EVOLUTIONARY STATUS AND ORIGIN OF EXTREMELY HYDROGEN-DEFICIENT STARS

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ABSTRACT. Our present knowledge about the evolutionary status of extremely hydrogen-deficient stars is reviewed. Possible schemes for their creation are discussed, with special emphasis on a recently proposed binary scenario, according to which they are the result of the merging of two white dwarfs. Finally, the possible generic links between the different groups of extremely hydrogen-deficient stars are briefly discussed.

1. INTRODUCTION

The main question that we have been interested in since the detection of the first extremely hydrogen-deficient (EHd) star by Popper in 1942 is the following: how can a low mass helium star come into being from a low mass precursor? Unfortunately, we are not yet in a position to answer this question definitively, although several scenarios have been put forward. However, we are able to say something about the internal stucture of EHd-stars and, in a few cases, also about their evolution. I will firstly, therefore, concentrate on our present knowledge of the internal structure and observed evolution of EHd-stars before I discuss the various schemes for their origin.

In the following, the term "EHd-star" means an object in which the atmospheric hydrogen content is reduced by at least a factor of 10^3 (i.e. $H/He \lesssim 10^{-3}$, by number fractions). Consequently, the Extreme Helium (EHe) stars, the R CrB-stars, and the Hydrogen Deficient Carbon (HdC) stars are also EHd-stars. All intermediate helium stars are thereby automatically excluded, as well as the somewhat "peculiar" helium star BD +13°3224, also known as V652 Her. I have also excluded the hydrogen deficient binaries since their origin and evolution is understood within the frame work of binary evolution (Schönberner and Drilling 1983; see also the review articles of M. Plavec and A. Tutukov in these proceedings). Furthermore, all helium rich underluminous O-stars are excluded, despite the fact that some of them are carbon-rich and might be further evolved EHe-stars (see the contribution by Husfeld, Heber and Drilling, these proceedings).

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2. INTERNAL STRUCTURE OF EHd-STARS

Spectroscopic observations and their interpretations by model atmospheres yield the data necessary for the determination of the internal structure of EHd-stars: effective temperature T_{eff}, gravity g, and chemical composition. With effective temperature and gravity known, the objects can be placed in a (g, T_{eff})-plane (equivalent to the conventional H.R.-diagram) and compared with the loci as predicted by stellar model calculations. Since the results of various fine analyses of EHd-stars have been compiled and discussed in the reviews by Heber and Lambert (these proceedings), I will therefore only briefly summarize the main results:

i) Besides their hydrogen deficiency, EHd-stars are carbon-rich with $C/N > 1$, as opposed to the hydrogen-deficient binaries which have $C/N < 1$ (cf. Schönberner and Drilling, 1984);

ii) they occupy a narrow strip in the (g, T_{eff})-diagram (cf. Fig. 1), ranging from the (normal) main sequence towards the giant region;

iii) the luminosity to mass ratio is about constant, and is given by $\log(L/M) = 4.1 \pm 0.5$ (solar units).

It should be noted that these results are only based on the analyses of a very limited number of objects, namely on 4 EHe- and 3 R CrB-stars. Furthermore, recent observations seem to indicate that the spread in L/M is intrinsic, i.e. not only caused by observational errors.

From their position in the (g, T_{eff})-diagram above and far to the right of the helium main sequence, we infer that EHd-stars are inhomogeneous helium stars evolved far beyond the core helium burning phase. The first comprehensive study on how low mass helium stars evolve after the core helium burning phase has finished was that of Paczynski (1971). Other calculations of relevance are those of Rose (1969), Biermann and Kippenhahn (1971), Dinger (1972), Trimble and Paczynski (1973), Savonije and Takens (1976), Schönberner (1977), Law (1982) and Habets (1985). It emerges from all these calculations that the observed loci of EHd-stars can be accounted for by inhomogeneous models within the mass range $0.7 \lesssim M/M_\odot \lesssim 2.7$ and luminosity range $3.8 \lesssim \log(L/L_\odot) \lesssim 4.7$. According to Dinger (1972), a small admixture of carbon does not change the results of these evolutionary calculations as long as $C/He \ll 1$ (number fractions). For instance, a $1\ M_\odot$ model with $C/He = 0.44$ does not become a giant at all after core helium burning has finished. Fortunately, the observed carbon to helium number ratio is ≈ 0.01, too small for any noticeable effects on the internal evolution of helium stars (Dinger, 1972). A small extra carbon content may, however, influence to some extent the redward excursion of the giant models. A comparison between the observations of EHd-stars and evolutionary calculations of Paczynski (1971) is shown in Figure 1. These calculations simulate the evolution of helium stars with $X = 0$, $Z = 0.03$, i.e. with no extra carbon, from their "main sequence" till the onset of carbon burning or the pre-white dwarf stage. If we neglect for the moment the problem of how to create helium main-sequence stars, we find a very gratifying agreement between stellar evolution theory and the observations.

