COMMISSIONS G1 AND G4 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS
Volume 62 Number 6198 DOI: 10.22444/IBVS.6198

Konkoly Observatory
Budapest
24 February 2017

HU ISSN 0374 – 0676

A TIME SERIES OF BV PHOTOMETRY AND Hα EMISSION FLUXES OF THE ECLIPSING BINARY VV Cep

POLLMANN, E.[1]; VOLLMANN, W.[2]; BENNETT, P.D.[3]

[1] Emil-Nolde Straße 12, 51375 Leverkusen, Germany

[2] Dammäckergasse 28/D1/20, A-1210 Wien, Austria

[3] Department of Physics & Atmospheric Science, Dalhousie University, Halifax, Nova Scotia, Canada

Introduction

The VV Cep binary is a red supergiant of mass 15–20 $M_{\odot}$, with a hot, presumably main-sequence, early B-type companion of comparable mass. The two stars are sufficiently well separated that Roche lobe mass transfer does not occur at present, and given the high orbital eccentricity ($e = 0.346$, Wright 1977), probably has not occurred over the evolutionary history of the system. (The orbits of binaries undergoing Roche lobe mass transfer rapidly circularize). In the ultraviolet (UV), the hot companion appears embedded in a region of circumstellar gas, as inferred from the veiled appearance of the UV spectrum (the spectrum of the naked B-star is never seen). The gas around the companion is probably a result of wind accretion from the massive wind of the M supergiant. In VV Cep, Hα emission is especially prominent, with peak fluxes of ∼10—30 times that of the (M star) continuum. This Hα emission exhibits radial velocity behaviour opposite to that of the M supergiant, implying a source near the hot companion (Wright 1977). Even though this emission declines sharply for higher Balmer lines, at times Balmer emission remains visible from levels up to $n \sim 16$. Balmer continuum emission is often observed at wavelengths shortward of 3700 Å, and at times, is strong enough to dominate this part of the UV spectrum (Bennett & Bauer 2015). In the UV, lines of Fe II also appear strongly in emission, and are probably pumped by Lyman-α and Lyman-β emission (Bennett & Bauer 2015). The great width of these Fe II emission lines (with wings out to ∼300 km s^{-1}) suggests the line-forming region is in Keplerian rotation around the B star companion, as these velocities are far larger than any other observed in the circumstellar environment of VV Cep. Although the source of the companion's emission spectrum is usually attributed to "accretion" of circumstellar gas from the M star onto the hot star, it is likely that the emission luminosity comes not from the release of gravitational energy, but from recombination of circumstellar hydrogen photoionized by the B star's Lyman continuum.

The Hα emission is variable on both short timescales and longer timescales of several years. The slow variability in Hα flux appears to correlate with the orbital separation of the two stars, with larger emission flux seen when the companion is near periastron (Bennett, private communication).

Observations

VV Cep is a 5th magnitude system of variable visual brightness, with V magnitudes ranging from 4.9–5.4. Due to its high declination (+64°), VV Cep is circumpolar and well-suited for year-round observations at northern mid-latitude sites. In preparation for the VV Cep international campaign, contemporaneous observations of B and V band DSLR photometry and Hα emission equivalent width (EW) have been obtained over the past eight years.

The V band photometry was obtained by W. Vollmann (DSLR, AAVSO+BAV), B. Hassforther (DSLR, BAV-Germany) and G. Samolyk (CCD, AAVSO data base). W. Vollmann and G. Samolyk also obtained B photometry, concurrent with the DSLR V observations. However because of the lower DSLR pixel sensitivity in Vollmann's B photometry, these data are inevitably not as precise, nor as accurate, as the V photometry. Vollmann used the Johnson B brightness of the reference stars, but did not transform to the Johnson B system, and that process resulted in an offset in the derived B magnitudes compared to Samolyk's more accurate Johnson B magnitudes. Data reduction was performed using MaxIm-DL 3.06 (Diffraction Limited, Sehgal Corporation) for Pollmann's data, while data from other amateur observers were reduced with software packages developed for amateur spectrographs, such as SpcAudace3, Audela4, VSpec5, and IRIS36.

