1989ApJ...339L..75S

THE ASTROPHYSICAL JOURNAL, 339: L75–L78, 1989 April 15
© 1989. The American Astronomical Society. All rights reserved. Printed in U.S.A.

V PERSEI: BRIDGING THE PERIOD GAP

ALLEN W. SHAFTER AND TIMOTHY M. C. ABBOTT
Department of Astronomy and McDonald Observatory, University of Texas at Austin
Received 1988 December 1; accepted 1989 February 3

ABSTRACT

We report spectroscopic and high-speed photometric observations of the classical nova V Per (Nova Persei 1887). The photometric data reveal eclipses which recur with a period of 0.10712(1) days (2.57 hr). This places V Per in the middle of the gap in the orbital period distribution of cataclysmic variables. Current models for the origin of the period gap require that the secular mass transfer rate in V Per be relatively low. The eclipse morphology and spectrum suggest, however, that the present mass transfer rate is quite high. We argue that this recent increase in the mass transfer rate is a result of the nova eruption and can be understood within the context of the hibernation scenario of Shara *et al.*

Subject headings: stars: individual (V Per) — stars: eclipsing binaries — stars: novae

I. INTRODUCTION

V Per (Nova Persei 1887) is a relatively unstudied classical nova with a quiescent visual magnitude of ~ 18. In what is believed to be the first spectrum of a nova ever recorded, V Per was discovered on a Harvard objective prism plate taken on 1887 November 3. V Per remained nearly constant in brightness at $m_{pg} = 9.4$ between 1887 November 30 and December 19. The initial spectroscopic observations (Cannon 1916; McLaughlin 1946) indicated that V Per was already in the advanced nebular stage of its spectral development at the time of its discovery. It is therefore likely that V Per erupted several months before discovery (when Perseus was unfavorably positioned for observation), probably reaching 4th or 5th mag.

In this *Letter* we report the discovery of eclipses in the light curve of V Per. The eclipses reveal the orbital period to be 2.57 hr placing V Per in the middle of the gap in the period distribution of cataclysmic variables. After a brief description of the observations, we discuss the significance of the 2.57 hr orbital period within the context of current evolutionary scenarios for compact binaries.

II. OBSERVATIONS AND ANALYSIS

a) Photometry

The McDonald Observatory high-speed CCD photometer (Abbott and Opal 1988) was used at the Cassegrain focus of the 2.1 m reflector in order to measure the light curve of V Per. We initially optimized our observations for detection of ellipsoidal variations by using an RG 610 filter. This filter has a "red" response, blocking light below ~ 6100 Å. Because the photon count rate through the RG 610 filter was modest, we chose relatively long integration times of 56 s. A 4 s dead time between integrations resulted in an overall time resolution of 1 minute. The reduction consisted of division by a nearby comparison star in order to correct for minor variations in atmospheric extinction.

The red light curve from our initial run is shown in Figure 1. The eclipses, which recur with a period of ~ 2.5 hr, are approximately 1.3 mag deep, have a "V" shape, and a full width at the half-intensity point of ~ 11 minutes (or ~ 0.07 of the orbital period). V Per was observed again over the next several nights to improve the precision of the orbital period. Because it was no longer necessary to optimize for the red, we decided to use a broad-band "*BVR*" filter which transmits from ~ 4000 Å to ~ 7000 Å. The resulting *BVR* light curves are shown in Figure 2.

The times of mid-eclipse were determined from least-squares parabolic fits to sections of the data centered near eclipse. The timings were fitted with a linear least-squares routine yielding the following ephermeris for the times of mid-eclipse:

$$T_{\text{mid-eclipse}} = \text{HJD } 2{,}447{,}445.9322 + 0.10712E\,.$$
$$\qquad\qquad\qquad\qquad (2) \qquad\qquad (1)$$

b) Spectroscopy

The only published spectrum of V Per is the discovery spectrum taken over a century ago (Cannon 1916; McLaughlin 1946). In order to study the general spectral character of V Per in quiescence, we obtained a spectrum using the CCD spectrograph on the McDonald Observatory 2.7 m reflector. The spectrum, shown in Figure 3, covers 4200 Å to 6700 Å at a resolution of approximately 15 Å FWHM. The data were obtained on 1988 November 9 between 9:48 and 10:52 UT corresponding to orbital phases $0.56 \lesssim \Phi_{\text{orb}} \lesssim 0.95$. The spectrum shows Balmer (Hα, Hβ, and Hγ) and He II λ4686 and λ5411 emission. Neutral helium, which is commonly observed in dwarf novae, is barely detectable in our spectrum of V Per.

