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# THE LONG-TERM BINARY SYSTEM VV Cep

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## 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 in 1933 by Harper & Christie (1936), and McLaughlin (1934) described the behaviour of the wide emission lines of Hydrogen and those of ionized 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, McLauglin (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 an H$\alpha$ emitting disk. Kawabata et al. (1981) and Moellenhoff & Schaifers (1978, 1981) further described what appeared to be an accretion disk around the B star.

The dimension of the disk around the Be star was determined by Peery (1966) 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 is more dense in the direction of the stellar equator, 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.

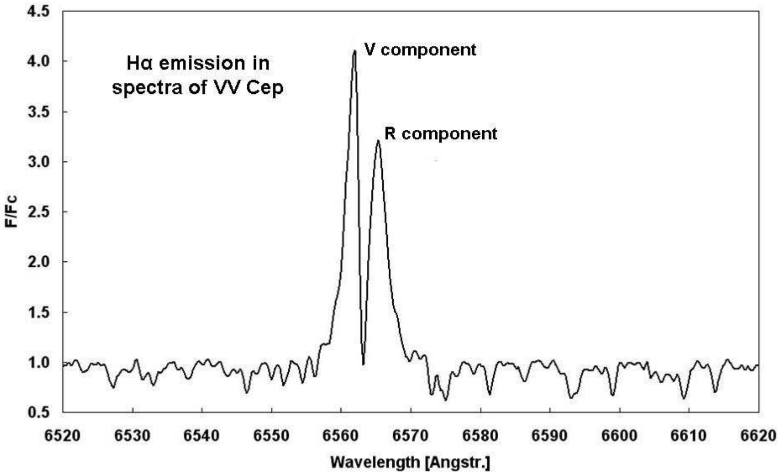

**Figure 1.** Representative spectrum of VV Cep with its typical H$\alpha$ emission splitted into two components, the $V$ (blueshifted) and $R$ (redshifted) components.

## 2 Goals and motivation

According to investigations of Wright (1977), the source of the central absorption in the profile of the H$\alpha$ 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$\alpha$ emission can be well explained as being created in the outer shell of the companion. The gas stream coming from the M supergiant spiralling 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 Moellenhoff & Schaifers (1981). H$\alpha$ $V/R$ variation from these spectra provide for the first time a rough explanation about a possible quasi-cyclic behavior of the structure of density of the Be star disk, however, even though these data had covered almost the complete orbital phase by measurements, the number of their observations is insufficient for a reliable analysis.

## 3 Observations

The H$\alpha$ emission line is the only indication of the presence of the disk. Figure 2 shows monitoring of the H$\alpha$ 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) ($E_{\rm min}$ = 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) determined the mid-point of the eclipse 1997/99 from $UBV$ photometry at approximately JD 2450855, thus with 65 d delay. Leedjärv 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.

