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UV ENERGY DISTRIBUTION OF AZ CASSIOPEIAE [1]

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ABSTRACT

The IUE low dispersion spectra of AZ Cas have been analyzed for line identifications and energy distribution in ultraviolet region. Highly ionized atoms, Si IV and C IV are identified. We could infer a temperature range of the B star between 15,000K and 20,000K. The energy density distribution shows a hump between IUE short wavelength and long wavelength regions. Photometric and spectroscopic elements were revised based on the Florkowisk photoelectric observations and collected radial velocities. The temperature of both stars were reduced as 16,000K and 3,800K. The radii of both stars are 10 $R_\odot$ and 320 $R_\odot$. The eccentricity and longitude of periastron are 0.61 and 10.5°, respectively.

1. INTRODUCTION

AZ Cassiopeiae is one of the long period eclipsing binaries which have extended atmosphere. Its characteristics are very close to the spectroscopic binary, VV Cephei. AZ Cas contains an M0 Ib (Cowley *et al.* 1977) and a hot B star. Ashbrook (1956) found its variability from magnitudes estimated on Harvard patrol plates covering the eclipses between 1901 and 1947. He derived the ephemeris:

$$Min\ I = JD\ Hel.\ 2432484 + 3406^d E.$$

The priod is relatively short compared to other VV Cephei type stars whose periods are all longer then 20 years. Since Ashbrook's study, AZ Cas had been observed

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during its eclipses. Larson-Leander (1959) noted that his photoelectric coverage of the 3rd and 4th contacts during the 1957 eclipse occurred about 6 days earlier than predicted from Ashbrook's ephemeris. Photoelectric observations were carried out for the 1966 eclipse by Tempesti (1966). Bonnell and Herczeg (1976) revised the period to 3402 days. However, Florkowski's (1975) photoelectric observations suggested the period of 3402 days was too short. Cowley *et al.* (1977) reduced the orbital period from the information available for the 1957 and 1975 eclipses:

$$Min\ I = JD\ Hel.\ 2432481 + 3401^{d}E.$$

Very little photoelectric data, and even less on the spectrum, have been published for AZ Cas. Florkowski (1975) carried out *UBV* observations during 1975 eclipse and found the eclipse depths as $1^{m}.77$ in *U*, $0^{m}.68$ in *B*, and $0^{m}.25$ in *V*, respectively. Cowley *et al.*'s observations show that the totality lasted at least 105 days which is longer than Ashbrook's 95 days. Most photometry for AZ Cas were carried out during primary eclipses. Thus the analysis of light curves produced limited solutions only. The results of the solution show a high eccentricity in the range of $0.25 \sim 0.55$.

The aim of this paper is to revise photometric and spectroscopic elements of AZ Cas. For this purpose the IUE archival spectra have been collected from the IUE Observatory. The low dispersion spectra have been analyzed for line identifications and energy density distribution in UV region. From optical photometric data we have adjusted photometric and geometric elements while orbital elements have been adjusted from the radial velocity curve.

Table 1. IUE LOG Database for AZ Cas.

Image No.	Disp.	Aparture	Phase	Yr.	Day
LWP 10247	Low	Large	0.22	87	61
LWP 11890	Low	Large	0.29	87	290
SWP 3320	Low	Large	0.34	78	316
SWP 3320	Low	Small	0.34	78	316
SWP 32111	Low	Large	0.29	87	290

2. ENERGY DISTRIBUTION IN UV REGION

AZ Cas contains a hot B star and a M supergiant. Because of temperature difference between two stars, it is very useful to examin the IUE spectra for determining a temperature of the B star. The B star's light dominates that of the M star at the IUE spectral range whose wavelength is between 1000Å and 3000Å. A UV observation is blind for the M star. Thus the flux distribution in UV region provides a good chance for temperature determination of the hotter star. We search the IUE Merged log which includes all spectra taken by the IUE satellite since its launch. Unfortunately only 5 spectra were listed in the Merged log. They are all low dispersion spectra, because AZ Cas is too faint to expose a high dispersion spectrum with the IUE instruments. All five spectra were taken outside eclipse. Two of five spectra were taken in 1978, while other three were taken in 1987. We selected only three spectra taken in 1987 for this work because of sensitivity degradation during time interval. The orbital phase were calculated using the light element determined by Cowley *et al.* (1977). Table 1 lists information of IUE spectra analyzed in this work.

