Near infrared light variations of chemically peculiar stars. The SrCrEu stars[*]

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Abstract. Twenty magnetic Chemically Peculiar (CP2) stars of the SrCrEu subgroup mostly brighter than the 7.5 visual magnitude have been investigated in the near infrared at 1.25, 1.6 and 2.2 μ. The stars HD 3980, HD 24712, HD 49976, HD 83368, HD 96616, HD 98088, HD 118022, HD 125248, HD 148898, HD 203006, and HD 220825 have been found to be variable in the infrared with the same period as the visible light, spectrum, and magnetic field variations. HD 221760 is also variable with a period of 12.45 days, which has to be confirmed. The stars HD 72968, HD 111133, HD 126515, HD 153882, and HD 164258 do show some hint of variability, although the data are too few. Infrared variability has been detected for the first time in the stars HD 101065, and HD 206088, which have not yet been considered as variable. No variability has been detected for the star HD 137949 within a time scale of the order of ten days.

Key words: stars: chemically peculiar — stars: variables: other — infrared: stars

1. Introduction

Until recently it was generally believed that the properties that characterize Chemically Peculiar stars (or CP stars, according to Preston's 1974 scheme): peculiar abundances, magnetic fields, and so on, do not influence the longer wavelength part of the spectrum, since the present knowledge indicates the absence of significant flux redistribution and less important line blocking in this region than at shorter wavelengths (Muthsam & Weiss 1978; Hensberge & Van Rensbergen 1986). In fact, starting from the consideration that the spectral peculiarities of the CP stars make

rather unreliable classical indirect methods for determining effective temperatures, Shallis & Blackwell (1979) used infrared fluxes as cornerstones of their method of integrated fluxes (Blackwell & Shallis 1977; Blackwell et al. 1979) which determines simultaneously effective temperature and angular diameters of stars.

Kroll et al. (1987) could finally show that the near infrared fluxes and colors of CP stars, when compared to a black body, are normal, like that of early main sequence stars. IRAS data could even prove that the normality of IR fluxes is guaranteed to at least 25μ (Kroll 1987): only two CP4 stars showed flux excesses longward of 60μ, showing cold circumstellar material, which is not uncommon among early B stars.

Moreover Leone & Catalano (1991) have shown that the solar composition Kurucz model atmospheres, which are used to fit the CP stars spectra from $\lambda5500$ to $\lambda16500$ 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 stars, 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.

In order to test the validity of common idea that the infrared region is not affected by all those phenomena that characterize the ultraviolet and visible parts of CP2 stars spectra, we have started an observational campaign to search for infrared variability, also in order to understand better the origin of the light variability, which is one of the outstanding observational aspects of these stars.

In this paper we report the results concerning twenty CP2 stars of the subgroup showing overabundances of Sr, Cr, and/or Eu.

Table 1. Program stars, comparison stars, and their characteristics. Spectral types for the program stars are taken from the *General Catalogue of CP stars* (Renson et al. 1991), those of comparison stars are from the Bright Star Catalogue (Hoffleit & Jaschek 1982). IR magnitudes are from the present observations

		Program Stars							Comparison Stars				
HD	HR	Sp. type	m_V	$<J>$	$<H>$	$<K>$	HD	HR	Sp. type	m_V	$<J>$	$<H>$	$<K>$
3980	183	A7 SrCrEu	5.71	5.606	5.621	5.598	4150	191	A0 IV	4.36	4.354	4.345	4.317
24712	1217	A9 Sr	5.99	5.454	5.325	5.285	25165	1235	gK5	5.90	3.109	2.340	2.159
49976	2534	A1 SrCrEu	6.29	6.301	6.333	6.321	49481	—	B8	6.7	7.035	7.083	7.093
72968	3398	A2 SrCr	5.72	5.717	5.754	5.752	73997	3285	A8 IV	6.15	6.640	6.666	6.657
83368	3831	A7 SrCrEu	6.17	5.750	5.647	5.614	82578	—	A9 IV/V	6.54	6.060	5.950	5.915
96616	4327	A3 Sr	5.15	5.066	5.060	5.049	95370	4293	A3 IV	4.39	4.155	4.104	4.075
98088	4369	A9 SrCrEu	6.14	5.842	5.806	5.774	96620	4315	F0 Vn	6.09	5.531	5.393	5.347
101065	—	F0 HoDy	8.02	7.166	7.001	6.955	101388	—	A5	7.8	7.396	7.311	7.272
111133	4854	A1 SrCrEu	6.34	6.341	6.376	6.368	109860	4805	A1 V	6.33	6.288	6.301	6.282
118022	5105	A2 CrEuSr	4.94	4.915	4.940	4.926	121607	5244	A8 V	5.91	5.507	5.402	5.359
125248	5355	A1 EuCr	5.87	5.902	5.922	5.917	124683	5332	A1 V	5.43	5.582	5.606	5.599
126515	—	A2 CrSr	7.1	7.132	7.164	7.162	121607	5244	A8 V	5.91	5.515	5.399	5.367
137949	—	F0 SrEuCr	6.7	6.352	6.319	6.293	138268	5756	A8 V	6.22	5.938	5.857	5.824
148898	6153	A7 Sr	4.45	4.261	4.233	4.210	150453	6202	F4 IV	5.57	4.718	4.478	4.425
153882	6326	A1 CrEu	6.31	6.227	6.205	6.178	153809	—	A0	7.0	7.089	6.997	6.954
164258	6709	A3 SrCrEu	6.37	6.069	6.019	5.982	164259	6710	F2 IV	4.62	3.955	3.772	3.725
203006	8151	A2 CrEuSr	4.82	4.744	4.725	4.700	202135	8117	K2 III	6.21	5.885	5.924	5.915
206088	8278	F0 p	3.68	3.202	3.093	3.045	206677	8302	F0 V	5.99	5.565	5.460	5.418
220825	8911	A1 CrSr	4.95	4.957	4.979	4.968	221675	8944	A2m	5.87	4.609	4.065	3.948
221760	8949	A2 SrCrEu	4.70	4.547	4.525	4.498	220401	8896	K0	6.09	3.681	2.932	2.753

2. Observations

We mainly selected bright stars, i.e. not fainter than about 7.5 mag, whose period was known from visible light variability.

The observations have been carried out in the near IR bands J, H, and K at the 1 m photometric telescope at ESO, La Silla, Chile, using an InSb detector cooled with liquid nitrogen. Central wavelengths and bandwidths (in μm) of the used filters are:

J	1.24	0.32
H	1.63	0.28
K	2.19	0.39.

A detailed description of the ESO infrared photometers can be found in Bouchet (1989). The integration times, the number of cycles, and the desired rms 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.

All program stars were measured relative to closeby comparisons, which were chosen to have as similar color and brightness as possible. Magnitudes in the standard IR system (Bouchet et al. 1991) have also been obtained by observing suitable standard stars from the ESO list. The program stars and their comparisons are listed in Table 1.

The data have been collected during several observing runs from July 1986 through January 1993. The list of the observing runs is given in Table 2 together with the symbols used in the figures to identify the observations made in each run.

For many stars we could get phase covering observations which we shall present here in more detail.

