1995ApJ...448L..33S

The Astrophysical Journal, 448:L33–L36, 1995 July 20

QU VULPECULAE: AN ECLIPSING NEON NOVA IN THE PERIOD GAP

A. W. Shafter[1] and K. A. Misselt
Department of Astronomy and Mount Laguna Observatory, San Diego State University, San Diego, CA 92182;
shafter@proteus.sdsu.edu; misselt@mintaka.sdsu.edu

P. Szkody[1]
Department of Astronomy
University of Washington, Seattle, WA, 98195; szkody@astro.washington.edu

and

M. Politano[1]
Department of Physics and Astronomy,
Arizona State University, Tempe, AZ 85287; politano@phyast.la.asu.edu

Received 1995 March 3; accepted 1995 May 12

ABSTRACT

Time-resolved photometric and spectroscopic observations of the neon nova QU Vul are presented. Our spectroscopic data show that the radiation from QU Vul is still dominated by emission from the shell that was ejected a decade ago. Our photometric data establish that QU Vul undergoes eclipses that are ~0.5 mag deep in *V*, and recur with a period of 2.68 hr, placing QU Vul near the middle of the 2–3 hr gap in the orbital period distribution of cataclysmic variables. The addition of QU Vul raises the number of novae in the period gap to three, equal to the number of AM Her binaries in the gap. The orbital period distributions of novae and AM Her systems are discussed within the context of the evolution of cataclysmic variables.

Subject headings: binaries: eclipsing — novae, cataclysmic variables — stars: individual (QU Vulpeculae)

1. INTRODUCTION

QU Vul (Nova Vul 1984, No. 2) reached apparent visual magnitude of ~5.5 on 1984 December 25 (Collins 1984; Yusa 1984). Within ~3 weeks, the system had faded by ~2 visual magnitudes, establishing QU Vul as a moderately fast nova. (A description of the outburst has been reviewed in Saizar et al. 1992.) It was not until several months after eruption that interest in QU Vul intensified after spectroscopic observations revealed the ejecta to be strongly enhanced in intermediate-mass nuclei, particularly neon. Since that time it has become apparent that about one-third, and perhaps as many as one-half, of the classical novae discovered within the last decade are similarly enriched. These systems have become known collectively as "neon" novae. Since it is believed that intermediate-mass elements such as neon cannot be easily produced at the temperatures expected in thermonuclear runaways on CO white dwarfs (e.g., Prialnik & Kovetz 1992), large enhancements are believed to be the result of dredge-up of material from the surface of a relatively massive ONeMg white dwarf (e.g., Starrfield et al. 1992).

In an attempt to constrain the orbital parameters of this interesting nova, we initiated a program of simultaneous photometric and spectroscopic observations of QU Vul in 1994 June, after the system had returned to near its preoutburst luminosity. In this Letter we report the discovery of eclipses in the light curve of QU Vul, which reveal the orbital period to be 2.68 hr. Thus, in addition to its identification as a neon nova, QU Vul now joins V Per (Shafter & Abbott 1988) and V2214 Oph (Baptista et al. 1993) as one of three novae in the 2–3 hr period gap. The relatively high percentage of novae in the period gap is discussed within the context of the evolution of cataclysmic variables (CVs).

2. OBSERVATIONS

2.1. *Photometry*

Time-resolved photometric observations of QU Vul were obtained during four nights in 1994 June and August using the 1 m reflector at the Mount Laguna Observatory. On each night a series of 2 minute exposures were taken through a broadband *V* filter using a TI 800 × 800 CCD. The CCD was used in a fast photometry mode, whereby images of QU Vul and two comparison stars were recorded simultaneously (e.g., see Shafter, Misselt, & Veal 1993). The data were debiased and flat-fielded using standard routines in the Image Reduction and Analysis Facility (IRAF).[2]

Magnitudes for QU Vul and the comparison stars were then determined using the IRAF APPHOT package. Atmospheric extinction variations were removed to first order by differencing the magnitude of QU Vul with the brighter of the two comparison stars. The resulting differential light curves were then placed on an absolute scale by calibration of the comparison stars against the standard stars in Landolt (1992). The *V* magnitude outside eclipse is ~17.9, which is ~1 mag brighter than the preoutburst magnitude reported by Duerbeck (1987).