Line identifications were carried out in the short wavelength spectrum SWP 32111. We have investigated highly ionized atoms Si IV, C IV and N V in the wavelength region 1200Å ~ 1600Å. The Si IV doublet 1394Å and 1403Å , and C IV doublet 1549Å and 1555Å are shown in Figure 1. The N V is not shown clearly in the low dispersion spectrum of AZ Cas. Cassinell and Abbott (1980) noted that N V doublet is not seen as late as B2.5 while C IV until B6 and Si IV throughout the whole range of B type. The theoretical calculation of absorption line of N V is expected in the temperature of 20,000K, at $Ne = 10^{11}\mathrm{cm}^{3}$. N V, C IV, and Si IV lines are produced in the highly ionized region and in the transition between photosphere and x-ray forming region. The low dispersion spectrum of AZ Cas shows relatively strong Si IV doublet, medium C IV doublet and no evidence of N V doublet. Therefore we could infer that temperature of the B star is between 15,000K and 20,000K. The temperature of the B star has not been deduced in any other way except its spectral type roughly B. Therefore our result of the line identification above gives that the temperature of the B star is less than 20,000K.

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 2000Å and

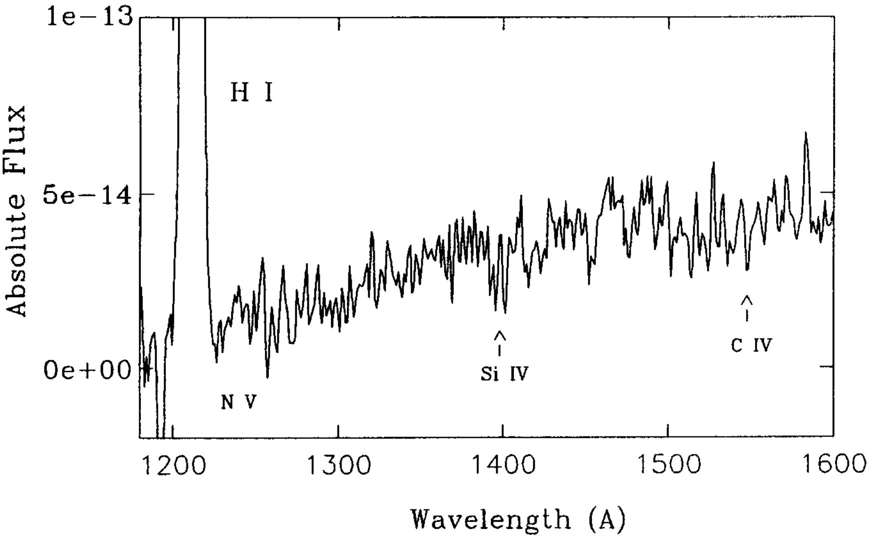

Figure 1. Line identifications in the IUE spectrum of AZ Cas. Highly ionized atoms Si IV and C IV are identified in the SWP 32111. N V is not seen in the spectrum of AZ Cas.

3000Å has been selected as a continuum in order to see the energe distribution in UV region. The absolute fluxes were integrated in every 100 angstrom interval from the low dispersion spectra. The integrated fluxes were converted into the magnitude scale to measure the brightness of the continuum (Kang 1990). Table 2 lists the magnitudes with their center wavelengths reduced from the IUE spectra, LWP 10247, LWP 11890, and SWP 32111.

The UV magnitudes are plotted against wavelengths to investigate the UV energy distribution of AZ Cas in Fugure 2. The Long Wavelength Prime (LWP) camera covers the wavelength region of 1700Å ~ 3300Å while the Short Wavelength Prime (SWP) camera covers the wavelength region of 1000Å ~ 1900Å. As seen in Figure 2, the brightness decreases as the wavelength shortens until 2000Å. In the short wave length region the maximum brightness appears at 1700Å. There is a discontinuity at the wavelength of approximate 2200Å.

We have calculated theoretical fluxes of AZ Cas and converted the fluxes to

Table 2. Wavelengths vs magnitudes for AZ Cas in UV region.

Wavelength (Å)	Mag.[1]	Mag.[2]	Wavelength (Å)	Mag.[3]
2050	7.82	8.80	1050	8.56
2150	8.35	8.84	1150	7.65
2250	8.83	8.35	1250	6.45
2350	8.30	7.78	1350	7.75
2450	7.51	7.45	1450	7.39
2550	7.37	7.17	1550	7.36
2650	7.15	6.91	1650	7.22
2750	6.85	6.70	1750	7.16
2850	6.70	6.56	1850	7.47
2950	6.62	6.46		
3050	6.64	6.50		
3150	6.55	6.30		
3250	6.43	6.30		

