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Preliminary report

Mg II h AND k LINES IN THE IUE SPECTRA OF THE COOL DUSTY SUPERGIANT μ Cep*

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SUMMARY: In this paper we present our results of investigation of the Mg II h and k lines in the IUE archive high resolution spectra of cool dusty supergiant μ Cep. We have obtained the profile parameters of the Mg spectral lines and found the total chromospheric radiative loss. We also showed that existing chromospheric models are not usable for very dusty stars as μ Cep.

1. INTRODUCTION

Spectroscopic investigation of μ Cep (HD206936, BD+58°2316), one of the most luminous stars ($M_v = -8^m, M_{bol} = -10^m$ (Querci 1986,)), were rare and sporadic. Boesgard and Boesgard (1976) analyzed Fe II emission lines around 3200 Å. Bernat (1977) determined abundances of elements in the outer atmosphere of μ Cep, and also, observed (Bernat 1981) multiple circumstellar and interstellar absorption lines in the CO_2 (3-1) line. Rogers et al. (1983) explained the spectrum of μ Cep from ultraviolet to infrared as a 'black-body' emission affected by a dusty envelope (large basalt grains, grains of basaltic glass). Hagen et al. (1983) analyzed Ca II H and K and Sr II (4077 Å) lines and obtained mass loss $7 \times 10^{-7} M_\odot$ /year. They also defined the gas to dust index by $log(\tau(Sr\ II)/\tau(9.7\mu m))$ and found value 1.8. Stencel et al. (1986) concluded that chromospheres exist in stars whose outer atmospheres and circumstellar shells contain high level of dust, but total output flux is reduced by presence of dust. In their analysis, they used the IUE LWR 8300 spectrum of μ Cep. In that spectrum they found chromospheric emission features of Al II at 2670 Å and Mg II at 2800Å.

The resonance doublet of singly ionised Mg, occurring at 2795.5Å(k) and 2802.7Å(h) frequently displays emission cores in stars later than spectral type F. Mg II observations are very important in increasing our knowledge about the chromospheres of cool stars. Also, Mg II h and k lines are better diagnostics of the physical properties in the stellar chromosphere than Ca II K and H lines, because of the larger abundance and higher ionization potential of magnesium. Linsky (1991) pointed out that total flux of the Mg II resonant doublet can be used to obtain total chromospheric radiative loss. Basri and

* Based on the IUE archival research

Linsky (1980) and Stencel et al. (1980) presented the first results of investigation of the Mg II doublet in the IUE spectra of cool stars. High dispersion IUE spectra of μ Cep were taken later (1985-1986), but have not been studied in detail.

2. ARCHIVE SPECTRA AND REDUCTION

In the IUE archive we found only two long wavelength high dispersion spectra of μ Cep. Basic data of these spectra are shown in Table 1.

We dearchived spectra processed with standard IUESIPS and applied absolute calibration according to Cassatella et al. (1988). Before analysis, we binned spectra and filtered them using FFT window filtering. We also applied wavelength correction to these spectra following the procedure described by Carpenter et al. (1988). This correction was $\Delta\lambda$=−0.52 Å in LWP 7264 and $\Delta\lambda$=−0.43 Å in LWP 8306.

We were concerned with 82-nd and 83-rd order of spectra. Portions of the filtered spectra, containing the Mg II doublet from 82-nd (h) and 83-nd (k) order in the IUE LWP 7264 and LWP 8306 images, are shown in Figures 1. and 2. Note that spectra have been shifted down for 1×10^{-13} flux units, because of procedure of background subtraction in IUESIPS.

Table 1. IUE data on long-wavelength high dispersion spectra of μ Cep

Date	Camera	Image number	Aperture	Exposition	Program
December 08, 1985	LWP	7264	Large	4500	CCHJL
May 30, 1986	LWP	8306	Large	23400	MGIKC