A high temperature is required to produce the He II emission seen in V Per. The inner regions of accretion disks in nova and nova-like systems, which have relatively high rates of mass transfer, are known to produce some He II λ4686 emission (Honeycutt, Schlegel, and Kaitchuck 1986; Downes *et al.* 1986; Shafter, Hessman, and Zhang 1988). When He II is stronger than Hβ, as in V Per, the system usually harbors a magnetic white dwarf. Our suspicion that V Per may be a magnetic system is strengthened by the presence of He II λ5411 emission which is rarely observed in nonmagnetic cataclysmic variables. AM Her systems typically exhibit strong optical linear and circular polarization, while the DQ Her systems exhibit significant polarization mostly in the infrared (Penning, Schmidt, and Liebert 1986; Berriman *et al.* 1986; West, Berriman, and Schmidt 1987). In this regard, polarimetry will be useful in further probing the nature of V Per.

III. DISCUSSION

a) Models for the Period Gap

Cataclysmic variables typically have orbital periods between 1.4 and 10 hr (Robinson 1983). The orbital period distribution,

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1989ApJ...339L..75S

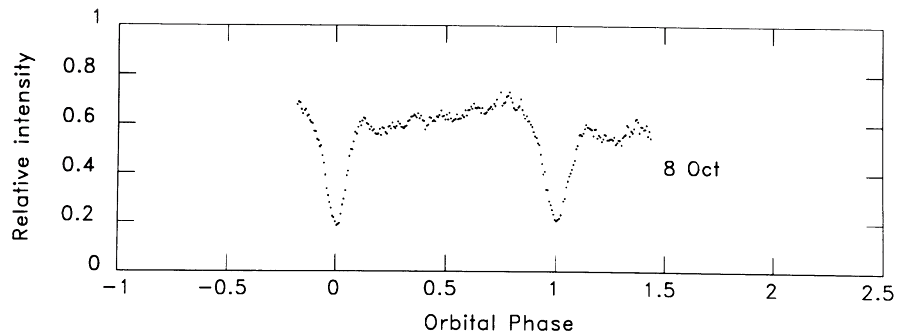

FIG. 1.—The "red" light curve of V Per obtained using an RG 610 filter. The data, which have been divided by a nearby comparison star, are plotted on an arbitrary intensity scale. There appears to be a orbital "hump" just prior to eclipse.

which is based on approximately 100 systems with known orbital periods, is clearly bimodal. There is a statistically significant "period gap" lying roughly between 2 and 3 hr (Whyte and Eggleton 1980). Approximately one-third of all systems, the so-called ultrashort period systems, lie below the gap.

Most current theories which attempt to explain the gap invoke a temporary cessation of mass transfer during the secular evolution of the binary (Robinson *et al.* 1981). Because the accreting component (the primary) is usually the more massive component, mass transfer can be sustained only by a loss of orbital angular momentum from the binary system. For the ultrashort period systems, angular momentum loss (AML) due to gravitational radiation appears sufficient to drive the observed mass transfer rates (see Pacyński and Sienkiewicz 1981; Rappaport, Joss, and Webbink 1982, and references therein). Available observational evidence suggests that longer period systems have much higher mass transfer rates (Patterson 1984; Shafter, Wheeler, and Cannizzo 1986). For these systems magnetic braking of the secondary's rotation (which is tidally coupled to the orbit) is believed to provide the dominant AML mechanism (Verbunt and Zwaan 1981; Taam 1983; Rappaport, Verbunt, and Joss 1983). The high mass transfer rates produced by magnetic braking cause the secondary to depart significantly from thermal equilibrium. The higher the mass transfer rates, the larger the departure from thermal equilibrium.

