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SPECTRUM SYNTHESIS OF THE HEAVILY BLANKETED WHITE DWARF LP 701-29

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ABSTRACT

Synthetic spectra are constructed for the white dwarf LP 701-29, assuming a hydrogen-rich atmospheric composition. The observed spectrum is consistent with a metal abundance, [M/H] ~ -3.0. The possibility of a helium-rich atmosphere is also discussed.

Subject headings: stars: abundances — stars: atmospheres — stars: individual — stars: white dwarfs

I. INTRODUCTION AND OBSERVATIONS

The spectrum-synthesis technique has made abundance determinations possible in spectral regions which are too crowded for individual line measurements. This synthesis method has been applied to cool stars with a wide range of luminosities. Generally, cool degenerate spectra can be analyzed by constructing individual line profiles (e.g., van Maanen 2; Wegner 1972). Recently, however, two white dwarfs, G165−7 (Hintzen and Tapia 1975; Greenstein 1976*a*,*b*) and LP 701-29 (Dahn *et al.* 1977), have been discovered which show strong line blanketing in the blue spectral regions. This strong absorption, which can be identified with low-excitation potential metal lines, provides an opportunity to extend the spectrum-synthesis analysis to white-dwarf spectra.

The former star, G165−7, has been interpreted as a cool He-rich degenerate star (Hintzen and Tapia 1975) from the absence of hydrogen lines at its effective temperature, T_e, of 7000 K (Greenstein 1976*a*,*b*). However, for cool, $T_e < 5000$ K, H-rich white dwarfs, both Shipman (1977) and Wickramasinghe, Bessell and Cottrell (1977, hereafter WBC) have shown that the hydrogen lines would not be detectable on observational material obtained with current instrumentation. Thus, H- and He-rich white dwarfs in this temperature regime would not be distinguishable by this criterion. Two estimates of the effective temperature of LP 701-29 were made by Dahn *et al.* (1977). They obtained a $T_e \sim 4200$ K by fitting a blackbody curve to their scanner observations, in particular in the region 5500 Å to 7500 Å. However, their energy distribution indicated a $T_e < 4000$ K when compared with the continuum fluxes of Shipman's (1977) zero metal, H-rich model atmosphere with $T_e = 4000$ K and $\log g = 8.0$. For our abundance analysis we assume an H-rich atmospheric composition and adopt a $T_e = 4000$ K for LP 701-29. We discuss the H-rich assumption and this temperature estimate further in § III. The effects of a He-rich atmosphere are also considered in this section.

Using $\log g = 8$, appropriate for H-rich white-dwarf atmospheres (see Wehrse 1975) and a $T_e = 4000$ K, we constructed model atmospheres with varying metal abundance, as described by WBC. Finally, using a spectrum-synthesis technique (§ II), we estimate the metal abundance, [M/H], for LP 701-29 by comparison of this spectrum with the observational data of Dahn *et al.* (1977, their Fig. 3).

II. SPECTRUM-SYNTHESIS TECHNIQUE

Atomic lines used to construct the representative synthetic spectrum were limited to those lines whose equivalent widths were greater than 150 mÅ in the solar atlas (Moore, Minnaert, and Houtgast 1966). Clearly this procedure for determining the violet blanketing spectrum relies on the extensive broadening of the strong lines, e.g., Ca II and Ca I, produced by the extremely high gas pressures ($\log P_g \sim 8$–9) in these model stellar atmospheres, but neglects the contribution of the many weaker lines, both atomic and molecular (e.g., CN). Hence the blanketing effects are, in general, underestimated. The broadening of the lines at these gas pressures is predominantly by van der Waals interactions. The present analysis uses the theory of these encounters as developed by Unsold (1955).

A final line list included approximately 220 lines of Mg, Si, Ca, Ti, Cr, Mn, Fe, and Ni, in the wavelength interval from 3400 Å to 5400 Å, the limits of the high-resolution blue spectrum shown by Dahn *et al.* (1977). The *gf*-values for this list were taken from the extensive tabulations of Kurucz and Peytremann (1975).

We then calculated the line opacity, and hence emergent flux, by employing a technique similar to that described by Cottrell and Norris (1978), using a modified version of the ATLAS model-atmosphere program (Kurucz 1970). Two significant changes were made.

First, the wavelength-sampling interval was increased from 0.05 Å to 10 Å. Second, in computing the emergent flux at any wavelength point, we included all lines within ±500 Å. Both these changes resulted from the extremely broad line profiles produced by the high gas pressures existing in the atmospheres of stars with these temperatures and gravities. For example, the wings of the Ca I line at λ4226 sometimes extend several hundred angstroms from the central wavelength.

III. RESULTS AND DISCUSSION

Figure 1*a* shows two synthetic spectra, constructed from model atmospheres with $T_e = 4000$ K, log $g = 8$, and [M/H] $= -2, -3$. The major features, Ca I, Ca II, and Mg I, are indicated; the remaining structure is principally due to Fe I. In Figure 1*b* we have superposed the observation from Dahn *et al.* (1977) upon the synthetic spectrum with [M/H] $= -3$, which is our estimate of the metal abundance in LP 701-29.

There are three important discriminants for inferring this abundance from the synthetic spectra. They are (1) the long-wavelength wing of the Ca I line at 4226 Å; (2) the plateau between 4400 and 4500 Å; and (3) the region around the Mg I *b* lines at λ ∼ 5180 Å.

