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IUE ARCHIVAL SPECTRA OF 31 CYGNI*

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Abstract

UV light curve of 31 Cygni has been made from the IUE high dispersion spectra. The depth of primary minimum of the light curve is 5.2 magnitudes because the B4 star's steep spectral gradient. The light curve has been analyzed by the method of Wilson and Devinney Differential Correction(WD). The radial velocities have been measured using the Mg II h lines. The spectroscopic elements have been determined by the method of WD. The change of the Mg II resonance doublet has been investigated based on the eight representative spectra taken at well distributed orbital ohases.

1. Introduction

The Zeta Aurigae-type eclipsing binary star 31 Cygni consists of K4 supergiant and B4 main-sequence stars. Its orbital period is 3784 days. The B4 star passes behind the supergiant at primary eclipse. However the K4 star is more massive than the B4 star. Thus the K4 supergiant is called a primary component in the spectroscopic analysis while it is a companion in the photometric analysis. The system was discovered to be spectroscopic binary by Campbell(1901). The spectrographic orbit was first determined by Vinter-Hansen(1944). The 1951 eclipse established the concept of an atmospheric eclipse. At the 1961, 1971, and 1982 eclipses, extensive photoelectric and spectroscopic observation confirmed fully the atmospheric nature of the eclipse. Some of these works are described by Sahade and Wood(1978). Classical studies of the eclipses with high-dispersion visible light spectroscopy demonstrated that the late-type supergiant possesses an outer atmosphere and the temperature rises analogous to the solar chromosphere.

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With the launch of the IUE satellite in 1978, the extension of observation into ultraviolet has greatly expanded the study of the extended atmospheres of late type supergiants. With the advent of high-resolution ultraviolet spectroscopy, P Cygni profiles were discovered in the resonance lines of the UV in contrast to optical line profiles. The mass loss rates have been studied from ultraviolet lines formed in the winds of these objects by Chapman(1981) and Che *et al.*(1983). Schroder(1985) has used column densities through chromospheres of three Zeta Aurigae systems to determine scale heights of chromospheres. The observation of the 1982 eclipse of 31 Cyg have been reported by Stencel *et al.*(1984). They obtained *UBV* light curves and optical-UV spectroscopy during the primary eclipse.

In this paper the UV light curve and radial velocity curve of 31 Cyg will be reduced from 34 archival IUE high dispersion spectra. We will investigate the change of Mg II features in the high dispersion spectra against the orbital phase.

2. Light curve from IUE spectra

Archival IUE spectra of 31 Cyg are all high dispersion spectra except two spectra. For IUE photometry of 31 Cyg, we selected the spectral regions between the wavelengths 2806 Å and 2809 Å, just after Mg II k line, in the 34 high dispersion spectra. The IUE extracted image has been converted to the wavelength versus absolute flux using the Regional Date Analysis Facility in the IUE observatory. The method was described by Kang(1990). The flux in the selected spectral range was integrated and converted into the magnitude scale to construct the light curve at the center wavelength 2807 Å in UV region. Table 1 lists information of the spectra, phases and magnitudes.

The depth of primary minimum is 5.2 magnitudes in the region of wavelength 2800 Å while it is 1.70, 0.45, 0.15 magnitudes in *UBV* system. Compared with the light curves in optical region, the depth of the primary eclipse in IUE wavelength region is much deeper because the B4 main sequence star's steep spectral gradient. Figure 1 shows the depth variations against center wavelengths with theoretical values. The theoretical values of the primary eclipse in Figure 1 was calculated by the Wilson and Devinney light curve program. Table 2 lists the observed and computed depth of primary minimum in magnitude scale. The observation does not match the theoretical value. When the shorter wavelength shows good agreement, the longer wavelength does poor agreement between observation and computed value. This implies the extended atmosphere absorbs more light at the shorter wavelength region.

