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The near-infrared variation of the magnetic star HD 125248*

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Abstract. The magnetic chemically peculiar star HD 125248 has been found to be variable in the near infrared at 1.25, 1.6 and 2.2 μ. The infrared variation occurs within the same period as the visible light, spectrum and magnetic field variations. The infrared light curves are all in phase with each other and their amplitude, although smaller than in the visible, is nearly the same in all three filters.

Using our *uvby* observations and those available in the literature we have also found the best value of the period to be: P = 9.29571 ($\pm$0.00018) d.

From the analysis of the phase relations among the near infrared light curves, the visible ones and the magnetic field variation of HD 125248, we have found that the magnetic field extrema do coincide in time with infrared light extrema. This result is hence discussed in terms of the possible influence of the magnetic pressure term on the hydrostatic equilibrium of the upper atmosphere.

Key words: stars: chemically peculiar – stars: individual: HD 125248 – stars variables: other – infrared: stars

1. Introduction

In recent years there has been a growing interest in the infrared properties of chemically peculiar stars of the upper main sequence (CP stars, according to Preston's (1974) nomenclature). Such an interest derives from the belief that CP stars and their complex atmospheres look much simpler in the infrared. It is in fact generally accepted that, at the longer wavelengths, the radiation field is normal, due to the absence of any significant ultraviolet flux redistribution and line blocking. Indeed it has been shown by Kroll et al. (1987) that for CP stars infrared fluxes and colors in the range 1 to 5μ are not different from those of normal main sequence stars when compared to a black body. Moreover Leone & Catalano (1991) have shown that the solar composition Kurucz model atmospheres, which are used to fit the CP stars spectra from λ5500 to λ16500 Å, give a fair representation of the overall flux distribution, with the exception of the Balmer region, where CP stars appear generally brighter than normal, this excess being just a few percent of the total flux.

In spite of this normality of the infrared behavior, peculiar abundances and/or magnetic fields seem to affect the near infrared. In fact, Catalano et al. (1991, hereafter CKL) have shown that, out of the eight CP stars monitored throughout their rotational periods, at least six are variable in the near infrared, although the amplitudes shown are smaller than in the visible. Within the accuracy of the adopted ephemeris, these authors also found evidence that the extrema of the infrared light curves tend to coincide in phase with those of the magnetic field variation.

HD 125248 (= HR 5355 = 236G. Vir = CS Vir, A1 EuCr) is one of the few stars whose light, spectrum, and magnetic field variations are well known, it is thus possible to try to correlate them with the near infrared variability.

HD 125248 is an outstanding magnetic, spectroscopic and light variable and is the first star for which an oblique rotator model has been put forward in order to describe the observed variations (Stibbs 1950). HD 125248 is also the first star for which Deutsch (1958) carried out a spherical harmonics analysis aimed at synthesizing a surface map of the abundance anomalies and of the magnetic field, based on his own spectroscopic observations (Deutsch 1947) and the magnetic field measurements of Babcock (1951). A lot of observational work has been devoted to HD 125248 (see Catalano & Renson 1984 for references).

Here, we present photometric observations of the star HD 125248 in the infrared to investigate the above mentioned phase relation between the infrared and the magnetic field variations. We also report photometric observations in *uvby* carried out in order to check the value of the period and allow a high accuracy in the phase relations.

2. The observations

Infrared observations of HD 125248 were carried out in April 1989 and March 1991 in the near infrared bands J, H, and K at the 1m photometric telescope at ESO, La Silla, Chile, using an InSb detector cooled with liquid nitrogen. A detailed description of the ESO infrared photometers can be found in Bouchet (1989). The integration times, the number of cycles and the desired r.m.s. accuracy in the mean level were optimized to get a 2% maximum error in the observations: the resulting accuracy in the final reduced data is typically 0.006 mag. ESO standard software was used for all reduction steps.

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Magnitudes of HD 125248 in the standard IR system, established by means of standard stars from the ESO list, are: J=5.902 (σ=0.016), H=5.922 (σ=0.009), K=5.917 (σ=0.009).