During the four nights of observation, we observed a total of seven eclipses. Times of mid-eclipse were determined by fitting a parabola to the region near the minima of the eclipse profiles. A linear least-squares fit of the times of mid-eclipse yield the following eclipse ephemeris:

$$T_{\text{mid-eclipse}} = \text{JD}_{\odot}2{,}449{,}547.4015(3) + 0.1117648(9)E. \quad (1)$$

---

[1] Visiting Astronomer, Kitt Peak National Observatory, NOAO, operated by AURA, Inc., under contract with the National Science Foundation.

[2] IRAF is distributed by National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

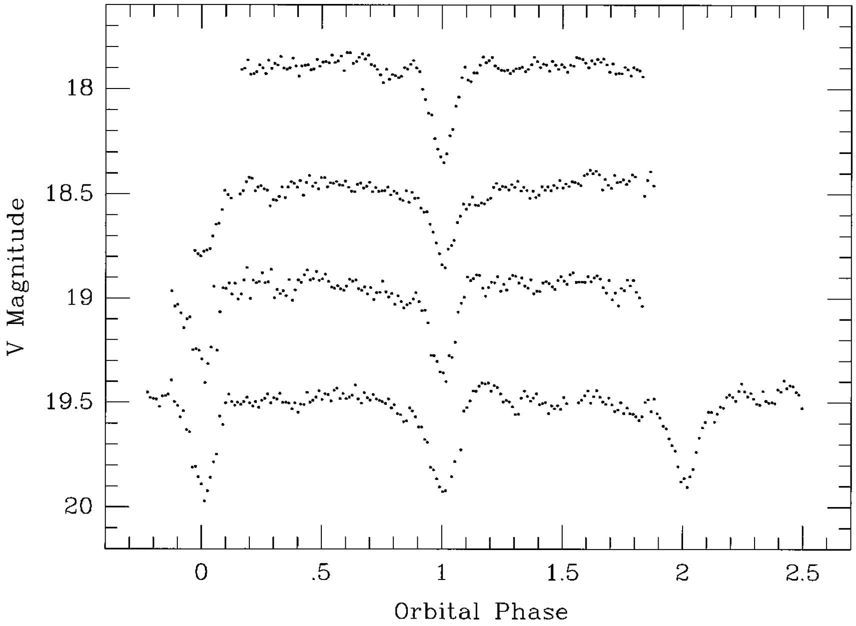

FIG. 1.—*V*-band light curves of QU Vul. The data have been folded on the orbital period and plotted as a function of orbital phase. The light curves from 1994 June 11, 12, 13, and August 15 have been offset by 0, 0.5, 1.0, and 1.5 mag from top to bottom, respectively. Note the relatively shallow eclipse depth, which indicates that the white dwarf and inner disk likely remain unocculted at mid eclipse.

The photometric data have been folded on this ephemeris and the light curves plotted as a function of orbital phase in Figure 1. A summary of the eclipse parameters is given in Table 1.