Table 2. The list of the runs and the symbols used to represent in the figures the observations collected in different runs

Run N.	Dates	symbol	observer
1	1986 Oct. 13 - 23	□	RK
2	1987 Nov. 1 - 8	▽	FAC
3	1989 Apr. 19 - 26	○	FAC
4	1991 Mar. 23 - 31	●	FAC
5	1991 Oct. 19 - 31	×	FAC
6	1993 Jan. 19 - 31	■	FAC
7	1993 Oct. 1 - 11	*	FAC

3. Light curves of individual stars

The assumed ephemeris elements of the infrared light curves for the programme stars are listed in Table 3; they have mainly been taken from Catalano & Renson (1984, 1988, 1997), Catalano et al. (1991, 1993), and references therein.

For each light curve a least square fit of all the data has been performed with a function of the type:

$$\Delta m = A_0 + A_1 \sin(2\pi(t - t_0)/P + 2\pi\phi_1) \\ + A_2 \sin(4\pi(t - t_0)/P + 2\pi\phi_2). \tag{1}$$

In this relation 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, P is the period in days. This procedure can be partially accounted for by considering that within the accuracy of the measurements a sine wave and its first harmonic appear to be generally adequate to describe the light curves (North 1984; Mathys & Manfroid 1985) and the magnetic field variations (Borra & Landstreet 1980; Bohlender et al. 1993).

In the figures, where the infrared variations are plotted, open squares do represent the data collected in the 1986 run (i.e. the data with an accuracy lower than 0.01 mag), while the other symbols, listed in Table 2, represent the observations of the successive runs, having a better accuracy. In the same figures, the continuous line represents the fit to the observations obtained by means of Eq. (1) and which has to be considered only as indicative, just to evidentiate the observed variations. For most of the stars the individual fit of the differential J, H, and K variations did show very similar behavior although with different amplitudes.

Indeed in the fits performed by means of (1), whose A_1 and A_2 coefficients and σ are given in the last three columns of Table 3, the second harmonic was not retained

for the stars HD 72968 and HD 126515, because of a too small number of observations (HD 72968) and of a very poor phase coverage (HD 126515).

HD 3980 A = HR 183 A = ξ Phe A

An analysis of the photometric and magnetic variability of the late type CP2 star HD 3980 has been carried out by Maitzen et al. (1980) who found the period to be 3.9516 (±0.0003) days. The visible light curves show a double wave with different amplitudes, the maximum amplitude occurring in the v filter, where it amounts to 0.13 mag peak to peak. A well defined double-wave variation with the same period is indeed shown by the peculiarity index Δa (Maitzen & Vogt 1983).
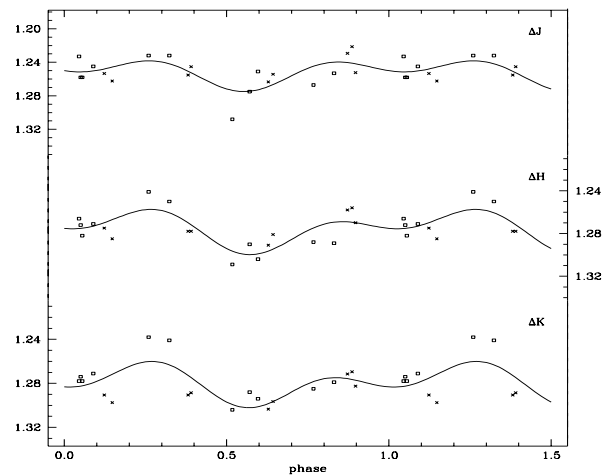

Fig. 1. Differential infrared light curves of HD 3980. The phases are computed according to the ephemeris elements in Table 3. The solid line is a least-square fit of the observations by Eq. (1) as described in the text

The infrared variability of HD 3980 was discovered by CKL. However further infrared observations have been carried out which are here reported. The infrared differential light curves, displayed in Fig. 1, are plotted versus the phase computed by means of Maitzen et al.'s ephemeris elements reported in Table 3. From Fig. 1 a double wave variation is quite evident with the same amplitude (of the order of 0.03 mag peak to peak) in all three filters, although it looks better defined in the H and K filters.

HD 24712 = HR 1217 = DO Eri

The cool magnetic star HD 24712 has had many studies made since the measurements of the magnetic field strength, of the radial velocity and of the line strengths of Mg and Eu carried out by Preston (1972), who found all of these to vary with a period of 12.448 days.

Table 3. Ephemeris elements used to compute the phases of the variations, coefficients of the fits and their errors

HD	JD($\phi = 0$)	Instant of	P(days)	coeff.	J	H	K
3980	2 442 314.48	v min.	3.9516	A_1	-0.0114	-0.0138	-0.0126
				A_2	0.0116	0.0125	0.0135
				σ	0.0130	0.0105	0.0136
24712	2 440 577.23	$< H_z >$ pos. extr.	12.4610	A_1	-0.0031	-0.0027	0.0076
				A_2	-0.0095	0.0059	-0.0077
				σ	0.0093	0.0052	0.0058
49976	2 441 615.10	$uvby$ max	2.97666	A_1	0.0090	0.0107	0.0080
				A_2	0.0088	0.0055	0.0035
				σ	0.0137	0.0089	0.0072
72968	2 432 897.68	H_{eff} max.	11.305	A_1	-0.0073	0.0002	0.0069
				A_2	—	—	—
				σ	0.0047	0.0037	0.0033
83368	2 444 576.169	$< H_z >$ neg. extr.	2.851982	A_1	0.0021	-0.0021	0.0017
				A_2	0.0075	0.0043	-0.0045
				σ	0.0072	0.0069	0.0088
96616	2 444 329.000	$uvby$ max.	2.4394	A_1	0.0122	0.0086	0.0098
				A_2	-0.0056	-0.0064	-0.0079
				σ	0.0040	0.0032	0.0067
98088	2 434 419.130	periastron	5.905130	A_1	-0.0084	0.0054	-0.0100
				A_2	-0.0136	-0.0094	0.0107
				σ	0.0109	0.0095	0.0124
101065	2 447 640.652	—	7.593	A_1	-0.0110	0.0039	0.0033
				A_2	0.0016	-0.0029	-0.0047
				σ	0.0098	0.0089	0.0087
111133	2 448 597.040	$uvby$ max.	16.30720	A_1	0.0035	0.0054	0.0047
				A_2	-0.0091	0.0087	-0.0069
				σ	0.0046	0.0059	0.0050
118022	2 434 816.90	y max.	3.722084	A_1	0.0125	0.0096	-0.0028
				A_2	0.0064	0.0049	-0.0025
				σ	0.0065	0.0094	0.0074
125248	2 430 143.07	u max.	9.295710	A_1	-0.0062	-0.0092	0.0051
				A_2	-0.0110	0.0096	0.0105
				σ	0.0062	0.0041	0.0046
126515	2 437 015.0	H_s max.	129.99	A_1	0.0157	0.0080	-0.0137
				A_2	—	—	—
				σ	0.0103	0.0077	0.0063
148898	2 447 645.0	—	0.7462	A_1	0.0041	0.0025	0.0017
				A_2	0.0068	-0.0026	0.0049
				σ	0.0059	0.0049	0.0056
153882	2 432 752.730	pos. crossover	6.00890	A_1	-0.0109	-0.0101	-0.0109
				A_2	0.0104	0.0140	-0.0155
				σ	0.0038	0.0133	0.0069
164258	2 448 339.77	$uvby$ min.	0.829	A_1	-0.0052	-0.0046	-0.0053
				A_2	-0.0058	-0.0053	-0.0032
				σ	0.0073	0.0048	0.0056
203006	2 440 345.32	$uvby$ I max.	2.1224	A_1	-0.0029	0.0045	-0.0048
				A_2	0.0072	-0.0141	-0.0106
				σ	0.0137	0.0111	0.0095
206088	2 441 615.0	—	2.78	A_1	0.0094	0.0054	0.0022
				A_2	-0.0040	0.0025	-0.0039
				σ	0.0103	0.0099	0.0053
220825	2 446 013.0		1.418	A_1	-0.0061	0.0038	0.0109
				A_2	0.0024	-0.0036	-0.0005
				σ	0.0063	0.0057	0.0082
221760	2 448 300.0	$uvby$ max.	12.45	A_1	0.0098	0.0075	0.0052
				A_2	0.0032	0.0019	-0.0008
				σ	0.0048	0.0065	0.0074

