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THE LONG-TERM BINARY SYSTEM VV Cep

POLLMANN, E.¹; BENNETT, P. D.²; HOPKINS, J. L.³

¹ International Working Group ASPA, Emil-Nolde-Str. 12, 51375 Leverkusen, Germany, e-mail: ernestospec@hotmail.de

² 7812 West Clayton Drive, Phoenix, Arizona USA, e-mail: phjeff@hposoft.com

³ Department of Astronomy & Physocs, Saint Mary's University, Halifax, NS B3H 3C3, e-mail: pben-
nett@ap.smu.ca

1 Introduction

VV Cep is an eclipsing binary with a period of about 20.4 years that is comprised of an M2Iab primary star and an early B secondary star. A preliminary orbit was announced by Harper & Christie (1933), and McLaughlin (1934) described the behavior of the wide emission lines of Hydrogen and those of ionized Calcium CaII, the H & K lines, which were divided by sharp absorption and shifted in velocity, and presented the V/R (violet to red component) ratio for the Hydrogen Balmer lines. In October 1936, McLaughlin (1936) announced that the hot star in VV Cep had been eclipsed, establishing the system as an eclipsing binary. Goedicke (1939a,b) carried out the first detailed spectroscopic analysis of this system. Wright (1977) inferred the existence of intermittent mass transfer and a H α emitting disk. Kawabata et al. (1981) and Moellenhoff et al. (1978, 1981) further described what appears to be an accretion disk around the B star.

The dimension of the disk around the Be star was determined by Peery (1965) to be less than 1/18 of the diameter of the M supergiant's photosphere and according to investigations of Hutchings & Wright (1971) it is not spherically symmetrical, but rather in the direction of the stars equator more dense as in the case of a normal Be star. This seems to be quite logical in view of the remarkable stream of gas in this system.

Long-term monitoring of the intensity variations of the V and R emission peaks (the so-called V/R ratio) delivers important information about the peak strength as measure for the mass and/or density of the gas in the disk, expressed as equivalent width EW of the emission, and the direction of movement of the corresponding gas region within the disk (Figure 1). The violet and the red (V and R) components into which the emission line of the VV Cep spectrum is split can be linked to the radiation of the gas disk around the Be star. Due to its counterclockwise rotation around the central star, in relation to the line of sight of the observer, it results in a blueshift by moving towards the observer (V component) and a redshift by moving away (R component) from the observer.

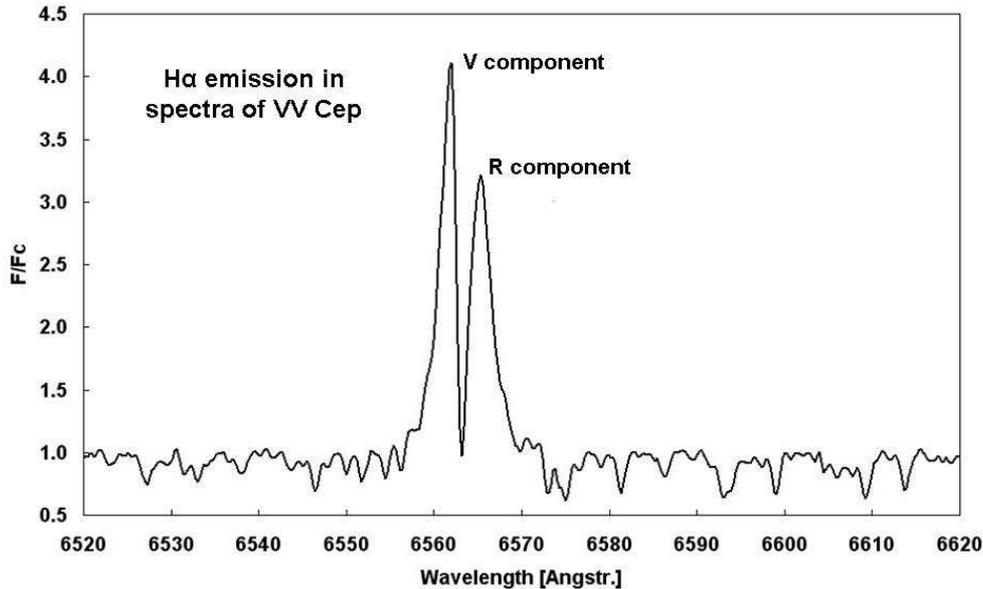


Figure 1. Representative spectrum of VV Cep with its typical H α emission splitted into two components, the *V* (blueshifted) and *R* (redshifted) components.