The details of the helium star evolution are as follows: models with $M > 1.1\ M_\odot$ start carbon burning at, or on their way to, the Hayashi limit. Paczynski (1971) found a mild off-center carbon ignition in his 1.5 and 2.0 $M_\odot$ models but did not compute any further. Rose (1969) argued that such off-center ignition of carbon in only weakly electron-degenerated regions does not seriously alter the structure of the model. Instead, his 1.45 $M_\odot$ model was evolved further to larger radii until carbon burning started in the highly degenerated center of the CO-core ($M_{CO} \approx 1.4\ M_\odot$). More massive helium stars ($M \gtrsim 2\ M_\odot$) do not develop degenerate CO-cores at all, but for $M \lesssim 2.7\ M_\odot$, they also expand to the Hayashi limit during carbon burning (Savonije and Takens, 1976; Habets, 1985). More massive helium stars do not evolve into the cool region of the H.R.-diagram. If mass loss is neglected, the ultimate fate of all helium stars with $M \gtrsim 1.4\ M_\odot$ will be a supernova explosion (Wheeler, 1978).

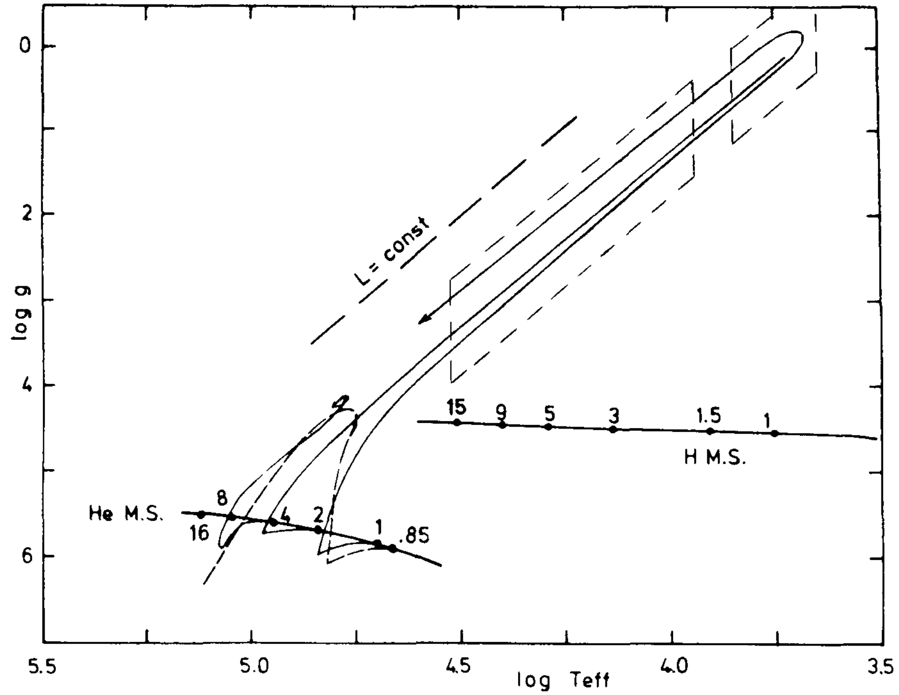

Fig. 1 Observed loci of EHd-stars in the (g, T_{eff})-plane and evolutionary tracks of helium stars with different masses according to Paczynski (1971). EHe-stars occur for $4.5 \gtrsim \log T_{eff} \gtrsim 3.95$, whereas the HdC- and most of the R CrB-stars are confined to $\log T_{eff} \lesssim 3.85$. The numbers along the main sequences give stellar masses in solar units.