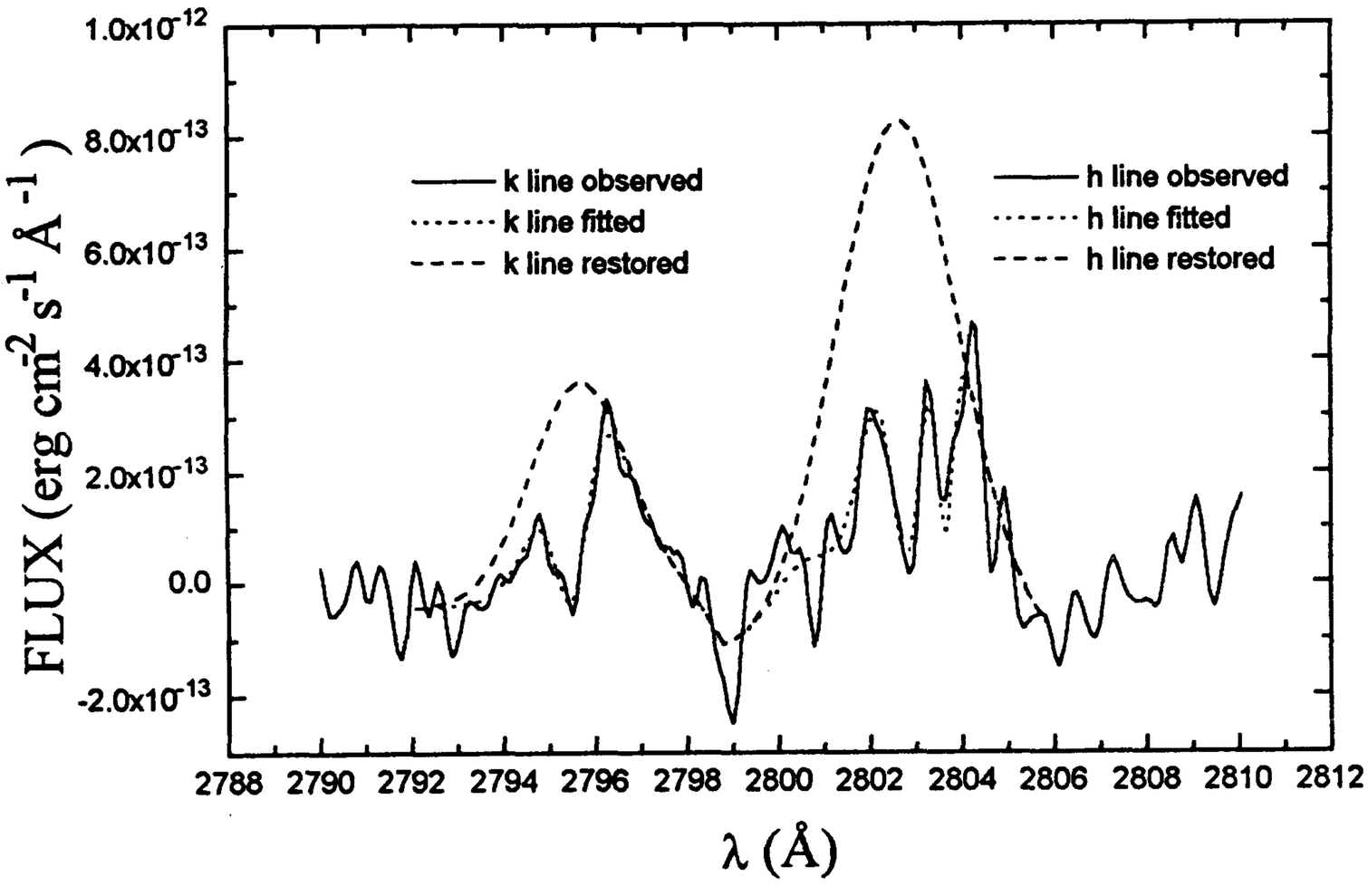

Fig. 1. Mg II k and h line profiles in LWP7264 - solid line, fitted profiles - dotted line and restored profiles - dashed line.

3. THE Mg II h AND k LINES AND CHROMOSPHERIC RADIATIVE LOSS

The Mg II k and h lines are clearly visible in both the LWP 7264 and LWP 8306 spectra. In spectra of μ Cep these lines do not dominate like in UV spectra of other late type giant and supergiant stars (e.g., α Ori, γ Cru).

From Figures. 1. and 2. we can see that the spectral line profiles are extremely complicated. There are many absorption features superposed on emission ones. Emission lines have chromospheric origin, contrary to absorption ones that have circumstellar or interstellar origin. We estimated two main minima in k line, and three main minima in h line. We have chosen the product of three and four gaussian functions, respectively, to fit these profiles and to obtain their parameters:

