J. Astron. Space Sci. 9(1), 97–110 (1992)

SPECTROSCOPIC STUDY OF VV CEPHEI[1]

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(Received May 28, 1992; accepted June 9, 1992)

ABSTRACT

Observed spectra of the long period eclipsing binary VV Cephei show emission features of Balmer and some ionized metal lines. These features were interpreted as the result of the extended envelope activity surrounding the secondary star. Radial velocities and equivalent widths were calculated from some metal lines.

1. INTRODUCTION

VV Cephei has the longest period among ζ Aurigae type eclipsing binaries with the period of 7450 days (McLaughlin 1952). This binary system consists of a M type supergiant as a primary (Keenan and Wright 1957) while the secondary is an early B type.

Spectroscopic observations of VV Cephei show the complexity due to the rapid change of line intensities and features. McKellar *et al.* (1957) obtained high dispersion spectrum during the 1956 eclipse, and found a quite marked change in TiII lines at λ3759 and λ3761. Outside of the eclipse, red part of spectrum is normal. However, blue side of spectrum showed that absorption lines are much weaker than in a normal M type stars (Keenan and Wright 1957).

From the study of combined photometric, spectroscopic and astrometric observations, Fredrick (1960) derived 90° as an inclination of the orbit of VV Cephei and estimated the size of the giant M component as $600R_\odot$. Peery (1966) estimated the size of M star as $1962R_\odot$ and $88R_\odot$ for B star from the study of 1956-58 eclipse. He found that permitted and forbidden emission lines like FeII at λ4233 and [FeII] at λ4244 are presented at all phases and interpreted the Balmer emission as a result of the gas falling upon the B component in VV Cephei.

Batten (1968) assumed the VV Cephei as the most massive known binary system with masses of 84.8 and 41.3 $M_\odot$. From the orbital study of VV Cephei, Cowley (1969) estimated that component masses are in the excess of $30M_\odot$. Her high dispersion spectrum indicates the steady mass loss from the primary component.

[1] 이 연구는 교육부의 1991년도 기초과학연구소 학술연구조성비로 수행된 것임.

Infrared observations of M giant indicate the existence of the circumstellar dust shell (Gehrz and Woolf 1971). From the study of the emission line feature of H_α, Wright (1977) suggested an extensive envelope surrounding B star and a stream of gas flow from M star. Möllenhoft and Schaifers (1978) assumed that the hot companion is surrounded by an extended Balmer line emitting envelope. They interpreted intensity variations of H_β and H_γ as the result of the gradual disappearance of the hot companion and the rotating ring shaped envelope behind the primary.

From the study of H_α emission during 1976-78 eclipse, Saijo (1981) suggested the axisymmetric flat disk around the early type component with radius of $500R_\odot$. The variation of H_α emission intensity was interpreted as the result of the atmospheric time variation of M star (Kawabata *et al.* 1981).

All spectral features of VV Cephei clearly indicate that there are strong atmospheric activities. In this paper we present spectrum of VV Cephei in the blue region (3,800Å~5,000Å) and calculate physical parameters like radial velocities and equivalent widths.

2. OBSERVATIONS AND REDUCTIONS

Observations were made using the 122cm reflecting telescope equipped with the Cassegrain A spectrograph at Asiago Observatory, Italy. Focal distance of the camera was 287 mm and the linear dispersion at H_α was 42Å/mm. Used plates were 103a-O with the size of 9 cm × 12 cm . In Table 1 we list the observed spectroscopic plates with exposure times. The comparison light source was FeI arc with 20 minutes exposure.

Table 1. Observed plates

Plate number	Date	U. T	Exposure time
18233	Aug. 1, 1989	22^h28^m	10 min
18235	Aug. 1, 1989	22^h55^m	40 min
18237	Aug. 2, 1989	23^h45^m	40 min
18238	Aug. 2, 1989	24^h42^m	70 min

All reductions were made using the PDS microdensitometer 1010Å at the Padova Observatory. Scanning size was 12.5 × 50 microns and the scan speed was 10mm/sec with the density mode. Measured density was reduced using IHAP FITS format.

Comparison line identification, wavelength calibration and the normalization of line intensity were made using the same method described by Song and Chun (1991). The intensity versus the calculated wavelength of VV Cephei spectra is plotted in Figure 1.

