Absolute magnitudes and kinematics of CP stars from Hipparcos data

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Abstract. The position in the HR diagram and the kinematic characteristics of different kinds of CP stars of the upper main sequence are obtained using the LM method (Luri et al., 1996). Most of the CP stars are main sequence stars occupying the whole width of the sequence. From a kinematic point of view, they belong to the young disk population (ages $\lesssim$ 1.5 Gyr). It has also been found that, on kinematic grounds, the behaviour of λ Bootis stars is similar to the one observed for normal stars of the same spectral range. On the other hand, roAp and noAp stars show the same kinematic characteristics. The peculiar velocity distribution function has been decomposed into a sum of three dimensional gaussians and the presence of Pleiades, Sirius and Hyades moving groups has been clearly established. Finally, a small number of CP stars are found to be high-velocity objects.

Key words: Stars: chemically peculiar - Hertzprung-Russell (HR) diagram - Stars: kinematics

1. Introduction

The release of Hipparcos data (ESA, 1997) allows to reconsider the luminosity of CP stars of the upper main sequence and their kinematic behaviour on sounder bases. In the present paper the following kinds of CP stars have been considered: He-rich, He-weak, HgMn, Si, SrCrEu and the related group of λ Bootis stars.

The LM statistical method (Luri et al., 1996) has been applied to the different samples. This method has the advantage that all the available astrometric data (whatever the quality of the parallax is) as well as radial velocity data

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are used for each star for the luminosity calibration. It also provides the kinematic characteristics of the samples. The method is able to identify and separate groups of stars with different luminosity, kinematic or spatial properties, allowing the treatement of non homogeneous samples.

2. Material

For Bp - Ap stars, in order to minimize misclassifications, the samples have been selected using different sources and intercomparing the spectral classifications between them. First, all the stars in Renson's Catalogue (Renson, 1991) observed by Hipparcos were retained. This first list was cross-correlated with the Catalogue of Stellar Groups of Jaschek & Egret (1981) and the Michigan catalogues: Houk & Cowley (1975), Houk (1978; 1982) and Houk & Smith-Moore (1988). After that, the stars with discrepant spectral classifications were excluded. The group named Si+ contains intermediate types like SiCr and SiEu. For Am stars, two samples have been selected from Hauck's Catalogue (Hauck, 1992): "normal" Am and "mild" Am stars. A star was considered "mild" when the difference between the spectral types obtained using metallic lines and the K - line of Ca II was smaller than 5 subtypes. Table 1 gives the number N of stars in the selected samples and the spectral type and effective temperature ranges. Finally, a sample of 41 λ Bootis stars, taken from the Catalogue of Pauzen et al. (1997), has also been considered.

Table 1. Samples of Bp-Ap and Am stars

Sample	N	Sp. range	$T_{\rm eff}$ range	N_f
He-rich	14	B2	18000 - 23000 K	14
He-weak	58	B4 - B8	13000 - 17000 K	58
HgMn	76	B8 - A0	10000 - 14000 K	44
Si	440	B7 - A2	9000 - 14000 K	415
Si+	87	B8 - A2	8000 - 13000 K	66
SrCrEu	378	A0 - F0	7000 - 10000 K	353
Am "normal"	852	A0 - F0	7000 - 10000 K	781
Am "mild"	207	A0 - F0	7000 - 10000 K	184

For each star, astrometric data (parallax and proper motion components) as well as photometric data and their corresponding errors have been taken from the Hipparcos Catalogue. Radial velocity data come from different sources: Barbier-Brossat & Figon (1997), Dufflot et al. (1995), Grenier et al. (1997), Levato et al. (1996) or from Coravel (North, private communication). When a star had more than one radial velocity source, a mean weighted value was adopted.

Effective temperatures ($T_{\rm eff}$) were evaluated using Geneva photometry for all the Bp - Ap groups with the exception of the He-rich group. In this last

case, the values given in Zboril et al. (1997) were used. For Am stars, effective temperatures were obtained from Strőmgren photometry and for λ Bootis stars the spectroscopic values from Cayrel de Strobel et al. (1997) were used.

Absolute magnitudes may be affected by interstellar absorption and duplicity effects. The effect of the interstellar absorption on the apparent magnitude has been taken into account using the tridimensional model of Arenou et al. (1992) which is included in the LM method. The correction for binary companions has been applied when the difference of magnitude between the components was known, otherwise the star was rejected. The final number of stars in the selected samples (N_f) is given in Table 1. In the sample of λ Bootis stars 39 stars remained.

3. The method

The LM method is based on a Maximum-Likelihood algorithm. Given a selected sample and a model for the luminosity, the velocity and spatial distributions, the method:
- uses all the available information (astrometric, photometric and spectroscopic);
- takes into account the observational censorship of the sample and the observational errors;
- is able to treat a mixture of stars coming from different groups and to separate them;
- provides a mean luminosity calibration as well as individual absolute magnitudes and the spatial and kinematic characteristics of the samples.

