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# NOVA V2214 OPHIUCHI 1988: A MAGNETIC NOVA INSIDE THE PERIOD GAP[1]

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## ABSTRACT

We have discovered a coherent photometric modulation in Nova Oph 1988 with period $0.117515 \pm 0.000002$ d (2.82 hr) which we associate to the orbital period of the underlying binary. This places the system at the upper side of the gap of the cataclysmic variables' (CVs) period distribution. The striking similarity of the orbital light curve with that of AM Her and the presence of prominent He II lines in the optical spectrum—similar to the magnetic nova candidates V1500 Cyg, GQ Mus, and CP Pup—strongly suggest that this is also a magnetic nova.

Inclusion of this object in the statistics of novae raises an interesting scenario. There are presently four novae with known orbital period $P_{orb} \lesssim 3$ hr, half of which lie in the period gap. All these systems are suspected to harbor magnetic white dwarfs. This evidence suggests (1) that there is no period gap for novae, and (2) that magnetic CVs are strongly favored among novae for $P_{orb} \lesssim 3.3$ hr. Implications and support for these conclusions are discussed in the light of thermonuclear runaway models and the hibernation model of classical novae, and of current models to explain the period gap.

*Subject headings:* binaries: close — novae, cataclysmic variables — stars: individual (V2214 Ophiuchi) — stars: magnetic fields

## 1. INTRODUCTION

Nova Ophiuchi 1988 (≡V2214 Oph) was discovered on photographic plates by Wakuda & Kosai (1988) early in 1988 April. McNaught (1988a) identified the prenova as a blue star of magnitude $\simeq 20.5$ flanked by two red stars of similar brightness, 3″ north and 3″ south. Measurements of saturated interstellar sodium lines made by Jablonski et al. (1988) gives $D \gtrsim 2$ kpc as a lower limit for the distance to the nova. Lynch et al. (1989) presented near-infrared (IR) spectroscopic observations and suggested a classification as slow nova from an estimated value of $t_3 \simeq 220$ d. This estimate was the result of an extrapolation of visual magnitudes published in IAU Circulars to prediscovery dates. They have obtained $m_v(\mathrm{max}) \simeq 8.0$ mag and noted that the inferred amplitude of $\Delta m_v \simeq 12.5$ mag is larger than the mean value for novae of the same speed class. Those authors also gave an estimate of $D = 1.6 \pm 0.8$ kpc for an extinction $A_v = 2.6$. For a review of the literature published so far on this object see Erwin et al. (1992).

Following the outburst we collected *UBVRI* photoelectric photometry and also some optical spectrophotometric data. The complete analysis of these data will be published elsewhere. In this *Letter* we present the results of time series photometric observations to determine the orbital period of V2214 Oph. In § 2 we describe the data and time series analysis procedure. Implications and possible explanations for the results are discussed in § 3.

## 2. OBSERVATIONS, DATA REDUCTION, AND RESULTS

We observed V2214 Oph with a GEC CCD camera (0″.58 pixel$^{-1}$, 385 × 578 pixels) attached to the 0.6 and 1.6 m telescopes of Laboratório Nacional de Astrofísica (LNA/CNPq) in southern Brazil during 1991 and 1992. The instrument was operated in the time series mode with $V$ and $R$ filters. Table 1 presents a summary of these observations. $N$ is the number of points of each run and $\Delta t$ the integration time. The typical dead time between integrations was $\simeq 10$–15 s. The last column lists the quality of the sky on each night. The seeing ranged from 1″.0 to 1″.8. For the 1991 runs the object presented an average magnitude of $V \simeq 16.0$, while for the 1992 observations $V \simeq 16.5$. The fading in the $R$ band was more pronounced in the same period and reached $\simeq 1.0$ mag.

Data reduction was carried out with the Image Reduction and Analysis Facility (IRAF[5]) software. Images were corrected for bias and flat-field effects. Automatic identification and removal of cosmic rays were performed for all runs. Photometry was performed with the aperture photometry routines of the APPHOT package. Fluxes were extracted for the variable and for 8–12 field stars selected as comparisons using a diaphragm of 2″.9 radius. The sky level was evaluated from the centroid of the histogram of the pixels in the annulus of internal radius 3″.5 and width 14″.5 centered on each star. Our time series were constructed by computing the magnitude difference between the variable and each of the secondary comparison stars with respect to the main comparison (labeled star A in the finding chart shown in Fig. 1). The uncertainty in the photometry of V2214 Oph was estimated from the dispersion in the magnitude difference for stars of similar brightness and ranged from 0.01 to 0.035 mag. Star B ($V \simeq 16.0$) had similar brightness to the nova on the 1991 runs. The weighted average of 17 photoelectric measurements of star A gives $V = 12.97 \pm 0.04$, $(U-B) = 0.20 \pm 0.03$, $(B-V) = 0.71 \pm 0.03$, $(V-R) = 0.43 \pm 0.02$, and $(R-I) = 0.44 \pm 0.02$. The faint red stars to the north and south of the nova can be seen in Figure 1. Both contribute to the fluxes obtained for V2214 Oph; however, the