The Hα EW study used 86 spectra, obtained by members of the ARAS spectroscopy group between July 2004 and October 2016, at times with simultaneous V band photometry. These Hα spectra were obtained with 0.2m to 0.4m telescopes with a long-slit (in most cases) and echelle spectrographs with resolutions of $R = 1000$–22000. All spectra included the 6400–6700 Å region, with a S/N of ∼100 for the continuum near 6600 Å. Spectral line parameters were measured with the spectral classification software package MK32. The EWs reported here included the entire Hα emission profile (including both red and blue components) from 6550–6571 Å. Since the Hα emission originates from a different source (the B-type companion) than the optical continuum of the M supergiant, the EWs calculated relative to the M stars (variable) continuum were corrected for this variability in order to provide a reliable estimate of total Hα emission flux. This correction was done by scaling the previously calculated Hα EWs by a factor of $10^{-0.4\Delta V}$, where $\Delta V = V - \overline{V}$ and $\overline{V}$ is the mean magnitude of the out-of-eclipse V time series.

Results

Here we present the data and analyses.

Figures 1, 2, and 3 show the time series of the V and B data, and the Hα emission fluxes (Hα emission EWs, corrected for continuum variability). These observations are from July 2004 to October 2016 (JD 2455500 to 2458000), or from orbital phases of 0.625–0.961, measured from mid-eclipse.

Figure 4 compares VV Cep Hα emission fluxes to simultaneous V band photometry from July 2004 to October 2016 (JD 2455500–2458000).

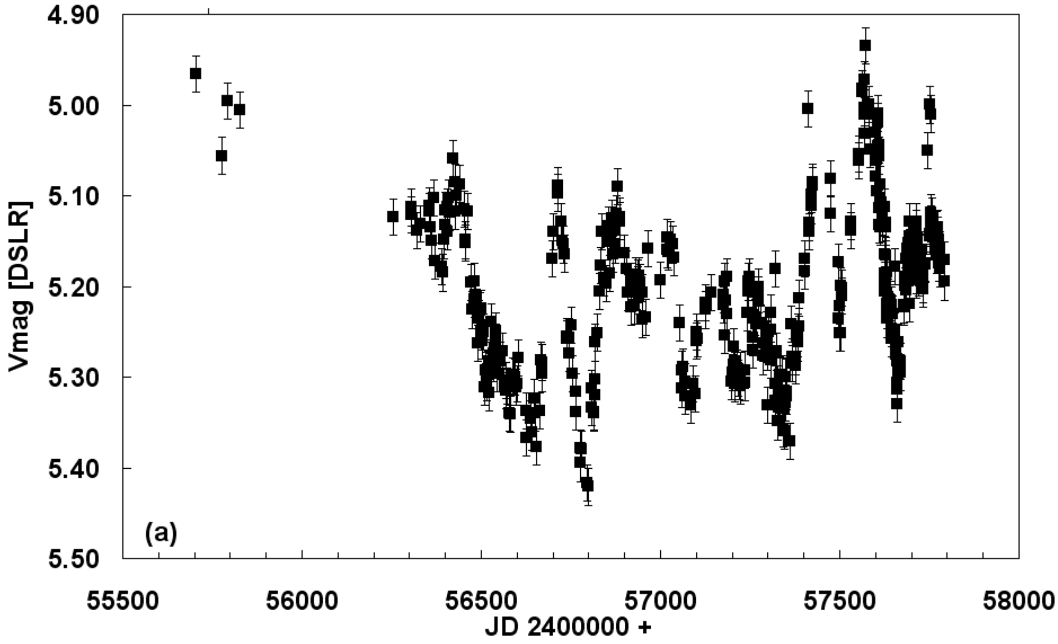

Figure 1. VV Cep DSLR *V* magnitudes: July 2004 to October 2016.

