

A possible orbital period for the dwarf nova V1101 Aql*

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Abstract. We have performed a Discrete Fourier Transform on 136 CCD B , V and R frames of the Z Cam-type dwarf nova V1101 Aql. Our analysis indicates as possible orbital period $P_{\text{orb}} = 3^{\text{h}}.46$, though we cannot exclude the alias at $4^{\text{h}}.00$. We estimate the distance to the system to be about 300 pc. We possibly discovered a bright bow-shaped nebulosity around the object.

Key words: binaries: close – stars: individual: V1101 Aql – novae, cataclysmic variables – accretion, accretion disks

1. Introduction

Dwarf Novae (hereafter DNe) are Cataclysmic Variables (CVs) characterized by periodic outbursts, lasting few days, followed by longer periods of quiescence lasting from few weeks to several months. These outbursts (see Cannizzo 1993 and references therein) are originated by cyclic instabilities in the accretion disk surrounding a hot white dwarf (WD) or subdwarf. Z Cam stars form a subclass of DNe in the sense that they are characterized by outburst ‘standstills’ (see Warner 1995), i.e. by prolonged phases in which their luminosity is halfway between maximum and quiescence. According to Osaki (1996), in these systems the mass transfer rate from the secondary is very close to the limit at which the accretion rate from the secondary ceases to trigger periodic instability episodes in the accretion disk and maintains the disk in a stable state (Frank et al. 1992). According to the observations, Z Cam stars are above the Period Gap (Warner 1995).

V1101 Aql is listed in the *General Catalog of Variable Stars* (Kholopov 1987) as an irregular variable, although Richter (1961) stated that this object was an RR Lyr star. On the contrary, Meinunger (1965), Vogt & Bateson (1982) and Downes

& Shara (1993) classified it as a Z Cam-type DN. This would be confirmed by the observations of Pastukhova & Shugarov (1994), which noticed that the star shows an ultraviolet excess, generally varies in the B band between magnitudes 13.8 and 14.8 and has ‘Algol-like fadings’ down to magnitude $B = 17.3$ (these might possibly be observations made during the quiescent phase). Actually, they classified V1101 Aql as a CV. The same conclusion was reached by Downes et al. (1995) from the analysis of spectra acquired on September 1992 and on August 1994, when the object was at $V = 14.7$ and $V = 14.3$, respectively. However, it should be noted that the latter authors find some spectral similarities between V1101 Aql and the class of Herbig Ae/Be stars.

In this paper we present high-time resolution photometry of V1101 Aql obtained on September 1993 and on July 1996, together with a spectrum secured on June 1996. Sect. 2 will describe the employed instruments and the reduction techniques, Sect. 3 will analyse the spectrophotometric data and Sect. 4 will discuss the results. Finally, Sect. 5 will draw our conclusions.

2. Observations

The images of V1101 Aql are divided into two data sets. The first one has been acquired on September 10, 1993 with the 0.9m Dutch telescope at La Silla. This run was composed of 71 V and 3 B frames. The second data set was obtained on July 13 and 14, 1996 with the 1.2m telescope of the Asiago Astrophysical Observatory: here, 58 V , 2 B and 2 R frames were collected. Table 1 reports the log of the observations.

After the standard cleaning procedure for bias and flat field, the frames were processed with DAOPHOT II (Stetson 1987) and ALLSTAR inside MIDAS. Magnitude calibration was performed using the secondary photometric sequence (stars 2, 5, 6 and 7) established by Misselt (1996). The typical error on photometry is $\lesssim \pm 0.02$ mag. The internal magnitude differences of the comparison stars were nearly constant within the errors (see Fig. 3a,b): this confirms that only V1101 Aql is responsible for the observed variability. The observation times at mid-exposure were then converted to Heliocentric Julian Days for each magnitude measurement.

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* Based on observations obtained at the European Southern Observatory, La Silla, Chile and at the Osservatorio Astrofisico di Asiago, Italy.

