VV Cephei Eclipse Campaign 2017/19

Jeffrey L. Hopkins (187283)
Hopkins Phoenix Observatory
7812 West Clayton Drive, Phoenix, Arizona USA
phxjeff@hposoft.com

Philip D. Bennett
Department of Astronomy & Physics
Saint Mary's University
Halifax, NS B3H 3C3
Canada
pbennett@ap.smu.ca

Ernst Pollmann
International Working Group ASPA
Active Spectroscopy in Astronomy
Emil-Nolde-Str. 12
51375 Leverkusen, Germany
ernestospec@hotmail.de

Draft 23 March 2015, Revised 23 April 2015 (PDB)

Abstract

VV Cephei is an eclipsing binary star system with the second longest known period (7430 days, or 20.4 years). The longest known eclipsing binary star system is Epsilon Aurigae with a period of 9890 days, 27.1 years. Both Epsilon Aurigae and VV Cephei are visually bright (3rd and 5th magnitude respectively) massive binary stars of great interest. The last eclipse of Epsilon Aurigae ended in 2011. VV Cephei is up next with its eclipse beginning in August of 2017. The eclipse lasts nearly two years (~650 days) from 1st to 4th contact. A campaign is planned for the next eclipse of VV Cephei. This paper will provide information on VV Cephei, explain the campaign goals and provide an invitation to observers to do photometry and/or spectroscopy.

1.0 Introduction

The binary star system VV Cephei is a cool red supergiant star (M2 Iab) with a smaller hot blue companion star (B0-2V). The primary star of VV Cephei is a massive red supergiant star, with an estimated mass of about 20 solar masses. The two stars in this binary are well-separated and significant mass transfer between the stars does not occur. However, the M supergiant has a massive wind which results in a wind-interaction (shell or accretion) region around the hot companion. The primary M star has a radius of about 1000 times that of the Sun making it one of the largest stars in our galaxy. Placed in the location of our Sun, its surface would extend out to about the orbit of Jupiter.

The VV Cephei binary has the second known longest orbital period with a period of

20.35 years or 7430.5 days. Primary eclipse occurs when the brighter M supergiant primary eclipses the fainter B star companion. VV Cep is a 5th visual magnitude system that varies from 4.9 to 5.4 in the visual band. The eclipse lasts nearly two years and is slightly shorter duration than that of Epsilon Aurigae (Epsilon Aurigae = 670 days, VV Cephei = 650 days).

Due to its high declination (+64 degrees) VV Cephei is circumpolar and well suited for year-around observations in the northern hemisphere. While the eclipse is two years away, out-of-eclipse observations are needed now.