We conclude that helium giants can be modelled in two ways:

i) by low mass models ($0.7 \lesssim M/M_\odot \lesssim 2$) which burn helium in a shell on top of a degenerate, inert CO-core;

ii) by more massive models ($2 \lesssim M/M_\odot \lesssim 2.7$) which burn carbon in the center or in a shell.

Helium giants which are able to avoid a supernova explosion, either by mass loss or because they started their evolution with $M < 1.4\ M_\odot$, will finally contract again when their envelope mass falls below a certain value ($\approx 10^{-2}\ M_\odot$), thereby crossing the observed loci of EHd-stars for a second time before they become white dwarfs. Thus, a definite assignment between the evolutionary tracks and the observations is not possible. This is a serious problem because it is crucial for our understanding of the origin and evolution of EHd-stars to know whether they are born as helium main sequence stars which evolve to the Hayashi limit, or as red giants which then further contract from the Hayashi limit to the white dwarf region.

Detailed calculations for models contracting from the Hayashi limit have only been performed by Schönberner (1977). It turned out that the times for crossing the B-type spectral region (i.e. the region where the EHe-stars are found) are very dependent on the direction of evolution: the predicted lifetimes as B-type stars are about ten times larger for evolution "to" the Hayashi limit than those for evolution "from" the Hayashi limit (Table I). Since the latter models, owing to their more advanced evolution, also have larger luminosities (cf. the 1 $M_\odot$ track in Fig. 1), comparision between theory and observation also leads to different mass assignments. The details are given in Table I. It is clear that birthrate estimates are practically impossible as long as we are unable to discriminate between both directions of evolution.

TABLE I

	M_*	M_{CO}	t(B-star)/yr	$(L/M)/(L_\odot/M_\odot)$
"TO" :	(1-2) $M_\odot$	(0.6-0.7) M_*	2.10^4	$10^{3.9}$
"FROM":	$\approx 0.7\ M_\odot$	$\approx M_*$	2.10^3	$10^{4.1}$

3. THE OBSERVED EVOLUTION OF EHd-STARS

Concerning the present evolution of EHd-stars, some progress has been made recently by analyzing the the radial pulsations of some R CrB-stars. Pugach (1977) was the first to notice that the period of RY Sgr ($P \approx 39$ days) had decreased by about 1 day within the last 40 years. More detailed analyses performed by Kilkenny (1982) and Marraco and Milesi (1982) yielded a period decrease of $\dot{P} = -0.011$ and -0.015 days/yr, respectively, which corresponds to a pulsational lifetime of about 3000 years. Other R CrB-stars seem also to exhibit period variations (Kilkenny and Flanagan 1983), but the analyses of these are as yet inconclusive. At least one EHe-star, BD+1°4381, also pulsates radially, with a period of about 21 days (Jeffery and Malaney, 1985), but these observations are still too preliminary to be able to say something about period changes. Thus, our information on the present evolution of EHd-stars is based, strictly speaking, on only one single object, namely on RY Sgr.

The consequences, however, are very important. First of all, RY Sgr is obviously evolving to hotter effective temperatures, i.e. it is shrinking and will become a white dwarf in the future. This implies that its mass (more precisely, the mass of its CO-core) is definitely below the SN-limit of 1.4 $M_\odot$, and probably also below 1.1 $M_\odot$, the carbon burning mass limit. Moreover, Kilkenny (1982) has shown its observed evolutionary speed to be consistent with that of post-red giant helium star models of 0.7 to 1 $M_\odot$ as computed by Schönberner (1977).

Recent theoretical calculations of nonlinear radial pulsations of helium-carbon envelopes (Saio and Wheeler, 1985; Saio, these proceedings) have also given interesting results. They show that stellar models with T_{eff} = 7000 K pulsate with a period of 40 days (as is observed for RY Sgr), and that this period is stable even for $M = 0.7\ M_\odot$. At lower effective temperatures ($\lessapprox$ 6000 K), the pulsation amplitudes grow without bound if the stellar mass is below 1.6 $M_\odot$. Since the effective temperature of RY Sgr is about 7000 K (Schönberner, 1975; Cottrell and Lambert, 1982), these new calculations do not contradict a mass estimate for RY Sgr of less than 1 $M_\odot$. In the past, when RY Sgr was cooler, it may have experienced severe mass loss owing to these unstable pulsations. Such mass loss leads to an accelerated blueward evolution, thereby reducing the lifetime of R CrB-stars with $T_{eff} \lesssim$ 6000 K as compared to the hotter ones and leading to a deficit of such cool R CrB-stars. It would be very important to check this prediction by determining the effective temperatures of as many R CrB-stars as possible. Pulsationally induced mass loss may also prevent more massive R CrB-stars from exploding as Supernovae.

