A COOL GIANT WITH A CIRCUMSTELLAR CLOUD

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Abstract. The IUE spectrum of the star HD 139521, a giant of class G8III is obtained and based on the analysis of the narrow structure of 2795 (k) and 2803 (h) Mg II emission profiles, the existence of a circumstellar cloud around the giant star is assumed. This conclusion is confirmed also by the anomaly of the small observed power of the doublet Mg II emission at 2800. The absorption cores on the peaks of the emission profiles Mg II k and h are mainly of interstellar origin and only partly – due to self-absorption in the star's chromosphere.

1. Introduction

The narrow structure of the emission profiles of the doublet 2800 Mg II has rarely been used as a sensitive indicator for the discovery of stellar atmospheric peculiarities, particularly for giants and supergiants of mid- and late-classes. The star HD 139521, a giant of G8III type, is the subject of this kind of investigation in the present article based on its IUE spectrum.

The basic data of this star are as follows (Buscombe, 1977; Hirschfeld and Sinnot, 1982):

HD	139521	M_V	$+0\overset{m}{.}3$
(1950)	$15^h39^m45\overset{s}{.}9$	$B-V$	$+0\overset{m}{.}99$
(1950)	$-34°24'42\overset{''}{.}6$	$U-B$	$+0\overset{m}{.}74$
l	$338\overset{\circ}{.}19$	T_{eff}	4930 K
b	$+16\overset{\circ}{.}7$	r	63 pc
Spec. class	G8III	V_r	-23 km s^{-1}
V	$4\overset{m}{.}66$		

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The high dispersion ultraviolet spectrum of this star was obtained on 19 July, 1989, with the *International Ultraviolet Explorer* in the wavelength range 2000–3000 Å, with an exposure time of 20 min.

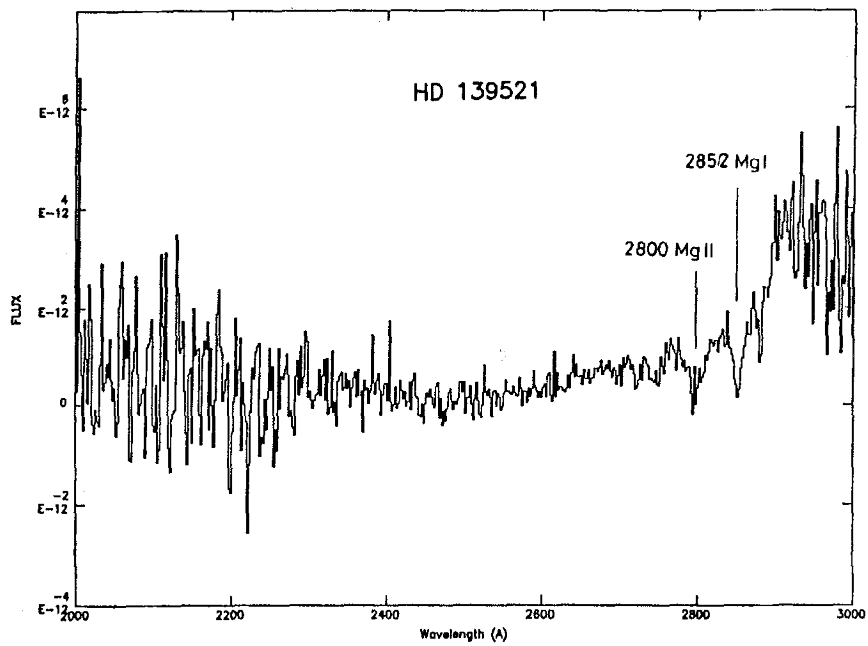

Fig. 1. IUE spectrum of the star HD 139521, a giant of class G8III, in the interval of 2000–3000 Å.

The exposure, however, is weak shortward of λ2500 Å (Figure 1). We shall concentrate on the region which includes mainly the Mg II doublet and Mg I λ2852 resonance line. Figure 2 shows the strong emission profiles 2795 (k) and 2803 (h) Mg II of chromospheric origin and the very deep absorption profiles k and h Mg II of photospheric origin.