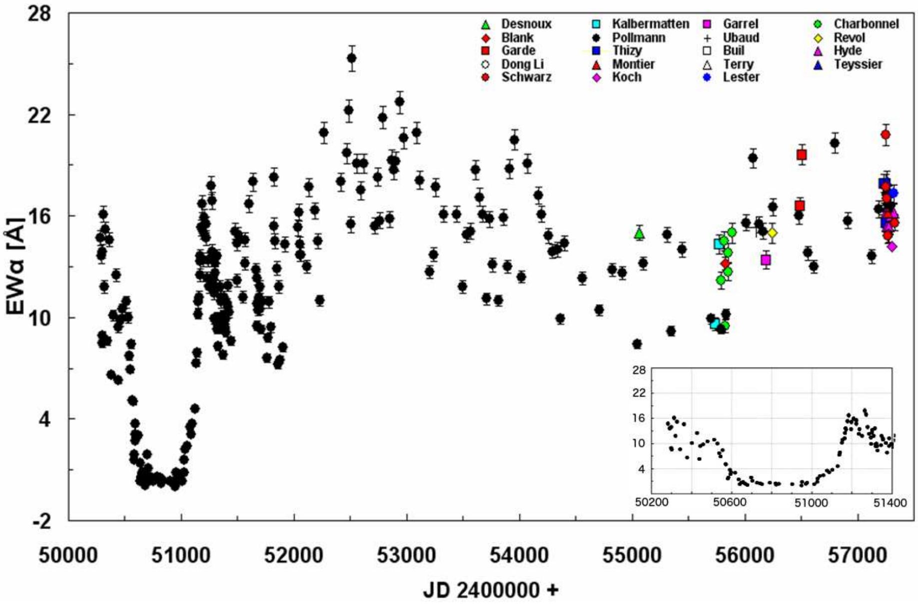

**Figure 2.** Long-term monitoring of the Hα equivalent width since 1996 until now.

Perhaps the most interesting feature of Figure 2 is the behavior of Hα 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). However from the findings of this observation material alone, it is not yet possible to judge to what extent these fluctuations are due exclusively to varying contributions by mass transfer between the two components or from the disk itself, or both together.

The amateur community's contribution to the EW and $V/R$ monitoring from July 1996 to November 2015 involved 20 observers of the ARAS group[1]. They used 0.2 m to 0.4 m telescopes with long-slit (in most cases) and échelle spectrographs with spectral resolving 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 most other amateur 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 Hα line equivalent widths were found between professional and amateur data.

Measurements of the $V/R$ ratio of Hα 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 large density in the left side of the disk

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[1] `http://www.astrosurf.com/aras`

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 = 11Å. At egress, with the left side emerging from eclipse, EW = 17Å.

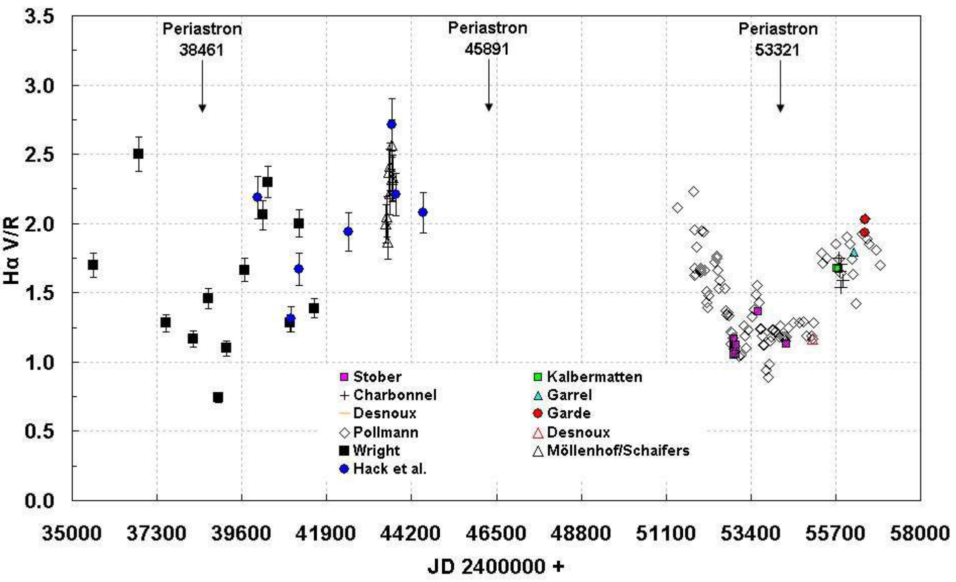

**Figure 3.** Long-term monitoring of the $V/R$ ratio outside the eclipses of 1956/57 and 1976–78 by Wright (1977), Moellenhoff & Schaifers (1981), Hack et al. (1992) combined with data of the author and the ARAS group since November 2000 (JD 2451413).

