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Mg II LINE VARIATION OF 32 CYGNI[1]

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ABSTRACT

The Mg II lines have been extracted from the IUE archival spectra of 32 Cygni to investigate the effect of the atmospheric eclipse. The UV light curve has been reduced from the continuum flux at the center wavelength of 2807.5Å in the IUE spectra. The equivalent width of the Mg II k absoption line has been measured for each spectra. The results of the light variation and flux tracing of the absorption line at the vicinity of the primary eclipse confirmed the atmospheric eclipse. The atmospheric effect lasted until the phase 0.06 in the absorptin line tracing, while it lasted until the phase 0.02 in the UV light curve, respectively.

1. INTRODUCTION

The Zeta Aurigae star, 32 Cygni, consists of B4IV-V and K5I (McKeller and Petrie, 1958). The late type supergiant is known to have a greatly extended atmosphere. The effect of an "atmospheric eclipse", observed when this component passes in front of the early type companion, is one of well known characteristics of the Zeta Aurigae systems classified by Bidelman (1954) and reviewed by Cowly (1969).

A radial velocity curve was observed and spectroscopic elements computed as early as 1918. Since the similarity to Zeta Aurigae was recognized from spectra taken in 1949, many investigators especially at Victoria published spectroscopic eclipse observations of 32 Cygni. For the spectroscopic analysis Wright (1950, 1951, 1970) showed the variation in intensity of the K-line of ionized calcium following the 1949, 1952, and 1959 eclipse with his observation. Wellmann (1951, 1957) analyzed his spectrophotometric data observed during 1952 eclipse. The spectroscopic observations were continued during the eclipse of 1962 by Hack (1962) and Faraggiana *et al.* (1965). Saijo and Saito (1977), and Saito and Kawabata (1988) discussed the wavelength dependence of the opacity in the atmosphere of the K-type component of 32 Cygni. Recently the radial velocity and a spectroscopic study of 32 Cygni were carried out

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by Tan and Peng (1984), Liu *et al.* (1984) and Griffin *et al.* (1990).

In 1960's the photoelectric observations had been carried out during 1961 eclipse by Kwee and Van Gendern (1963) and Herczeg and Schmidt (1963). In 1970's Griffiths and Stencel (1972), Griffiths *et al.* (1972), and Bloomer and Wood (1974) continued photoelectric observations for 32 Cygni. Jonhansen *et al.* (1970) made a thorough analysis of UBV observations in the 1959, 1962, and 1965 eclipses and found the atmospheric nature clearly demonstrated. In 1971 the object was included in the internationally coordinated program (Wright, 1970). Gauinan and McCook (1974, 1979) have published a series of photoelectric obervations at H-alpha and H-beta made outside eclipse and reported on variations in these regions. The narrow-band photometry of 32 Cygni was made by Cester and Pucillo (1975). Resently Bohme (1987, 1989), Dolzan (1987), and Nha *et al.* (1991) continued to observe this object as a long period eclipsing binary.

Since satellite observation was available in 1970's, UV photometry from the orbiting astronomical observatory during the 1971 eclipse of 32 Cygni was carried out by Doherty *et al.* (1974). The UV observation has been continued by the IUE launched in 1978. Stencel *et al.* (1979) analyzed the effects of the B star within the upper chromosphere of a late type supergiant using the IUE observations of 32 Cygni. Hempe (1982) developed theoretical model for the UV resonance line formations. Che *et al.* (1982, 1983) determined mass-loss rate of supergiant of 32 Cygni. Schroder (1983, 1987) analyzed the stellar prominance and chromospheric properties of 32 Cygni.

In this paper the IUE archived spectra have been collected to investigate Mg II line variations of 32 Cygni. In chapter 2, the UV light curve were reduced from the IUE spectra and has been analyzed for a limited solution. In chapter 3, the Mg II k emision line is decoupled for each star's radiation. The equvalent width has been measured for the absorption of Mg II k line in chapter 4. The parameters and atmosphere of the K star is discussed in the last chapter.

2. UV LIGHT CURVE AND ITS PARAMETERS

IUE spectra of 32 Cygni had been taken between 1979 and 1984 by many investigators. A total of 58 high disperion spectra had been accumulated and stored in the IUE observatory. We collected all high dispersion spectra and extracted the spectrum in the wavelenth region between 2790Å and 2810Å to investigate Mg II line variation and continuous flux variation against orbital phase.