Table 1. IUE photometry of 31 Cygni at 2807.5 Å

Date	Time	Image No.	JD	Phase	Wavelength
82/317	5: 1	LWR14613	45286.7109	0.0087	8.2768
82/324	3:42	LWR14671	45293.6523	0.0106	5.0483
83/ 93	2:55	LWR15645	45427.6211	0.0460	5.0297
83/260	15:12	LWR16816	45595.1328	0.0902	5.0619
84/240	19:29	LWP 4094	45940.3125	0.1815	4.9559
85/136	2: 4	LWP 5987	46201.5859	0.2505	4.9711
78/248	1:37	LWR 2274	43756.5664	0.6044	5.8967
78/254	3:17	LWR 2316	43762.6367	0.6060	5.8610
89/234	12:39	LWP16190	47761.0273	0.6626	4.9328
79/148	18:19	LWR 4623	44022.2617	0.6746	5.0105
89/319	8:31	LWP16789	47845.8555	0.6850	5.0405
90/ 4	0:33	LWP17078	47895.5234	0.6982	4.9855
90/ 4	1:22	LWP17080	47895.5586	0.6982	4.9524
90/ 4	4:43	LWP17082	47895.6953	0.6982	4.9176
79/307	19:38	LWR 6017	44181.3164	0.7166	5.0409
90/ 96	21:26	LWP17705	47988.3945	0.7227	4.9523
90/ 96	22:40	LWP17706	47988.4453	0.7227	4.9619
90/126	19:16	LWP17865	48018.3047	0.7306	4.9815
90/126	20: 7	LWP17866	48018.3398	0.7306	5.0080
90/160	17:14	LWP18068	48052.2187	0.7396	4.9696
90/160	18:27	LWP18069	48052.2695	0.7396	4.9547
80/ 30	19:25	LWR 6830	44269.3086	0.7399	4.9947
90/183	14:51	LWP18265	48075.1172	0.7456	5.0125
80/125	18:34	LWR 7667	44364.2734	0.7650	5.0302
80/243	15:25	LWR 8666	44482.1406	0.7961	5.0133
80/365	2:42	LWR 9602	44603.6133	0.8282	4.9754
81/ 60	14: 0	LWR10045	44665.0820	0.8445	5.0602
81/ 65	23:15	LWR10085	44670.4687	0.8459	5.0153
82/103	21:52	LWR13018	45073.4102	0.9524	5.0284
82/172	7:59	LWR13535	45141.8320	0.9705	5.0305
82/246	10: 3	LWR14083	45215.9180	0.9900	5.2187
82/264	12: 8	LWR14225	45234.0039	0.9948	9.6586
82/264	13:22	LWR14226	45234.0586	0.9948	10.2548
82/268	17:18	LWR14262	45238.2227	0.9959	10.2157

The light curve consists of 34 observations and is plotted with computed light curve in Figure 2. As seen in Figure 2, observational quality and the number of observations during eclipse

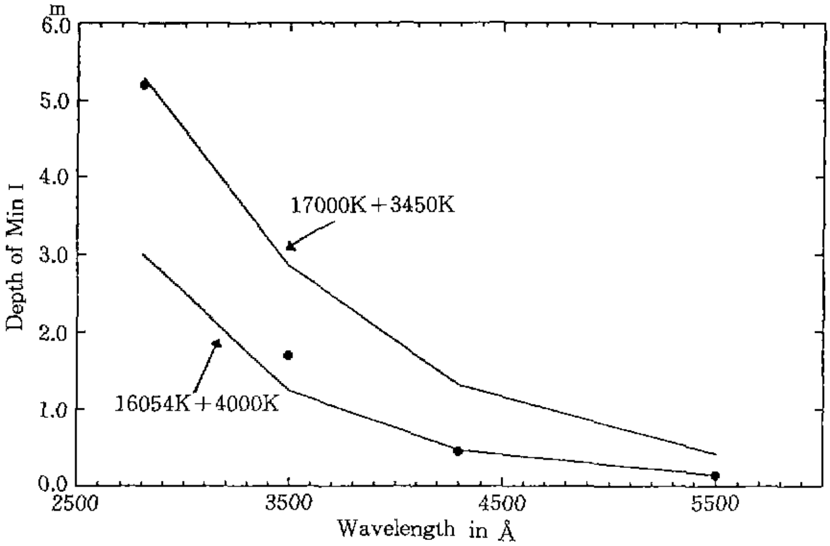

Fig. 1. Depth of primary minima versus center wavelengths. The depth of primary minima in UV region is much deeper than those in optical region due to B4 star's steep spectral gradient. The dots are observations and solid lines are computed with the temperature combinations of 17,000K+3,450K and 16,054K+4,000K by the WD light curve program.