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TABLE 1
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| Date | Filter | $N$ | $\Delta t$ (s) | Telescope (m) | Notes[a] |
|---|---|---|---|---|---|
| 1991 May 5 ....... | $R$ | 50 | 300 | 0.6 | A |
| 1991 May 16 ..... | $V$ | 42 | 300 | 0.6 | C |
| 1991 May 17 ..... | $V$ | 58 | 300 | 0.6 | B |
| 1991 May 19 ..... | $V$ | 64 | 240 | 0.6 | A |
| 1992 May 8 ....... | $R$ | 37 | 180 | 0.6 | B |
| 1992 May 24 ..... | $V$ | 73 | 300 | 0.6 | A |
| 1992 May 25 ..... | $V$ | 57 | 300 | 0.6 | B |
| 1992 May 26 ..... | $V$ | 4 | 300 | 0.6 | B |
| 1992 Jun 4 ........ | $V$ | 46 | 300 | 0.6 | B |
| 1992 Jun 6 ........ | $V$ | 42 | 300 | 0.6 | B |
| 1992 Jun 7 ........ | $V$ | 60 | 300 | 0.6 | B |
| 1992 Jun 23 ....... | $V$ | 60 | 300 | 0.6 | A |
| 1992 Jun 24 ....... | $V$ | 31 | 300 | 0.6 | A |
| 1992 Jun 25 ....... | $V$ | 36 | 300 | 0.6 | B |
| 1992 Jun 27 ....... | $V$ | 31 | 300 | 0.6 | B |
| 1992 Jun 29 ....... | $R$ | 28 | 300 | 0.6 | B |
| 1992 Jun 30 ....... | $R$ | 30 | 300 | 0.6 | A |
| 1992 Jul 30 ....... | $V$ | 53 | 25 | 1.6 | A |

[a] A = photometric, B = fair, C = poor.

effect is negligible since they are presently $\simeq$4.0 mag fainter than the nova itself.

In order to search for periodicities we gathered all data and removed nightly averages to account for the fading of the nova during the period of observations. We used a discrete Fourier transform (DFT) program to obtain separate power spectra for the $V$ and $R$ data in Table 1. In each case the resulting spectrum shows a complex structure as a consequence of the irregular observing window. We used an implementation of the CLEAN algorithm (Roberts, Léhar, & Dreher 1987) to deconvolve the effects of the spectral window on possible genuine

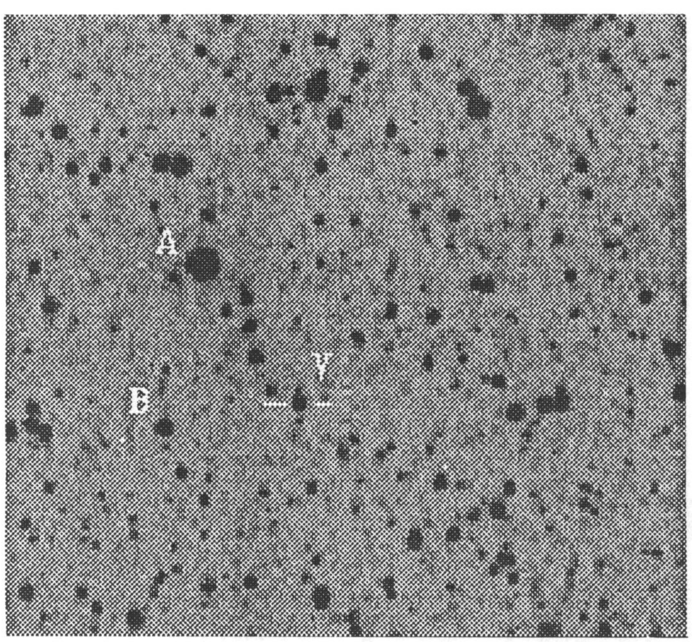


FIG. 1.—Finding chart for Nova V2214 Oph 1988 from a CCD image ($V$ filter) taken with the 1.6 m telescope at LNA observatory. The coordinates are R.A. = 17$^h$08$^m$50$^s$.8, decl. = −29°33′58″ (1950). The scale of the chart is $\simeq$2′ × 2′, north up and east to the left. The main stars used for differential photometry are labeled.

