ATMOSPHERIC EVIDENCE OF EVOLUTIONARY PROCESSES IN INTERACTING BINARIES

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The preceding invited paper by Sahade (1987) gave a balanced overall picture for the subject matter. I shall attempt to complement his talk in discussing two classes of atmospheric diagnostics of the evolutionary processes in interacting binary systems. These are: (I) Abnormal abundances of elements in the atmosphere resulting from the nuclear processes in the stellar interior. (II) Mass flow as a consequence of the evolution of either of the components and the Algol type binaries.

(I) Abundance Anomalies: There are several classes of objects with abundance anomalies, such as Am stars. At least some of these objects are known close binaries. In particular, most Am stars appear to be close binary stars. However, the physical causes of the metallic overabundances in those stars are still unclear. We shall in the following examine Algol type binaries for abundance anomalies.

The best place to look for abundance anomalies is the atmosphere of the evolved late-type component. However, the star is typically fainter than the early type companion and is difficult to observe spectroscopically at high resolution for abundance analysis. An optimum time to observe its spectrum is during a primary (total) eclipse when the spectrum of only that star is visible. Regrettably, the total eclipse usually does not last long enough to obtain a good exposure at high resolution. Spectroscopic observations with large telescopes using imaging device may provide valuable data on the relative abundances of N, C and O. A good candidate is S Cancri, whose late-type component has an estimated mass of only 0.18 solar mass while its unevolved hotter companion has an estimated mass of some 2.3 solar masses. The late-type star's atmosphere should reveal nuclear-processed material and overabundance of heavier elements. S Cnc may provide a rare opportunity to peel down the outlayer of an evolved star to see what it looks like inside.

Using Digicon spectra obtained during the total phase of eclipse, Parthasarathy, Lambert and Tomkin (1983) concluded that the late-type components in U Cephei and U Sagittae had an underabundance of C and an overabundance of N, which they construed as the result of the conversion of C into N.

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It is perhaps time that we utilized large telescopes and modern detector technology to study the abundance anomalies in close binaries during total primary eclipse, in a vigorous manner similar to that used, say, in extragalactic research. An up-to-date ephemeris would also be essential in such efforts.

(II) Mass Flow: Binaries that are the products of internal evolutionary processes also include Novae and X-ray binaries that are thought to contain compact objects. Also, there is strong evidence that many, if not all, symbiotic stars are binaries.

The very existence of the Algol-type binaries, in which the less massive late type component is the more evolved of the two stars, is strong evidence of the past mass loss from the late-type star as a result of its evolution. Presumably, the present late-type star was originally the more massive (component A) of the two and thus evolved off the main-sequence before its initially less massive companion (component B) did so.

Recent observations of Algol type binaries observed in the ultraviolet, in particular with the IUE satellite, show that some form of mass flow is occurring in virtually all of them (McCluskey and Sahade 1987).

Not many binaries are known to be in a stage where component A has evolved and expanded to fill its critical equipotential Roche surface and is in an active phase of mass transfer. However, several binaries observed in the ultraviolet with OAO-A2, Copernicus, ANS and IUE exhibit observational evidence that they are currently in such a phase; the examples include beta Lyrae (Hack et al. 1975), U Cephei (during its active phase), R Arae and HD 207739 (Kondo, McCluskey and Parsons 1985).

Observational evidence for the dynamic mass-flow phase includes (A) light-curves where the secondary eclipse becomes deeper at shorter wavelengths (Kondo et al. 1985), (B) the non-monotonic variation of the spectral energy distribution which is pronounced in the ultraviolet (Kondo et al. 1985), and (C) continued presence, both inside and outside the eclipses, of emission features observed in beta Lyrae (Hack et al. 1977). Phenomena (A) and (B) have been attributed to the presence of variable, optically-thick, extrastellar plasma.

In the mid-1960's a popular view was that the mass transfer occurred wholly conservatively between the two stars in a binary and that the process would be repeated back and forth, although there existed no theoretically compelling reason or viable observational evidence in support of such a speculation. With the availability of ultraviolet spectra from space, it has become clear that the mass flow is not conservative; however, a fraction of the outflowing matter from component A is often accreted to its companion, giving rise to spectral features (e.g., C IV and N V) that are too hot for component B (Kondo, McCluskey and Stencel 1979).

During the active mass outflow episode in 1986 June, U Cephei was observed with the IUE (McCluskey, Kondo and Olson 1987) and from ground. The unusual nature of the mass flow is quite evident: (1) partical covering, (2) secular and phase-dependent variation, and (3) maximum velocity of some 800 km/s, well in excess of the escape velocity from the binary.