2.0 VV Cephei Star System

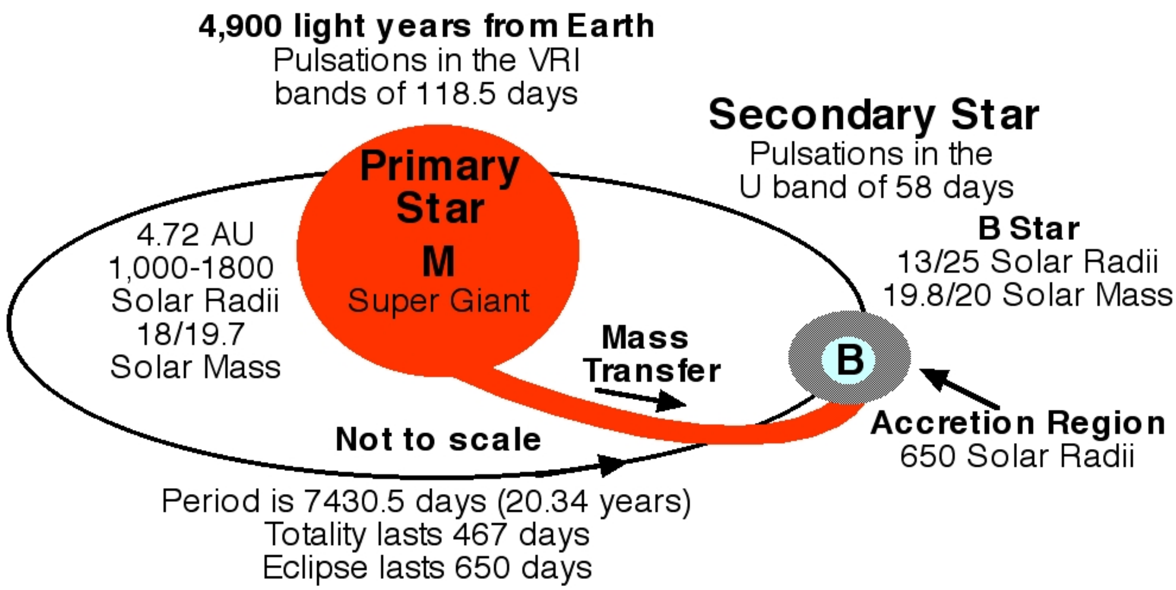

Figure 1 VV Cephei System Schematic

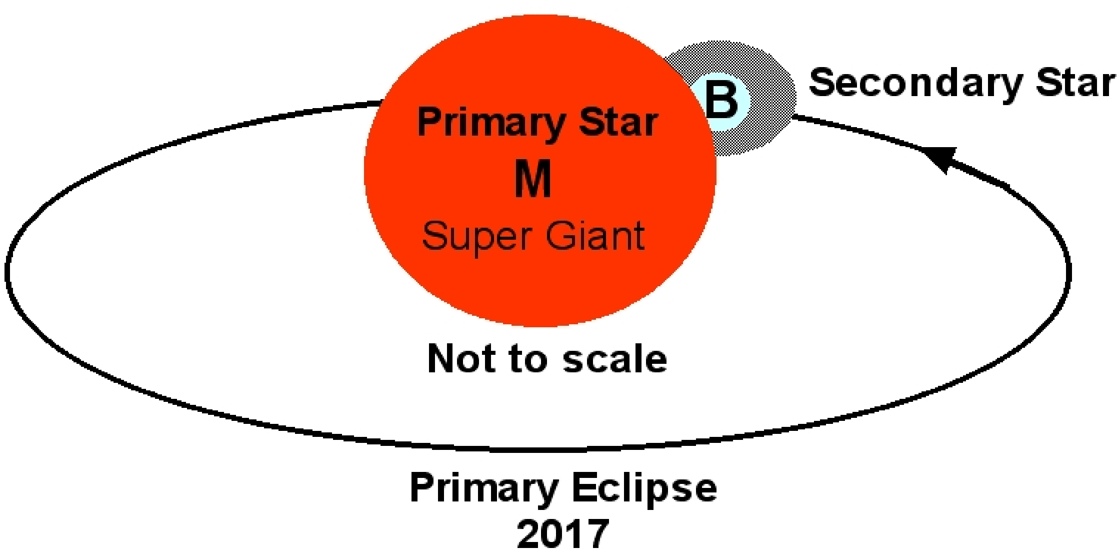

Figure 2 VV Cephei Primary Eclipse 2017

During the 2017 eclipse, the small and hotter B stars passes behind the large and cooler M star.

