

Preeruption light curves of novae

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A catalogue of all published preeruption photometry of novae is presented, and preeruption light curves are constructed for 11 of the stars. It is found that (1) with the possible exception of BT Mon, the preeruption and posteruption magnitudes are the same for all 18 stars for which both magnitudes are known. (2) Twelve stars have well-defined preeruption light curves. Six of the 12 show changes in their light curves in the 1–15 yr prior to their eruption. Five of the six stars show a rise in brightness by 0.25 to 1.5. None of the available theories of the nova eruption can account for this preeruption rise. RR Tel became a long-period regular variable prior to its eruption. It is argued that the behavior of RR Tel suggests that the M5 III star in the binary must control the eruption. (3) The preeruption and posteruption light curves of one star, V446 Her, are different. The prenova varied irregularly by almost 4 mag. The postnova does not vary by more than 0.4.

INTRODUCTION

DURING an eruption the light curve of a nova is determined by the matter which the nova ejects. While of considerable interest in itself, the ejected material gives little insight into and indeed often obscures, the nature of the underlying star. We note that many of the remarkable properties of cataclysmic variables, e.g., that they are binary stars with mass transfer from a late-type star onto a white dwarf, can only be detected from minimum light observations (cf. reviews by Kraft 1963; Mumford 1967; Smak 1971). In the case of dwarf novae and recurrent novae, the question of whether the stars are physically different in their preeruption and posteruption stages of minimum light is a moot point. The posteruption stage of one eruption is the preeruption stage of the next. However, the classical novae, by definition, have been seen to erupt only once. A clear division into preeruption and posteruption stages can be made, and the possibility of differences in the two stages arises.

Our present knowledge concerning prenovae comes primarily from early investigations by McLaughlin (1939a, b, c, 1941, 1960). McLaughlin argued vigorously in favor of two conclusions:

(1) There is no essential difference in the appearance of a nova before and after its eruption.

(2) Nova eruptions occur without warning, and with the exception of the RT Serpentis stars, the initial rise to maximum light is extremely rapid. Only in exceptional cases does the initial rise take more than a day or two.

A much larger body of data on prenovae is available now than was available in 1939. In order to reexamine the problem of prenovae, we have gathered here all of the published preeruption photometry of novae. Our results show that both of the earlier conclusions must be modified. The first conclusion, while basically correct, has an exception in the light curve of V446 Her. The second conclusion can no longer be supported. The light curves of many novae have shown significant changes, usually a small increase in luminosity, 1–15 yr prior to their eruptions.

Section I of this paper gives a catalogue of preeruption photometry of novae, and for those novae for which there is sufficient data, gives preeruption light curves. The data is discussed in Sec. II. Section III summarizes the results and discusses some of the implications of this investigation.

I. THE PREERUPTION LIGHT CURVES

A total of 33 novae now have one or more measurements of their preeruption magnitudes. These novae are listed in Table I along with the year of their eruption,

TABLE I. The magnitudes of novae.

Star	Year	Magnitude		
		Prenova	Maximum	Postnova
V356 Aql	1936	16.5	7.0	16.5
V603 Aql	1918	10.5	— 1.1	10.5
V1229 Aql	1970	19.4	6.5	...
OY Ara	1910	17.5	6.2	...
IV Cep	1971	15.4	7.5	...
WX Cet	1963	18:	10.5	...
V655 CrA	1967	17:	8:	...
V465 Cyg	1948	17.5	8:	...
HR Del	1967	12.3	3.3	...
DN Gem	1912	15:	3.5	14.8
DQ Her	1934	14.7	1.4	14.5
V446 Her	1960	15.0–18.0	3.0	15.8
V533 Her	1963	14.2	3.0	14.4
CP Lac	1936	15.5	2.1	15.6
DI Lac	1910	14.0	4.6	14.2
BT Mon	1939	16.8–<17	4.5	15.8
GI Mon	1918	15.1	5.6	15
GK Per	1901	13.8	0.2	13.5
RR Pic	1925	12.7	1.2	12.6
HZ Pup	1963	18.5	7.7	...
GR Sgr	1924	16.6	>11.4	16.5
V441 Sgr	1930	16.0	8.7	16.5
V999 Sgr	1910	16.5	8.0	16.5
V1016 Sgr	1899	15.0	> 8.6	14.9
V2572 Sgr	1969	13	6.3	13
Sgr	1962	17.1	> 8.4	...
Eu Sct	1949	16.3	8.0	17.0
FS Sct	1952	16.6	10.1	...
FV Sct	1960	21	7	...
V368 Sct	1970	19.3	7.7	...
FH Ser	1970	16.1	4.4	...
RR Tel	1946	16.6	6.8	...
LV Vul	1968(1)	16.9	4.5	...

their preeruption magnitudes, their magnitudes at the peak of the eruption, and their posteruption magnitudes.

Eight stars which might be expected to appear in Table I have been rejected. The preeruption magnitude of V528 Aql has occasionally been given as 17.5, but according to Hagopian and Sawyer (1946) the prenova was misidentified. The preeruption magnitudes of both AR Cir and V732 Sgr are contaminated by nearby stars (Swope 1940; McLaughlin 1939b). The preeruption magnitudes of HR Lyr and CP Pup are occasionally given as 16.5 and 17, respectively. Both magnitudes are actually upper limits (Bailey 1920a; Gaposchkin 1946). X Ser may be a symbiotic star and has been rejected (Payne-Gaposchkin 1957). According to Bailey (1920b) the preeruption magnitude of IM Nor is 16.5, but a recent photograph of the field by Elliot and Liller (1972) shows that the postnova must be fainter than 20th mag. Bailey's magnitude is due to a misidentification of the prenova. Finally, according to Payne-Gaposchkin (1958) the preeruption magnitude of V630 Sgr was 14^m4. We were unable to find the source of this number, and have not included it in Table I. In addition, the so called RT Serpentis stars have not been included.

