III HOT EXTREME HELIUM STARS

SPECTROSCOPIC ANALYSES OF HOT EXTREME HELIUM STARS

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ABSTRACT. Spectroscopic fine analyses of hot extreme helium stars are reviewed. The chemical composition is discussed in detail and conclusions as to the nuclear history of the atmospheric material are drawn. Evidence of inhomogeneities among the hot extreme helium stars is presented and it is concluded that the extreme helium stars can be found in the halo population (BD+10°2179) as well as in the disc population. Their mass loss rates are of the same order of magnitude (10^{-9} $M_\odot$/yr) as those of normal stars. Four helium rich sdO stars are identified as possible descendants of the B-type extreme helium stars.

1. INTRODUCTION

The hot extreme helium stars represent the most obvious cases for large atmospheric hydrogen depletion and helium enrichment among all classes of hydrogen deficient stars. Unlike in the case of cool hydrogen deficient stars, it is immediately evident from their spectra that helium replaces hydrogen as the most abundant element and that hydrogen, indeed, is a trace element only.

Spectroscopically, the class of extreme helium stars is defined by the following criteria:

i) They are giant stars with spectral types ranging from early A to late O.
ii) The helium absorption line spectrum is unusually strong.
iii) Hydrogen lines are very weak or absent.
iv) The carbon lines are strong.

Drilling (these proceedings) lists 17 stars which meet all criteria and, thus, are true class members.

Some other hot helium stars should be mentioned which, however, do not meet all the above criteria. In view of binary star evolutionary scenarios (e.g. Iben and Tutukov, 1985) it is important to point out that the four hydrogen deficient binaries known today (υ Sgr, KS Per, LSS 1922 and LSS 4300) can not be considered as extreme helium stars because they are carbon weak lined. The presumedly single helium stars BD+13°3224 and HD 144941 are also not class members for the same reason.

K. Hunger et al. (eds.), Hydrogen Deficient Stars and Related Objects, 33–48.

Since the properties of the hydrogen deficient binaries are reviewed by Plavec (these proceedings) only the latter will be discussed here. Some helium and carbon rich sdO stars (despite their somewhat larger gravities) appear to be closely related to the extreme helium stars as are two hot RCrB stars (see the review of Rao in these proceedings).

In the absence of reliable distance determinations for hot extreme helium stars, the best way to discuss their properties and evolutionary status is to find their position in the (g, T_{eff})- diagram. Clues to the origin of the hydrogen deficiency may come from their chemical composition which may also help to identify their progenitors and descendants. Detailed spectroscopic analyses are required to derive these quantities.

Quantitative spectroscopy of extreme helium stars began with the curve of growth analysis of HD 160641 (Aller, 1953) and was continued by the coarse analyses of BD+10°2179 (Klemola, 1961, Hill, 1965), HD 124448 and HD 168476 (Hill, 1965). The first modern quantitative spectral analysis using LTE model atmospheres was carried out for BD+10°2179 (Hunger and Klinglesmith, 1969). These early analyses have been discussed in previous reviews (Hunger ,1975, Scholz, 1972, Dinger, 1970, Hack, 1967, Underhill, 1966) to which the reader is referred. Here I will review only the more recent developments.

Since 1975, the observation techniques have improved considerably. In the mid seventies, high quality photographic spectra became available which provided a firm basis for four fine analyses. The IUE satellite opened a new spectral range - the ultraviolet - for the analysis. Very recently, the advent of efficient linear detectors combined with Echelle spectrographs (e.g. ESO - CASPEC) allowed all known extreme helium stars - even the faintest ones - to be observed at high spectral resolution and S/N.

The review begins with a brief outline of the model atmospheres and the method of analyses (section 2). Then I will summarize the results of four fine analyses of photographic spectra and discuss the conclusions as to their nuclear history (section 3) . The effective temperatures as derived from photometry and ultraviolet fluxes will be discussed in section 4 and the mass loss rates in section 5. The properties of some closely related helium stars are summarized in section 6. I conclude the review with an outlook on what can be expected from the new CASPEC spectra.

2. MODEL ATMOSPHERES AND METHOD OF ANALYSIS

The stellar spectra are analyzed by means of model atmosphere techniques. This method is usually referred to as a fine analysis and has been widely applied to many classes of stars. Because of the extreme helium stars' peculiar chemical composition, the model atmospheres have to be adapted adequately. The atmospheric structure of a normal B star is determined esentially by two parameters: the effective temperature and the gravity. In the case of an extreme helium B-star an additional atmospheric parameter - the C/He ratio - enters into the analysis. Because neutral helium is a poor absorber, carbon dominates the opacity at many wavelengths and its abundance therefore influences the atmospheric structure. It is worthwhile to present here some details of the model atmospheres in use and compare them to normal composition model atmospheres.

2.1. Model atmospheres

Model atmospheres are calculated assuming LTE, plane parallel geometry and hydrostatic equilibrium. The continous opacities are (almost) the same as used by Kurucz (1979) except for carbon. All excited levels for which atomic data are available (Peach, 1970) have to be included in the opacity calculations. The effect of carbon continous opacities is largest in the UV. Several carbon absorption edges show up in the model flux distribution and cause a shallower UV-flux gradient than normal composition models have.

