ON THE ORIGIN OF HELIUM RICH STARS

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ABSTRACT: The modern theory of stellar evolution leads to several possible scenaria for the formation of many types of hydrogen deficient (usually helium rich) stars. Some of these scenaria are briefly discussed in this paper to provide possible explanations for origins of R Cr B, hot helium and Wolf-Rayet stars; hot sub dwarfs, non-DA degenerate dwarfs and helium stars in binaries like KS Per. The merger of two degenerate stars in close binaries due to the radiation of gravitational waves can lead to several types of helium and carbon rich stars as well as to supernova explosions.

Stars with hydrogen-deficient (and usually helium rich) envelopes have been found in many regions of the Hertzsprung-Russel diagram (Fig. 1). The brightest of all helium rich stars are massive Wolf-Rayet stars. Most of them are products of the evolution of close binaries with initial component masses above $\sim 20\ M_\odot$. About one third of all classical WR stars can be products of the evolution of single massive stars with initial masses exceeding $\sim 40\ M_\odot$. The theoretical frequency of their formation together with their lifetimes leads to a reasonable estimate of $\sim 10^3$ for the total number in our Galaxy. Masses of WR stars, as a rule, exceed $\sim 10\ M_\odot$. The natural extension of helium burning helium rich stars in binaries to lower luminosities in the H-R diagram is observationally less known. The theoretical estimate of the total number of such stars in our galaxy, most of which have masses in the range 0.3-1.0 $M_\odot$ is about 10^7 (Iben and Tutukov, 1985). The observational estimate of the number of sdB and sdO stars, which are possible counterparts of these helium stars in the core helium burning stage now exceeds $\sim 10^6$ (Heber, 1985). Additional studies of these stars will be helpful in understanding the reasons behind this persistent discrepancy. Some fraction of hot subdwarfs can also be explained as limiting cases of horizontal branch stars which have lost their hydrogen rich envelopes during the core helium flash (Greenstein and Sargent, 1977). Their possible position on the line marked helium stars in binaries is shown by a black square in Figure 1. The differences in their luminosity functions can help in distinguishing these two populations. Possible products of the merger of the two helium degenerates, due to the radiation of gravitational waves, will have masses in the range $0.25\ M_\odot$- $0.95\ M_\odot$ and can be hot subdwarfs.

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About 30 stars have been discovered, thus far, that are giants with hydrogen deficient envelopes and which display from time to time large decreases in their visual brightness (Warner, 1967). These stars are known as R Cr B stars. The temporary dimming is usually attributed to the formation of an optically thick dust shell above the helium and carbon-rich envelopes. The hydrogen abundance in their atmospheres by mass is less than 10^{-4}. Members of another class, the non-variable hydrogen deficient stars have usually higher surface temperatures but approximately the same luminosities (Fig. 1). The total number of helium rich giants (both variable and non-variable) in our Galaxy consists of several thousands. The z-distribution of helium rich giants is very wide, spread over 400-1500 parsecs (Warner, 1967, Iben and Tutukov, 1985). Several mechanisms have been proposed till now to explain the origin of helium rich giants. Evolution of close binaries with components of initial masses 5-10 $M_\odot$ which undergo two mass exchange phases produces giants with helium rich envelopes. KS Per and Upsilon Sagitarii are examples of such giants. The estimated number of their total population in our Galaxy. agrees well with the observed number, but the z-distribution and especially the chemistry are still unsolved problems for this scenario. The merging of two degenerate dwarfs, the lighter of which is composed of helium and the other of carbon + oxygen or oxygen + neon has been proposed as an alternative possibility to explain the helium giant formation (Tutukov and Yungelson, 1979; Iben and Tutukov, 1985). The lifetime of a star with a helium rich envelope is $\sim 10^4$ - 10^5 yr. A more detailed study of this scenario is required now. The details of the process of merger are still not clear, e.g., the result of the rather frequent (0.1 yr^{-1}) merging of a close pair consisting of two degenerate helium dwarfs. If the product of merger is a non-degenerate helium star a fraction of hot subdwarfs could be such stars which will evolve finally into non DA dwarfs. Non-degenerate products of the merger of CO dwarfs with masses between 1 - 2.8 $M_\odot$ will populate the short sequence of CO stars (Fig. 1). Models of these stars have been computed by Beaudet and Salpeter (1969). Their lifetime is $\sim 10^5$ yr because most of their energy is carried away by neutrinos. The total number of carbon burning stars in our Galaxy can thus be estimated to be about several thousand.

The natural evolution of a helium rich giant with a CO-core will produce a CO degenerate dwarf after the loss of a part of the helium rich envelope. Evidently this is a way to form non-DA white dwarfs, if the mass of such a star doesn't exceed $\sim 1.4\ M_\odot$. But the production rate of this scenario, is possibly not enough to explain all non DA dwarfs. Additional possibilities can be attributed to stellar wind from cooling degenerate dwarfs (Iben and Tutukov, 1986). This way can be, of course, applied to double helium dwarfs that are products of close binary evolution with components of initial masses below $\sim 2.5\ M_\odot$. The track of the cooling 0.3 $M_\odot$ helium dwarf is shown in Fig. 1 according to Iben and Tutukov (1986).