Every attempt has been made to include all of the published preeruption magnitudes of novae. Although the possibility that some observations have been missed cannot be excluded, it is believed that the following compilation is complete. Upper limits on the brightness of the prenovae have not been included unless, in our judgment, they place significant limits on the variability of the prenova. One of the most serious problems encountered in this study was that the multiplicity of magnitude systems and measurement techniques in use made it impossible to accept any magnitude measurement at face value. The case of FH Ser demonstrates that this problem exists even for recent data. Both Burkhead and Seeds (1970) and Kosai (1971) measured the preeruption magnitude of FH Ser on the Palomar Sky Survey, but the magnitudes measured on the E plates differ by 0^m7, and the discrepancy in the O-plate magnitude is 1^m1! Fortunately, in nearly every case it was found possible to reduce the data for a given star to a common magnitude scale. The discussion in Sec. II rests only on these stars, and on stars for which the data was already on a uniform magnitude scale.

The sources of the preeruption magnitudes are given in the following list. For 11 of the prenovae, the data is sufficiently extensive to allow a light curve to be constructed.

(1) *V356 Aql* JD 2428378 (1936). According to Hoffmeister and Morgenroth (1936) the prenova appears on Wolf-Palisa Chart No. 77 (JD 2416667) at about magnitude 16. They also examined a total of 217 Sonneberg plates of the field of V356 Aql taken between 1928 and 1936. The best of these plates show

a star of about magnitude 16 at the position of the nova. The dates on which the plates were taken are not given. Bohrmann (1936) found the prenova at 16^m5 on a Bruce plate taken in 1924. Beyer's (1936) measurement of 14^m8 in 1931 may be due to a misidentification. The postnova measurement of 16^m7 comes from a Moscow plate taken on JD 2432092 (Parenago 1949).

(2) *V603 Aql* JD 2421755 (1918). With a magnitude of about 10.5, V603 Aql is the brightest known prenova, and can be seen on hundreds of plates taken at many observatories. The preeruption light curve has never been published, and since, with very few exceptions, individual magnitudes have not been published, a light curve cannot be constructed from the available data. Pickering (1918a, b, c) has described the extensive series of plates of the prenova from Harvard, and Barnard (1918) has described his 54 photographs of the prenova. Both sets of plates show that between May 1888 and its eruption, V603 Aql was a low-amplitude variable with a range of 0.5–1.0 mag. On a photograph taken at Heidelberg by Wolf two days before the eruption the prenova was still at its normal brightness (cf. Campbell 1919).

(3) *V1229 Aql* JD 2440690 (1970). The prenova has been found on the Palomar Sky Survey by Kosai (1971). It is at 19^m4 on the O plate and 17^m6 on the E plate (JD 2434157). Measurement of the postnova magnitude must wait until V1229 Aql has reached its true minimum.

(4) *OY Ara* JD 2418738 (1910). Walker (1923) reports that the prenova was detected on one Harvard plate at 17^m5 (JD 2427028). The prenova was invisible on an additional 48 Harvard plates taken between 1889 and the eruption in 1910. The plate limits were between 11.2 and 16.3 with most at 13.5. Apparently the posteruption magnitude of OY Ara has never been measured. On JD 2421462 its magnitude was less than 15.3.

(5) *IV Cep* JD 2441141 (1971). Kosai (1971) and Walker and Keyes (1971) have identified the prenova on the Palomar Sky Survey. The magnitudes given by Kosai are probably more reliable. He gives 15^m4 on the O plate, and 17^m3 on the E plate (JD 2434269). IV Cep may not yet have returned to minimum light.

(6) *WX Cet* JD 2438294 (1963). On JD 2434982 the prenova is at magnitude 18 on the O plate and magnitude 19 on the E plate of the Palomar Sky Atlas (Strohmeier 1964). The magnitude of the postnova does not appear to have been measured.

(7) *V655 CrA* JD 2439610 (?) (1967). Sanduleak (1969) identified the prenova with a star of about magnitude 17 on the Whiteoak extension to the Palomar Sky Survey (JD 2438653). The magnitude is a red magnitude. As the maximum of the light curve of the nova was not observed, both the maximum magnitude and the Julian date of maximum may be in error. The postnova has not been observed.

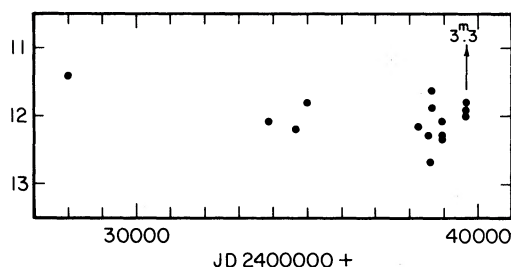


FIG. 1. The preeruption light curve of HR Del. The arrow marks the beginning of the eruption, and the number above the arrow gives the magnitude reached at the peak of the eruption. The vertical scale is photographic magnitude.

(8) *V465 Cyg* JD 2432700 (1948). Ashbrook and Nail (1950) found threshold images of the prenova on two Harvard plates. On JD 2431326 and JD 2432004 the prenova was at about $17^m.5$.

(9) *HR Del* JD 2439660 (1967). The published magnitudes of the prenova are shown in Fig. 1 (Solomon 1967; Schweitzer 1968; Fehrenbach *et al.* 1967; Barnes and Evans 1970). In addition, Wenzel (1967) has examined 222 Sonneberg plates of HR Del taken between 1928 and 1966 and finds the prenova to be only slightly variable around a mean photographic magnitude of 11.9 . Liller (1967) has examined the entire Harvard plate collection and finds no evidence that HR Del was brighter than magnitude 10 between June 1890 and July 1952. Stephenson (1967) has found the prenova on the Franklin-Adams charts. HR Del is an extremely slow nova and has not yet returned to its minimum magnitude.

