The Orbital Period of V368 Aquilae (Nova Aquilae 1936 No. 2)

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ABSTRACT. We report observations of the eclipsing classical nova V368 Aql (Nova Aql 1936 No. 2). These data reveal that the orbital period previously published by Diaz & Bruch is an alias of the true orbital period. A total of 14 eclipses (12 complete and two partial) over 25 nights of observation have established that the orbital period of V368 Aql is 0.6905093(1) day (16.57 hr), which is roughly twice the previously published period. With its revised orbital period, V368 Aql now joins other nova systems with periods in excess of 0.5 day that dominate the long end of the orbital period distribution of cataclysmic variables.

1. INTRODUCTION

V368 Aql (Nova Aquilae 1936 No. 2) was discovered at Kvistaberg Observatory on 1936 October 7 by Taam (1936) as an optical transient of roughly seventh magnitude. The outburst light curve based on observations by several observers (see Payne-Gaposchkin 1957; Klemola 1968), showed that maximum light occurred approximately two weeks earlier on 1936 September 25 at $m_{bg} = 6.6$. The nova faded relatively quickly, dropping by 3 mag in ~42 days ($t_3 = 42$ days), making V368 Aql a moderately fast nova. Spectroscopic observations made ~25 days after maximum revealed an absorption-line system consisting of H, Ca II, He II λ4686, N III, and probably He I and Fe II, along with strong, broad (~2000 km s$^{-1}$) Balmer emission (Wyse 1936). Based on these data, the spectroscopic class of V368 Aql is ambiguous, but the probable detection of Fe II, and the moderate width of the Balmer lines, suggest that the object was likely a member of either the “Fe II” or “hybrid” classes of novae as defined by Williams (1992).

Aside from its identification at minimum light by Klemola (1968), V368 Aql slipped into relative obscurity until time-resolved photometric observations by Diaz & Bruch (1994) revealed shallow eclipses in the light curve. A total of just two eclipses were observed during their 11 nights of observation in 1990 May, and 1993 July and August. Based on a periodogram analysis of their entire data set, Diaz & Bruch concluded that the orbital period of V368 Aql was likely to be 0.34521 ± 0.00015 days (8.29 hr).

As part of a program to study the eclipse morphologies of classical novae, we obtained a sequence of time-resolved observations of V368 Aql on the nights of 2005 September 3, 4, and 5 UT. To our surprise, although the night of September 4 revealed an eclipse, none were observed on the adjacent nights at the times expected for an orbital period of 8.29 hr. In order to establish the true orbital period and to better understand the eclipse morphology, we undertook a more extensive program of time-resolved, multicolor CCD photometry of the eclipses of V368 Aql. A preliminary report, establishing that the orbital period of V368 Aql is actually twice that originally reported by Diaz & Bruch (1994), has been posted in Shafter et al. (2008). Here we provide a more detailed discussion of our findings, including additional eclipse observations that have enabled us to improve the precision of the revised orbital period.

2. OBSERVATIONS

A finding chart for V368 Aql based on one of our $B$-band images from 2005 September 4 is presented in Figure 1. Observations of V368 Aql were carried out during 8 nights in 2005 September and October, and 17 nights in 2008 June through August using the Mount Laguna Observatory 1 m reflector. On each night a series of exposures (typically 60 s) was taken through one of the Johnson-Cousins $B, V, R, I$ filters (see Bessel 1990), and imaged on a Loral 2048$^2$ CCD. To increase the time-sampling efficiency, only a 400 × 400 subsection of the full array was read out. The subsection was chosen to include V368 Aql and several relatively bright nearby stars to be used as comparison objects for differential photometry. Twilight flat images of the same size were taken and averaged for each run.

The data were processed in a standard fashion (bias subtraction and flat-fielding) using IRAF. The individual images were subsequently aligned to a common coordinate system and instrumental magnitudes for V368 Aql and two nearby comparison stars were then determined using the IRAF APHOT package. Variations in atmospheric transparency were removed to first order by dividing the flux of V368 Aql by that of one of two nearby comparison stars marked C1 and C2 in Figure 1.

$^1$IRAF (Image Reduction and Analysis Facility) is distributed by the National Optical Astronomy Observatories, which are operated by AURA, Inc., under cooperative agreement with the National Science Foundation.
The differential light curves were then placed on an absolute scale by calibration of the comparison stars against the standard stars in Landolt (1992). Our calibration reveals that stars C1 and C2 are characterized by $B = 15.49 \pm 0.10$, $V = 14.71 \pm 0.10$, $R = 14.10 \pm 0.10$, $I = 13.76 \pm 0.10$, and $B = 16.14 \pm 0.10$, $V = 14.79 \pm 0.10$, $R = 13.60 \pm 0.10$, $I = 13.11 \pm 0.10$, respectively, where the errors quoted include the uncertainty in the mean extinction coefficients used in the calibration. The calibrated light curves of V368 Aql from our initial run in early 2005 September are shown in Figure 2, while the eclipse light curves from 2008 are segregated by color and displayed in Figures 3–6. A summary of all observations is presented in Table 1.

