Peculiar Versus Normal Phenomena in A-Type and Related Stars
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PHOTOMETRIC PROPERTIES OF CP STARS IN THE INFRARED

FRANCESCO A. CATALANO
Istituto di Astronomia, Città Universitaria, I–95125 Catania Italy

FRANCESCO LEONE
Osservatorio Astrofisico di Catania, Città Universitaria, I–95125 Catania Italy

REINHOLD KROLL
Institut für Astronomie und Astrophysik Am Hubland, D-8700 Würzburg Germany

ABSTRACT Eightysix chemically peculiar stars have been observed in the near infrared with the aim to extend the comprehension of the differences between normal and peculiar stars. These stars have been checked for variability. Most of the stars are previously known light variables, although their periods were not accurate enough to phase together different kinds of observations carried out several years apart. For about 20 stars the period has been refined by combining our own *uvby* observations with the ones available in the literature.

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.

To verify such a hypothesis, we have carried out photometric infrared observations of CP stars.

The observations were carried out in several runs since 1986 in the near IR bands J, H, and K, mainly 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 were selected to give a precision of 0.001 mag. in the measurements. ESO standard software was used for all reduction steps. Magnitudes in the standard IR system were also established by standard stars from the ESO list. To check for variability, closeby comparisons were chosen so as to have as similar colors and brightness as possible.

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OVERALL FLUX DISTRIBUTION

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. Combining ultraviolet, visible and infrared fluxes, Leone & Catalano (1991) have shown that CP stars can not be distinguished from normal stars in the plane $V-J$ vs. $V-H$. Effective temperatures, extending Adelman and coworkers (Pyper & Adelman 1985, and references therein) procedure to the near infrared, are even lower than the ones inferred from the Paschen continuum. 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. A straight consequence of a such flux distribution is that the effective temperature deduced by classical method from the visible part of spectrum can be too high and that from the UV and IR regions a value of the effective temperature closer to the real one can be determined.

VARIABILITY

In spite of this *normality* of the infrared flux behavior, peculiar abundances and magnetic fields seem to affect the near infrared. Catalano et al. (1991a, hereafter CKL) have shown that, out of the eight CP stars monitored throughout their rotational periods, at least six are certainly variable in the near infrared, although the amplitudes shown are smaller than in the visible. Moreover, CKL have found evidence that within the accuracy of the known ephemeris, the near infrared light curves seem to be phase related to the magnetic field variations in the sense that magnetic field extrema might coincide in time with infrared light extrema, although strong field regions can apparently coincide as well with infrared (primary or secondary) maxima or minima. Up to now 86 stars have been checked for variability in the infrared, but upon looking at the data, we soon discovered that for too many stars of the sample the period is not known within the requested accuracy to allow investigation of the above said phase relation. Since multicolor photometric observations are the most convenient way to determine the period, we have started a research program aimed to accurately determining periods on the basis of new photometric observations.

In Table 1 and 2 we list the stars and the degree of completeness for the observed variations in the infrared using the code:

vv ... well defined light curves;

v: ... definite variations, nearly complete light curves;

v? ... indication of variability: incomplete light curves;

::: ... insufficient data;

?? ... probably constant, although with a large dispersion of the observed points;

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TABLE I Stars observed in the infrared

