STRATIFIED MODEL ATMOSPHERES FOR HOT DA WHITE DWARFS

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Observations of hot DA white dwarfs in the EUV/soft X-ray range have revealed that, in a majority of cases, the detected flux is less than that expected from pure hydrogen atmospheres. This implies an extra opacity source which must be due to the presence of small traces of heavier elements. These elements are generally not spectroscopically detected in hot DA white dwarfs, but the large sensitivity of the EUV/soft X-ray broad-band flux to the presence of extra absorbers can be used with profit to *infer* their abundances. For simplicity, it has been assumed that *only* helium provides the required opacity source in the majority of the analyses carried out so far. In this context, Vennes *et al.* (1988a) have recently reviewed in details the mechanisms that could be responsible for the presence of small traces of helium in the atmospheres of hot DA white dwarfs. They favor a model in which these stars are interpreted as stratified objects with an outer layer of hydrogen which is sufficiently thick that radiation in the visible escapes only from H-rich regions, and yet sufficiently thin that the EUV/soft X-ray radiation escapes from deeper layers, polluted by the tail of the helium distribution which extends upwards. This model accounts naturally for the positive correlation observed between the inferred helium abundance and the effective temperature in hot DA stars studied at short wavelengths. If the model is correct, hot DA white dwarfs as a class must have very thin outer hydrogen layers with estimated masses in the range $-13 \gtrsim \log q(H) \equiv \log (M(H)/M) \gtrsim -15$.

In order to follow up on the work of Vennes *et al.* (1988a), it is necessary to compute stratified model atmospheres for detailed analyses of individual stars. Our aim is to take advantage of the homogeneous *EXOSAT* photometric measurements of several hot DA white dwarfs (Paerels 1987), and ultimately derive the values of log q(H) for these stars. Our model atmospheres consist of a pure H layer on top of a pure He layer in diffusive equilibrium. These models are similar to those of Jordan and Koester (1986) in the treatment of the

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composition transition layer, but extend to larger values of log q(H) as suggested by the work of Vennes *et al.* (1988a). Cruder stratified models based on discontinuous composition interfaces have already been discussed by Heise and Huizenga (1980) and Muchmore (1982). The present models assume LTE and are hydrogen line-blanketed. The current grid is for log g=8.0 and effective temperatures $T_e(10^3$ K)=25, 30, 40, 50, and 60. For each effective temperature, models are computed with hydrogen layer masses log q(H) = −15.5, −15.0, −14.5, −14.0, −13.5, and −13.0. Models with $T_e(10^3$ K)=25 and 30 and log q(H)< −14.5 were found to be convectively unstable in the composition transition zone and were therefore rejected as the presence of convection is inconsistent with the assumption of diffusive equilibrium. For comparison purposes, we have also computed another grid of models using the same physics but, this time, for homogeneous chemical compositions with He/H ratios in the range 10^{-10} to 10^{-2}. Details on these uniform models as well as the stratified models can be found in Vennes (1988).

We have used our grid of stratified model atmospheres to derive preliminary values of log q(H) for the sample of 15 hot DA white dwarfs observed with the *EXOSAT LE* filters (Paerels 1987). If an extra EUV opacity source is required, the procedure implicitly assumes that it is due to helium alone. The method is currently limited by the availability of models with only one value of the gravity (log g=8.0). According to Vennes *et al.* (1988a), scatter in gravity is likely to play an important role in the interpretation of short wavelength observations of hot DA stars. In the present experiment, we have used the best estimate of the effective temperature of a given object as available in the literature, and have sought a consistent solution for all filter measurements in the q(H)−n(H) plane (where n(H) is the interstellar neutral hydrogen column density). Self-consistent solutions were obtained for the vast majority of our sample stars. The most outstanding exception is HZ 43 for which no acceptable solution has been found. This is likely to be caused by its significantly larger than average gravity. Our results are summarized in Figure 1 which shows a plot of the inferred hydrogen layer mass log q(H) as a function of the effective temperature. Our procedure has led to the inference of two upper limits, four lower limits, and eight values of log q(H) in the *EXOSAT* sample of hot DA stars. The inferred values are in the range −13≥log q(H)≥−15 in agreement with the estimates of Vennes *et al.* (1988a), and show that hot DA white dwarfs must indeed have very thin outer hydrogen layers if helium absorption is responsible for the extra EUV opacity required by most of the observations. We note that our estimates of log q(H) are consistent with those of Koester (1988) who has recently performed an analysis similar to ours for 11 of the 15 objects in the *EXOSAT* sample (we express the hydrogen layer mass in terms of a

