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SPECTROSCOPIC AND PHOTOMETRIC ANALYSIS OF THE NOVA-LIKE CATACLYSMIC VARIABLE PG 1000+667: A NEW VY SCULPTORIS STAR

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ABSTRACT

Multiyear photometry and orbit-resolved spectroscopy of the nova-like cataclysmic variable PG 1000+667 show behavior associated with the VY Sculptoris subclass of nova-like cataclysmic variables. Photometric observations over a 35 month interval from Indiana University's robotic telescope RoboScope show two drops of 3 mag to a low state. Spectroscopy shows a periodic velocity variation in the Hβ emission line with $P = 3.47$ hr. This places the star just above the 2–3 hour period gap, which supports the VY Sculptoris classification.

Key words: binaries: close — novae, cataclysmic variables — stars: individual (PG 1000+667)

1. INTRODUCTION

The nova-like cataclysmic variable (CV) PG 1000+667 is one of a number of poorly studied variables found in the Palomar-Green survey (Green, Schmidt, & Liebert 1986). A study by Ringwald (1993) gives a preliminary period, but no mention is made of its photometric behavior. Spectroscopic and photometric observations are presented here and the results of these observations discussed, including the determination of a refined period.

Nova-like CVs have a number of subclassifications. One of these, the VY Sculptoris stars, exhibits high and low state behavior in the long-term light curves, at times dropping several magnitudes into a low state for weeks, months, or even years. These drops range from 1 to over 5 mag and show no apparent periodicity. The VY Sculptoris stars populate a fairly narrow region just above the 2–3 hr period gap for CVs, from about 3 to 5 hr (Warner 1995). In the high state their spectra resemble nova-likes, and in their low state the spectra appear similar to detached binaries with some chromospheric emission from the secondary star (Warner 1995 and references therein).

Of the 25 nova-like variables listed by Warner with orbital periods between 3 and 4 hr, 15 are classified as VY Sculptoris stars. Recent observations by Honeycutt & Robertson (1998) place V794 Aql in this period range as well, making 16 of these 26 nova-like variables VY Sculptoris type stars. Therefore, the likelihood of an individual CV in the period range 3–4 hr with nova-like properties being of the VY Sculptoris type is high. Considering the possibility that several of the 10 systems in this range not classified as VY Sculptoris stars are as yet not well studied photometrically, it is possible that others may belong to the VY Sculptoris subclass. In addition, some VY Sculptoris type stars have been seen to remain in either the high or the low state for a long period of time. MV Lyr, for example, has been seen to remain in high or low state for as long as 10 years (Rosino, Romano, & Marziani 1993). Therefore it is easily conceivable that some well-studied nova-like CVs may be VY Sculptoris stars without such behavior having yet been recorded.

Ringwald (1993) classifies PG 1000+667 as a nova-like variable on the basis of his preliminary period of 4.06 hr and the character of the spectrum, which shows narrow Hα and Hβ emission lines, no appearance of a red star, and a strong continuum. The data presented here agree with this identification and introduce an additional classification to the VY Sculptoris subclass. The major support for this classification comes from photometric data and is supported by the refined orbital period from time-resolved spectroscopy.

2. OBSERVATIONS AND REDUCTIONS

The photometric data consist of V-band CCD photometry of PG 1000+667 obtained during the interval from 1993 October to 1997 January with the Indiana Automated CCD Photometric Telescope, also known as RoboScope (Honeycutt et al. 1990; Honeycutt & Turner 1992). A total of 210 usable 4 minute exposures were reduced by inhomogeneous-ensemble photometry (Honeycutt 1992) using 15 comparison stars. The errors range from $\sim$0.02 mag, with good sky transparency and when the system is bright, to $\sim$0.15 mag when the system is faint and/or the sky is poor. The zero point is determined using four secondary standard stars (Henden & Honeycutt 1997).