Line blanketing is taken into account by including the detailed bound-bound opacity of the strongest UV metal lines as well as of helium lines. About 800 line transitions are taken into account as Voigt profiles. This approach allows to treat the line blanketing of the strongest lines properly but fails to include the effect of millions of weak lines. The following differences to normal composition model fluxes can be noted: Carbon resonance lines are the strongest absorption features. In the absence of a Lyman absorption edge, the emergent flux below 900 Å is considerably larger than for normal composition (see Figure 1). Since many ions of relevance have resonance lines below 900 Å, their line blocking is of greater importance for an extreme helium star than for a normal composition B star model.

2.2 Determination of atmospheric parameters

The three atmospheric parameters (T_{eff}, g, C/He) have to be determined simultaneously. The model fitting proceeds as follows: In the first step a reasonable C/He is assumed and kept fixed throughout the calculations. Then the gravity as a function of T_{eff} can be derived by matching the line profiles of the He I lines, which are Stark broadened and, therefore, sensitive to electron density. The ionization equilibria of various elements can be used to determine T_{eff} as a function of gravity. The intersection of these fit curves in the (g, T_{eff})- diagram defines a first estimate of the atmospheric parameters. Now the carbon abundance has to be determined and the fitting procedure has to be repeated for a fine adjustment of the atmospheric parameters. A fit diagram for BD+10°2179 is displayed in Figure 2 for illustration.

3. FINE ANALYSES OF VISUAL AND ULTRAVIOLET SPECTRA

Only four stars have so far been analyzed using model atmospheres: HD 124448 (Schönberner and Wolf, 1974), BD-9°4395 (Kaufmann and Schönberner, 1977), HD 168476 (Walker and Schönberner, 1981) and BD+10°2179 (Hunger and Klinglesmith, 1969, Heber, 1983). These analyses

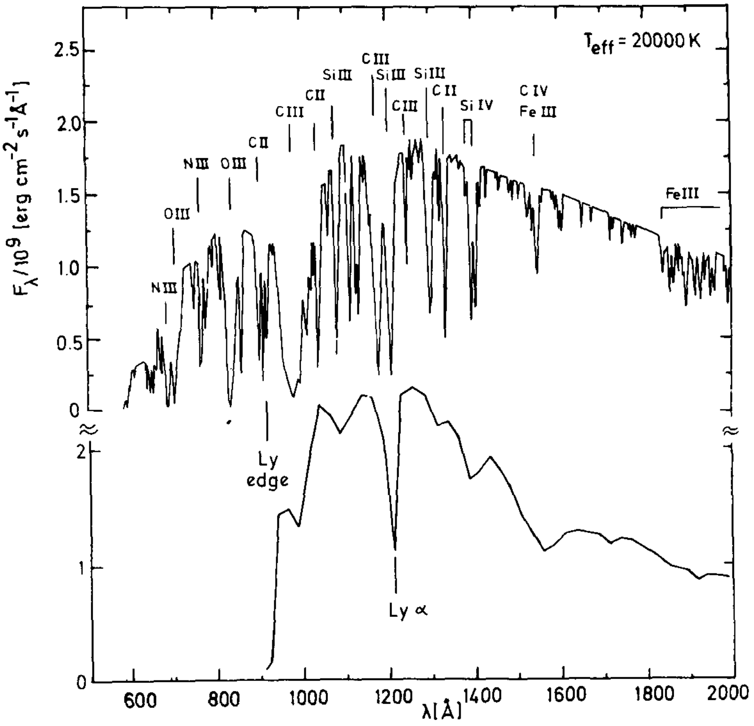

Figure 1: UV-model flux distribution for a He-C-atmosphere (He/C = 0.01, top) and for a normal composition (Kurucz, 1979; bottom). Both models have T_{eff} = 20000 K and log g =2.5. The He-C-model-flux distribution is sampled at 3Å whereas the other is sampled at 25Å.

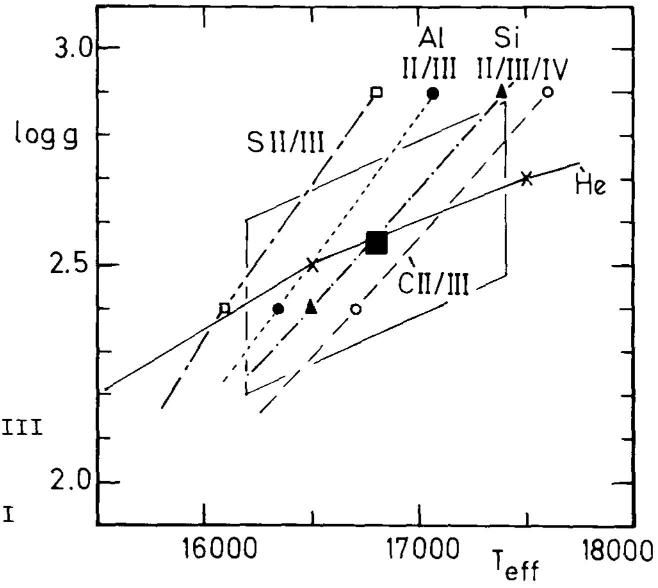

Figure 2: Determination of the final model of BD+10°2179 (■), with error box. The He I line profiles fit along the curve labelled 'He'. The ionization equilibria C II/III (dashed curve), Al II/III (dotted), Si II/III/IV (dashed dotted) and S II/III (— - —) hold along the corresponding curves.

were based on photographic spectra from which abundances of ten elements in all four stars were determined. Besides the light elements H, He, C, N and O, abundances for intermediate Z elements (Mg, Al, SI, P, S) were derived. For elements heavier than sulphur the analyses are rather incomplete, the reason being the weakness of their visual spectral lines. HD 168476 is considerably cooler than the other stars analyzed and, therefore, displays a rather large number of spectral lines of iron group elements (Ti to Ni) in the visual spectrum. In the hotter extreme helium stars the abundances of these elements can be derived from UV high resolution spectra. Other light elements of interest (e.g. boron) also become accessible to the analysis. However, an abundance analysis of ultraviolet spectra has so far been carried out for BD+10°2179 only (Heber, 1983). In this case the number of elements analyzed was almost doubled. However, there is a major drawback - the crowding of the lines in the UV - which renders an analysis difficult or even impossible. Extensive spectrum synthesis is required to derive the abundances.

