Bull. Natn. Sci. Mus, Tokyo, Ser. E, 7, December 22, 1984

On Abrupt Atmospheric Variation of VV Cephei

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Abstract

During the 1976–78 eclipse of VV Cephei, the abrupt variations of the Hα emission intensities on time scales of hours to a few days were observed on some occations. It is found that the abrupt variations are due to the intrinsic pulsation of the primary M supergiant, because the abrupt variations occur around the pulsation phases 0.2–0.3 and 0.8–0.9.

1. Introduction

VV Cephei is one of the long period eclipsing binary systems, so-called Zeta Aurigae stars, consisting of a late type supergiant star and an early type main sequence star. The atmospheric extinction of the supergiant star during the eclipse gives an information about the atmospheric structure. The eclipse of VV Cephei, which is composed of a M2Iab star and a Be star, occurs every 20.4 years. Observations during the recent 1976–78 eclipse were carried out by us photometrically and spectroscopically (Hayasaka *et al.* 1977, Saitō *et al.* 1980, Kawabata *et al.* 1981). We found some characteristics of the atmosphere of the M star and also the Hα emitting envelope around the B star.

The Hα emission line of VV Cephei shows a double-peak feature of a violet component and a red component. The line mainly originates at the rotating envelope around the B star. Profiles of the Hα line changes gradually with the progress of the eclipse. Analysing these changes of the profiles, the author (Saijo 1981) found that the envelope around the Be component has a rudius of 500 $R_{\odot}$.

Kawabata *et al.* (1981) found three instances of the abrupt change of the Hα line in which the emission intensities varied by a factor two or more on time scales of hours to a few days. They pointed out that these phenomena tended to occur on the desending branches of the pulsating light curve of the M star with semi-regular period of about 116 d (Saitō *et al.* 1980) and had to be caused by the atmospheric variation of the M star.

Abrupt changes on time scales of hours to several days have been reported by several authors. Frederik (1960) found a pulse-like light increase for several days and a flare-like phenomenon for 36 minutes from photometric observations in 1955–57 eclipse. Similar phenomena were also observed in this 1976–78 eclipse (*e.g.* Nakagiri and Yamashita 1979, Saitō *et al.* 1980). In spectroscopic study Möllenhoff and

Schaifers (1980) also reported such an abrupt variation of Hα line. In similar systems, Zeta Aurigae, 32 Cygni and Epsilon Aurigae, the abrupt variation with time scales of days to hours were also observed.

In this paper, using the observational materials taken by Kawabata *et al.* (1981), I investigate relation between the variation of the emission intensities within a few days, which shows the activity of the atmosphere of the M star, and the pulsation phase of the M star. The abrupt variation is very interesting phenomenon to examine the M star's atmosphere.

2. Abrupt Variations and Pulsation Phases

Observations of the Hα emission lines during the 1976–78 eclipse were compiled by Kawabata *et al.* (1981) in their table 1 and illustrated in their figure 2. From these observational materials, we can derive 15 series of observations taken within several days, which include more than two spectrograms. These observational series are tabulated in table 1. The second column of table 1 shows dates of the observations and the third column shows the number of spectrograms taken in each series. The degree of the variation is classified in three grades, which are indicated by the numbers of 2, 1, and 0. The grade for each seriee is shown in the fourth column in table 1. "2" denotes the most remarkable change, in which the difference between the largest and smallest values of the intensities is more than 50 percent of the largest value for both components, V and R. "1" denotes the recogni-

Table 1. Variation of the equivalent width of two components in the observational series

Number of series	Date	Number of plates	Grade of variation*		Pulsation phase	Times of the major change
			V	R		
1	1976 May 10–13	2	2	2	.83–.86	3 days
2	1976 Aug. 7–14	6	1	1	.59–.66	2 days
3	1976 Oct. 3–4	2	0	0	.09–.10	—
4	1976 Dec. 3–6	3	1	0	.62–.64	3 hours
5	1977 Jan. 28–30	3	1	1	.09–.11	1 hour
6	1977 Aug. 19	3	1	—**	.85	3 hours
7	1977 Oct. 20–21	3	0	0	.38–.39	—
8	1977 Dec. 19	3	2	0	.90	20 minutes
9	1978 Jan. 24–27	3	2	1	.21–.23	20 minutes
10	1978 May 24–27	5	2	1	.24–.27	1 hour
11	1978 Aug. 21–24	7	1	1	.01–.03	2 hours
12	1978 Oct. 17–21	5	0	1	.50–.53	1 day
13	1978 Nov. 20–21	2	0	0	.79–.80	—
14	1978 Dec. 27	2	1	0	.11	1 hour
15	1979 Jan. 25	2	0	0	.36	—

* see in the text.

