SUMMARY

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1. INTRODUCTION

This has been the first international conference devoted to hydrogen-deficient stars and related objects. As Professor Hunger stated in his introduction, one aim of a meeting such as this is to review our achievements and find out what conclusions we can reach about the nature and origin of the objects we study. However, it is even more important that we identify the questions that we must ask and particularly which questions it may be within our means to answer. A newspaper reporter is said to have asked the Chairman of our Local Organizing Committee what we proposed doing to correct this hydrogen deficiency!

Our meeting started with Drilling's review of the galactic distributions and velocity dispersions of the various groups of hydrogen-deficient stars. They cover a wide range from the Population I rapidly rotating intermediate helium stars to the extreme helium stars and cool hydrogen-deficient stars, including the R Coronae Borealis (RCB) variables, which show characteristics of Intermediate Population II. We certainly need to be very clear how each of these classes is defined, particularly as there are a few objects, very definitely hydrogen-deficient, which fail to fit neatly into any of our categories. One star which has been the subject of three contributed papers and mentioned in others has too much hydrogen and too much gravity to be an extreme helium star, too little hydrogen to be an intermediate and too little gravity to be a subdwarf. I refer to BD+13°3224, otherwise known as V652 Her. As many of these stars are discovered to be variable they will be allotted variable star names. To avoid confusion it seems best to mention all known names.

I will briefly summarize what we know about the various groups. Most are shown in the log g - log T_{eff} diagram (Fig.1).

K. Hunger et al. (eds.), Hydrogen Deficient Stars and Related Objects, 489–495.

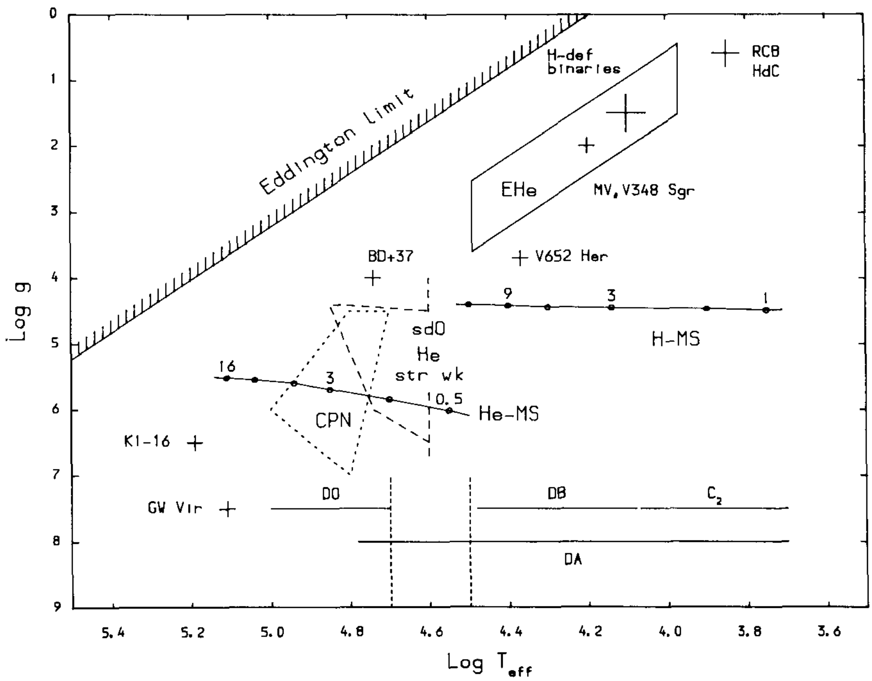

Figure 1. The log g - log T_{eff} diagram for low-mass hydrogen-deficient stars. The objects and regions shown are indicative rather than definitive.