3.1 Effective temperatures and gravities

The positions of the four analyzed stars in the (g, log T_{eff}) plane as derived from the fine analyses are shown in Figure 3. Since T_{eff} and gravity allow the luminosity over mass ratio L/M to be determined, lines of constant L/M are also shown in Figure 3. The four stars have log L/M = 4.2 (solar units), in the mean. Because the individual errors are smaller than the star to star scatter (see Figure 3) it has to be concluded that differences in L/M are real, HD 168476 having the largest L/M (log L/M = 4.6, solar units) and BD+10°2179 the lowest L/M (log L/M = 3.7 ,solar units). These L/M ratios are important observational constraints to be met by any evolutionary scenario. Additional constraints arise from the observed atmospheric composition.

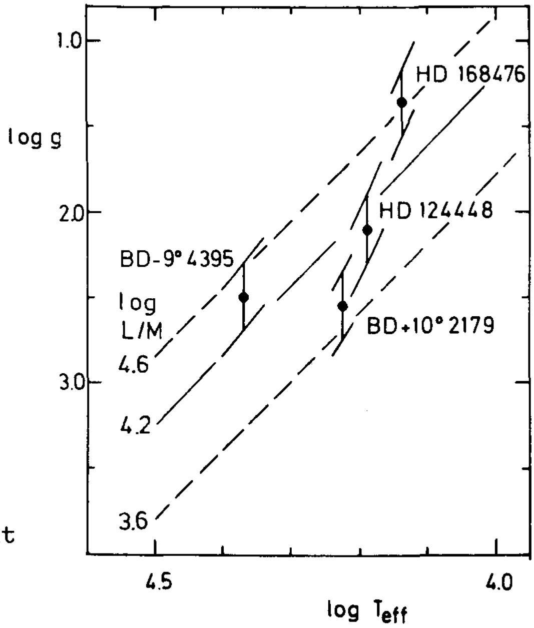

Figure 3:
Position of the extreme helium stars in the log g-log T_{eff}-plane. Dashed: lines of constant L/M, labelled with log L/M in solar units.

3.2 The abundance patterns

The elemental abundances derived by means of the fine analyses are summarized in Table I. The primary data are the abundances relative to helium. In order to compare them to normal composition stars, especially to the sun, they have to be normalized. Abundances normalized to $\log \Sigma \mu_i n_i = 12.15$ (μ_i being the atomic weight number and n_i the number fraction of element i) are given in Table I. This normalization is appropriate when we assume that all hydrogen has been burnt to helium (see below). Abundances relative to the sun are plotted in Figure 4. Before we discuss the implications of the observations with respect to the stars' nuclear history and their population caracteristics let us discuss the observational results for individual elements in some detail.

3.2.1 Hydrogen. Balmer lines are detected in BD-9°4395 and BD+10°2179 while they are absent in HD 168476 and HD 124448. Hence only upper limits to the hydrogen abundance were derived for the latter. Hydrogen is found to be a trace element and its abundance varies considerably form star to star.

3.2.2 Boron. Boron has been analyzed from its UV resonance line (B II) only for BD+10°2179. Boron is deficient by more than 1 dex.

3.2.3 Carbon, nitrogen and oxygen. Carbon is overabundant with respect to the sun by a factor of 5 to 7, while oxygen is underabundant by a factor of 3 to 6. Nitrogen is overabundant in HD 124448 and HD 168476 while it is about solar in the two other stars. The relevant abundance ratios are given in Table II. Two groups exist with respect to C/N (and also H/He): BD+10°2179 and BD-9°4395 have large C/N ratios while HD 168476 and HD 124448 have lower C/N. Nitrogen and oxygen are equally abundant ($N/O \sim 1$ within error limits) in all stars.

3.2.4 Neon through calcium. Considering the possible nuclear reactions during helium burning, the abundances of neon and magnesium would be most interesting among the elements of intermediate Z (Ne through Ca). Ne I lines are detectable only in the red spectrum and, therefore, HD 168476 was the only extreme helium star analyzed for Ne since no red spectra were available for the others. Its abundance, however, is regarded as uncertain (Walker and Schönberner, 1981) since NLTE effects are probably large (Auer and Mihalas, 1973). Deviations from LTE might also be important for Mg (Mihalas, 1972, Snijders and Lamers, 1975) and it is thus premature to discuss the LTE Ne/Mg ratio for HD 168476. Additional red spectra and NLTE calculations are required to derive reliable Ne/Mg ratios. The other elements of intermediate Z are more or less normal with the outstanding exception of phosphorus which is strongly overabundant in BD-9°4395 (and to a somewhat smaller extent also in HD 168476). This is reminiscent of the abundance pattern of some helium-weak-line-stars om the main sequence (the so called "phosphorus stars" ι Ori B and 3 Cen A, Baschek, 1975).