(10) *DN Gem* JD 2419476 (1912). According to McLaughlin (1939b) the prenova is at about magnitude 15 on one plate taken at Heidelberg (date unknown). The prenova is invisible on 30 Harvard plates of the field taken between 1890 and 1912. The plate limits were between $10^m.6$ and $13^m.8$ with most of the plates having a limit at about $12^m.5$ (Leavitt 1920).

(11) *DQ Her* JD 2427794 (1934). The preeruption light curve of DQ Her, shown in Fig. 2, is compiled from data given by Ahnert (1960), Gaposchkin (1956), Kukarkin and Vorontsov-Velyaminov (1934), and Shapley (1934). The Sonneberg plates measured by Ahnert are the same ones mentioned by Morgenroth (1934). There are a total of 74 Sonneberg plates of the field of the prenova, but Ahnert only gives the magnitudes measured on the 27 best plates. The Sonneberg magnitudes have been adjusted to match the Harvard magnitude scale. In addition to the Harvard magnitudes given by Gaposchkin and by Shapley, there are several hundred Harvard plates, taken between 1890 and the eruption, on which the prenova is fainter than the plate limits. The plate limits are always fainter than magnitude 11 or 12 (Shapley 1934). The prenova can be seen on the Franklin-Adams charts (anonymous 1935).

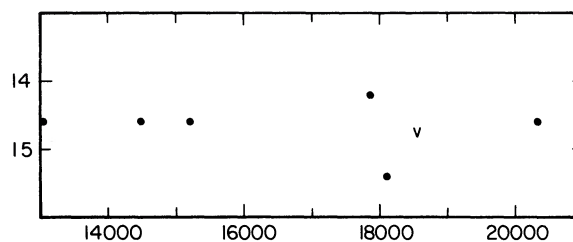


FIG. 2. The preeruption light curve of DQ Her.

DQ Her is the only nova for which there is direct evidence that the prenova was a binary system. Ahnert used the Sonneberg plates to show that in the years 1930–1934, DQ Her was an eclipsing binary with an orbital period of 0.1932084 day. According to Walker (1958), the orbital period of DQ Her for the years 1954 to 1956 was 0.19362060 day. Ahnert used the change in orbital period to deduce that $1.6 \times 10^{-3} M_{\odot}$ was ejected during the eruption. This is within a factor of 4 of other estimates of the mass in the ejected shell (cf. Beer 1974).

(12) *V446 Her* JD 2436998 (1960). The set of preeruption magnitudes of V446 Her is shown in Fig. 3 (Stienon 1963; Cragg 1960; Lowne 1960; Richter 1962; Apriamashvili 1960). The many upper limits on the brightness of the prenova given in these references have not been included in the light curve. Richter's measurements have been adjusted to match the magnitude scale used by Stienon. Figure 4 shows an

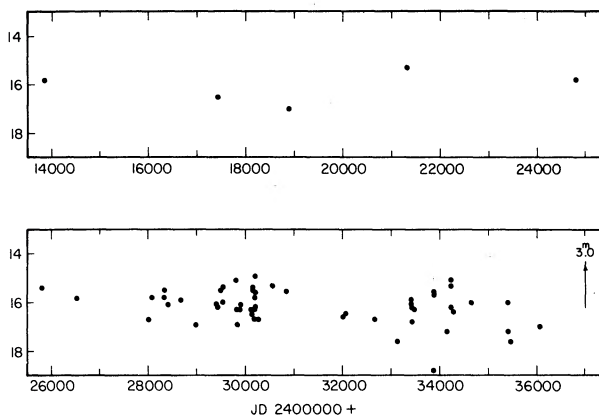


FIG. 3. The preeruption light curve of V446 Her.

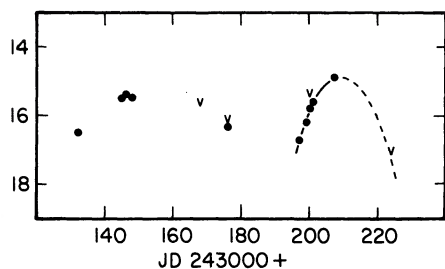


FIG. 4. An expanded portion of the preeruption light curve of V446 Her. The "v" symbol gives the plate limit of photographs of the field of V446 Her on which the prenova cannot be seen.

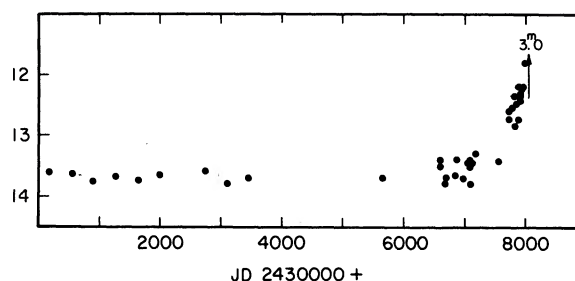


FIG. 5. The preeruption light curve of V533 Her.

expanded portion of Fig. 3, and gives a better idea of the nature of the variations of the prenova. Stienon (1971) has measured the posteruption light curve of V446 Her and finds it to be nearly constant in brightness with a mean magnitude of 15.8.