2. Parameters of the Photosphere

The equivalent widths of the absorption components of Mg II doublet 2795 (k) and 2803 (h) Mg II are unusually large: $W(k) = 15.6$ Å and $W(h) = 15.0$ Å. The total equivalent width of the doublet W(2800 Mg II) = 30.5 Å is a factor of ~ 1.5 times larger than average for the stars of this class $\overline{W}$(2800 Mg II) = 20 Å (Gurzadyan, 1984). This equivalent width of Mg II is smaller than usually observed for G5 stars, 30 Å, but is within the limits of dispersion for G8 stars. This is not the first example of such a large value for W(2800) in G8 giants; $W(2800) \approx 30$ Å is observed for at least a few giants that are listed in Table I (Cholakyan, 1986).

The equivalent width of resonance line Mg I λ2852 is 25.5 Å – in accord with the known results for the same stars (Table I). For comparison, in Table I, the data for

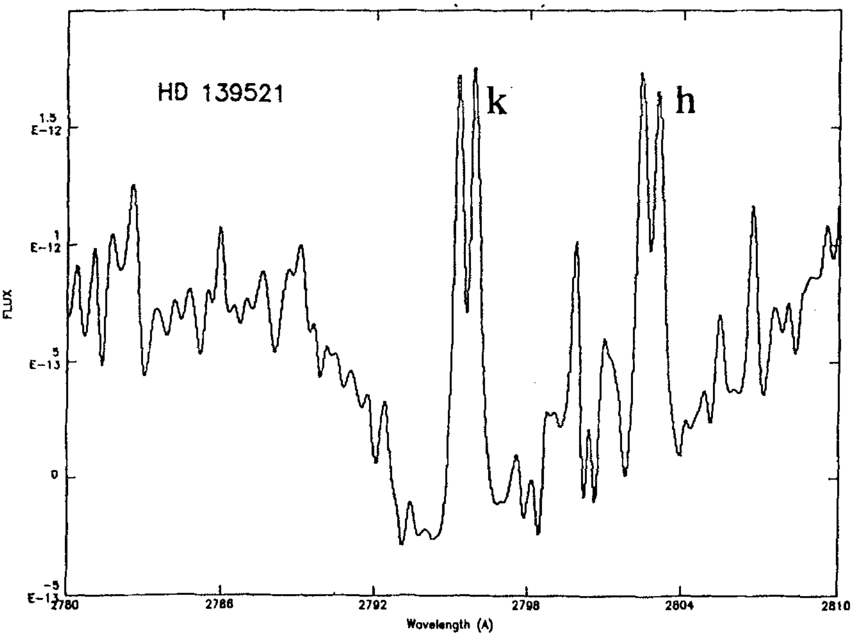

Fig. 2. An enlarged segment of the spectrum of HD 139521 including the region of the 2800 Mg II doublet.

TABLE I

Observed equivalent widths of the absorption doublet 2800 Mg II and the resonance line 2852 Mg I in the spectrum of HD 139521, a giant of class G8III. For comparison, the date for three stars of the same class are also given

Star	Spectral class	W(2800 Mg II) Å	W(2852 Mg I) Å	n_e cm^{-3}
HD 139521	G8III	30.5	25.5	3.0×10^{10}
HD 76294	G8III	32.2	26.2	7.2×10^{10}
HD 72324	G8III	30.0	24.6	4.5×10^{10}
HD 10700	G8V	45.0	27.2	13.0×10^{10}

$W(2800)$ and $W(2852)$ for a normal G8V star, HD 10700, is also given. As we see, both parameters, especially $W(2800)$ is noticeably higher in dwarfs.

The data obtained for $W(2800)$ and $W(2852)$ are used to determine the photospheric electron density n_e using the expression (Gurzadyan, 1984)

$$n_e = 0.74 \times 10^{15} \left[\frac{W(2852)}{W(2800)}\right]^2 T_* \exp\left(-\frac{90\,000}{T_*}\right) \mathrm{cm}^{-3}, \tag{1}$$

where T_* is the ionization temperature which for a G8 giant differs little from T_{eff}. From

Equation (1) we obtain $n_e = 3 \times 10^{10}\ \mathrm{cm}^{-3}$. This agrees with data for giants listed in Table I, and is smaller than for G8V stars (last line in Table I).