## 4 Results and 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.

A large density of $V/R$ data from the ARAS group has been added since November 2000 (JD 2451413; Figure 3).These additional data points demonstrate 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 shows a PDM (phase dispersion 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 behaviour. 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 (Wright 1977, Moellenhoff & Schaifers 1981, Hack et al. 1992). In Figure 6, the phase diagram of the 3916 d period

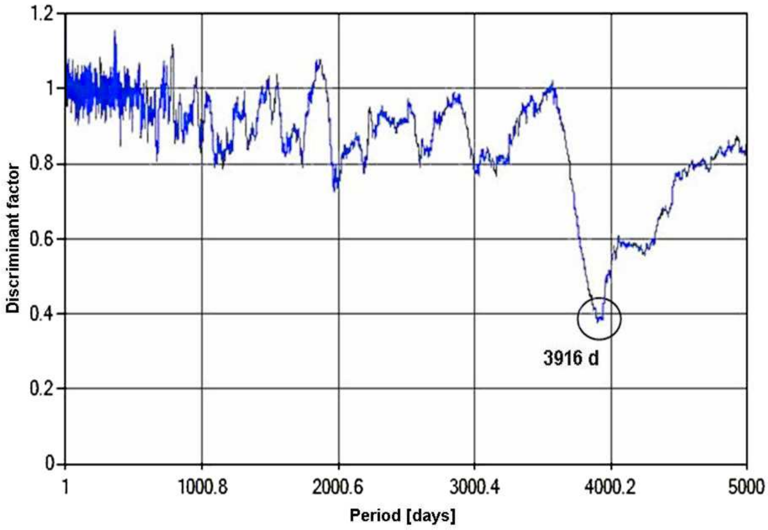

**Figure 4.** PDM period analysis of all $V/R$ data in Fig. 3

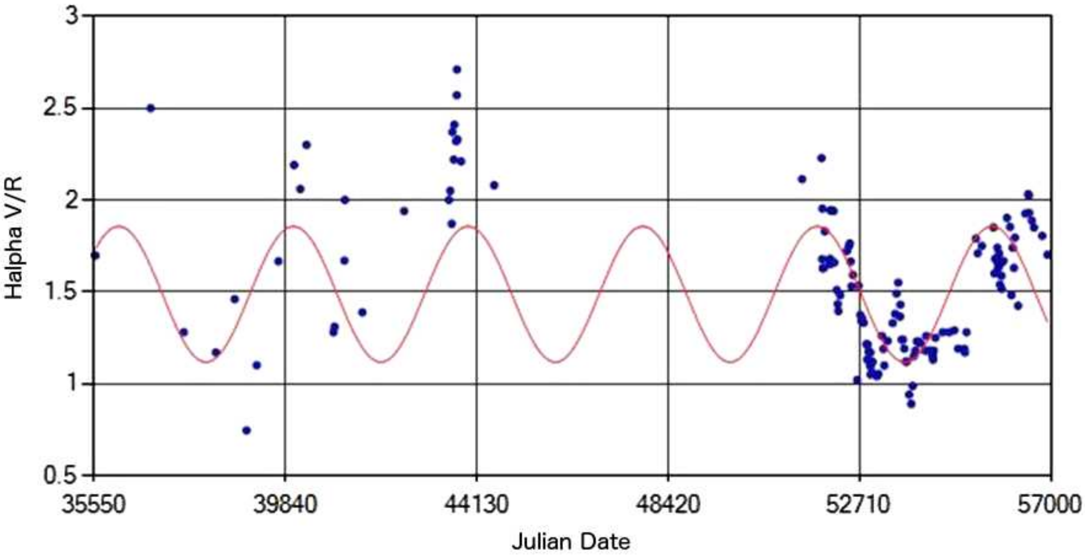

**Figure 5.** Period-adapted time series of all $V/R$ data in Fig. 3

is shown. It seems to be the half of the orbital period, approximately 7450 d. A possible explanation for that behaviour might be a tidal effect of the M supergiant on the Be star disk during each periastron.