Heber and Schönberner (1981) found that the temperature distribution of EHe-stars could be explained by Schönberner's (1977) models of contracting helium giants. The evidence is, however, weak because of the poor statistics and further investigations with a larger sample are necessary.

4. ORIGIN OF EHd-STARS

Each scenario for the origin of EHd-stars that we can think of must meet two observational constraints:

i) EHd-stars are evolved single objects of low mass, belonging to a rather old population;

ii) their surface abundances indicate that their envelope consists of a mixture between the original matter (trace of hydrogen), CN-processed matter (enhanced nitrogen content) and 3α-processed matter (enhanced carbon content).

Owing to the latter constraint, a simple mass loss scenario, according to which the hydrogen rich envelope is removed, is completely ruled out. Also, the exposed helium remnant would, in the case of an AGB-progenitor, be very compact ($R \approx 2R_{WD}$) and very hot ($T_{eff} \approx 10^5$ K). One could, of course, imagine more massive progenitors. For instance, a star with $M = 5\ M_\odot$ develops a helium core of $\approx 1\ M_\odot$ during the M.S.-phase. But how could the star get rid of $\approx 4\ M_\odot$ if not by binary evolution? Furthermore, a $5\ M_\odot$ has too short a life for its remnant to be considered as an old star. A violent core helium flash is also ruled out. A stripped-off helium core is also rather compact and has only $0.5\ M_\odot$. Helium giants with such a small total mass could not be constructed numerically. Instead, the high luminosity to mass ratio and the internal structure of EHd-stars suggest a relationship to asymptotic giant branch (AGB) stars (Schönberner, 1975, 1977).

Paczynski (1971) was the first to propose that deep envelope mixing on the AGB could be responsible for the formation of a helium giant. The first detailed modelling of such a mixing process was presented by Sackmann et al. (1974). In their so-called "Eruptive Model" they artificially extended the envelope convection in a low-mass AGB-star somewhat beneath the hydrogen-helium discontinuity. Owing to the large and very rapid energy production, triggered by the injection of fresh fuel, part of the envelope is rapidly blown off whereas the rest is processed. However, when hydrogen becomes sufficiently depleted ($H/He \lesssim 10^{-2}$), a carbon isotopic ratio $^{12}C/^{13}C \approx 6$ is established. This is in strong contradiction to the observations in R CrB-stars where $^{12}C/^{13}C \approx 40$ is found (Cottrell and Lambert 1982). Thus, this model cannot explain the observed surface abundances in R CrB-stars. It is also unclear if, and how the remnant is able to settle down into a quiet nuclear burning state after this explosive event. This is an important point since, as was mentioned in the previous chapter, the observed evolutionary time scale of RY Sgr is in agreement with helium star models in thermal equilibrium evolving to hotter temperatures and smaller radii.

Another mechanism proposed as leading to hydrogen-deficient giants is the so-called "Hot Bottom Burning" of Scalo et al. (1975). Their computations showed that the base of the convective envelope in AGB-stars of at least $1.5\ M_\odot$ and $10^4\ L_\odot$ is sufficiently hot as to allow nuclear processing via the CNO-bicycle. This can also lead to a hydrogen depletion of the whole envelope, provided the available time is sufficiently large. If we demand a hydrogen depletion by a factor of 100 during the typical lifetime of a luminous AGB-star of about 10^6 yrs, a minimum base temperature of $70 \cdot 10^6$ K, corresponding to $M \gtrsim 2\ M_\odot$, follows from the computations of Scalo et al. Such high progenitor masses are also difficult to reconcile with the observed population characteristic of EHd-stars. Moreover, any larger hydrogen reduction will obviously lead to structural changes of the envelope in such a way that the results of Scalo et al. are no longer applicable. We also expect, owing to the CNO-process, a nitrogen to carbon ratio $N/C > 1$ to be established very rapidly, even if fresh carbon is dredged up in the aftermath of a thermal pulse. In summary, we must state that this model also fails to explain the observed surface chemistry of EHd-stars.

