High Time Resolution Photometry of V458 Vul

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High Time-Resolution Photometry of Nova V458 Vul

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ABSTRACT

We observed the nova V458 Vul over the course of June 7 to June 10, 2010 at the Vatican Advanced Technology Telescope (VATT) on Mt. Graham, Arizona. The star erupted on August 8, 2007, reached its 8.1 magnitude peak in the following days (Rodríguez-Gil et al. 2010), and has since begun to evolve toward quiescence. We explore the properties of its current evolutionary state to identify quasi-periodic oscillations (QPOs) and the possibility of other variability. Our data reveal a 0.1-magnitudes variation that occurs over an approximately 20 minute period and strongly suggests quasi-periodic oscillation. The irregularity of the signal, particularly the difference between consecutive sets of data, provides evidence for this noncoherent variability. The orbital period is not evident in our observations, whose 2-4 hour spans do not favor the 98-minute period, too weak in amplitude to be distinguishable from random variations. Furthermore, visible light emitted from the system is dominated by the disk, which masks the signal from the systems orbital motion. We focus on investigating the pronounced signal from speculated QPOs.

1. Introduction

Nova V458 Vul is a cataclysmic variable star (CV). CV are binary systems comprising a white dwarf primary paired with a less compact secondary or donor star. The donor star is so named because it regularly loses a part of its mass to the white dwarf. The secondary exceeds its Roche lobe, the gravitational potential surface that takes a teardrop shape because of the systems distribution of gravity, and mass escapes through the Lagrangian point L_1. This escaped mass falls onto an accretion disk around the white dwarf at a distance dependent on its angular momentum. Dwarf nova outbursts occur when temperature rises in the disk and viscosity-slowed matter falls from the disk onto the star (La Dous 1993).

V458 Vul is peculiar in that it is surrounded by a planetary nebula, which indicates that the white dwarf primary formed in the last 14,000 years (Wesson et al. 2008). The existence of this nebula is not implausible, only statistically surprising.

Currently, V458 Vul is in a “nova-like” stage of evolution, its disk in a continuous bright state that resembles a dwarf nova outburst. This optically thick accretion disk radiates brightly, principally in the optical, to counteract the unrestrained temperature rise resulting from viscosity and ionization that increases with mass accretion (Rodríguez-Gil & Torres 2005). V458 Vul may eventually evolve into a dwarf nova but at this point in its evolution it has not yet reached quiescence. Its current “nova-like” state is a result of high mass transfer rate after the nova explosion rather than from a true dwarf nova outburst (Misuzawa et al. 2010). Often smaller scale flickering occurs during this phase (La Dous 1993). Material that falls from the disk onto the star can cause erratic surges in brightness. In some cases the spin of the white dwarf can contribute to small, precise variation frequencies. Other moderately consistent variations in magnitude that occur during this phase are often attributable to QPOs. QPOs have periods in the range of seconds to several minutes, which exhibit sizeable variations in amplitude and frequency over time. They are more regular than the erratic flickering that is always present in “nova-like” stars but less uniform than coherent oscillations. In this study, we probe our data for evidence of these small scale variations, finding strong evidence for the existence of QPOs.

2. Observations

Image data were obtained at the Vatican Advanced Technology Telescpe (VATT) at the Mt. Graham International Observatory (MGIO) on the nights of June 7-10, 2010. Data was filtered in the V band on June 7 and 9, in the B band on June 8, and in the R band on June 10, with all image exposures between 10 and 20 seconds. We read out a selected 1026x512 pixel portion of the chip to reduce readout time to 10 seconds. Using the VATTs 4K CCD and 2×2 pixel binning, we obtained a field of view of 0.376 ”/pixel. The average airmass over all four nights was 1.5.