The light curve for PG 1000+667 (Fig. 1) shows a 3 mag fall from 15th magnitude to a low state at $V \approx 18$ followed by an immediate rise back to the high state, as well as a recent fall back to an extended low state. The high state is typical of nova-like CVs, showing small variations with no outbursts. The high-state/low-state behavior of VY Sculptoris stars (Robinson et al. 1981) is believed to be caused by a decrease in mass transfer rate that is reflected in disk luminosity. No other low states were noted in the 1400 days covered. The longest observing window without coverage is about half of the $\sim$200 day duration of the initial low state. The average spacing of the data points is 4.7 days, excluding the three seasonal gaps. Therefore, it is unlikely that other low states were missed.

A total of 76 spectra of PG 1000+667 were obtained on 1996 March 26–29 with the WIYN[2] Hydra spectrograph using the blue fiber cable and the Bench Spectrograph

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[2] The WIYN Observatory is a joint facility of the University of Wisconsin–Madison, Indiana University, Yale University, and the National Optical Astronomy Observatories.

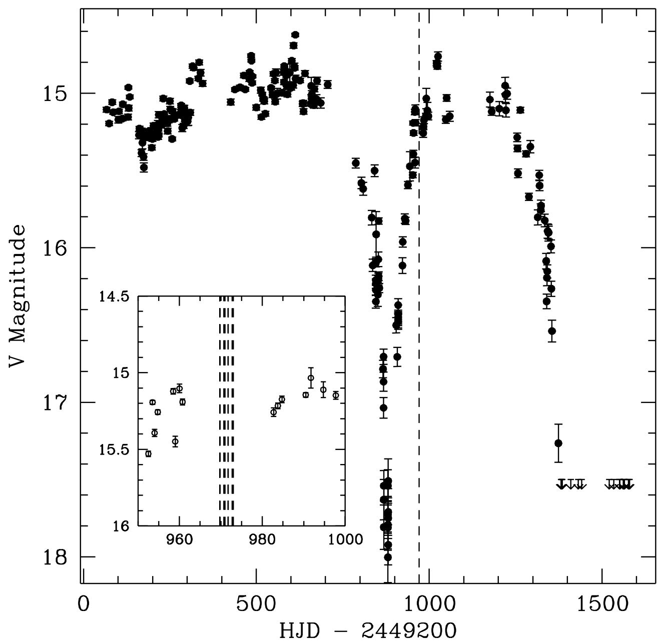

FIG. 1.—Photometry of PG 1000+667 over a 38 month interval showing two drops of 3 mag to a low state, as is typical of VY Sculptoris type stars. Downward-pointing arrows indicate limiting magnitudes. The inset shows nights on which spectra were taken (*dashed lines*).

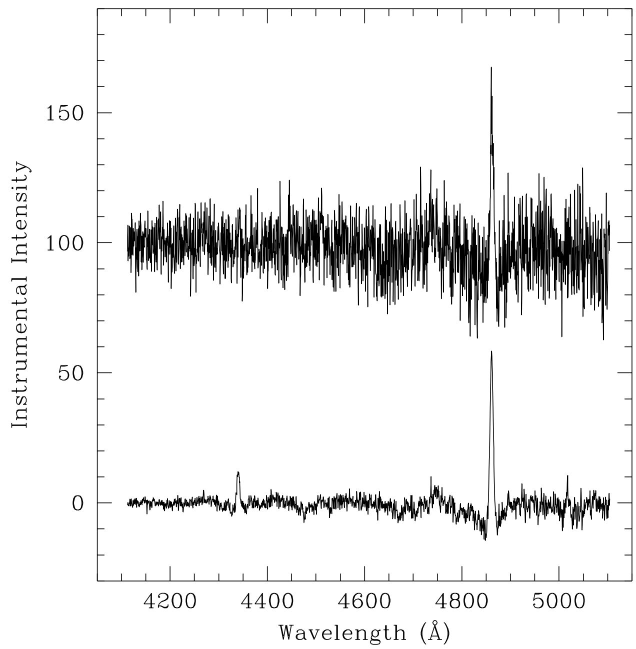

FIG. 2.—A single and an average (with orbital variations removed) spectrum of PG 1000+667 showing strong Hβ and weak Hγ emission lines.