(13) *V533 Her* JD 2438060 (1963). The preeruption light curve of V533 Her shown in Fig. 5 is entirely from Sonneberg plates (Gotz 1965; Löchel 1963). The magnitudes given for the years 1941–1950 are averages of two or more plates, and thus do not show the rapid intrinsic variations shown in the later individual observations. Stephenson and Herr (1963) found that the prenova has a companion at about $9''.5$ separation that is two magnitudes fainter than the prenova. The Sonneberg magnitudes refer to the combined light of the pair. The magnitudes measured on the Palomar and on the Lick Sky Atlases by Stephenson and Herr refer only to the prenova, and have not been included in the figure. The prenova has been found on a 1920 Harvard plate at about magnitude 15 (Newsom and Chester 1963).

(14) *CP Lac* JD 2428340 (1936). The preeruption light curve of CP Lac is shown in Fig. 6 (Hoffleit 1936; Parenago 1936, 1949). Additional magnitudes of the prenova are given by Becker (1936), Wachmann (1936), and Bohme (1936), but have been rejected as they probably refer to a star just to the north of the true prenova. The prenova has also been identified by Schewick (1936) on Sonneberg plates, but his magnitudes have not been included in Fig. 6 since they are only approximate. According to Parenago

(1936) the prenova is fainter than 15^m on 26 Moscow plates taken between May 1899 and December 1934.

(15) *DI Lac* JD 2419002 (1910). The preeruption observations of DI Lac are shown in Fig. 7, and are from Leavitt (1920) and from Barnard (1912). Barnard's magnitudes have been adjusted to match Leavitt's magnitude scale. Leavitt (1920) reports that the prenova is below the plate limits on an additional 24 Harvard plates. The plate limits are between $10^m.1$ and $13^m.9$, with most of the limits being in the neighborhood of $12^m.5$.

(16) *BT Mon* JD 2429640 (1939). The sparse set of observations of the preeruption light curve of BT Mon is compiled from Wachmann (1968) and Bertiau (1954) and is given in Fig. 8. A considerable adjustment ($1^m.0$) was made in Bertiau's magnitude scale in order to bring it into agreement with Wachmann's scale. Whipple (1940) and Whipple and Bok (1940) searched 150 Harvard plates of the field of BT Mon taken between 1898 and the eruption without a single positive detection of the prenova. Most of the plate limits were between magnitude 11 and 13, but a few of the early plates had limits near magnitude 17. The peak of the eruption of BT Mon was not observed, and the peak magnitude given in Table I is an extrapolation.

(17) *GI Mon* JD 2421595 (1918). Leavitt (1920) reports a single marginal detection of the prenova at magnitude 15.1 on a Harvard plate (JD 2425498). The prenova is fainter than the plate limit on 34 other Harvard plates taken between 1890 and 1918. The plate limits were between $10^m.6$ and $14^m.7$ with most of the plates having a limit near $14^m.0$.

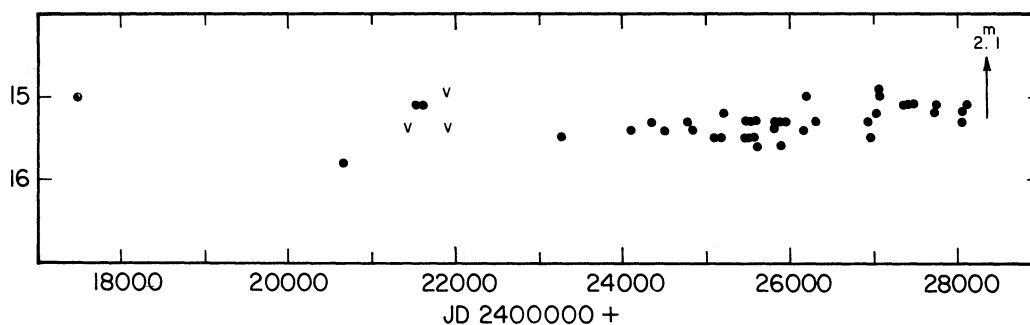


FIG. 6. The preeruption light curve of CP Lac.

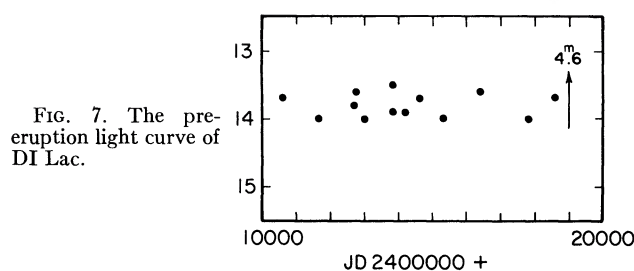


FIG. 7. The pre-eruption light curve of DI Lac.

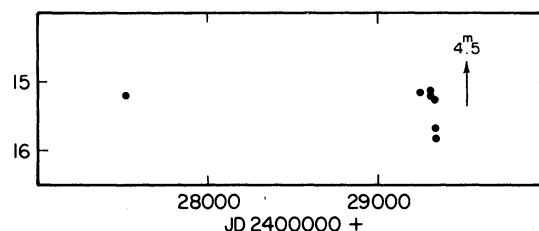


FIG. 8. The preeruption light curve of BT Mon.

(18) *GK Per* JD 2415439 (1901). The preeruption light curve of *GK Per* is from Leavitt (1920), and is shown in Fig. 9. The plate limits of the Harvard plates on which the prenova could not be seen are also given in the figure.

(19) *RR Pic* JD 2424310 (1925). Photographs taken at the Arequipa Station of the Harvard Observatory show the prenova to be at 12^m75 in 1889, 1890, and for every year in the interval 1894–1925. Shapley (1925) examined the photographs and found no evidence of variation in the star's magnitude. The data was not published. Spencer-Jones (1931) reports that photographs taken at the Union Observatory in 1914 and 1921 show the prenova at about 12^m75 on the Harvard scale. He rejects as unreliable a single measure of 14^m2 for the prenova on an Astrographic Catalogue plate.

