# EVOLUTION DIAGNOSTICS IN INTERACTING BINARIES

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Through the analysis and interpretation of observational material, particularly on the part of Otto Struve and his collaborators, the structure of an interacting binary is depicted (cf. Sahade and Wood 1978) as formed by a) the two stellar components; b) a gaseous stream from the less massive and more evolved component of the system towards the companion; c) a circumstellar gaseous envelope -designated as "ring" or "disk" depending on the density of the material; d) a circumbinary gaseous envelope that surrounds the whole system and is normally in expansion, as suggested by the conventional, ground-based observations.

The evolution of interacting binaries involves the effect of matter outflow and transfer in at least a stage of rapid mass loss and a stage of slow mass loss. As a result, the evolution of the components appreciably departs from the evolution of single stars and produces very bizarre objects which find no counterparts among non-binaries. Both the observational and the computational results suggest that the amount of mass involved in the process of mass outflow must be a large percentage of the total mass of the evolving component. It seems, therefore, reasonable to expect to find evidence, in evolved systems, for processed material from the interior of the mass-losing component.

1. With such an idea in mind, attempts were made in the middle 60's, to use Strömgren's metallic index m' to prove metal abundances in the atmosphere of the mass-losing member of the pair. The results obtained by several investigators were interpreted as indicating underabundance of metals, a conclusion that was questioned by Baldwin (1976), by Hall (1969) and by Koch (1972) on several grounds. More recently, Parthasarathy et al. (1979) pointed out that "the photometric index used as an indicator of metal abundances measured the strength of the G-band at 4300 A. The weakness of this index ... may indicate that CH, which is a mayor contributor to the G band, is weak in secondaries. This would suggest an underabundance of C ... consistent with the effect of CNO processing that, as a result of mass loss, the secondaries are expected to evidence".

2. Almost a quarter of a century before the photometric attempts we have just mentioned were carried out, Greenstein (1940) had called attention to the fact that in the spectrum of the 137.94-day period binary $\upsilon$ Sagittarii (B2 by the high excitation lines; early A by the metallic lines; fainter companion smaller and of larger surface brightness) H is very weak and He is strong.

Ten years later another similar case, that of KS Persei = HD 30353, a non-eclipsing 360.47-day period binary (about A5, by Ca II-H and K; F5, by ionized metals), was brought to the limelight by Bidelman (1950), who stated that the object "appears to be a lower-temperature analogue of υ Sagittarii".

And, again ten years later, Boyarchuk (1960) announced that the spectrum of the famous, peculiar interacting binary β Lyrae (B8 II; P= 12.9 days) suggested H-deficiency.

To these objects, which are always mentioned whenever the question of abundance anomalies in interacting binaries comes up, LSS 4300, which, according to Schönberner and Drilling (1984), should be the hot counterpart of υ Sgr and of KS Per, may perhaps be added.

Table 1 lists the abundance determinations in β Lyr.

Table 1

ABUNDANCE DETERMINATIONS IN β LYRAE

| Author | | $^{\mathrm{He}}/_{\mathrm{H}}$ | $^{\mathrm{C}}/_{\mathrm{N}}$ | $^{\mathrm{O}}/_{\mathrm{N}}$ | Method |
|---|---|---|---|---|---|
| Boyarchuk | 1960 | $\sim$25 | | | curve of growth |
| Struve, Zebergs | 1961 | | | | comparison of E.W.'s |
| Hack, Job | 1965 | 1-2.25 | | | E.W. comp. α Cyg (A2 Iae) |
| Leushin et al. | 1977 | 1.55 | | | |
| Leushin et al. | 1979 | 1.5 | 0.6 | 20 | comp. with theoretical profiles with the use of Klinglesmith's (1971) models |
| | | | 0.03 | 0.04 | |
| Leushin, Snezhko | 1980 | 1.5 | 0.25 | | |
| Bahýl | 1982 | 0.125 | | | |
| Balachandran et al. | 1986 | 1.5 | ≤0.011<br>± .022 | 0.025<br>±.050 | |

Note: normal Balmer discontinuity

In the case of υ Sgr Hack and Pasinetti (1963) derived, from a comparison with γ Pegasi, a B2 IV (Hoffleit and Jaschek 1982), that He is 40 times more abundant than H. υ Sgr does not appear to show a Balmer discontinuity.