2. HOT HYDROGEN-DEFICIENT STARS

2.1. Extreme helium stars

I shall consider first the extreme hydrogen-deficient stars. Heber defined the class of hot extreme helium (EHe) stars with $n_H/n_{He} < 10^{-3}$ and overabundant carbon ranging in temperature from spectral type A to late O. There are now 17 of these known, Drilling having been responsible for the discovery of a very large proportion of them. Spectroscopic analysis, particularly from Kiel, has been used to determine their surface abundances and place them in the log g - log T_{eff} diagram (Fig.1). Heber demonstrated how they occupy a small strip in the diagram but so far only 4 have a complete fine analysis and even these four are not homogenous in chemical composition for nitrogen and heavier elements. IUE and the new echelle spectrographs, particularly CASPEC, have provided a lot of improved data, with better equivalent widths at higher resolutions, on which to base future analyses. These will perhaps help to solve the evolutionary problem, discussed by Schönberner, of the origin of the range of masses and luminosities seen in preliminary analyses of these stars. We already find differences for one which has had a fine analysis. Are there more real differences?

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For those stars bright enough for high resolution IUE spectra to have been obtained the mass loss rate is of the same order of magnitude as for normal stars of the same luminosity. Variable emission lines are seen in the visible spectrum of BD-9°4395 (Jeffery), one of the hotter members of this group which appears to be a non-radial pulsator. V2076 Oph (HD 160641) is another non-radial pulsator (Lynas-Gray et al) and the hottest of the EHe stars which has had any sort of analysis. The cooler EHe stars vary in perhaps a more regular way, maybe radial pulsation (Jeffery et al), and would seem to fit much better the model for RCB pulsation discussed by Saio. In fact, as Landolt's review of the photometric properties demonstrated, most of these stars are variable in light. They are classified as PV Tel stars in the new (4th) edition of the General Catalogue of Variable Stars after the first (HD 168476) for which variability was established. One of the important needs for the future is to really ascertain the nature and timescales of these variations. The amplitudes are small and known timescales vary from hours to weeks. This work needs a lot of careful observing, good results not being possible just by occasional photometric sampling although relatively small telescopes can be used. We saw how important pulsation is to try and tie down parameters such as the mass.

2.2. Hot peculiar RCB stars

Rao discussed two peculiar stars usually classified as hot RCB stars. We don't know very much about them and understand less. Although there are considerable differences between them MV Sgr and V348 Sgr each have the appearance of a hot extreme helium star in a shell and have the IR excesses of the dust clouds. Their long-term light curves resemble those of the RCB stars. V348 Sgr was demonstrated by Schönberner to be in the same region of the log g - log T_{eff} diagram (Fig. 1) as the extreme helium stars of similar effective temperature. We clearly identify this as an area needing more investigation.

2.3. V652 Herculis

The radially pulsating extreme helium star V652 Her is probably an unrelated object. It is carbon-poor, nitrogen and silicon-rich (Jeffery et al). The period decrease rate was reviewed by Lynas-Gray and Kilkenny and a new radial velocity curve presented (Hill & Jeffery) showing an increase in the effective gravity by a factor of 4 at the phase of minimum radius. It is either a unique object or in a very rapid phase of evolution. Saio pointed out that it poses a major problem for pulsation theory as the excitation mechanism is not known and Jeffery's evolutionary model, which fits everything else, appears stable against pulsation.

2.4. Hydrogen-deficient binaries

The hydrogen-deficient binaries were reviewed by Plavec and their evolution discussed by Tutukov. They are nitrogen-rich and carbon-poor and may be a different type of object with different distribution, their hydrogen deficiency being caused by mass exchange. They tend to be discovered along with the extreme helium stars and observed in much the same way in the first place. Four of these are now known, the binarity and pulsation of CPD-58°2721 (LSS 1922) being demonstrated by Jeffery on behalf of a collaboration between Kiel, LSU and St Andrews. A paper from Bangalore showed variable polarization at H-alpha in KS Per (HD 30353) on a timescale of maybe a day. LSS 1922 also has variable Balmer line emission which may also change on the timescale of around a day. The AM CVn stars are hydrogen-deficient binaries of another sort for which flare activity was reported by Kutty. The known members of this group form an inhomogenous group of three. If they are related they may be the hydrogen-deficient analogues of the cataclysmic variables.