(20) *HZ Pup* JD 2438042 (1963). Hoffmeister (1964a, b) identified the prenova on the Palomar Sky Survey as a faint blue star of about 18^m5 (JD 2435546). The posteruption magnitude has not been published.

(21) *GR Sgr* JD 2423905 (1924). Woods (1927) examined some 435 Harvard plates, including the years from 1890 to the eruption, for evidence of the prenova. On two Bruce plates (JD 2423676 and JD 2423678) the prenova was identified at magnitude 16.6. The maximum of the eruption was not observed.

(22) *V441 Sgr* JD 2426230 (1930). *V441 Sgr* was found by Hoffleit (1932) on Harvard plates. She gives a prenova magnitude of 16.0 on JD 2426214. Hoffleit also found the prenova on other Harvard plates at

about the same magnitude, but does not give the individual measurements.

(23) *V999 Sgr* JD 2418680 (1910). Walker (1923) reports that on Harvard plates the prenova is at magnitudes 16.4 on JD 2414183, 16.5 on JD 2417773, and 16.3 on JD 2417801. On 46 other plates of the field taken between 1889 and the eruption in 1910, *V999 Sgr* is below the plate limit. The plate limits are between 10.5 and 16.0 with most in the neighborhood of 14.0.

(24) *V1016 Sgr* JD 2414878 (1899). Walker (1923) reports that the prenova could be seen on three Harvard plates. Its magnitude was 15.0 on JD 2414140, 14.9 on JD 2414846, and 14.9 on JD 2414870. The prenova was below the plate limit on 14 other Harvard plates of the field. The plate limits were between 12^m0 and 15^m0 with most in the neighborhood of 14.0. The peak of the eruption was not observed.

(25) *V2572 Sgr* JD 2440415 (1969). Knight (1972) gives magnitude 13 for the prenova from 90 Nantucket plates taken between 1957 and 1968. The prenova was fairly constant in magnitude, and the individual measures were not published.

(26) *Nova Sgr 1962* JD 2437818 (1962). This anonymous nova was discovered by Dinerstein (1973) on Nantucket plates. Hoffleit (1973) identifies the prenova with a faint star which can be seen on Harvard Bruce plates. The only published magnitudes of the prenova are shown in Fig. 10. The peak of the eruption was probably not observed, and the magnitude of the postnova is not known.

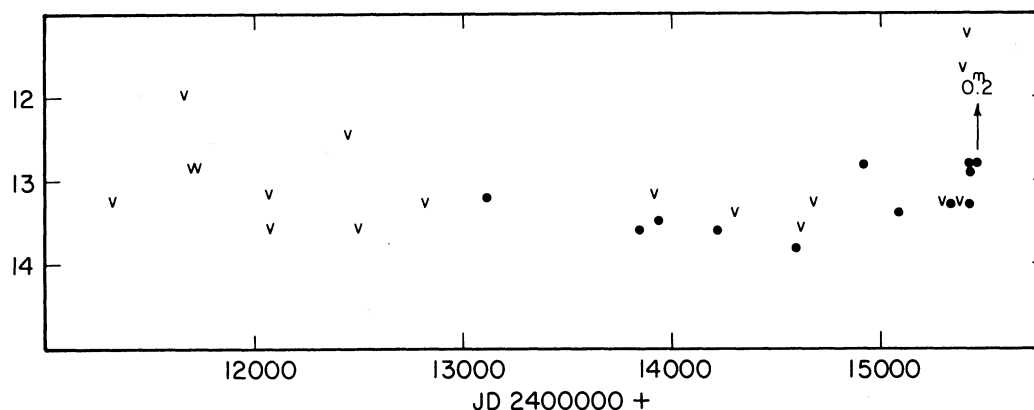


FIG. 9. The preeruption light curve of *GK Per*.

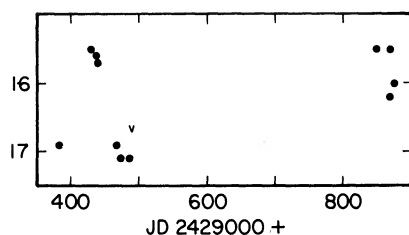


FIG. 10. The preeruption light curve of nova Ser 1962.

(27) *EU Sct* JD 2433135 (1949). Kurochkin (1949) found the prenova at 16^m28 on JD 2433117 and at 16^m23 on JD 2433123, but Bertaud (1953) considers these magnitudes to be uncertain.

(28) *FS Sct* JD 2434188 (1952). The prenova was found by Harwood (1962) on 24 Bruce plates from the Harvard collection. The magnitude was 16.6 and did not vary by more than 0^m2 . The details of the observations have not been published. The posteruption magnitude is not known.

(29) *FV Sct* JD 2437000 (1960). The prenova has been identified by Savelyeva (1960) and by Nassau and Stephenson (1961) on the Palomar Sky Survey. According to Savelyeva the star is at about 21 mag (JD 2434224). The maximum of the eruption was not observed. The maximum magnitude given in Table I is an extrapolation and may be in error. The posteruption magnitude is not known.

(30) *V368 Sct* JD 2440767 (1970). Kosai (1971) identified the prenova with a star of 18^m6 on the Palomar Survey O plate and of 16^m6 on the E plate (JD 2434894). Robinson and Harwood (1970) agree with the identification. On 45 O plates taken with the 48-in. Palomar Schmidt over the 5-day period JD 2435279–83 they found no evidence of variations of the prenova. The average magnitude on the 45 plates was 19.3. The posteruption magnitude has not been published.

