UV Observations of Epsilon Aurigae During Ingress and Totality

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Analysis of SWP and LWR spectra of Epsilon Aurigae taken during the pre-eclipse, ingress and total phases of the present eclipse has provided further constraints on models of this enigmatic system. High dispersion images show no significant change in the strength of the Mg II emission lines during the course of the eclipse. Both high and low dispersion spectra indicate that the eclipse starts earlier, ends later and is deeper in the UV compared to visual wavelengths. In addition, we confirm our earlier observation that the eclipse depth is wavelength dependent shortward of 2400 A. Abrupt changes in the light curve appear at all wavelengths, suggestive of discontinuities in the opacity of a ring of material surrounding the secondary object.

INTRODUCTION

At various times in the past the secondary in the Epsilon Aurigae binary system has been described as a swarm of meteorites (Ludendorff, 1924), a giant infrared star (Kuiper, et al., 1937), a small infrared star plus an ionized gas stream (Struve, 1956), a hot B star surrounded by an ionized gas shell (Hacker, 1961), a bar of optically thick material (Huang, 1965), a proto-planetary system (Kopal, 1971), a black hole plus a semi-transparent disk (Cameron, 1971) and a black hole within a thin, opaque disk with a central opening (Wilson, 1971). This rather lengthy list serves to underscore Wilson's comment that Epsilon Aurigae is the only binary system that can be described "with complete justification, as mysterious". In this paper we present SWP and LWR spectra taken in both the high and low dispersion modes from pre-eclipse right through to the beginning of egress and compare these data to visual observations.
OBSERVATIONS

The primary star (A8 - F2 Ia), an irregular period cepheid variable with an amplitude of 0.2 magnitudes, is visible during all phases of the eclipse. The additional cepheid variability complicates the eclipse light curve and makes the choice of a pre-eclipse fiducial spectrum a decision of some importance. With this in mind, and given the sparse sampling of the IUE data, we see that it is difficult to determine the actual dates of first and second contact in the UV eclipse, which are not necessarily the same as for the optical eclipse. A fairly reliable indicator of the time displacement between the UV and visible light curves may be obtained by matching the ingress slopes and the mid-eclipse brightening feature, as shown in Figure 1. The units of "eclipse phase" used in this and later figures are such that first contact corresponds to phase 0.00 and last contact to phase 1.00, based on contact dates predicted by Gyldenkerne (1970). In these units second contact is phase 0.20 and third contact is 0.79. The shift of 0.15 used to align the light curves in Figure 1 corresponds to approximately 100 days. It will be interesting to watch the system as the UV eclipse ends to see if a similar delay exists for the egress phase. At the time of this writing egress appears just to have begun in the UV whereas it is already well along according to the latest UBV photometry (Hopkins and Stencel, 1984). Figure 1 also illustrates that the UV eclipse is deeper than the 0.8 magnitude drop noted in the longer wavelength observations.

The most interesting high dispersion feature is the Mg II resonance doublet, seen in emission. A narrow (30 - 50 km/s) blueward absorption feature present in all the spectra is interpreted as being of interstellar origin. The emission lines became more pronounced as the eclipse progressed but this was due to the decreasing light level of the surrounding continuum. Figure 1 also shows just how little the flux in the Mg II K line changed relative to the continuum in the same echelle order. Thus, whatever source is responsible for the emission lines is probably not associated with the primary star.

Many of the models cited above are based on the belief that the eclipse is "gray", i.e., that eclipse depth is independent of wavelength. The IUE data we have obtained shows that this property holds in the UV all the way to 2400 A. However, in the wavelength range 1500<\lambda< 2400 A the eclipse appears to be non-gray, being deeper at shorter wavelengths. Chapman, Kondo and Stencel (1983) noted this in the earliest stages of the eclipse and interpreted it as an indication of a cloud of small grains surrounding the secondary. Such a cloud, extending above, below, in front of and behind the material responsible for the wavelength independent eclipse would explain the deeper and longer eclipse in the UV data. In Figure 2 we have plotted curves of eclipse depth versus wavelength for several typical phase points during ingress and totality to illustrate this wavelength dependence. The pre-eclipse SWP and LMR spectra we have chosen as our reference point
were taken on April 4, 1982 (phase, - 0.17) by T. Ake and T. Simon. The almost vanishing eclipse depth shortward of 1500 A has been discussed elsewhere (Parthasarathy and Lambert, 1983) and does indeed suggest the existence of an un eclipsed hot source associated with the extended occulting material. Hack (1961) first proposed this hot source to be a main sequence B star and Plavec (1981) speculated that it might be associated with heating as material from the supergiant wind falls onto the accretion disk of the secondary. It is noteworthy that the system has shown no secondary minimum in the past and no spectroscopic evidence for a hot star, other than the UV excess shortward of 1500 A first observed by Hack and Selvelli (1979).

In Figure 3 we have plotted eclipse depth versus phase for several wavelength bands (data are averaged in 100 A bins). The sharp jumps in light level at certain phases are too large to be attributed solely to the cepheid variability of the primary. We call attention to the downward slope of the light curve during totality which is also evident in the light curves of the 1929 and 1956 eclipses and which Wilson (1971) interpreted as a small tilt in the major axis of his proposed ring as it transits the primary. Certainly the discontinuities we note in the light curve are consistent with some kind of ring structure, i.e., gaps in a disk. That the discontinuities are deeper at the shorter wavelengths suggests that the gaps might be associated with the small particle component of the eclipsing object.

The question that arises from our observations to this point is clear: how does this obscuring material compare to matter responsible for interstellar extinction? To facilitate this comparison we have renormalized Seaton's (1979) mean extinction curve to E(1800-2900). Figure 4 shows this renormalized interstellar curve superimposed on the data for Epsilon Aurigae at several representative phases. Because we have been unable to remove the effects of the hot component from the eclipse curve, we display data longward of 1500 A only. The most noteworthy feature in Figure 4 is the large variability in the region 20000<λ<2400 A. Unfortunately for this kind of analysis, the most interesting part of the interstellar curve, the broad hump centered at 2200 A, falls on the least sensitive part of the LWR camera. Nevertheless, some of this variability may be intrinsic to the Epsilon Aurigae system. If so, it argues for a mixed population of grain sizes and types in the secondary cloud. Comparisons with model extinction curves for other kinds of small particle grains are planned.

REFERENCES

Hopkins, J.L. and Stencel, R.E., eds. 1984, Epsilon Aurigae Campaign Newsletter, No. 10.