If the mass of the carbon-oxygen degenerate core of an R Cr B star can exceed 1.4 $M_\odot$ the supernova explosion becomes inevitable (Fig. 1).

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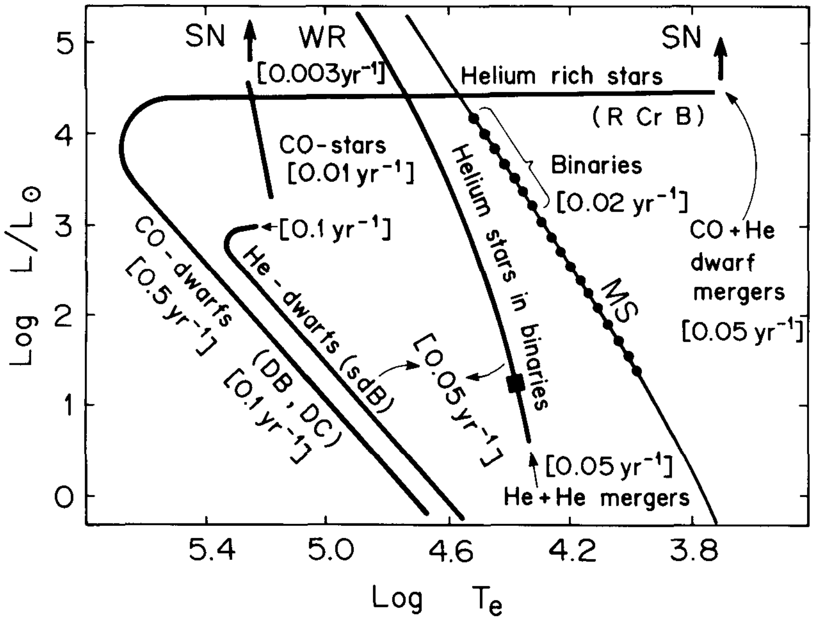

Fig. 1: The Hertzsprung-Russel diagram for Hydrogen deficient stars. The line MS showing the position of main sequence stars some of which can be helium enriched (dots). The position of helium star remnants from close binary evolution products is also shown. The position of a 0.5 $M_\odot$ helium star with a low mass hydrogen envelope is marked by the black square. The evolutionary track of a star consisting of a degenerate carbon-oxygen or oxygen-neon core and a helium rich envelope with the total mass below $\sim$ 1.4 $M_\odot$ is marked with positions of R Cr B and helium rich stars, and non-DA degenerate dwarfs. Also shown is the evolutionary track for the cooling of a 0.3 $M_\odot$ degenerate helium dwarf and the position of CO stars in the core carbon burning stage. Numbers in brackets are rough estimates for formation rates of the corresponding stars.

One more type of helium rich stars can exist as a prdocut of the evolution of close binaries with initial component masses of 5 - 10 $M_\odot$. The two-time mass exchange (BB-case) will evidently considerably enrich with helium the envelope of the initial secondary component of the close binary. This helium rich matter will mix with deeper hydrogen-rich shells. As the time scale of such mixing is not known yet, one may assume that some fraction (less than 0.02) of binary MS stars can be enriched by helium. Masses of these secondaries can be well outside the above range of initial masses because of, e.g., a low initial mass ratio. This possibility also needs to be studied for the explanation of the possible presence of helium rich stars on the main-sequence (Fig. 1).

Secondary components of classical Algols are frequently helium enriched stars. Their evolution has been understood as due to an extensive mass exchange between components of close binaries. As the evidence for the mass exchange is very reliable in this case it would be of interest to check whether the chemical composition of the atmospheres of both the components are similar in algol-type binaries.

In conclusion, I can say that the modern theory of stellar evolution can now lead to several promising possibilities for the origin and evolution of helium rich stars. Many of these scenaria at present involve binary stars. Thus it is now time to study all these possibilities in more detail to compare predictions of different scenaria with observations.

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DISCUSSION

SCHÖNBERNER: Your binary scenario for R CrB stars predicts nitrogen-rich and carbon-poor atmospheres, just the opposite to what is observed.

TUTUKOV: Yes, I know. I said that BB mass exchange works for stars like KS Persei. For the single extreme helium stars, the idea of merger was proposed by Iben, Webbink and myself. Then we have some part of the carbon-rich matter mixed with pure helium. Two or three years ago, nobody believed that merging of two degenerate stars would really be possible.

HUNGER: If you start with a specific star on the helium branch, then how would the evolution proceed?

TUTUKOV: It would depend on the mass of the star. If the mass of the helium star is above 4 solar masses then, as has been shown, for instance, by Paczynski and ourselves, it will develop a core of 2.5 solar mass. After the core helium-burning phase, it will never evolve to low effective temperatures.

HUNGER: What is your guess concerning the extreme helium stars: do they belong to the R CrB track or to the generalized main sequence?

TUTUKOV: It is very easy to make a guess; it is very difficult to prove something. So everything is consistent in the diagram.

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