(31) *FH Ser* JD 2440635 (1970). The prenova has been identified on the Palomar Sky Survey (JD 2434894) by Kosai (1971) and by Burkhead and Seeds (1970). Burkhead and Seeds give $m_v = 16.1$ and $B - V = 0.8$. Kosai gives 15^m4 on the E plate and 15^m8 on the O plate. FH Ser is a slow nova and has not yet returned to minimum.

(32) *RR Tel* JD 2431385 (1946). The remarkably complete preeruption light curve of RR Tel shown in Fig. 11 has been taken *in toto* from Mayall's (1949) measurements of Harvard plates. The Julian date of the eruption refers to the beginning of the eruption rather than to the maximum of the eruption which occurred in 1949. RR Tel is an extremely slow nova, and has not yet returned to minimum.

(33) *LV Vul* JD 2439965 (1968). The preeruption light curve of LV Vul is given in Fig. 12 (Meinunger 1968; Herbig 1968; Kukarkin and Efremov 1968). The prenova was only slightly variable, so only yearly

average magnitudes are given by Meinunger. The points in Fig. 12 are these yearly averages. The cross represents the statement by Kukarkin and Efremov that the prenova was between 16^m and 17^m on plates taken between 1949 and 1952. Liller (1968) has searched all Harvard plates of the field taken between July 1898 and July 1952, finding no evidence that the prenova became brighter than magnitude 14. The prenova can be identified on the Palomar Sky Atlas, but its magnitude there has not been measured. It is too soon to know if the most recently published magnitudes of LV Vul refer to the true posteruption magnitudes.

II. DISCUSSION

In order to discuss the large body of data contained in the previous section, we have grouped the novae into five classes. The classes are based as much on the completeness of the available data as on the morphology of the light curves and it should be recognized that to some extent the classes are artificial.

(a) *Class I*. This class includes all novae for which the data are so fragmentary that no statement about their preeruption light curves can be made. The class includes 12 stars: V1229 Aql, OY Ara, IV Cep, WX Cet, V655 CrA, V465 Cyg, HZ Pup, Nova Sgr 1962, FV Sct, V368 Sct, FH Ser, and FS Sct.

(b) *Class II*. Class II includes those stars for which both preeruption and posteruption magnitudes are available, but for which the data are insufficient to construct a light curve. The class includes nine stars: V356 Aql, DN Gem, GI Mon, GR Sgr, V441 Sgr, V999 Sgr, V1016 Sgr, V2527 Sgr, and EU Sct. Examination of the data for these stars shows that, without exception, the magnitude of the prenova and postnova are nearly the same. The small differences which do occur can be attributed entirely to measurement error and to the small intrinsic fluctuations in brightness which other novae show in both their preeruption and posteruption light curves.

(c) *Class III*. This class includes those novae which have preeruption light curves that are well known, and that fit the classical picture of a prenova. The class includes V603 Aql, HR Del, DQ Her, DI Lac, and RR Pic. The prenovae in this class are low-amplitude variables whose mean brightness remains unchanged until a few days before the eruption. The mean magnitudes before and after the eruptions are the same. With the sole exception of HR Del, the novae in class III erupted prior to 1935. This historical accident strongly biased earlier investigations on prenovae, and resulted in the conclusion that *all* novae would fit in this class if the observations were sufficiently complete.

(d) *Class IV*. Class IV includes the five novae whose preeruption light curves displayed a small but significant increase in luminosity in the 1–6 yr just prior to their

