SYSTEMATICS OF CP STARS

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ABSTRACT. This review is concerned with the following topics: 1. The occurrence of chemical peculiar stars in binaries; 2. Determination of masses of CP stars; 3. Determination of radii of CP stars; 4. CP stars in clusters. The paper emphasizes the literature from the 23rd Liège Colloquium in 1981 on, and does not refer systematically to earlier papers.

1. INTRODUCTION

This review discusses the empirical data on binarity, cluster membership and fundamental stellar quantities for CP stars, emphasizing the progress made in the last four years.

Binaries may give fundamental information about important physical quantities as stellar mass and radius. The distribution of orbital parameters, and the incidence of peculiarity among the companions of CP stars may give clues to the understanding of a either stellar structure-related or environment-related origin and development of the observed peculiarities. Aspects subject to evolution on time scales of the order 10^7-10^8 years may be studied preferentially using open cluster members, with known age.

2. CP STARS IN BINARIES

2.1. Occurrence of CP stars in binaries

Jaschek and Gomez (1970) analyzed a large sample of published radial velocities for normal stars and found a rather constant frequency of 47% ± 5% all along the main sequence from B0 to M.

The search for spectroscopic binaries among the brightest northern CP stars by Abt and Snowden (1973) revealed that duplicity among magnetic stars is significantly lower, while it is quite normal for HgMn stars. Many, but not all, Am stars are binaries (see Stickland,

C. R. Cowley et al (eds.), Upper Main Sequence Stars with Anomalous Abundances, 151–158.

1975 for references).

Studies of larger samples have confirmed the genuine difference in incidence of duplicity among magnetic and non-magnetic CP stars. However, there are indications that duplicity among magnetic stars might be less rare than believed previously (but nevertheless lower than along the main sequence, Floquet (1983), Gerbaldi et al. (1985)), while HgMn stars might have a larger than average incidence of duplicity (Schneider, this volume).

Recent analyses for HgMn stars (Schneider, this volume; Gerbaldi et al., 1985) are based on Schneider's (1981) catalogue. Depending on the adopted criteria, Schneider finds 57% to 72% binaries, included 7% of visual binaries. This agrees essentially with Gerbaldi et al. (1985) who find 54% of spectroscopic binaries from radial velocity data for stars in the BS catalogue; a percentage that has to be raised to nearly 70% if stars brighter than sixth magnitude are considered.

Gerbaldi et al. (1985) confirm the low binary frequency for magnetic stars. Radial velocity data from a sample of 31 He-w, 120 Si and 113 Sr-Cr-Eu stars show that the binary frequency of all but the coolest magnetic stars is not higher than 40%, in accordance with the 35% estimate of Floquet (1983) for magnetic stars. The coolest CP stars may occur as frequent in binaries as normal stars.

No data on He-rich were found, except for a qualitative remark by Bolton (1983) that their incidence in binaries is low.

2.2. Characteristics of CP binaries

Orbit determinations lack for most systems. Only 23 out of 97 HgMn binaries and 26 out of 233 classical CP2 studied by Gerbaldi et al. (1985) have known orbital parameters. Their sample is somewhat larger than the one studied by Zelwanowa et al. (1976), from the Osawa (1959) catalogue, and confirms the original results. There is a lack of short periods (HD15144 has P_{orb} = 3 days) and circular orbits. Double-lined spectroscopic binaries are rare, and only one marginally peculiar star is known to show eclipses (NGC2516- Cox nr.38, North, 1984). The secondaries may well have normal masses, since the statistical distribution of the mass function is not significantly different from systems with normal A primaries.

HgMn binaries share with the magnetic stars the lack of short periods (HD2019 has P_{orb} = 3.1 days) and the herewith connected deficiency of eclipsing systems. Eclipses are observed only in AR Aur = HD34364 (Nassau, 1935). But in other aspects, they are similar to binaries with normal late B primaries. More details are given elsewhere in this volume by Schneider.

Abt and Bidelman (1969) conclude that all stars in the range A4-

F1, IV-V, that are primaries of binaries with periods of approximately 2.5 to 100 days have metallic-line (Am) spectra. This does not exclude that some Am stars have shorter periods (δ Cap=HD207098 has P=1.2d; HD106112=HR4646 has P=1.27d).

3. MASSES OF CP STARS

Fundamental stellar masses are derived from the observations of eclipsing binaries. Popper (1980) lists 9 Am stars in five systems, having masses in the range 1.6 to 2.1 solar masses (and radii around 2 solar radii). This is what one expects for normal main sequence A stars. The mass of the B9 HgMn primary of the eclipsing binary AR Aur is 2.5 solar masses.