When a cataclysmic binary initially above the gap evolves to a sufficiently short orbital period ($\sim$3 hr), the secondary star will become fully convective. At this point, the magnetic activity of the secondary is thought to diminish, plausibly causing a concomitant decrease in the AML rate and hence the mass transfer rate. If the decrease in magnetic activity does indeed occur and if it occurs sufficiently rapidly, the secondary will detach from its Roche lobe and evolve toward thermal equilibrium (Spruit and Ritter 1983; Rappaport, Verbunt, and Joss 1983). The system will subsequently evolve in a detached state until gravitational radiation (and possibly reduced magnetic braking) have decreased the orbital period to the point where

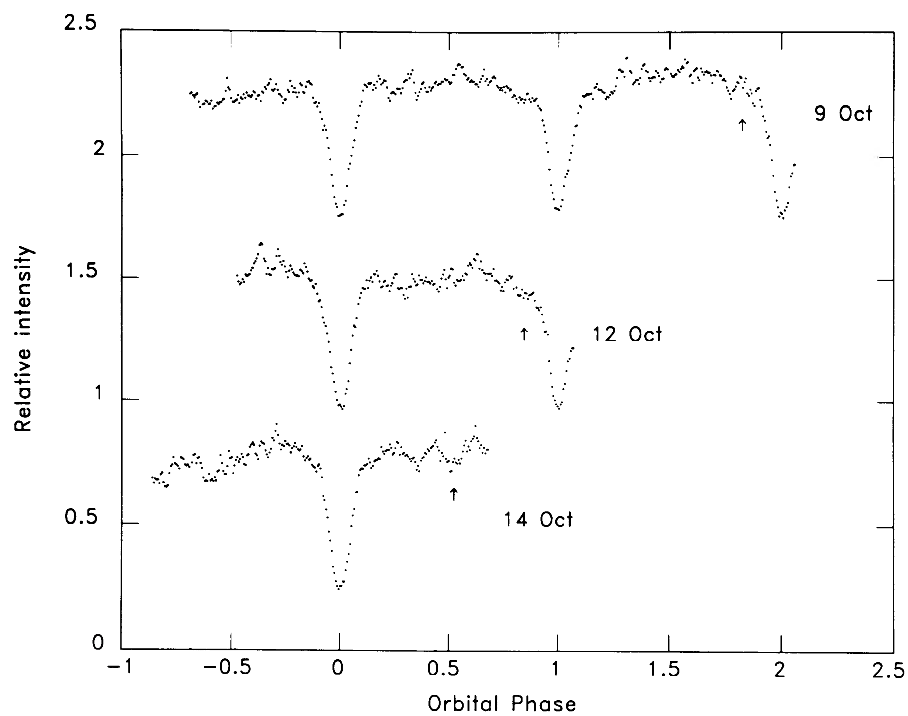

FIG. 2.—The "BVR" light curves of V Per obtained using a filter combination which transmits between $\sim$4000 Å and $\sim$7000 Å. The data were reduced by division by the same comparison star as in Fig. 1. There is no evidence for a pre-eclipse hump. Arrows indicate the onset of astronomical twilight.

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1989ApJ...339L..75S

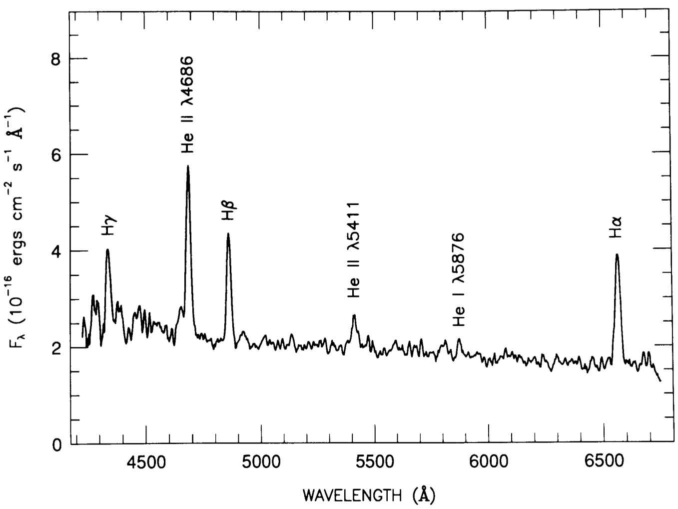

FIG. 3.—The absolute flux of V Per plotted as a function of wavelength. Note the strong He II λ4686, λ5411 emission usually associated with systems containing magnetic white dwarfs.