Table 1. Journal of the observations reported in this paper

Imaging				
Date	Telescope	Filter or passband	Number of frames	Exp. times (minutes)
Sep. 10, 1993	ESO 0.9m Dutch	<i>B, V</i>	3,71	2,3
Jul. 13, 1996	Asiago 1.20m	<i>B, V, R</i>	2,32,2	3 to 10
Jul. 14, 1996	Asiago 1.20m	<i>V</i>	26	5 to 10
Spectroscopy				
Jun. 9, 1996	Asiago 1.80m	3500–6000	1	30

A single spectrum of the system was taken on June 9, 1996 with the 1.80m telescope of the Asiago Observatory, equipped with a 300 grooves mm^{-1} grating, (wavelength range: 3500–6000 Å), and a slit width of 2'' (resolution of 4.3 Å/pixel). This spectrum was extracted and reduced with IRAF, and calibrated in wavelength with a Fe–Ar lamp. Flux calibration was performed with the spectroscopic standard Feige 92.

3. Data analysis

3.1. Photometry

On September 10, 1993, the mean *V* magnitude of the star was 14.49, whereas on July 1996, it was $\langle V \rangle = 14.72$. The *B* – *V* color index remained constant, being 0.28 on September 1993 and 0.29 on July 1996; the *V* – *R* was 0.16 on the night of July 13, 1996.

The search for periodic light variations in the *V* band has been performed with a Discrete Fourier Transform (DFT) algorithm.

To reduce the noise in the DFT power spectrum, we have shifted the data points to a common magnitude level, computed by using the mean magnitude for each night. This could appear somewhat arbitrary, but is suggested by the fact that we are able to determine the mean luminosity of V1101 Aql in both parts of the observing run since we observed the object for more than one orbital cycle (see below) during each night.

The DFT power spectrum of the *V* data points (Fig. 1a) shows a series of peaks, the most prominent being at ~ 7 cycles day^{-1} ($=0.144193$ days, or $3^{\text{h}}.46$), with a slight prevalence on its one-day alias at ~ 6 cycles day^{-1} ($=0.166809$ days, or $4^{\text{h}}.00$). All the peaks belong to the same family of one-day aliases and are therefore produced by the sampling of one single real periodicity of the *V* lightcurve. We therefore applied the CLEAN algorithm (Roberts et al. 1987) to discriminate the modulation responsible for producing the alias series. The results of this analysis, reported in Fig. 1b, suggest as real period the $3^{\text{h}}.46$ modulation. As a further check, we subtracted this periodicity with appropriate amplitude and phase to the *V* data set and computed a new DFT (Fig. 2a): its power spectrum peaks at ~ 7 cycles day^{-1} , but the power of the peak is lower than that of Fig. 1a. We followed the same procedure using the $4^{\text{h}}.00$ modulation (Fig. 2b): in this case, the DFT power spectrum is

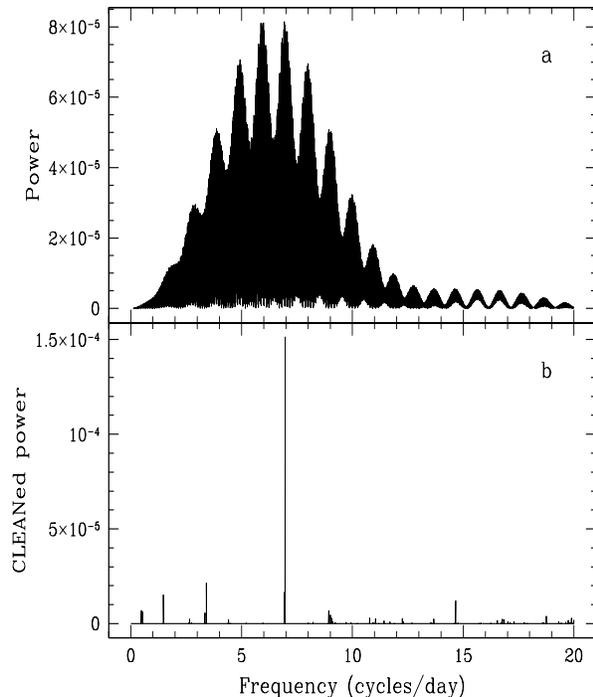


Fig. 1. **a** DFT and **b** CLEANed power spectra of the *V* data set. The strongest peak in the lower panel corresponds to 0.1442 days ($=3^{\text{h}}.46$)