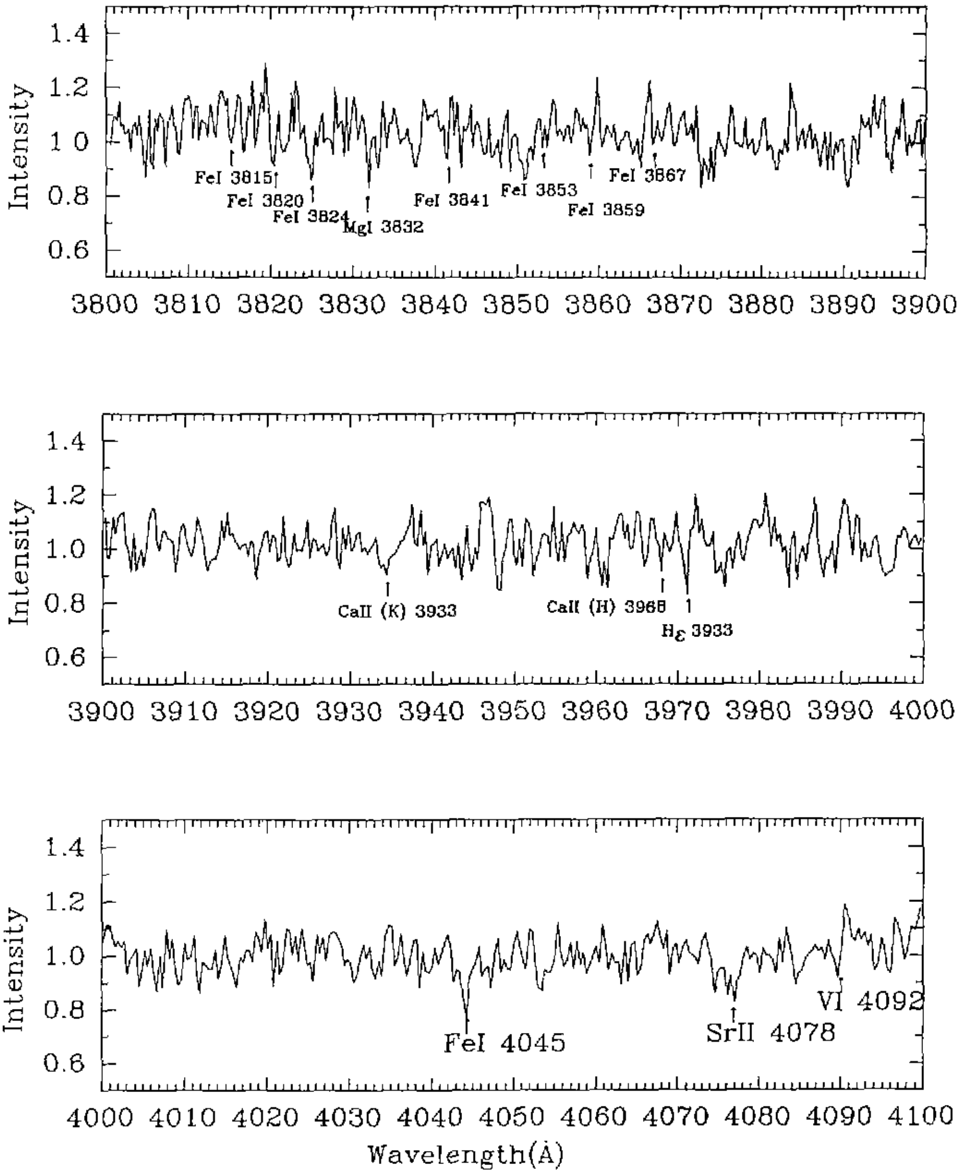

Figure 1. Normalized spectra of VV Cephei wavelength region $\lambda3800 \sim \lambda5000$. There are many emission line features in this spectra.

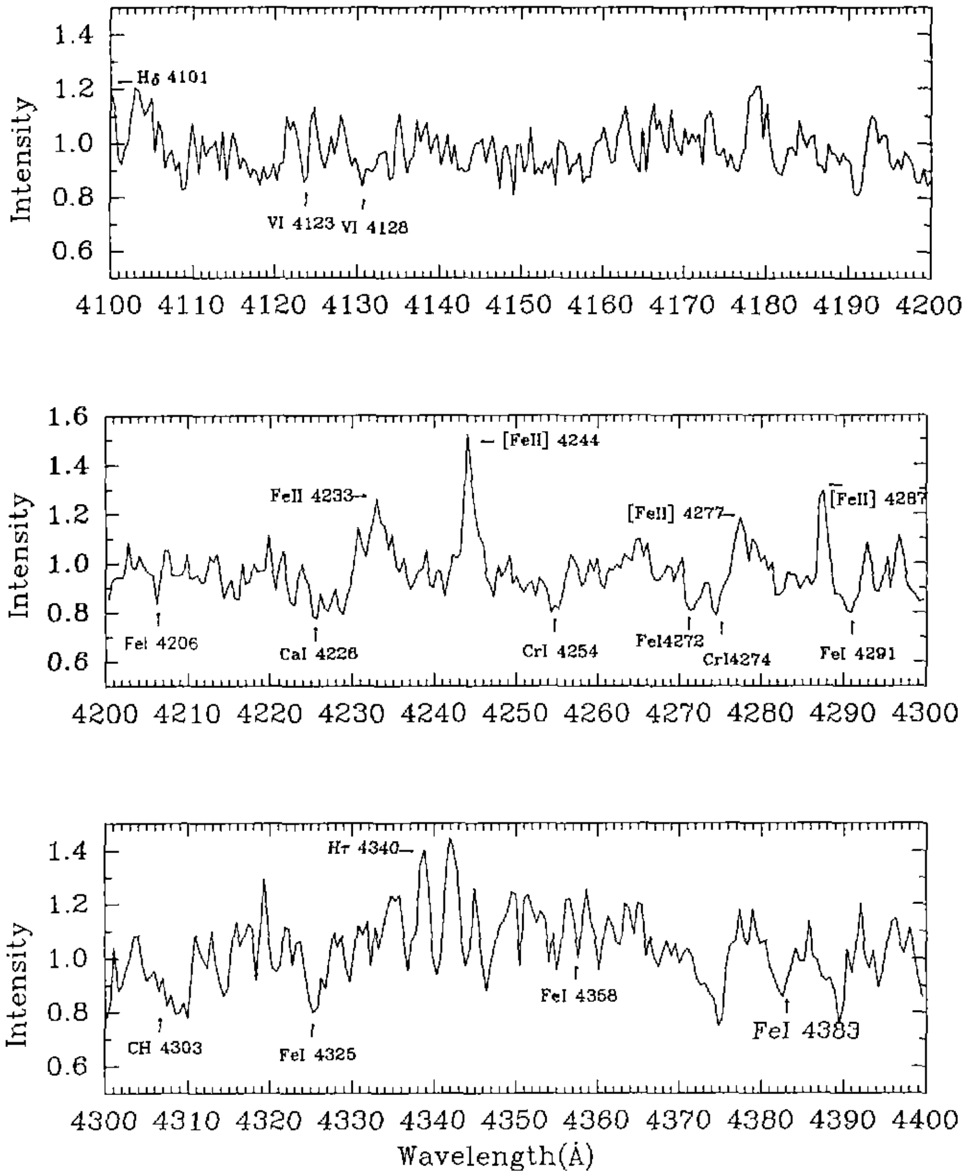
Intensity
Hδ 4101
VI 4123
VI 4128
4100 4110 4120 4130 4140 4150 4160 4170 4180 4190 4200
FeII 4233
[FeII] 4244
[FeII] 4277
[FeII] 4287
FeI 4206
CaI 4226
CrI 4254
FeI4272
CrI4274
FeI 4291
4200 4210 4220 4230 4240 4250 4260 4270 4280 4290 4300
Hγ 4340
FeI 4358
CH 4303
FeI 4325
FeI 4383
4300 4310 4320 4330 4340 4350 4360 4370 4380 4390 4400
Wavelength(Å)