3. Chromospheric Emission

The relative emissivity of the chromosphere is one of the most important parameters characterizing the physical condition, radiation field, and radiative losses of stellar chromospheres. This is measured by the dimensionless parameter R_{Mg}, which is the ratio of the emission flux of 2800 Mg II to the bolometric flux F_{bol} of the star:

$$R_{\mathrm{Mg}} = \frac{F(\mathrm{Mg\,II})}{F_{\mathrm{bol}}}\,, \tag{2}$$

where

$$F(\mathrm{Mg\,II}) = 4\pi r^2 [f(k) + f(h)]\,, \tag{3}$$

$$F_{\mathrm{bol}} = 4\pi R_*^2\, \sigma T_*^4\,; \tag{4}$$

in which $f(k)$ and $f(h)$ are the observed fluxes in Mg II h and k emission lines outside the Earth's atmosphere, and r and R_* are the distance and radius of the star, respectively.

From our measurements (Figure 2) we obtain

$$f(k) = 2.29 \times 10^{-12}\ \mathrm{ergs\ cm^{-2}\ s^{-1}}\,, \tag{5}$$

$$\mathrm{f(h)} = 2.00 \times 10^{-12}\ \mathrm{ergs\ cm^{-2}\ s^{-1}}\,, \tag{6}$$

The star's radius R_* is determined from the bolometric luminosity

$$\log \frac{L(T_{\mathrm{eff}})}{L_\odot} = \log \left(\frac{R_*}{R}\right)^2 \left(\frac{T_*}{T}\right)^4 = 1.9 - 0.4 M_{\mathrm{bol}}\,, \tag{7}$$

where $M_{\mathrm{bol}} = M_V + \mathrm{BC}$. Taking for the bolometric correction $\mathrm{BC} = -0.44$, we obtain $M_{\mathrm{bol}} = -0.14$, so that $R_* = 9.1 \times 10^{11}$ cm. If we take $r = 63$ pc, we obtain

$$F(\mathrm{Mg\,II}) = 2.03 \times 10^{30}\ \mathrm{ergs\ s^{-1}}\,,$$

$$F_{\mathrm{bol}} = 3.4 \times 10^{35}\ \mathrm{ergs\ s^{-1}}\,.$$

From these data we then obtain

$$R_{\mathrm{Mg}} = 0.60 \times 10^{-5}\,.$$

This is noticeably smaller than we usually have for G8 giants (see Table II). With the exception of one star, HD 122563, all remaining cases display chromospheres 3 to 4 times stronger than HD 139521. We shall return to this question in Section 5.

TABLE II

Relative power of 'magnesium' chromosphere for a group of G8III class giants, including the star under considereation HD 139521

Star	Spectral class	R_{Mg}	Reference
HD 139521	G8III	0.60×10^{-5}	Present work
HD 122563	G8III	0.44×10^{-5}	Böhm-Vitense, E.: 1982, *Astrophys. J.* **252**, 628
77 Tau	G8III	2.0×10^{-5}	Hartman, L. *et al.*: 1982, *Astrophys. J.* **252**, 214
η Dra	G8III	2.4×10^{-5}	Linsky, J. L. *et al.*: 1978, *Astrophys. J.* **220**, 619
β Her	G8III	2.8×10^{-5}	Linsky, J. L. *et al.*: 1978, *Astrophys. J.* **220**, 619

4. Structure of Emission Lines: Absorption Cores

The emission profiles of the Mg II h and k lines usually display absorption cores with various depths and degrees of asymmetry. We have this kind of profile in the case of the star HD 139521: the classified form of this profile is most likely to be E3 (Gurzadyan, 1987).

The origin of the absorption in both Mg II emission profiles is due to self-absorption in the chromosphere and/or absorption in the interstellar medium (Vladilo *et al.*, 1987). Chromospheric self-absorption produces a characteristic profile. The short wavelength peak $f(-)$ is higher than the long wavelength one, $f(+)$, and the points k_3 and h_3 are shifted by 0.07 Å to the red (Basri and Linsky, 1979; Stencel and Mullan, 1980).