The IUE raw data have been converted to the ASCII code and reduced to the wavelength versus absolute flux (erg/cm^2/sec/Å) measured at the earth using the RDAF software of the IUE Observatory The spectral region between 2806Å and 2809Å has been selected as a continuum. The absolute fluxes within the selected range as the continuum were integrated and converted into the magnitude scale to measure the brightness of the continuum at each phase using the method described by Kang (1990). The magnitudes of the continuum flux at the center wavelength 2807 5Å are listed in Table 1 with their image sequence numbers of the IAU spectra and orbital phases. The orbital phases were calculated using the light element (Wood *et al.* 1980) listed below;

$$Min\ I = JD\ Hel.\ 2433225.1 + 1147^d.6E$$

Magnitudes in Table 1 are plotted against phases in Figure 1. The light curve in Figure 1 is the first UV light curve of 32 Cygni. Eight points of 58 are omitted in the plotting. These points were reduced from the bad spectra which have negative epsilon values.

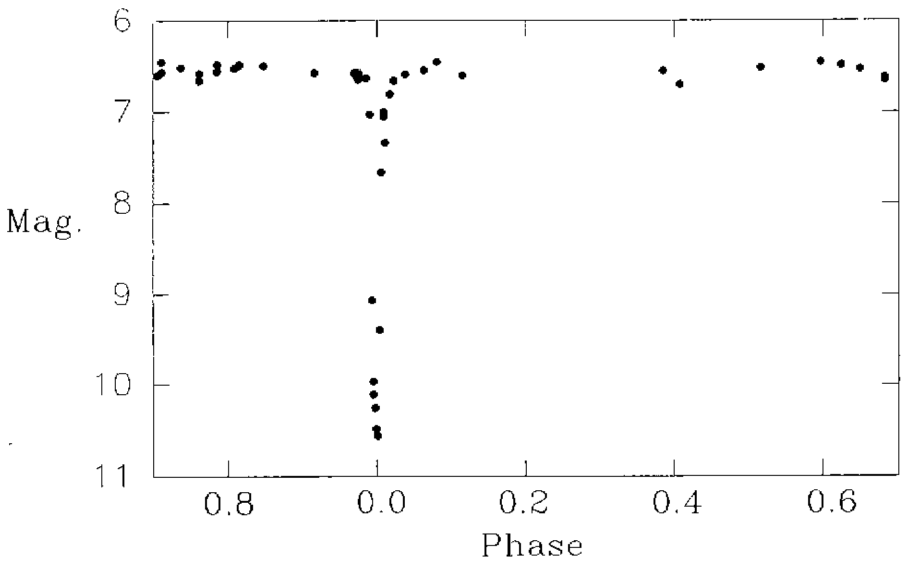

Figure 1. UV light curve of 32 Cygni. The magnitudes converted from the integrated fluxes of the IUE spectra in the wavelength region of 2806-2809Å.

The depth of primary eclipse, computed from the average of outside eclipse, is approximately 4.1 magnitudes in UV range while it is 0.2 magnitude in V. The secondary eclipse was not detected in the UV region, because of large temperature and size differences between two stars. A deep depth of the primary eclipse in the UV spectral range gives better determinations of parameters which affect a shape of primary eclipse. A limited solution were found by the modified Wilson and Devinney (1971) computer model for the observations during the primary eclipse.

The variation of brightness outside eclipse, found in the optical light curve of the Zeta Aurigae stars, is shown in the UV light curve of 32 Cygni. The model, adopted in this work

Table 1. UV magnitudes reduced from IUE spectra of 32 Cygni at 2807.5Å.