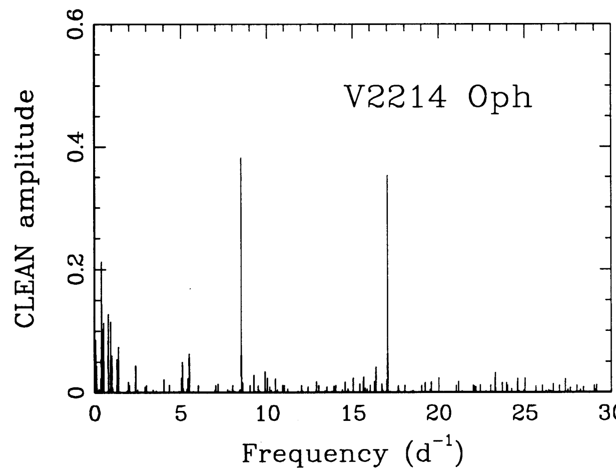


FIG. 2.—The CLEANed amplitude spectrum of V2214 Oph from the $V$ data showing the 0.1175147 d period and its first harmonic.

features in the power spectrum. The CLEANed amplitude spectrum (Fig. 2) shows a prominent signal at a period of 0.1175147 d and its first harmonic. We have further submitted the whole data set to the phase dispersion minimization (PDM) task of IRAF. The dispersion in the phase diagram has a minimum for the ephemeris,

$$HJD_{min} = 2{,}448{,}394.7708(\pm 2) + 0.117515(\pm 2)E \quad (1)$$

where the epoch corresponds to primary minimum light. The phase diagrams for the $V$ and $R$ filters with respect to this ephemeris are shown in Figure 3, where the points were repeated in phase for better visualization. A double wave behavior is evident with peak-to-peak amplitude $\simeq$0.3 mag in both filters. We interpret this modulation as related to the orbital period of the binary. The phase diagram for the $R$ data includes only points from the 1992 runs. The 1991 $R$ data are not consistent with the phase diagrams of Figure 3, despite the existence of variations of up to 0.2 mag.

A low-resolution (10 Å) spectrum in the range 4400–6600 Å was obtained on 1991 March 9. The spectrum was extracted, wavelength and flux calibrated using IRAF packages TWOD and ONED. Figure 4 shows the reduced spectrum, where forbidden lines of highly ionized species can be seen beside the Balmer series. The intensity of the He II lines 4686 and 5412 Å is remarkable. The presence of these He II lines with such intensity is usually associated to the existence of magnetic fields in the white dwarf, being a sort of signature of the magnetized subclasses of AM Her and DQ Her stars. It is illustrative to see the similarities between this spectrum and the one for GQ Mus $\simeq$ 3 yr after eruption (Krautter & Williams 1989).

Our photoelectric observations were combined with visual magnitudes published in IAU Circulars to construct an improved historical light curve. These data and the very reasonable constraint provided by the first measure of Wakuda & Kosai (1988) as the earliest possible date for visual maximum (see also McNaught 1988b) lead to $m_v$(max) $\simeq$ 8.0 mag, consistent with the determination of Lynch et al. (1989). However, we obtain a considerably faster decline rate, $t_3 = 100 \pm 20$ d, which places Nova Oph 1988 among the moderately fast novae. We also find $t_2 = 60 \pm 10$ d. Using the $M_v(\max) \times t_2$ relation of Cohen (1985) we obtain $M_v(\max) = -6.4 \pm 0.5$ mag. Taking the mean value ($\langle A_v \rangle = 2.25$) inferred from Lynch et al. (1989) and the above value of $m_v$(max), we find