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fraction of the stellar mass of a 0.6 $M_{\odot}$ object, whereas Koester expresses log q(H) in terms of a fraction of the solar mass). In agreement with Koester (1988), we point out to a possible weak trend between log q(H) and T_e; the hotter stars appear to have smaller values of q(H).

Before further conclusions can be drawn as to the properties of layered models of hot DA stars, it is appropriate to recall that the short wavelength *photometric* measurements do not permit to discriminate between helium and other potential absorbers. Fortunately, however, H/He layered model atmospheres leave spectral signatures which are quite characteristic. This is particularly true in the EUV range where the flux is very sensitive to the presence of small traces of helium as indicated previously. As an illustrative example, Figure 2a shows synthetic EUV spectra for uniform models with various He/H ratios, and log(g) = 8.0 and T_e = 60 000 K. Profiles for the He II Lyman series are computed following Auer and Mihalas (1972) and the spectrum is convolved with a gaussian of FWHM=6 Å, representative of the *EXOSAT* resolution. Note that the curves are displaced vertically for clarity. By contrast, Figure 2b shows the synthetic EUV spectra of stratified models with log q(H) = −15.0, −14.5, −14.0, and −13.5, respectively. The gravity and the effective temperature are the same as for the uniform models. A comparison of the two figures clearly shows that the continuum shortward of the 228 Å edge behaves quite differently in the two cases. Likewise, the line profiles are different; they are obviously broader in the layered models because the lines are formed deeper into the photosphere. Our own experience with theoretical count rate spectra of *EXOSAT* indicates that EUV spectroscopy can distinguish between layered and uniform atmospheres in DA white dwarfs. Currently, such data exist for only three DA white dwarfs: Sirius B (Paerels *et al.* 1988) and HZ 43 (Heise *et al.* 1988) which appear to have pure hydrogen atmospheres (corresponding to lower limits on log q(H)), and Feige 24 (Vennes *et al.* 1988b) which is better explained in terms of a H-rich atmosphere polluted by a host of heavier elements presumably supported by radiative levitation. Thus, the jury is still out on the existence of layered DA atmospheres with very thin hydrogen layers. The DAO stars, particularly the interesting object PG 1210+533 discussed by Holberg *et al.* (1987) could well represent the most promising tests of the stratified model. Future experiments, such as *EUVE* and *ROSAT* may provide definitive answers to these questions.

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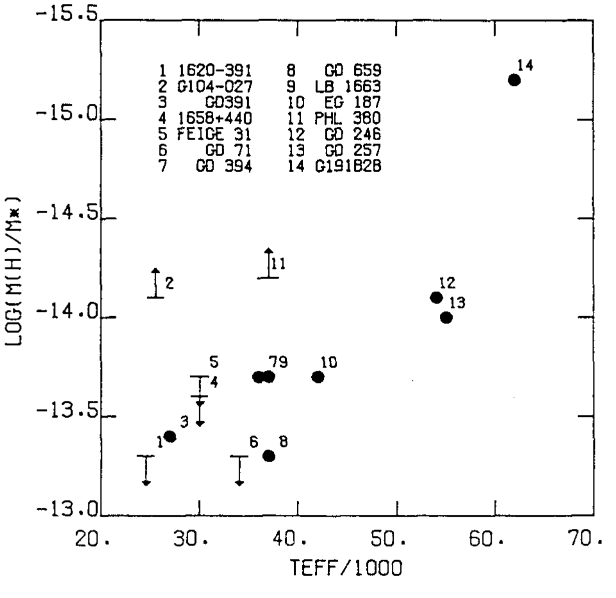

Figure 1. Relationship between the inferred hydrogen layer mass log q(H) and the effective temperature for 14 hot DA stars observed photometrically with *EXOSAT*.