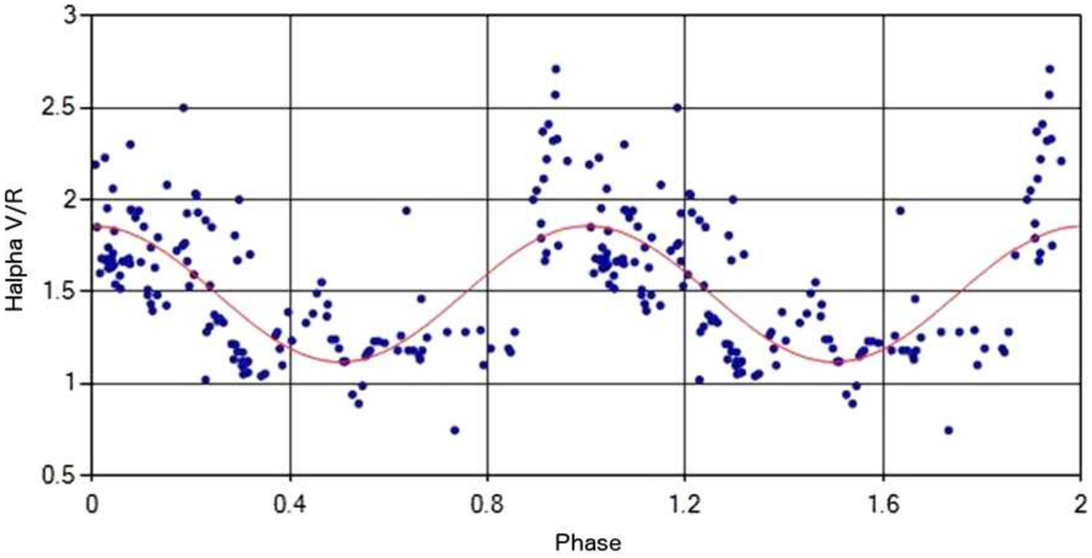

**Figure 6.** Phase diagram of the PDM period of 3916 days (it seems to be the half of the orbital period).

A further relevant issue is 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 $V/R$ behaviour 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 a Be star disk in VV Cep. The results of both period analyses are shown in Table 1.

Table 1: Period analysis of VV Cep. Second line is the analysis of the residual after subtracting 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 |

The next eclipse in 2017–18 provides excellent opportunities to investigate the binary system VV Cep in very different aspects. This event has triggered a world-wide campaign, resulting in cooperation between both professional astronomy and amateurs, in order to collect photometric and spectroscopic data.

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

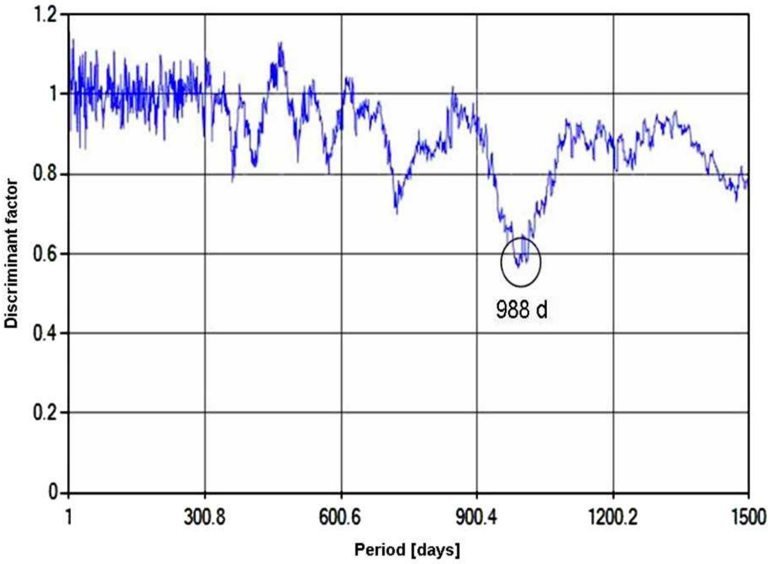

**Figure 7.** Subtraction (residuals) of the 3916 d period from the $V/R$ time series (section 2451413 to 2456917) and its PDM analysis with the dominant period of 988 days.