Table I: Atmospheric parameters and abundances of four extreme helium stars (Heber, 1983). The atmospheric parameters are based on the set of partially line blanketed model atmospheres as described in section 2.1. L/M is given in solar units. Uncertain abundance values are marked with colons. The abundances of the sun are from Holweger (1979).

	HD 168476	HD 124448	BD+10°2179	BD-9°4395	
T_{eff}/K	13700	15500	16800	23500	
log g	1.35	2.10	2.55	2.50	
log (L/M)	4.6	4.1	3.7	4.4	
Abundances normalized to $\log \Sigma \mu_i n_i = 12.15$					sun
H	<7.8	<7.5	8.5	8.7	12.0
He	11.54	11.53	11.53	11.54	11.0
B			<1.3		2.3
C	9.4	9.46	9.54	9.36	8.67
N	8.9	8.83	8.11	8.0	7.99
O	8.4	8.5	8.1	8.24	8.92
Ne	9.3:				7.73
Mg	7.7	8.2	8.02	7.4:	7.53
Al	7.2:	6.2	6.25	6.25	6.43
Si	7.7	7.51	7.32	7.8	7.50
P	6.3	5.6	5.5	6.8	5.35
S	7.0	7.2	7.12	7.6	7.20
Ar		6.6	6.4		6.83
Ca	7.0	<6.9	<5.9:		6.36
Sc	4.3		<2.0:		2.99
Ti	5.6	6.0	4.06		4.88
V	4.4:				3.91
Cr	6.2		5.0		5.61
Mn	6.2		4.4		5.47
Fe	7.5	7.4	6.49	6.8:	7.46
Co			4.4		4.85
Ni	6.5		5.1		6.18
Cu			4.0		4.24

Table II: Abundance ratios (an uncertain value is marked with a colon)

	HD 168476	HD 124448	BD+10°2179	BD-9°4395
$H/10^4He$	<2	<1	10	15
C/N	3	4	27	23
N/O	3	2	1	0.6
$Fe/10^5He$	10	8	0.9	2:

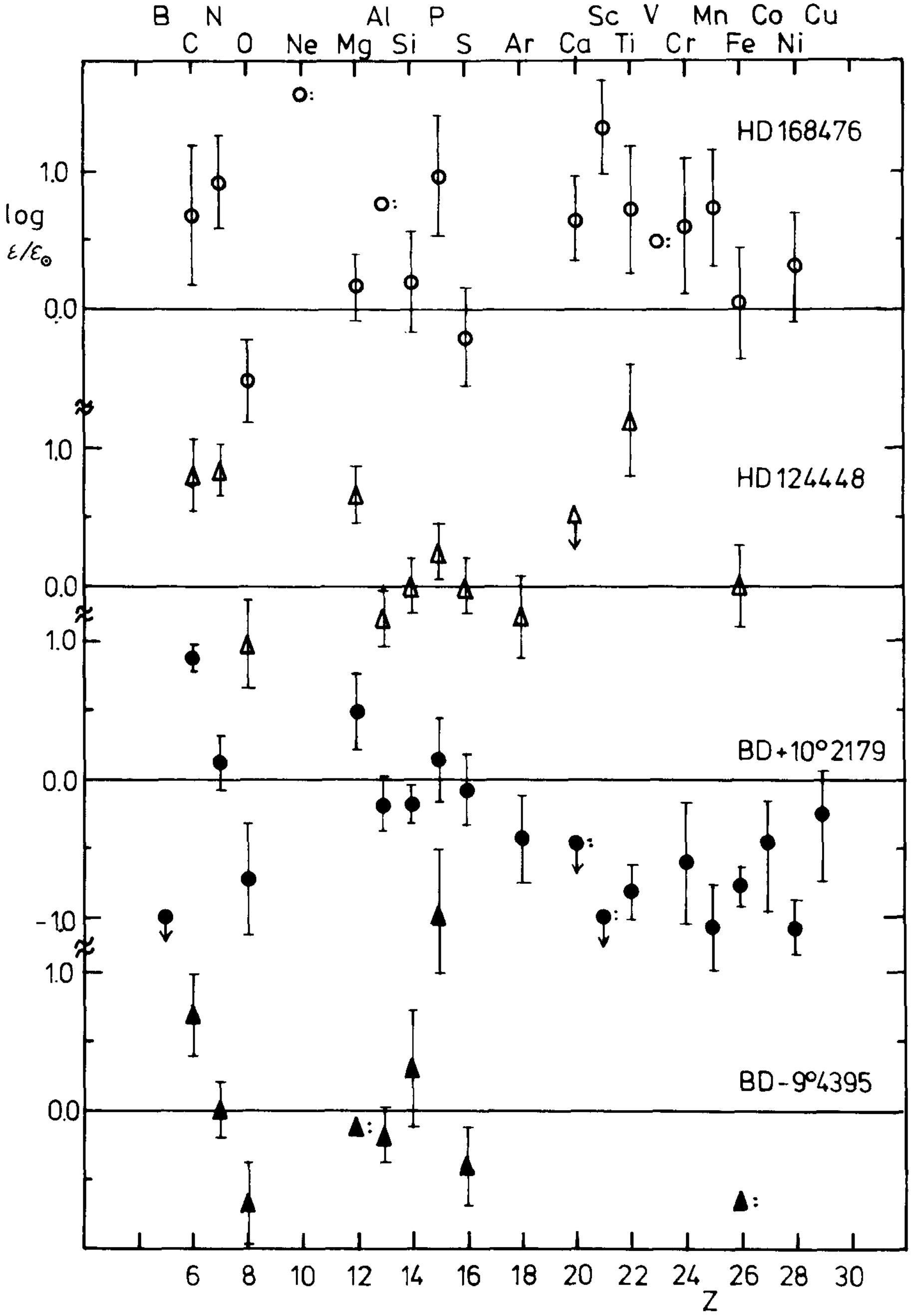

Figure 4: Abundances of extreme helium stars relative to the sun. Open circles: HD 168476; open triangles: HD 124448; filled circles: BD+10°2179; filled triangles: BD-9°4395. Uncertain values are plotted without error bars and are marked with colons. Upper limits are marked with downward arrows.