HD	HR/other	Name	Sp.	P(d)	
36485	1851	δ Ori C	B2 He	0.830056	vv
37017	1890	V1046 Ori	B2 He	0.901195	v?
37479	1932	σ Ori E	B2 He	1.19081	vv
37776	BD–1°1005	V901 Ori	B3 He	1.53869	v:
58260	GC 9873	...	B3 He	1.657:	v?
60344	CoD–23°5673	...	B3 He	1.2:	v?
64740	3089	216G. Pup	B2 He	1.33026	v:
184927	BD+30°3645	V1671Cyg	B2 He	9.52973	:::
5737	280	α Scl	B6 He wk	21.647	:::
21699	1063	V396 Per	B8 He wk Si	2.492	:::
28843	1441	DZ Eri	B9 He wk	1.373813	vv
35456	GC 6661	...	B7 He wk	1.8:	vv
37151	GC 6961	V1179 Ori	B8 He wk Si	0.804404	v:
49333	2509	HK CMa	B7 He wk Si	2.1800	vv
74196	3448	55G. Vel	B7 He wk	0.3880:	v?
125823	5378	a Cen	B5 He wk	8.8171	vv
142990	5942	V913 Sco	B6 He wk	0.4885035	v:
144334	5988	V929 Sco	B8 He wk	1.494971	vv
175362	7129	V686 Cra	B5 He wk Si	3.67375	vv
12767	612	ν For	A0 Si	3.7453	v:
19832	954	SX Ari	B8 Si	0.72789761	v:
22470	1100	EG Eri	B9 Si	1.92895	vv
25267	1240	τ^9 Eri	A0 Si	1.21005	vv
29305	1465	α Dor A	A0 Si	2.943176	vv
30466	GC5857	V473 Tau	A0 Si	1.39?	:::
34452	1732	IQ Aur	B9 Si	2.466	:::
40312	2095	θ Aur	A0 Si	3.619	:::
54118	2683	V386 Car	A0 Si	3.275170	??
56455	2761	PR Pup	A0 Si	2.06370	vv
66255	3151	PY Pup	A0 Si	6.81780	v?
73340	3413	HV Vel	B9 Si	2.667588	v?
92664	4185	V364 Car	B9 Si	1.67309	vv
114365	4964	V824 Cen	A0 Si	1.271925	v:
116890	5066	EZ Mus	B9 Si	4.301176	vv
122532	5269	V828 Cen	B9 Si	3.6807	vv
124224	5313	CU Vir	B9 Si	0.52067688	vv
144231	GC 21650	LL TrA	B9 Si	4.39136	v:
145102	GC 21737	31G. Sco	B9 Si	1.417951	??
203585	8180	θ^2 Mic	A0 Si	0.83:	v:
215441	BD+54°2846	GL Lac	B9 Si	9.4875	:::
221006	8919	CG Tuc	A0 Si	2.31483	vv

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TABLE II Stars observed in the infrared

HD	HR/other	Name	Sp.	P(d)	
9996	465	GY And	A0 SiSrEu	85000	:::
10783	GC 2141	UZ Psc	A2 SiCrSr	4.13281	v?
12447	596	α^2 Psc	A2 SiSrCr	1.49070	v?
18296	873	LT Per	A0 SiSr	2.884	:::
25823	1268	GS Tau	B9 SrSi	7.227	:::
32633	GC 6222	HZ Aur	B9 SiCr	6.430	:::
49606	2519	OV Gem	B8 MnHgSi	3.35?	:::
71866	GC 11639	TZ Lyn	A1 EuSrSi	6.8005	:::
74521	3465	BI Cnc	A1 SiEuCr	7.76	vv
81009	3724	KU Hya	A3 CrSrSi	33.96	v?
90044	4082	SS Sex	B9 SiCrSr	4.37894	vv
116458	5049	67G. Mus	A0 SiEuCr	(4.27:)	??
119419	5158	V827 Cen	A0 SiCrEu	2.69562	v:
125630	GC 19369	BS Cir	A2 SiCrSr	2.205	v:
137509	GC 20810	...	B9 SiCrFe	4.4912	vv
147010	GC 21960	V933 Sco	B9 SiCrSr	3.920676	vv
148199	GC 22126	...	B9 SiSr	7.905	v:
166469	6802	V4045 Sgr	A0 SiCrSr	2.88632	v:
170397	6932	V432 Sct	A0 SiCrEu	2.19133	vv
173650	7058	V535 Her	A0 SiSrCr	9.9754	:::
223640	9031	ET Aqr	B9 SiSrCr	3.735236	vv
3980	183	ξ Phe A	A7 SrEuCr	3.9516	vv
4778	234	G0 And	A1 CrSrEu	2.562	:::
8441	GC 1692	HN And	A2 Sr	69.5	:::
24712	1217	DO Eri	A9 SrEuCr	12.4610	v:
49976	2534	V592 Mon	A1 SrCrEu	2.9760	v:
51418	GC 9158	NY Aur	A0 HoDy	5.438	:::
65339	3109	AX Cam	A3 SrEuCr	8.027	:::
72968	3398	HY Hya	A2 SrCr	11.305	v?
83368	3831	IM Vel	A8 SrCrEu	2.851962	??
96616	4327	V815 Cen	A3 Sr	2.4394	vv
98088	4369	SV Crt	A8 SrCrEu	5.90513	vv
111133	4854	EP Vir	A1 SrCrEu	16.304	:::
118022	5105	78 Vir	A2 CrEuSr	3.7220	v:
125248	5355	CS Vir	A1 EuCr	9.29477	vv
126515	GC 19462	FF Vir	A2 CrSr	130.0	:::
128898	5463	α Cir	A9 SrEu		??
137949	GC 20814	GZ Lib	F0 SrEuCr	23.26:	:::
148898	6153	ω Oph	A6 SrCrEu	0.74618	v:
153882	6326	V451 Her	A1 CrEu	6.00890	v:
164258	6709	V2126 Oph	A3 SrCrEu	0.359/0.719	v?
188041	7575	V1291Aql	A6 SrCrEu	5.438	:::
203006	8151	θ^1 Mic	A2 CrEuSr	2.1221	vv
220825	8911	κ Psc	A1 CrSrEu	1.412	??
221760	8949	ι Phe	A2 SrCrEu	12.5:	v?