2.2. *Spectroscopy*

On the first night of our photometric observations, 1994 June 11, we obtained simultaneous time-resolved spectroscopy at Kitt Peak National Observatory using the RC spectrograph and the T2KB CCD at the Cassegrain focus of the Mayall 4 m reflector. Grating KPC-18C was used in second order with a 1".7 slit, resulting in a resolution of 1.0 Å and a wavelength coverage of 4250–5300 Å. The data, which consist of a sequence of 15 900 s exposures, were acquired in order to search for radial velocity variations that would reveal the orbital period of the system, and possibly constrain the mass of the (ONeMg) white dwarf. Our photometry removed the need for a spectroscopically determined orbital period, which was fortunate since the spectrum is dominated by emission from the nova shell, and significant radial velocity variations were not observed. Over ~4 hr of observation, the radial velocities of the He II λ4686 and Hβ features clustered near means of -44 and -49 km s^{-1} with 1 σ dispersions (8 and 5 km s^{-1}, respectively) comparable to the measurement errors. It is worth keeping in mind that, even in the absence of shell contamination, the observed emission-line velocity amplitude may be relatively low if the mass ratio is extreme, as it is likely to be if the primary is a massive ONeMg white dwarf. The grand sum spectrum, with the principal emission lines identified, is displayed in Figure 2. The strongest emission feature is Hβ, which has an equivalent width and flux of 395 Å and 6.7×10^{-14} ergs cm^{-2} s^{-1}, respectively. These values are approximately twice those of the second strongest feature, [O III] λ5007.

TABLE 1

ECLIPSE PARAMETERS

UT Date (1994)	Filter	Time of Minimum ($\mathrm{JD}_\odot - 2{,}440{,}000.0$)	$O - C$ (cycles)
Jun 11	*V*	9514.8778	−0.00124
Jun 12	*V*	9515.8847	0.00785
Jun 13	*V*	9516.777	−0.00842
Jun 13	*V*	9516.8899	0.00174
Aug 15	*V*	9579.7018	0.00239
Aug 15	*V*	9579.8127	−0.00535
Aug 15	*V*	9579.9254	0.00302

3. DISCUSSION

3.1. *QU Vulpeculae as a Neon Nova*

Early spectra of QU Vul were characterized by moderately low excitation emission lines of H, He I, N II, O I, Na I, and Fe II and associated P Cyg features. The system then evolved to the nebular phase within ~4 months of outburst as evidenced by the emergence of [O III] λλ4959, 5007 and [Ne III] λλ3869, 3968 features (Rosino & Iijima 1987; Rosino et al. 1992). These data, along with infrared observations of the 12.8 μm [Ne II] emission feature by Gehrz, Grasdelen & Hackwell (1985), suggested that the ejecta were significantly enhanced in neon, and that QU Vul was, in fact, a neon nova. Detailed modeling of the nebular spectrum by Saizar et al. (1992) has since confirmed that the intermediate-mass nuclei N, O, Ne, Mg, Al, and Si are indeed enhanced significantly relative to the Sun. Our spectra, which were obtained nearly a decade after outburst, show that QU Vul is still in the nebular phase, although the strength of the [O III] λλ4959, 5007 lines has decreased significantly relative to Hβ since the 1990 observations reported in Rosino et al. (1992).

As recently emphasized by Livio & Truran (1994), an enhanced abundance of neon in the ejecta of a nova does not necessarily imply the presence of an underlying ONeMg white