The eclipse light curves are quite variable, with the out-of-eclipse light levels in a given bandpass varying by up to 0.5 mag on timescales from weeks to months. The eclipse depths for a given color are also variable, but at reduced level. The fact that the eclipse depths are less variable than the out-of-eclipse light...
levels suggests that most of the variability comes from un-
eclipsed regions of the system (i.e., the outer accretion disk, 
the secondary star, or both.). Not unexpectedly, the eclipse 
depth is greatest in the $B$ band, where the light level drops 
$\sim 0.75$ mag at mideclipse, indicating that roughly half of the 
total system light is eclipsed. At longer wavelengths, the eclipse 
depth decreases as the contribution from the secondary star to 
the total system light begins to dominate. This increased con-
tribution manifests itself through the emergence of ellipsoidal 
variations, which are seen most clearly in the $R$-band light 
curves.

3. THE ORBITAL PERIOD OF V368 AQL

During our 25 nights of observation, a total of 14 eclipses (12 
complete and two partial) of V368 Aql were observed. Eclipse 
timings for the 12 complete eclipses were measured by fitting a 
parabola to the lower half of the eclipse profile and taking the 
vertex as the time of mideclipse. The resulting timings, plus the 
two available from Diaz & Bruch (1994) are summarized in 
Table 2.

Although all of the timings can be fit with the 8.29 hr period 
found by Diaz & Bruch (1994), as mentioned earlier, their 
period also predicts eclipses at times when none are observed 
to occur (e.g., see Fig. 2). Thus, the true orbital period must be 
an integer multiple of the 8.29 hr period. Partial eclipse obser-
vations on consecutive nights with an ingress observed just 
before sunrise on 2008 June 30 UT followed by an egress ob-
served just after sunset on 2008 July 1 UT (see Fig. 3) resolved 
the cycle count ambiguity and established that the true orbital 
period was (roughly) twice the $P = 8.29$ hr period. A linear 
least-squares fit of all the mideclipse times yields the following 
revised ephemeris for V368 Aql:

$$T_{\text{mid–eclipse}} = JD_{\odot} 2,449,189.5231(8) + 0.6905093(1) \ E.$$  

(1)

Residuals of the individual eclipse timings with respect to 
this ephemeris are also given in Table 2, and are plotted as a
function of cycle number in Figure 7. There is no evidence for any second-order trend that might suggest a change in period over the interval spanned by the observations.

4. DISCUSSION

Our observations have revealed that the orbital period of V368 Aql is roughly twice that previously accepted, making it one of the longest periods known among the cataclysmic variables (CVs). The orbital period of V368 Aql is compared with the periods of other classical novae and with CVs in general in Figure 8. Of 741 CVs with known orbital period (Ritter & Kolb 2003), only 16 have periods longer than V368 Aql, with eight of those also being nova systems.

It is well known that the orbital period distribution of novae differs from that of CVs generally. The most striking difference is the relative paucity of nova systems below the period gap ($\log P_{\text{orb}} \lesssim 1.0$). This difference can be explained by the fact that systems below the gap, where the accretion rates driven by gravitational radiation are low, require a higher envelope mass to trigger a thermonuclear runaway (TNR) is triggered (e.g., Townsley & Bildsten 2005). The envelope mass required to trigger a TNR increases sharply with decreasing white dwarf mass. The necessity for the larger envelope mass coupled with the low accretion rate requires the system to