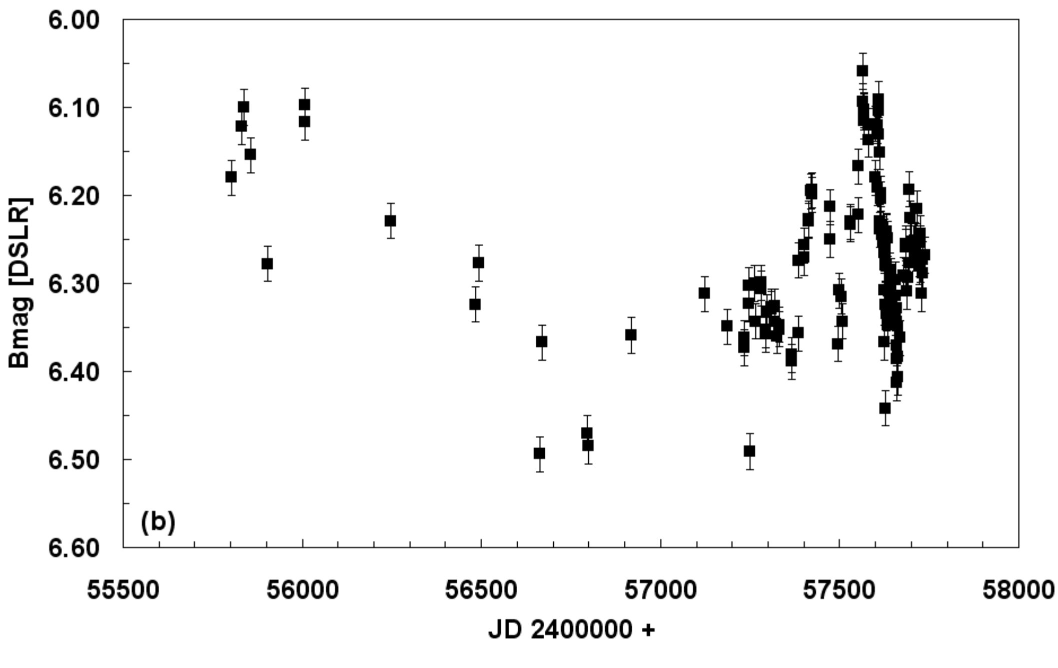

Figure 2. VV Cep *B* magnitudes: July 2004 to October 2016.

