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CHROMOSPHERES AND MASS LOSS IN METAL-DEFICIENT GIANT STARS

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ABSTRACT

Semiempirical atmospheric models indicate that the characteristic emission in the wings of the Hα line observed in Population II giant stars can arise naturally within static chromospheres. Radial expansion gives an asymmetric, blueshifted Hα core accompanied by greater emission in the red line wing than in the blue wing. Wind models with extended atmospheres suggest mass loss rates much smaller than 2×10^{-9} $M_\odot$ yr^{-1}. Thus Hα provides no evidence that steady mass loss can significantly affect the evolution of stars on the red giant branch of globular clusters.

Subject headings: clusters: globular — stars: chromospheres — stars: mass loss

I. INTRODUCTION

Evolutionary calculations for globular cluster stars suggest that mass loss occurs during the red giant phase in order to match (1) the observed morphology of the horizontal branch and (2) the maximum luminosity attained by stars on the ascending giant branch (Renzini 1977; Iben and Renzini 1983). However, the only observational evidence for quasi-steady mass loss in metal-deficient stars is generally taken to be the detection of emission in the wings of the Hα line (Cohen 1976). Emission wings frequently occur on one side (either short or long wavelength) or both sides of a deep absorption core. Cohen (1976) assumed that the emission originated in an optically thin, expanding circumstellar shell, and adopted case B recombination at 10^4 K to derive a minimum mass loss rate of 2×10^{-9} $M_\odot$ yr^{-1}. Mass loss rates of 1–8 $\times 10^{-8}$ $M_\odot$ yr^{-1} have been derived by many authors using this technique (Mallia and Pagel 1978; Peterson 1982; Cacciari and Freeman 1983).

With such an interpretation, it is puzzling that the emission wings exhibit the characteristic signature of downflow (i.e., short-wavelength peak > long-wavelength peak) as often as that of outflow (short-wavelength peak < long-wavelength peak). This is demonstrated, for instance, in the tabulations of Cacciari and Freeman (1983) and illustrations of Cohen (1976). Moreover, the emission wings in globular cluster giants have been found to vary in strength and asymmetry on times as short as a few days (Cacciari and Freeman 1983). These properties suggest that a chromospheric phenomenon could be the origin of the emission. In fact, Reimers (1981) had previously speculated on a chromospheric explanation.

Recent detections of the Mg II ultraviolet emission lines in two metal-deficient field giants show that chromospheres are present in these stars. Surface fluxes of the Mg II emission are comparable to those of Population I stars even though the field giants have lower metal abundances (Dupree, Hartmann, and Smith 1984). Thus, the structure of a metal-deficient atmosphere must differ substantially from that of a Population I star. For the same energy input, metal-deficient chromospheres will have higher equilibrium temperatures than those with normal metal abundances in order for radiative cooling to balance the mechanical energy input. Metal-deficient atmospheres cannot cool as effectively in the region 4000–10,000 K where Ca II and Mg II dominate the radiative cooling curve in a low-gravity atmosphere (Avrett 1981). A hotter chromosphere can easily produce emission wings in Hα as previous calculations have demonstrated (see Baliunas *et al.* 1979).

We argue that emission in the wings of Hα can arise in a static chromosphere, and that this emission is not necessarily indicative of mass loss. In this *Letter*, we construct semiempirical model chromospheres that reproduce the characteristics of the observed Hα profiles and the observed Mg II fluxes in metal-deficient stars. These suggest that the mass loss rates derived in previous studies are at least an order of magnitude too large.

II. MODEL CALCULATIONS

Guided by our calculations for normal abundance stars (Baliunas *et al.* 1979) in which emission wings occurred in Hα for a sufficiently steep temperature gradient, we constructed both static and expanding semiempirical atmospheres for a metal-deficient star. The temperatures and gravities are typical of globular cluster giants showing Hα emission (see Tables 2 and 3 of Cacciari and Freeman 1983). Hα and Mg II line profiles were evaluated with the Pandora code using multilevel atoms and partial frequency redistribution for the Mg II *k* line (Vernazza, Avrett, and Loeser 1981).

a) *Static Models*

Photospheric models for cool, metal-deficient, low-gravity atmospheres were kindly calculated by R. Kurucz. To these we attached chromospheric models in hydrostatic equilibrium. Models were selected that gave approximate agreement with observations of the Hα line profiles and that were consistent with observed Mg II fluxes. The behavior of the Planck function and the source function for the Hα transition (see Fig. 1, models 1 and 2) shows that emission arises predominantly from atmospheric regions at temperatures of 7000–8000