Table 2. Depths of Primary Minima at Different Wavelengths

Wavelength (angstroms)	Observed (mag.)	Computed 1 (mag.)	Computed 2 (mag.)
2807	5.28	5.28	3.00
3600	1.70	2.85	1.24
4300	0.45	1.31	0.46
5500	0.15	0.42	0.15

are not good enough to give the detailed information of the proximate effect in eclipsing binary star. Thus temperatures, potentials, and inclination were only adjusted by the method of Wilson and Devinney Differential Corrections. The initial parameters were adopted from Eaton(1988). The final adjusted parameters as well as adopted parameters are tabulated in Table 3. The secondary eclipse is not shown in the theoretical light curve in Figure 2 because the size of the B4 star is negligible compared to the supergiant. However two observations at the phase of 0.6 are approximate 0.8 magnitude dimmer than those outside eclipse.

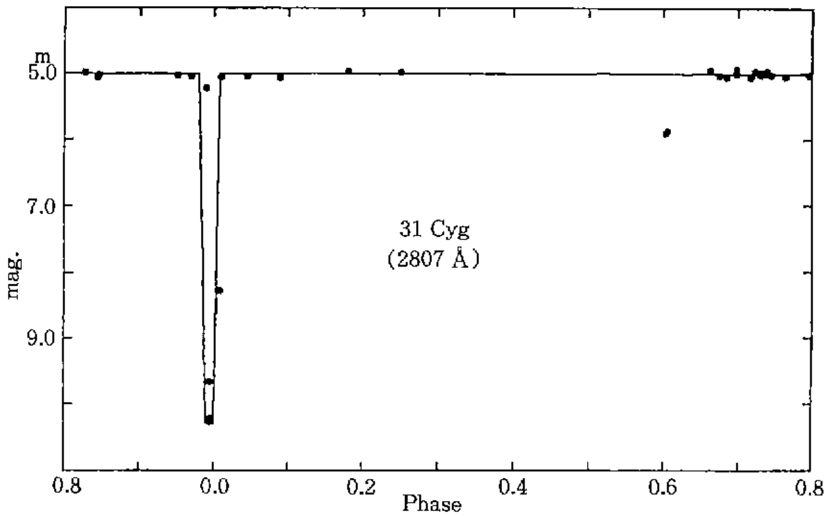

Fig. 2. IUE light curve of 31 Cygni, with our fitted model light curve.

Table 3. Photometric Elements of 31 Cygni

Inclination	88.0 Degrees	Phase Shift	0.93
Eccentricity	0.22	Mass ratio	1.5
Temp 1.	17000 K	Temp 2.*	3450±90K
Potential 1	450.0	Potential	22.0
Radius 1	0.0021	Radius 2*	0.0751±0.0040

* Adjusted

3. Radial velocity curve from IUE spectra

The radial velocity was reduced from each long wavelength spectra. A total of 34 spectra in the long wavelength region of IUE give an opportunity to construct radial velocity curve of 31 Cyg. The Mg II h line was selected to measure the radial velocity because the line is dominant in the K4 supergiant rather than the B4 star. First we used a Gaussian fitting to read off the center wavelength of the line. However some of lines are too asymmetry because of strong damping wings. Thus we measured the absorption core point of the Mg II h emission line rather than taking the result of Gaussian fitting. The pixel resolution is 0.02 to 0.05 Å in the high dispersion spectra so that it is good enough to read the absorption core position in the Mg II h emission line. We also take care the epsilon value recorded in the IUE extracted spectra which gives an information of saturated or other bad observation. We don't use the image which has negative epsilon value. Thus eighteen of thirty four spectra were used for the measurement of radial velocity. All radial velocities are converted to the heliocentric radial velocities. The radial velocity curve is plotted with theoretical curve computed by the WD radial velocity curve program(light program). We used photometric phase which is 0.0 at the primary eclipse. The system velocity was adjusted while other parameters are adopted from previous publications and fixed because the observation does not cover the full phase. The system velocity is −4.5km/sec which is slightly lower than −8km/sec in Hofflite(1988). The final results of the spectroscopic elements of 31 Cygni are listed in Table 4.