Figure 1.

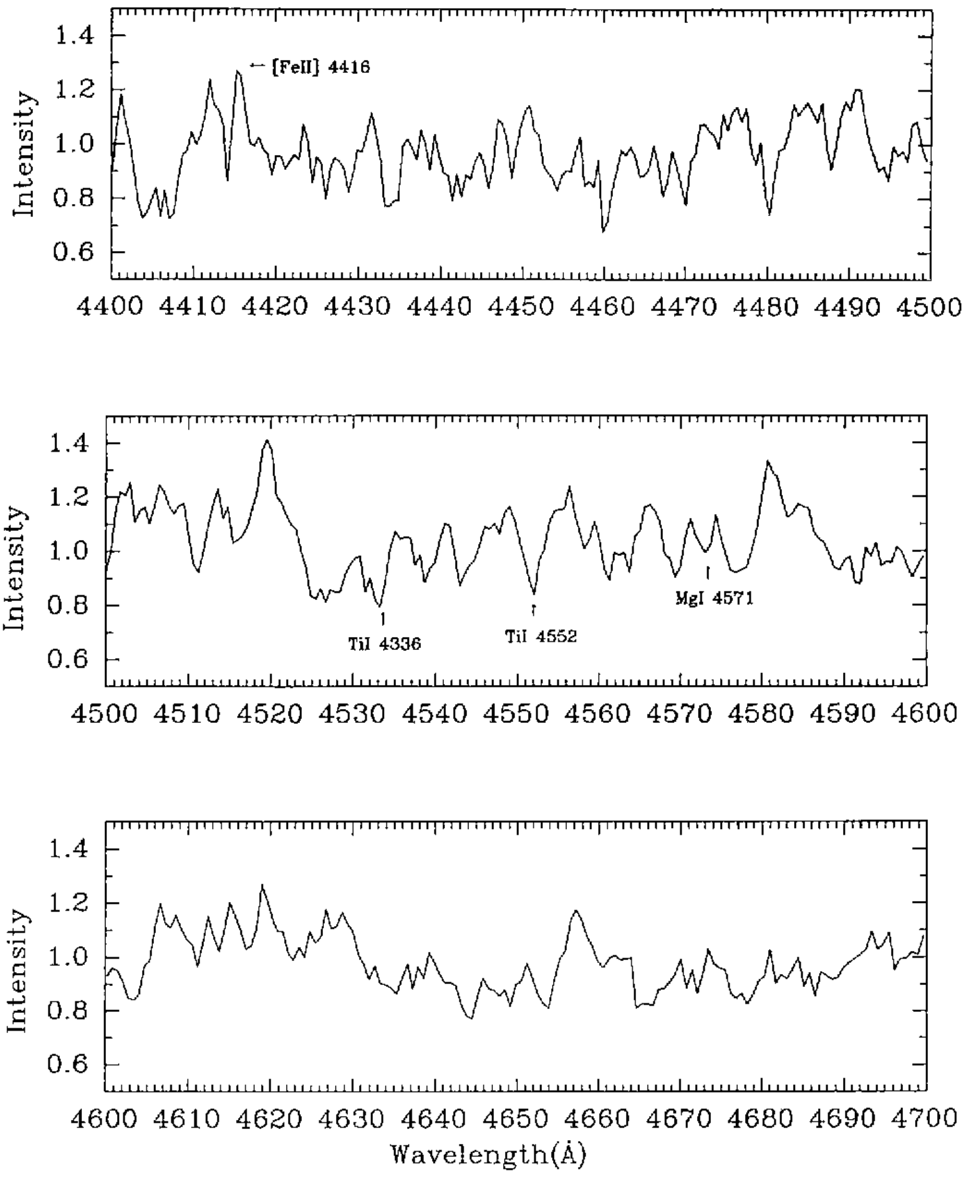
Intensity
1.4
1.2
1.0
0.8
0.6
← [FeII] 4416
4400 4410 4420 4430 4440 4450 4460 4470 4480 4490 4500
TiI 4336
TiI 4552
MgI 4571
4500 4510 4520 4530 4540 4550 4560 4570 4580 4590 4600
4600 4610 4620 4630 4640 4650 4660 4670 4680 4690 4700
Wavelength(Å)

Figure 1.