A normal distribution for the absolute magnitude (M_0, σ_M), a Schwarzchild ellipsoid $(U_0, V_0, W_0, \sigma_U, \sigma_V, \sigma_W)$ for the velocity distribution and an exponential-disk for the spatial distribution (Z_0 being the scale height in the direction perpendicular to the galactic plane) have been adopted. U, V and W are the heliocentric velocity components in the direction of the galactic center, of the galactic rotation and of the north galactic pole, respectively. The galactic differential rotation effect on the kinematic data has been taken into account using the Oort-Lindblad model at first order. Moreover, the sample selection in apparent magnitude has been described by a selection function which is uniform up to a certain magnitude m_c (treated as a parameter to be determined) and then linearly decreases up to the limiting magnitude of the sample.

4. Results

The LM method has been applied separately to the different samples and for all of them, with the exception of the samples of He-rich, He-weak and λ Bootis stars, secondary groups were found. Table 2 gives for the main groups, which contain the largest number of stars, the dispersion (σ_M) of the intrinsic visual absolute magnitude, expressed in magnitudes, the velocity dispersions (σ_U, σ_V

and σ_W) given in km s^{-1} and the scale height (Z_0) expressed in pc. Individual absolute magnitudes and more details on the luminosity calibration and the spatial and velocity distributions will be given in a forthcoming paper to be published in Astronomy & Astrophysics.

Table 2. Dispersions of the intrinsic visual absolute magnitude, kinematics and scale heights for the main groups

Group	N_f	σ_M	σ_U	σ_V	σ_W	Z_0
He-rich	14	1.2 ± 0.4	8.7 ± 4.3	7.6 ± 3.1	5.0 ± 4.3	81 ± 76
He-weak	58	0.6 ± 0.2	8.6 ± 1.2	8.2 ± 1.8	3.7 ± 0.8	58 ± 9
HgMn	44	0.6 ± 0.4	9.3 ± 1.9	10.9 ± 1.7	5.4 ± 0.8	57 ± 10
Si	415	0.76 ± 0.09	9.7 ± 0.3	10.2 ± 0.5	5.8 ± 0.3	69 ± 3
Si+	66	0.75 ± 0.15	14.6 ± 1.8	9.0 ± 1.4	6.0 ± 0.7	49 ± 8
SrCrEu	353	0.76 ± 0.06	19.1 ± 1.2	9.5 ± 0.8	7.0 ± 0.4	96 ± 8
Am "normal"	781	0.51 ± 0.06	20.8 ± 1.4	9.8 ± 0.5	7.4 ± 0.4	122 ± 11
Am "mild"	184	0.86 ± 0.12	20.4 ± 1.3	9.5 ± 0.7	6.7 ± 0.8	75 ± 8
λ Bootis	39	0.54 ± 0.12	19.8 ± 2.7	10.6 ± 1.4	6.5 ± 1.1	56 ± 11

4.1. Absolute magnitudes

Fig. 1 displays the position of the different subgroups in the HR diagram (M_{bol}, $log\, T_{\rm eff}$). The bolometric absolute magnitudes M_{bol} have been calculated using the bolometric correction of Stępień (1994) for magnetic stars, otherwise the correction of Flower (1996) has been used. Notice that not all stars have $T_{\rm eff}$ data available. In the figure, the isochrones of Schaller et al. (1992) for solar metallicity are also indicated. CP stars belonging to the main groups occupy the whole width of the main sequence. The width reaches up to 2 mag; a similar result has been found by Gómez et al. (1997a) for non-peculiar stars of the same spectral range. The intrinsic dispersion in absolute magnitude is rather high, varying from 0.5 to 0.8 mag for most of the types, except He-rich stars which spread a large range in luminosities. λ Bootis stars are concentrated in the main sequence, but their evolutionary status remains controversial (Pauzen, 1997). On kinematic grounds, their behaviour is similar to the one of non-peculiar stars of the same spectral range.

Secondary groups may differ from the main groups in luminosity, in kinematics or in both. Most of them are inhomogeneous and contain possible misclassified and/or high-velocity objects.