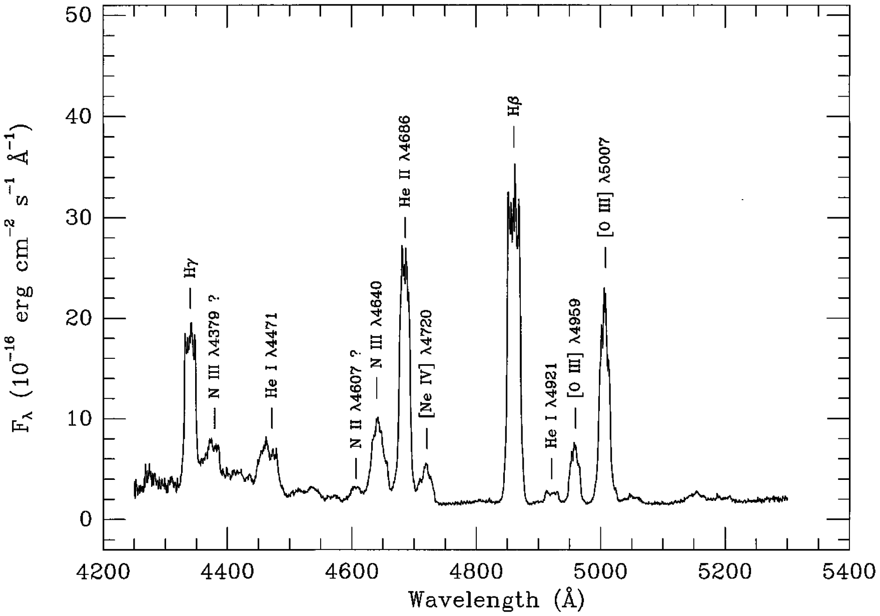

FIG. 2.—The sum of our 15 individual spectra of QU Vul. The spectrum is dominated by emission from the ejected shell. Note the presence of the [Ne IV] line at 4720 Å. There is no evidence for accretion disk emission, nor for radial velocity variations of any of the emission features during our ~4 hr of observation.

dwarf. Not only are there large uncertainties in the estimates of elemental abundances, but modest enhancements of neon can be produced even if the outburst occurs on a carbon-oxygen white dwarf. In an attempt to determine abundances in a consistent way, Andreä, Drechsel, & Starrfield (1994) determined abundances for a sample of 11 novae using a common analysis procedure. They find that V693 CrA (a recurrent nova), V1370 Aql, and QU Vul have abundances of neon greater than ~100 times solar.[3]

Livio & Truran (1994) identify the same three systems as clear examples of neon novae and argue that the seat of the outburst is almost certainly an ONeMg white dwarf. Independent evidence for an ONeMg white dwarf in V693 CrA is provided by its short recurrence time as masses near the Chandrashekhar limit seem to be required by models of recurrent novae (Webbink et al. 1987). In the case of QU Vul, Shara (1994) has pointed out that it is puzzling that estimates of the mass of the ejecta are relatively high, ~10^{-3} $M_\odot$ (Taylor et al. 1987; Greenhouse et al. 1988; Saizar et al. 1992), as massive white dwarfs are expected to undergo thermonuclear runaways after accreting a relatively small mass before ejecting a low-mass shell (Shara 1981; Truran & Livio 1986), although it now appears to be true that most novae which are believed to contain an ONeMg white dwarf have ejected large masses (S. Starrfield, private communication). Politano et al. (1995) have suggested that erosion of the white dwarf as a result of continued nova outbursts may partially explain this discrepancy in QU Vul and similar systems.

To probe the discrepancy between theory and observations concerning ejecta masses in novae suspected of containing an ONeMg white dwarf, a determination of the white dwarf mass in these systems would be extremely helpful. Aside from the fact that determination of nova masses is notoriously difficult, it is extremely unlikely that reliable masses can be determined for V1370 Aql or V693 CrA in the forseeable future since both systems are quite faint at minimum ($V \sim 19.5$ and 23, respectively), and the orbital periods are not known at present. V1974 Cyg is still fading and the attempt to estimate the mass of V838 Her (Szkody & Ingram 1994) suffered from its faintness and the presence of a close companion. QU Vul offers more hope because it is the brightest of the group and because it is eclipsing. However, until the spectrum becomes dominated by the underlying binary, mass estimates will not be possible.

3.2. *QU Vulpeculae as a Nova in the Period Gap*

The orbital period distribution of all CVs displays a prominent gap between ~2 and 3 hr (e.g., Robinson 1983; Ritter & Kolb 1995). Over the past decade, several systems have been found to lie well within the gap: including QU Vul, there are presently 11 systems reported to have periods between 2.25 and 3 hr (see Table 2). Among the certified gap-dwellers, three are classical novae, three are AM Her systems, and one is an SU UMa dwarf nova. The remaining two systems, V348 Pup and V795 Her are not easily classified, but are possibly magnetic (Tuohy et al. 1990; Shafter et al. 1990). Although the statistical significance of the gap for CVs in general remains intact, the significant increase in the number of AM Her systems with known periods resulting from the *ROSAT* survey has raised doubt as to whether a gap exists for magnetic CVs (e.g., Wickramasinghe & Wu 1994; although others would argue that the *ROSAT* data merely shows that there is an overabundance of magnetic systems in the gap when compared with nonmagnetic systems, but that a gap for magnetic systems still exists [e.g., Kolb 1995]).