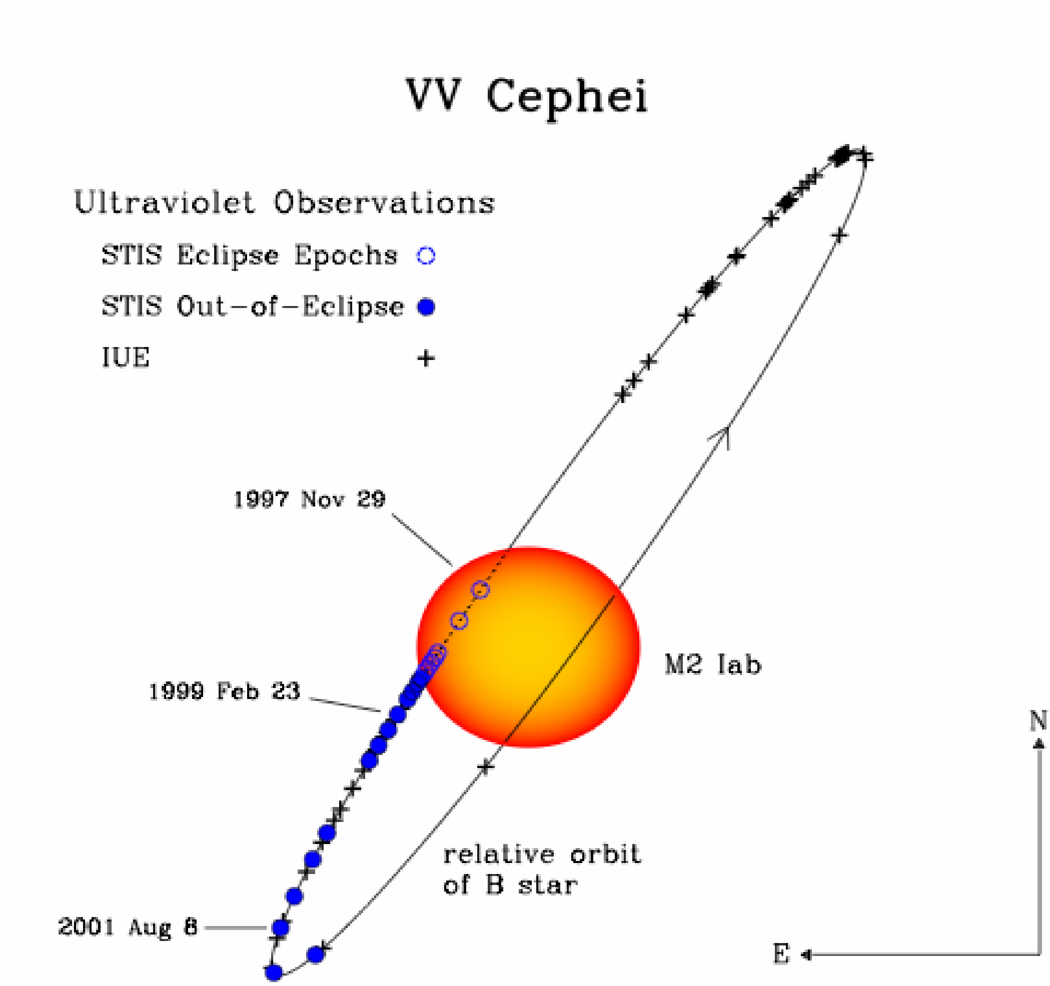

Figure 3 VV Cephei UV Observations

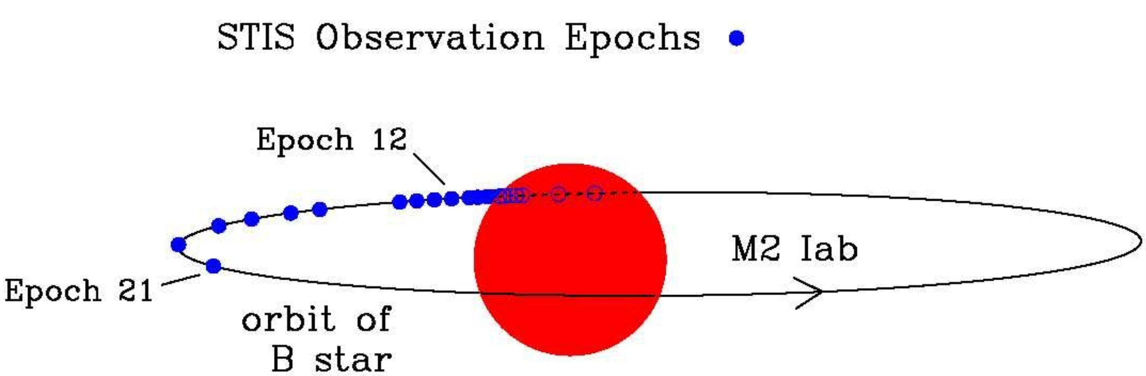

Figure 4 VV Cephei STIS Observation Epochs

3.0 VV Cephei Star System Parameters

As can be seen below some of the system parameter data vary considerably.

3.1 Primary Star

Solar masses:
18.3 Hutchings & Wright 1971
19.7 Wright 1977
2.5 Grascyk, Mikolajewsi, Janowski 1999
20 Möllenhoff, Schaifers 1981
Solar radius:
1800 Möllenhoff, Schaifers 1981
1600 Hack et al. 1992
1600 Wright 1977
1015 Bennett 2007

3.2 Secondary Star

Solar masses:
19.8 Hutchings & Wright 1971
20 Wright 1977
8 Grascyk, Mikolajewsi, Janowski 1999
Solar radius:
25 Hack et al. 1992
13 Wright 1977
13 Möllenhoff, Schaifers 1981

3.3 Shell (accretion region)

Solar radius: 650 Wright 1977

4.0 VV Cephei Stellar and Orbital Parameters

The stellar and orbital parameters of VV Cephei are still rather uncertain because of the lack of a good orbit for the companion B star. Even the spectral type of the hot companion has been difficult to determine because the spectrum of the hot star is never seen directly. It is always obscured by a variable amount of circumstellar material that hampers spectral classification. The best of the orbital motion are the spectroscopic analyses (K1 and K2 -- orbital RV semi-amplitudes) of Wright (1970 -- M star) and Wright (1977 - B star). The latter was found from the hydrogen alpha emission, assuming it follows the B star. This is approximate. The mass of the B star inferred from the hydrogen alpha solution is probably a bit overestimated by Wright (1977).

Interferometry would solve this problem, but there have been no measurements (to our knowledge) that have resolved the two stars in VV Cephei.