4.2. Kinematics

It is well known from the study of Bp - Ap and Am stars in associations and open clusters that they belong to the young disk population (see North, 1993). Consequently, it is expected that their spatial and velocity distributions agree with those observed for non-peculiar main sequence stars of the same spectral

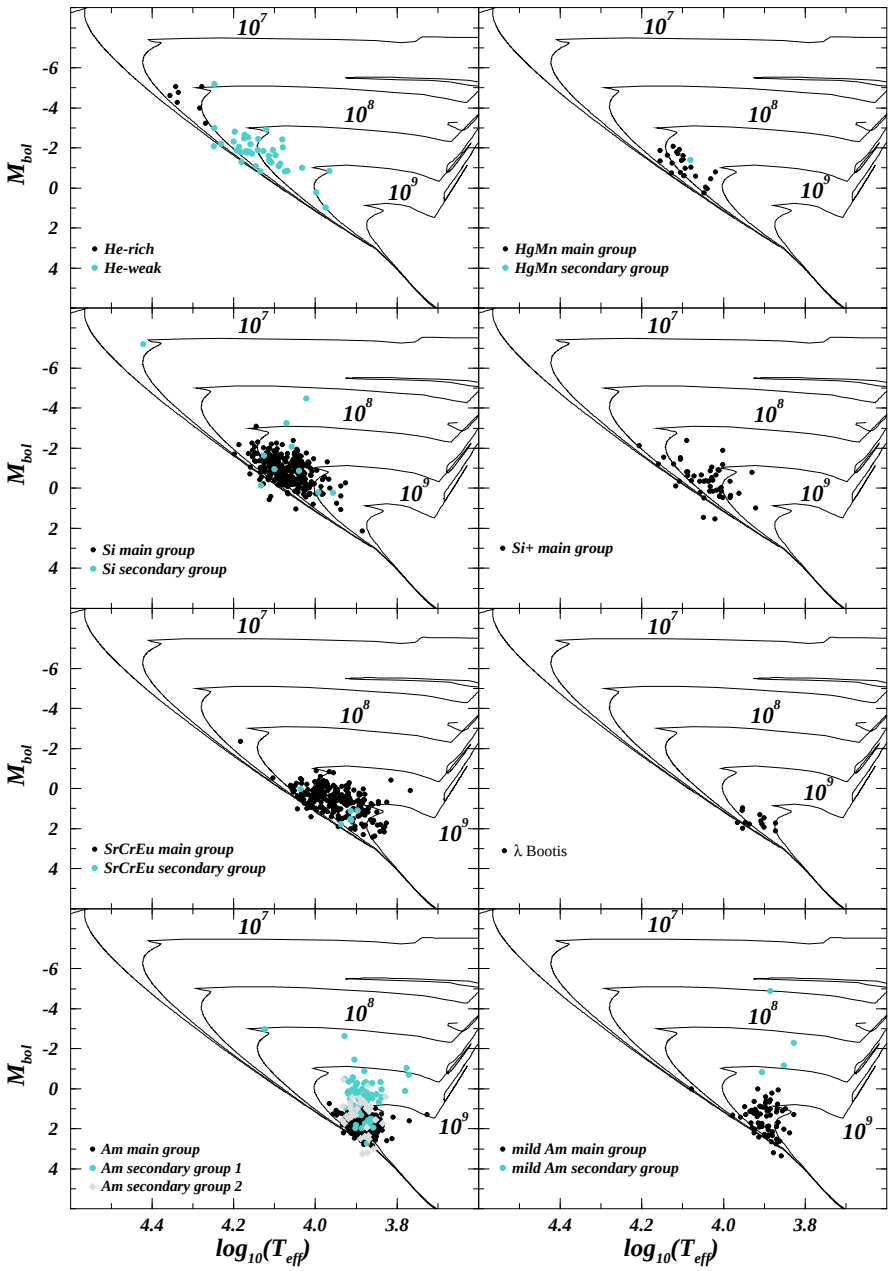

Figure 1. Distribution in the $[T_{\rm eff}, M_{bol}]$ plane of the stars in the subgroups: He-rich, He-weak, HgMn, Si, Si+, SrCrEu, λ Bootis, normal Am and mild Am stars