HD 24712 has been extensively studied by Kurtz and coworkers, with the aim of investigating the short period oscillations of the cool magnetic SrCrEu stars which have been successfully interpreted as high-overtone p-modes with the pulsation axis aligned with the magnetic axis of the star which is itself oblique to the rotation axis (the oblique pulsator model: Kurtz 1982; Kurtz & Marang 1987; Kurtz et al. 1992, and references therein).

Magnetic field observations have recently been carried out by Mathys (1991), Bagnulo et al. (1995) and Mathys & Hubrig (1997). The ephemeris elements resulting from these observations are given in Table 3.

The infrared variability of HD 24712 was also discovered by CKL, however some more infrared observations have been carried out which are here reported. The infrared differential light curves are plotted in Fig. 2 versus the phase computed by means of the above cited
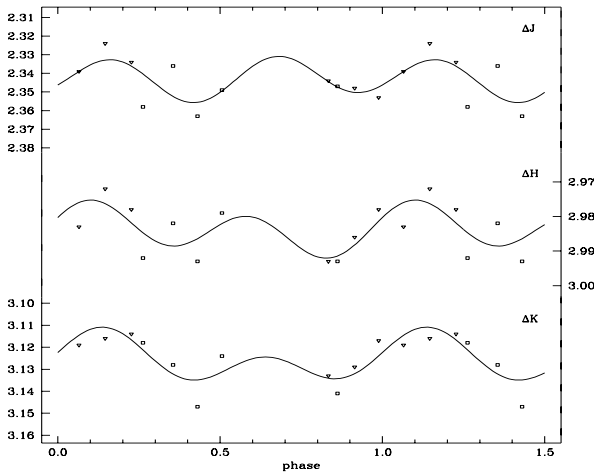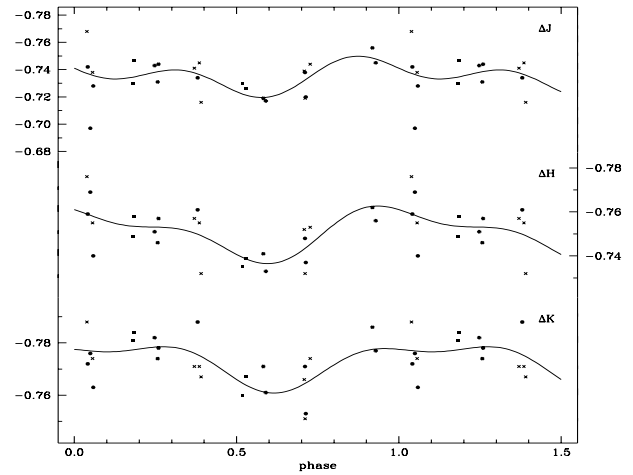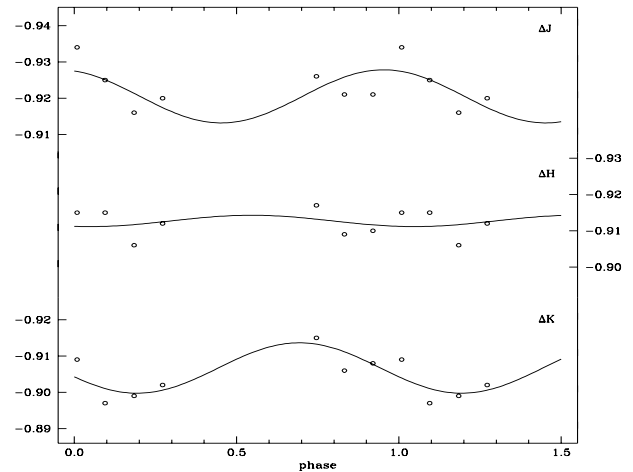
Fig. 2. Differential infrared light curves of HD 24712. The phases are computed according to the ephemeris elements in Table 3. The solid line is a least-square fit of the observations by Eq. (1) as described in the text

Fig. 3. Differential infrared light curves of HD 49976. The phases are computed according to the ephemeris elements in Table 3. The solid line is a least-square fit of the observations by Eq. (1) as described in the text

ephemeris elements. From this figure a double-wave variation in all three filters seems evident, with an amplitude of the order of 0.03 mag.

HD 49976 = HR 2534 = V592 Mon

A rather strong magnetic field was measured in HD 49976 by Babcock (1958a) who also found evidence of an extraordinary range of variation of the SrII lines.

Observations by Pilachowski et al. (1974), Maitzen & Albrecht (1975), Mathys (1991), and Catalano & Leone (1994) have allowed to refine the value of period to 2.97666±0.00008 d.

The infrared differential light curves of HD 49976 are plotted in Fig. 3 versus the phase computed by means of the ephemeris elements reported in Table 3, where the assumed initial epoch is the actual time of maximum visible light as taken from the observations of Pilachowski et al. (1974). The infrared light variations are in phase with each other, and show quite the same amplitude, of the order of 0.03 mag peak to peak, in all three filters.

HD 72968 = HR 3398 = 3 Hya = HV Hya

HD 72968 is the first star for which an estimate of the surface magnetic field intensity has been carried out on the basis of the study of the Zeeman intensification of spectral lines on the saturated part of the curve of growth (Hensberge & de Loore 1974).

Photoelectric observations of HD 72968 have been carried out by Wolff & Wolff (1971), Maitzen et al. (1978), Heck et al. (1987), and Catalano & Leone (1990). From

these studies the resulting value of the period of HD 72968 is 11.305 d.

Fig. 4. Differential infrared light curves of HD 72968. The phases are computed according to the ephemeris elements in Table 3. The solid line is a least-square fit of the observations by Eq. (1) as described in the text

The infrared differential light curves of HD 72968 are plotted in Fig. 4 versus the phase computed on the basis of Maitzen et al. (1978) ephemeris elements reported in Table 3. From Fig. 4 a slight variability is better evident in the K filter, with an amplitude of the order of 0.02 mag.