The eclipse duration depends on exactly what is being measured. We used the 650 day duration from the times of 1st and 4th contact in Leedjarv (1999). This depends on

exactly what you consider to be the times of 1st and 4th contact since the eclipse onset is gradual.

Pollman's eclipse duration (of 673 days) refers to hydrogen alpha data, which implies a longer duration eclipse because hydrogen alpha emission comes only from the extended volume of the B star. This means that hydrogen alpha 1st contact occurs earlier and 4th contact later than the B star's contact points.

5.0 VV Cephei orbital elements

Our best estimates, so far unpublished, of the VV Cephei parameters are:
From Wright (1977)
P= 7430.5 d
e= 0.346 +/- 0.01
w= 59.2 +/- 2.8
K1= 19.4 +/- 0.3 km/s
K2= 19.1 +/- 0.7 km/s
V0= -20.2 +/- 0.2 km/s

Omega= 147 deg Van de Kamp (1977)
incl= 84.0 +/- 3.4 deg Bennett (2007) preliminary

Spectroscopic orbit solution using above values
a1= 12.5 AU
a2= 12.3 AU
a= a1+a2 = 25.4 AU

From Bennett (2007) photometric modeling of M star, assumes A_V= 1.24
Teff= 3826 K
Angd= 6.38 mas stellar angular diameter

Eclipse timing constraints on orbit (using Leedjarv et al. T2 and T3 below) and Bennett (2007) angular diameter:
alpha= 16.2 +/- 3.7 mas orbit semi-major axis, angular size Bennett (2007)
d= a/alpha = 1.5 kpc = 4900 light years distance
R1= d*Angd/2 = 1015 R_solar M star radius

6. Previous eclipse timing

Epoch of 1977/78 mid-eclipse from Moellenhoff & Schaifers (1981)
T0= JD 2443365.0 09 August 1977
Epoch of 1997/98 mid-eclipse from Leedjarv et. al. (1999)
T0= JD 2450858 13 February 1998
mid-eclipse ph0= 0.0000 (orbital phase, from mid-eclipse)
T1= JD 2450540 11 April 1997
1st contact ph1= -0.0428
T2= JD 2450624 24 June 1997

2nd contact   ph2= -0.0315
T3= JD 2451091   04 October 1998
3rd contact   ph3= 0.0314
T4= JD 2451190   11 January 1999
4th contact   ph4= 0.0447

7. VV Cephei 1956 - 1958 Eclipse

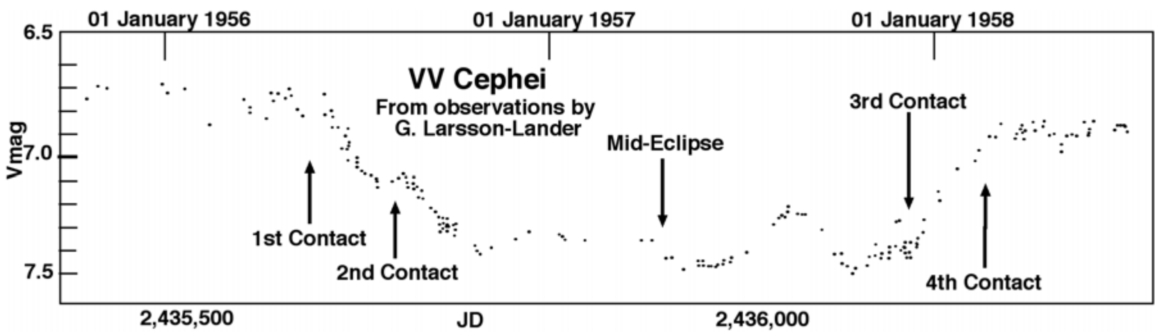

Figure 4 VV Cephei 1956-1958 Eclipse Light Curve

8. VV Cephei Data

Other Identifiers:
HR 8383, HD 208816, HIP 108317
R.A. (2000) 21h 56m 39.1s
DEC. (2000) +63d 37' 32.01"
Distance: 4900 light years
Diameter (solar dimeters):
1000 – 1800
1015 (Bennett)
Epoch: JD 2,435,931.4
Period: 7430.5 days/(20.34 years)
Ingress/Egress:
Based on 1998 eclipse 84 /99 days
Totality:
467 days (from 1998 eclipse)
373 days (Pollmann)
Duration:
650 days (from 1998 data)
673 days (Pollmann)
Next eclipse timing:
Data based on 1998 eclipse
T1- 04 August 2017
JD 2,457,970 (early evening)
T2- 27 October 2017
JD 2,458,054 (early evening)
T0- Mid 01 June 2018

JD 2,458,288 (early evening)
T3- 06 February 2019
JD 2,458,521 (early evening)
T4- 16 May 2019
JD 2,458,620 (late evening)

9. The VV Cephei Campaign

A campaign has been started to cover the 2017 eclipse of VV Cephei. A Campaign web site has been created at http://www.ap.smu.ca/~pbennett/vvcep/campaign2017.html. Anyone interested in the Campaign is encouraged to periodically visit the web site for the latest information on the Campaign. The following is a very brief summary of what would be useful for the campaign.