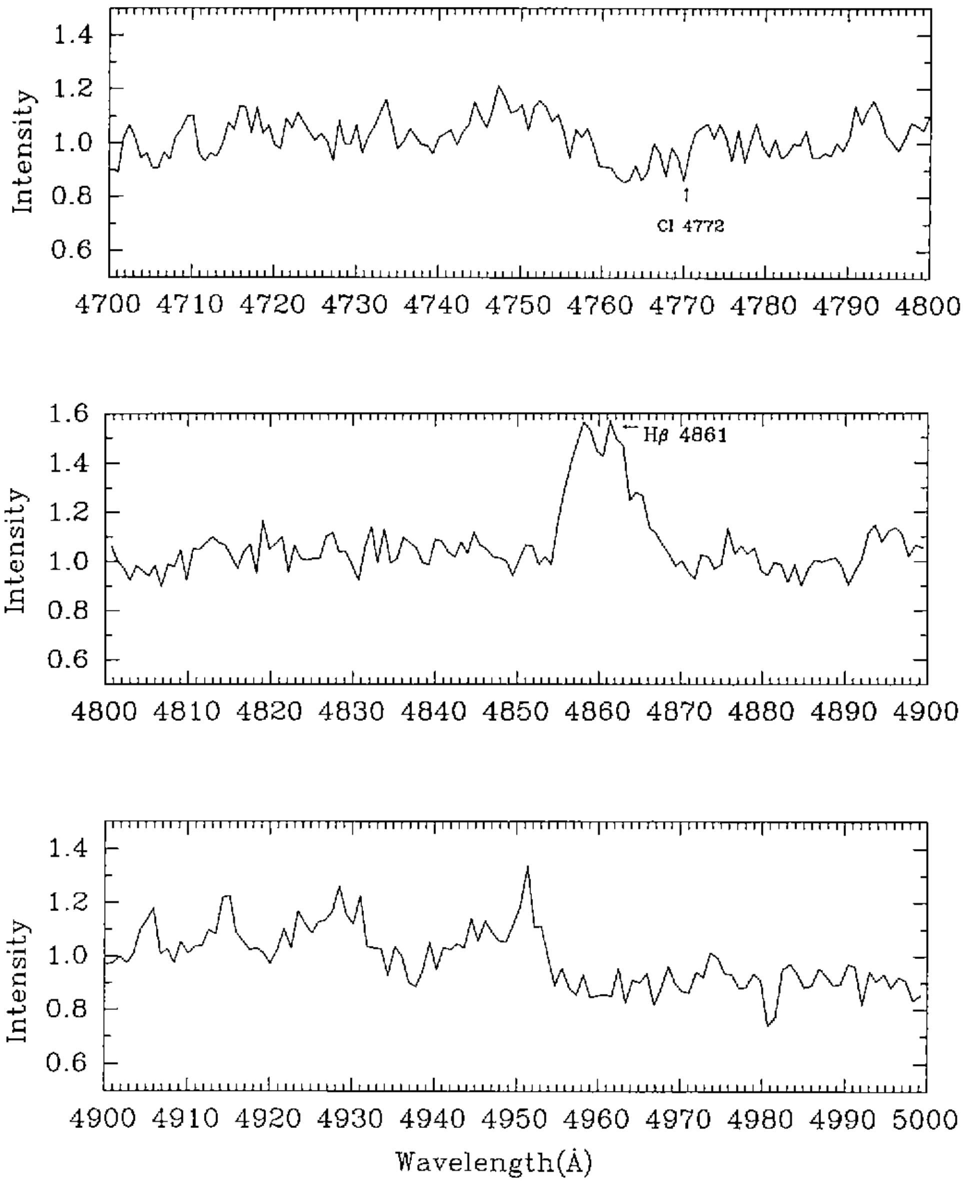
Intensity
1.4
1.2
1.0
0.8
0.6
CI 4772
4700 4710 4720 4730 4740 4750 4760 4770 4780 4790 4800
1.6
Hβ 4861
4800 4810 4820 4830 4840 4850 4860 4870 4880 4890 4900
4900 4910 4920 4930 4940 4950 4960 4970 4980 4990 5000
Wavelength(Å)

Figure 1.

3. SPECTRAL PECULIARITY

Balmer lines of \ V Cephei show the emission feature during the most of the time, but these hydrogen emission lines disappear at the time of eclipse. These phenomena were interpreted as the result of the infalling matter from the primary M star to the B companion (McLaughlin 1952, Peery 1966, Hutchings and Wright 1971, Wright 1977, Saijo 1981). However Kawabata *et al.* (1981) noticed that the H_α emission intensity varied abruptly with the time interval of hours to a few days. They interpreted this change as the atmospheric time variations of the M star.

In Figures 2a-c, we plotted H_β, H_γ and H_δ Balmer emissions for each plates. These features show the intensity variations of emission lines. It is quite noticeable of the variation of H_β and H_δ emission features from plate to plate. These sudden changes might come from the gas flow from the primary M star to the envelope of the secondary star.

