture of coronal activity in RS CVn stars as a consequence of a rapidly rotating convection zone. Walter (1982) has observed the coronal X-ray fluxes of RS CVn binaries and other rapid rotators and shows that V471 Tau has the largest ratio of X-ray to bolometric luminosity of all of the late-type stars observed. Using a distance modulus of 3.21 mag for the Hyades, our observations lead to X-ray luminosities of 4.3×10^{29} ergs s^{-1} and 2.8×10^{29} ergs s^{-1} for February 10 and February 16, respectively. With only two high quality observations, we cannot distinguish whether these differences are due to the different aspects being observed at different orbital phases, or to real variability in the coronal output, or both. The wave ephemeris of Guinan and Sion (1982) indicates that wave minimum should be at orbital phase 0.56 during these observations. Hence, the presumed spotted region would have been essentially on the visible hemisphere when the possible X-ray flare of February 16 occurred. However, the spotted region would not have been on the observable hemisphere when the X-ray flux was largest, and vice-versa. That is contrary to what is typically observed on the Sun. Spot regions with closed loop fields are generally associated with the brightest coronal X-ray emission on the Sun. Based on the other evidence presented so far, this would lead us to infer that we observed a genuine variation in the coronal X-ray luminosity rather than an aspect effect.

Optical measurements of the reddening toward the Hyades given by Taylor (1980) give an upper limit of 0.005 magnitudes for E_{B-V}. That value corresponds to a column density of 3×10^{19} cm^{-2} since $N_x = 6 \times 10^{21}$ E_{B-V} as given by Bohlin, Savage, and Drake (1978). In Figure 8 we show a probability contour diagram in which we search for the best fitting Raymond thermal spectrum and include the effects of absorption. The 90% and 99% confidence contours are shown, with a vertical line at the upper limit of absorption column density previously mentioned. The contours turn downward toward increasing N_x because the effects on the fit of decreased plasma temperature and increased flux over the energy band are mimicked to some extent by larger

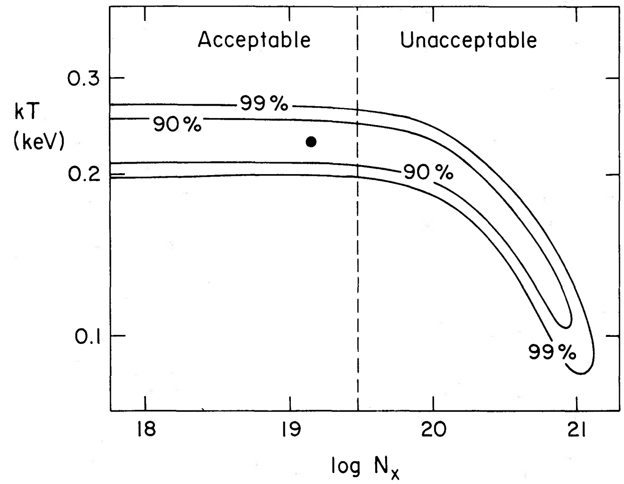

FIG. 8.—Spectral fit to a model of a Raymond thermal spectrum to the IPC data. The 90% and 99% contours are shown, and the dot is the best fit. The vertical line is the upper limit to the optically measured column density. Models to the left of that line are allowed.

column densities of absorbing material. Acceptable fits must lie to the left of the vertical line, and they have statistically insignificant interstellar absorption of X-rays. Elimination of the right side of the diagram permits an unambiguous solution at the 90% confidence level represented by the dot. The solution yields an X-ray temperature of the coronal gas of $2.8 \pm 0.3 \times 10^6$ K, and leads to the value of N_x which is given in Table 2. This temperature is lower than the typical values found for RS CVn stars by a factor of 2.

We suggest that V471 Tau exhibits the RS CVn phenomenon scaled up in magnitude and operating on shorter time scales, and that similarly it exhibits the BY Dra phenomenon scaled down in magnitude and operating on longer time scales (vis-à-vis flare outbursts). In essence, this star may be the Rosetta Stone which provides the connection between these two syndromes, and as such is worthy of intense observation. In particular we urge flare monitoring, and wave migration and period-variation studies to improve the statistics and accuracy of all these characteristics. High accuracy and intensive monitoring may enable us to discern the presence of differential rotation from spot migrations in latitude by the alterations produced in the wave ephemeris, and will certainly permit the testing of some current ideas about stellar flares.

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