HD 83368 = HR 3831 = IM Vel

The late type CP2 star HD 83368 is a visual double with a magnitude difference $\Delta V = 2.85$ and a separation of 3.3 arcsec, which implies that both components are measured in the photometric observations.
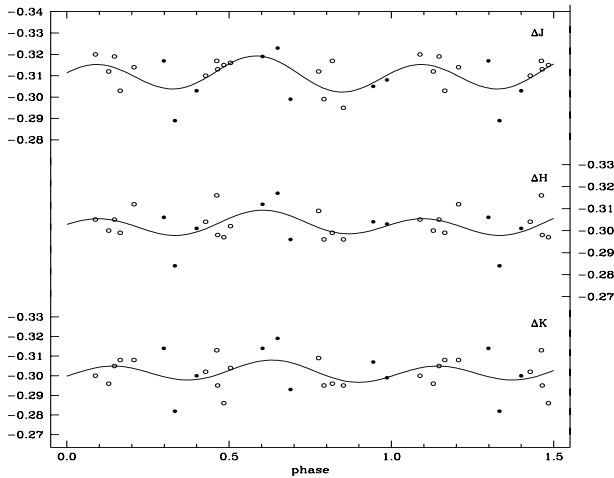

Fig. 5. Differential infrared light curves of HD 83368. The phases are computed according to the ephemeris elements in Table 3. The solid line is a least-square fit of the observations by Eq. (1) as described in the text

The photometric variability of HD 83368 has been detected by Renson & Manfroid (1978). Thompson (1983) measured a magnetic field symmetrically variable from $+800$ to -800 gauss within a period of 2.857 d. Kurtz (1982) discovered that HD 83368 shows pulsations with periods of ~ 6 and 12 min modulated within a period of about 2.85 d. More recently Kurtz et al. (1992) have shown that the period of the pulsation amplitude modulation is equal to the period of the mean-light variation and have refined the rotation period to the value 2.851982 ± 0.000005 d. This value of the period has been confirmed by Mathys & Manfroid (1985), Heck et al. (1987), Kurtz & Marang (1988), and Catalano & Leone (1994), and represents quite well also the magnetic observations of Mathys (1994) and Mathys & Hubrig (1997).

The infrared differential light curves of HD 83368 are plotted in Fig. 5 versus the phase computed by means of Mathys & Hubrig (1997) ephemeris elements reported in Table 3. From Fig. 5 we see that the HD 83368 shows a small amplitude double-wave variation, although with a quite large dispersion of the data, which could be due to the light dilution due to the presence of the close companion (Renson et al. 1984).

HD 96616 = HR 4327 = 4G. Cen = V815 Cen

HD 96616 is a visual double with a secondary component 2.6 mag fainter than the primary and separated only by 2 arcsec.

The light variability of HD 96616 has been studied by Renson & Manfroid (1977, 1978), Manfroid & Renson (1983). However Manfroid & Mathys (1985) noted an ambiguity between various aliases, preferring the value of 2.4394 d.
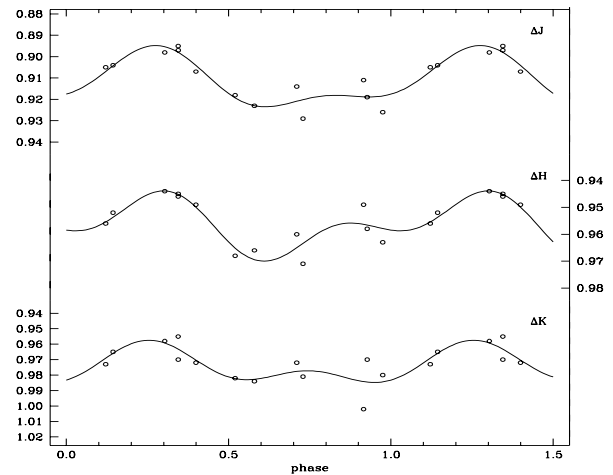

Fig. 6. Differential infrared light curves of HD 96616. The phases are computed according to the ephemeris elements in Table 3. The solid line is a least-square fit of the observations by Eq. (1) as described in the text

Only one measurement of the magnetic field of HD 96616 has been made by Borra & Landstreet (1975) but no field significantly different from zero was measured.

Our infrared differential observations of HD 96616 are plotted in Fig. 6 versus the phase computed by means of the ephemeris elements reported in Table 3. The infrared variation of HD 96616 is clearly evident in all three filters and amounts to about 0.03 mag peak to peak.

HD 98088 = HR 4369 = SV Crt

HD 98088 is the brightest component of a visual binary (ADS 8115) whose components are separated by 57.2 arcsec and the secondary is 3.8 mag fainter. It is also a double-lined spectroscopic binary with a known orbit (Abt 1953; Abt et al. 1968; Wolff 1974) and a period of 5.90513 d.

The magnetic field of HD 98088 has been measured by Babcock (1958a,b), who showed it to vary with the same period as the orbital motion.

The light variations of HD 98088 have been studied by Maitzen (1973), Wolff & Morrison (1975), and Catalano

& Leone (1994). From all these data it appears that the period of this star is very well defined and still adequately represents observations carried out many years apart.
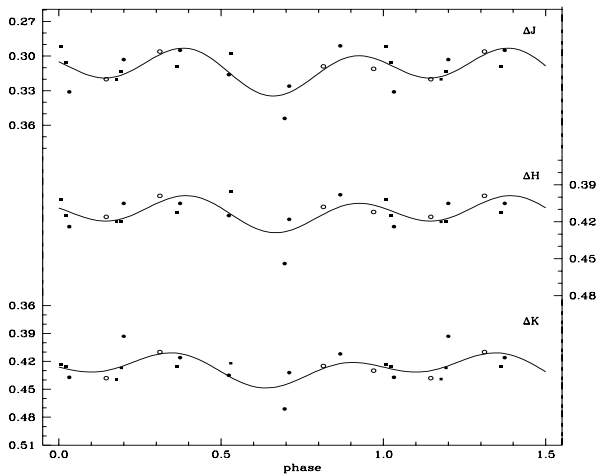

Fig. 7. Differential infrared light curves of HD 98088. The phases are computed according to the ephemeris elements in Table 3. The solid line is a least-square fit of the observations by Eq. (1) as described in the text

The infrared differential observations of HD 98088 are plotted in Fig. 7 versus the phase computed by means of Abt et al. (1968) ephemeris elements reported in Table 3. The infrared light variation of HD 98088 is double-waved in all three filters, with amplitudes of the order of 0.03 mag.

HD 101065 = CoD−46° 7232 = V816 Cen

HD 101065, also known as Przybylski's star, is one of the most peculiar stars known: its visible spectrum is strongly dominated by the rare earth lines (Przybylski 1961, 1963, 1966; Cowley et al. 1977) whose abundances are estimated as high as five orders of magnitude if compared to cosmic abundances (Wegner & Petford 1974). The iron peak elements, formerly considered to be underabundant in the visible spectrum, have been found to be strongly represented in the ultraviolet region $1900 - 3200$ Å (Wegner et al. 1983).