the system becomes semidetached again. A gap in the orbital period distribution is formed because, robbed of its accretion luminosity, the detached system becomes very difficult to detect.

b) *Possible Evolutionary Scenarios for V Persei*

Until now, the period gap was defined by the SU UMa systems YZ Cnc ($P = 2.08$ hr; Shafter and Hessman 1988) at the lower edge and TU Men ($P = 2.82$ hr; Stoltz and Schoembs 1984) at the upper edge.[1]

V Per, having a period of 2.57 hr, falls essentially in the middle of the period gap. It is therefore of interest to attempt to understand the evolution of V Per within the context of present period gap models. In particular, we would like to know whether V Per is somehow avoiding evolution through the gap in a detached state or whether it has yet to enter, or has already emerged from, a detached state.

The orbital period at which a system becomes detached and enters the gap depends on the degree to which the secondary star is out of thermal equilibrium when it becomes fully convective. The degree of departure from thermal equilibrium is a function of the mass loss rate which in turn depends on the strength of the magnetic braking. The stronger the braking, the longer the orbital period will be when the system enters the gap *and* the wider the gap will be (Rappaport, Verbunt, and Joss 1983; Spruit and Ritter 1983). On the other hand, if the magnetic braking is sufficiently weak, the mass-loss time scale of the secondary ($\tau_M = M_2/\dot{M}_2$) may never become shorter than its thermal time scale (τ_{KH}). In this case the system would never be driven far enough out of thermal equilibrium to produce a significant gap when magnetic braking shuts down. In summary, it does not matter whether V Per has passed through the gap, has yet to enter the gap, or has avoided the gap altogether; historically, its mean mass transfer rate must have been quite low. Assuming the systems above the period gap have a range of mass-accretion rates, we expect the mean mass transfer rate in V Per to be very near the minimum of the distribution.

The fact that V Per has experienced a nova eruption provides additional constraints on plausible mass transfer rates and other system parameters. In a nova system, the mass transferred from the secondary star builds up in a layer on the surface of the white dwarf. Eventually the temperature and density at the base of the accreted layer becomes sufficiently high so that thermonuclear burning of hydrogen will begin. The future evolution of the burning will depend on factors such as the mass-accretion rate, the mass and luminosity of the white dwarf, and the chemical composition of the accreted material. If the mass-accretion rate is too high, the accreted material will burn under nondegenerate conditions and a nova eruption will be suppressed. If, on the other hand, the accretion rate is sufficiently small ($\dot{M} \lesssim 10^{-8}\ M_\odot\ \mathrm{yr}^{-1}$) and the white dwarf is sufficiently massive, then the burning can initiate under degenerate conditions, creating a thermonuclear runaway, and causing the explosive ejection of the accreted material. Thus, the fact that V Per is a classical nova is consistent with our suspicion that, historically, the mean mass transfer rate has not been particularly high. We wish to stress, however, that our argument is only supportive because no direct estimate of the long-term mass transfer rate for V Per exists.

It is difficult to estimate the *present* mass transfer rate without a knowledge of the distance to V Per. Nevertheless, the morphology of the light curve may provide some clues concerning the system's present mass transfer rate. At the very least, the presence of flickering outside of eclipse establishes that mass transfer is indeed taking place. The eclipse profile, displaying a steep ingress and egress without any obvious evidence of a differentiated white dwarf eclipse, is typical of nova-like systems with high mass accretion rates and optically thick disks. For example, the eclipse profiles of V Per are similar to those of DW UMa (Shafter, Hessman, and Zhang 1988), SW Sex (Penning *et al.* 1984), LX Ser (Eason *et al.* 1984), UX UMa (Frank *et al.* 1981), and RW Tri (Horne and Stiening 1985) all of which are nova-like variables believed to have relatively high mass accretion rates. On the other hand, dwarf novae are believed to have lower accretion rates and correspondingly lower disk luminosities than nova-like variables. According to disk instability theories, dwarf nova eruptions occur only if the mass-transfer rate lies below a critical value, $\dot{M}_{\mathrm{crit}}$ (see Shafter, Wheeler, and Cannizzo 1986 and references therein). For systems where $\dot{M} > \dot{M}_{\mathrm{crit}}$, stable accretion occurs and the system is classified as a nova-like variable.