Image No.	Phase	Mag.	Image No.	Phase	Mag.
lwr10298	0.0002	10.5561	lwr16025	0.6817	6.6205
lwr10325	0.0028	9.3890	lwr7666	0.7064	6.6025
lwr10339	0.0047	7.6600	lwr16274	0.7110	6.5642
lwr10358	0.0080	7.0475	lwr16275	0.7111	6.4501
lwr10359	0.0080	7.0264	lwr16487	0.7371	6.5135
lwr10362	0.0082	7.0045	lwr16685	0.7614	6.5750
lwr10363	0.0082	7.0244	lwr16686	0.7615	6.6591
lwr10373	0.0097	7.3395	lwr8413	0.7842	6.5544
lwr10374	0.0098	7.4421	lwr16862	0.7850	6.5492
lwr10378	0.0100	7.4533	lwr16863	0.7851	6.4796
lwr10377	0.0100	7.4825	lwr8665	0.8091	6.5191
lwr10384	0.0115	7.0544	lwp2161	0.8147	6.4886
lwr10406	0.0132	6.7360	lwp2162	0.8147	6.4767
lwr10442	0.0167	6.8044	lwp2353	0.8477	6.4914
lwr10494	0.0219	6.6548	lwr9603	0.9151	6.5671
lwr10656	0.0377	6.5868	lwr10044	0.9686	6.5786
lwr10876	0.0622	6.5447	lwr10047	0.9687	6.5706
lwp4093	0.0798	6.4537	lwr10083	0.9732	6.6047
lwr11322	0.1134	6.5998	lwr10084	0.9733	6.6010
lwr2275	0.1770	8.0402	lwr10086	0.9733	6.5987
lwr12894	0.3105	7.0938	lwr10087	0.9734	6.5717
lwr3914	0.3328	7.5524	lwr10088	0.9734	6.6378
lwr13540	0.3845	6.5508	lwr10165	0.9837	6.6296
lwr4622	0.4084	6.6959	lwr10202	0.9889	7.0281
lwr14672	0.5164	6.5129	lwr10230	0.9924	9.0581
lwr15337	0.5963	6.4490	lwr10252	0.9944	9.9654
lwr6829	0.6237	6.4877	lwr10255	0.9947	10.1021
lwr15784	0.6487	6.5268	lwr10273	0.9968	10.2530
lwr16024	0.6817	6.6504	lwr10285	0.9984	10.4766

does not include the variation outside eclipse except a spot model. It is clear the variation is not due to the spot. Two reasons, variation outside eclipse and no secondary eclipse, force to us to find a limited solution of 32 Cygni. We used the observations near and during the primary eclipse for the limited solution. To fit the theoretical light curve to the observation during primary, we adjusted inclination and temperature of K star rather than the size of K star. Parameters for the proximate effects were adopted from mean values or theoretical values. We found that the inclination is most sensitive for the length of the totality because of the size difference between two stars. The combination of the K star's temperature of 3600K and the inclination of 82.38 degrees produces the best fit to the observation. The duration and totality of the primary eclipse are 23 days and 11 days, respectively in the UV light curve while the totality, measured in optical region, lasted 12 days in 1949 and 1952 eclipse (Wright 1970). The length of the totality has been changed in every eclipse.

The fit to the observations for the primary eclipse is plotted in Figure 2. The fit is not acceptable at the vicinity of the fourth contact. The observation are fainter than the theoretical ones at the phase 0.007-0.020 and at the phase 0.983. This is due to the B star's radiation is attenuated by the atmosphere of the K star. The effect of the atmosperic eclipse at the fourth contact is larger than that at the first contact because of the eccentric orbit of the system.

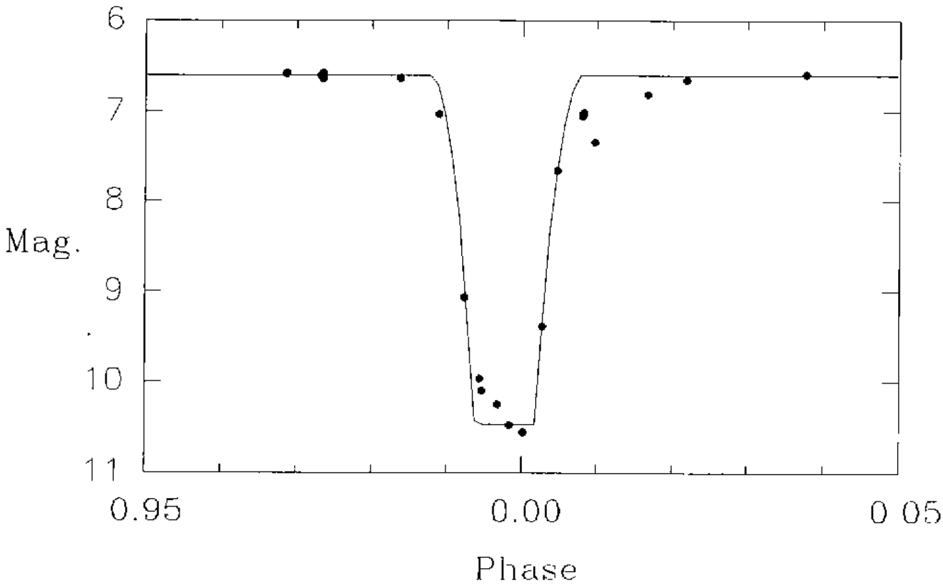

Figure 2. The fit to the UV observations for the primary eclipse of 32 Cygni. The fit is not acceptable at the fourth contact because of the atmospheric eclipse.