3.2.5 The iron group.

The elements scandium through copper are well studied only in BD+10°2179 and HD 168476. For HD 124448, titanium and iron were accessible only. Iron is approximately solar. For BD-9°4395 only a rough estimate of the iron abundance (based solely on one spectral line) was obtained. The abundance pattern for the iron group of BD+10°2179 is strikingly different from those of HD 168476 as can be seen from Figure 4. The whole group of elements is underabundant by 0.75 dex (in the mean) for the former. The odd elements Co and Cu seem to have larger abundances which might not be real since hyperfine structure splitting was neglected in the analyses due to the lack of atomic data. In contrast, HD 168476 has a solar iron abundance and the other iron group elements are even enriched with respect to the sun (mean overabundance of the iron group 0.6 dex.)

3.3 Discussion of abundance patterns

The observed abundances can give important clues to the stars' nuclear history and to the stellar population they belong to. The abundances of the lighter elements can be affected by nucleogenetic processes whereas the heavier elements presumedly have maintained their primordial abundances.

3.3.1 Population caracteristics.

The abundances of the iron group elements are indicators of the stars' metallicities. HD 168476 and HD 124448 have solar iron abundances whereas BD+10°2179 is iron deficient. Another metallicity indicator is the abundance ratio of intermediate Z elements (Mg through S) to iron. This quantity is independent of any normalization of the abundance scale and was found to be larger than in the sun for old disc and population II stars (Mäckle et al., 1975, Tomkin et al., 1985). In BD+10°2179 the intermediate Z elements are about solar while the iron group is deficient. This abundance pattern is strikingly similar to that of the old disc star Arcturus (α Boo, Mäckle et al., 1975) as can be seen in Figure 5. The abundance pattern of Arcturus is essentially that of the interstellar medium out of which the star formed. (Note that in Arcturus C,N and O are as deficient as Fe). Besides the iron underabundance of BD+10°2179 relative to the sun (which depends on the abundance normalization), this similarity is further evidence for the low metallicity of BD+10°2179. Note that no such gradient in the abundance patterns of HD 168476 and HD 124448 is present, see Figure 4. Hence we can conclude that HD 168476 and HD 124448 belong to the disc population while BD+10°2179 belongs to an old population. Considering also its location in the galaxy, far away from the galactic plane (z = 2.7 kpc, Heber, 1983), it is safe to state that BD+10°2179 belongs to the halo population. The situation is not so clear for BD-9°4395. Although no reliable iron abundance is available for BD-9°4395, the estimated underabundance might be regarded as a slight hint that it belongs to an old poulation too. There are two additional arguments to support this conjecture: (i) The observed C/N and N/O ratios are very similar to those of the low metallicity star BD+10°2179 but distinctly different from those of the metal rich extreme helium stars (HD 168476 and HD 124448).

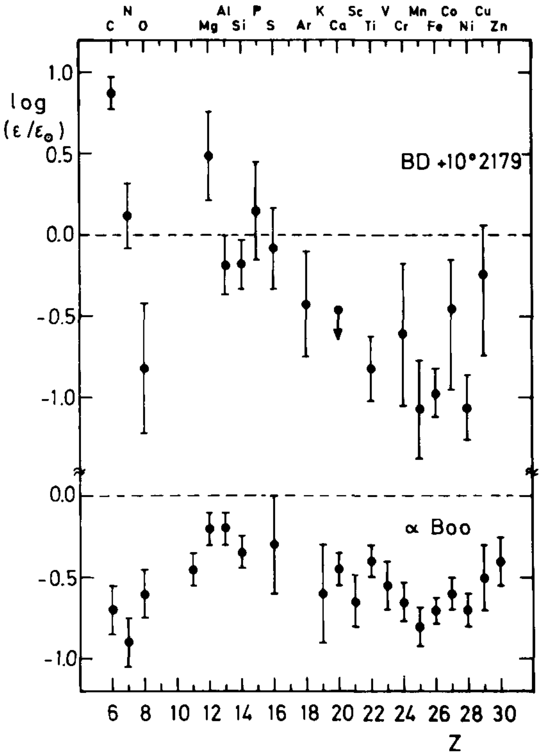

Figure 5:
Chemical composition of BD+10°2179 (top) relative to the sun and of the comparison star α Boo (bottom). the abundances of α Boo are taken from Mäckle et al. (1975).

(ii) Its radial velocity does not follow the galactic rotation (see Drilling and Heber, these proceedings, for a discussion of the extreme helium stars' radial velocities). An abundance analysis for the iron group in BD-9°4395 is urgently needed to unambiguously determine its metallicity. Let us assume in the following that BD-9°4395 is a low metallicity star similar to BD+10°2179.

Apparently, the analyzed extreme helium stars do not belong to one single population.