2 Goals & Motivation

According to investigations of Wright (1977) the source of the central absorption in the profile of the H α emission line is caused by the transferred and absorbed material between observer and shell of the Be star. Because of the mass transfer from the M supergiant towards its Be star companion in the VV Cep system, the presence of the strong H α emission can be well explained as being created in the outer shell of the companion. The gas stream coming from the M supergiant spirals around the Be star has to be less dense in the polar regions than around the equator.

Long-term spectroscopic observations clearly outside the eclipses of 1956/57 and 1976–78 have only been published by Wright (1977), Hack et al. (1992) and Möllenhof & Schaifers (1981). These provide by the H α V/R variation for the first time a rough explanation about a possible quasi-cyclic behavior of the structure of density of the Be star disk, but although these research had covered almost the complete orbital phase by measurements, the number number of their observations is not sufficient for a reliable analysis.

3 Observations

The H α emission line is the only indication of the presence of the disk. Figure 2 shows monitoring of the H α equivalent width (EW) since July 1996 until today. The eclipse of the emitting Be star disk by the M supergiant started in March 1997 (JD 2450511) and ended 673 days later. The period from the beginning of the disk coverage (contact 1) up

to coverage end (contact 2) lasted 128 days, from first appearance of the disk (contact 3) up to the complete visibility (contact 4) 171 days. The full eclipse period was 373 d. Saito et al. (1980) observed the 1976–78 eclipse with *UBV* photometry. In that case, totality lasted about 300 days, significantly shorter than the latest eclipse, and the entire event required about 1000 days.

While after the ephemeris of Gaposchkin (1937) ($E_{\min} = \text{JD } 2421070 + 7430 E_0$) the mid-point of the eclipse was expected at JD 2450790, the time determined from Figure 2 is JD 2450827, thus with a delay of 37 d. Graczyk et al. (1999) ~~against~~ determine the mid-point of the eclipse 1997/99 from *UBV* photometry at approximately JD 2450855, thus with 65 d delay. Leedj arv et al. (1999) obtained a similar value of 68 d compared with the ephemeris of Gaposchkin (1937) likewise from *UBV* photometry, as well as optical spectroscopy.