HD 101065 is an extremely highly blanketed star, so much that no available model atmosphere can fit the entire energy distribution as deduced from low resolution IUE spectra and visible and infrared photometry (Wegner et al. 1983). This fact can explain the difficulty in obtaining a reliable value of the effective temperature: values as low as 6075 ± 200 K have been proposed (Przybylski 1977a).
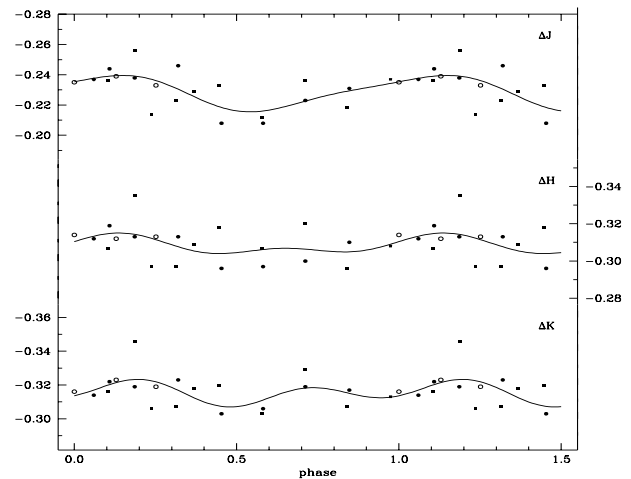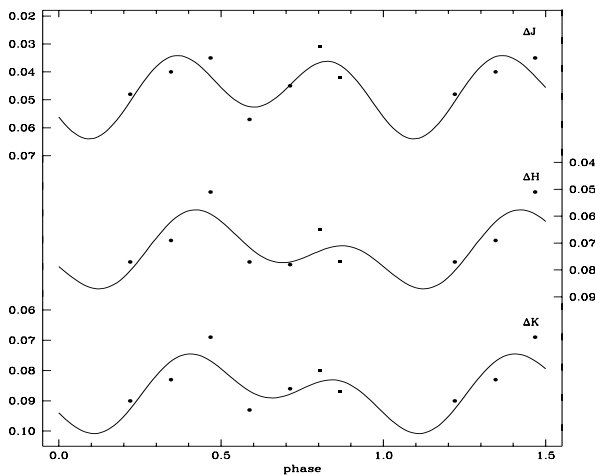

Fig. 8. Differential infrared light curves of HD 101065. The phases are computed according to the ephemeris elements in Table 3. The solid line is a least-square fit of the observations by Eq. (1) as described in the text

In spite of the several spectroscopic studies carried out, no clear evidence of variations of HD 101065 has been found so far in the line spectrum (Wolff & Hagen 1976; Cowley et al. 1977) nor in the -2200 gauss magnetic field measured by Wolff & Hagen (1976).

Photometric observations of HD 101065 aimed at detecting light variations have been carried out in the past by several authors. The most extensive photometric work has been done from 1969 to 1977 by Przybylski (1977b) who reported possible small amplitude long-period brightness variations of the order of two to three hundredths of a magnitude in Johnson V. However *uvby* observations appear to exclude systematic variations on a time scale of a week (Heck et al. 1976; Renson et al. 1976; Heck et al. 1987).

The only kind of variability so far detected to occur in HD 101065 is the rapid light variation with $P = 12.14$ min. (Kurtz 1978; Kurtz & Wegner 1979; Kurtz 1980, 1981). Kurtz (1982) discovered HD 101065 to show pulsations with periods of ∼12 min modulated within a period of about 2.85 d and interpreted this result within the context of the oblique rotator model, suggesting the presence of a polarity reversing magnetic field.

Near infrared photometric observations have been carried out by several authors and some discrepancies are evident from these data (Hyland et al. 1975; Glass 1982). For this and on the basis of the fact that from Przybylski's (1977b) photometric observations some evidence of light variability could be present at the longer wavelengths, we decided to observe HD 101065 for variability in the near infrared.

According to our observations spanning several runs, HD 101065 is quite clearly variable in the J filter, although some hint of variability seems to be present in the other filters. Period search led to the value 7.596 ± 0.005 d, which was found to represent quite well the observations. Other possible period values are 0.858 and 1.827 d, which however should be excluded if the rotational velocity $v_e \sin i$ is lower than 7 km s^{-1}, as suggested by Wegner (1979) and Martinez & Kurtz (1990).

The infrared differential observations of HD 101065 are plotted in Fig. 8 versus the phase computed by means of the ephemeris elements reported in Table 3.

HD 111133 = HR 4854 = EP Vir

The presence of a fairly strong magnetic field in HD 111133 has been revealed by Babcock (1958a).

The magnetic variation has been studied by Wolff & Wolff (1972), who found it occurring within a period of 16.31 d. The same period was found for the spectral line intensity of CrI, CrII, FeI, and FeII, and the light variations. Further magnetic field measurements have been carried out by Glagolevsky et al. (1982).

Fig. 9. Differential infrared light curves of HD 111133. The phases are computed according to the ephemeris elements in Table 3. The solid line is a least-square fit of the observations by Eq. (1) as described in the text

The spectrum variations have been studied by Engin (1974), while the Δa peculiarity index and $b-y$ variations have been studied by Buchholz & Maitzen (1979).

Recent photometric observations of HD 111133 have been carried out by Adelman et al. (1992), Catalano & Leone (1994) and North & Adelman (1995). The best representation of all photometric observations was obtained by North & Adelman (1995) whose ephemeris elements

reported in Table 3, we have assumed in Fig. 9 to plot our infrared differential observations. From this figure it appears that the infrared light curves of HD 111133 show constant amplitudes of about 0.03 mag and are in phase with each other.

HD 118022 = HR 5105 = 78 Vir = CW Vir

HD 118022 is the first star in which a magnetic field has been detected (Babcock 1947). The magnetic field variation has been subsequently studied by Preston (1969), who first determined the correct period to be 3.7220 d from the analysis of the crossover effect. Several authors have provided further magnetic measurements (Wolff & Wolff 1971; Wolff & Bonsack 1972; Wolff 1978; Borra 1980; Borra & Landstreet 1980; Leroy 1995), all of them confirming the period found by Preston.
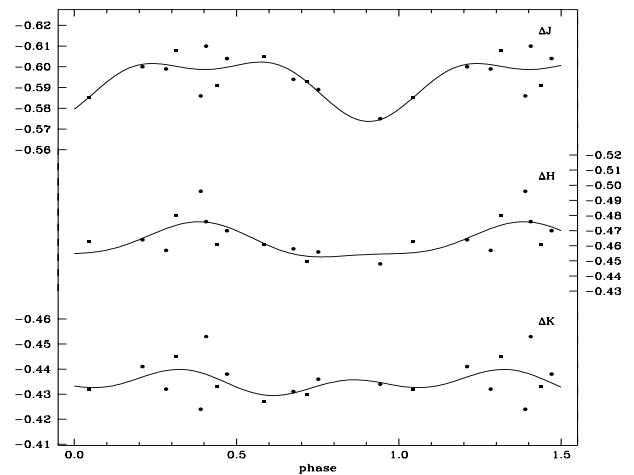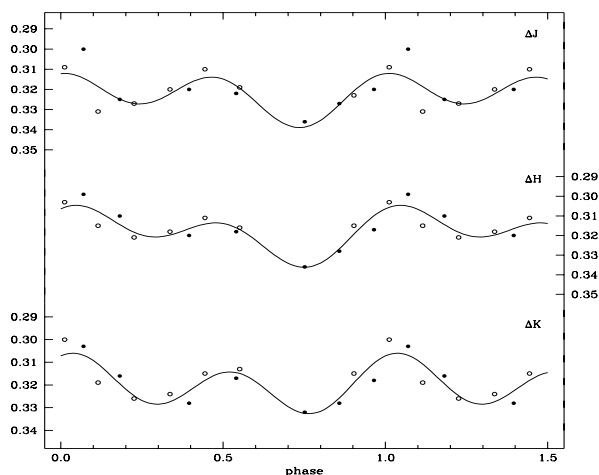
Fig. 10. Differential infrared light curves of HD 118022. The phases are computed according to the ephemeris elements in Table 3. The solid line is a least-square fit of the observations by Eq. (1) as described in the text

The light variability of HD 118022 has been studied by Stepien (1968), Winzer (1974), van Genderen (1971), Wolff & Wolff (1971), and Catalano & Leone (1994).

