EMPIRICAL EVIDENCE FOR CRYSTALLIZATION SEQUENCES OF DA TYPE WHITE DWARFS

S. Tapia

Lunar and Planetary Laboratory
University of Arizona

The determination of the distribution of white dwarfs in the HR diagram is marred by two observational difficulties: The recent discoveries of degenerate stars with unusual spectral characteristics and the controversy over the existence of crystallization sequences. Observationally, the origin of the controversy can be traced to the single band displayed on the M_V *vs.* (b-y) diagram by several white dwarfs with accurate parallax (Graham 1972). The discrepancy between this single band and the two bands evident in the M_V *vs.* (U-V) diagram (Eggen and Greenstein 1965) is far too great to be attributed to observational errors (Eggen 1969). Theoretically, the number of sequences in the HR diagram is directly related to the cooling properties of degenerate dwarfs, for which crystallization is expected on rather general grounds. On one hand, Van Horn (1968) considered a discontinuous transition to the solid phase with the release of latent heat and the addition of it to the total internal energy. Since the amount of latent heat depends upon the chemical composition, bright and faint crystallization sequences should be observed according to the different stages of evolution reached by the parent stars. On the other hand, Mestel and Ruderman (1967) proposed a gradual transition to the solid phase, and consequently the formation of a single cooling sequence. The purpose of this contribution is to report observational results indicating the existence of two crystallization sequences of DA type white dwarfs.

An analysis of several photometric attempts to derive atmospheric parameters of degenerate dwarfs led Wickramasinghe and Strittmatter (1972) to suggest photometric bands designed to optimize determinations of gravity and effective temperature. For DA white dwarfs they propose three intermediate bands that measure the

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continuum plus one band that measures the absorption of Hβ. With these spectral bands two reddening-free indices are formed. The first index, w, is directly related to the strength of Hβ while the second index, d, provides a broad baseline comparison between the Balmer and Paschen continua. For the hotter white dwarfs (T_{eff}> 12000 K) w is only sensitive to gravity and d is only sensitive to temperature. However, a combination of both indices can extend their use to T_{eff} = 7000 K.

A sample of 46 DA white dwarfs, most of them with accurate determinations of trigonometric parallax, was observed with this new photometric system employing a computer controlled photometer and the Steward Observatory 2.29 m telescope. The observed w and d indices were compared with synthetic w and d indices computed with the grids of model atmospheres published by Wickramasinghe (1972) and Wehrse (1976) to determine gravities and temperatures. In general, the results agree with a value log g = 8 for the majority of the white dwarfs, as determined in an earlier analysis (Weidemann 1975). Derived uncertainties for the effective temperatures are typically 700 K. In the mentioned sample of DA white dwarfs 25 stars have absolute magnitudes determined to 0^{m}25 or better. These stars have been included in the M_V vs. log T_{eff} diagram presented in Fig. 1. In this diagram nine stars for which the trigonometric parallax are larger than 0"06 plus seven Hyades members outline two bands of different slope. Aside from the smaller number of stars Fig. 1 bears strong resemblance to the M_V vs. (U-V) diagram obtained by Eggen and Greenstein (1965). Also, two bands with different slopes are obtained if the (u-b) colors published by Graham (1972), instead of the (b-y) colors, are plotted versus the absolute magnitude. It appears therefore, that the two bands have been observed in three different photometric systems.

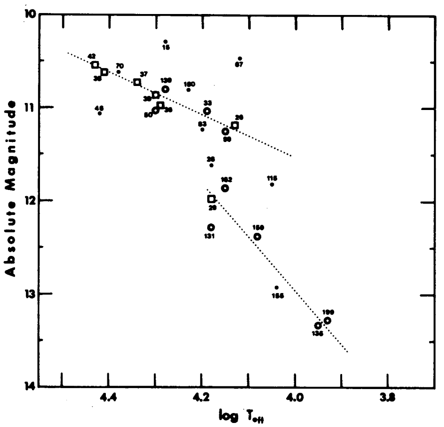

Fig. 1. The M_V vs. log T_{eff} diagram for 25 DA white dwarfs with uncertainty smaller than 0^{m}26 in the distance modulus. Squares represent Hyades members. Circles are used for stars with parallax larger than 0"06. Identification is made in terms of the EG numbers.