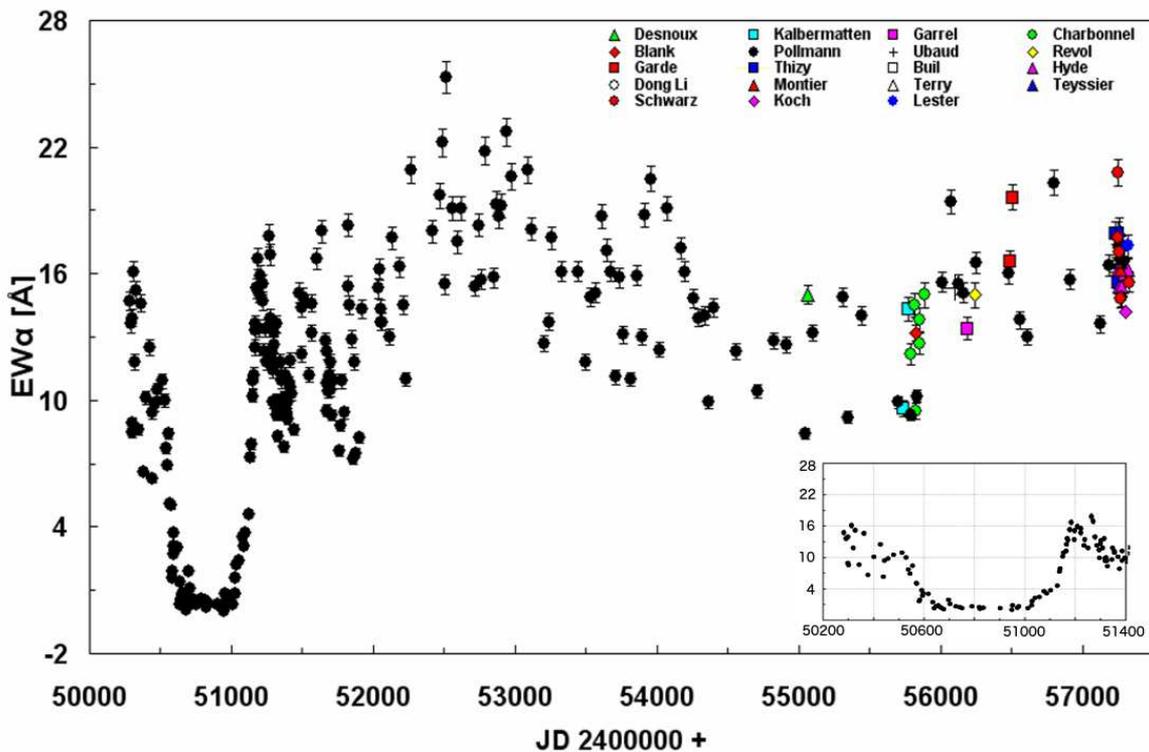


Figure 2. Long-term monitoring of the $H\alpha$ equivalent width since 1996 until now.

Perhaps the most interesting feature of Figure 2 is the behavior of $H\alpha$ emission outside of eclipse. Large fluctuations in EW occurred continuously over about 15 years. A possible explanation might be a variable mass accretion from the M supergiant to the accretion disk as described by Wright (1977) and Stencel et al. (1993). But from the findings of this observation material alone it is not yet possible to judge to what extent these fluctuations are due exclusively on varying contributions by mass transfer between the two components or from the disk itself, or both together.

The amateur community contribution to the EW and V/R monitoring from July 1996 to November 2015 involved 20 observers of the ARAS group¹. They used 0.2 m to 0.4 m telescopes with long-slit (in most cases) and  echelle spectrographs with spectral resolving

¹<http://www.astrosurf.com/aras>

power from $R = 1000$ to $R = 22000$. Data reduction was performed using MaxIm-DL 3.06 (Diffraction Limited, Sehgal Corp.) for Pollmann’s data, while the most other amateur’s data were reduced with software packages developed for amateur spectrographs, such as VSpec3 and IRIS34. Spectral line parameters were measured with the spectral classification software package MK325. No systematic difference in the V/R ratios or the $H\alpha$ line equivalent widths were found between professional and amateur data.

Measurements of the V/R ratio of $H\alpha$ by Kawabata et al. (1981) during the 1976–1978 eclipse may indicate that the distribution of matter in the disk is not homogeneous. The stronger violet emission peak may be formed by greater density in the left side of the disk which rotates counterclockwise. Different strengths of the violet and red peaks during the 1997–1999 eclipse can be inferred from the ingress and egress branches of the plot in Figure 2. During ingress, with the disk’s left side hidden and its right side in view, on average $EW = 11\text{\AA}$. At egress, with the left side emerging from eclipse, $EW = 17\text{\AA}$.