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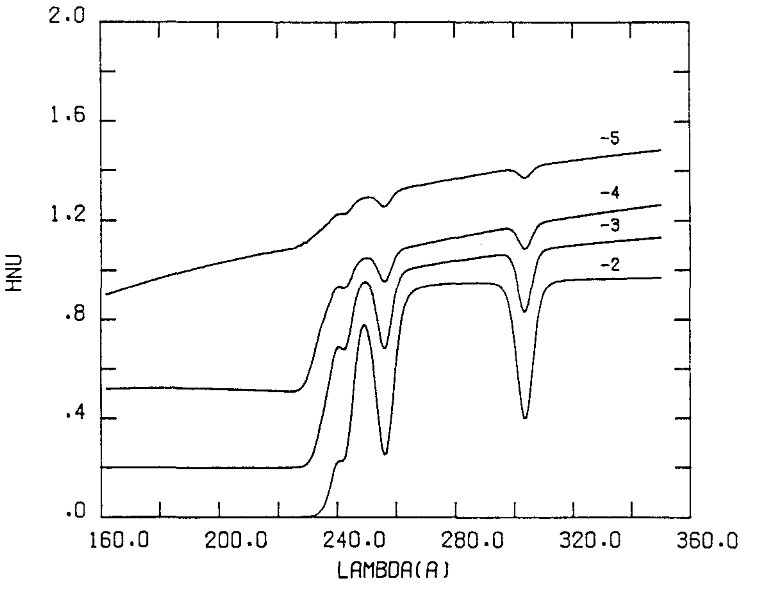

Figure 2a. Synthetic EUV spectrum of homogeneous model atmospheres with log He/H = -5, -4, -3, and -2 from top to bottom, respectively. The models have log g = 8.0 and T_e = 60 000 K.

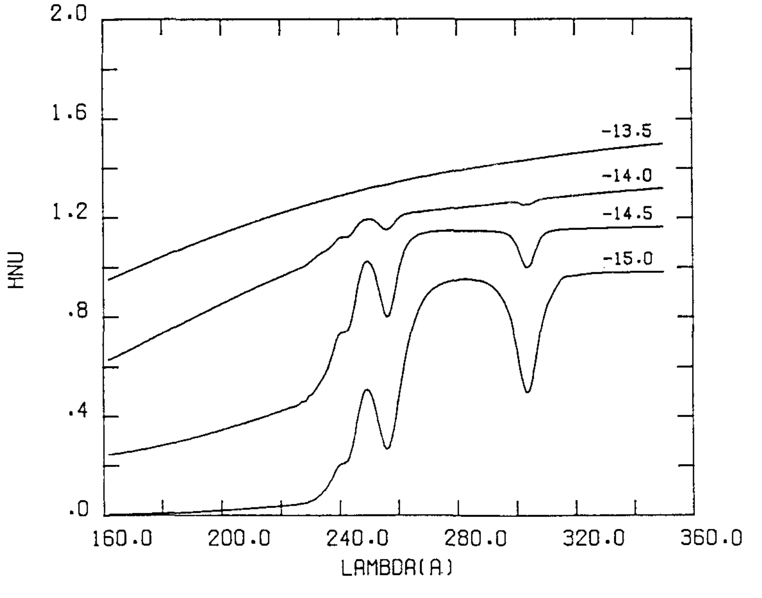

Figure 2b. Similar to Fig. 2a, but for stratified models with log q(H) = -13.5, -14.0, -14.5, and -15.0, from top to bottom, respectively.