The variation of emission features was also found on the permitted iron line FeII λ4233 and the forbidden line [FeII] λ4244. Figure 3 shows these emission lines for each observed plates.

4. RADIAL VELOCITIES AND EQUIVALENT WIDTHS

The Gaussian fitting method was used to calculate radial velocities of VV Cephei. The spectrum lines used in this work are metal lines which are assumed to come from the primary M star. Table 2 listed identified lines, referenced wavelengths, observed wavelengths, calculated radial velocities and equivalent widths.

Figure 4 is the fitting example of the sample of FeI line λ3815. The mean radial velocity of VV Cephei was estimated as -25.7 ± 6.60 km/sec, which value was plotted in Figure 5.

Table 2. Calculated radial velocities and equivalent widths

Line	Vref	Vobs	Vr(Km/sec)	E.W.(Å)
Fe I	4271.16	4270.601±0.010	- 27.69	0.20
Cr I	4403.37	4403.016±0.009	- 12.59	0.13
Fe I	4809.94	4809.266±0.014	- 30.43	0.16
Fe I	3815.851	3815.196±0.003	- 40.42	0.13
Fe I	4325.77	4325.391±0.010	- 14.83	0.55
Fe I	4938.18	4937.401±0.010	- 35.86	0.87
Ti I	4449.14	4448.700±0.005	- 18.22	0.26
	Mean Velocity		-25.72±6.60	

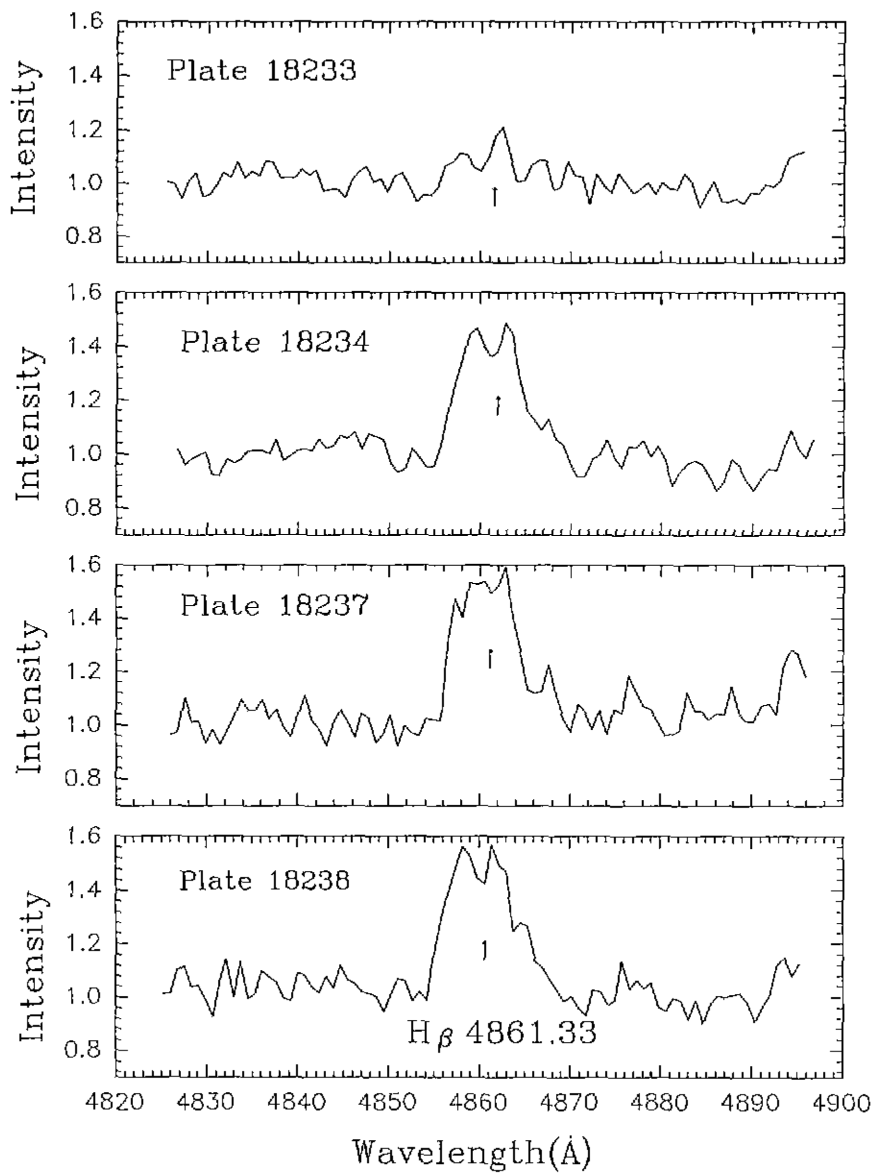

Figure 2 a-c. Balmer line emissions for each plates. The shape and intensity varied from plate to plate, which is connected with the envelope activity (possible infalling gas from the primary star) in the secondary star.