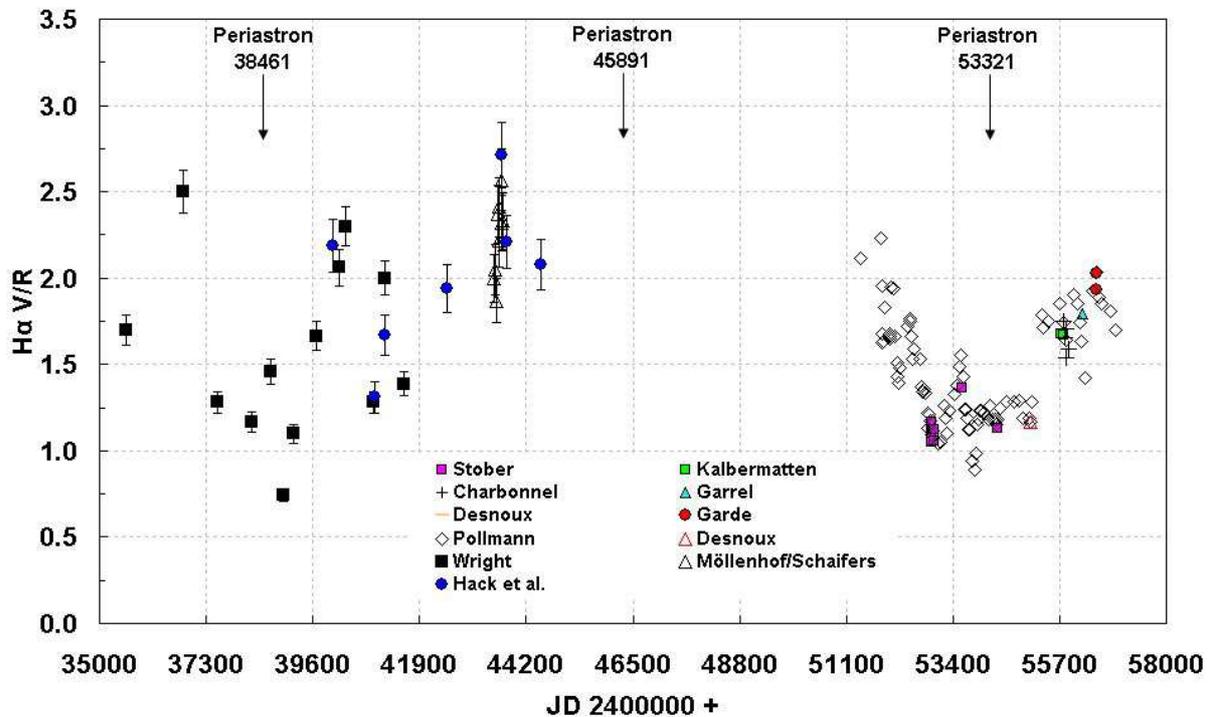


Figure 3. Long-term monitoring of the V/R ratio outside the eclipses of 1956/57 and 1976–78 by Wright (1977), Hack et al. (1992) and Möllenhof & Schäifers (1981) combined with data of the author and the ARAS group since November 2000 (JD 2451413).

4 Results & Discussion

The long term monitoring of the variations in intensity of both components (so called V/R relation) results in important information about:

1. emission peak intensity as a measure of the mass or density of the gas in its shell expressed in equivalent width EW of the emission,
2. the direction of motion of the gas shell’s region.

Since November 2000 (JD 2451413) the V/R data of the ARAS group with good density of observations could be added (Figure 3). It became evident how dramatically the V/R relation is changing. The combined data confirm clearly the time evolution of the V/R relation. The V/R variation in Figure 3 asks for a more detailed evaluation about its periodic behavior.