3. COOL HYDROGEN-DEFICIENT STARS

3.1. R Coronae Borealis stars

Feast described the so-called "consortium of puffs" model of the RCB minimum which seems to be well-established and in reasonable agreement with the crude description of the observations. Approximately every 40 days at the maximum of the pulsation light curve, where Lawson demonstrated line-splitting at minimum radius in RY Sgr and therefore some correlation with a shock in the pulsation, a puff of carbon particles is emitted which appears in our direction on average every 1000 days or so. The resultant dust shell produces the IR excess which is confirmed by the IRAS results (Walker). The correctness of this model seems confirmed by the relative constancy of fluxes at wavelengths of the L band and longer which arise from the dust cloud and the minima shown at J and shorter wavelengths arising from the eclipse of the star by a puff in our direction. On the other hand L varies with small amplitude in a cycle of about 1000 days. An interesting test is proposed by Menzies who predicts a deep minimum for RY Sgr in the middle of 1986 on the basis of the last two happening about a year after the 1000 day maximum in L. There are many details to be filled in for this model and many problems. How and where do the puffs originate? What is the origin of the 1000 day variation in the dust cloud? Do all the RCB stars pulsate? Do they all have the same effective temperature around 7000 K and if so how do we explain the strengthened carbon bands in some and the apparent historical variations in the carbon bands in others? Lambert showed us how to analyse the spectra of RCB stars but with only two or three analysed in a dozen papers on their composition in the last 50 years there is a clear need for more studies.

Saio demonstrated that the pulsation models are stable at an effective temperature of 7000 K. Indeed, the results of non-linear pulsation analysis fit the observations extremely well, including the period and amplitude irregularities although the calculated amplitudes are just a little large. Another confirmation is that the masses derived from pulsation agree very well with those determined from spectroscopic parameters and evolutionary models.

3.2. Hydrogen-deficient carbon stars

The hydrogen-deficient carbon (HdC) stars occupy the same region of the log g - log T_{eff} diagram (Fig. 1) as the RCB stars, but are not known to be variable. There are only 4 or 5 known and it seems that these do not have the dust shells seen around the RCB stars. There is no recent spectroscopic analysis of HdC stars, the last being a curve of growth analysis in 1967. The RCB star XX Cam does not have the IR excess characteristic of the dust shells surrounding the RCB stars. This raises the possibility that it may be an HdC star and that variations in other HdC stars have not been detected.

4. ORIGIN AND EVOLUTION OF HYDROGEN-DEFICIENT STARS

The evolution of the extreme hydrogen-deficient group (RCB, HdC and EHe stars) was discussed by Schönberner who left us with the conclusion that these stars evolve blueward from the Hayashi limit in the Red Giant region rather than leaping up from the helium main sequence. The evidence from pulsation and evolutionary models and spectroscopic analyses suggested that as being more likely. The RCB stars which have been analysed have compositions like the extreme helium stars but as the latter have no IR excess there may not be a direct evolutionary link. Schönberner asked if the dust cloud could dissipate or whether the extreme helium stars originate from the hydrogen-deficient carbon stars which also don't show the dust clouds.

What about their origin? The IRAS results for R CrB itself and possibly one other show very extended wings at 60 and 100 microns, suggested by Rao to be evidence for a very cool "fossil" shell. On the other hand RY Sgr looks like a point source to IRAS. Rao also reported observations of nebular emission during a minimum of R CrB. Taken together these were proposed as evidence for the "Born Again" planetary nebula theory of Iben. Many theories of the origin of extreme hydrogen-deficient stars were considered by Schönberner but most fail to predict the observed abundances or lifetimes. Most favoured, in the sense of raising the fewest objections, is the binary white dwarf coalescence hypothesis first proposed by Webbink, but the situation is still very confused.