In order for a system to lie in the period gap, it must either avoid the disrupted magnetic braking scenario (Rappaport, Verbunt, & Joss 1983) or it must be "born" (i.e., the secondary star must make its initial contact with the Roche lobe) inside the gap. Population models of CVs predict that CVs born in the gap comprise 0.5%–2% of the CV population (Kolb 1993),

---

[3] Recent studies of V1974 Cyg (Woodward et al. 1995, and references therein) and V838 Her (S. Starrfield, private communication) suggest that these systems are also strong candidates to be neon novae.

TABLE 2

CATACLYSMIC VARIABLES IN THE PERIOD GAP

Object	Class	Period (hr)	Notes	Reference
CC Cnc............	DN UG?	2.33:	Period uncertain	1
RX J1938 − 46....	NL AM	2.33	···	2
V348 Pup..........	NL	2.44	HEAO-1 source	3
V Per..............	N	2.57	Magnetic?	4
V795 Her..........	NL SH	2.60	Magnetic?	5
V2009 − 65.5......	NL AM	2.66	···	6
DR V211B	NL AM	2.67	···	7
QU Vul............	N	2.68	···	8
V2214 Oph........	N	2.82	Magnetic?	9
TU Men...........	DN SU	2.82	···	10
PG 2133 + 115....	NL UX	2.90:	Period uncertain	11

References:—(1) Munari et al. 1990; (2) Buckley et al. 1993; (3) Tuohy et al. 1990; (4); Shafter & Abbott 1988; (5) Shafter et al. 1990; (6) Wickramasinghe et al. 1993; (7) Drissen et al. 1992; (8) this work; (9) Baptista et al. 1993; (10) Stoltz & Schoembs 1984; (11) Ringwald 1993.

which is consistent with the observed fraction in the gap. However, the recognition that at least one-third of the systems in the gap are magnetic suggests that perhaps some of these systems could have evolved from longer periods and avoided a discontinuity in their angular momentum loss near the upper edge of the period gap. In particular, Wickramasinghe & Wu (1994) and Li, Wu, & Wickramasinghe (1994) have suggested that CVs with synchronously rotating magnetic white dwarfs may have substantially reduced angular momentum loss at all periods. This reduction is a result of coupling between the white dwarf's magnetic field and that of the secondary star, which disrupts the magnetically coupled wind that removes angular momentum from the system.

It has been suggested that the two novae previously known to lie in the gap, V Per (Wood, Abbott, & Shafter 1992) and V2214 Oph (Baptista et al. 1993), may harbor magnetic white dwarfs. Baptista et al. went on to suggest that there was no period gap for novae and that magnetic systems are strongly favored among novae with periods less than 3.3 hr. The discovery of yet another nova with an orbital period in the range of 2.25–3 hr strengthens the evidence that the period distribution for novae differs from that of CVs as a whole. However, the question of whether the apparent absence of a period gap for novae is related to the possible absence of a gap for magnetic systems is unclear. Although, at present, there is no evidence that QU Vul is magnetic, as may be the case for the other two novae and for several of the other systems in the gap, it is important for our understanding of CV evolution to pursue future observations that may establish conclusively if this and other novae in the gap are in fact magnetic.

We thank Drs. U. Kolb and S. Starrfield for useful discussions. Support through NSF grants AST91-15131 and AST 93-15280 (A. W. S) and AST92-17911 (P.S.) is gratefully acknowledged. This research has made use of the Simbad database, operated at CDS, Strasbourg, France.