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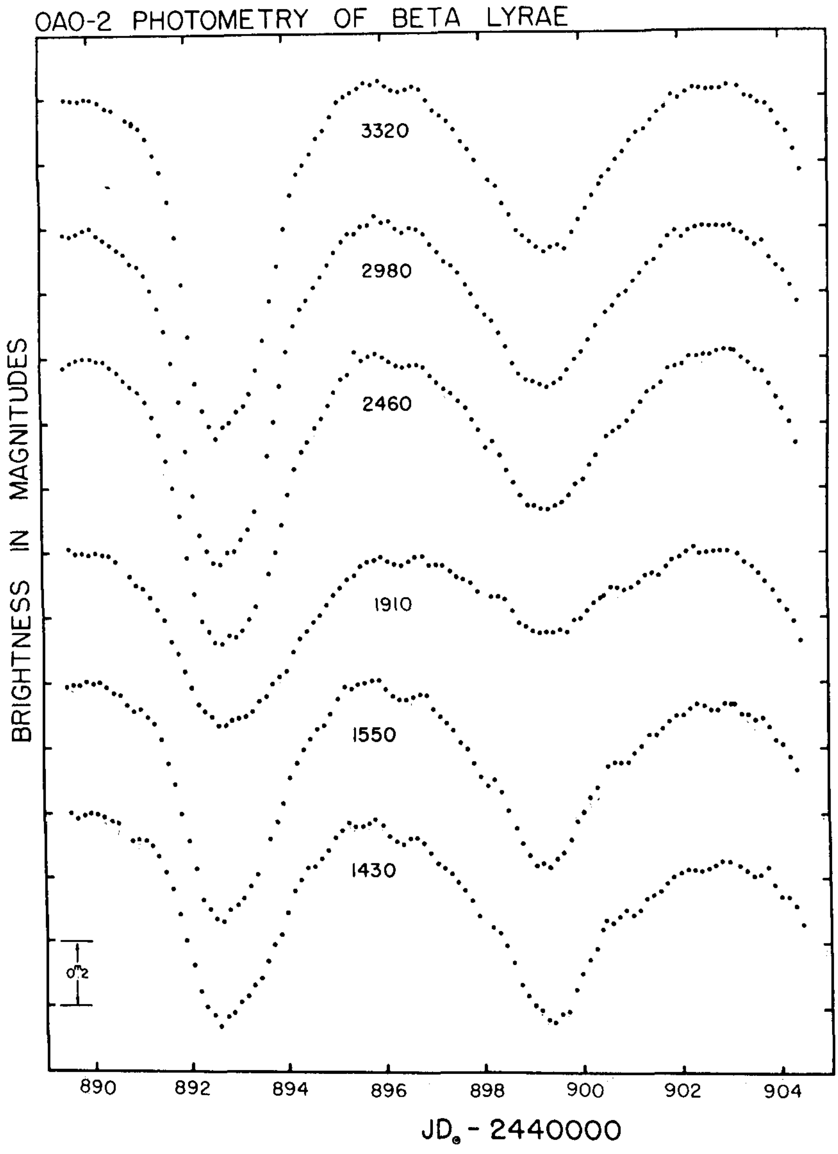
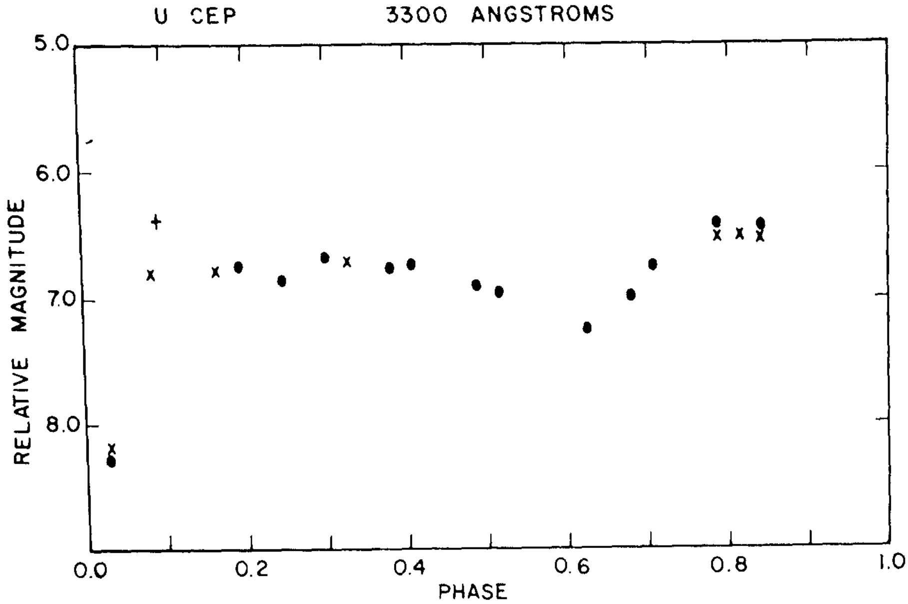
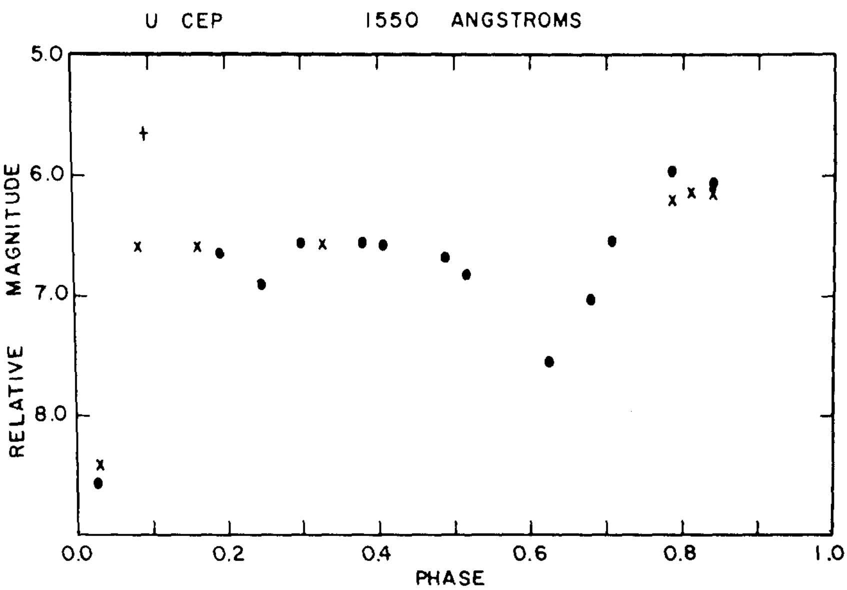