As for KS Per, which also does not display a Balmer discontinuity Danziger et al. (1967) and Wallerstein et al. (1967) compared fluxes and profiles with those suggested by Böhm-Vitense's H-poor model atmosphere calculations and derived a value of the ratio of H over He of the order of $10^{-4}$, and a high abundance of N relative to C and to O.

2.1 In regard to the three binaries that are considered as H-deficient objects, I would make the following comments:

2.1.1 In the first place, β Lyr's brighter component is a B8 II object, whose effective temperature is of the order of 11.500ºK (Böhm-Vitense 1981), and, although there is no doubt that its mass is smaller than that of the companion, by no means it is certain how large or how small the actual value is.

In the second place, the spectrum of β Lyr is a very peculiar one, characterized not only by photospheric absorption lines but also by emissions that are strong in H, and are also present in He, and by other features, which arise partly in the gaseous stream from the B8 II component and partly in the outer edges of the opaque disk that surrounds and hides the so far unobservable companion. As it has been shown by Batten and Sahade (1973), in the case of Hα , and by Aylin et al. (1987), in the case of the resonance lines of C IV, Si IV and N V in the IUE ultraviolet range, the line profiles can be interpreted in terms of a superposition of two profiles, one of them a broad, relatively faint emission that shifts back and forth throughout the orbital cycle. The behavior of the radial velocities from this feature suggests that it shares roughly the expected orbital motion of the companion to the B8 II component and, therefore, that it may arise in the optically thick disk that surrounds it.

In view of these considerations, is it at all reasonable to derive abundance anomalies from such a complex spectrum by using, as comparison, stars that appear to be normal and models that are valid for certain sets of physical and abundance parameters with no consideration of complicated and strongly emitting gaseous structure as one finds in β Lyr?

As a consequence, I feel skeptical in regard to the conclusions thus far derived in regard to H-deficiency in the case of β Lyr.

2.1.2 I am somewhat skeptical also in relation to the similar conclusion in the case of υ Sgr, because here again there is a gaseous structure in the systems which gives rise, at some phases, to strong Hα emission and weak diluted He I, the latter having been discovered by Sahade and Albano (1970) nearly twenty years ago.

2.1.3 As for KS Per, which also displays Hα in emission and weak H in absorption, at the moment I have nothing to comment upon, perhaps because I know less about this system. However, it might be appropriate to point out that Schönberner and Drilling (1984) have suggested that the degree of H-deficiency that is attributed to objects like KS Per imply that the same component is in its second episode of mass loss, that is, that the system is undergoing Delgrado and Thomas (1981) case BB of binary star evolution.

3. Let us now deal with the cases that do not display H-deficiency but have been announced as showing evidence of CNO-processed material in the system.

3.1 Rather recently, Parthasarathy *et al*. (1979, 1983) carried out a study of the secondaries of U Cephei (G8 III-IV) and U Sagittae (G3 III-IV) on spectra with a resolution of 1.9 A with 0.46 A per diode. The approach used was that of a spectrum synthesis, the comparison star for U Cep being $\kappa$ Geminorum (G8 III) and, for U Sge, $\delta$ Coronae Borealis (G3.5 III-IV) and the result was that, for both cases, $[Fe/H] = 0.0 \pm 0.3$.

The same authors (Parthasarathy *et al*. 1983) undertook also to examining the C and N abundances in the secondaries of the same two Algol systems, with application of the spetrum synthesis method. The result obtained suggests that in the two cases the late-type mass-losing components are carbon-deficient, $[C/Fe] \sim -0.5$, and nitrogen-rich, $[N/Fe] \sim +0.5$.

3.2 As it is well known and has been pointed out in a recent review paper (Sahade 1986), all the ultraviolet spectra of close binary systems - except Algols - are characterized by the presence of high temperature resonance doublets of C IV, Si IV and N V, normally in emission, the ions being listed in order of decreasing intensity.