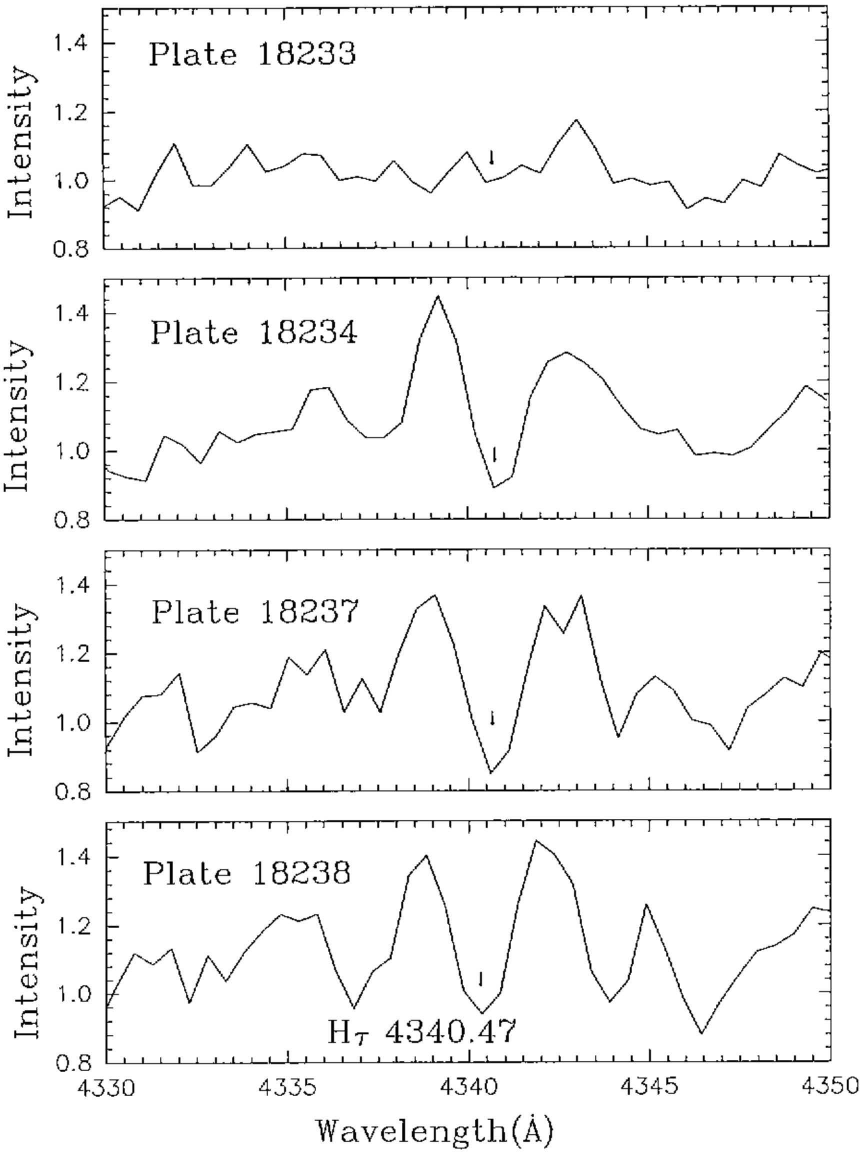

Plate 18233
Plate 18234
Plate 18237
Plate 18238
Intensity
1.4
1.2
1.0
0.8
H$_\gamma$ 4340.47
4330
4335
4340
4345
4350
Wavelength(Å)

Figure 2a-c.

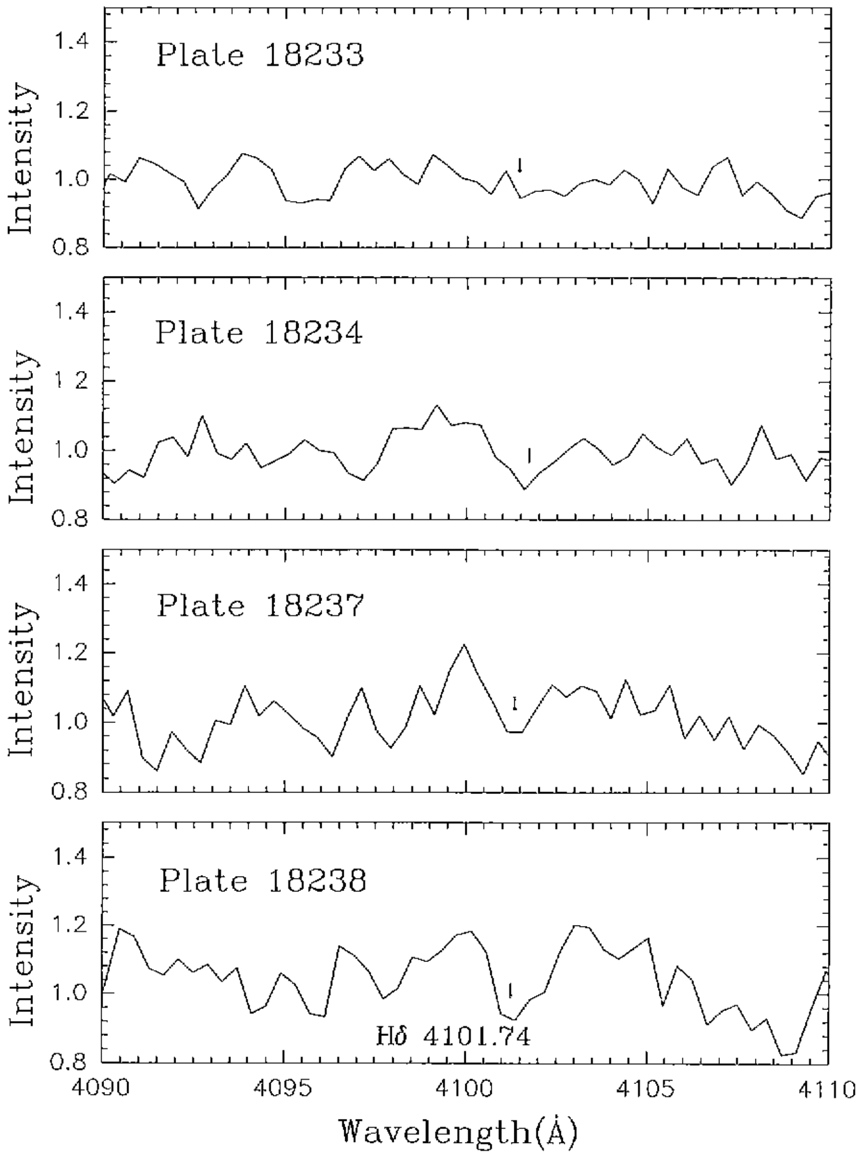
Plate 18233
Plate 18234
Plate 18237
Plate 18238
Intensity
1.4
1.2
1.0
0.8
Hδ 4101.74
4090
4095
4100
4105
4110
Wavelength(Å)