The infrared differential observations of HD 118022 are plotted in Fig. 10 with the ephemeris elements reported in Table 3. As it is evident from Fig. 10, HD 118022 is variable in J and H, with light curves which are essentially single-waved and have amplitudes of about 0.04 mag, while it is almost constant in the K filter.

HD 125248 = HR 5355 = 236G. Vir = CS Vir

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, 1988, 1987, and Catalano et al. 1991, 1993 for references).

same period of the magnetic field and in phase with the magnetic variations.

From the Δa study of the $\lambda 5200$ continuum depression carried out by Hensberge et al. (1986) it was inferred that the surface region, in which the high peculiarity values originate, are associated with the regions of enhanced spectral line strength, rather than with the local magnetic field.
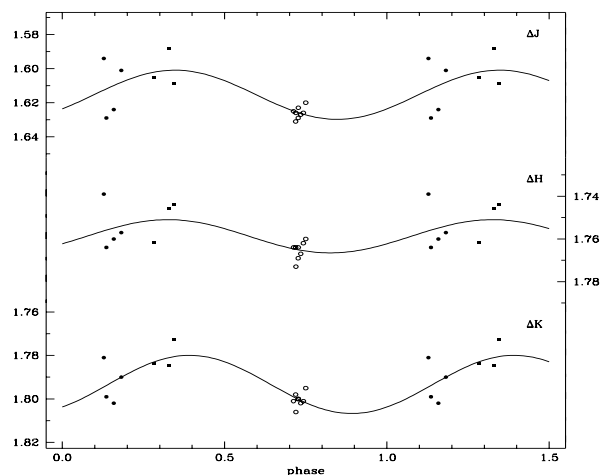

Fig. 11. Differential infrared light curves of HD 125248. The phases are computed according to the ephemeris elements in Table 3. The solid line is a least-square fit of the observations by Eq. (1) as described in the text

Fig. 12. Differential infrared light curves of HD 126515. The phases are computed according to the ephemeris elements in Table 3. The solid line is a least-square fit of the observations by Eq. (1) as described in the text

Photoelectric observations of HD 126515 have been carried out by Catalano & Leone (1990) and North & Adelman (1995). The latter authors refined the period to the value 129.99 d. This value of the period has recently been confirmed by Mathys et al. (1997), from magnetic field observations.

The infrared differential observations of HD 126515 are plotted in Fig. 12 versus the phase computed by means of Mathys et al. (1997) ephemeris elements reported in Table 3. As it is evident from Fig. 12, due to the incomplete coverage of the light curves of HD 126515, nothing can be said about the amplitude of the variability.

HD 125248 has been found to be variable in the near infrared by Catalano et al. (1992) with the same period as the visible light, spectrum and magnetic field variations. The infrared differential observations of HD 125248 are plotted in Fig. 11 versus the phase computed by means of the ephemeris elements reported in Table 3. The infrared variations do show a nearly constant amplitude larger than 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.

HD 126515 = GC 19462 = FF Vir

The star HD 126515 is the first star in which the spectral lines split in the Zeeman components have been observed. This fact allowed Preston (1970) to succeed in measuring the average surface field H_s which resulted to vary between 10 and 17 kG with a periodicity of 130 d. Preston also observed spectral line intensity variations of the lines of such elements as Si, Cr, Fe, Ti, Sr, and Eu with the

HD 137949 = ζ^2 Lib = GZ Lib

The unusual strength of the lines of SrII in the spectrum of HD 137949 has been noted by Adams et al. (1935). Babcock (1958a) also noted the unusual intensity of the EuII lines and found evidence of a rather strong magnetic field (≈ 1 kgauss). Further magnetic measurements were carried out by van den Heuvel (1971), who suggested that the magnetic field variation occurs within 18.4 d. This value of the period was not confirmed by Wolff (1975),

who instead supported evidence of a magnetic variation occurring within a period of 23.26 d, but did not detect light variations larger than 0.01 mag. Further magnetic observations have been carried out by Mathys et al. (1997), who have pointed out the possibility of a very long period ($\geq$ 75 years).

From photometric observations Kurtz (1982) suggested that the rotation period of HD 137949 could be 7.194 d. However, the light variability of this late CP star, if ever exists, is controversial. Essentially, no variability was evident from photometric observations carried out by Wolff (1975), Deul & van Genderen (1983), and Catalano & Leone (1994). No variations have also been found in the UV by van Dijk et al. (1978).

Our infrared observations are consistent with no light variation in excess of 0.01 mag.

HD 148898 = HR 6153 = ω Oph

The spectrum variability of HD 148898 has been discovered by Morgan (1932) who noted that maxima and minima of the spectral line intensity of $\lambda 4215$(SrII) occurred within a few days. Deutsch estimated the period to be of the order of 2 d (Bowen 1952). The existence of a polarity reversing magnetic field has been inferred by Babcock (1958a), but not measured because of the large spectral line width. Four measurements of the magnetic field intensity have been carried out by Borra & Landstreet (1980) with low values inside the 3σ level.
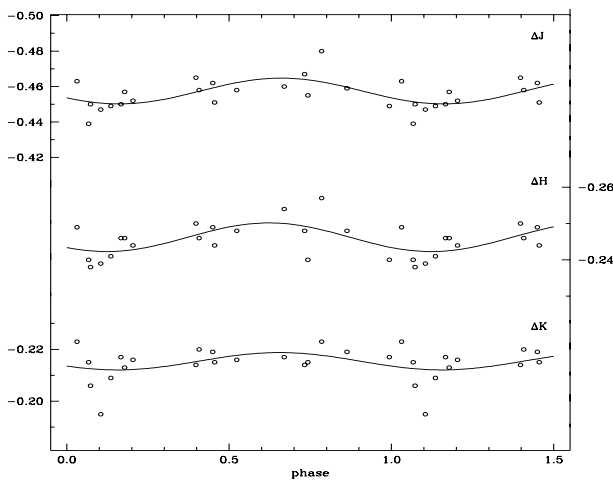

Fig. 13. Differential infrared light curves of HD 148898. The phases are computed according to the ephemeris elements in Table 3. The solid line is a least-square fit of the observations by Eq. (1) as described in the text

HD 148898 has been found to be a low amplitude light variable with several possible values of the period

such as 0.7462 ± 0.0002, 1.4922 ± 0.0004, and 2.968 ± 0.003 d or nearby values (Renson & Maitzen 1978). Subsequent *uvby* observations led to the most probable periodicities 1.79 (± 0.02) d, 4.67 (± 0.08) d or, less probably, 2.33 (± 0.02) d (Manfroid & Mathys 1985; Mathys & Manfroid 1985).

Among the above mentioned possible values, we have found that the best representation of our infrared differential observations was obtained with the period of 0.7462 d, hence the infrared light curves of HD 148898 are plotted in Fig. 13 versus the phase computed by means of the ephemeris elements reported in Table 3. As it is evident from Fig. 13 the infrared variations of HD 148898 show an essentially single-waved trend and are in phase with each other, with very low amplitudes.

HD 153882 = HR 6326 = V451 Her

The star HD 153882 has been discovered by Gjellestad & Babcock (1953) to be a magnetic variable with the period 6.005 d. Further magnetic observations of HD 153882 have been carried out by Hockey (1971), Preston & Pyper (1965) and very recently by Mathys (1991) and Mathys & Hubrig (1997).

