ON THE ORIGIN OF THE BARIUM STARS

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ABSTRACT

We show that Ba stars cannot originate from single stars, they can only be formed in binaries by mass transfer. The companion must then have been an evolved star with log $L/L_{\odot} \geq 3.2$, requiring a radius larger than 0.5 a.u., explaining the long periods of the observed Ba star binaries. If the companion lost half of its mass to the present Ba star we expect to see a white dwarf companion now. Companions with $T_{eff} \gtrsim$ 12000K have been seen for the nearest Ba stars. For Ba stars at larger distances companions can only be detected if they have $T_{eff} \geq$ 20000K.

In order to make a Ba star the slow neutron capture process has to go on in the interior of a star, and some process has to bring the newly formed elements to the surface of either the same star or a companion. In order to understand how this happens we first have to know where in the H-R diagram we find the Ba stars. Temperatures can be determined spectroscopically, so can gravities, at least to within a factor of 2. If we know the masses then radii and luminosities can be computed. For different masses we find different luminosities. The luminosity increases proportional to the assumed mass M. Another relation between mass M and luminosity L is given by the evolution theory. From these two relations between M and L we can determine approximate masses for the Ba stars. In figure 1 we show the approximate positions for the Ba stars in the H-R diagram assuming masses of 2.5 $M_{\odot}$. Also shown is the evolutionary track for a 2.5 $M_{\odot}$ star as extrapolated from the calculations of Becker, Iben and Tuggle (1977). The spectroscopic luminosity for a 2.5 $M_{\odot}$ star fits this track rather well. The observed luminosity, assuming a 5 $M_{\odot}$ star, would not fit on the corresponding evolution track. We conclude that the Ba stars have masses between 2.5 and 1.5 $M_{\odot}$, except for ζ Cap which seems to have a larger mass. Absolute M_V determined from the Wilson Bappu relation are generally in rough agreement with the spectroscopic M_V.

The Ba stars reside in a region of core He burning. They probably have gone through the He flash but they have not gone through double shell

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source flashes. According to present stellar evolution theory they have not yet gone through a phase where the slow neutron capture process can have taken place, which needs log $L/L_\odot > 3.2$ according to Iben (1981). The only way out of this difficulty is a neutron capture process that took place in another star, a companion, which then shed its envelope on to the present Ba star.

The companions of the Ba stars must then all be evolved stars which have lost their envelopes, they must be white dwarfs. They have been confirmed for ζ Cap, ζ Cyg (Böhm-Vitense 1981, Lambert 1982), 56 Peg, (Schindler et al. 1982), and for ζ^1 Cet, (Böhm-Vitense and Johnson 1983).

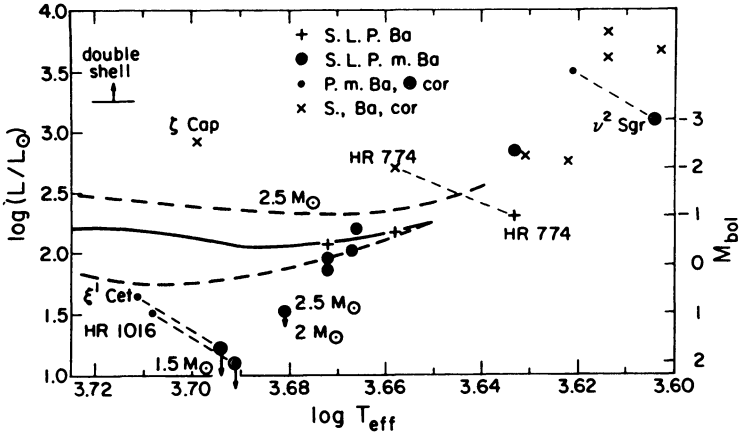

Figure 1: The position of the Ba stars in the H-R diagram suggests a mass of about 2.5 $M_\odot$. They appear to be at a stage of core helium burning.

Indirect evidence is seen for HR 1016 and 56 U Ma (Böhm-Vitense 1983), for which forbidden lines of OIII and NIV are observed.

The last Figure shows in a diagram the distances of the Ba stars which have been observed. We also indicate for which stars the white dwarf companions have been seen. Cool white dwarfs have been seen for the nearest stars. For the Ba stars which are further away we can see the companions only if they are still very hot. I think the observations confirm what we expect to be able to see.

If mass transfer leads to the formation of Ba stars, why are the binary periods so long? McClure (1982) observed periods between 80 days and several years. Before the mass transfer the present WD companion must have been evolved enough for the slow neutron process to have occurred. If this requires log $L/L_\odot >$ log $L_{crit}/L_\odot = 3.2$ (Iben 1981), then we calculate that log $R/R_\odot > 2$ if $T_{eff} = 3500$ K at this time. The distance d of the stars must then be d > 0.5 a.u. Otherwise mass transfer occurs

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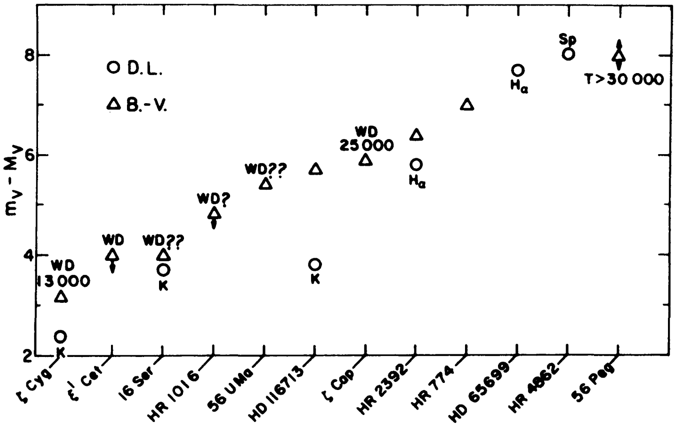

Figure 2: The distances of the Ba stars are shown. Stars for which white dwarf companions have been seen are indicated and approximate temperatures are given. Question marks indicate stars for which indirect evidence for the companions has been seen.

too early. For $M_1 + M_2 \sim 3\ M_\odot$ we find that the period must be longer than 72 days. This seems to agree rather well with the shortest observed period of 80 days for HD 77247, which could, however, turn out to be a triple system. If that should be the case, then the shortest observed period is a factor 6 larger which could mean either that the distance of the binaries increased during the mass transfer or that the critical luminosity is larger than log $L_{crit}/L_\odot = 3.2$.

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DISCUSSION

Renzini: I don't quite see the difficulty with evolutionary timescales. Accreting secondaries could well have been main sequence stars, and then one can have any delay whatsoever between the formation of the WD and the arrival of the Ba star on the red giant branch.

Böhm-Vitense: The problem is that main sequence Ba stars have not yet been discovered. If I did my statistics right, one would expect to see one Ba star out of 1000 main sequence stars. We may have missed the one, then this may well be the answer. But Dr. Lambert feels that we should have seen it.

Renzini: But there will certainly be selection effects against discovering MS Barium stars.

Despain: Does your model assume that ^{22}Ne is the neutron source, as for Iben and Truran's scenario?
Why couldn't the s-processing occur during some hydrodynamic event during the core flash?

Böhm-Vitense: No, the source is not specified.
The abundances of any neutron donor element is too low at that time. At least 80 neutrons have to be available per Fe atom in order to make the observed abundances of the s-process elements. It also seems to me that the times available at the flash are too short for the slow neutron capture process.