5. HYDROGEN-POOR SUBLUMINOUS STARS

These occupy the lower part of the log g - log T_{eff} diagram (Fig. 1). Why do we call them "related objects" when many are as deficient in hydrogen as the RCB and EHe stars? Because they tend to be classified as something else first and only some are found to be hydrogen-deficient. The subdwarf O stars and Central Stars of Planetary Nebulae

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(CPN), reviewed by Mendez, had tended to occupy distinct regions in the log g - log T_{eff} diagram until 3 new helium-rich sdO stars found by Drilling, and with no sign of any nebulosity, came into the CPN region as the result of an NLTE analysis described by Heber. These may connect with the extreme helium star region via the two BD+37 stars which are variously described as either sdO or EHe stars. About 20-25 per cent of all subdwarf O stars, including some of the extremes discussed by Heber where hydrogen is completely depleted, appear to be helium-rich. Subdwarf O stars with temperatures less than 40000 K are helium-weak, the boundary being due to gravitational settling rather than a definite abundance effect. The connection with the extreme helium stars is not clear because only about two-thirds of the sdO stars analysed (including two of the three new ones discussed above) are carbon-rich and the effect is not temperature dependent.

Mendez divided the Central Stars of Planetary Nebulae into hydrogen-rich and hydrogen-deficient groups on the basis of a revised classification scheme with about one-third of them apparently being hydrogen-deficient including those in the strange planetary nebulae of the A78 type. Pottasch demonstrated for us with new spectra how abundances in these nebulae change with distance from the centre. Could these be the precursors of the RCB stars?

Further down the diagram (Fig. 1) between most of the planetary nebulae nuclei and the white dwarfs we find the nucleus of the planetary nebula K1-16. This is known to pulsate and may be intermediate between the CPN and the very hot pulsating hydrogen-deficient pre-white dwarfs of the GW Vir (PG1159-035) type described by Liebert. An interesting similarity that has arisen between the hydrogen-deficient CPN and the DO/DB white dwarfs is the apparent absence in both groups of any stars in the effective temperature range from about 30000-50000 K. Another interesting comparison is that there is little evidence for differences in mass between the hydrogen-deficient and hydrogen-rich CPN, as is also the case for DA and DB white dwarfs as shown in Liebert's careful analysis. Liebert demonstrated the two sequences of hydrogen-rich DAs, on the one hand, and hydrogen-deficient DOs and DBs, on the other, with arrows joining them together showing the stars popping up and down between the two sequences as one possible consequence of evolution.

Finally, a careful study by Bues of polarization spectrum variability in the carbon bands of cool DB white dwarfs, the C_2 type, suggests that these could evolve from intermediate helium stars with magnetic fields.

6. INTERMEDIATE HELIUM STARS

The intermediate helium (IHe) stars were reviewed by Hunger. To avoid confusion they have not been included in Fig. 1. A detailed analysis is needed in the first place to identify them because they have abundance ratios N_H/N_{He} from about 3 to 0.1. These appear to split into a low mass non-rotating group for which the helium enrichment could be evolutionary, and a high mass rotating group of probably main sequence stars with magnetic fields which appear to form a continuous temperature sequence with the helium-weak and Ap stars, as described by Barker. The apparent helium enrichment is due to the interaction of diffusion with the stellar wind and magnetic field which Michaud showed should apply to the limited effective temperature range of the intermediate helium stars. Sigma Ori E is the best studied of the IHe stars. It has a shell and radio emission suggesting interaction in a magnetosphere between the stellar wind and the magnetic field. But there are a number of problems with the observations, problems with the equivalent widths which will not resolve the problem of whether these stars have main sequence masses until new high resolution data from linear detectors has been analysed. From the point of view of looking at the end points of stellar evolution through hydrogen deficiency it seems that this particular group of stars perhaps belongs properly with the Ap stars in the chemically-peculiar upper main sequence star stable rather than in the stable of true hydrogen deficiency.

7. CONCLUSIONS

What conclusions can we draw? Our understanding of the origin of the hydrogen deficiency and the evolution of many of these stars is still extremely uncertain. We need many more observations, a lot of good observations with the best detectors and of course we must find the best way to use the new devices becoming available. By combining results we can see how the various groups of stars fit together in the log g - log T_{eff} diagram (Fig. 1). I think this is of extreme value. People like me who have been working very much in one limited region of the diagram have learnt a great deal of what is happening elsewhere and how this will interact with our work on the more luminous extreme helium stars. I am sure that this will also be true for those more experienced with other groups of hydrogen-deficient stars.

ACKNOWLEDGMENTS

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