3. Data Reduction

We used the standard IRAF photometry packages for the bias subtraction and flat-field reduction of the data. We combined biases, omitting those whose mean values fell in the upper and lower 5 percent. We subtracted the combined bias from each flat-field and applied *implot* to the overscan regions to evaluate the success of the bias subtraction. In the R and V bands there remained nonzero values in the overscan region, which we subtracted interactively. We combined the flat fields with the same standards for omission and normalized the results.

We specified an aperture of 4 pixels in the package *photpar* in approximate agreement with the full-width at half-maximum measurement (in pixel units), comprising roughly 80 percent of the starlight. Using *imexam* we identified coordinates for three stars: the variable star, a bright (noise-resistant) comparison star, and a third check star to evaluate the stability of the comparison star. We performed aperture photometry with *phot*, run non-interactively with the centering algorithm set to centroid and a maximum shift of 5 pixels. We used the magnitude and error from the output to create a light curve.

4. Results

4.1. Light Curves

We derived two light curves from each dataset. The relevant data is displayed in the first, which plots the difference in magnitude between variable and comparison stars against the observation time extracted from the image header. The second curve compares the magnitudes of the comparison and check stars to verify that the comparison star does not vary.

The light curve in the V band from the first night of observation is the clearest indicator of a QPO, showing a nearly sinusoidal variation of $\sim$0.1 magnitudes with an oscillation period of $\sim$20 minutes. The light curves resulting from the following nights of data display variation on about the same order, though considerably less regularly. In the data taken in the R and B bands, sinusoidal oscillation is not easily discernable. This is unlikely to be a consequence of filter choice

