ULTRAVIOLET OBSERVATIONS OF 31 and 32 CYGNI

Robert E. Stencel and Yoji Kondo
NASA - Goddard Space Flight Center;
Andrew P. Bernat
Kitt Peak National Observatory, and
George McCluskey
Lehigh University

Ultraviolet observations of the Zeta Aurigae systems appear to have several advantages over comparable visual wavelength studies. A wide range of large optical depth resonance lines of abundant species permit the study of the supergiant atmosphere and circumstellar environment at virtually all phases. The International Ultraviolet Explorer satellite (Boggess, et al., 1978) is well suited to obtaining spectra between 1150 and 3200 A, although the competition for observing time is non-negligible.

Our initial observations of 31 and 32 Cygni were made in Sept. 1978, as part of the observing program of Kondo and McCluskey on interacting binary stars. 31 Cygni was observed at phase 0.62, and 32 Cygni at phase 0.17. Detailed reports on these observations are forthcoming (Stencel, et al., 1979; Bernat et al., 1979), but some of the highlights of the observations are presented here.

A. 32 CYGNI

Qualitatively, the UV spectrum of 32 Cyg is best described as a superposition of P Cygni features among strong lines on a bright B star continuum. Numerous lines of Si II, O I, C II, Al II and III and Fe II appear with P Cygni characteristics. Higher excitation lines, Si III 1298A and Si IV 1402A, are also present in the SWP2491 image. The LWR-2275 image is dominated by the Mg II 2800A resonance doublet and numerous Fe II lines in the 2200 - 2700 A region, all showing P Cygni profiles. Generally, the P Cygni-like features are centered symmetrically about the rest wavelength of the line.

Further, the detailed profiles of the stronger lines which exhibit P Cygni shapes indicate a complex of several absorption components separated by tens of km/s, with shifts ranging above -200 km/s of the rest velocity, and possibly as high as -400 km/s (O I lines). Satellite absorption components in the Ca II K line have been previously reported

M. J. Plavec, D. M. Popper and R. K. Ulrich (eds.), Close Binary Stars: Observations and Interpretation, 555–559.

https://doi.org/10.1017/S0074180900065499 Published online by Cambridge University Press

(Wright and Hesse, 1969), but only near eclipse and at displacements under -150 km/s. The cores of the Mg II resonance lines exhibit these absorptions nicely (Figure 1). We have measured the wavelengths of well defined absorption components in the entire IUE spectrum and computed relative velocities with respect to the absorption-emission crossover wavelength, which was itself generally within 15 km/s of the lab wavelength for the transition. The means of the velocity groupings are 54, 147, 250 and 392 km/s, all shortward shifted with respect to the rest wavelength. The latter three are greater than the escape velocity along the line of sight to the B star. Neither velocities of this magnitude nor strong absorption satellites so far from eclipse have been seen in previous visual studies. We suspect the total excitation might be dominated by the distance from the B star along the line of sight, and indeed, the incidence of the largest velocities is among the lowest excitation lines, which are also the weakest features. The temperature and density thus may fall off with the distance squared in the circumstellar envelope, as suggested among other cool supergiants. The discrete absorption components could be a consequence of the acceleration mechanism for the mass outflow, tempered by the gravitational dynamics within the system. High excitation lines like Si IV show a more gradual transition from absorption to emission than is the case for the lower excitation lines like Mg II and Fe II which exhibit a large gradient of flux with wavelength at the absorption to emission crossover in their P Cygni profiles. This gradient is controlled by the density and velocity dispersion in the line forming region, which suggests the hotter, denser material is near the B star, while the reduced velocity dispersion but increased blueshift material is farther away, possibly in response to some form of radiative acceleration. The image is that of a hot turbulent region near the B star, and a cooler calmer but faster moving wind somewhat removed from the binary.

Wilson and Abt (1954) and Wright (1959) deduced on the basis of curve of growth studies that discrete condensations were possible in the atmosphere of the K supergiant. They discussed their findings with a solar prominence analogy. This result must be re-examined since over-ionization (NLTE) effects are likely in the outer atmosphere. Further, it now appears that K supergiants do not possess coronae, and the role of strong magnetic fields is not resolved. Although the details of atmospheric structure revealed near eclipse might not compare in detail with our out-of-eclipse spectra, the discrete absorption components may reveal some temporal variation connected with the structure and evolution of such "condensations". To investigate this we have pursued the repeated observation of 32 Cyg each few months. The first two spectra were obtained by Kondo and McCluskey, the third in collaboration with R. Wing. Pending further analysis, it appears as though a slight increase in the strength of the most shortward component (in Mg II) has occurred, despite no change in displacements. Geometry might suggest that as phase 0.5 is approached, we see the purely radial outflow component (-150 km/s) as the radial vector converges with the line of sight and the optically thick path at its velocity is maximized.