1: LWP10247, 2: LWP11890, 3: SWP32111

magnitudes by the modified Wilson and Devinney (1971, hereafter WD) computer code. For this job we have to modified the Light Curve program of the WD code. The WD light curve program integrates amount of light in the direction of line of sight to construct a light curve for monochromatic light. It does not calculate light for multicolor light curves. It calculates normalized light for each light curve independently so that it is impossible to compare the light for multi color light curves. Our aim is to calculate a theoretical brightness for various wavelength regions and comapre the theoretical ones with observations to adjust the wavelength dependent parameters by the method of trial and error. The WD differentail correction program takes care multi-color curve but it requires enough phase coverage. Thus we modified the Light Curve program which can calculate multi color light curves and color curves. It also calculates lights and radial velocities for given phases rather than whole phases so that we could concentrate for the interrested phases only.

First of all we have adjusted temperatures and sizes of both stars in optical region. Florkowiski found the depths of primary eclipse as $1^m.77$ in *U*, $0^m.68$ in

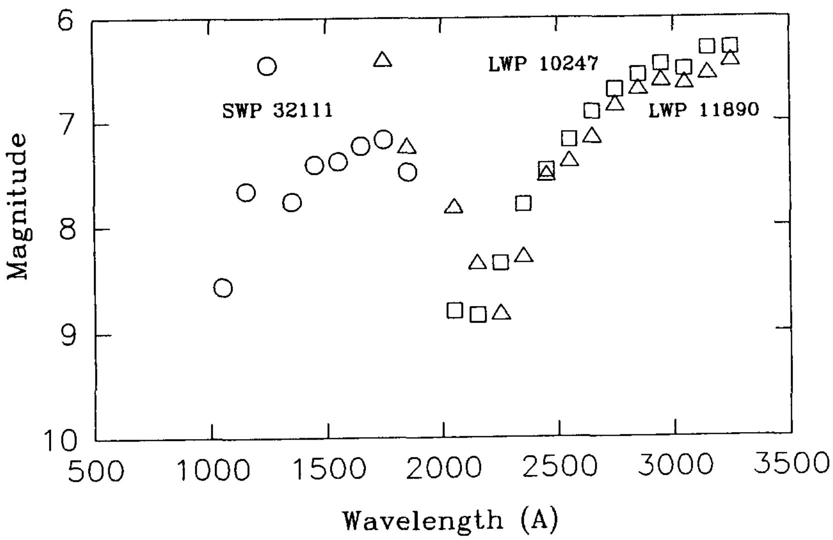

Figure 2. Energy distribution of AZ Cas in UV region. Squares, triangles and circles are magnitudes reduced from LWP 10247, LWP 11890 and SWP 32111, respectively. The absolute fulxes were integrated in every 100 angstrom interval from the low dispersion spectra and were converted into magnitude scale.

B, and $0^m.25$ in *V*, repectively. Whole light curve has not been published but the totality and eclipse duration were estimated as 105 days and 125 days which are correspond to $0^p.031$ and $0^p.036$, respectively. Based on the *UBV* depths, totality and eclipse duration of primary eclipse the best combination set of temperatures and sizes was found by the method of trial and error, using the modified WD light curve program. We have adjusted temperatures of both stars, and potentials of both stars assuming 90°of the orbital inclination. Other proximate effects were not adjusted. The temperatures of both stars were adjusted as 16,000K and 3,800K, and the radii of both stars were 0.0044 and 0.1338, respectively. The B star's temperature is reasonable, but the M star's temperature is little higher than previous result. The radii of AZ Cas were reduced as 10 $R_\odot$ and 320 $R_\odot$, respectively.

3. RADIAL VELOCITY CURVE

Published radial velocities of AZ Cas were collected from various sources because of its long period. One of charateristics in spectroscopic orbit of AZ Cas is a high eccentricity. The system shows a single line spectrum so that the measurement of radial velocities were carried out for the M star. Previous solution shows the eccentricity of AZ Cas is in the range of 0.3 $\sim$ 0.6. Collected radial velocities were re-analyzed by the method of the WD Differential Correction to revise the spectroscopic elements.

