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IUE OBSERVATIONS OF A HOT DAO WHITE DWARF: IMPLICATIONS FOR DIFFUSION THEORY AND PHOTOSPHERIC STRATIFICATION

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ABSTRACT

We have obtained IUE observations of the DAO white dwarf PG1210+533, including the first high dispersion spectrum of a hybrid H-He object of this nature. In contrast with hot DAs in the 50,000 K temperature range, PG1210+533 shows *no* narrow interstellar-like metal lines, in spite of an optically observed He/H abundance of 10^{-2}. This lack of metals makes accretion from the ISM an unlikely source for the He in the PG1210+533 photosphere. A significant discovery in the high dispersion spectrum has been the existence of a sharp, non-LTE like, core seen in the He II λ1640 line. Such features have been previously detected in DO white dwarfs. In addition, a small aperture SWP low dispersion observation has also revealed the Ly α profile of PG1210+533 to be surprisingly weak and narrow. Fits of this profile using pure H models yielded a T_{eff} = 56,000 K Fits of the Balmer Hγ profile, however, yield T_{eff} = 42,300 K and log g = 8.5 ± 0.5 for the same models. It is unlikely that homogeneously mixed H-He atmospheres can resolve the inconsistency between the Ly α and Hγ features in this star. Stratified models involving thin H photospheres may be necessary to explain these results.

Key Words: White Dwarfs, Ultraviolet Spectra

1. INTRODUCTION

One of the more surprising things to arise from IUE observations of degenerate stars has been the discovery of narrow interstellar-like features due to ions of C, N and Si in high dispersion IUE spectra of many white dwarfs (Refs. 1-2). Prior to this discovery the atmospheres of the vast majority of white dwarfs were commonly regarded as having photospheric compositions of either pure hydrogen (DAs) and pure helium (DOs and DBs). The accepted explanation for this situation lies in the short time scales for the complete chemical stratification of white dwarf atmospheres. Under the strong gravitational field of a white dwarf the lightest element, normally H but perhaps He if the atmosphere is extremely H poor, will form the visible photosphere. The presence of metallic ions implies either an external source of material or some ongoing processes which can counteract the downward forces on He and metal ions.

Certain heavy ions can, under proper conditions, be supported by radiative forces against gravitational settling. In the absence of external influences such as the accretion of interstellar material the primary factors which ought to govern observed abundance patterns of metallic elements are temperature and gravity. A significant number of DAs, covering a wide range of temperature and gravity, have now been observed with IUE at high dispersion. What has emerged from these observations seems to conform to the expected pattern For example, as the intensity of the UV radiation field increases with temperature the most readily supported ions, such as Si II, Si III, and Si IV, are observed At higher temperatures (~35,000 K) ions of C and N are also observed. There are important exceptions to this picture but they all appear to involve DAs of known (Sirius B) or suspected (HZ 43) high gravity. Initial evidence for such a pattern of metal abundances in DAs has been presented in Ref. 2. An effort summarizing nearly all of the usable DA high dispersion observations lends further support to this picture (Ref. 3). In hot DO white dwarfs similar metallic features are seen (Refs 4-6). For these hot He degenerates, however, the features tend to be much broader and the presence of O ions becomes apparent.

From observations of hot DAs in the soft X-ray He abundances on the order of 10^{-5} to 10^{-3} are inferred (Refs. 7-10) It has been suggested that such He is 1) supported by radiation pressure in a manner similar to the metal ions (Ref 7) or 2) primarily the product of the accretion of interstellar material (Ref. 9). In either case the presence of metal ions could reasonably be expected to correlate with He abundance. Such expectations make DAOs attractive candidates for observation with IUE. Unfortunately there exists only one known DAO bright enough to observe at high dispersion with IUE. This is PG1210+533, a V = 14 12 star having an effective temperature of 50,000 K and helium abundance of He/H = 10^{-2} (Ref. 11).

2 IUE OBSERVATIONS

On July 1 1987 we obtained a single SWP high dispersion image of PG1210+533 (SWP 31277) using a combined USI/ESA shift for a total exposure of 13 hr. A continuum level approximately 100 DN above background was achieved for wavelengths shortward of 1750 Å. In addition a doubly exposed large and small aperture low dispersion SWP image (SWP 31278) was obtained. The latter were intended to provide a clean H I Ly α profile of the star. Following standard IUE extraction, the high dispersion image was examined for the presence of any of the metal features which have been previously detected in DA and DO white dwarfs. Specifically, evidence for the following features were sought. Si II λλ1206.510, 1260.421, 1264.737, 1265.001; Si III λλ1294.543, 1296.726, 1298.891; Si IV λλ 1548.202, 1550.774, C II λλ1334.536, 1335.708; N V λλ1238.821, 1242.804; C IV, 1548.202, 1550.774. *No metallic features. clearly identified with the star. were found*. Characteristic upper limits on the equivalent widths of these features are on the order of 100 mÅ. Only a single interstellar feature due to Si II λ1260.421 was observed. This feature, shown in Fig 1, has an equivalent width of 145 mÅ and a heliocentric radial velocity of -16.8 km s^{-1}.