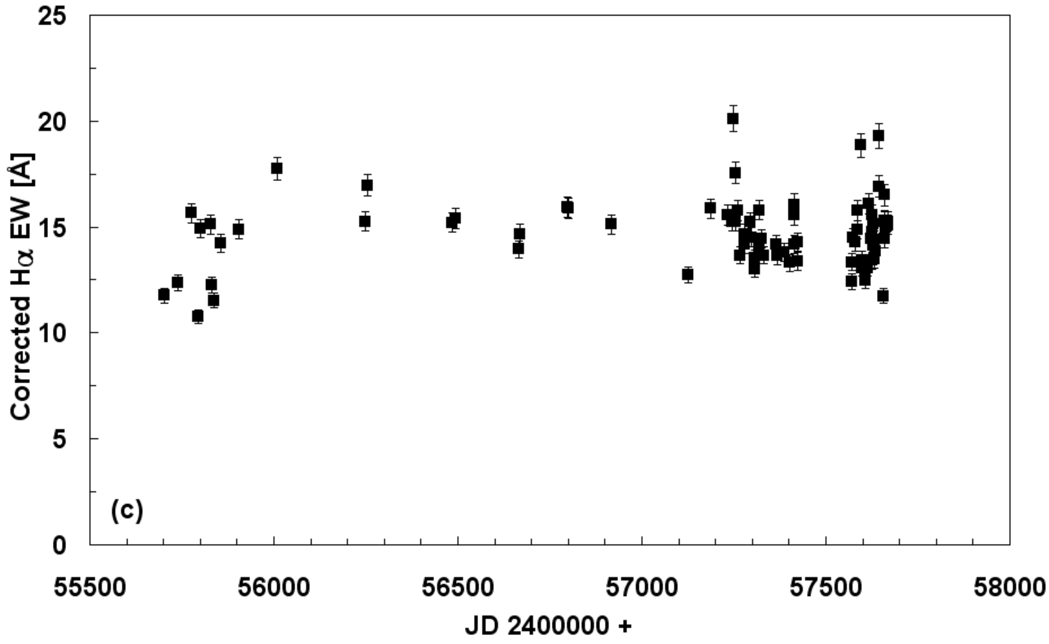

Figure 3. VV Cep Hα emission fluxes: July 2004 to October 2016.

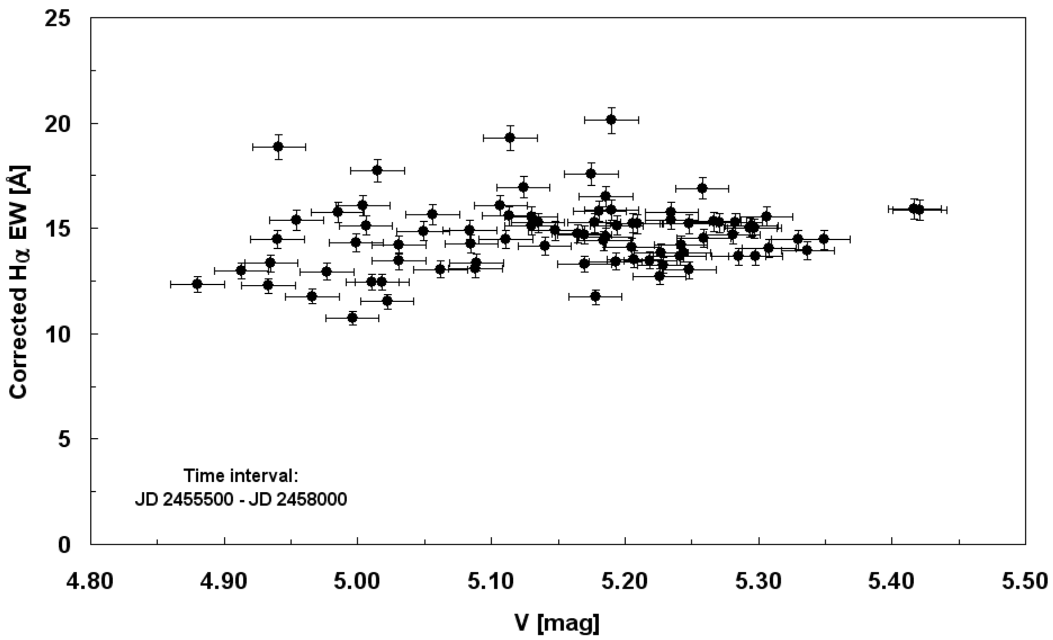

Figure 4. VV Cep Hα emission fluxes versus DSLR V magnitude.

Figure 5 shows the power spectrum of the *V* photometry of VV Cep obtained using the Period04 code (Lenz & Breger 2005). The strongest peaks in the power spectrum of the *V* photometry are near 145 and 656 days. The first period lies close to the 150 day period first proposed by Hayasaka et al. (1971) and is almost certainly real. The second period is about one-half of the time spanned by the vast majority (406 out of 412 points) of the photometry, and may be an artifact resulting from long-term variations over this period.

Figure 6 shows the corresponding phase diagram of the *V* photometry produced by program AVE (Barberá 1998), of Figure 1, phased with a 145.5 day period. Many other periods have been reported in the literature over the years: e.g., periods of 60, 110, 114, 116, and 280 days (Graczyk et al. 1999; Saito et al. 1980; McCook et al. 1978; Baldinelli et al. 1979; Pfeiffer et al. 1989), and it apparent from Figure 5 that there is significant power at other frequencies with periods longer than about 30 days, and especially longer than 100 days. This behaviour suggests the short-term variability is somewhat irregular in nature, and probably has a substantial stochastic component. Indeed, the plot of the V variability, phased to a period of 145.5 days (Figure 6), shows a substantial fraction of this variability remains unexplained by this regular short-period oscillation.