Camera. An 860 line mm^{-1} grating with a 30°.9 blaze angle was used. The central wavelength was 4600 Å, covering the range 4288–4901 Å with 0.7 Å resolution. Figure 2 shows a representative spectrum and a mean spectrum. The mean spectrum is an average of all 76 individual spectra, each corrected for orbital motion. As is the case with some nova-like CVs (Honeycutt, Schlegel, & Kaitchuck 1986; Szkody & Piché 1990), there is no double-peaked structure apparent in either the Hβ or Hγ emission lines in the mean spectrum. Neither do the individual spectra show significant double-peaked structure.

The Hβ emission line of each spectrum was fitted with a Gaussian profile of variable width and height to determine the line center, and a radial velocity curve was constructed. The heliocentric radial velocities obtained are listed in Table 1. The periodogram (Fig. 3) was produced using the technique of Scargle (1982) as modified by Horne & Baliunas (1986). The major peak occurs at a period of ∼3.47 hr. The Hγ emission line in the individual spectra (see Fig. 2) had a signal-to-noise ratio too low to yield accurate results. The mean FWHM of the Hβ line was 490 ± 10 km s^{-1}.

To obtain a better result for the period, the radial velocity data were fitted with a sine curve of the form

$$v_r = \gamma + K_1 \sin [2\pi(T - T_0)/P] ,$$

with the above period used as the initial value. This yielded $P = 3.465 \pm 0.003$ hr and a velocity semiamplitude of

TABLE 1

Hβ EMISSION-LINE HELIOCENTRIC RADIAL VELOCITIES FOR PG 1000+667

HJD	v_r (km s^{-1})	HJD	v_r (km s^{-1})	HJD	v_r (km s^{-1})	HJD	v_r (km s^{-1})
2,450,169.7123......	−169	2,450,169.8570......	−123	2,450,170.8793......	−120	2,450,172.7961......	−2
2,450,169.7202......	−109	2,450,169.8642......	−151	2,450,170.8865......	−59	2,450,172.8037......	32
2,450,169.7274......	−126	2,450,169.8714......	−170	2,450,170.8941......	−83	2,450,172.8109......	9
2,450,169.7346......	−112	2,450,169.8787......	−120	2,450,170.9013......	−45	2,450,172.8182......	42
2,450,169.7476......	−25	2,450,169.8859......	−66	2,450,170.9086......	−28	2,450,172.8254......	−13
2,450,169.7548......	−8	2,450,170.7675......	−11	2,450,170.9158......	−13	2,450,172.8326......	−20
2,450,169.7621......	−16	2,450,170.7772......	23	2,450,170.9230......	27	2,450,172.8402......	−52
2,450,169.7693......	4	2,450,170.7844......	42	2,450,171.7516......	−108	2,450,172.8474......	−75
2,450,169.7765......	17	2,450,170.7916......	52	2,450,171.7589......	−90	2,450,172.8547......	−97
2,450,169.7840......	−5	2,450,170.7989......	2	2,450,171.7661......	−85	2,450,172.8619......	−92
2,450,169.7912......	25	2,450,170.8061......	−3	2,450,172.7304......	−136	2,450,172.8691......	−89
2,450,169.7984......	−10	2,450,170.8157......	−69	2,450,172.7377......	−115	2,450,172.8768......	−115
2,450,169.8057......	−63	2,450,170.8230......	−27	2,450,172.7449......	−158	2,450,172.8840......	−137
2,450,169.8129......	−46	2,450,170.8302......	−84	2,450,172.7521......	−175	2,450,172.8913......	−100
2,450,169.8206......	−84	2,450,170.8374......	−43	2,450,172.7594......	−147	2,450,172.8985......	−120
2,450,169.8278......	−93	2,450,170.8446......	−112	2,450,172.7672......	−109	2,450,172.9057......	−118
2,450,169.8350......	−110	2,450,170.8576......	−139	2,450,172.7744......	−69	2,450,172.9146......	−66
2,450,169.8423......	−111	2,450,170.8649......	−146	2,450,172.7816......	−37	2,450,172.9218......	−113
2,450,169.8495......	−145	2,450,170.8721......	−111	2,450,172.7889......	−13	2,450,172.9290......	33