Note: some if the items are not suited for amateur observers, but are noted for possible professional involvement.

9.1 Photometry

Photometric time series (UBVIJK) is requested, as much data as possible should be obtained, and starting as soon as possible. It is useful to have a long baseline of photometry outside of eclipse, as well as during the eclipse itself. Any ultraviolet photometry would be extremely useful, including either Johnson U band, and/or Stromgren or SDSS u band observations. These ultraviolet observations provide a direct measure of accretion luminosity around the hot star. Since it is the hot B star that is being eclipsed the shorter wavelengths will show more pronounced brightness changes. For those who can do U and B band work, these bands will show a deeper eclipse than the V R I bands.

9.1.1 VV Cephei Photometric Magnitudes (out-of-eclipse):

U = 7.07, B= 6.68, V=4.91, Rj= 3.21, Ij= 1.86

9.1.2 Recommended Comparison Star:

20 Cep HR8426□
R.A. (2000): 22h 05m 00.4s□
DEC. (2000): +62d 47m 09s □
I = ?, R = ?, V = 5.27, B = 6.68, U = 8.46

9.1.3 Check Star: 19 Cep HR8428 □
R.A. (2000): 22h 05m 08.8s□
DEC. (2000): +62d 16m 48s □
Rj - Ij = 0.03, V = 5.11, B = 5.17, U =4.33

9.2 Spectroscopy

A long baseline of observations outside of eclipse will be very useful, as well as detailed monitoring during the eclipse phase. Hydrogen alpha, at least out-of-eclipse,

provides a measure of accretion luminosity around the hot star. The spectrum of the primary star is M2 Iab (or M2 Iabe) and the secondary star a B0-2 V.

9.2.1 Low-Resolution Spectroscopy

Low-resolution spectroscopy will not be able to provide sufficient resolution to measure EW, V/R or RV. However, it does have the advantages of showing a complete visible spectrum window and with a short exposure. This means it is also *very* useful for spectrophotometry: monitoring the overall behavior of the spectrum over time. The ALPY 600 (R=600) is ideal for this as seen in the 180 second exposure using an ALPY 600 in Figure 5 and 6. Use of an ALPY for low-resolution observations is encouraged -- just not so much for hydrogen alpha, but for other absorption lines (Na D, K I, etc).