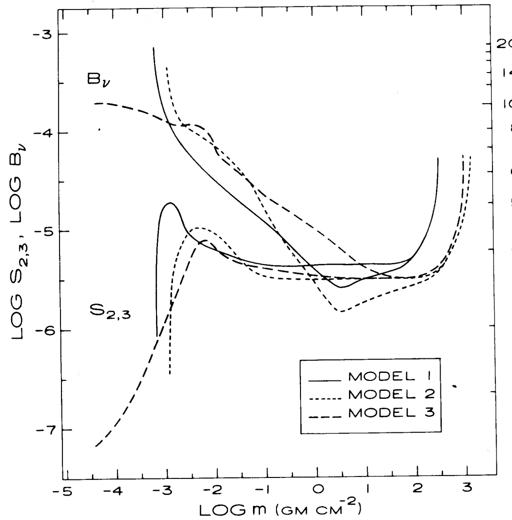

FIG. 1.—The Planck function B_ν and source function $S_{2,3}$ for the Hα transition are shown for three models as a function of the mass column density m (g cm^{-2}). Model 1: $T_{\rm eff}$ = 4200 K, log g = 1, [metals/H] = −1.5; model 2: $T_{\rm eff}$ = 4400 K, log g = 2, [metals/H] = −1.5; model 3: $T_{\rm eff}$ = 4250 K, log g = 0.75, [metals/H] = −1.6. Models 1 and 2 are plane-parallel while the outer layers of model 3 ($T \geq$ 8500K) extend from 1.2 to 3.6 stellar radii (see § IIb).

K. Emission wings are not produced unless there is sufficient material at these temperatures.

Calculated Hα line profiles for two static models are shown in Figure 2 in comparison with two observations of metal-deficient field giants (Dupree, Hartmann, and Smith 1984). The observations have been smoothed and are not corrected for scattered light that can reduce the depth of the central core. These profiles also appear to be typical of globular cluster stars when compared to the measured parameters of Cacciari and Freeman (1983). The agreement between calculations and observations is quite good in all respects: core depth, absorption-line width, separation of emission peaks, and height of emission peaks. The observed long-wavelength emission peak of HD 232078 indicates outflow, but the shift of the central core, if present, was less than the error of measurement of 3 km s^{-1} (Dupree, Hartmann, and Smith 1984). Comparison of the symmetric Hα profile for model 2 with the observation of HD 165195 suggests excess emission is present at the short-wavelength side of the line—this emission would not be apparent from inspection of the profile. It appears difficult to set limits on emission unless the profiles are carefully measured and examined.

b) *Extended Atmosphere Models*

Since Population I giants have extended chromospheres (see, for instance, Stencel *et al.* 1981), with blueshifted absorption in Hα that indicates outflow (Goldberg 1979; Mallik 1982; Zarro and Rodgers 1983), it is plausible that metal-deficient giants have similar structure. The Alfvén wave–driven wind theory of Hartmann and MacGregor (1980) was used to assist in the construction of a semiempirical extended atmosphere. A field strength of 2 gauss and an initial wave flux of 9×10^4 ergs cm^{-2} s^{-1} was assumed, producing a wind with a terminal velocity of 21 km s^{-1}, and a mass loss rate of 2×10^{-9} $M_\odot$ yr^{-1}. The lower chromospheric temperature structure was calculated assuming the dissipation of an acoustic wave energy flux of 1×10^6 ergs cm^{-2} s^{-1} (Hartmann and MacGregor 1980). It was necessary to introduce an *ad hoc* plateau in the outer chromosphere at approximately 8500 K in order to produce wing emission (see model 3 in Fig. 1). The Hα profiles for this model are shown in Figure 3. Several parameters of the observed line are well matched by these calculations—the core depth, the peak separation, the wing shape, and the peak height. The observed line is narrower than the calculations indicate, and a blueshift is not detected at a level less than 1 km s^{-1} with respect to the photosphere. Obviously, a large mass loss rate is not needed to fit the profile. In other observations (Cohen 1976; Mallia and Pagel 1978; Peterson 1981; Ramsey 1979), only about half of the red giants show a blueshift of the Hα core with an average value of −5 km s^{-1}; the maximum measured velocity is −13 km s^{-1} (Mallia and Pagel 1978). The radiative loss in Mg II from model 3 is predicted to be 8×10^5 ergs cm^{-2} s^{-1}—a value several times higher than observed (Dupree, Hartmann, and Smith 1984); however, the discrepancy may not be important, given the simplicity of the model and the uncertainty in metal abundances for the field giants.

The wind model, with an extended region of several stellar radii at 8000–10,000 K, is quite similar to the model proposed by Cohen (1976). However, these calculations disagree with Cohen's simple analysis in several important respects. Hα is optically thick; the emission originates in the nonmoving deep chromospheric layers; and the true wind signature is the blueshift of the overlying absorption and the apparent blueshift of the core. The reason for these differences is that the stellar Balmer continuum radiation is sufficiently intense that Hα is photoelectrically controlled at these densities (cf. Thomas 1957). Under these circumstances, Hα will appear in absorption unless the line is very optically thick.