Dwarf novae have eclipse profiles which differ in two specific respects from those of nova-like variables. First, dwarf novae typically show "stepped eclipses" where the white dwarf and hot spot ingresses and egresses are differentiated from the disk ingress and egress. Second, because of the lower disk luminosity, the hot spot is more conspicuous in dwarf novae resulting in a pronounced hump in the light curve prior to eclipse. Examples of eclipsing dwarf novae displaying light curves with these characteristics include IP Peg (Wood and Crawford 1986), U Gem (Warner and Nather 1971; Smak 1971; the eclipse is not stepped because it is only partial), Z Cha (Wood *et al.* 1986), and OY Car (Schoembs, Dreier, and Barwig 1987; Wood *et al.* 1989). The only exception is the dwarf nova HT Cas which does not show a pronounced hump in the light curve prior to eclipse. In summary, based on the light curve morphology, it appears that the current mass trans-

[1] Recent observations of V795 Her (= PG 1711+336) by Shafter *et al.* (1988) and by Rosen *et al.* (1989) reveal a spectroscopic period near the 2.78 hr photometric period of Mironov *et al.* (1983). If interpreted as the orbital period, these data do not support the tentative period of 14.76 hr suggested by Thorstensen (1986).

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1989ApJ...339L..75S

fer rate in V Per is higher than the mean secular rate inferred from likely evolutionary scenarios.

In a recent series of papers, Shara and collaborators (Shara *et al.* 1986; Prialnik and Shara 1986; Livio and Shara 1987; Kovetz, Prialnik, and Shara 1988) have argued that novae go into "hibernation" during a significant period of time between eruptions. As a result of mass loss during the nova eruption, the stellar separation in the binary system increases slightly. At first, because the nova eruption heats the secondary causing it to expand, the mass transfer rate should increase. This period of enhanced mass transfer is expected to last for a few hundred years after the eruption. Later, after the white dwarf cools, the secondary shrinks back to its equilibrium radius and now slightly underfills its Roche lobe. Mass transfer is interrupted at this point until, after a few thousand years, angular momentum losses bring the system back into contact. Since V Per erupted a century ago, within the context of the hibernation scenario, it is not surprising that the present mass transfer rate appears to be significantly higher than its mean secular rate.

We thank Austin Tomaney for assistance with the spectroscopic data acquisition and reduction and Rob Robinson for comments on the manuscript. The times of eclipse minima were measured by Janet Wood for which we are grateful. This work was supported in part by NSF grant AST 87-04382.