the same of Fig. 1a but the peaks had their spectral power doubled. Finally, we applied two least squares best-fit methods to the *V* data points, i.e. the Sterken's (1977) and the Schöneich–Lange's (1981) algorithms, and both methods indicate as best fit the periodicity at 0.144 days.

The *V* lightcurves folded with the $3^{\text{h}}.46$ and $4^{\text{h}}.00$ are shown in Fig. 3a,b, respectively.

All the images taken at La Silla under photometric conditions (seeing $\lesssim 1''.5$) seem to reveal around V1101 Aql the presence of an asymmetric nebulosity, best seen in *V* (Fig. 4a) rather than in *B* (Fig. 4b). This feature was not detected in the frames obtained on July 1997 frames due to poor seeing conditions.

To better disentangle the faint nebulosity from the background, we have designed, through DAOPHOT II, the average PSF using nearby field stars, and then we have subtracted it to

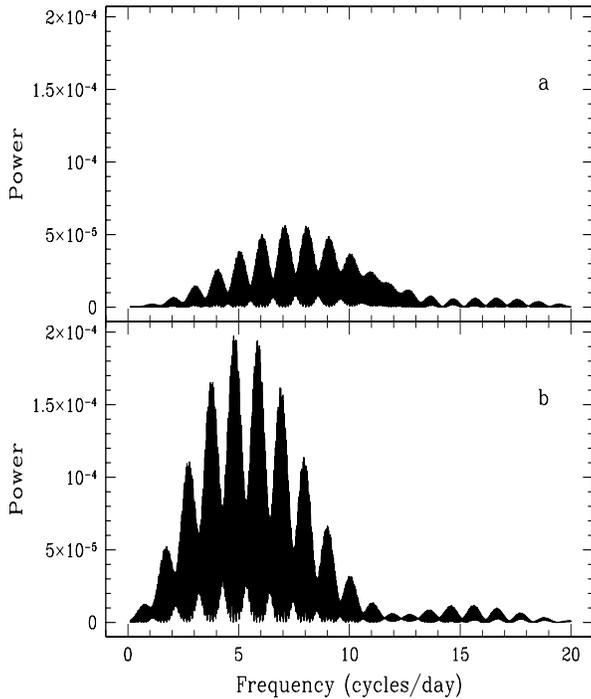


Fig. 2a and b. DFT power spectra of the V data set after the subtraction of **a** the $3^{\text{h}}.46$ and **b** of the $4^{\text{h}}.00$ periodicities, respectively. While in the former case the power of the peaks decreases, in the latter it doubles with respect to Fig. 1a

the image of V1101 Aql. The result is presented in Fig. 5a,b: an underlying bow-shaped nebulosity is visible in V (Fig. 5a) and in B (Fig. 5b).

3.2. Spectroscopy

The spectrum secured on June 9, 1996, is shown in Fig. 6. We can notice the Balmer lines in absorption with a small emission core and, perhaps, the presence of a noisy emission of He II at 4686 \AA . Fluxes and EW's of these lines are reported in Table 2. H_{α} is outside the spectral range as well as the absorption lines and bands of the secondary, possibly present at longer wavelengths.

The NaD interstellar absorption at 5890 \AA is also present. This line might be possibly contaminated by the presence of He I $\lambda 5876$ in absorption; a double gaussian fit yields $\text{EW}_{\text{NaD}} = 1.2 \text{ \AA}$, which corresponds, according to the relation by Barbon et al. (1990), to a $E(B - V) \sim 0.3 \text{ mag}$. This value is higher than that ($\approx 0.1 \text{ mag}$) found by Pastukhova & Shugarov (1994) using the $(U - B)/(B - V)$ color ratio.