3. DECOUPLING OF THE Mg II LINE PROFILES

IUE long wavelength spectra covers the wavelength region between 1900Å and 3000Å. One of most dominant emission line in the IUE long wavelength region is Mg II h and k resonance line. We concentrated to analyze the Mg II k line profile for the characteristics of 32 Cygni. The laboratory wavelength of Mg II k line is 2795.523Å. This line is most sensitive at the temperature between 10,000K and 100,000K. 32 Cygni consists of B4 main sequence and K5 supergiant stars. The Mg II line is formed by the radiation from B star's photosphere and K star's chromosphere. The spectral line is superimposed rather than showing double lines. To investigate each star's characteristics the line should be decoupled for each star. The spectra taken at the conjunction, where only K supergiant is in the line of sight, was formed by the radiation of K star only. If we substract the spectrum taken at the conjuction from the superimposed spectrum, we could get the spectral line formed by the B star's radiation only. Thus all spectra except those taken at the conjunction can be decoupled by substracting the K star's line profile as below;

$$F\ (B\ star) = F\ (obs : B + Kstars) - F\ (Doppler\ shifted\ K\ star)$$

Before the substraction we corrected a Doppler effect due to the binary orbit motion with the radial velocities for each star. The theoretical radial velocity curves are computed by the Wilson and Devinney program. The input parameters for the program are adopted from the spectroscopic parameters by Wright (1970). The phase used in this paper is a photometric phase where the phase is 0.0 at the conjunction.

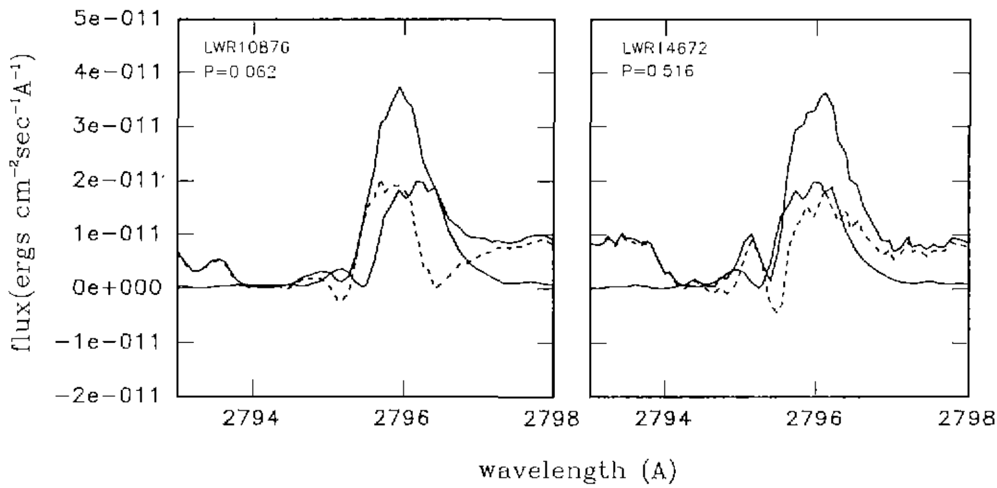

Figure 3. Mg II line profile at phases 0.0064 and 0.5194. The observed line profile contains radiation from B and K star. Dotted line is a line profile for B star, which is computed by substracting the K star's line profile from the observed line profile.

Two representative spectra at the phase *0.0622* and *0.5164 are plotted in Figure 3*. Figure 3 contains observed spectrum, and computed B and K star's spectra. The computed spectrum of the B star is plotted with dashed line. Because of high eccentric orbit and the longitude of periastron ($\omega = 212$) for the system, K star is away from us and B star is approaching to us at the phase 0.0622 while it is opposite at the phase 0.5164. The direction