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FIG. 1

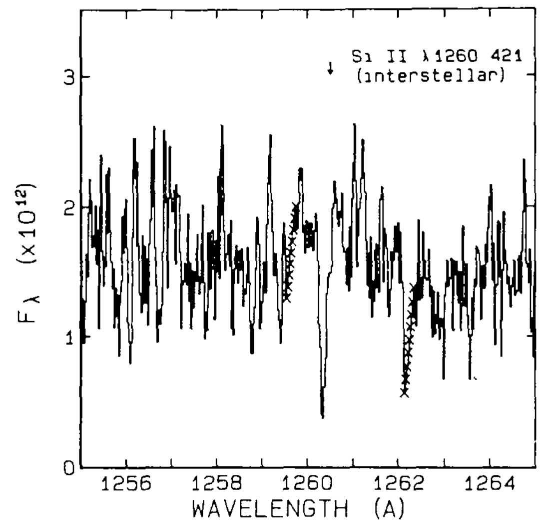

Fig. 1 An *interstellar* feature due to Si II λ1260.421. This is the only narrow metallic feature found in the high dispersion spectrum of PG1210+533. It has an equivalent width of 145 mÅ and a radial velocity of -16.6 km s^{-1}.

In spite of the fact that no metallic features associated with PG1210+533 were detected, the broad He II λ1640 line did reveal a central, narrow core. This feature has a saturated equivalent width of 380 mÅ and a heliocentric radial velocity of -5.8 km s^{-1}. In Fig. 2 we show the region of the He II λ 1640 feature at both low (Fig. 2a) and high (Fig. 2b) dispersion. The existence of the He II line had been previously noted by Ref. 11 in an earlier low dispersion SWP image of PG1210+533. The low dispersion profile shown in Fig. 2a, which is a coaddition of the large and small aperture images, has an over all ~ 3 Å equivalent width. The narrow central core of the He II line in PG1210+533 is similar to features seen in the hot DO white dwarfs PG1034+001 (Ref. 5) and HD 149499 B (Ref. 6) In both instances these narrow cores were identified as non-LTE features, analogous to the non-LTE cores seen in H I Balmer lines of moderate temperature DAs (Ref. 12).

3. IMPLICATIONS

This first high dispersion spectrum of a DAO has interesting implications for several current ideas concerning the composition and structure of white dwarfs. First, the lack of any metal lines poses serious difficulties for models which would invoke the accretion of interstellar matter to account for the presence of He in DAOs As has been pointed out by Ref. 13 the accretion of sufficient interstellar material to explain the observed He abundance in PG1210+533 would also yield observable quantities (assuming solar proportions) of C III, C IV, and N V. Second, the lack of any metal lines in PG1210+533, a 50,000 K H-rich white dwarf, is anomalous in view of the fact that nearly all DAs observed to date in this temperature range exhibit metal lines (Ref. 3). The most notable exception has been HZ 43 a hot (T_{eff} = 57,500 K, Ref. 14) DA showing no metal lines. In the case of HZ 43 high gravity (Ref. 14) can be invoked to explain the lack of any metal lines. A similar explanation may hold for PG1210+533 (see below) but this remains uncertain. Third, the non-LTE like core in the He II λ1640 feature has considerable significance. If this is a non-LTE feature its formation in a fully stratified atmosphere is puzzling. Normally such features are envisioned as being formed at low optical depths high in the photosphere.