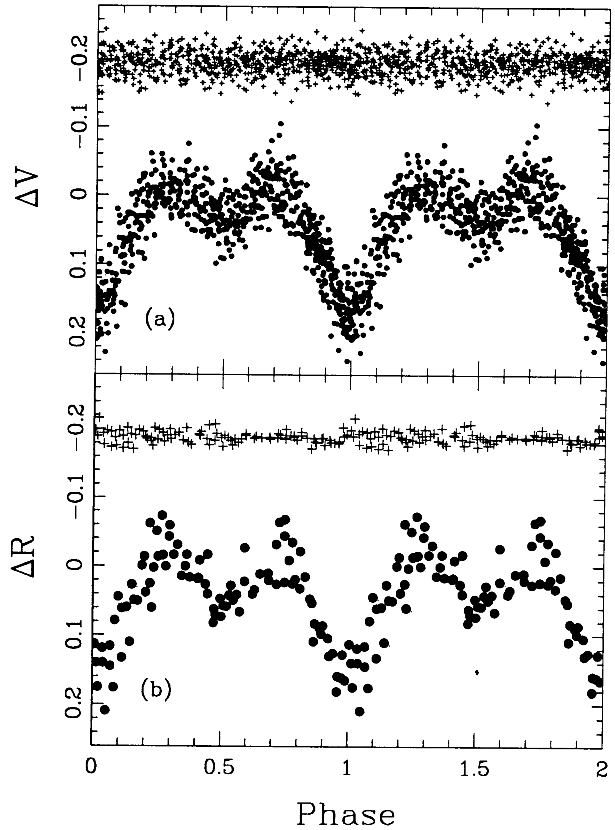


FIG. 3.—The phase diagram of V2214 Oph with respect to the photometric period of 0.117515 d, (*a*) for the *V* filter, and (*b*) for the *R* filter. The points corresponding to the comparison star B are also plotted in each panel, displaced by −0.2 mag.

$D = 2.7^{+0.7}_{-0.5}$ kpc, consistent with the value that can be obtained from the strength of the Na I lines. Taking this value for the distance to the nova we derive an absolute magnitude $M_v = +2.1$ mag at the present time and a magnitude of the pulsed component in the light curve for 1992 of $M_v(\text{puls}) = +3.6$ mag. Assuming blackbody emission, this result is consistent with the modulation being produced by the changing aspect of a reprocessing region at the surface of the secondary star if $1.5 \times 10^4 \lesssim T_{\text{eff}} \lesssim 4 \times 10^4$ K. It would only be consistent with

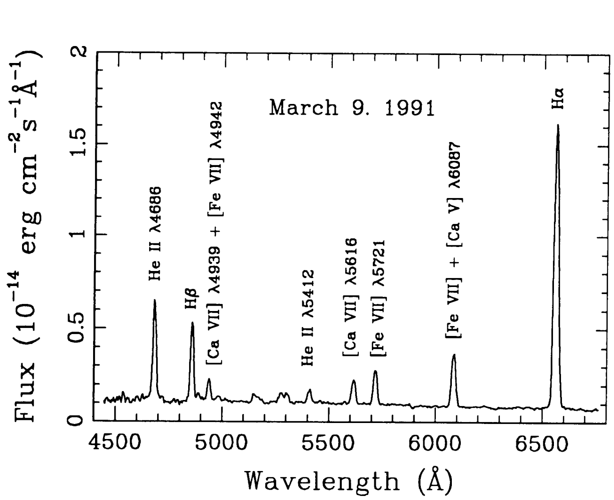


FIG. 4.—Optical spectrum of V2214 Oph taken with the Cassegrain spectrograph at the 1.6 m telescope at LNA observatory.

emission in a small hot region on the surface of the white dwarf if we allow unreasonably high temperatures, $T_{\text{eff}} \gtrsim 10^6$ K.

## 3. DISCUSSION

There is a striking similarity between the orbital light curve seen on Figure 3 and that of AM Her (Crampton & Cowley 1977). Evidence that this resemblance is not fortuitous is given by the optical spectrum of Figure 4, which presents prominent He II lines (He II 4686/H$\beta$ = 1.4) typical of magnetic cataclysmic variables. From the features in the light curve and in the optical spectrum we suggest V2214 Oph is a magnetic nova similar to V1500 Cyg (Stockman, Schmidt, & Lamb 1988; Kałużny & Chlebowski 1988), GQ Mus (Diaz & Steiner 1989), and CP Pup (O'Donoghue et al. 1989; Diaz & Steiner 1991). The observed amplitude of the eruption in V2214 Oph ($\Delta m_v \simeq 12.5$ mag) is larger than that expected from the measured $t_3$ value by at least 2.0 mag (Vogt 1990). This can be explained if the prenova was fainter than the average absolute magnitude of quiescent novae with disks ($\langle M_v \rangle \simeq 4.2$ mag, Patterson 1984) by the same amount. From the distance estimate of § 2 we obtain $m_v(\text{min}) \simeq +6.0$ mag. This means either a high-inclination disklike system—in which case marked eclipses would be expected—or a fainter prenova system. AM Her stars are intrinsically fainter than disklike systems even in their bright states ($\langle M_v \rangle \simeq 8.6$ mag). We note that V2214 Oph falls in the same region as the magnetic novae V1500 Cyg and GQ Mus in Figure 2 of Vogt (1990).