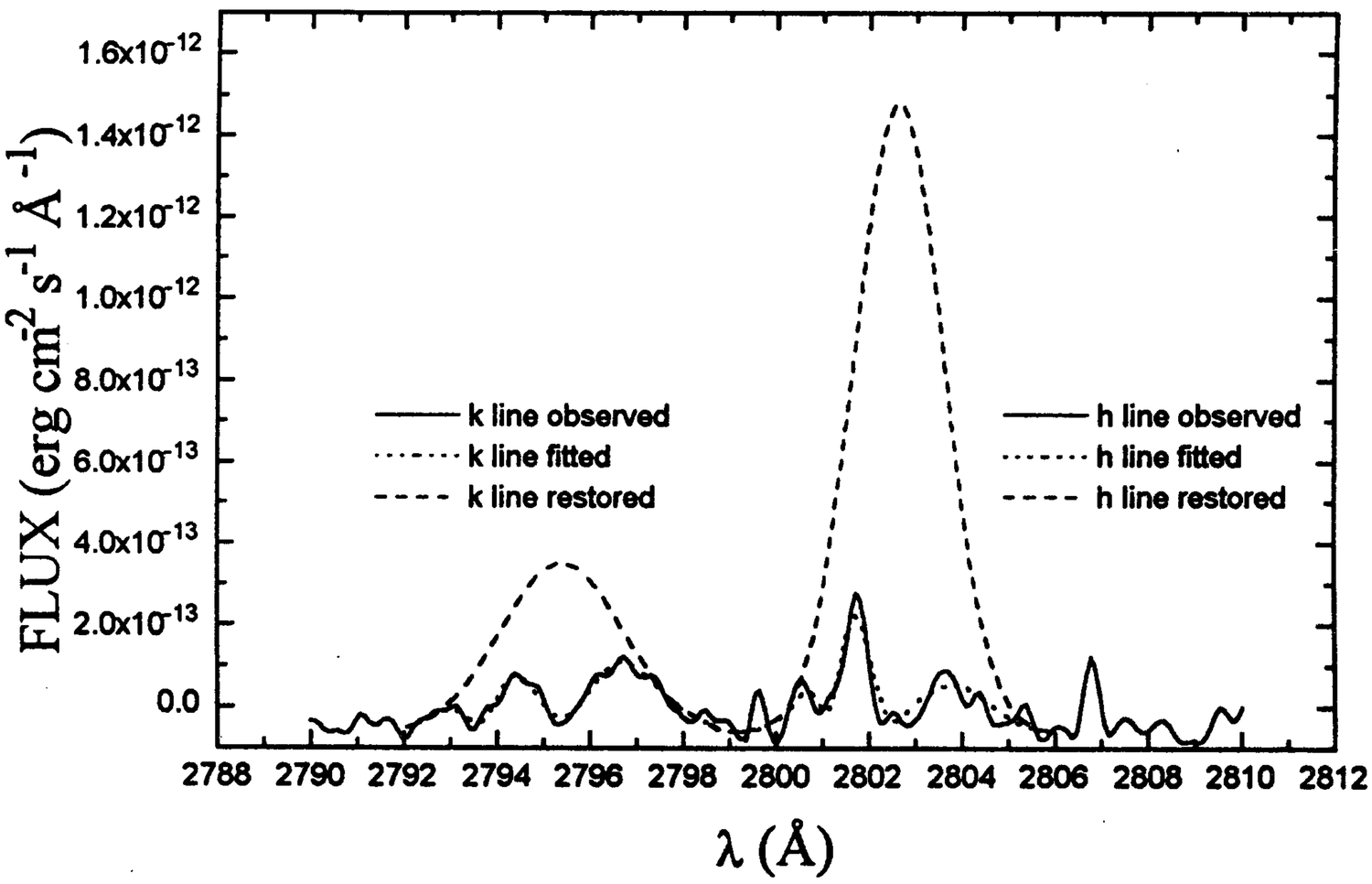

Fig. 2. Mg II k and h line profiles in LWP8306 - solid line, fitted profiles - dotted line and restored profiles - dashed line.

$$Flux = C + a_1 \cdot e^{-4ln2((\lambda-\lambda_1)\cdot w_1)^2} \times \times \prod_{i=2}^{3(4)} (1 - a_i \cdot e^{-4ln2((\lambda-\lambda_i)\cdot w_i)^2}), \quad (1)$$

where C is the continuum level, a_i is the intensity, λ_i is the wavelength and w_i is the inverse full width at half maximum of the gaussian function. We obtain parameters of these lines by fitting fluxes with function (1) using direct search fitting procedure described by Jevremović (1994). Gaussian line profiles are chosen because they are simple and quite applicable for our purposes. The line parameters are given in Table 2.

Table 2. Parameters of Mg k and h lines

Image	Line	C	a_i ($\times 10^{-13}$erg/(cm^{2}sÅ))	λ_i Å	w_i 1/Å
LWP 7264	k_1	-0.446	4.061	2795.722	0.388
	k_2		0.729	2793.207	0.314
	k_3		0.981	2795.448	1.132
LWP 7264	h_1	-1.251	9.513	2802.638	0.317
	h_2		0.678	2803.657	2.184
	h_3		0.795	2802.804	1.058
	h_4		0.658	2801.303	0.523
LWP 8306	k_1	-0.678	4.170	2795.416	0.322
	k_2		0.821	2793.622	1.112
	k_3		0.897	2795.411	0.474
LWP 8306	h_1	-0.631	15.424	2802.665	0.447
	h_2		0.901	2802.540	0.862
	h_3		0.893	2803.239	0.261
	h_4		0.799	2801.121	1.564