In our case, however, both peaks are nearly the same height, and the shifts of the points k_3 and h_3 are only 0.04 Å and -0.04 Å. Therefore, the absorption is likely not due primarily to self-absorption.

Let us turn to interstellar absorption. The equivalent widths of the absorption lines of Mg II h and k are $W(k) = 0.15$ Å and $W(h) = 0.14$ Å. With the help of Jenkin's curve of growth (Gurzadyan, 1984) we obtain for the column density of magnesium ions $N(\mathrm{Mg}^+) = 1.5 \times 10^{14}$ cm^{-2} at the value of $b = 3.5$ km s^{-1}. This gives the volume density of hydrogen atoms in the local interstellar medium, assuming solar abundance Mg/H $= 2.5 \times 10^{-5}$ of $n(\mathrm{H}) = 0.03$ cm^{-3} for the distance of 63 pc. This is a factor 2.5 times smaller compared with the standard value of 0.074 cm^{-3} for the interstellar medium within 100 pc of the Sun.

However, the derived value of $n(\mathrm{H})$ must be revised if the interstellar Mg is depleted. If, for example, we take the depletion to be a factor of 10, which is probable, we shall have for the hydrogen density $n(\mathrm{H}) = 0.3$ cm^{-3}. This is four times *larger* than the mean value for the local ISM.

We may conclude that the absorption in the emission peaks of the k and h lines in the case of the star HD 139521 are mainly due to (80%) the absorption (scattering) of these photons in the interstellar medium, on Mg^+ ions, and only a small part (20%) are caused by self-absorption in the chromosphere.

5. Asymmetry of Emission Lines: Circumstellar Cloud

Both Mg II profiles in HD 139521 display asymmetric wings: the red wing is broader than the blue one. The difference is nearly 0.25 Å. Otherwise, the profiles are similar.

We suppose that the asymmetry in the wings of the *k* and *h* lines are produced by scattering of line photons in a *circumstellar cloud* containing Mg^+. However, according to observations, the weakening takes place at the short wavelength wings, hence, this circumstellar cloud must be expanding with respect to the star.

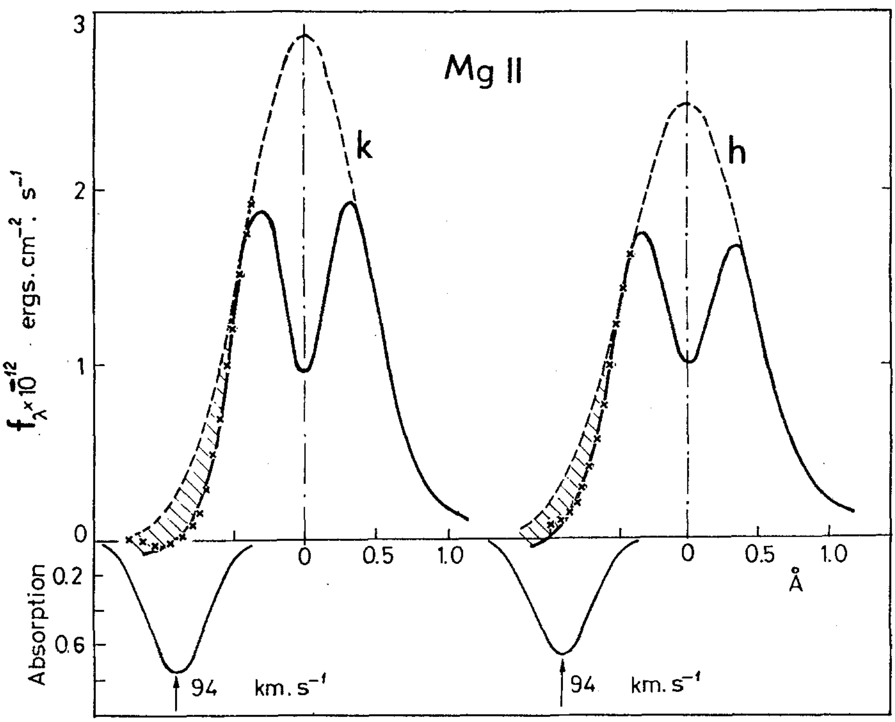

Fig. 3. Three profiles of the emission lines *k* and *h* Mg II in the spectra of HD 139521: observed-asymmetrical, Gaussian-symmetrical, and calculated with the existence of a circumstellar cloud expanding with a velocity of 94.5 km s^{-1}. *Below*, Gaussian absorption profiles are drawn.

