INTERACTING BINARIES AS Be STARS

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Abstract. Semidetached close binary stars of the Algol type often have primary components of spectral type A0 or earlier and display emission at Hα (sometimes also at higher Balmer lines). They are therefore Be stars. Many binaries of this type are not eclipsing and must look like "ordinary" Be stars. We have discovered high-ionization emission lines of N V, C IV, Si IV, Fe III, etc. in the ultraviolet spectra of totally eclipsing Algols. They probably originate in circumstellar turbulent regions at fairly high electron temperatures, of the order of 100 000 K. They are not detectable in most non-eclipsing systems, but may be there and may play an important role in the dynamics of accretion and mass outflow from the systems.

ALGOLS AS Be STARS

Figure 1 shows three scans of the optical spectrum of the eclipsing binary system RS Cephei. The uppermost scan was obtained in full light of the system, but it does clearly show the Hα line in emission. When the hotter component of the binary system is totally eclipsed, more emission lines show, mainly because the overall light level has been greatly reduced. This is seen in the middle scan. But the emitting region is also eclipsed at a certain phase, as the bottom scan shows, or else the emission may be variable. Probably both events occur and the emitting region has the shape of a ring encircling the hotter component, with an unequal distribution of matter.

The primary component in RS Cephei has traditionally been classified as an A5 III star, but this classification is wrong. It was based on the presence of numerous sharp metallic lines, but these lines originate in a circumstellar shell. The slope of the Paschen continuum also suggests a middle A star, and again this is misleading; the slope is affected by the contribution to the combined flux by the secondary star, which is a G8 III-IV subgiant. Almost pure spectrum of the primary component is visible in the ultraviolet, and the *IUE* spectrum shows very clearly that the star is of spectral type B9.7 V. Its complete flux distribution from 123 nm through 680 nm is seen in Fig. 2, top. Note that the match between the *IUE* spectrum and the optical scan near 320 nm is almost perfect.

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Fig. 1. - Optical scans of a representative semidetached binary system, RS Geminorum. The uppermost scan was taken outside the eclipse, the lower two during a total eclipse of the B component. Light cirrus makes the flux distribution of the bottom scan dubious, but cannot cause loss of emission.

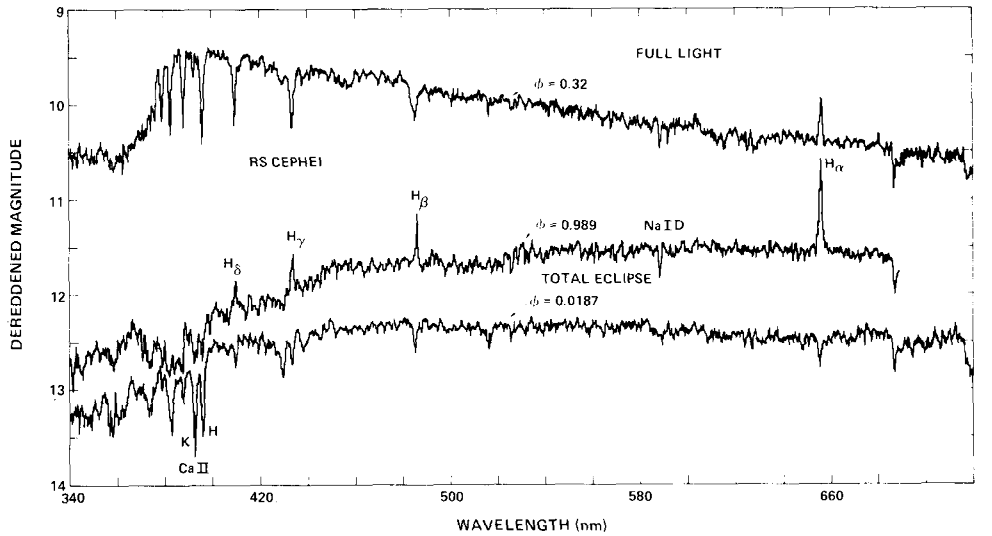
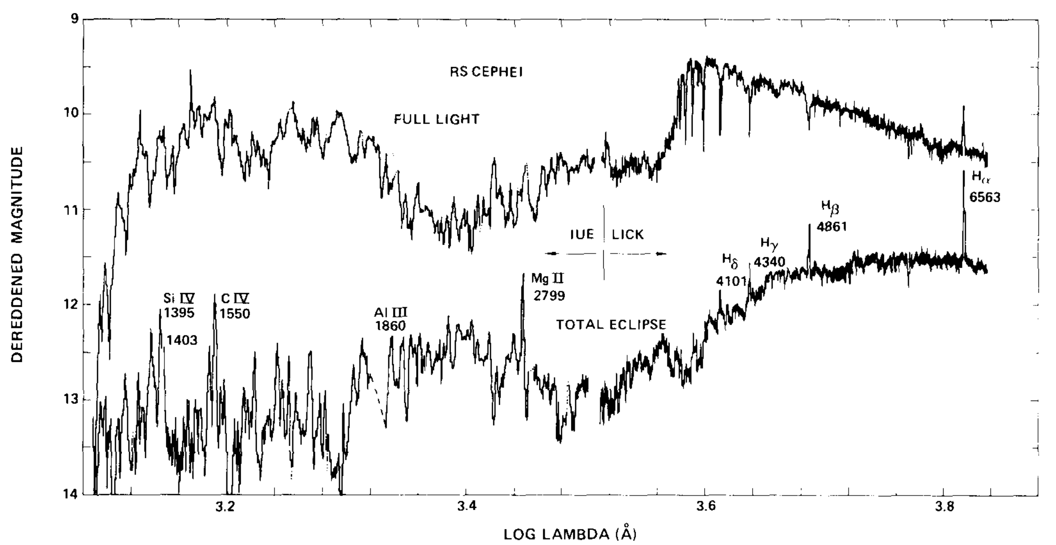