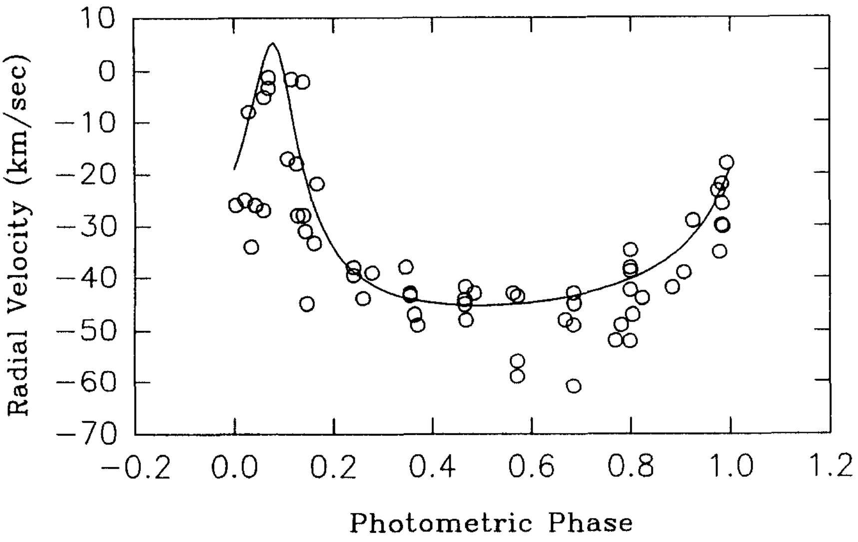

Figure 3. Radial velocity curve of AZ Cas. Circles are observations collected from various literatures and solid line is a theoretical curve produced by the WD program.

Because of high eccentricity, combination of a semi-major axis, eccentricity and mass ratio is critical to form the system's Roche configuration. Some classical analysis shows a radius of M star exceeds its Roche lobe at the periastron passage. Thus it is requirable to determine an eccentricity correctly. Whole light curve has not been published yet. Also we do not expect to detect the secondary eclipse in the light curve. Thus parameters for the eccentric orbit should be adjusted from the radial velocity curve. Althrough a period of AZ Cas is extreamly long, gathering of all spectrogram makes it possible to construct a radial velocity curve for whole phase.

Initial parameters were adopted from Cowley *et al.* (1977) to run the WD Differential Correction program. The initial parameters of an eccentricity, a longitude of periastron, a semi-major axis and a system velocity are 0.55, 4°, 4000 $R_\odot$, and −33.6 km/sec, respectively. Our goal here is to adjust eccentricity and longitude of periastron for the radial velocity curve. We assumed 90°of the orbital inclination as we did in the light curve. The eccentricity, longitude of periastron and semi-major axis have been adjusted to 0.61, 10.55°, and 2400 $R_\odot$, respectively. The fit to the observations of radial velocity curve is plotted in Figure 3.

4. DISCUSSION

As results of analyzing the IUE low dispersion spectra and collected radial velocity curve, temperatures, sizes, eccentricity and longitude of periastron have been re-adjusted. Table 3 lists their values with previous solutions.

Table 3. Parameters adjusted in this study with previous ones.

Parameters	This paper	Cowley *et al.*
T_1	16,000K	—
T_2	3,800K	3,200K
R_1	0.0044	—
	10 $R_\odot$	36 ~ 62 $R_\odot$
R_2	0.1338	—
	321 $R_\odot$	350 ~ 600 $R_\odot$
e	0.41	0.55
ω^*	1.55°	4.0°

* longitude of periastron

Cowley *el al.* reported the absorption spectrum seen in the near optical UV region roughtly resembled a B0 or B1 star. If we assume the B star is a main-sequence star its temperature range in 20,000K ~ 27,000K. Such high temperature range could not adjust the depth of primary eclipse in *UBV* region. From the light curve analysis the B star's temperature was converged to 16,000K. Thus the temperature that we inferrd here is quite reasonable when we compare with the temperature reduced from line identifications.

We note that correlation between spectroscopic and photometric parameters. The main parameters for forming a radial velocity curve are an eccentricity, a longitude of periastron and a semi-major axis. For the best fit to the radial velocity curve of AZ Cas the eccentricity shoud be larger than 0.5 and semi- major axis shorter than 2500 $R_{\odot}$. With this limitation the minimum separation of AZ cas reaches approximately 1,000 $R_{\odot}$ and radius of the M star is around 350 $R_{\odot}$. Of course the limitation depends the mass ratio, (q=M_M/M_B). Published mass ratio is in the range of 0.7 $\sim$ 2.0. The most reasonable ratio is known to 1.4. A size of the M star is as big as a size of its Roche lobe at the periastron passage. Generally photometric pameters are reduced from light curve independently. It does not require absolute value such as a separation. Also a size of star does not affect a radial velocity curve for normal stars. For the eccentric orbit, the size of Roche lobe changes as the separation changes. The best parameters adjusted from radial velocity curves could not fit to the photometric model. Thus it is requireable to find solutions for AZ Cas, simultaneously from photometric and spectroscopic observations, because an eccentricity of the orbit is so high and the system consists of a super giant.

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