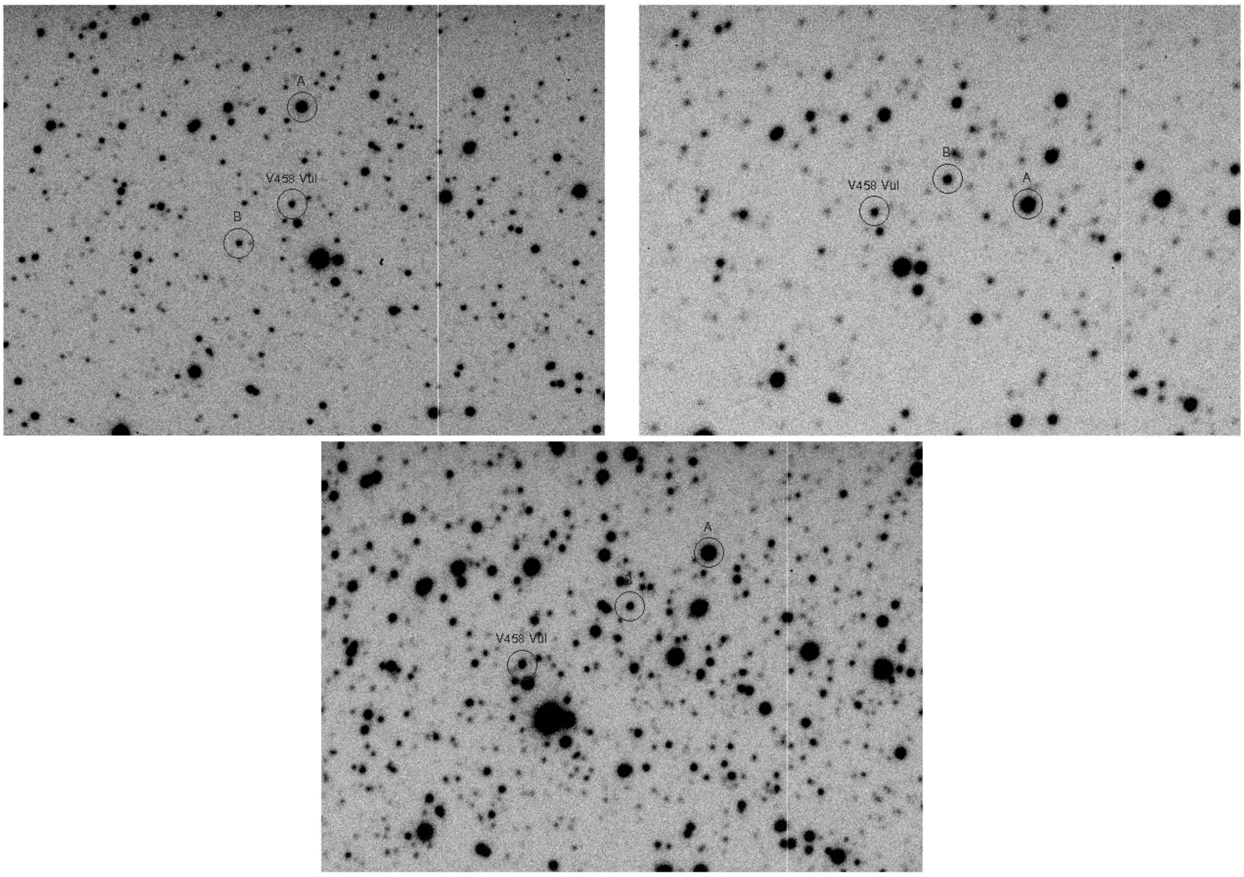

Fig. 1.— V458 Vul in the V, B, and R bands, respectively. ‘A’ identifies the comparison star, ‘B’ the check star.

and is probably a temporal effect, because the results of the power spectrum analysis that follows provide evidence for oscillation at the same frequency, though not obvious in the light curve. This suggests that some of the random variation characteristic of cataclysmic variables may have had some role in cluttering the signal from the primary QPO. Moreover, the noncoherence of the oscillation at this frequency over time broadens the peaks and lowers their strength. The power spectrum analysis, extended to all our data, further explores the nature of the speculated QPO.

4.2. Power Spectrum Analysis

The system’s approximately 98-minute orbital period is not apparent in our observations, yet the star exhibits an irregular variation on all four nights that is suggestive of quasi-periodic oscillation (QPO). As a diagnostic, we created a power spectrum for each light curve to analyze