3.3.2 Nuclear history. The surface composition of the extreme helium stars is obviously dominated by the products of hydrogen and helium burning. The CNO elements (besides H and He) are expected to be the elements primarily affected by these nuclear processes. The composition of the extreme helium stars' atmospheres is that of an helium and nitrogen rich zone in which essentially all hydrogen has been processed by the CNO-cycle. The primordial N abundance of BD+10°2179 (and perhaps also of BD-9°4395) is presumably subsolar and therefore the observed normal abundance is coincidental. The observed N/O ratio of about unity can be explained if ^{16}O, which is the slowest species to come into equilibrium in the CNO bi-cycle, has not reached its (low) equilibrium abundance, or if it has been enriched by helium burning (see below).

Note in passing that the low boron abundance of BD+10°2179 is consistent with this picture, since Boron is rapidly destroyed by protons under conditions that prevail in hydrogen burning shells.

The large carbon abundance indicates that there must be some admixture of helium burnt material: About 1% of the helium has been converted to ^{12}C by helium burning. C/O > 8 (see Table II) indicates that very little ^{16}O has subsequently been produced by α capture. Available data on α capture products Ne and Mg are insufficient for any conclusions to be drawn. However, the high C/O ratio implies that the abundances of these elements will not be enhanced via α captures.

During helium burning subsequent α captures could give rise to the liberation of neutrons via the chains of reactions

$$^{14}\mathrm{N}(\alpha,\gamma)^{18}\mathrm{F}(\beta^{+},\nu)^{18}\mathrm{O}(\alpha,\gamma)^{22}\mathrm{Ne}(\alpha,n)^{25}\mathrm{Mg}$$

$$\mathrm{or}\ ^{12}\mathrm{C}(p,\gamma)^{13}\mathrm{N}(\beta^{+},\nu)^{13}\mathrm{C}(\alpha,n)^{16}\mathrm{O}.$$

Large temperatures ($T \gtrsim 3\ 10^{8}$ K) are required for the former chain of reactions while protons have to be present in the helium burning shell for the latter chain. The abundances of s-process elements (e.g. Ba, Sr) would give important clues to whether the atmospheric material has been exposed by neutrons. These elements, however, are not observable in the extreme helium stars. It is worthwhile to note that elements of intermediate Z are also characteristically enriched if a neutron exposure had taken place. Truran and Iben (1977) calculated the nucleosythesis in thermally pulsing stars due to the operation of the ^{22}Ne neutron source and found that three quarters of the neutrons are absorbed by the ^{22}Ne progeny which, in consequence, leads to an enrichment of abundant isotopes of intermediate Z elements (e.g. ^{26}Mg, ^{31}P, ^{40}Ar, ^{45}Sc, ^{59}Co). Since however the extreme helium stars have rather low masses (0.6 $M_{\odot}$ to 1.0 $M_{\odot}$, Schönberner, 1977), the ^{13}C neutron source is more likely than the ^{22}Ne source provided that protons can be mixed into the helium burning shell. Whether the enrichment of some intermediate Z elements (e.g. P in BD-9°4395) could be due to neutron exposures remains to be investigated from detailed evolutionary calculations.

Last but not least it should be mentioned that a small admixture ($\sim$0.1%) of the original hydrogen rich material is still present in the atmospheres of BD+10°2179 and BD-9°4395.

4. THE EFFECTIVE TEMPERATURE SCALE FOR EXTREME HELIUM STARS

In view of the inhomogeneity of the extreme helium stars' abundance patterns, it is premature to regard the four stars analyzed so far as being representative of the whole group. It was deemed necessary to analyze all class members. A first step towards this goal was the determination of their effective temperatures. Synthetic colours were calculated from model fluxes by Heber and Schönberner (1981) and the effective temperatures determined from Johnson and Strömgren colours. The IUE satellite allowed the accuracy of the effective temperatures to be improved considerably since the flux maxima can be observed. Drilling et al. (1984) observed 12 extreme helium stars and derived T_{eff}'s from the total fluxes. Results are given in Table III and are plotted in

Figure 6 as a histogram. Most of the extreme helium stars are rather cool (9000 K to 18000 K), while only two stars are hotter than 18000 K. However, this temperature distribution is biased, since hot extreme helium stars - at the same luminosity and distance - are apparently fainter in the visual than cooler ones due to the bolometric corrections and are, therefore, difficult to discover. Indeed, two out of five newly discovered faint helium stars have been found to be hot, too (Heber, Jonas and Drilling, these proceedings). The cool hydrogen deficient stars have T_{eff} between ~ 5000 K (HdC stars) and ~ 7000 K (RCrB stars). Hence, there is a gap in the temperature distribution of hydrogen deficient stars between 7000 K and 9000 K. LS IV-14°109 (T_{eff} = 8400 K) might be a transition object. Since non-variable helium stars in this temperature range are difficult to discover, this gap might be due to a selection effect (Heber and Schönberner, 1981).