Table 4. Spectroscopic Elements of 31 Cygni

Longitude of periastron	201 degrees
Semi major axis	2537 Solar radii
System velocity *	-4.5 ± 0.04 km/sec

* Adjusted

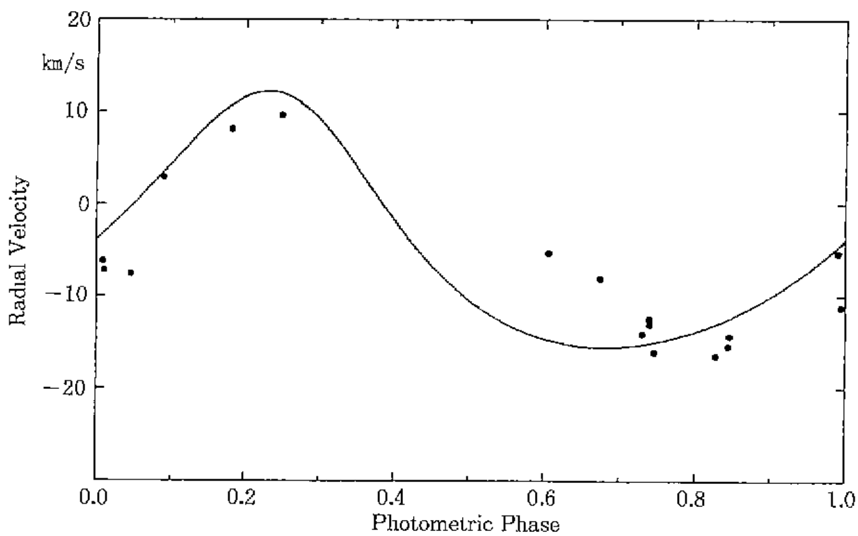

Fig. 3. Radial velocity curve of 31 Cygni, with our fitted model velocity curve

4. Mg II h and k Resonance lines

Ultraviolet spectra of 31 Cyg system have been taken, covering nearly 0.8 in phase, with the IUE satellite between 1978 and 1990. Out-of-eclipse, the ultraviolet spectrum of 31 Cyg is qualitatively similar to that of 32 cyg, featuring P Cyg structure in the strong Mg II resonance lines (Stencel *et al.* 1979). Mg II h and k lines are known as radiative cooling agents in stellar chromospheres. The stars in the red giant branch(KO III and later) appear to exhibit somewhat weaker chromospheric Mg II emission ratios than the dwarfs or supergiants of similar spectral type.

In order to see changes of Mg II features against the orbital phase, the wavelength region between 2790 Å and 2810 Å, where the Mg II resonance doublet exits, were extracted from the high dispersion spectra of 31 Cyg. Eight representative spectra of thirty four spectra are only plotted in Figure 4. The spectra in Figure 4 cover the whole phase except secondary eclipse. Two spectra at the bottom in Figure 4 were taken during totality of the primary eclipse. They show strong Mg II h and k emission lines come from only K4 supergiant. The "triple" emission components seen during totality was interpreted, by Stencel(1984), as P Cygni emission profiles sliced by interstellar absorption near the rest wavelength and circumstellar absorption probably associated with the cool star wind. Before and after the primary eclipse. the lines show the strong damping wings arising from scattering in the denser, lower chromosphere of the supergiant. Even the spectra at the phases of 0.75 and 0.25, completely out of eclipse, show the strong damping wings. This implies that the atmosphere of the cool supergiant is extended to the binary separation.

5. Discussion

We have reported here UV light curve and radial velocity curve obtained from IUE high dispersion spectra. Both curves have been analyzed by the method of Wilson and Devinney differential Correction respectively. The depth of primary eclipse at UV region is deeper than the theoretical one which is well fitted to the optical one. This might be explained that the extended atmosphere of K4 supergiant absorbs more light in the shorter wavelength region.