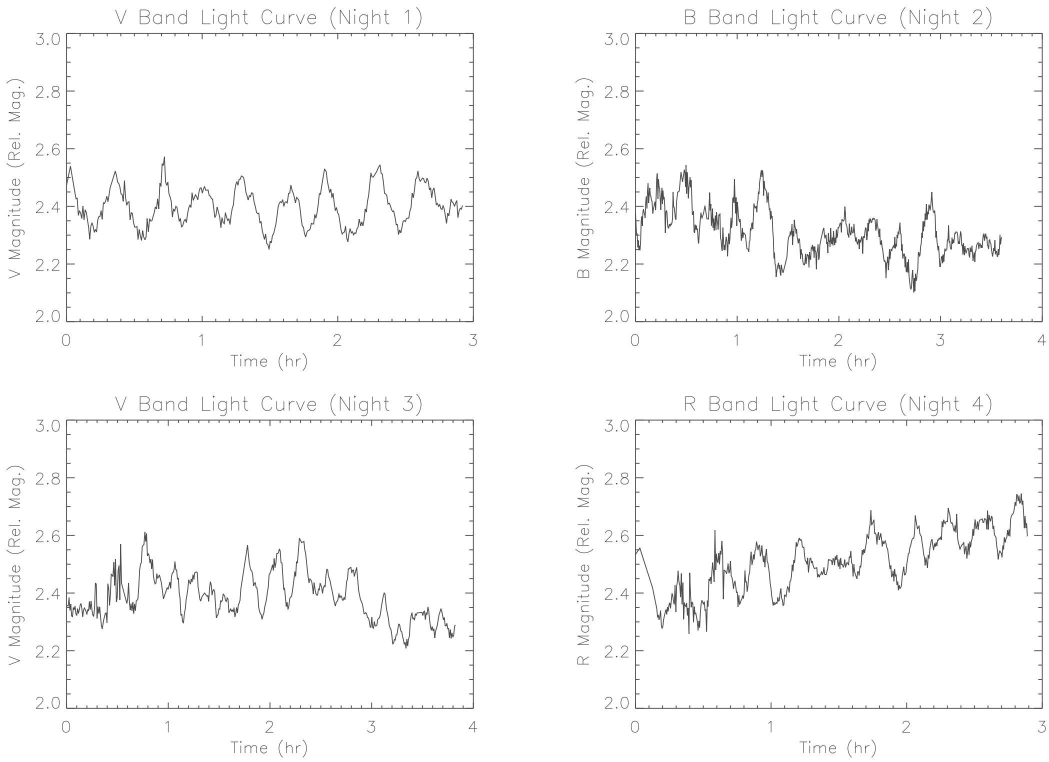

Fig. 2.— Light curves in V, B, and R bands relative to comparison star A.

the variation. We read the light curve data into a program that performed a Fourier transform and output a plot of power against frequency, its spikes indicating frequencies of oscillation.

Each set of data exhibited a prominent spike at a frequency of ∼0.001 Hz. To evaluate the amplitude of the variation by the magnitude of the spike, we simulated the oscillation of the star with a sine curve at this frequency, adjusting its amplitude such that the spike produced by the simulation had the same value as that produced by the data. This amplitude represents the percent change in magnitude of the variable star over a cycle.

Speculating that lower frequency oscillations would become more apparent over the longer duration of the combined observations, we combined all the datasets for simultaneous analysis. When this dataset was finely resolved (with 1600 data points), the ∼0.001 Hz spike resolved into two narrowly separated spikes of like size. This further supports the argument for QPOs, characterized by small temporal instabilities in the frequency of oscillation. This refutes the possibility of the white dwarfs spin being a factor in this variability, since its spin frequency is necessarily perfectly coherent.

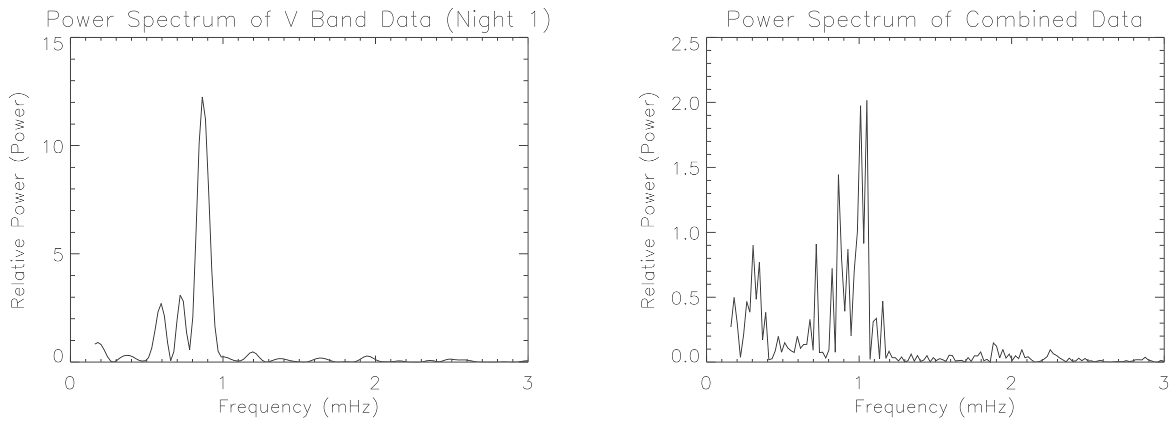

Fig. 3.— Two power spectra. The left frame shows the broad peak at 0.83 mHz obtained in the V band from one night. The right frame shows a higher resolution spectrum of the combined data from four nights and indicates two equal-amplitude frequencies of oscillation at 1.00 mHz and 1.05 mHz.