4. Discussion

4.1. The orbital period and the distance to V1101 Aql

We can interpret the modulation in the V lightcurve of V1101 Aql as due to the orbital motion of the secondary star around the hot WD (see Warner 1995 and references therein). The UV illumination from the disk and the WD heats the inner face of the

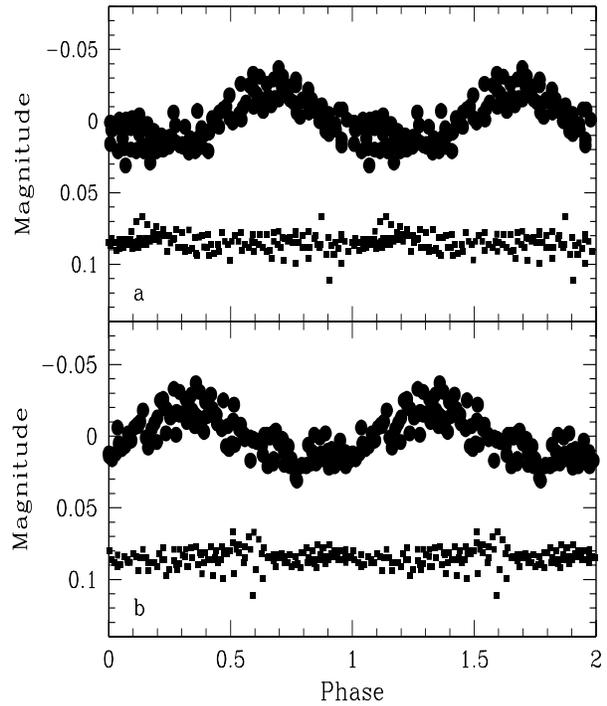


Fig. 3a and b. V lightcurves (filled dots) folded with **a** $P_{\text{orb}} = 3^{\text{h}}.46$ and **b** $P_{\text{orb}} = 4^{\text{h}}.00$. Data points have been rescaled to a common zero magnitude level. Phases are arbitrarily referred to $\text{JD} = 0.00$. In both panels the mean of the internal differences among the comparison field stars is reported (filled squares), folded with the two periodicities and shifted of -0.18 mag for clarity

Table 2. Fluxes (in units of $10^{-15} \text{ erg cm}^{-2} \text{ s}^{-1}$) and EW's (in \AA) of the lines detected in the spectrum of Fig. 6. If an emission core is present, emission and absorption fluxes and EW's are both reported

Spectral line	Flux		EW	
	em.	abs.	em.	abs.
H_{β}	7.2	18.7	1.2	2.9
H_{γ}	11	68.9	1.6	7.9
H_{δ}	—	67.9	—	6.8
H_{ϵ}	3.1	58.0	0.38	5.9
H_{ζ}	4.9	81.4	0.62	7.9
He I $\lambda 5876$	—	1.8	—	0.46

secondary and makes it brighter than the other side. This, combined with the orbital motion, produces a sinusoidal lightcurve with the maximum in correspondence of the superior conjunction of the secondary. The small amplitude of the modulation also indicates that eclipses are absent, and thus that the inclination of the system must be small.

The periodic variation of $\sim 3^{\text{h}}.5$ is consistent with the mean orbital period of Z Cam stars, which is always more than 3 hours (Warner 1995). DNe with these periods have early-mid M type secondaries (Ritter & Kolb 1995) with masses around $0.3\text{--}0.4 M_{\odot}$.