The light curve with its double wave can be explained with a model of emission from two regions with changing aspect with orbital phase. An extended source, possibly due to the heated surface of the secondary star by reprocessing of UV and soft X-rays from the hot white dwarf photosphere and/or magnetic pole, may be responsible for the primary minimum in the light curve. The secondary minimum may be produced by a smaller auto-occulting source, which could be a hot region directly above the accretion column.

Our photometry shows that V2214 Oph has an orbital period of 2.82 hr, which places the system at the upper edge of the period gap of the cataclysmic variables (CVs). The inclusion of this system in the statistics of novae with known orbital period raises an interesting scenario. From the latest edition of Ritter's (1990) catalog one sees that for seven CVs inside the period gap ($2.2 < P_{\text{orb}} < 3$ hr) there are two recorded novae (V Per and V2214 Oph). For the following discussion we will make the assumption (to be confirmed by observations) that the ratio between the number of novae and the total number of CVs is the same in and below the gap. Presently there are 45 CVs below the gap. From the above assumption, one should expect to find 13 novae at periods $P_{\text{orb}} \lesssim 2.2$ hr. However, there are only two known systems, GQ Mus and CP Pup. Despite the small number of objects involved, the relative frequency of novae inside the period gap is much higher than that expected from the inferred statistics of CVs below the gap. Extending our sample to include novae with orbital periods slightly above the gap (V603 Aql and V1500 Cyg), we see that the distribution of novae around the period gap is roughly constant, independent of $P_{\text{orb}}$. Hence, *there seems to be no period gap for novae.* Another striking conclusion that can be drawn is that all these novae are magnetic CV candidates (see Wood et al. 1992 for evidences of a magnetic white dwarf on V Per). *There is a clear correlation between the occurrence of novae with short orbital periods ($P_{\text{orb}} \lesssim 3.3$ hr) and the presence of magnetic white dwarfs.*

The existence of CVs in the period gap indicates the occurrence of mass transfer, which could be sustained, for example, by the coupling of the residual secondary stellar wind to the white dwarf magnetic field (Hameury, King, & Lasota 1989 and references therein), for magnetic systems inside the gap. We suggest that the differences arising from the funneling of the accreted matter onto the magnetic poles favor the conditions for a thermonuclear runaway (TNR) on magnetic white dwarfs. The compressional heating due to the relatively high local accretion rates could accelerate the process and shorten the time needed for a TNR to proceed. As a consequence, magnetic white dwarfs may have considerably lower recurrence times for TNR, which would result in a prevalence of magnetic CVs among novae in the relatively low-accretion regimes expected for the short orbital period systems.

Unlike other magnetic novae, V2214 Oph had a somewhat slower decay. Diaz & Steiner (1991) have argued that large amplitudes and rapid decay times are expected for magnetic novae. According to Livio (1992) the speed class of a nova seems to be closely related to the white dwarf mass, with more massive white dwarfs presenting faster eruptions. Nova Ophiuchi may have a relatively low-mass white dwarf as compared to V1500 Cyg, GQ Mus, or CP Pup. Since the decline rate may be affected by differences in the masses of the white dwarfs, a good criterion to select magnetic nova candidates is a large eruption amplitude as compared to novae of the same speed class.

## 4. CONCLUSIONS

On the basis of our photometric observations we conclude that Nova V2214 Oph 1988 is a magnetic nova with an orbital period inside the period gap. The inclusion of this system in the statistics of novae suggests that (1) there is no period gap for novae, and (2) there is a clear correlation between the occurrence of novae with short orbital periods ($P_{\rm orb} \lesssim 3.3$ hr) and the presence of magnetic white dwarfs. We suggest that funneling of the accretion flow onto the magnetic poles favors the conditions for a TNR, increasing the frequency of eruptions for magnetic systems. This mechanism may be efficient even for the very low accretion regimes that seem to occur in the period gap.

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