5. Other Considerations

In addition to QPOs, CVs of this type are also sometimes found to exhibit dwarf nova oscillations (DNOs), high-frequency oscillations that occur in the range of 5-15 times the QPO frequency (Warner et al. 2002). Our data do not support DNOs but do not eliminate the possibility. Because these data are susceptible to noise, a greater number of data points may be necessary to reveal a spike in the power spectrum. Our data is at a particular disadvantage given that the postulated frequency of oscillation of a DNO has a period in the range of the time between images. It is possible then that DNOs are not apparent or do not exist currently but will become observable later.

Our merged images reveal a nebula that surrounds the nova, including a region that appears somewhat more extensive than the planetary nebula emission seen before the outburst. The nebula is seen in all three bands, raising the possibility that V458 Vul has produced a light echo scattering off of dust originally in the planetary nebula. We make the geometrical assumption that nova and planetary nebula lie on a line in the plane of the sky at a separation of 0.28 pc (Wesson et al. 2008), or 8.6×10^{13} km and calculate that in the 1035 days between the nova explosion and our observations, light traveled 2.68×10^{13} km. This rough calculation supports the possibility of observing a light echo, which may be interesting to re-examine in later observations.

6. Conclusions

Variations in magnitude of nova V458 Vul in this early, “nova-like” state of its evolution are strongly suggestive of quasi-periodic oscillation. The rough oscillatory variation detectable in each light curve is unambiguously defined in the resultant power spectrum. Evidence for QPOs arises from the night-to-night variation in frequency. Since the QPO wobbles about a small range of frequencies, it appears in the power spectrum as a broad curve, which would be a delta function in the case of fixed frequency. QPO is further supported by the higher resolution power spectrum of the combined data, in which the broad spike resolves into two equal-magnitude spikes of near-equal frequency.

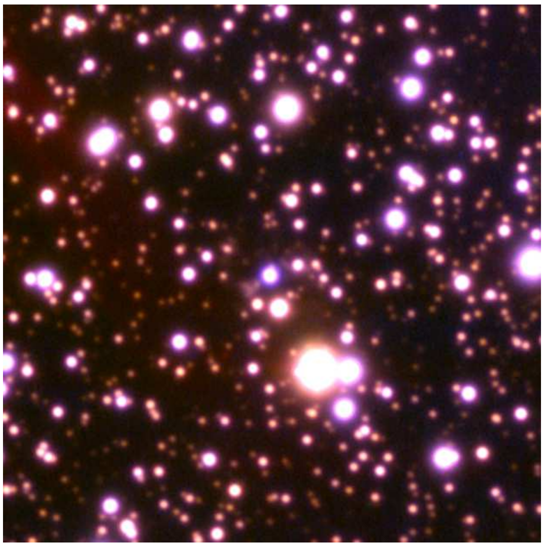

Fig. 4.— This combined color image of V458 Vul shows that the star appears rather blue. The image is scaled logarithmically to bring out the nova’s faint planetary nebula, which appears just to the left of the nova.

Table 1. Magnitudes of comparison stars are calibrated to standard values for apparent magnitude found at www.aavso.org. Magnitudes are measured in three bands and listed for each night of observation. The varying magnitude of V458 Vul can be extrapolated from these values and the relative magnitudes used to plot the light curves.

Star	V Magnitude	B Magnitude	R Magnitude
V Star A	14.36	15.27	13.91
B Star A	14.96	15.98	14.39
R Star A	14.77	16.12	14.07

Table 2. Frequency and amplitude of spike obtained from each power spectrum.

Date	Filter	Duration (hr)	Frequency (mHz)	Amplitude (mag)
June 7, 2010	V	2.9	0.84	0.088
June 8, 2010	B	3.6	1.05	0.045
June 9, 2010	V	3.8	1.05	0.050
June 10, 2010	R	2.9	1.00	0.060

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