The *uvby* photometry was carried out during March 1991 run at the 50 cm danish telescope in La Silla to check the period and allow a high accuracy in the phase relations.

HD 124683 (= HR 5332, A1V, V= 5.43) was observed as a comparison star both in the infrared and in the visible. The infrared magnitude differences between HD 125248 and HD 124683 are listed in Table 1, the *uvby* ones are listed in Table 2.

Table 1. Differential observations HD 125248 - HD 124683 in the infrared

$JD - 2440000$	ΔJ	ΔH	ΔK
7636.694	0.323	0.315	0.315
7637.703	0.309	0.303	0.300
7638.662	0.331	0.315	0.319
7639.693	0.327	0.321	0.326
7640.725	0.320	0.318	0.324
7641.724	0.310	0.311	0.315
7642.721	0.319	0.316	0.313
8339.799	0.322	0.318	0.317
8341.760	0.336	0.336	0.332
8342.751	0.327	0.328	0.328
8343.744	0.320	0.316	0.318
8344.718	0.300	0.299	0.303
8345.761	0.325	0.310	0.316
8347.743	0.319	0.320	0.329

Table 2. *uvby* magnitude differences HD 125248 - HD 124683

$JD - 2440000$	Δu	Δv	Δb	Δy
8339.738	0.265	0.319	0.289	0.345
8339.785	0.271	0.324	0.289	0.350
8340.723	0.301	0.338	0.300	0.351
8340.723	0.301	0.338	0.301	0.350
8341.688	0.340	0.366	0.312	0.346
8342.766	0.357	0.423	0.313	0.321
8343.754	0.340	0.444	0.309	0.307
8344.762	0.334	0.431	0.310	0.315
8345.766	0.343	0.383	0.314	0.337
8346.832	0.296	0.339	0.301	0.350
8347.730	0.378	0.349	0.348	0.452

To better define the period of the visible light variations we have combined our *uvby* observations with the data sets of Wolff & Wolff (1971), Maitzen & Moffat (1972) and Pyper & Adelman (1985). By means of Renson's (1978, 1980) algorithm we find $P = 9.29571 \pm 0.00018$ d. The error of the period value has been computed by means of the relation derived by Kovacs (1981) and discussed in Horne & Baliunas (1986). Exactly the same period comes out by performing a least square fit of the data with a function of the type:

$$\Delta m = A_0 + A_1 * sin2\pi[(t - t_0)/P + \phi_1] + A_2 * sin2\pi[2(t - t_0)/P) + \phi_2] \qquad (1)$$

where Δm is the magnitude difference in each filter between the CP star and the comparison star, t is the JD date, t_0 is the assumed initial epoch, and P is the period in days.