The procedure for determining the cloud parameters is illustrated in Figure 3. Here three profiles are drawn for both lines *k* and *h*: symmetric Gaussian, observed, and calculated as a result of asymmetric absorption in a circumstellar cloud. The absorption profile shifted to shorter wavelength by 0.88 Å is drawn below each profile which corresponds to an expansion velocity of 94.5 km s^{-1}. We have the best agreement between both wings, observed and calculated, at 30% transparency in the center of the Gaussian absorption profile, that is when the optical depth of the circumstellar cloud is equal to $t_0 = 1.20$ in the frequencies of the Mg II lines.

We note that the cloud must be ionized by the radiation shorter tan 1620 Å from the central star at $T_{\text{eff}} = 5000$ K. The cloud itself must be within the ionization zone of magnesium. On the other hand, the outer size of this cloud must be smaller than the radius of the magnesium ionization zone r(Mg II). According to calculations (Gurzadyan, 1981), we obtain r(Mg II) = 0.043 pc at $T_{\text{eff}} = 4900$ K and an electron density of $n_e = 0.001$ cm^{-3}. For values of n_e equal to 0.01, 0.1, and 1 cm^{-3} we have for the upper limit of the ratio r(Mg II)/R_* of the cloud's radius to the radius of the star (9.1×10^{11} cm): 4.6×10^4, 1.4×10^4, and 0.5×10^4 indicating $\sim 10^{16}$ cm for the cloud's radius.

The approximate radius of the cloud may also be estimated by using the difference between both profiles (dashed part in Figure 3) which amounts to $W(k) = 0.41$ Å and $W(h) = 0.35$ Å. If we relate this absorption completely to the cloud, then we have for the Mg II column density in the cloud $N(\text{Mg}^+) = 5.6 \times 10^{13}$ cm^{-2} (using $b = 14$ km s^{-1}). This gives $N(\text{H}) = 2.2 \times 10^{18}$ cm^{-2}, which corresponds to a cloud radius of 10^{15} cm and 10^{16} cm for hydrogen densities of 10^3 cm^{-3} and 10^2 cm^{-3}, respectively. This is in accord with the above result for the radius of the cloud. In this case, the cloud mass will be of the order 10^{-5}–$10^{-6}\,M_\odot$.

The high value of the velocity of internal motions (~ 14 km s^{-1}), and the large Doppler width of the line corresponding to a velocity gradient of the order of 25 km s^{-1} are unusual. This problem, and the cloud's expansion velocity of the order of 100 km s^{-1}, must be examined. The asymmetry in the profiles and the proposed interpretation – the necessity of the existence of a circumstellar cloud around this giant – is an unexpected and unusual result. Early attempts to explain the asymmetry in Mg II emission line profiles by the existence of circumstellar clouds were carried out before (Stencel and Mullan, 1980). However, the interpretation of the observations was complicated by the roles of chromospheric self-absorption, stellar winds, etc. (Ayres *et al.*, 1982; McClintock *et al.*, 1978).

In Section 3, the unusually weak Mg II emission was described for HD 139521. If the weakening of magnesium emission is characterized by an effective optical depth of the order of $\tau = 1.5$, then $R_{\text{Mg}} = 2.7 \times 10^{-5}$ corrected for the effects of the cloud. This is just the order which we have for 'normal' giants of this class (see Table II).

In connection with this last remark, does the star, for example, HD 122563 for the same class G8III (Table II), also possess a circumstellar cloud? We can have a potential answer to this question by measuring the IUE spectra of the profiles for the Mg II lines of this and similar stars.

Thus, the model of the existence of a circumstellar cloud around the giant star HD 139521 explains two results: the asymmetry in the profiles of the Mg II lines and the low observed power of the Mg II emission.

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