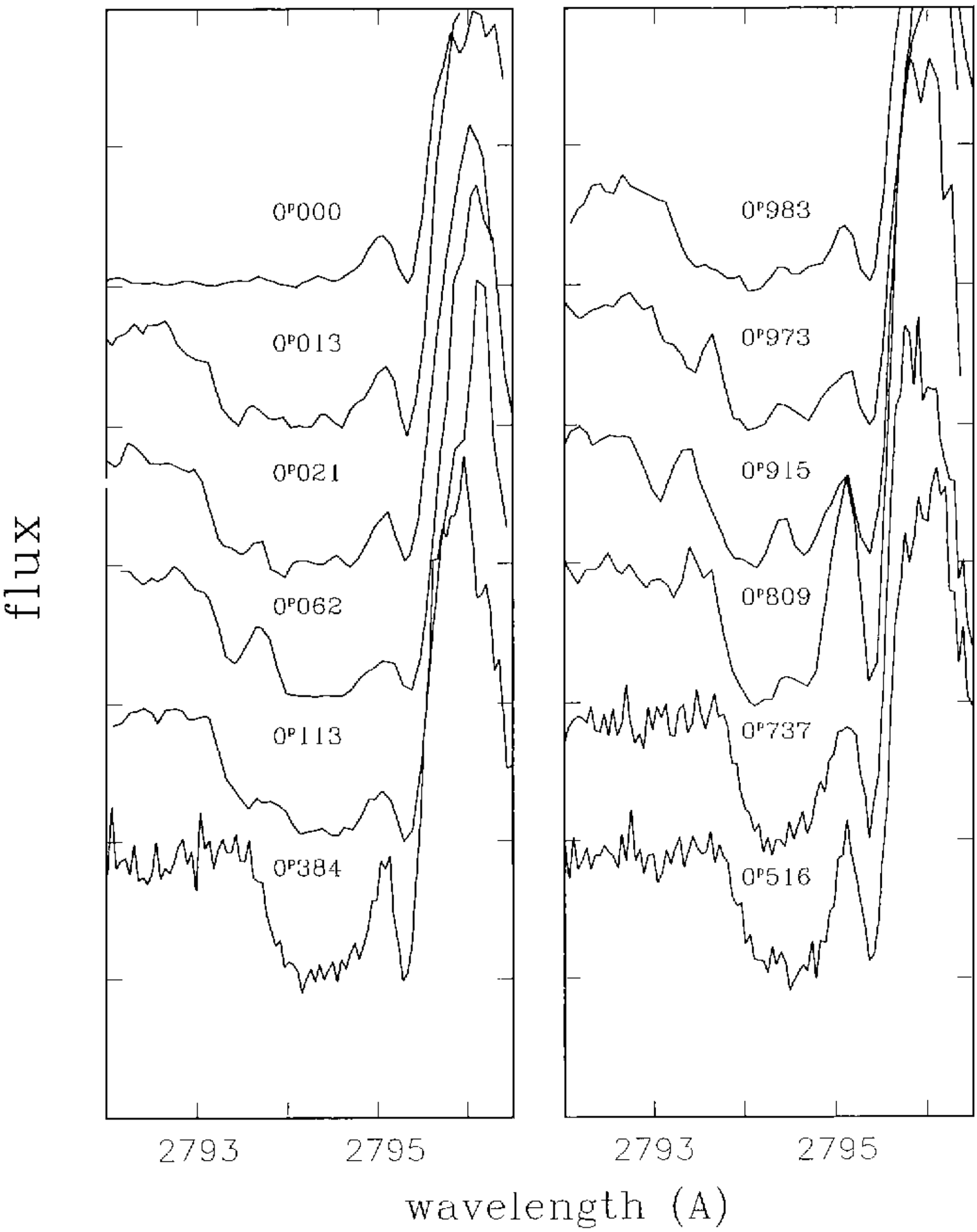

Figure 4. Flux tracings of Mg II k absorption line drived from IUE spectra of 32 Cygni.

of the motion of each component agrees with theoretical radial velocity computed based on the published elements. Rest of spectra agree with the direction of motion. We note that all observed lines were red-shifted so that the radial velocity curve reduced from the IUE spectra does not agree the published one.

4. ATMOSPHERIC ECLIPSE

An evidence of the atmospheric eclipse, shown in the spectra of this group of star, has reported since the time of the 1932 eclipse of Zeta Aurigae. Write (1970) showed enhancement of the K line of ionzed calcium, λ 3933.66Å, in the spectra of 32 Cygni well before and after the eclipse. His result has been interpreted as absorption of the radiation of the B star by the outer atmosphere of the K supergiant star. Similar approch has been attempted in UV spectral region. *Mg II h and k resonance lines*, λ *2795.523Å* λ *2802.698Å, are known to* a chromospheric indicator in UV spectral region while CaII H and K are in optical region. In this paper Mg II k lines at different orbital phases were reinvestigated for the atmospheric eclipse in UV region. At the conjunction, where the only K star is seen at the earth, the Mg II h and k emision lines are not so dominated compared to those at other phases and no absoption is shown. But the emission lines are getting dominated as well as the absortion of the B star's radiation when the B star is out of eclipse. This means the B star's radiation from the photosphere merged with the K star's radiation from the chromophere. We confirmed this phenomenon in the UV light curve of the chapter 3.