The damping wings at the out of eclipse suggest that the atmosphere of the supergiant is ex

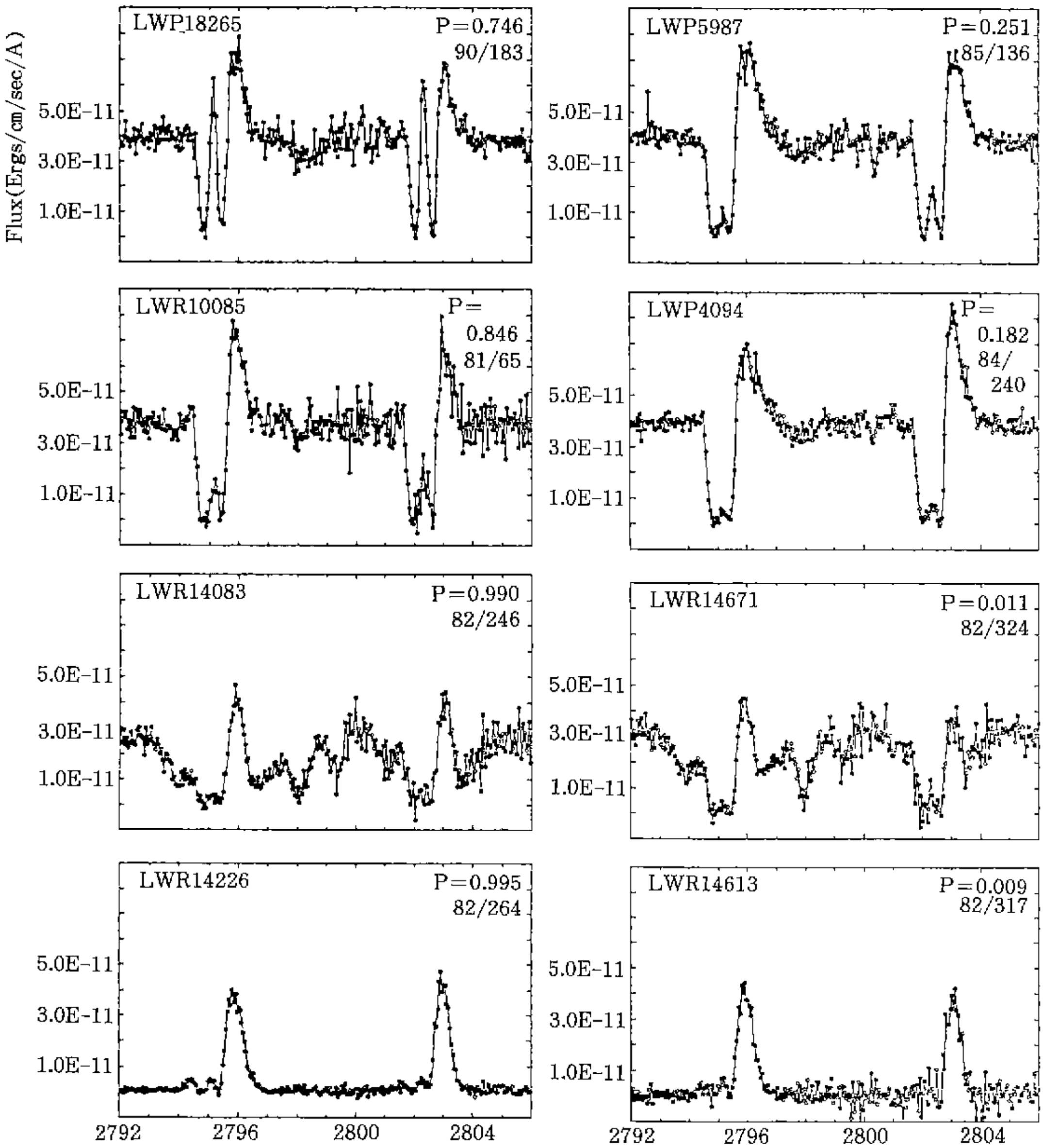

Fig. 4. Changes in the Mg II features of 31 Cygni. Bottom two spectra were taken during totality.

tended to the binary system.

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