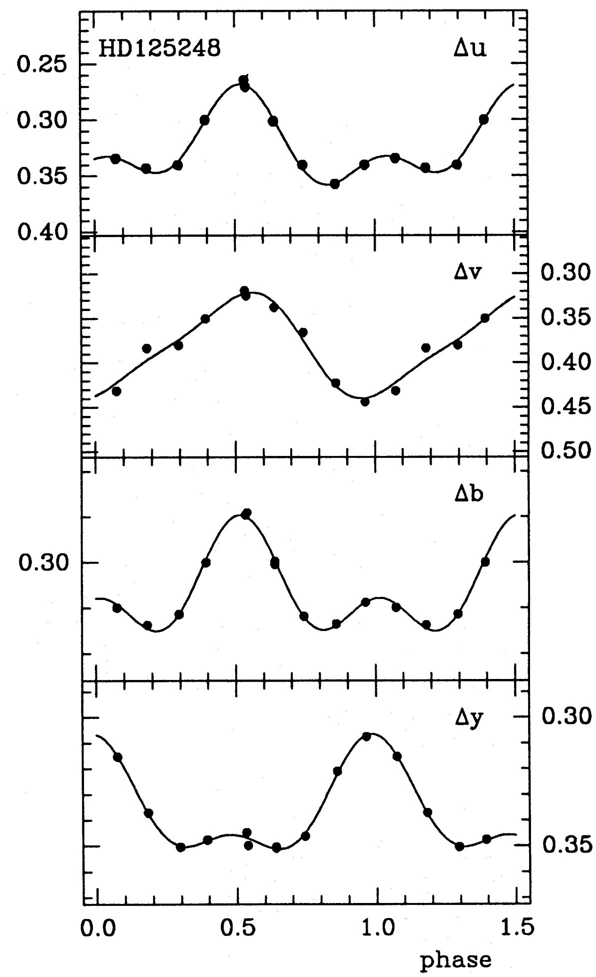

Fig. 1. Visible light curves of HD 125248. The phases are computed according to the ephemeris elements (2)

Our *uvby* observations are plotted in Fig. 1 versus the phase computed by means of the ephemeris elements:

$$JD(H_{eff} maximum) = 2430143.07 + 9.29571E \qquad (2)$$

The visible light variations of HD 125248 are rather complex: in the Strömgren system the u, v and b light curves are in phase with each other, the maximum of light occurring at the phase of EuII minimum and CrII maximum (Wolff & Wolff 1971). The y light curve behaves in antiphase with respect to the others. An incipient double wave characteristic is present in the u, b and y. The peak-to-peak light amplitude is maximum in v (0.13 mag.) and minimum in b (0.04 mag.).

The infrared light variations of HD 125248 are plotted in Fig. 2 versus the phase computed by means of the ephemeris (2): the continuous line represents the fit to the data obtained by

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Table 3. Fit coefficients of infrared and visible light variations and relative errors. m_o and m_e represent the observed and estimated magnitudes respectively, n is the number of measurements.

Filter	$A_0 \pm \sigma$	$A_1 \pm \sigma$	$\phi_1 \pm \sigma$	$A_2 \pm \sigma$	$\phi_2 \pm \sigma$	$\sqrt{\sum(m_o - m_e)^2/n}$
u	$+0.324 \pm 0.0009$	$+0.033 \pm 0.0013$	$+0.25 \pm 0.01$	$+0.023 \pm 0.0013$	-0.31 ± 0.01	0.0028
v	$+0.381 \pm 0.0009$	$+0.055 \pm 0.0013$	$+0.24 \pm 0.01$	$+0.012 \pm 0.0013$	-0.56 ± 0.02	0.0090
b	$+0.306 \pm 0.0009$	$+0.009 \pm 0.0013$	$+0.23 \pm 0.01$	$+0.007 \pm 0.0014$	-0.28 ± 0.03	0.0008
y	$+0.336 \pm 0.0009$	-0.020 ± 0.0013	$+0.26 \pm 0.01$	$+0.010 \pm 0.0014$	-0.22 ± 0.02	0.0012
J	$+0.323 \pm 0.0015$	-0.006 ± 0.0018	-0.10 ± 0.04	$+0.010 \pm 0.0016$	$+0.69 \pm 0.02$	0.0089
H	$+0.319 \pm 0.0011$	-0.009 ± 0.0017	$+0.03 \pm 0.03$	-0.009 ± 0.0015	$+0.13 \pm 0.03$	0.0059
K	$+0.320 \pm 0.0011$	-0.004 ± 0.0016	$+0.11 \pm 0.05$	-0.010 ± 0.0014	$+0.10 \pm 0.03$	0.0046