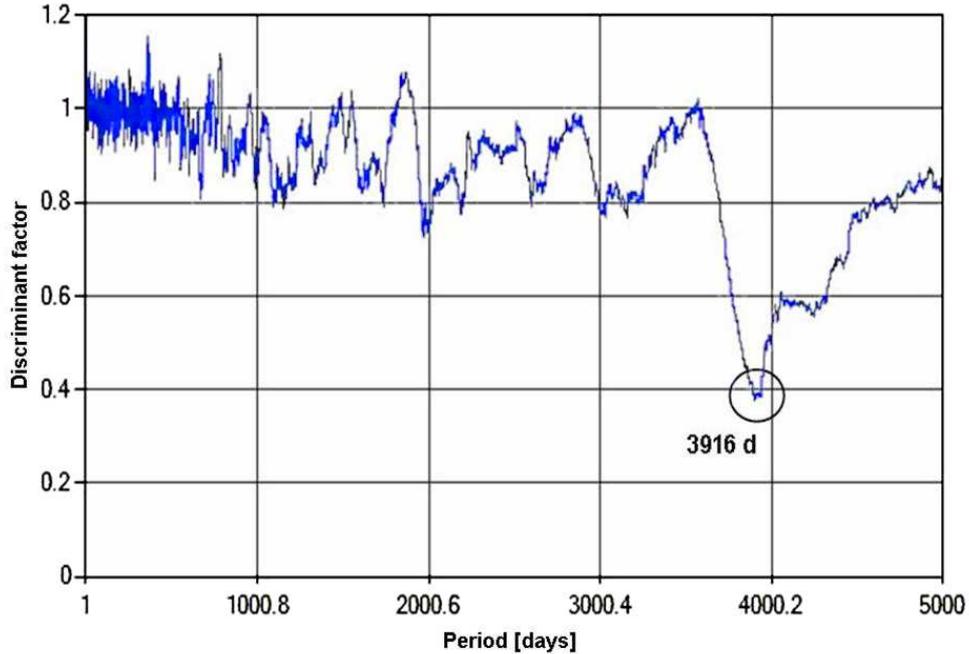


Figure 4. PDM period analysis of all V/R data in Fig. 3

Figure 4 shows a PDM (phase dispersed minimization) (Stellingwerf 1978) period analysis of the entire V/R data set in Figure 3, with a dominant period of 3916 d. Figure 5 demonstrates the sine fit of this period to the V/R time behavior. Figure 5 shows that only the data beginning at JD 2451413 and later are well fit, likely due to the low observation frequency of the time section from JD 2435572 to 2444511 (Möllenhof & Schaifers, Hack et al. 1992., Wright 1977). In Figure 6 the phase diagram of the 3916 d period is shown. It seems to be the half of the orbital period, approximately 7450 d. A possible explanation for that behavior might be a tidal effect of the M supergiant on the Be star disk during each periastron.

A further relevant issue has to be, whether there are V/R variations independent of the orbital period. Figure 7 shows the subtraction (residuals) of the 3916 d period from the V/R time series (section JD 2451413 to JD 2456917, the amateur data) and its PDM analysis with the dominant period of 988 d. Figure 8 demonstrates the sine fit of this period to the V/R behavior of the corresponding time section. Finally in Figure 9 the corresponding phase diagram of the found 988 d period is shown. This is the first time, that amateur observations provide evidence of periodic density variations of the Be stars disk in VV Cep. The results of both period analyses are shown in Table 1.

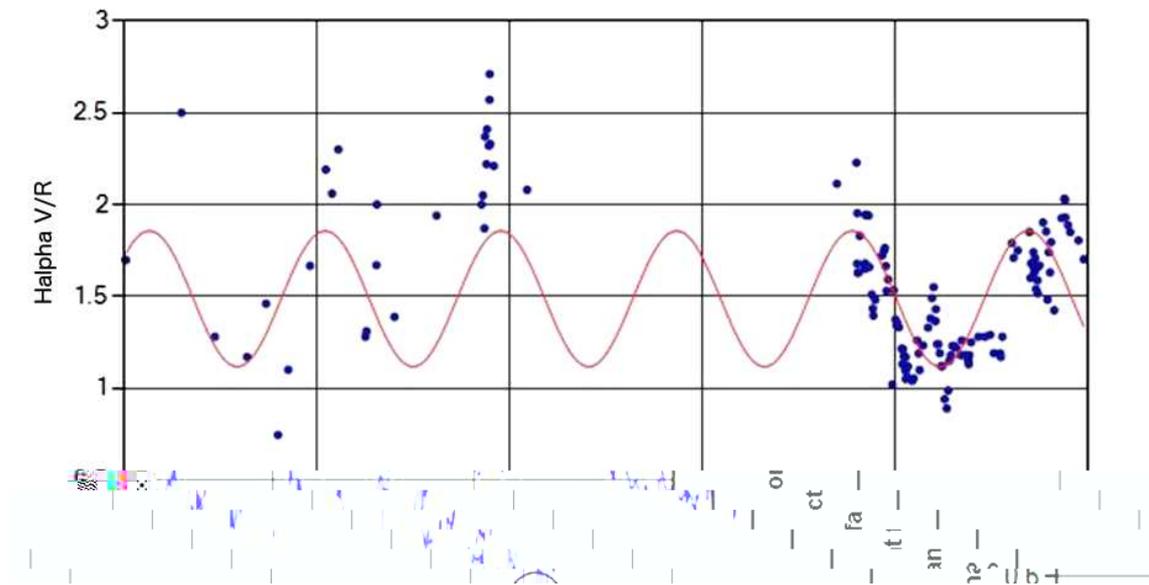


Figure 5. Period-adapted time series of all V/R data in Fig. 3

Figure 6. Phase diagram of the PDM period of 3916 days (it seems to be the half of the orbital period).