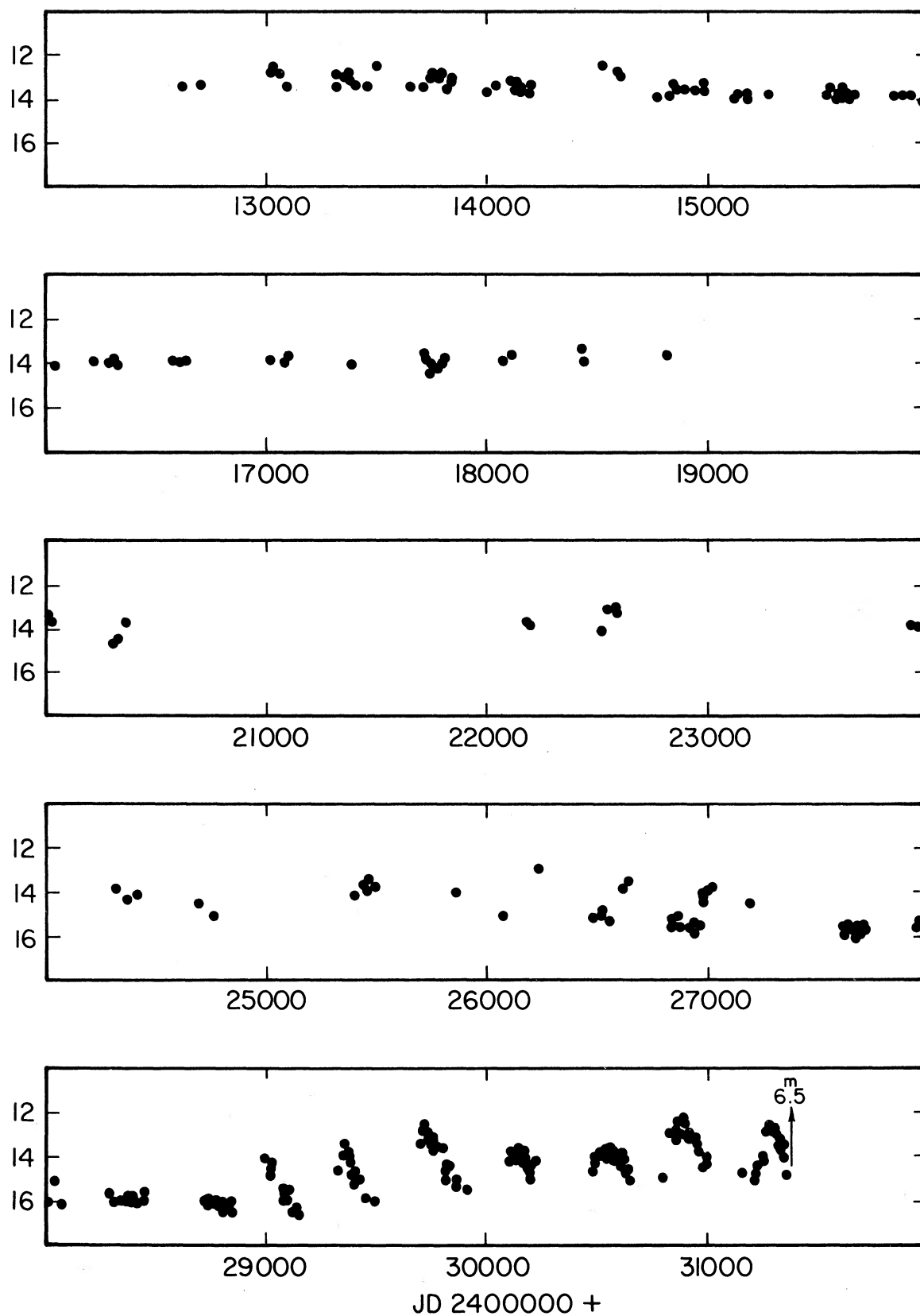


FIG. 11. The preeruption light curve of RR Tel.

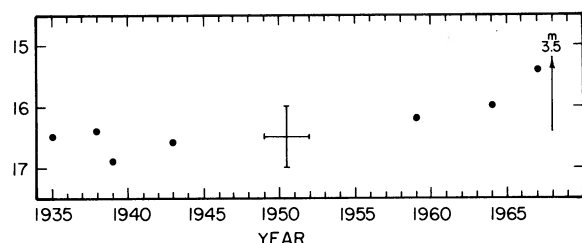


FIG. 12. The preeruption light curve of LV Vul. The points represent yearly average magnitudes. The significance of the cross is described in the text.

eruption. V533 Her and LV Vul clearly belong in this class. The magnitude of V533 Her gradually rose from about 13.6 to about 12.2 in the 1.5-yr period just prior to its eruption. Before the slow rise, V533 Her was a low-amplitude variable with a mean magnitude of about 13.6 or 13.7. The preeruption light curve of LV Vul is similar to that of V533 Her, but the increase in brightness was slightly smaller.

We tentatively assign three other stars to this class: CP Lac, BT Mon, and GK Per. The early plates of the field of BT Mon show the prenova to be fainter than 17th mag, while Fig. 8 shows that in the six years just prior to its eruption BT Mon was at about 15^m.4. Figure 9 shows GK Per to be brighter than normal by about 0^m.75 in the two years just prior to its eruption. However, the postnova light curve of GK Per is known to vary randomly between magnitude 14 and 12 (McLaughlin 1960). The possibility that the increased brightness was a random fluctuation unconnected to the eruption cannot be excluded. CP Lac shows a marginal increase in brightness of about one-quarter magnitude in the three years prior to its eruption. The increase in brightness, while small, was seen on both Harvard and Sonneberg plates (Hoffleit 1936). With the possible exception of BT Mon, the stars which have shown the preeruption rise have all returned to a minimum magnitude equal to the preerise magnitude.

Although not strictly within the purview of this investigation, the recurrent nova T CrB clearly belongs in class IV. Prior to the 1946 eruption, the visual light curve of T CrB, which is dominated by the gM3 component of the binary system, remained nearly constant until the eruption began. The photographic light curve, which is dominated by the blue component of the system, showed an increase in brightness by one magnitude at JD 2429000, about nine years prior to the eruption. About 1.5 years prior to the eruption the photographic magnitude returned again to its normal level (Payne-Gaposchkin and Wright 1946).

(e) *Class V.* Class V is reserved for the two unique novae V446 Her and RR Tel. V446 Her is the only nova whose preeruption and posteruption light curves differ. Prior to the eruption the light curve displays rapid variations of nearly 4 mag. The expanded portion of the light curve of V446 Her shown in Fig. 4 bears

a vague resemblance to a dwarf nova. While it would be tempting to classify the prenova light curve as a dwarf nova, such a classification would be quite incorrect. The rise time of individual "flares" is at least 10 to 12 days, and the rate of increase in brightness is only about 0.5 mag day⁻¹. Stienon (1971) suggests a recurrence time of about 60 days for the flares. These characteristics are incompatible with a dwarf nova classification (cf. Petit 1958). Following the eruption, the rapid variations in the light curve of V446 Her almost disappeared, and have an amplitude no larger than 0^m.4. Whether the change is permanent or not remains to be seen. It is entirely possible that the large amplitude variations will reappear in the future. It should be noted that the mean luminosity of V446 Her prior to and following its eruption is nearly the same.

Mayall's (1949) preeruption light curve of RR Tel, also shown in Fig. 11, deserves special notice. Prior to JD 2426000 RR Tel was a low-amplitude irregular variable with a mean magnitude near 14, and an amplitude of up to 2 mag. Beginning at about JD 2426000 regular variations with a period near 387 days appeared, and gradually grew in amplitude until the beginning of the eruption. In the neighborhood of JD 2430000 the amplitude of the pulsations was at least 3.5 mag. From JD 2426000 until JD 2429000 the mean magnitude of RR Tel dropped to about 15^m.0, and then from JD 2429000 until the eruption increased again to 14^m.0. Gaposchkin (1952) classified RR Tel prior to its outburst as a peculiar long-period semi-regular variable.