Table III. Effective temperatures and interstellar reddening of extreme helium stars as derived from UV fluxes (Drilling et al., 1984)

star	T_{eff}/K	E(B-V)
LS IV-14°109	8400	0.20
LSS 3378	9400	0.35
BD+1°4381	9500	0.10
BD-1°3438	10900	0.40
LS IV-1°002	11900	0.45
HD 168476	12400	0.12
LSE 78	13600	0.10
LS II+33°005	15000	0.22
HD 124448	15500	0.08
BD+10°2179	17700	0.00
BD-9°4395	23000	0.30
HD 160641	31900	0.40

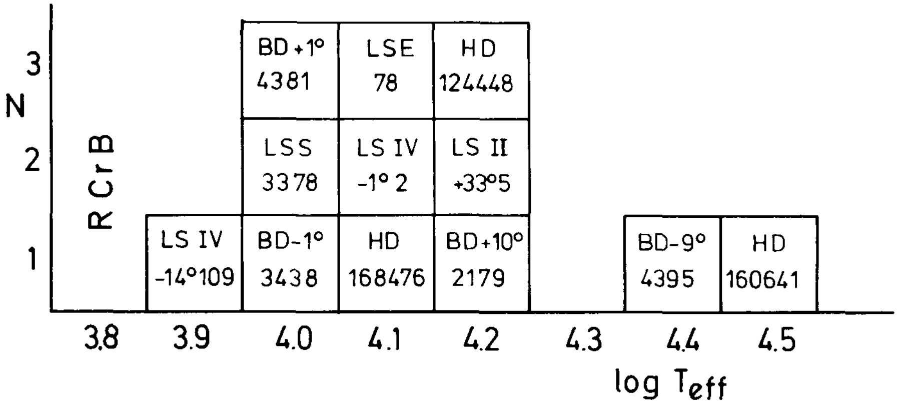

Figure 6: Temperature distribution of the extreme helium stars as derived from UV measurements (Drilling et al., 1984).

5. THE MASS LOSS RATES OF EXTREME HELIUM STARS

The high resolution IUE spectra revealed the existence of expanding envelopes around three extreme helium stars. Some of the resonance lines are obviously formed or affected by a stellar wind. Since high stages of ionization are encountered (N V in HD 160641, C IV in BD-9°4395 and BD+10°2179), the winds cannot be in radiative equilibrium, but are "superionized". This phenomenon is commonly observed in normal early type stars, too, but its physical cause is still unknown. Hamann et al. (1982) constructed empirical wind models for three extreme helium stars by means of the comoving frame formalism. Three different models for the heating of the wind where assumed in the calculations of the ionization balance. The resulting empirical limits on the mass loss rates are given in Table IV. The "corona model", which assumes that the heating is due to a X-ray source, or the "warm wind model", which assumes an electron temperature raised to 10^5 K, can consistently explain the "superionization". The unknown heating mechanism is responsible for the large uncertainty of the mass loss rates.

The three extreme helium stars were found to lose mass on rates of the same order of magnitude as normal stars of similar luminosity.

The mass loss rates of extreme helium stars apparently increase with increasing effective temperature, at variance with the results for normal stars (Lamers, 1981), which, at constant luminosity, decrease with increasing T_{eff}.

Table IV: Mass loss rates of three extreme helium stars (Hamann et al., 1982)

star	T_{eff}/K	log $\dot{M}/(M_\odot/yr)$
HD 160641	31900	-8.2....-7.2
BD-9°4395	23000	-8.5....-7.7
BD+10°2179	16800	-11.0....-8.9

6. RELATED OBJECTS

After having discussed the properties of the true class members, we will now draw attention to some helium stars which might be related to the extreme ones. These are the unique object BD+13°3224 and four helium- and carbon rich sdO stars.

6.1. BD+13°3224

BD+13°3224 is carbon weak lined and, therefore, cannot be termed an extreme helium star. Furthermore, it has a L/M ratio smaller than the latter (Hill et al., 1981) and its hydrogen abundance (1% by numbers) is intermediate between the extreme (≤ 0.1%) and the intermediate (50%)

helium stars. BD+13°3224 appears to be more comparable to HD 144941 (Hunger and Kaufmann, 1973) and both stars may define a new sub-group of the hydrogen deficient stars.

BD+13°3224 is of special interest because it is the only helium star for which distance and mass have been determined. BD+13°3224 is a radial pulsator with a well established period (Landolt, 1975). A modified Baade-method based on UV fluxes has been used to determine its mean effective temperature, radius and luminosity (T_{eff} = 23450 K, $R = 1.98\ R_\odot$, $\log L/L_\odot = 3.03 \pm 0.12$, Lynas-Gray et al., 1984). The distance as derived from the angular diameter is 1.5±0.1 kpc. From the spectroscopically determined gravity ($\log g = 3.7$) the mass $M = 0.7^{+0.4}_{-0.3}\ M_\odot$ is derived.

6.2 Helium- and carbon rich sdO stars

Some extremely helium rich objects are known among the subluminous O stars (see Hunger, 1975; Berger and Fringant, 1980, Heber et al., these proceedings). It seems to be tempting to search for an evolutionary link between these hot subdwarfs and the B-type extreme helium stars. Most of the subdwarfs are of high gravity (i.e. have small L/M ratios) and cannot be related to the extreme helium stars, since the evolution of an extreme helium star proceeds at constant luminosity (Schönberner, 1977). Recent NLTE analyses revealed that four helium rich subdwarfs have L/M ratios as large as the extreme helium stars: Giddings (1980) analyzed BD+37°442 and derived T_{eff} = 55000 K, $\log g = 4.0$ (i.e. $\log L/M = 4.35$, solar units). He noted that BD+37°1977 displays a spectrum very similar to BD+37°442 and, therefore, must have similar atmospheric parameters. Husfeld et al. (these proceedings) analyzed LSE 153 and LSE 259 and found T_{eff} = 70000 K, $\log g = 4.75$ (i.e. $\log L/M = 4.0$, solar units) and T_{eff} = 75000 K, $\log g = 4.4$ (i.e. $\log L/M = 4.5$, solar units), respectively. Since all four stars are carbon strong lined it has been conjectured, that they are the immediate descendants of the B-type extreme helium stars and should be considered as very hot extreme helium stars.