In the Algols observed outside of eclipse, however, the resonance doublet line appear in absorption and, contrary to what we have described for the rest of the close binary systems, C IV is the weakest of the ions. This fact prompted Peters and Polidan (1984) to advance the idea that in the atmosphere of the more massive components in Algol systems, C is underabundant and N overabundant, in confirmation of Parathasarathy *et al*'s (1983) results.

It was interesting that a few Algols, namely, U Cep (Plavec 1983), RW Tauri (Plavec and Dobias 1983) and TT Hydrae, U Sge and UX Monocerotis (Plavec *et al*. 1984) were observed with the IUE satellite at principal eclipse. And on these images the resonance doublets of C IV, Si IV and N V are displayed in emission and, as far as intensities and sequence of intensities go, they behave like in the rest of the close binary systems, that is, C IV is the strongest feature of the three.

These observations, which are reminiscent of the behavior of H, particularly of Hα , in Algol systems in the photographic spectra (cf. for instance, Sahade and Wood 1978), and the emission intensity measurements made by Plavec (1983) at partial and total phases during the principal eclipse of U Cep, led McCluskey and Sahade (1987) and Sahade (1986) to suggest that the behavior of C IV outside of eclipse must arise from the filling in of the absorption by "incipient" emission from the circumstellar envelope. This suggestion is in the process of being checked with a scrutiny of IUE archival data.

3.3. An interesting peculiar interacting system which is considered to evidence the result of CNO-processing in the interior of the evolving component, is V453 Scorpii=HD 163181 which was found by Walborn (1972) to display strong N lines in its spectrum which was classified as BN 0.5 Iae. A few years later, Hutchings (1975) compared the spectrum of V453 Sco with those of κ Cassiopeiae (B1 Iae), $\chi^2$ Orionis (B2 Iae) and HD 190603 (B1.5 Iae) and reached the conclusion that there is practically no difference in Hγ , that O II is weaker by a factor of around 2 and that N II is stronger by a factor larger or equal than 2.

In regard to this object, I would point out that its spectrum varies with phase, shows the effect of a veiling at some phase interval and that the circumstellar envelope around the fainter, larger mass component is quite opaque, at least it is not completely transparent to the stellar radiation.

3.4 We have discussed in a condensed way the question related to the objects and evidence that are normally considered when talking about abundance anomalies found in interacting binaries, and offered relevant comments. It seems that the evidence for CNO-processed material is probably there but the evidence for H-deficiency is at least subject to doubt. And the doubts are even greater when one realizes that in interacting binaries, well advanced in their evolution, one does not find the sort of abundance anomalies that we would seem to find in less evolutionary advanced systems.

4. For the sake of completeness I would like to finish this review paper by referring to the working hypothesis that I suggested (Sahade 1986, 1987a) to try to make sense out of the peculiar interacting binaries. If the working hypothesis was proven to be right, then it would imply that we have a sequence for the evolution of the gaseous structure that characterizes interacting binaries.

Since I have earlier given the rationale for the working hypothesis, in order not to take up more space than alloted to invited papers I refer the reader to the previous papers. I would only add the different stages that are consistent with the working hypothesis (see also Sahade 1987b):

a) stage of rapid mass loss which is preceded by the presence of variable, optically thick plasma: The R Arae stage;

b) stage at which systems are embedded in gaseous matter, not totally opaque, that dominates the spectrum: The W. Serpentis stage ;

c) stage at which systems are embedded in thick plasma and the spectrum shows emissions arising in the circumstellar and in the circumbinary envelopes: The GG Carinae stage;

d) stage at which one component, the now more massive one - after mass - ratio reversal - is surrounded by an opaque disk: The β Lyrae stage;

e) stage at which the opaque disk has become semitransparent: The V453 Scorpii stage;

f) the envelope around the more massive component becomes thinner as time goes by and we have then U Cephei and then the typical Algols: The Algol stage.

In order to check this suggestion we would have to being able to determine mass loss rates and abundances in the typical objects.

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