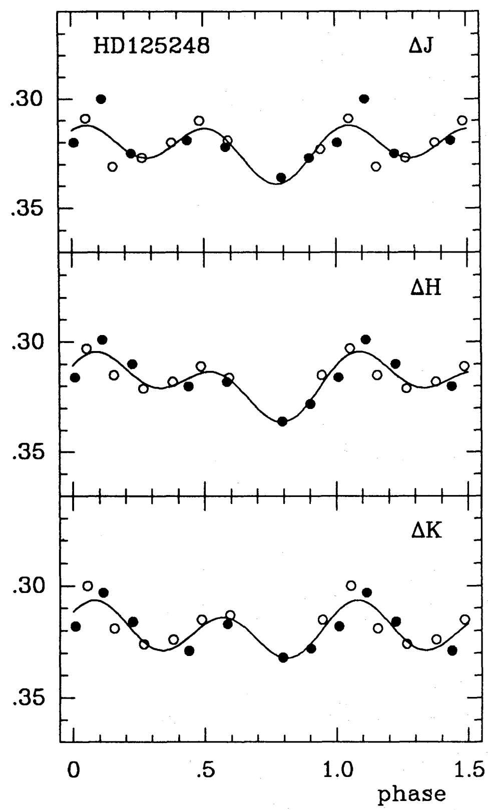

Fig. 2. Infrared lightcurves of HD 125248. The phases are computed according to the ephemeris elements (2). Empty circles represent the 1989 observations, solid circles the 1991 ones. The solid line is a least-square fit of the observations by formula (1) as described in the text

means of relation (1). Table 3 reports the fit coefficients with the relative errors.

The infrared variations do show an amplitude of the order of 0.03 mag. peak-to-peak and look almost unchanged in all filters. All three light curves are in phase with each other, presenting a more pronounced double wave behavior than the visible light curves.

Magnetic field observations with the photoelectric technique (Borra & Landstreet 1980) are well represented by a sinusoidal curve. The field has quite a large amplitude and varies from +2800 to −2500 gauss, the positive extremum coinciding in phase with the EuII maximum, CrII minimum and u light minimum. Magnetic field measurements have been recently performed by Mathys (1991) from CCD spectra simultaneously recorded in both circular polarizations using the Zeeman analyzer of the ESO Cassegrain Echelle Spectrograph fed by the ESO 3.6 m telescope. It is interesting to observe that the magnetic curve derived from CASPEC observations looks more harmonic than the photographic one by Babcock (1960).

The magnetic field and visible light variations phase relation is well established: the magnetic minimum is at the same phase of the v maximum, hence from our concurrent visible and infrared observations we see that the magnetic field extrema occur at the same phase as the infrared light maxima and the minimum of infrared occurs at the phase of null magnetic field.

3. Discussion

The starting point for a discussion about the origin of the infrared variations found in HD 125248 is the consideration that the J, H, and K light curves do show:

a) the same amplitude and in phase behavior,
b) a double wave with nearly equal amplitude maxima at the same phases as the magnetic field extrema (which also do have almost the same strength),
c) the minima at the phases of null field.

The origin of light variations in the ultraviolet and visible part of the spectrum is still unclear, only qualitative considerations have been made based on the assumption that elements are not homogeneously distributed over the surface. Leckrone et al. (1974) and Leckrone (1976), pointing out that CP stars are flux deficient in the ultraviolet if compared to normal stars having the same Balmer jump, have suggested the presence of a greatly enhanced ultraviolet line opacity source, distributed more or less uniformly over the entire Balmer continuum region, and the redistribution of the absorbed UV flux longward of the null-wavelength region, that is the wavelength region with no observed variation. However, the complex behavior of the visible light curves of HD 125248 is a direct evidence that this mechanism cannot fully explain the observed light variations.

Another possible origin of the light variations is the local line blocking. However, Pilachowski & Bonsack (1975) have examined the influence of local line blocking on the light variations of HD 125248, and concluded that line blocking is certainly important but not sufficient to explain the observed amplitudes.

According to Babcock (1958) and Deutsch (1958), Rare Earths and Fe are mainly concentrated in the positive magnetic

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pole region, while Cr and Sr are concentrated at the negative one. In a previous paper (CKL) we investigated the effects of high metallicity at the near infrared wavelengths and showed that a Kurucz model atmosphere with a metal content ten times the solar one could explain a three percent variation in the near infrared brightness, which is the typically observed value. Thus, for HD 125248 there is the possibility of qualitatively interpreting the observed infrared variations and the coincidence of their maxima with the extrema of the magnetic field as a consequence of the elemental abundance concentration at the magnetic poles which change the atmosphere temperature gradient.