REFERENCES

Andreä, J., Drechsel, H., & Starrfield, S. 1994, A&A, 291, 869
Baptista, R., Jablonski, F. J., Cieslinski, D., & Steiner, J. E. 1993, ApJ, 406, L67
Buckley, D. A. H., et al. 1993, MNRAS, 262, 93
Collins, P. 1984, IAU Circ., No. 4023
Duerbeck, H. W. 1987, Space Sci. Rev., 45, No. 1/2
Drissen, L., Shara, M., Dopita, M. A., & Wickramasinghe, D. T. 1992, IAU Circ., No. 5609
Gehrz, R. D., Grasdalen, G. L., & Hackwell, J. A. 1985, ApJ, 298, L47
Greenhouse, M. A., Grasdalen, G. L., Hayward, T. L., Gehrz, R. D., & Jones, T. J. 1988, AJ, 95, 172
Kolb, U. 1993, A&A, 271, 149
———. 1995, in ASP Conf. Ser., Cape Workshop on Magnetic Cataclysmic Variables, ed. D. A. H. Buckley & B. Warner (San Francisco: ASP), in press
Landolt, A. U. 1992, AJ, 104, 340
Li, J., Wu, K., & Wickramasinghe, D. T. 1994, MNRAS, 268, 61
Livio, M., & Truran, J. W. 1994, ApJ, 425, 797
Munari, U., Bianchini, A., & Claudi, R. 1990, IAU Circ., No. 5024
Politano, M., et al. 1995, ApJ, in press
Prialnik, D., & Kovetz, A. 1992, ApJ, 385, 665
Rappaport, S., Verbunt, ., & Joss, P. C. 1983, ApJ, 275, 713
Ringwald, F. 1993, Ph.D. thesis, Dartmouth
Ritter, H., & Kolb, U. 1995, in X-Ray Binaries, ed. W. H. G. Lewin, J. van Paradijs, & E. P. J van den Heuvel (Cambridge: Cambridge Univ. Press), in press
Robinson, E. L. 1983, in Cataclysmic Variables and Related Objects, ed. M. Livio & G. Shaviv (Dordrecht: Reidel), 1
Rosino, L. & Iijima, T. 1987, Ap&SS, 130, 157
Rosino, L., Iijima, T., Benetti, S., D'Ambrosio, V., Di Paolantonio, A., & Kolotilov, E. A. 1992, A&A, 257, 603
Saizar, P., et al. 1992, ApJ, 398, 651
Shafter, A. W., & Abbott, T. M. C. 1988, ApJ, 339, L75
Shafter, A. W., Misselt, K. A., & Veal, J. M. 1993, PASP, 105, 853
Shafter, A. W., Robinson, E. L., Crampton, D., Warner, B., & Prestage, R. M. 1990, ApJ, 354, 708
Shara, M. 1981, ApJ, 243, 926
———. 1994, AJ, 107, 1546
Starrfield, S., Shore, S. N., Sonneborn, G., Politano, M., & Truran, J. W. 1992, ApJ, 391, L71
Stoltz, B., & Schoembs, R. 1984, ApJ, 268, 710
Szkody, P., & Ingram, D. 1994, ApJ, 420, 830
Taylor, A. R., Seaquest, E. R., Hollis, J. M., & Pottasch, S. R. 1987, A&A, 183, 38
Truran, J., & Livio, M. 1986, ApJ, 308, 721
Tuohy, I. R., Remillard, R. A., Brissenden, R. J. V., & Bradt, H. V. 1990, ApJ, 359, 204
Webbink, R. F., Livio, M., Truran, J. W., & Orio, M. 1987, ApJ, 314, 653
Wickramasinghe, D. T., Ferrario, L., Bailey, J. A., Drissen, L., Dopita, M. A., Shara, M., & Hough, J. H. 1993, MNRAS, 265, L29
Wickramasinghe, D. T., & Wu, K. 1994, MNRAS, 266, L1
Wood, J. H., Abbott, T. M. C., & Shafter, A. W. 1992, ApJ, 393, 729
Woodward, C. E., Greenhouse, M. A., Gehrz, R. D., Pendleton, Y. J., Joyce, R. R., Van Buren, D., Fischer, J., Jennerjohn, N. J., & Kaminski, C. D. 1995, ApJ, 438, 921
Yusa, T. 1984, IAU Circ., No. 4024