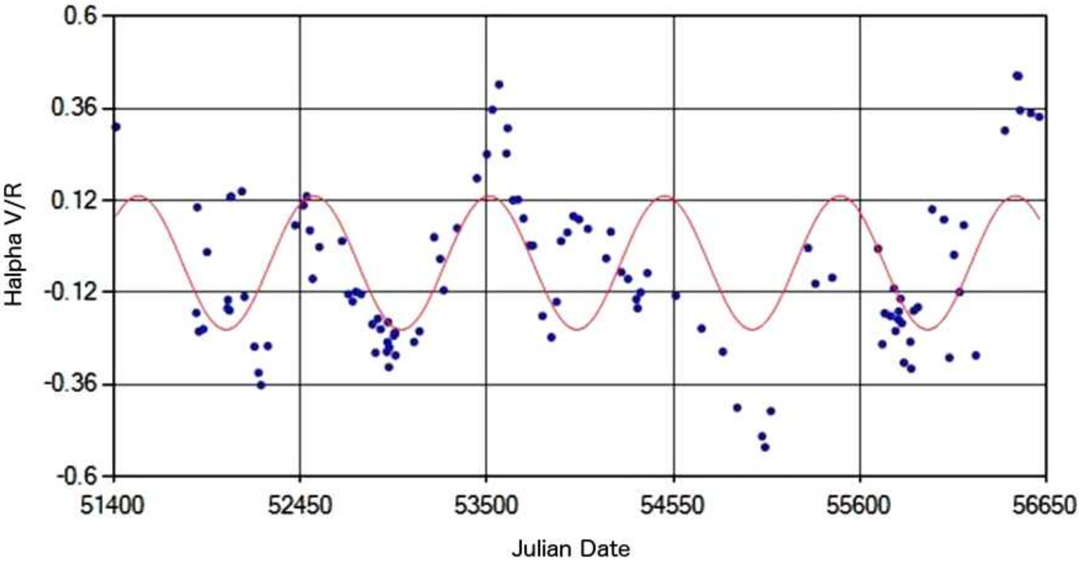

**Figure 8.** Adjustment of the 988 d period to the corresponding $V/R$ time series.

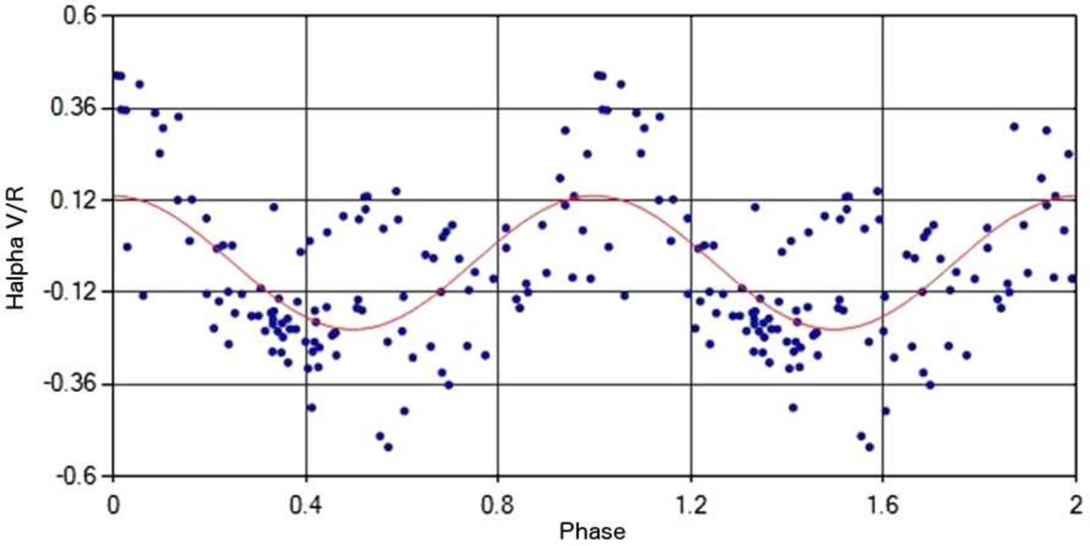

**Figure 9.** Phase diagram of the found 988 day period.

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