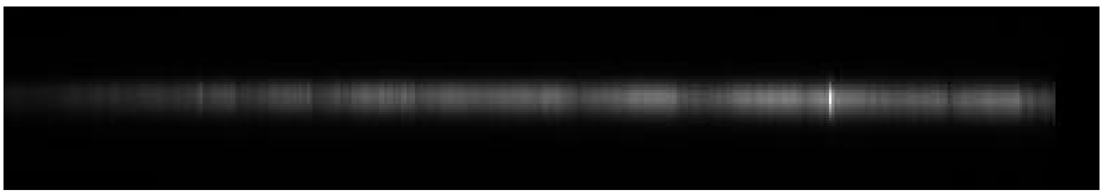

Figure 5 ALPY 600 VV Cephei RAW Spectrum

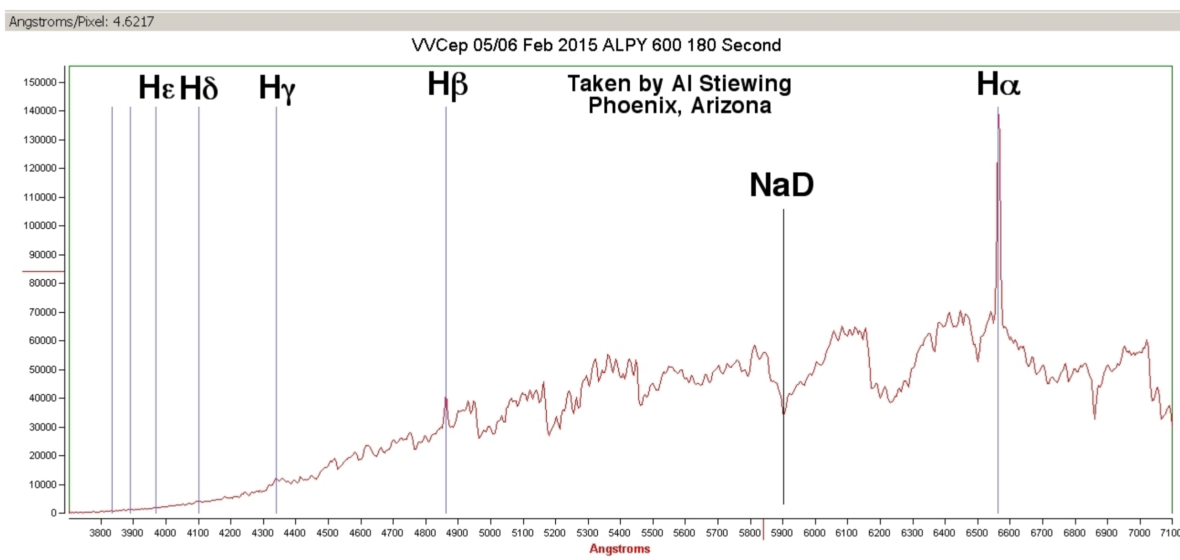

Figure 6 ALPY 600 VV Cephei Spectrum Line Profile

9.2.1.1 Important Line Wavelengths

Hα – 6562.81 Å
Hβ – 4861.35 Å
Hγ – 4340.47 Å
Hδ – 4101.73 Å
Hε – 3970.08 Å
Na D1 – 5889.95 Å

Na D2 – 5895.93 Å
K – 7664,90 Å
I – 7698.96 Å

Note: The K and I lines may not be seen in the ALPY 600 spectrum window.

9.2.2 High-Resolution Hydrogen Alpha Spectroscopy

A Lhires III or equivalent spectrograph with a 2400 line/mm grating is suggested for the high-resolution work. The star system's optical spectrum is characterized by strong Balmer and Fe II emission lines. Out-of-eclipse VV Cephei displays dual large hydrogen alpha emission lines that disappear during the eclipse.

To provide quantitative data from a spectrum's line profile one characteristic that is measured is the so-called equivalent width (EW) of a line. This is the area of the line below the continuum and is a measure of the strength of the line. The VV Cephei Hydrogen alpha line, usually appears double with two emission components present. See Figure 7. Further characteristics are defined by taking the ratio of the left (shorter wavelength or "Violet") component's EW and dividing it by the right (longer wavelength or "Red") component's EW. This is the so-called V/R ratio of the two components. The intensity variations of the V and R components provide important information about the peak strength as measure for the mass and/or density of the gas in the disk, expressed as equivalent width of the emission, and the direction of movement of the corresponding gas region within the disk. At the beginning of the eclipse the V line should decrease to the continuum as the left side of the gas cloud is eclipsed. The R line should continue with minor changes until the right side of the gas cloud is eclipsed.