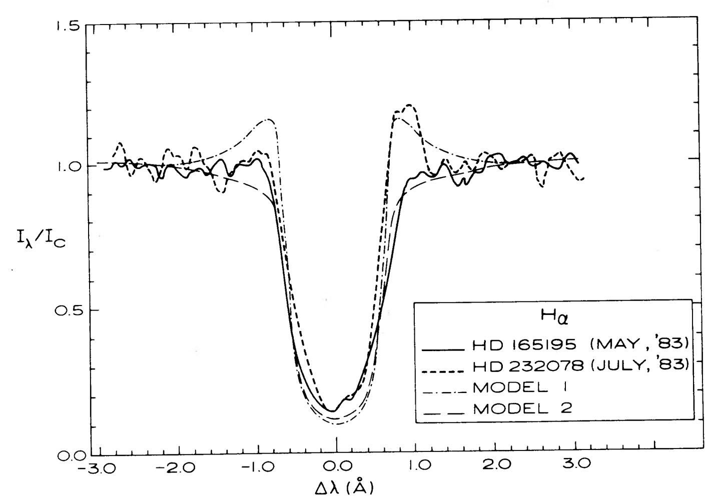

FIG. 2.—Calculated Hα profiles for two static models (models 1 and 2) from Fig. 1. Observed profiles for two metal-deficient giant stars are from Dupree, Hartmann, and Smith (1984).

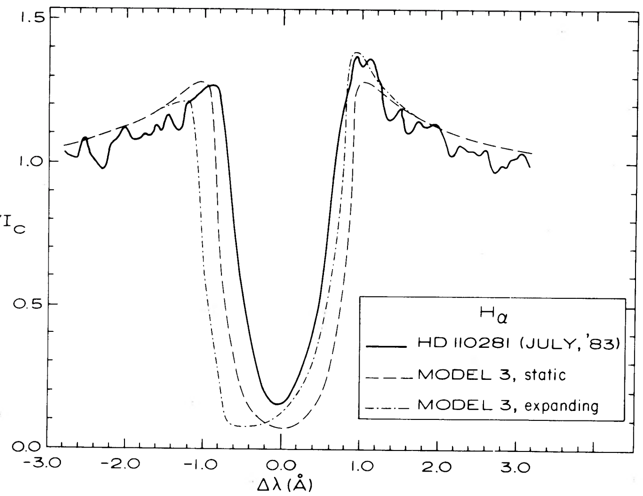

FIG. 3.—Calculated Hα profiles for an extended atmosphere model (model 3 from Fig. 1) in static and expanding versions. The shift of the line core to short wavelengths corresponds to roughly 21 km s^{-1}, the terminal wind velocity. The observed profile of HD 110281, a metal-deficient field giant, is from Dupree, Hartmann, and Smith (1984).

III. DISCUSSION

The existence of emission wings in Hα does not necessarily imply mass loss as previous authors have conjectured, since these emission wings can naturally arise in a warm chromosphere. The intense stellar Balmer continuum radiation probably will cause significant departures from case B recombination unless the emission arises from a distant, expanding shell. It seems more likely that the emission is produced close to the star, since the Hα profiles can change substantially on a short time scale (Ramsey 1979; Cacciari and Freeman 1983; Dupree, Hartmann, and Smith 1984) and the physics of simple models suggest a chromospheric origin. It is possible that the line asymmetries may result from some disturbance causing local mass flows in the atmosphere that are unrelated to a steady state mass loss. While the Hα line profiles exhibit great sensitivity to the temperature structure, the magnitude of emission in the line wing is not directly related to the mass loss rate. A clear, but difficult, test of our models can be provided by observations of the Ca II H and K and Mg II *h* and *k* chromospheric emission fluxes to constrain the radiative losses and models.

A detailed evaluation of a metal-deficient atmosphere heated by acoustic waves shows that the temperature minimum occurs at $\tau_{5000} \approx 0.02$, a substantially larger optical depth than that found in typical Population I giants. Such a deep temperature minimum may have some effect on the formation of photospheric lines and therefore abundance determinations.

We can fit the Hα emission with steady mass loss rates much smaller than $2 \times 10^{-9}\ M_\odot\ yr^{-1}$. This value is a factor of 20–50 less than the relation proposed by Reimers (1975) for Population I stars and 5–40 times less than the mass loss rate inferred from a circumstellar interpretation. This does not rule out a massive cool wind typical of Population I giants (Reimers 1975). Observations of Mg II or Ca II line profiles (cf. Dupree 1980) are needed to detect such winds. Existing observations also do not eliminate the possibility of substantial mass loss by transient events perhaps associated with pulsation. It may be that Hα emission results only at times of short-lived maxima in energy dissipation.

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