Figure 2a-c.

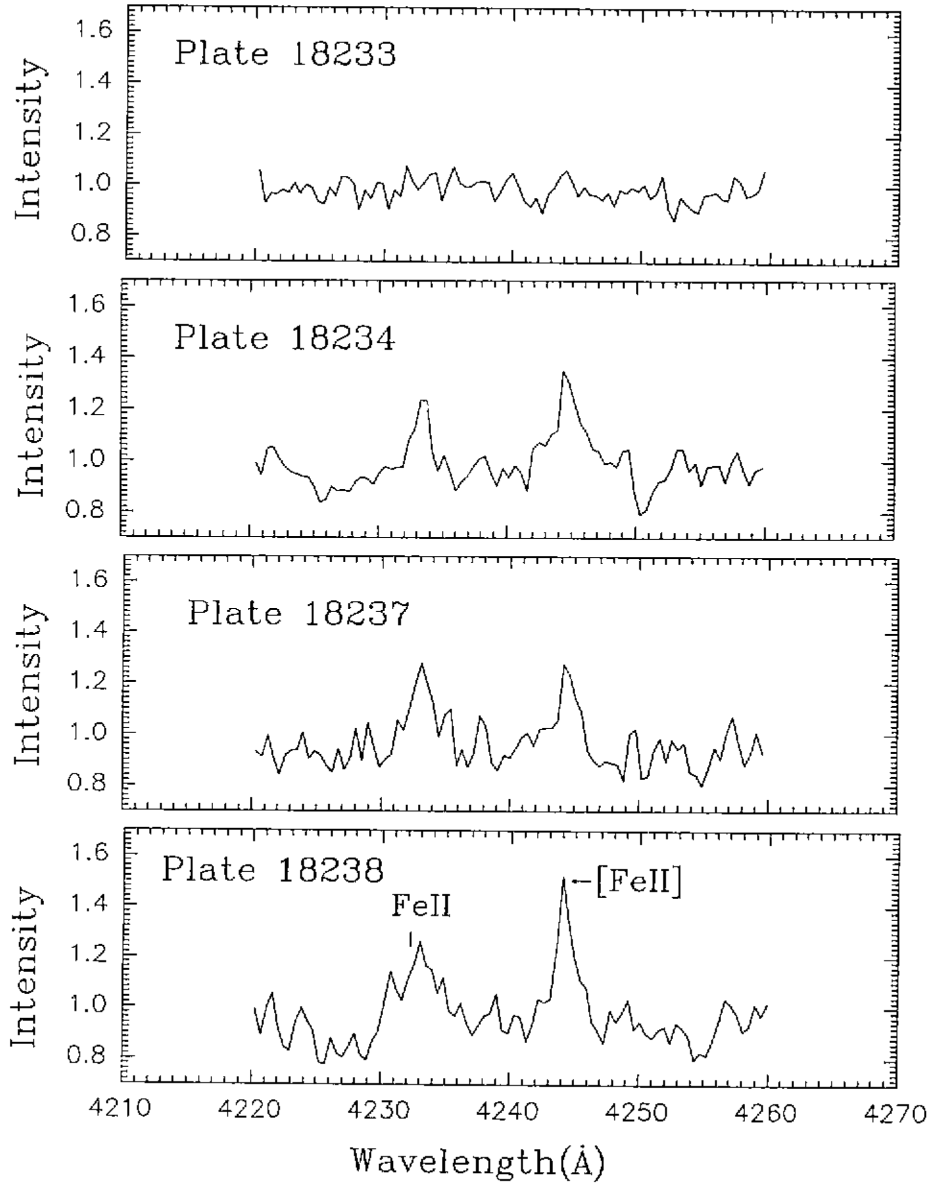

Figure 3. Ionized iron spectrum show strong emission feature as the result of the atmospheric activity in VV Cephei.