The light variability of this star has been studied by Jarzebowski (1960), Chugainov (1961), Stepien (1968), van Genderen (1971), Panov & Schöneich (1975), Schöneich et al. (1976), Rakosch & Fiedler (1978), Hempelmann (1981), and Catalano & Leone (1994). All these authors have confirmed the value 6.009 d of the period as given by Babcock (1958a).

Taking into account all magnetic data, relative to a time interval of more than forty years, Mathys (1991) refined the value of the period to $6.00890(\pm 0.000015)$ d. Mathys also confirmed the quite sinusoidal character with polarity reversal of the magnetic variation, occurring with the same period as the photometric one, and extrema in the range -1600 to $+1600$ gauss. Moreover Mathys studied the equivalent width of the FeII $\lambda 5961$ line and found large anharmonic variations whose extrema coincide in phase with the light variations but show no simple phase relation with the extrema of the magnetic field.

The infrared differential observations of HD 153882 are shown in Fig. 14, where they are plotted versus the phase computed by means of the ephemeris elements reported in Table 3. From Fig. 14 we see that HD 153882 is slightly variable in the infrared with an amplitude of the order of 0.04 mag peak to peak.

HD 164258 = HR 6709 = V2126 Oph

Babcock (1958a) included HD 164258 in the list of the stars with probable magnetic fields and noted the unusual strength of the SrII lines. Bonsack (1974) found indication of variability in the lines of EuII but did not determined any period.
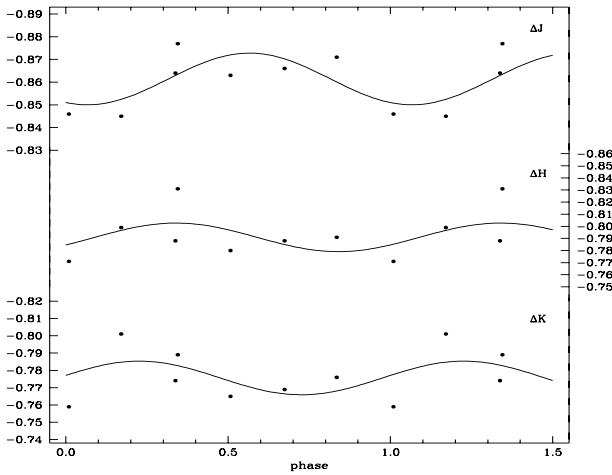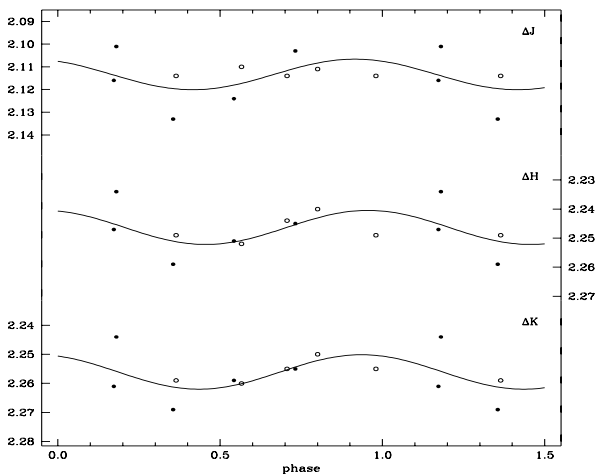
Fig. 14. Differential infrared light curves of HD 153882. The phases are computed according to the ephemeris elements in Table 3. The solid line is a least-square fit of the observations by Eq. (1) as described in the text

HD 164258 has been found to be variable by Renson & Manfroid (1980) who gave indication of a period of about 2.41 d. However, Manfroid & Mathys (1985) suggested shorter periods such as 0.719 or 0.359 d. On the basis of new *uvby* observations Catalano & Leone (1994) have found a period of 0.829(±0.005) d, which gives quite a good representation of the observations.

Fig. 15. Differential infrared light curves of HD 164250. The phases are computed according to the ephemeris elements in Table 3. The solid line is a least-square fit of the observations by Eq. (1) as described in the text

The infrared differential observations of HD 164258 are shown in Fig. 15, where they are plotted versus the phase computed by means of the ephemeris elements reported in Table 3. From Fig. 15 we see that HD 164258 shows a very small single-waved variation, better evident in *J* where it has an amplitude of the order of 0.02 mag.

HD 203006 = HR 8151 = θ¹ Mic

HD 203006 has been found by Babcock (1958a) to be both spectrum and magnetic variable, on the basis of the fact that the magnetic field polarity appeared to reverse polarity in one day while lines of EuII and of SrII showed intensity variations of opposite sign.

The first determination of the period has been performed by Morrison & Wolff (1971); from *uvby* observations these authors found HD 203006 to vary within 1.062 ± 0.001 d. Maitzen et al. (1974) found a double wave in their *UBV* and *uvby* observations and stated the correct period to be 2.1219 d. From more recent photoelectric observations Deul & van Genderen (1983), have argued for a slightly shorter period, i.e. 2.1215 ± 0.0001, while from spectroscopic measurements Brandi & Žižňovský (1990) favoured a slightly longer one, i.e. 2.1221 ± 0.0002 d, although both values are very near to Maitzen et al.'s value.
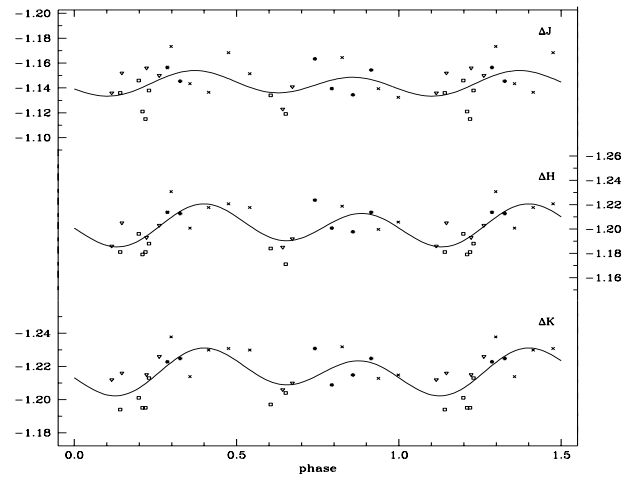

Fig. 16. Differential infrared light curves of HD 203006. The phases are computed according to the ephemeris elements in Table 3. The solid line is a least-square fit of the observations by Eq. (1) as described in the text

Our infrared differential observations of HD 203006, phased with all of these period values, do show too large a dispersion, in fact they are better represented with a slightly longer period value, i.e. 2.1224 d, which is just outside of the error bar. The resulting light curves are

shown in Fig. 16, where they are plotted versus the phase computed by means of the ephemeris elements reported in Table 3. As it is evident from Fig. 16 the light curves of HD 203006 show essentially the same high dispersion double-waved variations, in phase with each other, as in the *uvby*, with amplitudes of about 0.04 mag.

HD 206088 = HR 8278 = γ Cap

HD 206088 was initially used as a standard, however, since we noted an anomalous scatter of the observations, it was included among the programme stars to look for variability.