Fig. 1. Ultraviolet light curves of beta Lyrae observed with the OAO-2 (Kondo, McCluskey and Eaton 1976, Ap. Space Sci., 41, 121). Note the deepening of the secondary minimum in the far-ultraviolet.



The *ANS* observations of U Cep 3300 Å.



The *ANS* observations of U Cep at 1550 Å.

Fig. 2a & 2b. Ultraviolet light curves of U Cephei observed with the ANS. Note the deepening of the displaced secondary minimum in the far-ultraviolet.

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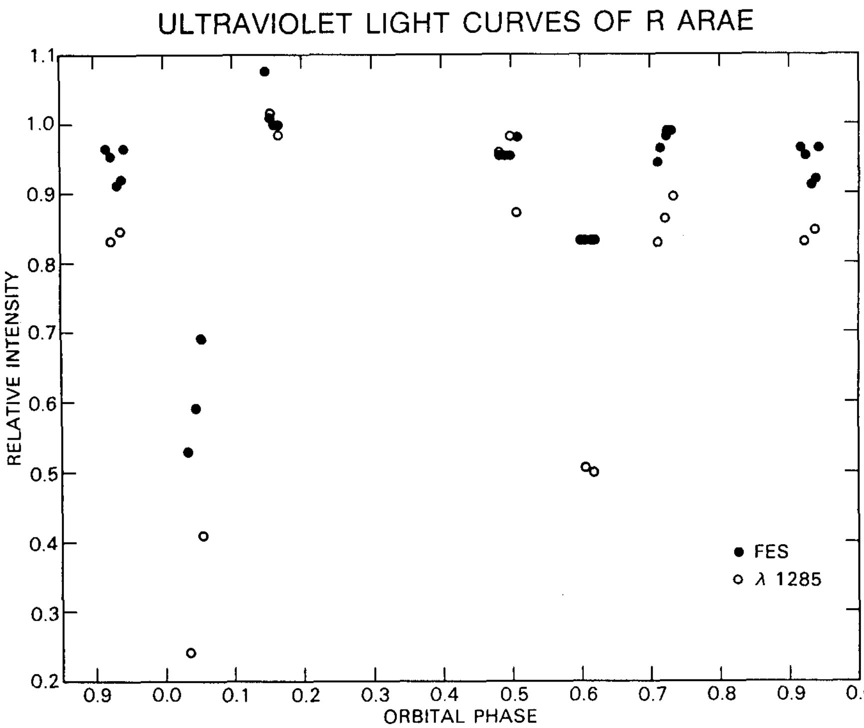

Fig. 3. Ultraviolet light curves of R Arae observed with the IUE. FES stands for the IUE Fine Error Sensor, whose color is approximately Blue.