The fact that infrared variations of HD 125248 tend to be in phase with respect to the magnetic field variations lends support to the idea that mechanisms other than blanketing and back-warming, are at work in producing the observed near infrared variations. The way a large-scale organized magnetic field may influence the conditions of a stellar atmosphere can be outlined as follows:

i) modification (or even complete control) of the mechanisms determining the formation of the chemical peculiarities;

ii) modification of the radiation transfer in the lines through the Zeeman effect;

iii) modification of the atmospheric structure of the star due to the contribution of the Lorentz force term in the hydrostatic equilibrium equation.

Item *i*) is important in determining the link between the geometry of the field and the nonhomogeneous distribution of the surface abundances: it could give rise to the abundance concentrations which contribute to the infrared variations (as explained before).

Items *ii*) and *iii*) are more directly related to our problem of interpreting the suggested phase relation between the infrared light variation and the magnetic field extrema. As far as it concerns item *ii*), magnetic line intensification increases with the square of wavelength, thus this effect should be very important in the infrared region. HD 125248 is brighter in the infrared, when the magnetic field is maximum, that is, in the oblique rotator model, when the line of sight is closest to magnetic poles: this fact implies that, at least, for HD 125248, the line intensification due to the poloidal component of the field cannot account for the observed variations. However, since a toroidal component may well be present, to investigate the importance of this effect time resolved spectroscopy in the near infrared should be performed.

The influence of the magnetic field in the atmosphere structure has been quantitatively discussed by some authors in some particular configurations (Trasco 1972, Staude 1972). The most general approach has been carried out by Stepien (1978) who considered an essentially dipolar magnetic field slightly distorted by additional toroidal electric currents and calculated the stellar atmosphere structure taking into account the magnetic pressure term in the hydrostatic equilibrium equation. One of the most important results of Stepien's calculations is the star shape via the τ_{5000} parameter. According to the currents direction in the outermost layers, the star shape can be prolate or oblate with respect to the magnetic axis: the differences between the polar and equatorial values of the radius being up to 3%.

The results obtained by Stepien lend support to a distorted figure of the star up to few percent and to small variations (2-3%) of the effective temperature over the surface, which in some cases, can contribute to the observed light variations.

Several attempts have been made in the past to interprete the light variations of CP stars as a consequence of an oblate or prolate configuration: see, for example, Molnar (1974) for *a* Cen and Böhm-Vitense & Van Dyk (1987) for α^2 CVn. This explanation alone is not sufficient as far as it concerns the visible light variations of HD 125248 because of the different behavior presented by the u, v, b, and y curves. However, since the magnetic pressure importance increases in the outer layers, it cannot be excluded that the non-spherical shape of the star as seen at the infrared wavelengths is the origin of the observed variability.

4. Conclusion

The magnetic chemically peculiar star HD 125248 has been found to vary in the near infrared at 1.25, 1.6, and 2.2 μm. These variations occur within the same period as the visible light, spectrum, and magnetic field. Infrared light curves are all in phase with each other and show the same amplitude although smaller than in the visible.

Using our *uvby* observations and the ones available in the literature we have also slightly improved the period to the value: P = 9.29571 ($\pm$0.00018) d.

The possibility that the magnetic pressure could have non-negligible influence on the hydrostatic equilibrium of the stellar atmosphere has been suggested in the past to explain the light variations of CP stars, although it does not always match the observations. The characteristics of the observed infrared light variations could be considered supporting the magnetic pressure influence on the hydrostatic equilibrium pressure since the infrared radiation comes from the outermost layers where the gas pressure becomes lower. However, because of the overabundances in the magnetic pole regions, the expected modification of the atmospheric temperature gradient produced by the overabundant elements could be the origin of the infrared variations.

To understand if the magnetic pressure is really as much important as considered for the atmospheric structure, stars like HD 112413 which show abundance concentrations at poles and metals at equator (Floquet 1979) or HD 119419 (Fe and Si at the negative pole, Mathys 1991) should be observed.

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