DISCUSSION

The light variability of CP stars in the visible and in the ultraviolet has been ascertained in the past. On the basis of infrared photometry of 86 CP stars, we have now established that these stars are also variable in the near infrared with the same period as visible light, spectrum, and magnetic field. This means that the properties which characterize CP stars (i.e. anomalous abundances, presence of magnetic fields, and variability) influence all parts of their spectra, although at a different rate, which is a surprising fact considering that the influence of the chemical peculiarities should gradually diminish in the infrared. Some regularities emerge from the bulk of data:

(i) Variations in the infrared have smaller amplitudes than in the ultraviolet and in the visible;

(ii) The infrared light curves do show nearly the same amplitude in all three J,H,K bands and the same shape and phase behavior with each other;

(iii) The extrema of the infrared light curves do not appear to correlate with the magnetic field polarity.

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. Unfortunately Kurucz model atmospheres cannot exactly reproduce the flux distribution of magnetic CP stars but can describe their behavior at a qualitative level only, so, if larger variations are detected, we cannot exclude that other effects could be connected with the infrared variability. Among others, one such mechanism could originate from the presence of large-scale organized magnetic fields. The way in which a magnetic field may have influence on the conditions in a stellar atmosphere can be outlined in the three following:

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

ii) modification of the atmospheric structure of the star because of the contribution of the Lorentz force term in the hydrostatic equilibrium equation;

iii) modification of the radiation transfer in the lines through the Zeeman effect.

Item *i)* is important in determining the link between the geometry of the field and the nonhomogeneous distribution of the surface abundances.
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)*, the treatment of a model atmosphere in which a magnetic field is present is a very difficult problem: it has been discussed by some authors in some particular configurations (Trasco 1972, Staude 1972), but a more general approch 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 into 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 the 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.
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 many stars which show different behavior in the u, v, b, y light 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.
At the moment the observational data are not sufficient to investigate further the problem, especially because the period of too many stars is not known with the requested accuracy to derive accurate phase relations for data taken several years apart, but we think that the study of the relation between the infrared and magnetic variations may supply valuable information to understand the puzzling problem of magnetic CP stars.

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DISCUSSION (Catalano, Leone and Kroll)

SMITH: Did you consider fitting line profiles rather than equivalent widths? And is there more information in the line profiles than in the equivalent widths?
KROLL: There is certainly more information in the line profile than in the equivalent width. I fitted the line profiles with Peterson's BALMER models with 10 $\times$ solar metals. However, it is usually not possible to fit T_{eff} and $\log g$ simultaneously. You need to have more information to restrict one of those parameters.
ADELMAN: Is BD +24°3675 a known variable?
KROLL: The period is about 7.52 days, as measured by Schneider (1986, IBVS 2870).

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