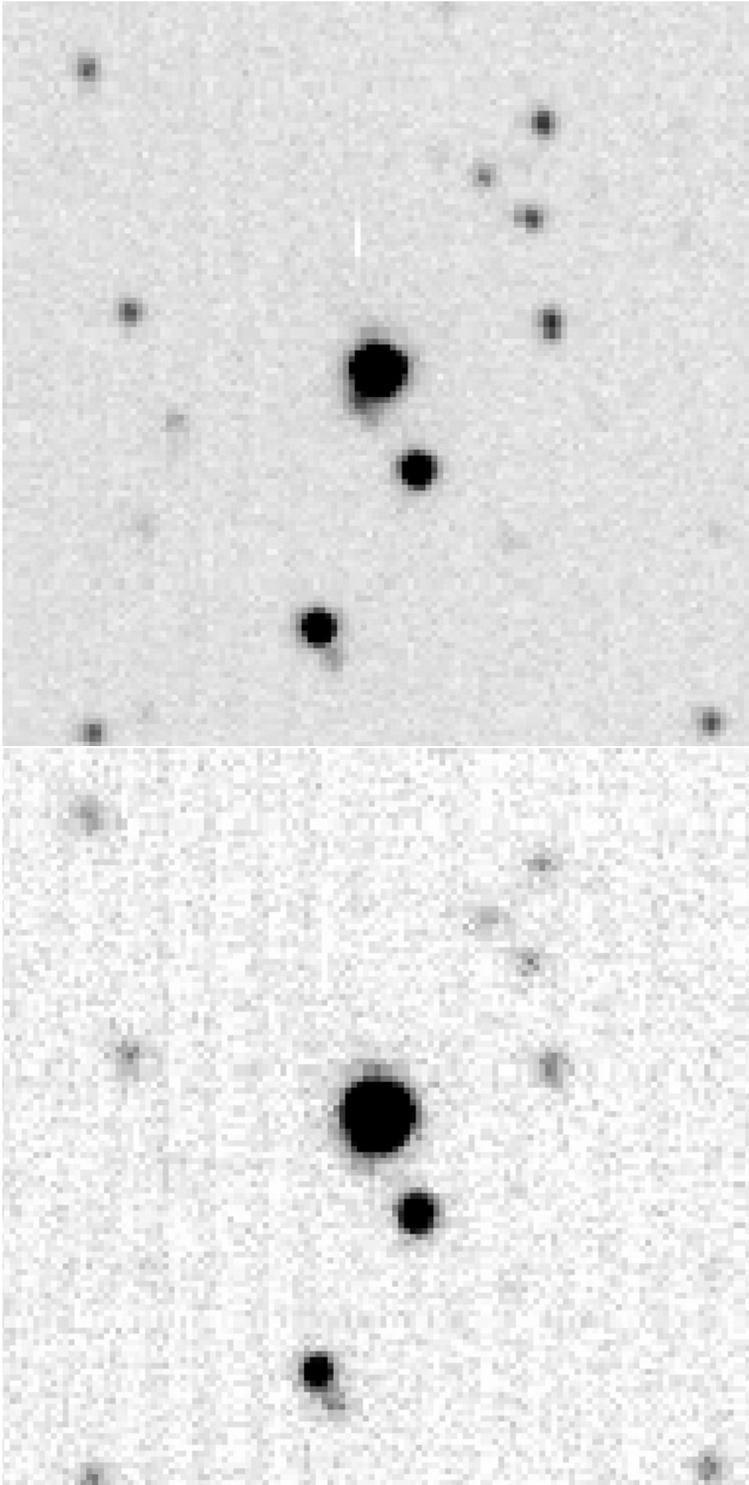


Fig. 4. **a** V and **b** B images of the asymmetric nebulosity around V1101 Aql (exposure times: 2 and 3 minutes, respectively). The field is $0'.75 \times 0'.75$; north is at top and east is on the right

This orbital period determination can also lead us to attempt an estimate of the absolute magnitude M_V of the system and hence its distance. According to Warner (1995), Z Cam DNe with orbital periods around $3^h.5$ should have $M_V \sim 6.5 \pm 0.3$ (1σ) at standstill. If V1101 Aql has, at standstill, $V \sim 14.7$, (we assume the magnitude at quiescence to be $V \sim 17$; see Pastukhova & Shugarov 1994) we derive, after taking into ac-

count the interstellar absorption in the V band, a distance of $\sim 300 \pm 50$ pc. This value is about one half the previous estimate given by Pastukhova & Shugarov (1994) and, together with the galactic latitude $b^{\text{II}} = -10^\circ.16$, implies a height on the galactic plane $z \sim 55$ pc.