FIG. 2a

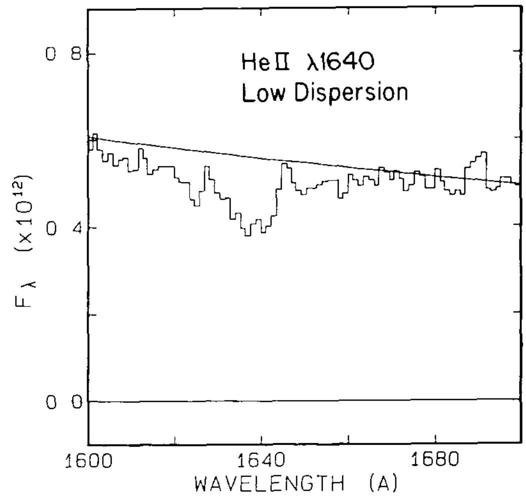

FIG. 2b

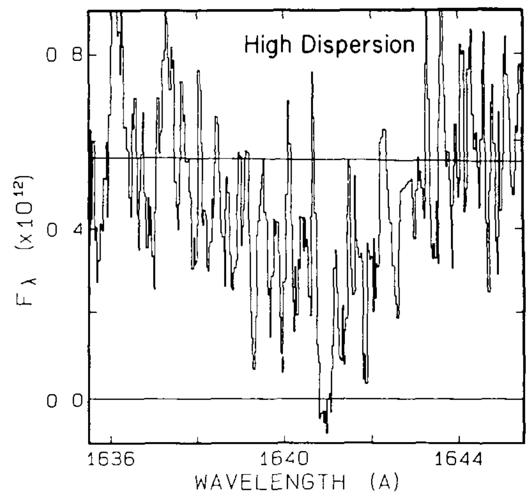

Fig. 2 The He II λ1640 feature in PG1210+533. a) At low dispersion the pressure broadened component has an equivalent width of 3Å. b) At high dispersion a narrow saturated core is present, which is similar to non-LTE features seen in hot DO white dwarfs. This narrow feature has an equivalent width of 380 m Å and a radial velocity of -5.8 km s^{-1}. The sloping line in both plots is the same model atmosphere continuum.

The small aperture low dispersion spectrum of PG1210+533 also poses interesting implications. In Fig. 3 we show the H I Lα profile derived from this spectrum together model atmosphere fit to the data. This Ly α profile is surprisingly narrow. Following the technique of Ref. 15 of fitting the Ly α profile in the T_{eff}-log g plane we obtain a best fit temperature of T_{eff} = 56,000 K ± 5000 K This is marginally consistent with Ref. 11 who obtain T_{eff} = 50,000 K ± 5000 K from optical and IUE data. It is not consistent, however, with fits of the same model atmospheres to the Balmer Hγ profile for PG1212+533 shown in Fig. 4. The Hγ profile yields T_{eff} = 42,600 K ± 4000 K and log g = 8.5 ± 0.5. Results obtained from the joint analysis of Ly α and H I Blamer profiles in hot DAs (Ref. 15 and 16) indicate such a large discrepancy is unusual. Although we have used pure H non-LTE models to fit the Ly α and Hγ profiles it is unlikely the addition of homogeneously mixed He at an abundance level of 10^{-2} will explain this discrepancy between the line profiles (Ref. 17). It remains to be seen if these results are explainable in terms of a thinly stratified atmosphere in which a thin H photosphere

FIG. 3

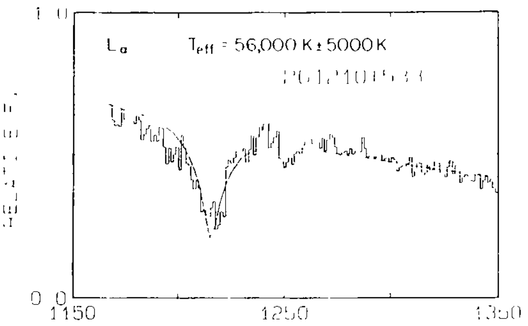

Fig. 3 The Ly α profile of PG1210+533 obtained from the IUE small aperture image The smooth curve is a model atmosphere fit yielding T_{eff} = 56,000 K ± 5000 K.

FIG. 4

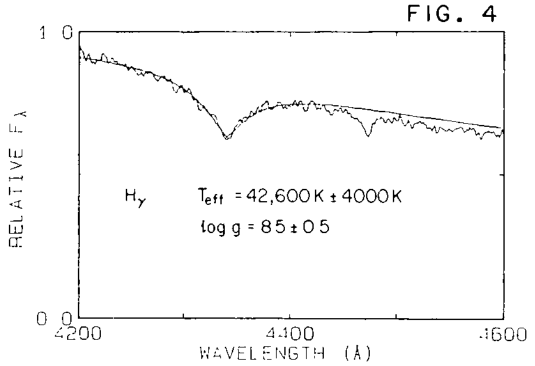

Fig. 4 The Balmer Hγ profile of PG1210+533 obtained with the Steward Observatory Blue Pluse Counting Reticon. The smooth curve is a model atmosphere fit yielding T_{eff} = 42,600 K ± 4000 K and log g = 8.5 ± 0.05, a result inconsistent with the Ly α profile in Fig 3 The weaker feature to the right of the Hγ line is He I λ4471

overlies deeper He rich regions. It has recently been demonstrated (Ref 13) that radiative forces are ineffective in maintaining He in DA photospheres Because of this, such stratified models are receiving increased attention as means of accounting for the He abundances inferred form soft X-ray observations

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