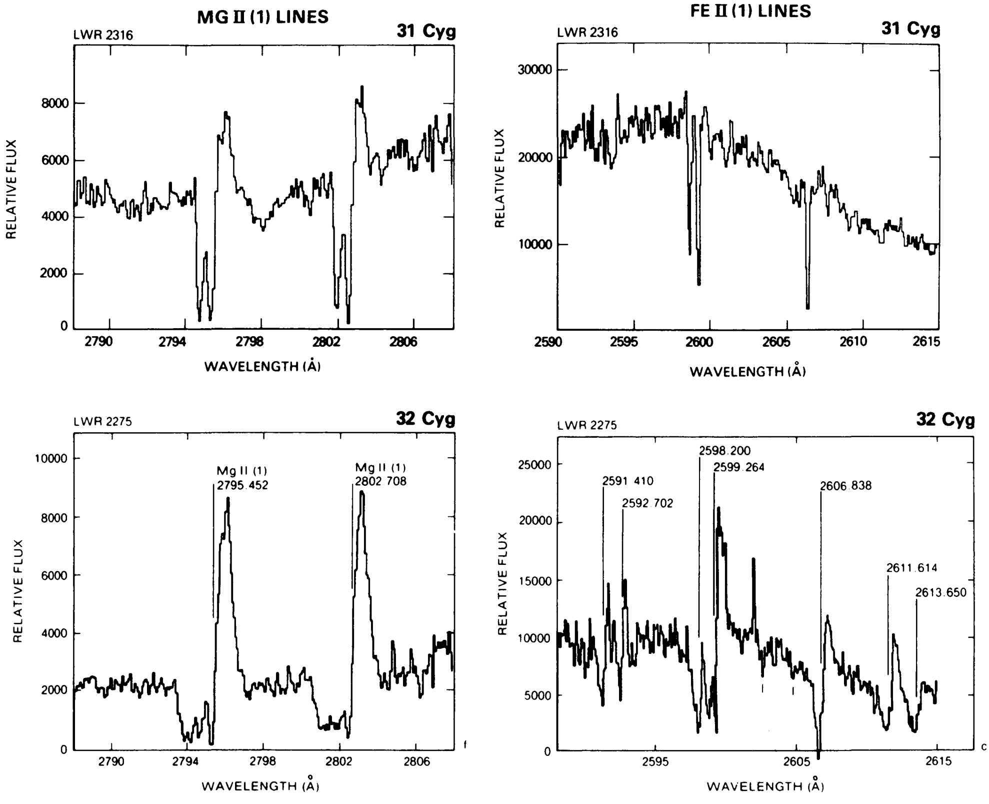

Figure 1. UV lines of Mg II and Fe II in 31 and 32 Cygni.

More quantitatively, ionization modeling for the B star environs was made by comparing observed and computed equivalent widths to deduce density, temperature and turbulence values. From the known geometric configuration of the B star in the system, its UV radiation field and separation in the plane of the sky, we used photoionization-recombination detailed balancing to compute ionization equilibrium and densities at each point along the line of sight for a specified density and inverse distance squared falloff. A Doppler and wind outflow velocity was also assumed to obtain the equivalent widths. Then by iterating on the specified density, one converges to the observed values. At the projected separation between the stars, the log particle density obtained was 7.2, neglecting dust and molecule formation. Assuming continuity and spherical symmetry, the estimated log of the mass loss rate is -6.4 (solar masses per year). This value is consistent with other estimates for this sort of system and the general mass loss rates for K supergiants (saito, 1970, 1973; Sanner, 1976).

In 32 Cyg, the mutual interaction between the B and K star may be greater than previously anticipated. The strong P Cygni profiles of the UV spectrum suggest that the B star resides within the upper atmosphere of the K supergiant and that its ionizing radiation penetrates substantially, possibly setting up moving shocks along the egress side of the chromosphere. The wide range of velocities observed in the circumstellar components presumably arise from the combined energetics of the K supergiant stellar wind, the B star radiation field and orbital motions. Further monitoring of the UV spectrum of this system is desirable.

B. 31 CYGNI

This system is similar to 32 Cyg except that its orbital period is about three times longer. Its Mg II and Fe II lines are shown in Fig. 1 also, and while they show a P Cygni shape, both the intensity, and number of absorption components is reduced. This occurs because of the larger orbital separation. Careful analysis shows that generally higher ionization stages are seen compared to 32 Cyg, including more lines of Si III and IV and stronger Al III. No Fe II lines other than zero volt are seen, suggesting an interstellar-like contribution. Since the phase (0.62) places the B star in front of the K supergiant and the separation is greater than in 32 Cyg, the lower density may favor the higher excitation. In any case, the Mg II lines still clearly show the presence of strong outflow near 31 Cyg.

We thank the IUE Observatory for their tremendous assistance, and R.E.S. also thanks the NAS-NRC for research support.

REFERENCES

Bernat, A., Stencel, R., Kondo, Y. and McCluskey, G., in preparation.
Boggess, A., et al. 1978 Nature 275, 2.
Saito, M. 1970 Publ. Astron. Soc. Japan 22, 455.
________ 1973 Astrophys. and Space Science 22, 133.
Sanner, F. 1976 Astrophys. J. Suppl. 32, 115.
Stencel, R., Kondo, Y., Bernat, A. and McCluskey, G. 1979 Astrophys. J. (In Press, October).
Wilson, O. and Abt, H. 1954 Astrophys. J. Suppl. 1, 1.
Wright, K. 1959 Publ. Dominion Astrophys. Obs. 11, 77.
Wright, K. and Hesse, K. 1969 Publ. Dominion Astrophys. Obs. 13, 301.

DISCUSSION FOLLOWING STENCEL, KONDO, BERNAT AND MC CLUSKEY

Guinan: 32 Cyg is in an eccentric orbit with e ≃ 0.3. Perhaps you may see changes in the spectra as a function of the varying separation between the stellar components in addition to those changes expected from the eclipses. Have you detected any spectral changes that could arise from this?

Stencel: Not yet. We did observe near periastron and after, and perhaps temperature changes might be seen. This is a good idea. Also your recent photometry (Publ. Astron. Soc. Pacific, 91, 1979) is valuable for new dimensions to incorporate in this analysis.