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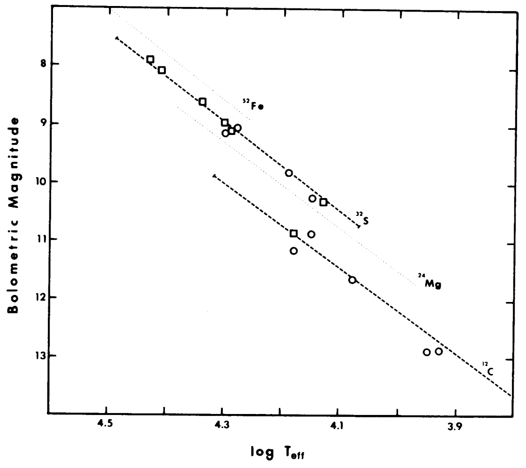

Fig. 2. The M_{bol} vs. log T_{eff} diagram for 16 DA white dwarfs with accurate distance determination. Symbols as in Fig. 1. Crystallization sequences computed by Van Horn are presented with dashed and dotted lines. The ^{32}S sequence is restricted here to mass in the range 0.88 to 0.40 solar units, with larger masses at the upper end.

Adding the bolometric corrections to the absolute magnitudes produces a homologous transformation of these bands into the M_{bol} vs. log Teff diagram. The results are presented in Fig. 2, where the 16 stars with better distance determination are included. The two bands now display the same slope of the crystallization sequences derived by Van Horn (1968). However, the interpretation is not straightforward: Current trends in nucleosynthesis research question the presence of elements much heavier than carbon in the core of degenerate dwarfs.

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DISCUSSION

WEIDEMANN: There are three arguments against your hypothesis of crystallization sequences: first, the new model atmospheres are changing the locations in such a way that the average radius is constant from the highest to the lowest temperatures, as mentioned by Shipman and as shown in my HR diagram; second, it has been demonstrated that even if latent heat is released at crystallization the additional energy would be radiated away so smoothly - over a larger luminosity interval - that no sequence would be visible in the HR diagram (Koester, Astron. Astrophys. 16, 459, 1972), and third, according to more recent investigations by the van Horn group, the latent heat is probably freed over a larger range of state variables - which again tends to smooth out visible effects in the HR diagram.

TAPIA: I think that we should take a more open attitude on this subject. Using the best temperature indicators from three different photometric systems, in each instance we find two sequences of DA white dwarfs on the HR diagram. If there are doubts that the system described in this paper is free of contamination from the Balmer lines, let me say that the separation of DA white dwarfs is also detected when the near monochromatic color index (2.80) - (1.85) is used in the abscissa of the HR diagram (Greenstein, Astron. J. 81, 332, 1976). Better yet, I was pleased to see that in Fig. 1 of your paper the Hyades white dwarfs define a tight sequence with the same slope as the brighter sequence found with my data. Retaining only the high quality bolometric magnitudes in your Fig. 1, there are indications of two sequences also. It is useful to know which model atmospheres or color indices give only one sequence. However, that there are two sequences appear to be a persistant observational result. Even if there are some reasons to believe that crystallization has unobservable effects on the evolution of white dwarfs, the nature of these two sequences remains to be explained.

BIDELMAN: What are the sources of the absolute magnitudes of the stars of your upper sequence? Are they from trigometric parallaxes?

TAPIA: For the Hyades members the distance modulus $3^{m}.29 \pm 0^{m}.20$ was adopted. For the other DAs, trigometric parallaxes were used, mainly the new results from the Naval Observatory.