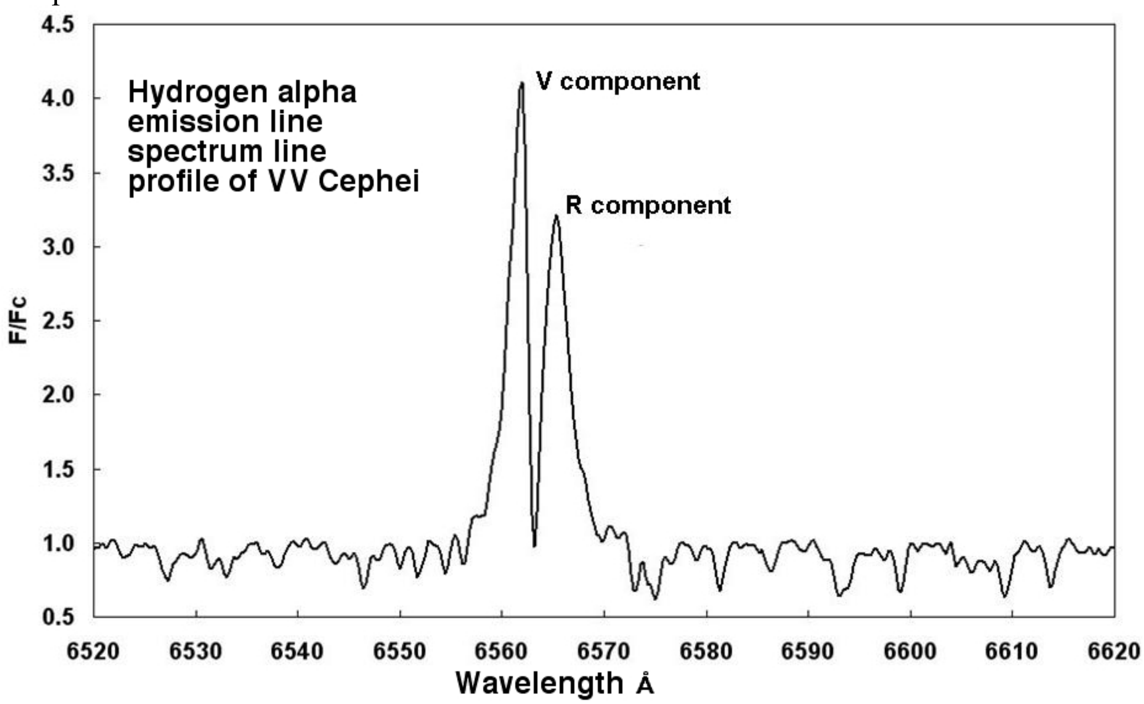

Figure 7 V/R of VV Cephei's Hydrogen Alpha (Pollmann)

The dimension of the fog-like accretion shell around the secondary Be star was determined by Peary (1965) to be less than 1/18 of the diameter of the primary M super giant's photosphere and is according to investigations by Wright & Hutchings (1971) not

spherically symmetrical but rather in the direction of the star's 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. The Hα-emitting shell is believed to be fed by accretion from the massive wind of the M supergiant.

The violet and the red components of the VV Cephei spectrum's line profile can be linked to the radiation of the gas shell around the Be star. Due to its counter clockwise rotation around the central star, in relation to the line of sight of the observer, it results in a blue shift by moving towards the observer (V-component) and a red shift by moving away (R-component) from the observer.

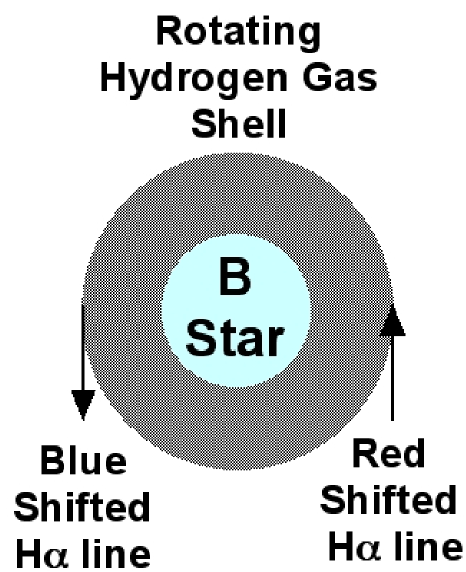

Figure 8 Dual Hydrogen Alpha Doppler Shifted Lines

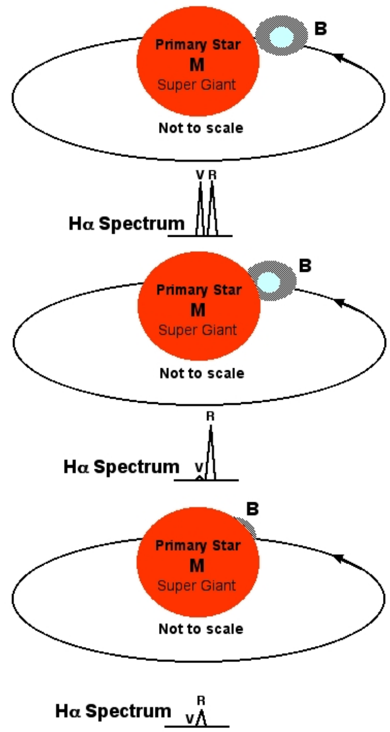

Figure 9 Eclipse of B Star Gas Cloud

As the B star's rotating cloud of hydrogen gas begins to pass behind the primary M star, the V (blue) hydrogen alpha line will first begin to decrease. When the left part of the cloud has been completely eclipse the V line will blend into the continuum. There will be a pause as the B star passes behind the M star, but the right side of the gas cloud is still uneclipsed. The R (red) line will remain steady until the right side of the cloud becomes eclipsed. When the cloud has been completely eclipsed the R line will blend into the continuum. The reverse will occur when the B star and gas cloud emerge at 4^{th} contact.

Spectroscopy in the ultraviolet and the blue-violet part of the spectrum would be very useful, as the spectrum of the hot star dominates in this spectral region (below about 4000 A). It would be useful to get a spectral time-series of this region. This is more or less what was done from space using HST in 1997, but the spectrum at wavelengths longer than 3000 A is accessible from the ground, albeit with some difficulty. Nevertheless, the 3000-4000 A region is perhaps the most useful of the entire spectrum. This would be a good program for automated spectroscopic telescopes which are starting to appear, or for dedicated observers able to devote sufficient time to the project.