Yet another scheme was proposed by Iben et al. (1983), and may be called the "Last Helium Shell Flash Scenario". As is well known from evolutionary calculations, post-AGB models may experience a last thermal pulse immediately before they embark onto the white dwarf track (Schönberner, 1979; Iben 1982). The energy output of this last shell flash leads to large-scale mixing and a brief expansion of the envelope to giant dimensions. Only very approximate calculations are as yet available, but it is clear that the brief excursion to the vicinity of the Hayashi limit is governed by the thermal time scale of the envelope. Because of the high luminosity ($\approx 10^4$ $L_\odot$) and the small envelope mass ($\approx 10^{-4}$ $M_\odot$), this time scale is very short: the model lifetime in the R CrB-star domain is only about 10^2 yrs (Iben et al. 1983), much too short to account for the observations. In particular, the lifetime of RY Sgr, as indicated by its pulsation properties (cf. Chapter 3) is about thirty times larger. We conclude that this scenario also seems to fail in explaining the origin of EHd-stars.

So far, all the schemes that have tried to trace the origin of EHd-stars back to the AGB have severe drawbacks and are thus not convincing. A scenario proposed by Webbink (1984) is completely different and has no relationship to the AGB-evolution of single stars. It is essentially based on two merging white dwarfs which are the product of binary evolution. The details are as follows (cf. Webbink, 1984): the initial systems in question are fairly massive ($2 \lesssim M_p/M_\odot \lesssim 3.5$), with mass ratios close to unity, and begin their evolution with primordial periods between 1 and 10 d. Conservative case B mass transfer transforms the primary into a helium degenerate of about 0.3 to 0.4 $M_\odot$. In the meantime the secondary, which is now much more massive ($M_s/M_p \approx 10$), is able to evolve to the giant branch and to develop a degenerate CO-core before it overflows its Roche lobe. Owing to the large mass ratio, this second mass transfer is very unstable and will obviously lead to a common envelope stage, the result of which being a substantial systemic loss of mass and angular momentum. The secondary is thereby transformed into a CO-white dwarf, and the final periods are now between 1 and 10 h. The system now consists of two close white dwarfs (a He-degenerate and a CO-degenerate) which emit gravitational radiation and thereby lose angular momentum. After a time span of between 10^8 and 10^{10} yr, depending on their final separation, the lighter of these two white dwarfs, which is the He-degenerate, is forced to overflow its Roche lobe and transfer to the companion mass at a rate of about 10^{-4} $M_\odot$ yr^{-1}. It is thought that accretion of helium at such a rate very soon leads to quiet helium burning at the base of the helium envelope which is built up on top of the CO-degenerate. This growing helium envelope is expected to increase in radius and eventually to engulf the remains of the He-degenerate within only about 10^3 yr. If, in this final mass exchange, no matter leaves the system, we end up with a single helium red giant (i.e. a R CrB- or HdC-star) with a total mass between 0.8 and 1.4 $M_\odot$, consisting of a CO-core of about 0.5 to 1.0 $M_\odot$ (originating from the CO-degenerate), and a helium envelope of 0.3 to 0.4 $M_\odot$ (originating from the He-degenerate).

At a first glance, although this scenario leads to helium giants in the appropriate mass range, it seems to violate the population constraint posed above. The observations can surely not be reconciled with progenitor masses of 2 or 3 $M_\odot$! The solution comes from the fact that the gravitational radiation emitted from the white dwarf binary leads to only a very slow orbital decay, which may last up to the order of 10^{10} yrs. Thus, even if a helium giant is presently created by the merging of two white dwarfs which originated, according to Webbink's scenario, from rather massive progenitors, it may still belong to an old stellar population. Webbink's scenario also has other advantages:

i) The trace of hydrogen that is observed in the surfaces of EHd-stars stems from the thin layer of unburned hydrogen at the surface of the He-degenerate after case B mass exchange. For instance, a He-degenerate of 0.38 $M_\odot$ still contains 2.10^{-4} $M_\odot$ of unburned hydrogen (Iben and Tutukov, 1985). This hydrogen would be mixed with helium during the mass transfer process, leading to a hydrogen to helium ratio of 5.10^{-4} in this particular case.