REFERENCES

Abbott, T. M. C., and Opal, C. B. 1988, in *Instrumentation for Ground-Based Optical Astronomy: Present and Future*, ed. L. B. Robinson (New York: Springer), p. 380.
Berriman, G., Bailey, J., Axon, D. J., and Hough, J. H. 1986, *M.N.R.A.S.*, **223**, 449.
Cannon, A.J. 1916, *Harvard Ann.*, **76**, 35.
Downes, R. A., Mateo, M., Szkody, P., Jenner, D. C., and Margon, B. 1986, *Ap. J.*, **301**, 240.
Eason, E. L. E., Worden, S. P., Klimke, A., and Africano, J. L. 1984, *Pub. A.S.P.*, **96**, 372.
Frank, J., King, A. R., Sherrington, M. R., Jameson, R. F., and Axon, D. J. 1981, *M.N.R.A.S.*, **195**, 505.
Honeycutt, R. K., Schlegel, E. M., and Kaitchuck, R. H. 1986, *Ap. J.*, **302**, 388.
Horne, K., and Stiening, R. F. 1985, *M.N.R.A.S.*, **216**, 933.
Kovetz, A., Prialnik, D., and Shara, M. M. 1988, *Ap. J.*, **325**, 828.
Livio, M., and Shara, M. M. 1987, *Ap. J.*, **319**, 819.
McLaughlin, D. B. 1946, *Pub. A.S.P.*, **58**, 218.
Mironov, A. V., Moshkalev, V. G., and Shugarov, S. Yu. 1983, *Inf. Bull. Var. Stars*, No. 2438.
Paczyński, B., and Sienkiewicz, R. 1981, *Ap. J. (Letters)*, **248**, L27.
Patterson, J. 1984, *Ap. J. Suppl.*, **54**, 443.
Penning, R. W., Ferguson, D. H., McGraw, J. T., Liebert, J., and Green, R. F. 1984, *Ap. J.*, **276**, 233.
Penning, W. R., Schmidt, G. D., and Liebert, J. 1986, *Ap. J.*, **301**, 885.
Prialnik, D., and Shara, M. M. 1986, *Ap. J.*, **311**, 172.
Rappaport, S., Joss, P. C., and Webbink, R. F. 1982, *Ap. J.*, **254**, 616.
Rappaport, S., Verbunt, F., and Joss, P. C. 1984, *Ap. J.*, **275**, 713.
Robinson, E. L. 1983, in *Cataclysmic Variables and Related Objects*, ed. M. Livio and G. Shaviv (Dordrecht: Reidel), p. 1.
Robinson, E. L., Barker, E. S., Cochran, A. L., Cochran, W. D., and Nather, R. E. 1981, *Ap. J.*, **251**, 611.
Rosen, S. R., Branduardi-Raymont, G., Mason, K. O., and Murdin, P. G. 1989, preprint.
Schoembs, R., Drier, H., and Barwig, H. 1987, *Astr. Ap.*, **181**, 50.
Shafter, A. W., and Hessman, F. V. 1988, *A.J.*, **95**, 178.
Shafter, A. W., Hessman, F. V., and Zhang, E.-H. 1988, *Ap. J.*, **327**, 248.
Shafter, A. W., Robinson, E. L., Crampton, D., and Warner, B. 1988, *Bull. Am. Ast. Bull. AAS*, Vol. **19**, No. 4, p. 1058.
Shafter, A. W., Wheeler, J. C., and Cannizzo, J. K. 1986, *Ap. J.*, **305**, 261.
Shara, M. M., Livio, M., Moffat, A. F. J., and Orio, M. 1986, *Ap. J.*, **311**, 163.
Smak, J. 1971, *Acta Astr.*, **21**, 15.
Spruit, H. C., and Ritter, H. 1983, *Astr. Ap.*, **124**, 267.
Stolz, R., and Schoembs, R. 1984, *Astr. Ap.*, **249**, 673.
Taam, R. E. 1983, *Ap. J.*, **268**, 361.
Thorstensen, J. R. 1986, *A.J.*, **91**, 940.
Verbunt, F., and Zwaan, C. 1981, *Astr. Ap.*, **100**, L7.
Warner, B., and Nather, R. E. 1971, *M.N.R.A.S.*, **152**, 219.
West, S. C., Berriman, G., and Schmidt, G. D. 1987, *Ap. J. (Letters)*, **322**, L35.
Whyte, C. A., and Eggleton, P. 1980, *M.N.R.A.S.*, **190**, 801.
Wood, J. H., and Crawford, C. S. 1986, *M.N.R.A.S.*, **222**, 645.
Wood, J. H., Horne, K., Berriman, G., and Wade, R. A. 1989, *Ap. J.*, in press.
Wood, J. H., Horne, K., Berriman, G., Wade, R. A., O'Donoghue, D., and Warner, B. 1986, *M.N.R.A.S.*, **219**, 629.

T. M. C. Abbott and A. W. Shafter: Department of Astronomy, University of Texas, Austin, TX 78712

© American Astronomical Society • Provided by the NASA Astrophysics Data System