Similar mass determinations lack for magnetic stars, because the first eclipsing system has been detected fairly recently. Double-lined spectroscopic binaries give lower limits to the actual mass. Under favourable inclination conditions, this lower limit is of the same order of magnitude as the actual mass (e.g. HD98088, $M \sin^3 i = 1.7\ M_\odot$, Abt et al., 1968; HD141556, $M \sin^3 i = 2.3$ and 1.6 for primary Hg and secondary Am star resp., Dworetsky, 1972) and points again to roughly normal masses with respect to their MKK-classification. We like to call to your attention the recent mass determination for βCrB (Oetken and Orwert, 1985 and this volume). Knowledge of the visual orbit, the radial velocity variation of both components and the parallax - the latter introducing the largest uncertainty - leads to a mass of 1.8 solar masses for this cool Ap star.

We will not discuss here the body of circumstantial evidence, from positions in the HRD obtained generally after correcting for the influence of the peculiarities on the stellar flux distribution and interpreted with the use of standard evolutionary tracks. It places the CP stars in the mass range of 1.5 $M_\odot$ for the coolest to over 5 $M_\odot$ for the helium variables.

4. RADII OF CP STARS

The radius of a star is related through the Stefan-Boltzmann law to the total flux emitted by the star and its effective temperature,

$$M_{bol} = 42.31 - 5 \log R(R_\odot) - 10 \log T_{eff}$$

Both the stellar luminosity and T_{eff} are derived generally using the measured flux and its wavelength dependence in a restricted wavelength interval, and model atmosphere predictions outside that interval. A number of specific problems occur in the case of CP stars. Redistribution of ultraviolet flux produces a change in the slope of the Paschen continuum compared with normal stars (Leckrone et al., 1974), broad depressions in the continuum alter its shape, and

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differential line blocking influences the colours. All these factors are variable from star to star, depending on its peculiarity degree, and may be aspect dependent for a given star.

Ultraviolet astronomy has relieved part of the difficulties in obtaining the total stellar flux received at the earth, since at least for the cool and intermediate temperature CP stars the major part of the flux has become directly measurable. Information on the effective temperature may be obtained most accurately probably from the infrared, since our present knowledge indicates the absence of significant flux redistribution into this spectral region and since the IR line blocking is much less severe than at shorter wavelengths.

This is why the infrared flux method (IRFM) developed by Blackwell and Shallis (1977) is favourable. A monochromatic infrared flux $F_{E,\lambda}$ and the total stellar flux $\mathcal{F}_E$ at the earth are needed to solve the two basic equations

$$\sigma T^4_{eff} = (4/\Theta^2)\,\mathcal{F}_E$$

$$F_{E,\lambda} = (\Theta^2/4)\ \phi(T_{eff},g,\lambda)$$

for the angular diameter Θ and for T_{eff}. ϕ relates the dependence of surface flux on the stellar model atmosphere. Shallis et al. (1985) claim an accuracy on Θ of 8%. The conversion to linear radii is much more uncertain because of the less accurate parallaxes. They find in their sample of 9 stars $\langle R\rangle = 2.4 \pm 1.3$ (s.d.) R_o, and compare this to a mean value of 2.1 R_o obtained from normal stars of similar spectral types. The method is recently also applied by Lanz (1985).

Babu and Shylaja (1981) used observed fluxes in the wavelength interval 4000 -7800 Å and bolometric corrections related to T_{eff} for obtaining with a similar formalism radii for 23 Am and 69 CP2 stars. Their angular diameters for the 9 stars of Shallis et al. (1985) scatter around the IRFM results with a standard deviation of 17%. Their mean radii are 2.2 ± 0.6 (s.d.) R_o for Am stars and 2.9 ± 0.8 (s.d.) R_o for CP2 stars.

An indirect method for determining radii which has been applied with some success to diverse objects is based on the Barnes-Evans relation (Barnes et al., 1978). This relation has been established from a sample of stars having their radii estimated by more fundamental methods, mostly by lunar occultations. It is based on the correlation between the colour index determined from Paschen continuum measurements (reddening corrected V-R) and the surface brightness parameter, which in turn is related to the angular diameter of the star. In this way, the angular diameter of a star is found from photometric parameters alone.