ii) Furthermore, the nitrogen is also provided by the helium degenerate, where all the primoridal carbon and oxygen have been converted to nitrogen.

iii) The high atmospheric carbon content of EHd-stars can be accounted for by assuming that the accretion onto the CO-degenerate occurs through a heavy disk (Iben and Tutukov, 1985). Shear mixing may then dredge up some carbon (^{12}C!) from the surface of the white dwarf into the accreted helium envelope. A total amount of only 5.10^{-3} $M_\odot$ would be sufficient! Of course, some oxygen also has to be dredged up.

According to this binary scenario, EHd-stars are born as cool giants due to the above described merging process and, subsequently, evolve to higher effective temperatures. Their lifetime in the vicinity of the Hayashi-limit can be estimated by $M_{env}/\dot{M}_{co} \approx (0.3\text{-}0.4)/1.10^{-6}$ = (3-4) 10^5 yr, which is only an upper limit since mass loss is neglected. Mass loss rates in excess of 10^{-6} $M_\odot$ yr^{-1} (i.e. $|\dot{M}| > \dot{M}_{co}$) would shorten the lifetime considerably.

Despite the apparent success of Webbink's proposal for the origin of EHd-Stars, a cautionary remark seems to be in order: we urgently need its confirmation by detailed evolutionary calculations! Assuming for the moment that Webbink's scenario is correct, we can go even further since he also estimated a birthrate for He-Co white dwarf close binary systems, i.e. for the immediate progenitors of EHd-stars: 2.10^{-11} pc^{-2} yr^{-1}, or 0.015 yr^{-1} for the whole galaxis. With this birthrate, and assuming that each merging He-Co system leads to a shell burning helium giant, we estimate a galactic total of $\approx 0.015 \times 2.10^3$ = 30 EHe-stars. A significant fraction of our galaxis has been surveyed for EHe-stars (see Drilling, these proceedings) and 17 objects have been detected so far. It is difficult to estimate the fraction of objects hidden behind the galactic dust layer, but it seems very likely that the total galactic population of EHe-stars is not an order of magnitude different from the figure estimated above.

The situation is unclear in the case of the cool EHd-stars, i.e. the R CrB- and HdC-stars. Assuming a lifetime of 2.10^5 yr, we estimate in the same way as above a total of about 3.10^3 objects. If cool R CrB-stars suffer severe mass loss ($> 2.10^{-6}$ $M_\odot$ yr^{-1}), their lifetime is reduced accordingly and thus also their space density. For instance, in order to end up with a total of 50 R CrB-stars in our galaxis, their lifetimes must be reduced to only 3.10^{3} yr, i.e. to values comparative to those of EHe-stars. Mass loss rates of the order of 10^{-4} $M_{\odot}$ yr^{-1} are necessary to speed up the evolution to this extent. It would be very important in this context to determine the actual mas loss rates of cool R CrB-stars. It should also be noted that, according to Feast (these proceedings), the mass loss rates of the hotter R CrB-Stars are only of the order of 10^{-6} $M_{\odot}$ yr^{-1}, and therefore of minor importance for the evolutionary time scale. The mass loss rates of EHe-stars are even smaller: $< 10^{-7}$ $M_{\odot}$ yr^{-2} (Hamann et al. 1982).

5. ON THE RELATIONSHIP BETWEEN THE DIFFERENT CLASSES OF EHd-STARS

In closing this review, I would like to speculate about the evolutionary connections between the different classes of EHd-stars. As outlined in Chapters 2 and 3, the EHe-, R CrB- and HdC-stars are linked together by evolutionary tracks, the main difference between them being the effective temperatures or the envelope masses, respectively. They also seem to have the same, or at least a very similar, surface chemistry (cf. the reviews of Heber and Lambert, these proceedings). But differences must certainly exist, an important one being the existence of dust shells around cool and hot R CrB-stars, which are most likely made up of carbon grains. The EHe- and HdC-stars, on the other hand, have no observed IR-excess, hence no dust shells (Feast and Glass, 1973; Drilling et al., 1984; Walker, 1985). Maybe they lost their dust shells during an earlier evolutionary phase when they were close to the Hayashi-limit. It might also be that the HdC-stars are the ancestors of the EHe-stars and that they did not develop dust shells at all. This would be consistent with their lack of pulsations since it is believed that these lead to heavy mass loss (see Chapter 3).