** grade is not decided. see in the text.

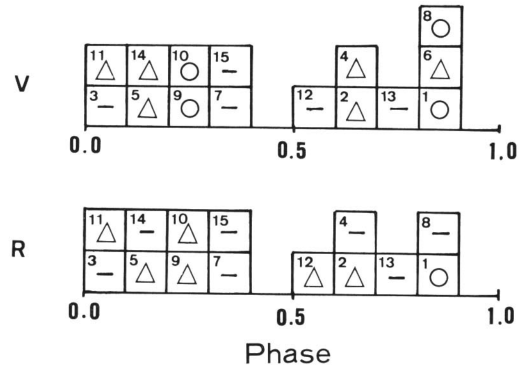

Fig. 1. Distribution of 15 observational series against the pulsation phase for two components. "V" denotes the violet component of the Hα emission and "R" the red component. Symbols in the square represent the grade of the variation given in table 1 and in the text.

zable change, which the difference is more than 20 percent. "0" denotes no meaningful change.

The most remarkable changes were shown in series 1, 8, 9, and 10 for violet component and in series 1 for red component. The changes in series 1, 9, and 10 were noted by Kawabata *et al.* (1981). The variation for the red component in series 6 is not decided, because of the flaw on the red component in the spectrogram C4-5059 taken in this series.

The fifth column of table 1 shows the pulsation phases of the M star, which are derived by the ephemeris formula, $JD_{max}=2443045+116 \cdot E$, at the maximum light by Saitō *et al.* (1980). In the last column times between the major changes in the series are given. It is noted that the most remarkable changes occured within 3 days to 20 minutes.

Figure 1 shows distribution of 15 series against the pulsation phase divided by the step of 0.1. These series are rather equally distributed for both components. In figure 1 the degree of the variation is also denoted in each series by symbol of circle, triangle and dash, according to the grade number 2, 1, and 0, respectively. The number at upper left in each square in figure 1 represents the number of the series. We can find from this figure that the abrupt variations tend to occur around the phases 0.1–0.3 and 0.6–0.9, especially 0.8–0.9.

3. Discussion

Saitō *et al.* (1980) reported light fluctuations with time scales of days to hours in the light curve at 3500 A and 4170 A during the partial phase of the eclipse. This is explained that B star's light is obscured by the cloud or condensations in the M star's atmosphere. Similar to that, Kawabata *et al.* (1981) pointed out that the variation of