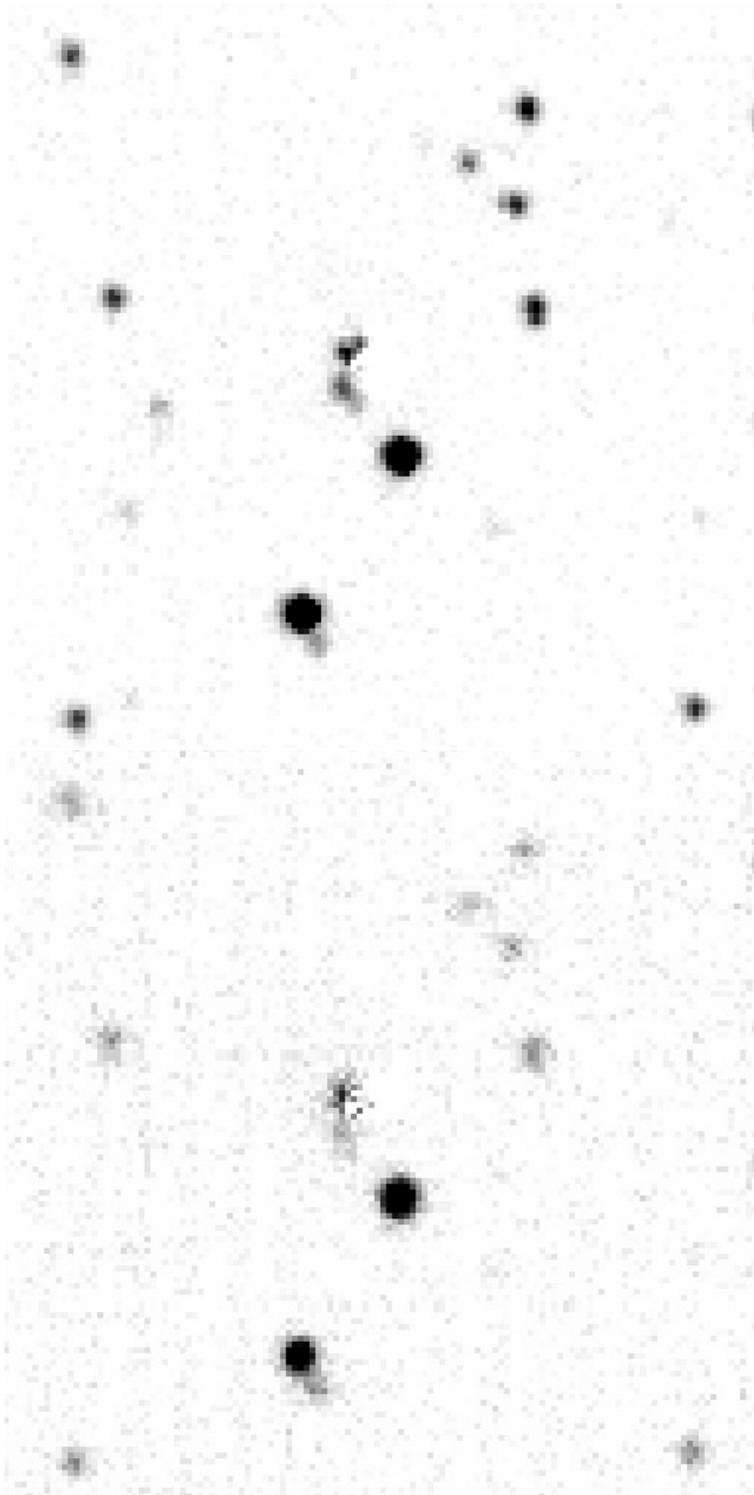


Fig. 5a and b. The same as Fig. 4, but after the subtraction of V1101 Aql. The nebulosity appears brighter and more characterized **a** in the V band than **b** in the B

4.2. The spectrum and the nebulosity

The spectrum presented in Fig. 6 shows the presence of absorption Balmer lines filled in with emissions, thus supporting, in agreement with Pastukhova & Shugarov (1994), that this system might be a CV.