According to theory, however, HdC-stars should pulsate (Saio and Wheeler, 1985); either the HdC-stars are hotter than believed and on the stability side of the instability line, or their luminosity to mass ratio is smaller than that of R CrB-stars in such a manner that they pulsate only with a very small, not easily detectable amplitude. The luminosity to mass ratios of post-red giant helium stars depend very much on their masses: for instance, a model with $M = 0.6$ $M_{\odot}$ has $L/M = 10^{3.8}$ $L_{\odot}/M_{\odot}$, that of 1 $M_{\odot}$ has $L/M = 10^{4.5}$ $L_{\odot}/M_{\odot}$.

In concluding, it must be stated that we are still far from clearly understanding the origin and evolution of EHd-stars. Also, the connection between the different subclasses is not well-understood. Obviously, more observational and theoretical studies are needed.

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DISCUSSION

HILL: If these are 10^{10} years old where do the solar metal abundances come from?

SCHÖNBERNER: I don't know. We know that some of the extreme helium stars probably have lower than solar metallicity. Please remember that this scenario has to be worked out in detail and that the metallicity of most of the extreme He stars is also still unknown.

FEAST: I would think it is fairly risky to divide the hydrogen-deficient carbon stars from the R CrB stars on the basis that they don't pulsate. The evidence that hydrogen-deficient carbon stars do not pulsate is very thin.

SCHÖNBERNER: I only tried to find a reason why hydrogen-deficient carbon stars do not pulsate. Careful photometric observations should be done in the future to settle this question.

RAMADURAI: In the case of the core He flash you mentioned, I would like to bring to your attention the work of Eggleton and Schramm on the role of meridional circulation during the first ascent on the giant branch.

SCHÖNBERNER: I doubt whether a meridional circulation of this sort would be able to mix hydrogen down and bring helium up to such an extent as that observed in the extremely hydrogen-deficient stars.

FEAST: I am puzzled about the discussions on changing periods of RY Sgr and S Aps. I really don't understand, if your are invoking mass loss to explain S Aps, why it is of no importance for RY Sgr. It seems to me that largely the mass loss is comparable in the two cases.

SCHÖNBERNER: I don't know of any reliable mass loss determinations for R CrB stars. Thus, I cannot comment on your last sentence. You advocated a rate of about 10^{-6} $M_{\odot}$/yr, if I remember correctly. Such a rate is comparable to the growth rate of the helium-exhausted core and hence does not speed up the blueward evolution very much. My arguments were mainly based on the results of pulsational calculations, which predict a strong increase of the mass loss rate for effective temperatures below 6000 K.

FEAST: Do I understand that you think you would rule out the Iben's "born again" planetary business on the basis of abundances?

SCHÖNBERNER: I would rule it out because the predicted lifetimes in the R CrB-domain are too short.

FEAST: Too short for what?

SCHÖNBERNER: Too short for the observed pulsational lifetimes of R CrB and RY Sgr which are about several thousand years.

FEAST: Can we really say that? I mean, for instance, for R CrB stars we do not have a complete range from the hot to the cool end. If you want to connect the two together you have to go very rapidly between these two phases.

SCHÖNBERNER: A 0.7 $M_{\odot}$ contracting helium giant needs about 5000 yr to evolve from 7000 K to, say, 20000 K. I think that is a quite rapid evolution.

N.K. RAO: We know that R CrB has not changed much in the last two hundred years.

LIEBERT: What do you think of the relevance of Iben et al. scenario for the purpose for which it was proposed, i.e. for the formation of DB white dwarfs in an old population, presumably from the helium-rich progenitors, which we identified as SdOs.

SCHÖNBERNER: I think that is a reasonable explanation.

N.K. RAO: Is there any way to delay the evolution in the red giant phase and increase the time scale there?

SCHÖNBERNER: The timescale of the redward excursion is solely determined by the small envelope masses ($\approx 10^{-4}\ M_o$) and the large luminosities ($\approx 10^{+4}\ L_o$) involved.