7. FUTURE DEVELOPMENTS

Ultraviolet spectra obtained with the IUE spectrograph have considerably improved our knowledge of the hot extreme helium stars, since they allowed effective temperatures, abundances of heavy elements and mass loss rates to be determined. However, most of the extreme helium stars are to faint in the UV to be observable with IUE at the required high resolution. Moreover the analyses of the IUE spectra are hampered by strong line blocking. (It might be a fortunate coincidence that BD+10°2179, the only star analyzed from the UV, turned out to be metal deficient and, thus, line blocking was a less severe problem in the analysis than it appears to be for the others). Nevertheless, careful analyses of high resolution IUE spectra can give important information, e.g. the iron abundance of BD-9°4395 (see above). A complete picture of the chemical composition of all extreme helium stars, however, can not be drawn.

Recently, the advent of efficient linear detectors combined with Echelle spectrographs provides a powerful tool for visual spectroscopy. Using the ESO Cassegrain Echelle spectrograph (CASPEC), all but one of the known extreme helium stars have been observed at high resolution (0.25Å). A S/N of 100 was reached for the brightest ones in single short exposures (15 min.). Hence the quality of these spectra is superior to the photographic Coude spectra and will allow weak lines to be measured. These are important for accurate abundance determinations since they depend only weakly on model parameters such as microturbulence. On the CASPEC spectra, lines of equivalent width as low as 10 mÅ can be measured for stars brighter than B=12.0. For the faintest stars (B=13.5) a limiting equivalent width of 50mÅ is reached. Fine analyses of these spectra will certainly give a much clearer picture of the chemical composition of the extreme helium stars and, consequently, will give clues to the origin of their hydrogen deficiency.

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DISCUSSION

BHATT: Is there any correlation between the heavy element abundances and the excess IR emission from the two stars? Are there IR observations?

HEBER: IR photometry is available for most of the extreme helium stars. Some have also been observed with IRAS. No infrared excess has been found so far.

LAMBERT: Either using the Caspec or Space Telescope which is going up next year, would it be possible to detect the heavy elements and the S-process elements abundances?

HEBER: In the photospheres of the extreme helium stars, the s-process elements like Ba and Sr are two times ionized and, therefore, in a noble gas configuration. The strongest lines lie in the far UV and cannot be obsered from the ground or with the Space Telescope. Other heavy elements can be detected in the UV spectra.

MOHAN RAO: In the comoving frame calculations, what type of velocity law have you chosen?

HEBER: The usually adopted square-root law has been used mostly. Attempts to model the velocity law have been also made.

GARRISON: I see that there is a spread in T_{eff} and a variation of the abundances. Is there any systematic effect? I realize that there are only 4 stars, but, is there any trend, such as the cooler stars having more nitrogen?

HEBER: I don't think so. With only four stars analysed, it is hard to tell whether there is a correlation.

MICHAUD: Can you exclude the importance of NLTE effects?

HEBER: No. In fact, there might be some evidence for deviation from LTE in the outer layers of the atmospheres. In general, LTE-line profile calculations for the strongest helium lines (e.g. 4471 A, He I) cannot reproduce the observed line profiles in the line cores which are formed rather far out in the atmosphere. The observed profiles are too deep. Before NLTE calculations actually have been carried out, we cannot estimate their importance. Since NLTE effect might also influence the ionization equilibria, it is always important to have a second T_{eff} indicator, i.e. IUE flux measurements.

RANGARAJAN: In your analysis why did you use the pure scattering assumption? Why not thermal sources?

HEBER: Thermal sources are unimportant at the low densities prevailing in the expanding envelopes.

RANGARAJAN: Is not the Voigt broadening more appropriate than Doppler broadening?

HEBER: Taking into account Doppler broadening is sufficient since the shells absorbing at a given frequency (so called Sobolev shells) are thin. In fact, in order to match the observed widths of the lines, a microturbulent velocity of the order of 100 km/s has to be invoked.

RANGARAJAN: What is their terminal velocity?

HEBER: The terminal velocities range from 400 km s^{-1} to 600 km s^{-1}.

RANGARAJAN: Why cannot we use the Sobolev method for the expanding envelope?

HEBER: Whether the Sobolev approximation is valid or not depends on the velocity gradients in the expanding envelope. In any case the comoving frame method should give accurate results.

DRILLING: Is it true to say that the metals are like the Pop II abundances?

HEBER: The abundances of the iron group elements are well-established only for HD 168476 and BD +10°2179. These elements are overabundant in HD 168476 whereas they are underabundant (by ≈ 1 dex) in BD +10°2179. Therefore, only in BD +10°2179 the abundance pattern indicates that the star belongs to an old population (but not to an extreme Pop II).

HUNGER: This is rather a question to Dr. Michaud. Do you think it is possible that the abundances for the metals for these different objects might be enhanced by diffusion for these low gravity objects?

MICHAUD: Not if the mass loss rates are 10^{-10} solar mass/yr.

VENUGOPAL: What is the physical significance of the mass loss in these stars being of the same order as in normal stars of the same luminosity?

HEBER: Since radiation pressure is generally believed to drive the stellar winds, it has frequently been argued that the mass loss rate should depend on the chemical composition too. For the extreme helium stars whose chemical compositions differ considerably from normal, this seems not to be the case.