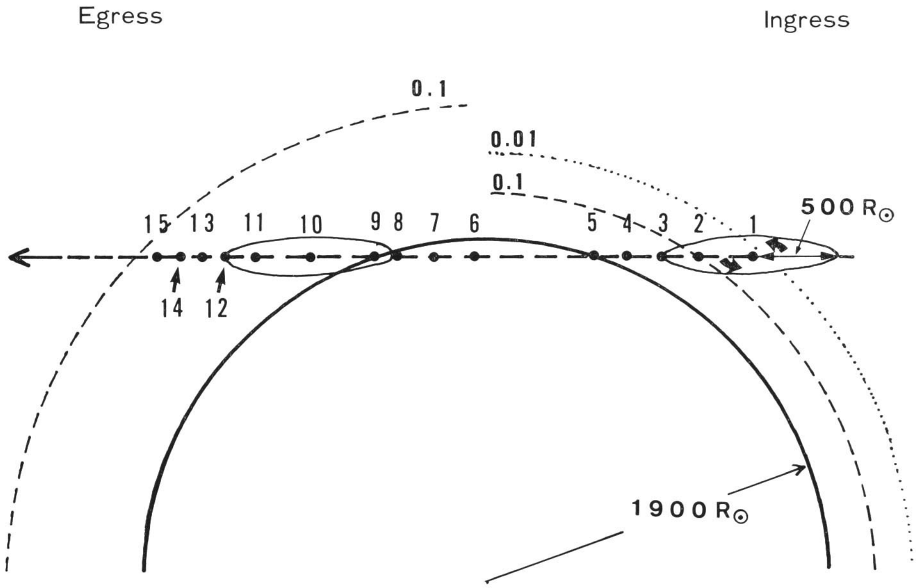

Fig. 2. The projected geometry of the eclipse. Dot with number represents a position of the B star at each series. The envelope around the B star is illustrated at series 1 and 10. Tangential optical depth, τ, in the atmosphere in ingress and egress are also shown. Dashed curve indicates $\tau=0.1$ and dotted curve $\tau=0.01$. The radius of the M star is 1900 $R_\odot$ (Saitō *et al.* 1980).

the Hα emission is caused by the variation of the physical state of the M star's atmosphere. Since the Hα emission comes from the envelope with the radius of 500 $R_\odot$ (Saijo 1981), a large scale variation of the atmosphere of the M star needs to explain the abrupt variation. If the pulsation is a non-radial one suggested by Saitō *et al.* (1980), a low-mode oscillation must be dominant corresponding to such large scale change of the atmosphere.

The projected geometry of the eclipse is illustrated in figure 2. The position of the B star at each observational series is plotted in figure 2 and the envelope around the B star is also shown for the series 1 and 10. From light curve analysis by Saitō *et al.* (1980) and analysis of the emission disk by Saijo (1981), opacity scale height of the atmosphere around Hα continuum is about 10^{13} cm. It is noted that the abrupt variations have time scales of hours, about 10^3 to 10^4 seconds. The extension of the atmosphere was different between in ingress and egress. The tangential optical depth, τ, around the Hα region is calculated from the equation by Saijo (1981) and shown in figure 2.

There appeared some extraordinary intensities of the Hα emission during the eclipse [see figure 1 of Kawabata *et al.* (1981)]. On some plates the intensities are extraordinary small in series 1, 6, and 8 while in series 9 and 10 the intensities are extraordinary large. The series 1, 6, and 8 correspond to the phases of 0.8–0.9, in asending branch of the light change and just before the maximum light, and the series 9 and 10 correspond to the phases of 0.2–0.3, in desending branch of the light pulsation. This shows another evidence for a close relation between the abrupt variation and the intrinsic pulsation of the M star.

Acknowledgement

The author is very indebted to Dr. M. Saitō, University of Kyoto, for reading the manuscript and discussions. He is also grateful to Mr. S. Murayama for reading the manuscript.

References

Fredrick, L. W., 1960. The System of VV Cephei. *Astron. J.*, **65**, 628.

Hayasaka, T., Sato, H., Saitō, M., Saijo, K., and Kitamura, M., 1977. Narrow-Band Photometry of VV Cephei during Ingress of the 1976–1978 Eclipse. *Tokyo Astron. Bull., 2nd Ser.*, No. 247.

Kawabata, S., Saijo, K., Sato, H., and Saitō, M., 1981. A Spectroscopic Study of VV Cephei during the 1976–78 Eclipse. I. Observations of the Hα Line. *Publ. Astron. Soc. Japan*, **33**, 177.

Möllenhoff, C., and Schaifers, K., 1981. Spectroscopic Observations of VV Cep. II. The Egress Phase of the 1976/78 Eclipse. *Astron. Astrophys.*, **94**, 333.

Nakagiri, M. and Yamashita, Y., 1979. UBV OBSERVATIONS OF THE 1976–1978 ECLIPSE OF VV CEPHEI. *Ann. Tokyo Astron. Obs.*, **2nd** *Ser.*, **17**, 147.

Saijo, K., 1981. A Spectroscopic Study of VV Cephei during the 1976–78 Eclipse. II. Structure of the Hα Emission Envelope around the Early-Type Component. *Publ. Astron. Soc. Japan*, **33**, 351.

Saitō, M., Sato, H., Saijo, K., and Hayasaka, T., 1980. Photometric Study of VV Cephei during the 1976–78 Eclipse. *Publ. Astron. Soc. Japan*, **32**, 163.