Fig. 2. - Combined IUE and optical scans of RS Cephei show the difference between full light and total eclipse. Note the optical and ultraviolet emission lines.



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The principal component of RS Cephei is a B star and there is Hα in emission in its spectrum; therefore RS Cephei is a Be star. It should not be disqualified because it happens to be an eclipsing binary, for this is a chance phenomenon due to the accidental orientation of the orbital plane. Many more similar systems will not be seen as eclipsing from the Earth, since the orbital planes are oriented at random. Such a statistical argument would not be valid if RS Cephei were unique. But it is not. In our limited survey of Algol binaries, we have found that RY Gem, RX Gem, TT Hya, and RW Per are closely similar to RS Cep, and several other systems are not very different. There must be many such binary systems around us in space.

Dear reader, pause for a while and make a guess: What is the chance that a given binary system will be seen as totally eclipsing? You may be surprised at the low probability. The above Algol systems can be well represented by the following "average binary": Masses 2.4 and 0.4 in solar units, radii 2.4 and 5.5 in terms of solar radii, the stars' centers 24 solar radii apart. Such a binary will be seen as totally eclipsing if the orbital inclination is greater than 82.6°, and will be at least partially eclipsing for inclinations greater than 70.8°. Now out of 120 randomly oriented systems, only one will be seen as totally eclipsing; about 6 (more accurately 5.6) systems will display partial eclipses. The rest, 113 systems out of 120, will be at best seen as spectroscopic binaries.

I say "at best", since in fact probably half of them will be recognized merely as spectrum binaries, or simply considered to be single stars. This is because with decreasing inclination, the radial velocity range of the hotter component decreases as well; and it is not too large in any case because of the typically small mass of the secondary star. In our model, the radial velocity range for $i = 90°$ is 25 km/s. But for 50% of all the systems it will be less than 12 km/s. With the few prominent absorption lines in a late B spectrum, broadened on top of it by rapid rotation, the chances of detecting such a binary system are small. So what will you see in most cases? Just a Be star! The shell absorption lines will most likely disappear when you observe outside the orbital plane, but the emission line(s) will remain. And the star will probably appear a little earlier in spectral type, since you will see mostly its polar regions.

THE ALGOL SYSTEM WILL LOOK LIKE AN ORDINARY Be STAR, AND THERE MUST BE MANY OF THEM! Even the other rather typical attribute of Be stars will be present, namely rapid rotation of the underlying star. The mass transfering stream, coming from the cooler star in the system, impinges on the hotter component under an oblique angle, and accelerates its rotation. A recent survey by Wilson (1986) finds rotational velocities of up to 310 km/s in the eclipsing systems, and 100 km/s is quite possibly a representative value. The "emission rings" from which the emission comes are actually Keplerian disks, whose formation is easy to explain in terms of mass transfer. The recent identification of these disks by Dachs et al. (1986) means, I think, that many Be stars are interacting binaries.