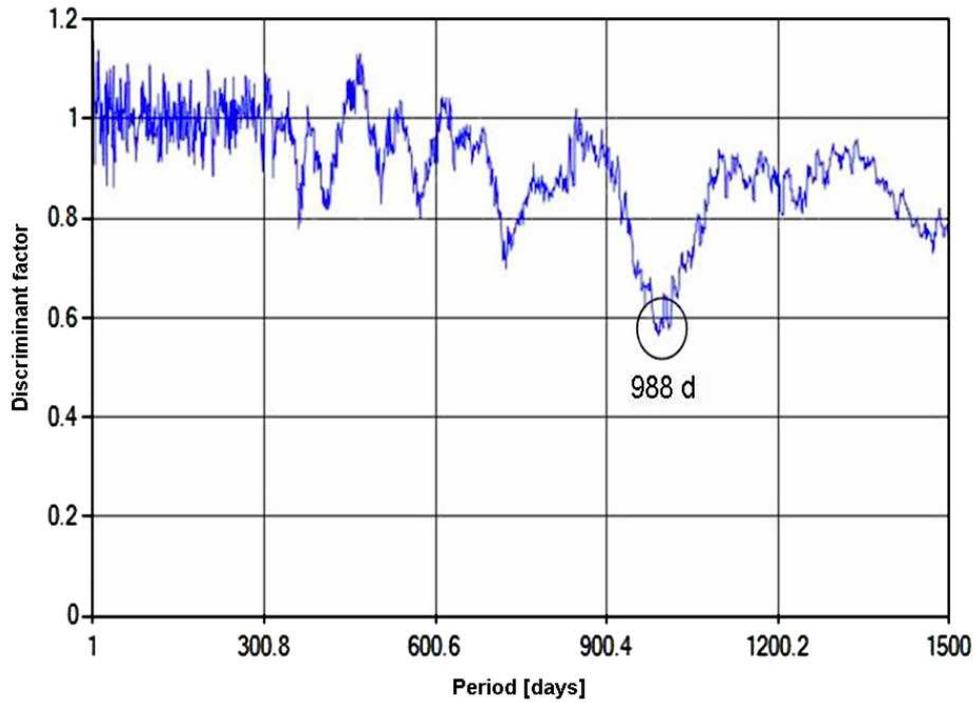


Figure 7. Subtraction (residuals) of the 3916 d period from the V/R time series (section 2451413 to 2456917) and its PDM analysis with the dominant period of 988 days.

