OBSERVATION AND INTERPRETATION OF ZETA AURIGAE STARS

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ABSTRACT. The ultraviolet observations of four Zeta Aurigau stars are reviewed. A, probably oversimplified, interpretation of the observations points to a straight forward connection between the spectral type of the B star and the amount of high temperature plasma in the systems.

1. INTRODUCTION

There are six stars that are considered to be Zeta Aurigae stars by various authors.

Table 1
Zeta Aurigae Stars

Star	Spectral Stars	Period (days)
Zeta Aur	K3II + B7V	972.2
31 Cyg	K4Ib + B4V	3784.
32 Cyg	K5Iab + B8V	1148.
22 Vul	G3Ib-II + B9V	249.1
Epsilon Aur	F0Iap + ??	9885.
VV Cephei	M2Ia + Be	7430

Of these stars, the last two will not be treated here because they are discussed elsewhere in the proceedings and because they differ somewhat from the first four stars on the list.

The most obvious feature of the Zeta Aurigae stars is the atmospheric eclipse. The orbital inclination of all the pairs is near 90°, and when the B star goes into eclipse behind the late-type primary, its light passes through the atmosphere of the primary giving a depth dependent probe of the atmospheric structure. The atmospheric eclipse of 22 Vul was discovered recently by Parsons and Ake (1983 a, b) using spectra taken by the International Ultraviolet Explorer (IUE). The atmospheric eclipses of Zeta Aur, 31 and 32 Cyg were discovered much earlier and have been studied at length using ground based spectra (cf, for instance, Wright 1970). Visible light spectra are complicated by the fact that at atmospheric eclipse one sees effects of the normal spectra of the two stars combined with the atmospheric eclipse lines.

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However, in the ultraviolet, the primary is considerably fainter than the B star, and the latter spectrum is relatively uncomplicated. Therefore the UV seemed a good wavelength region to study the systems. Several groups obtained spectra in the IUE. The evidence for circumstellar phenomenon was so interesting in the spectra that little attention has been paid to the atmospheric eclipse spectra. There are a number of Ph.D. theses in the IUE data archives.

The other characteristics of the spectra include the appearance of P cygni profiles in at least the Mg II resonance lines. During totality, the spectra show copious emission in the UV that is substantially stronger than the chromospheric emission from a single late-type supergiant. The spectra all show lines of C IV and Si IV, and some show NV. All these lines have a strong phase dependence, in the sense that the lines are weakest near primary eclipse and strongest near quadratures. Finally, the Mg II resonance lines show an additional broad, red-shifted absorption near secondary eclipse. From these observations we can imply certain physical characteristics about the stars. I will discuss the interpretation primarily for Zeta Aur, and then compare the others to it.

2. THE OBSERVATIONS

2.1 Zeta Aurigae

The Mg II lines show the existence of a strong, dense wind in Zeta Aur. Chapman (1981) found a mass loss rate of 2×10^{-8} solar masses per year from a simple analysis. Che, Hempe and Reimers (1983) carried out a more detailed study and arrived at a value of 0.6×10^{-8} solar masses per year. These numbers are in excellent agreement. The wind velocity determined by the latter group is in the range 20 to 45 km.

The wind is clearly supersonic, and when it interacts with the B star with its much weaker wind, one would expect a shock. Chapman (1981) has interpreted the phase dependence of the hot plasma lines (C IV, Si IV and NV) as being formed in a sheath of hot plasma inside the shock. Since the wind of the B7V secondary is very small, one would expect the shock to be almost in contact with the B star at its apex. The path length through hot plasma is therefore expected to be small and the hot plasma lines are weak, as observed. The sheath is thicker and the path length longer near quadrature leading to strong lines. Typical shocks in terrestrial situations exhibit a turbulent wake behind the obstacle. In the case of Zeta Aurigae, the signature of such a wake should be seen in spectra taken near secondary minimum. Ahmad, Chapman and Kondo (1983) found a broad, shallow, red-shifted absorption in the Mg II lines as expected. The shape is characteristic of a turulent plasma, and the red shift is due to the fact that the material is accreting onto the B star.

The interval of time over which the accreting material can be seen is related to the opening angle of the shock, which is a simple function