Table 1

| UT Date       | UT Time (start of observations) | Time Resolution* (s) | Number of Exposures | Filter | Eclipse? |
|---------------|---------------------------------|----------------------|---------------------|--------|---------|
| 2005 Sep 03   | 04:09:10                        | 122.4                | 90                  | B      | No      |
| 2005 Sep 04   | 03:14:00                        | 122.4                | 120                 | B      | Yes     |
| 2005 Sep 05   | 05:13:30                        | 62.06                | 160                 | V      | No      |
| 2005 Sep 29   | 04:05:40                        | 62.06                | 100                 | V      | No      |
| 2005 Sep 30   | 03:09:00                        | 62.06                | 173                 | V      | No      |
| 2005 Oct 04   | 02:50:00                        | 62.06                | 199                 | V      | No      |
| 2005 Oct 05   | 03:10:35                        | 62.06                | 80                  | V      | No      |
| 2005 Oct 06   | 02:45:00                        | 122.4                | 92                  | B      | No      |
| 2008 Jun 29   | 05:06:00                        | 62.06                | 377                 | B      | No      |
| 2008 Jun 30   | 04:39:11                        | 62.06                | 398                 | B      | Yes     |
| 2008 Jul 01   | 04:38:00                        | 62.06                | 414                 | B      | Yes     |
| 2008 Jul 02   | 04:28:00                        | 62.06                | 155                 | B      | No      |
| 2008 Jul 05   | 04:54:00                        | 62.06                | 326                 | B      | Yes     |
| 2008 Jul 07   | 04:28:00                        | 62.06                | 410                 | B      | Yes     |
| 2008 Jul 12   | 04:12:00                        | 62.06                | 198                 | V      | Yes     |
| 2008 Jul 14   | 04:27:02                        | 62.06                | 424                 | R      | Yes     |
| 2008 Jul 16   | 05:45:00                        | 62.06                | 359                 | I      | Yes     |
| 2008 Jul 23   | 04:14:00                        | 62.06                | 435                 | R      | Yes     |
| 2008 Jul 25   | 05:16:00                        | 62.06                | 369                 | V      | Yes     |
| 2008 Jul 27   | 04:12:00                        | 62.06                | 421                 | I      | Yes     |
| 2008 Aug 01   | 04:03:00                        | 62.06                | 419                 | B      | Yes     |
| 2008 Aug 02   | 04:20:00                        | 62.06                | 353                 | R      | No      |
| 2008 Aug 03   | 03:58:00                        | 62.06                | 445                 | R      | Yes     |
| 2008 Aug 05   | 03:40:00                        | 62.06                | 420                 | V      | Yes     |
| 2008 Aug 06   | 03:44:00                        | 62.06                | 417                 | V      | No      |

*Mean time interval between exposures (integration time plus readout time).
accrete for a relatively long interval between consecutive nova outbursts, resulting in a low observed nova rate among the short period CVs.

It is less well known that the orbital period distributions for novae and CVs in general differs at long orbital periods as well. For example, it is interesting to note that although among CVs with known orbital period novae make up just a little more than 10% of the total, among systems with orbital periods of more than 0.5 day, novae make up roughly half (12 out of 25) of the total. It is likely that a combination of generally higher mass accretion rates and higher white dwarf masses (required for stable mass transfer) among the longest period systems is responsible for the increased fraction of nova systems in this period regime.

Table 3 summarizes the known properties of the 12 classical novae with orbital periods in excess of 0.5 day. Of the 8 novae with information on their spectroscopic class available, roughly

| Nova     | Type | Orbital Period (days) | \( t_3 \) (days) | \( V_{\text{exp}} \) (km s\(^{-1}\)) | Spectroscopic Class |
|----------|------|-----------------------|-----------------|-----------------|-------------------|
| DI Lac   | Na   | 0.5438                | 43              | ...             | Fe II?            |
| V458 Vul | Na   | 0.5895                | 15              | 3000            | Hy                |
| V841 Oph | Nb   | 0.6013                | 130             | ...             | ...               |
| V368 Aql | Na   | 0.6905                | 42              | ...             | Fe II, hybrid?    |
| V723 Cas | Nb   | 0.6933                | ...             | 500?            | Fe II             |
| V394 CrA | RN   | 0.7577                | 6               | ...             | ...               |
| CP Cru   | Na   | 0.9440                | ...             | 2000            | He/N              |
| U Sco    | RN   | 1.2300                | 7               | ...             | He/N              |
| X Ser    | Nb   | 1.4800                | 170             | ...             | ...               |
| J0305+0547 | ... | 1.7700                | ...             | ...             | ...               |
| GK Per   | Na   | 1.9968                | 13              | 4000            | He/N              |
| V1017 Sgr| Nb   | 5.7140                | 130             | ...             | Fe II             |
half either belong to the He/N or hybrid classes. This contrasts with novae at all orbital periods where the He/N and hybrid classes combined make up a total of only \( \sim 20\% \) of the total (Shafter 2007). In addition, two of the 12 long-period novae are recurrent. The relatively high percentage of He/N, hybrid, and recurrent novae among the long-period systems is consistent with the expectation that these systems contain on average higher-mass white dwarfs accreting at higher rates.

5. CONCLUSIONS

We have found that the previously published orbital period for V368 Aql \((P = 0.345\) day, Diaz & Bruch 1994) was an alias of the true orbital period. A total of 14 eclipses (two partial) over 25 nights of observation have established that the orbital period of V368 Aql is actually 0.6905093(1) day (16.57 hr). The revised orbital period for V368 Aql places the system among the other long-period nova systems that dominate the statistics at the upper end of the CV period distribution. Future work on V368 Aql should include a radial velocity study and an effort to model the eclipse profiles in order to constrain system parameters, particularly the white dwarf mass and accretion rate.

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