Concerning the asymmetric nebulosity around V1101 Aql, we note that it is more visible in V than in B (see Fig. 5a,b). Actually, simple aperture photometry gives $V = 18.64 \pm 0.05$ and $B - V = 0.6 \pm 0.1$. The total angular size of the nebulosity is ~ 6 arcsecs; this, together with our distance estimate, leads to a linear size of $\approx 10^{16}$ cm.

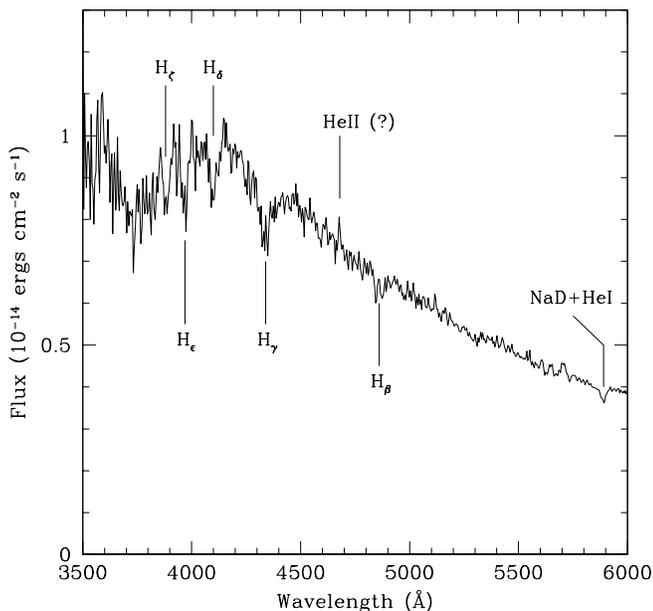


Fig. 6. Spectrum of V1101 Aql acquired on June 9, 1996. No correction for interstellar absorption has been applied. The major features indicated here are described in the text

5. Conclusions

We observed long-term variations of V1101 Aql in V magnitude, very likely triggered by disk activity. We have detected $P = 3^{\text{h}}.46$ as possible orbital period of V1101 Aql, with an important alias at $4^{\text{h}}.00$.

The secondary of a DN with such an orbital period should have $M_V \sim 10$ (Warner 1995). This means that the V emission of the UV-heated secondary star is about 25 times lower than that of the whole system; i.e., any variation coming from the secondary could modify the total V luminosity of the system by a factor $\lesssim 1/25$ at most, corresponding to a full amplitude fluctuation of $\lesssim 0.04$ mag. This is smaller than the amplitude (~ 0.1 mag) of the modulation in Fig. 3a,b, then indicating an extra contribution of ~ 0.06 mag due to the UV heating of the inner face of the secondary.

The discovery of a Z Cam-type DN with an orbital period just above to the 3-hr upper limit of the Period Gap of CVs is consistent with the presence of a sharp ‘luminosity bump’, in the period–absolute magnitude plane of CVs between 3 and 3.5 hr as suggested by Zangrilli et al. (1997).

Our results then, complemented with data gathered from literature, allow us to set the standstill magnitude of this Z Cam star close to $V \sim 14.7$ and to estimate for this system a distance of about 300 pc.

The spectrum, taken during standstill, seems to confirm the cataclysmic binary nature of V1101 Aql, though the discovery of an asymmetric nebulosity, which seems to be associated to the object, does not rule out the possibility, already pointed out by Downes et al. (1995), that V1101 Aql could be a Herbig Ae/Be star rather than a CV. In this case, the presence of an

associate nebulosity around the object is fully consistent with such a classification. However, due to the relatively poor seeing conditions ($\sim 1''.5$), we cannot rule out that the image of V1101 Aql has been contaminated by a background object.

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