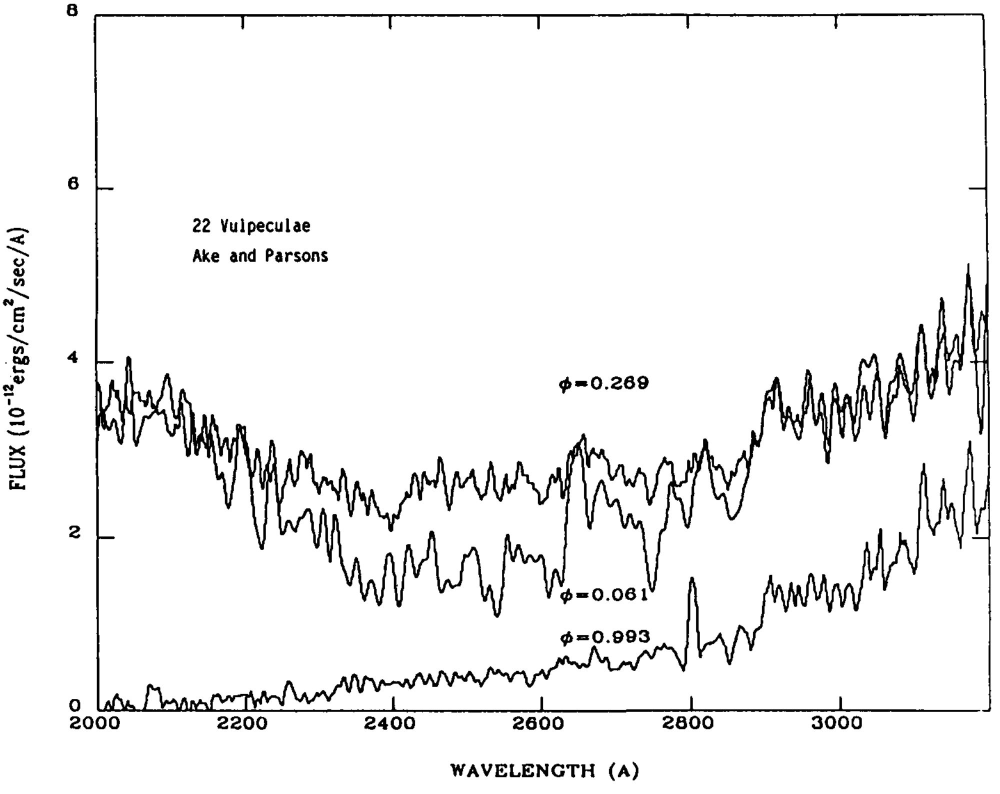

FIGURE 1. Three low dispersion IUE spectra of 22 Vulpeculae. Top to bottom the curves represent an out-of-eclipse spectrum, an atmospheric eclipse spectrum and a total eclipse spectrum. The depressed level of the atmospheric eclipse spectrum between 2200 and 2600A is due to the overlapping of a large number of atmospheric eclipse lines.

of the Mach number. Thus, we can infer the Mach number from the observations. Using the Che, et al, wind speed and the Mach number one can calculate the speed of sound in the wind plasma. In turn, the speed of sound is related to the temperature ($T^{\frac{1}{2}}$). We can therefore infer the temperature of the wind from observations of the accretion column. The temperature is about 15,000K.

Ahmad (1986) has reported on a study of the NV lines observed from the interaction region. McCluskey and Kondo (1984) have looked for X rays in Zeta Aur using Einstein, and the results were negative. They found an upper limit on Lx of 2.8×10^{30} erg s^{-1}.

2.2 22 Vulpeculae

The 22 Vul system has been discovered to be a Zeta Aur star by Parsons and Ake (1983 a, b) using IUE. Top to bottom the tracings are an out of eclipse spectrum, an atmospheric eclipse phase spectrum and a totality spectrum. Note that the top two tracings overlap around 2000A and around 3000A, but diverge between 2250 and 2650A. The divergence is due to the effects of a great many absorption lines which are blended together at this dispersion. The totality spectrum shows the emission features characteristic of these stars. Subsequently, Ahmad and Parsons (1985) discovered the accretion shock phenomenon in 22 Vul. Further study of this system is required.

2.3 31 Cygni and 32 Cygni

In 31 Cygni, the X ray observations with Einstein were positive, yielding Lx = 1.9×10^{32} erg s^{-1}. The X rays from 31 Cyg are at least 60 times more intense than from Zeta Aur. The difference appears to be attributable to the differences between the secondaries. The B4V secondary in 31 Cyg presumably has stronger wind than the B7V secondary in Zeta Aur, and therefore the interaction in 31 Cyg is the strongest of the two. A test of this interpretation is provided by 32 Cyg with its B8V secondary. Ahmad (1986) has observed the signature of the accretion column, indicating the presence of an interaction shock. However, he has found no evidence for the NV lines in the 32 Cyg spectra, indicating that the interaction is less energetic than the Zeta Aur case.

3. SUMMARY

We appear to be able to explain the high temperature plasma in the four Zeta Aur systems as being due to an interaction between the wind of the primary and the secondary. Differences in the systems are probably due to differences in the spectral types and therefore the winds of the secondaries. Further observations will determine whether 22 Vul fits this pattern. It may be possible, through some clever analysis, to ascertain the wind strengths of the B stars. A number of Ph.D. theses remain in the atmospheric eclipse data and in the further analysis of the interactions.

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