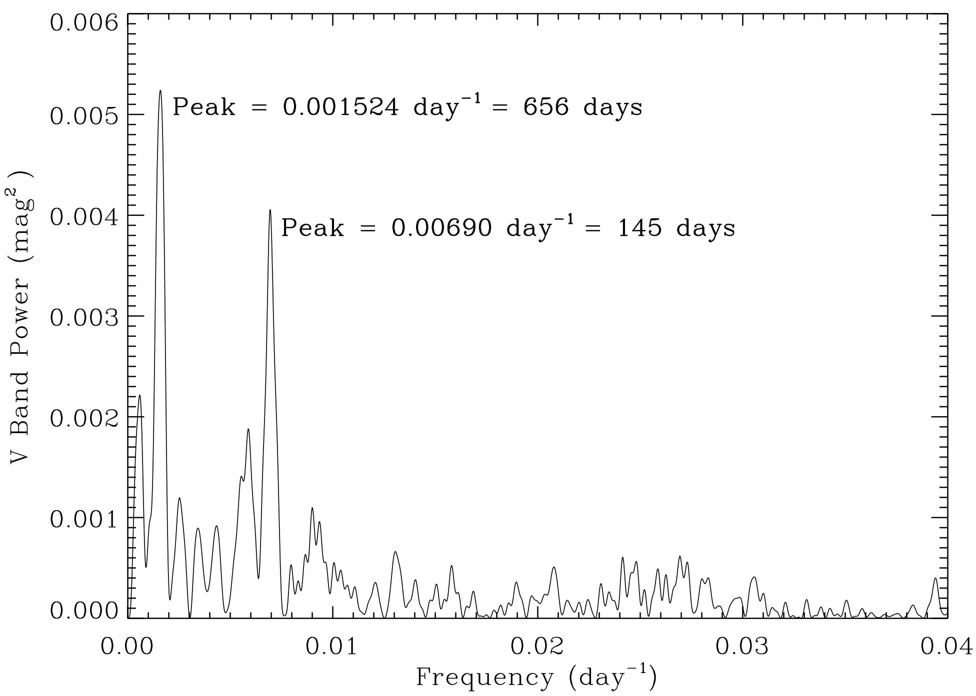

Figure 5. Power spectrum of *V* band photometry of VV Cep. The peak of 656 days may be an artifact due to the finite length of the time series; the second prominent peak at 145 days is probably real and due to intrinsic pulsation of the M supergiant.