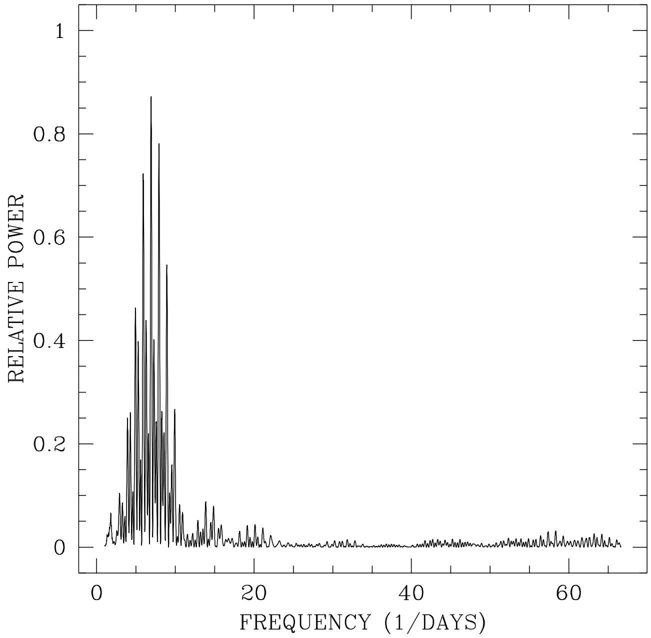

FIG. 3.—Periodogram for the radial velocity data, with major peak at a period of ∼3.47 hr.

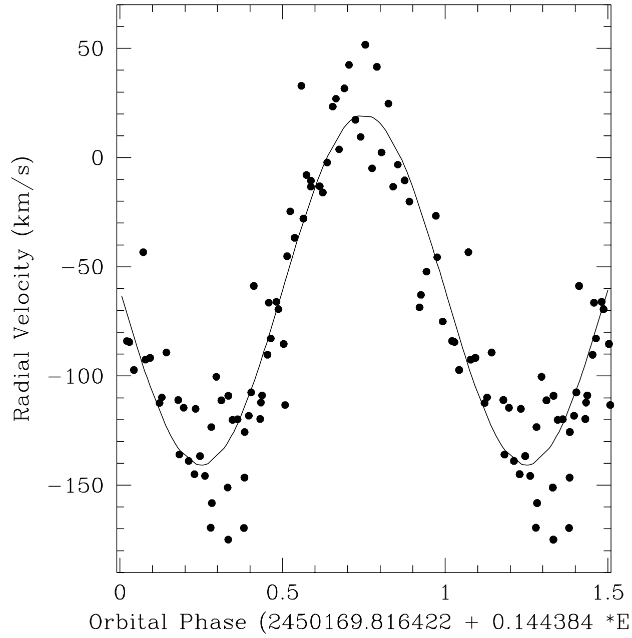

FIG. 4.—Phase-folded radial velocity data for PG 1000+667

$K = 80 \pm 4$ km s^{-1}. The sine fit to the folded data is shown in Figure 4. The ephemeris is

$$\text{HJD } 2{,}450{,}169.8164 \pm 0.0017 + (0.144384 \pm 0.00012)E ,$$

where E is the number of phase cycles and phase zero corresponds to inferior conjunction of the secondary.

The peaks in Figure 3 with the next highest powers (which occurred at $P \sim 0.169$ and 0.126 days) yield χ^2 values 1030 and 850 times larger, respectively, than the 0.144 day peak. The folded data also highly favor the maximum power peak described above as the true orbital period.

The light curve of Figure 1 was folded on the orbital period above, with low-state data omitted. No structure was seen in the folded light curve apart from typical random ∼0.5 mag flickering.

3. SUMMARY

Ringwald (1993) concluded that PG 1000+667 was a nova-like CV with a preliminary spectroscopic period of 4.06 hr, just above the 2–3 hr period gap. We support his nova-like classification and add PG 1000+667 to the list of VY Sculptoris stars that occupy the 3–4 hr period range. In addition, a refined period of 3.465 ± 0.003 hr has been derived.

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