High-resolution spectroscopy of the red part of the spectrum (perhaps the 6100-7000 Å region) would also be useful for improving the spectroscopic orbit of the M supergiant. Persons interested in contributing to ongoing spectroscopic time series should contact the authors for guidance.

10.0 Star Map

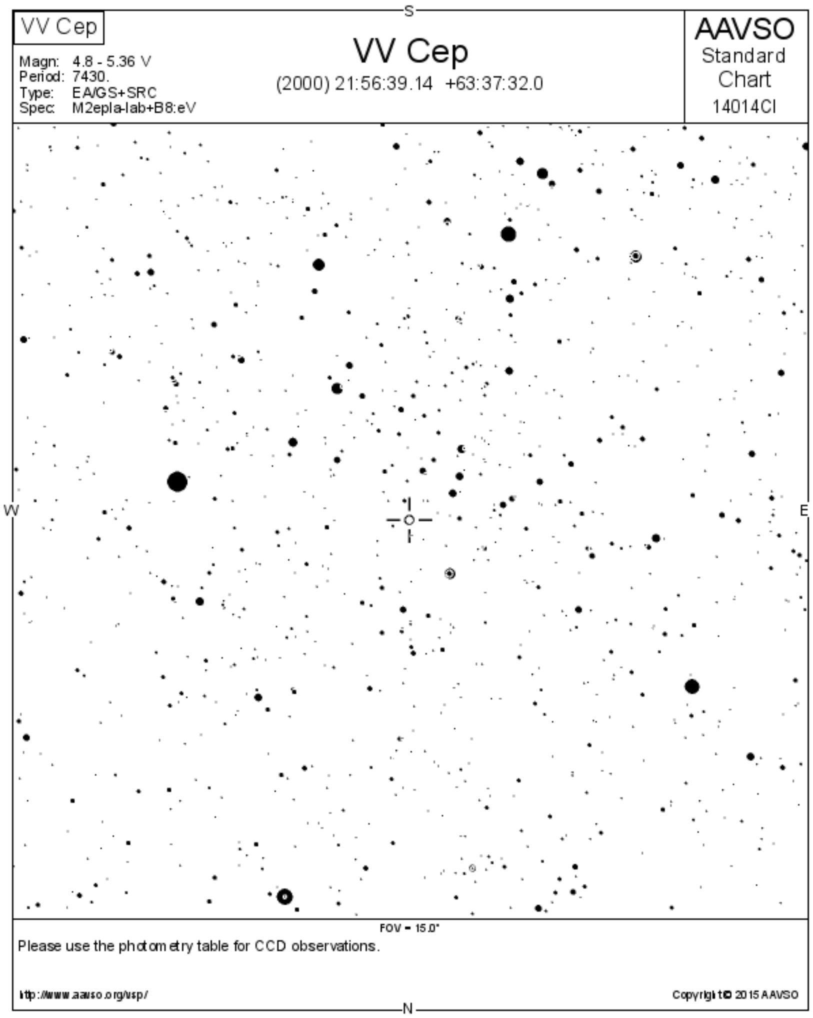

Figure 10 Star Map of VV Cephei, Courtesy of the AAVSO

11.0 References:

Van De Kamp, P. 1978, *Sky and Telescope*; *The Distances of V V Cephei and Epsilon Aurigae*, 397-399, November 1978.

Hopkins, J.L., and Bennett, P, Proceedings of the Society of Astronomical Sciences, *Single Channel UBV Photometry of Long Period Eclipsing Binary VV Cephei*, 105-110, May 2006.

Pollmann, E. , *Observations of H® Emission in VV Cephei*, Publ. Astron. Inst. ASCR 93, 44 {46 (2005)

Pollmann, E. , *VV Cep Outside Eclipse,* IBVS 5398, 23 March 2006

K.O. Wright, The system of VV Cephei derived from analysis of the H- alpha line, J. Royal Astr, Soc. Canada, 71, 152-193 (1977).

G. P. McCook, E. F. Guinan, 118 Day Optical Variations in VV Cep,IBVS Number 1385, 8 February 1978.

L. Baldinelli, S. Ghedini, S. Marmi, Semiregu- lar 58 Day Variations in VV Cep, IBVS 1675, 24 September 1979.

L. Leedjarv, D. Graczyk, M. Mikolajewski and A. Puss, The 1997/1998 eclipse of VV Cephei was late, 19 July 1999, Astron. Astrophys. 349, 511-514 (1999).

P.D. Bennett (University of Colorado), W.H. Bauer (Wellesley College), Six Years of HST/STIS Observations of Eclipsing Binary VV Cephei, AAS 204th Meeting June 2004, Poster Paper.