Webster (1974) found TiO bands in the posteruption spectrum of RR Tel. Glass and Webster (1973) showed that the infrared colors are consistent with a late-type giant. Feast and Glass (1974) suggest that these observations would be satisfied if the binary system contains an M5 III star. They also believe it reasonable to suppose that the periodic variations of RR Tel prior to its outburst were due to a semiregular pulsation of the M5 III star.

III. CONCLUSION

The observational results of this investigation may be summarized as follows:

(1) With the possible exception of BT Mon, the mean magnitudes of the prenova and the postnova are the same for all 18 of the stars for which both magnitudes are known.

(2) The 12 stars in classes III, IV, and V have well-defined preeruption light curves. Six of the stars show probable or conclusive indications of a change in the light curve 1–15 years prior to the eruption. Five of the stars increased in brightness by 0^m.25 to 1^m.5. RR Tel became a long-period regular variable.

(3) There is a difference between the prenova and postnova light curves of one star: V446 Her. The

preeruption light curve has rapid intrinsic variations with an amplitude of almost 4 mag. In the posteruption light curve the variations have an amplitude of no more than 0.4 mag.

These observational results imply that a nova eruption has very little effect either on the erupting star, or on the binary system as a whole. Ahnert's detection of eclipses in the preeruption light curve of DQ Her provides direct support for this conclusion. The only possible exception is V446 Her. The significance of the difference between the preeruption and posteruption light curves of V446 Her is difficult to assess from the available data, but it is entirely possible that the difference is due to a minor or impermanent change in the system. The suggestion by Bath *et al.* (1974) that a nova eruption might temporarily disturb the transfer of mass from the late-type star to the white dwarf may provide the best explanation of the light curves of V446 Her. The further suggestion by Bath *et al.* that dwarf novae might eventually become novae fails to find support in the available data. None of the prenova light curves displayed dwarf nova characteristics. Furthermore, since the prenovae have the same apparent magnitudes as the postnovae, their absolute magnitudes must also be the same. Thus, the mean absolute magnitudes of prenovae must be about +4.0 to +5.0 (McLaughlin 1960). The mean absolute magnitude of dwarf novae at minimum light is about +7.5 (Kraft and Luyten 1965). However, the available preeruption light curves are limited in time. The longest one is 80 yr for HR Del. The possibility that a change from dwarf nova characteristics to nova characteristics occurs more than 80 years prior to the eruption cannot be excluded.

It is tempting to hypothesize that every nova would display a preeruption rise in luminosity of the kind seen in the light curve of V533 Her if there were only one source of light in a prenova. There are at least three sources of light in a prenova: the two stars and the accretion disk. Particularly in those systems with a short orbital period, such as DQ Her, the accretion disk with its attendant "bright spot" is often the dominant source of light. Although the present data is insufficient to determine which of these three sources is producing the preeruption rise, it is clear that unless the source of the preeruption rise is a significant contributor to the total light of the system, the preeruption rise will be hidden by the other two sources of light.

It is not clear that any of the available theories of the nova eruption can account for the preeruption rise. Theories in which the nova eruption is caused by a thermonuclear runaway in the envelope of the white dwarf nearly always give *e*-folding times of a few years at some point in the evolution of the nuclear burning shell just prior to its runaway (Giannone and Weigert 1967; Saslaw 1968; Rose 1968; Starrfield 1971; Starrfield *et al.* 1974). However, hydrodynamical studies of

the runaway (Starrfield *et al.* 1974) indicate that the luminosity of the white dwarf does not respond to the evolution of the nuclear burning shell until mass ejection and the rapid rise to maximum has begun. Theories in which the nova eruption is caused either directly or indirectly by a dynamical instability in the envelope of the late-type star (Bath 1969) cannot produce a time scale as long as several years unless the late-type star is a giant. This last point brings us to RR Tel.

RR Tel presents the possibility that there is more than one cause of a nova eruption. As we have noted in the previous section, the simplest interpretation of the preeruption light curve of RR Tel is that the M5 III star in the binary system began to pulsate about 15 years prior to the eruption. If this interpretation is correct it severely strains any theory which proposes to give fundamental control of the eruption to the blue star. Such theories would require either that the beginning of the pulsations and their rapid growth is a remarkable accident, or that the M5 III star was somehow able to "guess" that an eruption was going to take place. The first possibility seems unlikely. Nor has any adequate mechanism been proposed to allow the M5 III star to make such a "guess," although a mechanism such as that proposed by Davidsen and Ostriker (1974) to stimulate mass transfer in Cyg X-3 may be possible. It seems more likely that the M5 III star itself caused the eruption. We note that Mayall (1949) was able to find evidence of the 387-day period in RR Tel *even during the eruption*. There appear to be only two ways to account for the continued 387-day periodicity. Either the M5 III star was itself the source of the increased light during the eruption, or the M5 III star modulated the eruption of its companion. Both of these possibilities would support our contention that the giant star controlled the eruption of RR Tel.

There is no theory which can account in detail for the behavior of RR Tel, but it may be possible to understand RR Tel in terms of a dynamical instability of the red giant. A variety of authors have suggested that late-type stars with deep convective envelopes should be dynamically unstable if they are in binary systems and in contact with their Roche lobes (Paczynski 1965; Bath 1969, 1972; Osaki 1970). The source of the increased luminosity has been variously described as due to a brightening of the late-type star itself, or to a brightening of the white dwarf due to increased mass accretion. These theories do not seem capable of producing eruptions as large as the 10–15-mag rises seen in ordinary novae, but it may be possible for them to produce the 7–9-mag (depending on which minimum magnitude is used) rise of RR Tel.

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