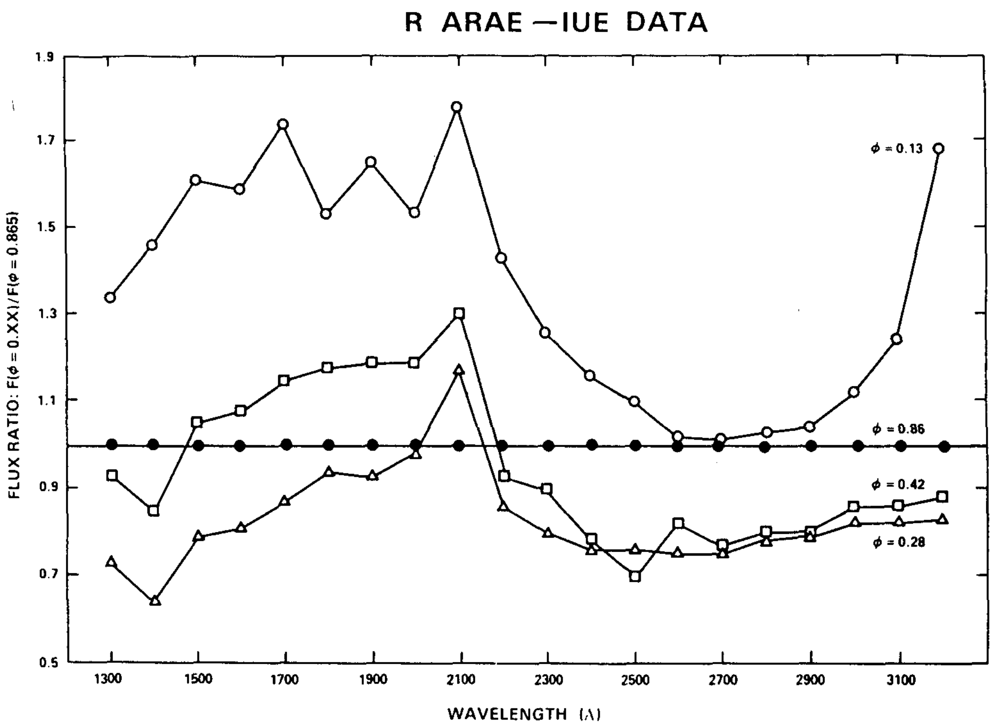

Fig. 4. Spectral engergy variations of R Arae observed with the IUE; flux at phase 0.86 is normalized to unity.

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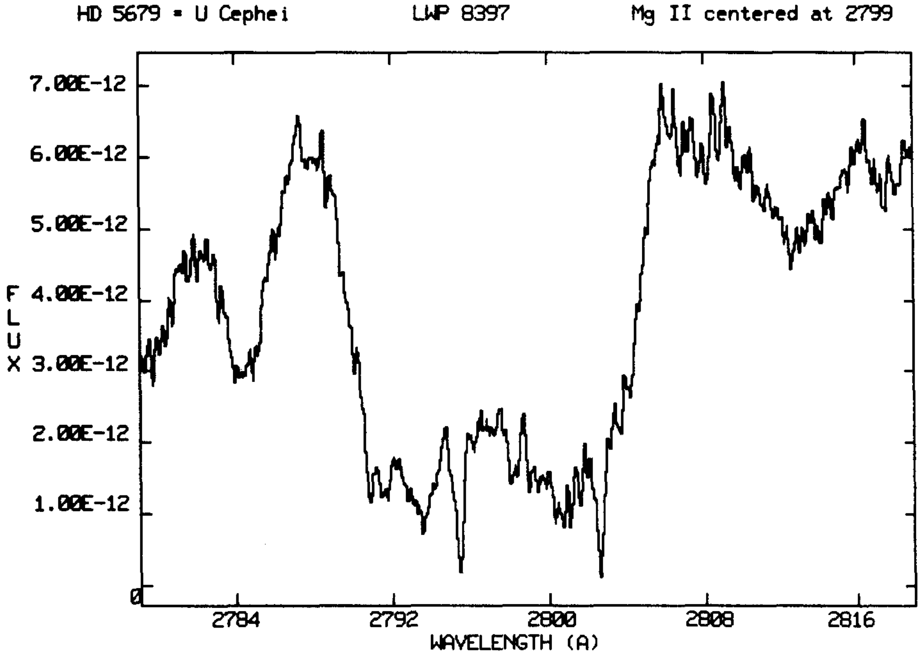

Fig. 5. High resolution spectra of U Cephei in the Mg II resonance doublet region at 2975 and 2802 A, at phase 0.58, during its active mass flow episode in 1986 (McCluskey et al. 1987). The maximum-velocity toward the observer is about 800 km/s. The flat bottom of the broad absorption feature indicates saturation but the absorption does not quite reach zero-flux level, suggesting only a partial covering of the surface of the B star by the plasma flowing out of the G giant.