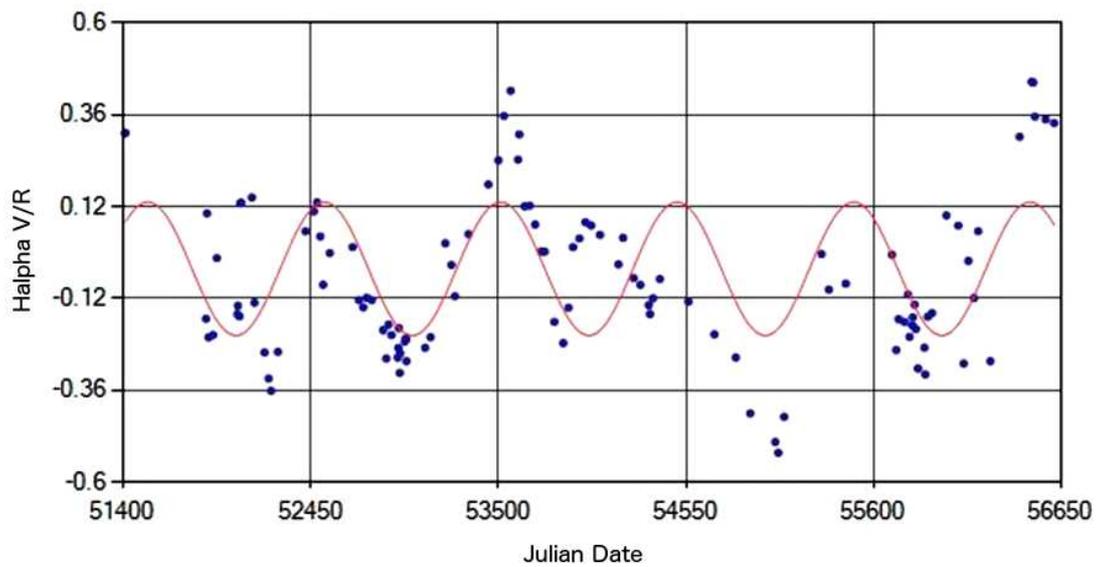


Figure 8. Adjustment of the 988 d period to the corresponding V/R time series.

Table 1: Period analysis of VV Cep. Second line is the analysis of the residual after subtraction of the orbital period.

V/R Ephemerides	Period [d]	Amplitude	T_0 [d]	RMS [d]
(Half) orbital period	3916 (± 44)	0.37 (± 0.03)	2435116 (± 192)	0.29
Residuals	988 (± 15)	0.17 (± 0.02)	2451290 (± 45)	0.16

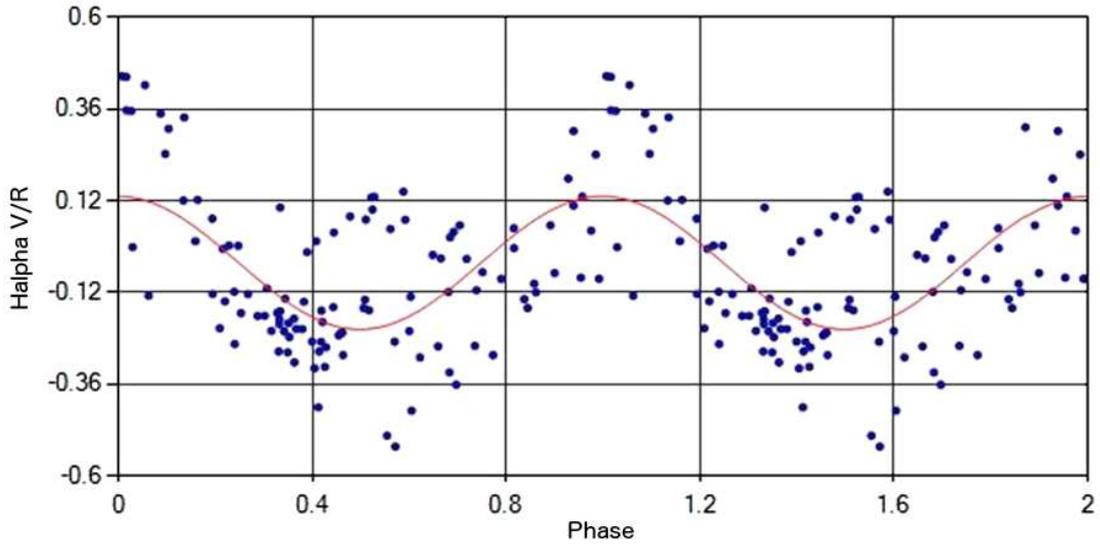


Figure 9. Phase diagram of the found 988 day period.

The next eclipse in 2017–18 provides excellent opportunities to investigate the binary system VV Cep in very different aspects. It has been created a world-wide campaign in the sense of cooperation of the professional astronomy and the amateurs, in order to collect data in the photometrical and spectroscopical field.

The web page <http://www.ap.smu.ca/~pbennet/vvcep/main.html>, designed by P. Bennet, will give detailed announcements of the different phases of this important eclipsing event.

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