range. For normal stars, Gómez et al. (1997b) obtained, using Hipparcos data, that up to 1 Gyr σ_V and σ_W remain pratically unchanged ($10 \pm 0.5\,\mathrm{km\,s^{-1}}$ and $5\text{-}7 \pm 0.5\,\mathrm{km\,s^{-1}}$, respectively), while σ_U increases from $11 \pm 0.5\,\mathrm{km\,s^{-1}}$ at 10^8 years to $20 \pm 1\,\mathrm{km\,s^{-1}}$ at 10^9 years. At 2 Gyr, σ_U, σ_V and σ_W increase up to $23 \pm 1\,\mathrm{km\,s^{-1}}$, $14 \pm 0.5\,\mathrm{km\,s^{-1}}$ and $11 \pm 0.5\,\mathrm{km\,s^{-1}}$, respectively. From the results given in Table 2, we find that, as expected, CP stars have the same kinematic behaviour of non-peculiar disk stars younger than about 1.5 Gyr. Moreover, as observed for normal stars (Sabas, 1997; Figueras et al., 1997), the velocity field of CP stars shows the presence of moving groups. The members of a moving group are believed to be the result of clusters or associations in the process of dissociation: they are still moving with similar velocities but are distributed over the whole sky. In order to identify moving groups in the sample of CP stars, stars known to belong to associations or clusters have been rejected as well as stars with total velocities greater than $65\,\mathrm{km\,s^{-1}}$. In order to compare the results for CP stars with those obtained by Sabas (1997) for normal stars using the same method, only stars brighter than V-magnitude 7.5 have been kept. The final sample contained 467 stars. The SEMMUL algorithm (Celeux & Diebolt, 1986), which allows the separation of gaussian components inside a sample (without a priori knowledge of the number of components), has been applied using as input data the velocity components and their errors. Table 3 summarizes the results obtained for the main moving groups by Sabas (1997) from a sample of 2578 normal B5 - F5 stars brigther than V-magnitude 7.5 and our results for CP stars. U_M and V_M are the mean velocity components and ($\sigma_{V,M}$) the V-velocity dispersion of the moving groups expressed in $\mathrm{km\,s^{-1}}$, the corresponding mean standard errors are $\leq 0.5\,\mathrm{km\,s^{-1}}$. The number of normal (NS) and peculiar (CP) stars found in each identified moving group is indicated as well as the percentage of CP stars with respect to normal stars (given between parenthesis). Finally, the mean logarithm of the age of the moving groups is also given. The mean standard error in the percentages varies between 5 and 8 %. Notice that the velocity dispersion of the moving groups in the direction of the galactic rotation is of about $5\,\mathrm{km\,s^{-1}}$ (see also Figueras et al., 1997).

Table 3. Main moving groups found using the SEMMUL algorithm

Moving Group	U_M	V_M	$\sigma_{V,M}$	$\log(age)$	(NS or CP)
Pleiades	-9.7	-23.9	4.6	8.2	NS: 362
	-12.7	-26.3	3.6		CP: 64 (18%)
Sirius	10.0	2.8	5.2	8.7	NS: 388
	9.4	3.8	5.9		CP: 93 (24%)
Hyades	-37.4	-15.2	5.2	8.9	NS: 207
	-38.8	-19.1	4.1		CP: 33 (16%)

Secondary groups obtained with the LM method in the samples of HgMn, Si and SrCrEu contain a few high-velocity stars (in total about 10). The ex-

istence of early-type stars with apparently near solar metallicities and main sequence surface gravities but with high-velocities and/or large distances away from the galactic plane, constitutes a long standing anomaly in the classical picture of stellar galactic populations (Lance, 1991). Several hypotheses have been advanced to explain these objects: ejection from the galactic plane of normal young stars, misclassified stars like blue stragglers (BS) or formation as the result of accretion of gas from a merged satellite galaxy. Among these mechanisms, the second one is very attractive in the case of CP stars because over 60% of the BSs observed in young and intermediate age open clusters are found to be peculiar B - A stars (see Stryker (1993) for details). However, it seems certain that more than one mechanism exists to form high-velocity early-type stars.

Mathys et al. (1996) performed a kinematic study of rapidly oscillating Ap stars (roAp) and found that, on kinematic grounds, these stars are older than the non-oscillating counterparts (noAp). We have 12 roAp and 9 noAp stars in common with their samples. Using these stars, the velocity dispersions have been calculated. We found that both groups have similar kinematic characteristics: σ_U, σ_V and σ_W values are $25 \pm 5\,\mathrm{kms}^{-1}$, $11 \pm 2\,\mathrm{kms}^{-1}$, $11 \pm 2\,\mathrm{kms}^{-1}$ and $21 \pm 5\,\mathrm{kms}^{-1}$, $15 \pm 4\,\mathrm{kms}^{-1}$, $9 \pm 2\,\mathrm{kms}^{-1}$ for roAp and noAp stars, respectively.

5. Conclusions

Our main results can be summarized as follows:
- Most CP stars are main sequence objects occupying the whole width of the sequence (about 2 mag). The intrinsic dispersion in absolute magnitude varies from 0.5 to 0.8 mag for all the groups except He-rich stars which spread a large range in luminosities. Some Am stars in the secondary groups are out of the main sequence, but before reaching a definitive conclusion it will be necessary to search for possible misclassifications.
- From a kinematic point of view, CP stars belong to the disk population younger than 1 - 1.5 Gyr. The velocity field shows the presence of moving groups as observed for normal stars of the same spectral range. In particular, the presence of Pleiades, Sirius and Hyades moving groups has been clearly established.
- λ Bootis stars are concentrated in the main sequence. The definition of this type of stars is not well established (see Gerbaldi, these proceedings). Their evolutionary status remains controversial, but the kinematic characteristics correspond to those of non-peculiar stars of the same spectral range.
- roAp and noAp stars show similar kinematic characteristics.

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