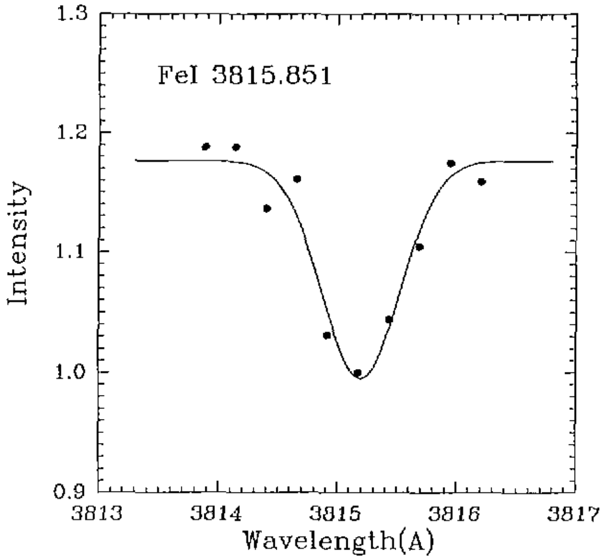

Figure 4. Gaussian fitting of FeI line to get the radial velocity. Filled circles are the observed intensities and the straight line is the curve fitting.

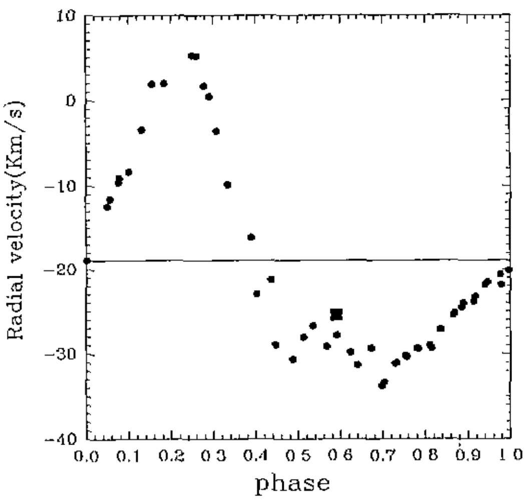

Figure 5. Radial velocities versus the phase of VV Cephei. Filled square is the calculated radial velocity of -25.7 km/sec, which value is in good agreement at the phase of 0.59. The straight line indicates the system velocity of -18.9 km/sec.

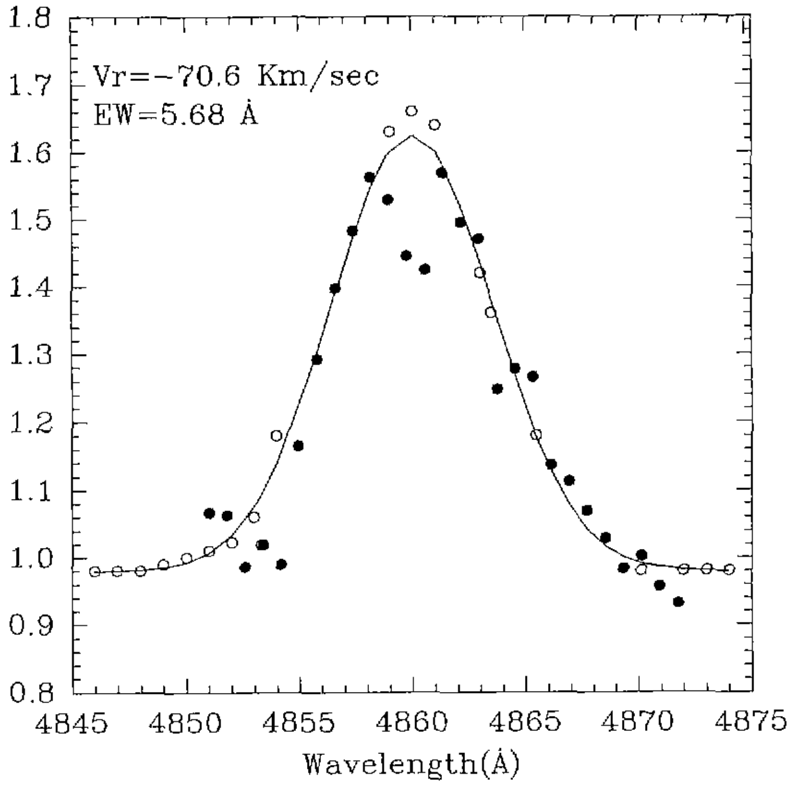

Figure 6. The Gaussian fitting of H_β emission line to get the radial velocity. Filled circles are the observed intensities and open circles represent artificial smooth points. Straight line is the fitting curve to get the radial velocity.

The calculated mean radial velocity (filled square) is in good agreement with the phase at 0.59. The straight line represents the system velocity of VV Cephei as -18.9 km/sec (Peery 1966).

The radial velocity of the secondary component was estimated from the Gaussian fitting of H_β emission lines. Figure 6 shows the fitting of H_β line where filled circles are the observed spectrum and open circles represent artificial smooth points of H_β emission line. From this fitting we can get radial velocities of the secondary component as -45.9 km/sec (plate 18237) and -70.6 km/sec (plate 18238) with the mean value of -58.3 km/sec.

5. CONCLUSIONS

From the observed spectrum of VV Cephei we confirmed strong emission features in Balmer lines. These emissions are also found in ionized iron lines. The observed emssion features change abruptly, which can be interpreted as the result of the atmospheric activity of the primary M star or the envelope of the secondary star.

The calculated radial velocity was -25.7 km/sec, which is in good agreement with the phase of 0.59.

ACKNOWLEDGEMENTS: This work was financially supported by the Ministry of Education, and we are grateful for this support.

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