The poor fit in the region λλ4000 to 4150 is probably due to our neglect of the weaker lines and has been mentioned in § II. In addition, the cores of the strong lines are stronger than observed. These cores are formed at low optical depths where the structure of these model atmospheres is not well determined owing to our neglect of metal-line blanketing. As well as these anomalies, two additional uncertainties must be mentioned: (1) the pressure broadening theory (Unsold 1955) used to compute the metal-line profiles is uncertain at the high gas pressure (log $P_g \sim 8$–9) existing in these metal-deficient white dwarfs; and (2) the observational data with which our synthetic spectra were compared have not been instrumentally corrected. In general, however, reasonable agreement was found with the observations.

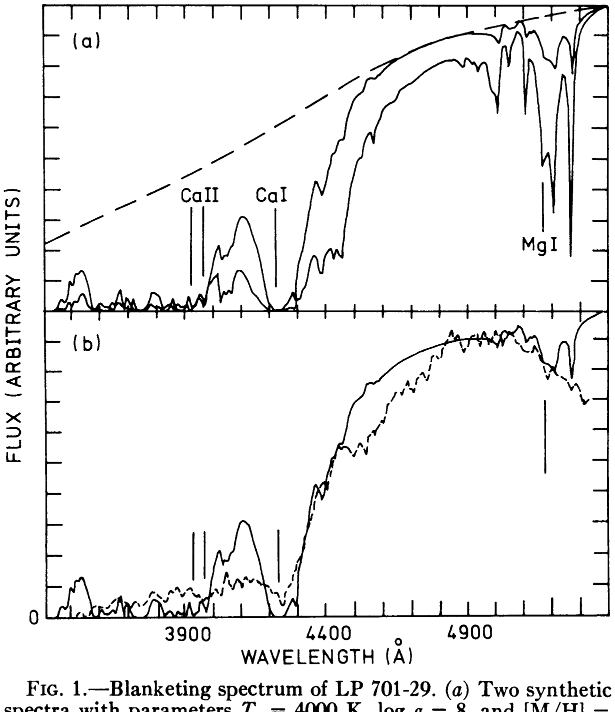

FIG. 1.—Blanketing spectrum of LP 701-29. (*a*) Two synthetic spectra with parameters $T_e = 4000$ K, log $g = 8$, and [M/H] $= -2, -3$ (*upper curve*). These spectra are normalized at 5400 Å. *Dashed line*, position of the continuum for the unblanketed [M/H] $= -3$ model. (*b*) Observation (*dashed line*) with a synthetic spectrum having parameters $T_e = 4000$ K, log $g = 8$, [M/H] $= -3$. The observed and synthetic spectra are fitted in the region λ ∼ 4950 Å. The divergence of the two spectra longward of 5100 Å is an instrumental effect.

Dahn *et al.* (1977) have suggested that LP 701-29 may have a He-rich atmosphere. We have investigated this possibility by computing cool He-rich model atmospheres with gravity, log $g = 8$. The important opacity sources in these atmospheres are He$^-$ and Rayleigh scattering by He. The latter becomes dominant in very metal-deficient ([M/H] ~ -7) atmospheres. If we compare the conditions prevailing at a given optical depth of a He-rich atmosphere with those of an H-rich atmosphere at the same metal abundance, in the former we have: (*a*) a lower opacity per gram, since both He$^-$ and He Rayleigh scattering are weaker sources of opacity in comparison to H$^-$ and H$_2$ dipole opacity; and (*b*) higher gas pressures (log $P_g \sim 10$–11) and hence greater pressure broadening. Both these imply considerably stronger lines in a helium atmosphere, which in turn would indicate a lower metal abundance in order to fit the observations of Dahn *et al.* (1977). Although this lower [M/H] gives weaker lines, the increase in pressure broadening, because of the lower opacity, gives a synthetic spectrum which is significantly different from the observations. In addition, the degree of ionization will increase with this decrease in metal abundance, as the metals are still the major electron contributors. This will not only weaken the blanketing due to Fe I, the principal source of blocking below λ3800, but also Ca I, λ4226, the strongest line observed in the spectrum. Correspondingly, we predict that in a He-rich atmosphere, Ca II H and K will become the strongest lines in the spectrum. Although we can dismiss a He-rich atmosphere for LP 710-29, the gas pressures which we computed for our most metal-deficient ([M/H] $= -6$) He model implied an atomic spacing of ∼2 Å. Thus the theory invoked in this latter computation may be suspect.

Finally, let us comment about the effective temperature of LP 701-29. Our adopted value of $T_e = 4000$ K may be in error by ±200 K, when one compares the observed fluxes (Dahn *et al.* 1977) with the energy distributions of our model atmospheres. However, this has no effect on our two major conclusions, (*a*) that LP 701-29 is an H-rich white dwarf which has (*b*) a metal abundance, [M/H] ~ -3.0. Additional infrared fluxes and cool blanketed model atmospheres are required in order that a more precise effective temperature may be derived for LP 701-29.

IV. CONCLUSIONS

In the preceding analysis we have attempted to synthesize the spectrum of LP 701-29, assuming a hydrogen-rich composition. Reasonable agreement with the observations was obtained for a model with $T_e = 4000$ K, $\log g = 8$, $[M/H] = -3.0$. Although there are uncertainties involved in the model computations and we do not obtain a detailed fit to the observations, a helium-rich composition does not seem appropriate for this star. Not only would the lines be significantly broader, but the degree of ionization would be greater. Thus LP 701-29 appears to be a cool counterpart of the DA sequence of white dwarfs.

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