The emission line parameters (a_1,λ_1 and w_1) are parameters of the restored chromospheric lines. Using these parameters we calculated the integrated flux in the Mg II h and k chromospheric lines. We also rescaled those fluxes to stellar surface using the following equation:

$$F(\Delta\lambda) = f(\Delta\lambda)\left(\frac{d}{R}\right)^2 = f(\Delta\lambda)(4.125 \times 10^8/\phi')^2, \quad (2)$$

where $F(\Delta\lambda)$ is the stellar surface flux in a wavelength bandpass $\Delta\lambda$, $f(\Delta\lambda)$ is the flux observed on Earth in the same bandpass, d is the stellar distance, R is the stellar radius, and ϕ' is the stellar angular diameter expressed in milliarcsec (marcs). We used Barnes-Evans relation for ϕ' in case $1.36 \leq V - R \leq 4.2$:

$$\log \phi' = 0.7674 - 0.2V_0 + 0.640(V - R), \quad (3)$$

where V_0 is the apparent visual magnitude corrected for interstellar absorption. We used for μ Cep the following values: $V_0 = 4^m.08$ and $V - R = 2^m.10$, which leads to $\phi' = 19.74$ *marcs*.

Radiative loss in the Mg II h and k lines normalized to the total surface luminosity of the star is defined by:

$$R_{hk} = \frac{F(h) + F(k)}{\sigma T_{eff}^4}. \quad (4)$$

Finally, using T_{eff} = 3500 K, we obtained R_{hk}(LWP7264) = 2.221×10^{-7} and R_{hk}(LWP8306) = 2.478×10^{-7}. These values are about an order of magnitude less than values for α Ori (R_{hk} = 23.7×10^{-7}, Stencel et al. 1986), the star with the same spectral type.

Linsky (1991) concluded from different chromospheric models that the radiative loss in Mg II h and k lines is about 10% of the total chromospheric radiative loss (R_{tot}). We obtained value R_{tot} = 2×10^4 erg/(cm^{2}s). Models predict values from 4.5×10^5 to 2.2×10^6 erg/(cm^{2}s). It means that chromosphere exist in μ Cep, but its output flux is very reduced by presence of circumstellar dust. Also, these results show that we cannot use existing models of chromospheres of the late type supergiants for very dusty star as μ Cep, because they do not include effects of dust.

4. CONCLUSION

We have used IUE archive spectra of dusty red supergiant μ Cep to investigate the Mg II resonant doublet spectral lines near 2800 Å. We found parameters of three gaussians fit for k line and four gaussians fit for h line. Also, we used restored emission lines for obtaining chromospheric radiative loss and concluded that it is about an order of magnitude less than in similar star α Ori. Finally we show that the existing chromospheric models are unusable for very dusty stars like μ Cep.

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REFERENCES

Basri, G. S. and Linsky, J. L.: 1979, *Astrophys. J.*, **234**, 1023.
Bernat, A. P.: 1977, *Astrophys. J.*, **213**, 756.
Bernat, A. P.: 1981, *Astrophys. J.*, **246**, 184.
Boesgard, A. M. and Boesgard H.: 1976, *Astrophys. J.*, **205**, 448.
Cassatella, A., Ponz, D. P., Selvelli, P. L. and Vogel, M.: 1988, *ESA IUE Newsletter*, **31**, 7.
Carpenter K. G., Pesce, J. E., Stencel, R. A., Brown, A., Johansson, S., Wing, R. F.: 1988, *Astrophys. J. Suppl.*, **68**, 345.
Hagen, W., Stencel, R. E. and Dickinson, D. F.: 1983, *Astrophys. J.*, **274**, 286.
Jevremović, D.: 1994, *M.Sc. Thesis*, Belgrade University, in Serbian (unpublished).
Linsky, J. L.: 1991, in *Mechanism of chromospheric and coronal heating* (eds. P. Ulmschneider, E.R. Priest and R.Rosner), Springer-Verlag, p.166.
Querci, F.R.: 1986, *NASA SP-492*, p. 1.
Rogers, C., Martin, D. G., Crabtree, D. R., 1983, *Astrophys. J.*, **272**, 175.
Stencel, R. E., Carpenter, K. G. and Hagen, W.: 1986, *Astrophys. J.*, **308**, 859.
Stencel, R. E., Mullan, D. J., Linsky, J. L., Basri, G. S. and Worden, S. P.: 1980, *Astrophys. J. Suppl.*, **44**, 383.

Mg II h И k ЛИНИЈЕ У IUE СПЕКТРИМА ХЛАДНОГ СУПЕРЏИНА μ Сер

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Претходно саопштење

Анализиране су Mg II h и k линије у IUE архивским спектрима хладног суперџина μ Сер. Одредили смо параметре ових линија и помоћу њих проценили укупне губитке зрачењем у хромосфери ове звезде. Такође смо показали да су постојећи модели хромосфера неприменљиви код звезда попут μ Сер.