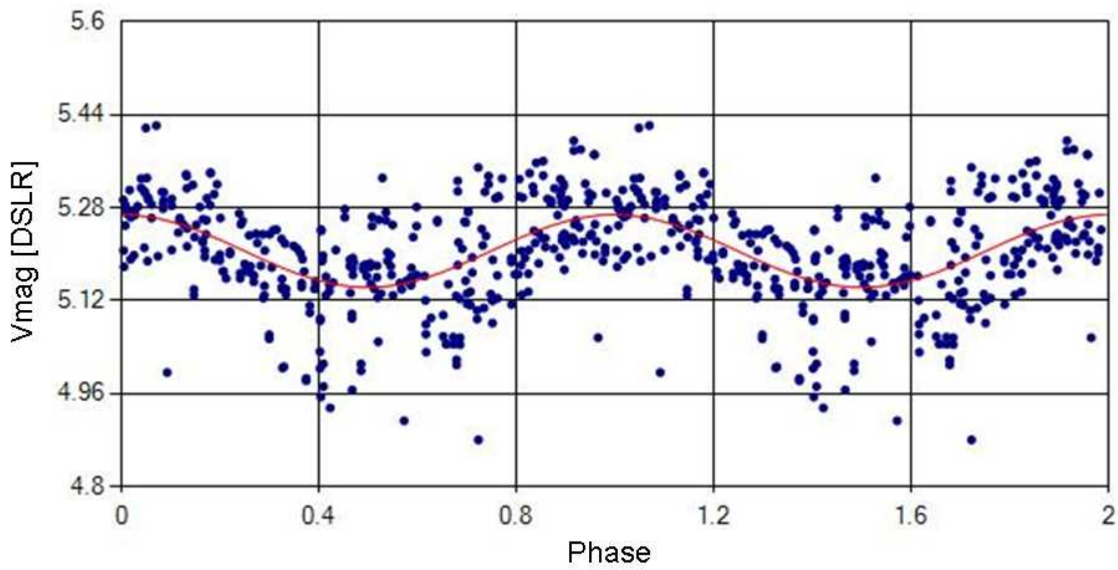

Figure 6. AVE phase diagram of the V photometry of Figure 1, with a fitted period of 145.5 ± 1.2 days, and epoch JD 2456750.

Conclusions

The observations presented here span the period from JD 2455500 to 2458000, corresponding to orbital phases 0.625–0.961. The amplitude of the photometric variability is $\Delta V \approx 0.4$–0.5 mag, whereas the amplitude of the total eclipse of the B star is only is $\Delta V \approx 0.15$ mag. The period and photometric amplitude of the variability is quite similar to that resulting from irregular pulsation in other, single late-type supergiants. We confirm the peak power of this pulsation lies near a period of 145 days. A second, longer period of 656 days may be an artifact arising from the finite length of the time series. All of this strongly suggests that the photometric variability observed for VV Cep is intrinsic, and due to irregular pulsation of the M star. The source of the variability of Hα, originating from an accretion region around the hot companion, remains unclear and the time sampling of these Hα observations are too sparse to permit a meaningful period analysis.

Acknowledgements

We are grateful to Sara and Carl Sawicki (Alpine, Texas, USA) for their helpful improvements and suggestions in language. We are grateful to the observers of the ARAS spectroscopy group for contributing Hα spectra of VV Cep. We wish to thank Bela Hassforther (Deutsche Arbeitsgemeinschaft Veränderliche Sterne, BAV) for supplying additional V photometry. Finally, we acknowledge, with thanks, the use of variable star observations contributed to the AAVSO International Database by Gerard Samolyk.

Observers of the ARAS Spectroscopy Group

J. N. Terry, B. Koch, O. Thizy, E. Betrand, O. Garde, F. Teyssier, T. Lester, J. Foster, Ch. Buil, M. Schwarz, J. Guarro, D. Hyde, E. Pollmann.
ARAS website — `http://www.astrosurf.com/aras/`

References:

Baldinelli, L., Ghedini, S., Marmi, S. 1979, *IBVS*, **1675**
Barberá, R. 1999, `AVE` code, version 2.51, `http://astrogea.org/soft/ave/aveint.htm`
Bennett, P.D., Bauer, W.H. 2015, *ASSL*, **408**, 85 DOI
Graczyk, D., Mikolajewski, M., Janowski, J. L. 1999, *IBVS*, **4679**
Harmanec, P., 1983, *Hvar Obs. Bull.*, **7**, 55
Hayasaka, T., Saijo, K. , Sato, H., Saito, M., Kitamura, M. 1977, *Tokyo Astr. Bull. Second Series*, **247**, 2865
Hutchings, J. B., Wright, K. O. 1971, *MNRAS*, **155**, 203 DOI
Lenz, P., Breger, M. 2005, *Comm. in Asteroseismology*, **146**, 53 DOI
McCook, G., P., Guinan, E., F. 1978, *IBVS*, **1385**
Pfeiffer, R. J., Maffei, J. C. 1989, *BAAS*, **21**, 792
Saito, M., Sato, H., Saijo, K., Hayasaka, T. 1980, *PASJ*, **32**, 163-177
Wright, K.O. 1977, *JRASC*, **71**, 152