The spectral type of HD 206088 is given as A8-F4 Sr in the *General Catalogue of Ap and Am Stars* (Renson et al. 1991), so it would be intermediate between late Ap stars and Am stars. No photometric nor spectroscopic studies of this star are available in the literature.
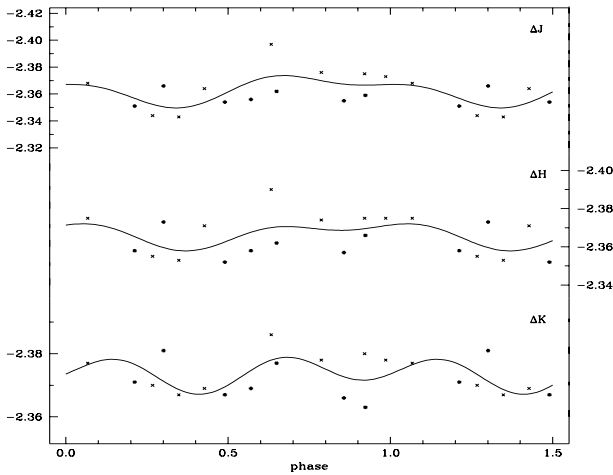

Fig. 17. Differential infrared light curves of HD 206088. The phases are computed according to the ephemeris elements in Table 3. The solid line is a least-square fit of the observations by Eq. (1) as described in the text

Period search led to the most probable value of the period of 2.78 d, although many other nearby values are possible. However the number of the observed points is too small to allow a better determination. The infrared differential light curves of HD 206088 are shown in Fig. 17, where they are plotted versus the phase computed by means of the ephemeris elements reported in Table 3. As it is evident from Fig. 17, of HD 206088 might be variable, at least in the J filter, but the period is too poorly defined to be fully reliable: it has to be considered as a trial value and needs to be confirmed.

HD 220825 = HR 8911 = κ Psc

A lot of photometric and spectroscopic studies of the SrCr star HD 220825 have been performed since Rakosch (1962) discovery of its variability with a period of 0.5805 d. Recent studies have allowed to determine the period to be 1.418 d (Ryabchikova et al. 1996, and references therein). A small amplitude magnetic field variation (Borra & Landstreet 1980) is also consistent with this period.
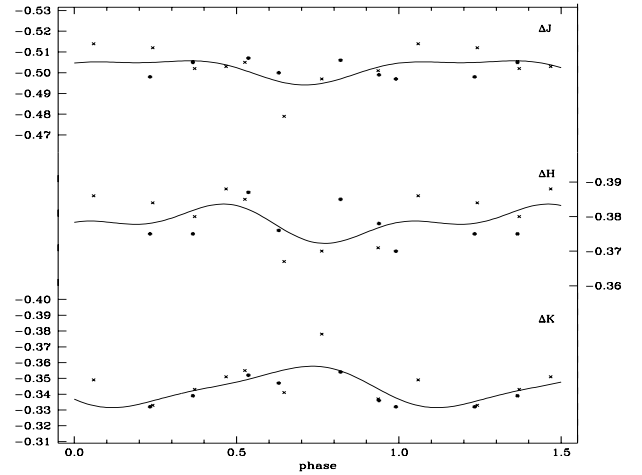

Fig. 18. Differential infrared light curves of HD 220825. The phases are computed according to the ephemeris elements in Table 3. The solid line is a least-square fit of the observations by Eq. (1) as described in the text

The infrared differential light curves of HD 220825 are shown in Fig. 18, where they are plotted versus the phase computed by means of the ephemeris elements reported in Table 3. As it is evident from Fig. 18, HD 220825 appears to be slightly variable in K with an amplitude of the order of 0.03 mag.

HD 221760 = HR 8949 = ι Phe

Babcock (1958a) found the SrII, CrI and CrII lines to be particularly prominent in the spectrum of HD 221760, and supported evidence for a rather weak magnetic field of positive polarity. Further magnetic field measurements by Borra & Landstreet (1980) confirmed the weakness of the field (≈ 0).

The only available photometric observations of this star are those by van Genderen (1971), who discovered HD 221760 to be variable in light with a period of 12.5 d.

HD 221760 was found to be variable in the infrared, at least in the J filter, and period search led to a number of values as 12.016, 12.224, 12.450, 12.655, and 12.886 days. We have preferred the value 12.45 days, which gives the minimum dispersion, but it has to be considered only

as preliminary and should be confirmed. Our infrared differential observations of HD 221760 are plotted in Fig. 19 versus the phase computed by means of the ephemeris elements reported in Table 3. From Fig. 19 we see that HD 221760 might be variable in J with an amplitude of the order of 0.02 mag. However, the period should be confirmed.
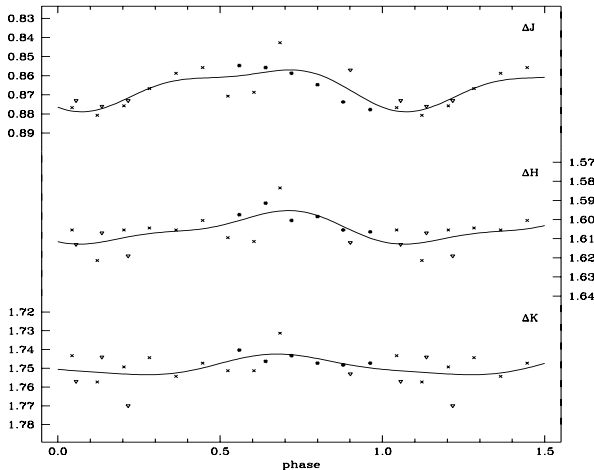

Fig. 19. Differential infrared light curves of HD 221760. The phases are computed according to the ephemeris elements in Table 3. The solid line is a least-square fit of the observations by Eq. (1) as described in the text

4. Discussion and conclusions

We have presented near infrared photometric observations of the CP2 SrCrEu stars HD 3980, HD 24712, HD 49976, HD 72968, HD 83368, HD 96616, HD 98088, HD 101065, HD 111133, HD 118022, HD 125248, HD 126515, HD 137949, HD 148898, HD 153882, HD 164258, HD 203006, HD 206088, HD 220825, and HD 221760.

Infrared variability has been observed in all program stars but HD 137949, which has been found to be constant within 0.01 mag. Variability of the stars HD 101065 and HD 206088 has been detected for the first time, although their periodicity has to be confirmed.

From the analysis of the visible light variations we know that the amplitudes shown by CP2 of the SrCrEu subgroup are in the average smaller than those of hotter CP stars, but they show almost the same very complicated morphology of different behavior in different filters, in the sense that the shape of the variations and the phases at which their extrema occur do change with the wavelength. This result has to be taken into consideration when looking for the interpretation of the observed variations.

The typical trend of CP2 stars to present smaller amplitude light variations at increasing wavelength is confirmed: the amplitudes in the near infrared are smaller than those in the visible. In most cases we find variations which appear to be in phase with each other in all filters.

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 some stars, as for example 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 (1958a,b) and Deutsch (1958), Rare Earths and Fe are mainly concentrated in the positive magnetic 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. Because of the numerous metallic absorption lines, the blanketing mechanism steepens the temperature gradient and redistributes the flux from the ultraviolet, where the metallic absorption is strongest, to longer wavelengths, yet conserving the effective temperature. Since the atmospheres of CP stars show locally inhomogeneous metal distributions, the stellar rotation should communicate these optical depth variations as infrared variability. CKL have shown 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.

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.

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