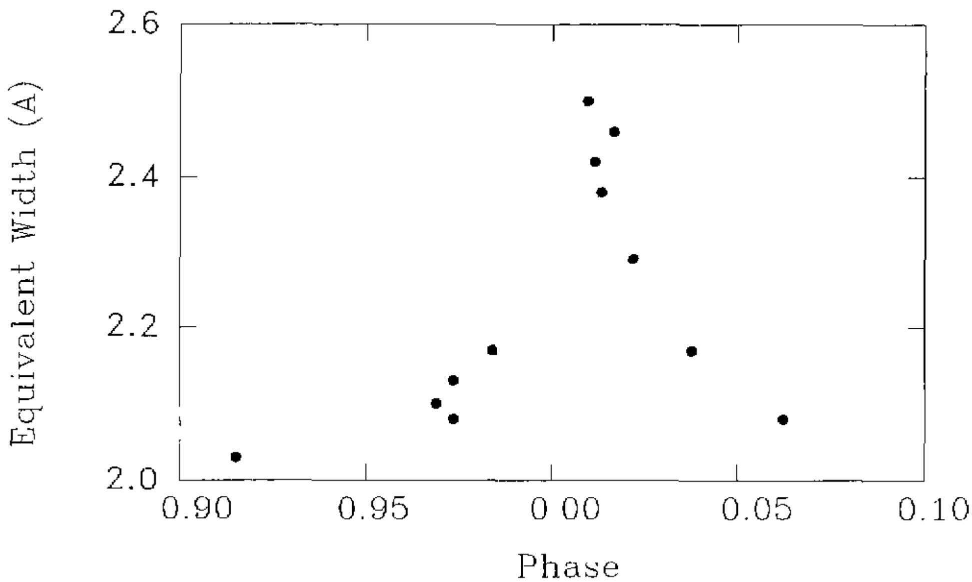

Figure 5. Equivalent-widths of Mg II k absoprtion line of 32 Cygni.

We investigate the relation between the orbital phase and the k line absorption for 32 Cygni. We measured the equvalent width for the intensity of the absorption lines in the 58 spectra of 32 Cygni. Twelve representative absorption lines are plotted in Figure 4 to trace the absroption lines according to phases. The width varid rapidly before the first contact and after the fourth contact of the primary eclipse. After fourth contact the width of the absorption line decreases until the phase 0.113. The widths of the absorptions between the phases 0.31 and 0.85 did not vary as seen in Figure 4. They are narrower than those at vicinity of the primary eclipse. The equivalent width measurments of the absorption lines from the phase 0.90 to the phase 0.10 are plotted against phases in Figure 5, in order to see the variation of the width near the primary eclipse. During ingress and egress, the flux is relatively so week that the absorption is not clear for the measurement. After fourth contact the width decreases rapidly. This result infers that the atmosphere surrounded the K star has two types. The inner atmosphere has high density and is an optically thick atmosphere and out atmosphere has low density and optically thin one. The outer atmosphere extended the whole binary orbit.

5. DISCUSSIONS

The UV light curve of 32 Cygni shows somewhat different from the optical light curves. The length of duration and totality are shorter those in the optical region. The result is similar to VV Cephei. In the UV light curve the totality is not seen. The brightness has varied continuously between phase 0.990 and 0.003. We do not accept this variation is real. First the K star is too faint in the UV region so that observation error is relatively larger than any other phases. Second the IUE spectra during the period did not show the line profile of the B star. This is why we fit the theoretical light curve including the totality to the observations for the primary eclipse for the limited solution listed in Table 2. According to the equivalent width measurement of the absorption line, the atmospheric effect lasted until the phase 0.06, while the effect lasted until the phase 0.02 in the UV light curve. This

Table 2. Limited solution for the primary eclipse of 32 Cygni in UV region.

Duration of the primary eclipse	23 days
Totality of the primary eclipse	11 days
Temperature of B star	17600K
Temperature of M star	3600K
Radius of B star	0.0033
Radius of M star	0.1750
Inclination of the system	81.38

is a result of the density distribution of the atmosphere. Especially the density of the inner atmosphere seems to decrease rapidly to the out atmosphere so that the continuum flux of the B star is not attenuated significantly while the absorption line is still broadening at the phase 0.02 Finally we note the atmospheric effect, deduced from the light curve and the absorption line tracing, shows asymmetry because of the eccentric orbit.

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