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HOT CIRCUMSTELLAR EMITTING REGIONS IN ALGOLS

It was rather disappointing for observers of Be stars to see that there are virtually no emission lines in the ultraviolet. However, for those Be stars that are members of interacting binary systems, the eclipses enable us to see weaker features in the ultraviolet, and then a rich emission spectrum is revealed with resonance lines of N V, C II, C IV, Si II - Si IV, Al II, Al III, and low-excitation subordinate lines of Fe III and Ni III. Fig. 3 shows a very representative spectrum of an Algol-type interacting binary TT Hydrae, observed during the total eclipse of its B9e component. The emission lines are collisionally excited and most likely the ionization is also collisional, the energy being supplied by the gravitational potential energy released by the impacting mass-transfering stream. These lines are not formed in the chromosphere of the cooler subgiant star; they are several orders of magnitude stronger. In β Lyrae, they can be studied at high dispersion and they display P Cygni profiles. Although they are associated with the accretion process, they signal outflow of matter! The electron temperature of the line-emitting region must be on order of 100,000 K (Plavec 1983; Peters and Polidan 1984).

Reference list

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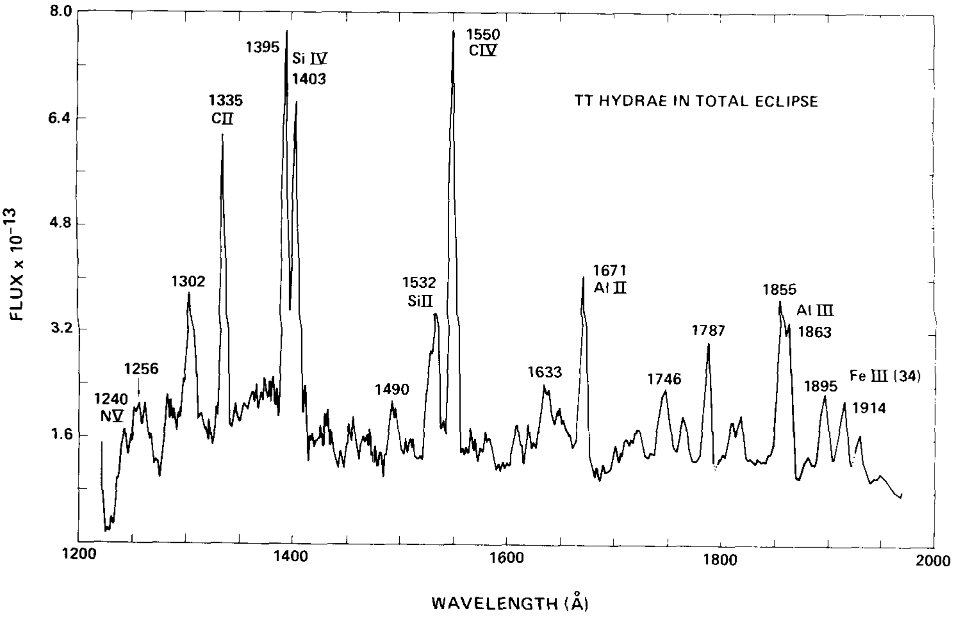
Fig. 3. - The ultraviolet emission spectrum of TT Hydrae, observed during the total eclipse of the B9e primary star.



DISCUSSION FOLLOWING PLAVEC

van den Heuvel:

Do you also include in your binary model for the formation of the Be stars that the mass transfer which has spun-up the rotation of the Be star took place long ago, and that the companion star at present is already dead; i.e.: a neutron star or a white dwarf? In fact, this seems to be the case in the Be- stars in Be-X-ray binaries, where the mass transfer certainly must have taken place in the past. With the same evolutionary model, but for systems with lower initial masses, one would expect that there must be many Be stars with a white dwarf companion in an orbit of several weeks to several years.

Plavec:

It is not so much a problem of a persistent accelerated rotation as a problem of persisting circumstellar disks. You know about the problems with the disk viscosity. Tentatively, I would say "yes" to your question.

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