Shore and Adelman (1979) conclude that the method may be useful to provide a first estimate for the radius, but cannot be applied with confidence indiscriminantly of the peculiar spectral characteristics of the CP stars. They find for individual stars significant discrepancies with radii determined from oblique rotator arguments (see further in this section), although the mean radius for their sample is in close agreement for both methods (2.7 ± 1.1 (s.d.) R_o on application of the Barnes-Evans relation, 2.5 ± 1.0 R_o from the oblique rotator model).

An alternative method for estimating radii of CP stars is based on the oblique rotator model. In particular the magnetic stars show light and spectrum variations which are modulated by the rotation period, P_{rot}. The rotation period is related to the radius R by

$$P_{rot}\, v_{eq} = 2\pi R,$$

so that R sin i is known when also the contribution of rotational broadening to the line widths is determined:

$$R \sin i = P_{rot}\, (v \sin i) / 50.613$$

when R is expressed in solar radii, P_{rot} in days and the apparent rotation velocity v sin i in km/s.

This relation has been used to derive a mean radius of samples of CP2 stars assuming a random orientation of the rotational axes relative to the line of sight. It may also be used for estimating radii of individual stars if sin i can be determined e.g. from magnetic field data when both H_e and H_s have been measured throughout the rotation cycle.

All mentioned methods agree statistically, in the sense that they add evidence to the conclusion that the radii of CP stars as a group are roughly equal or somewhat larger than those expected for main sequence stars of similar spectral type. More accurate individual radii may be expected after data of the Hipparkos project become available. Hipparkos satellite observations will extend the parallax horizon up to 75 parsec.

5. CP STARS IN CLUSTERS

The presence of CP stars in open clusters and associations has received an increasing attention in the last decade for both practical and theoretical reasons. From a practical point of view, an alternative to the time-consuming detection of CP stars by means of spectroscopic classification has been developed. The starting point of the photometric searches for CP stars is the recognition of the 5200 continuum depression as detection criterion for magnetic CP stars (Maitzen, 1976; see also Maitzen and Vogt, 1983). The detection probability is almost 100% for the silicon stars and the Sr-Cr-Eu stars hotter than spectral type A5, but diminishes significantly outside the corresponding temperature interval.

Photometric searches for CP stars are undertaken recently by Borra and coworkers (Joncas and Borra, 1981; Borra et al., 1982), by North and coworkers (North and Cramer, 1981; North, 1984; North and Waelkens, 1983; North, this volume), and by Maitzen and coworkers (Maitzen and Hensberge, 1981; Maitzen and Floquet, 1981; Maitzen, 1982; Maitzen and Wood, 1983; Maitzen and Schneider, 1984).

Borra and colleagues detected 3.5% of CP2 stars in the young Orion OB1 association, a percentage significantly lower than in the field. These stars have magnetic fields on the average a factor three stronger than the older stars (Borra, 1981). In this association as well as in Upper Scorpius, they find a relatively low peculiarity degree. They advanced the hypothesis that the frequency of Ap stars in the field would be reached ultimately in these associations when the helium-weak stars would develop classical Ap characteristics with time.

North and Cramer (1981) gave already a summary of their results in 36 clusters at the 23rd Liège Colloquium, using the Geneva Δ(V1-G) index as detection criterion. Since then, an important effort has been done to measure photometric periods for CP stars in clusters, to infer directly the importance of magnetic braking. They find no evidence for rotational braking on the main sequence, except for that expected from the conservation of angular momentum during the stellar evolution (North, this volume), a result that is recently confirmed by Borra et al. (1985).

Maitzen and colleagues concentrate on the detection of CP2 stars in a sample as large as possible, in order to obtain statistically significant results. Most of their work is presently unpublished. A summary of the meanwhile published results may be found in Hensberge et al. (1983). Additional clusters observed include IC 4725, NGC 5460, NGC 6087, NGC 1039, NGC 7092 (submitted papers) and NGC 225, 2232, 2244, 2264, 2301, 2323, 2343, 2437, 2447, 2451, 2547, 2548, 3114, 3532, 3766, 4103, 6231, 6871, 7160, IC 2391, 2395, 2602, Stock 2, Collinder 140, Trumpler 2 and 10, alpha Persei, Coma Berenices and the Plejades.

The most recent spectroscopic results are from Abt (1979) and Klochkova and Kopylov (1984 and this volume). Abt (1979) supported the occurrence of rotational braking on the main sequence, for magnetic stars, and has "the visual impression that the strengths of the peculiarity increases with time on the average". Klochkova and Kopylov, defining a quantitative spectroscopic peculiarity parameter and studying a larger sample, don't find any indication for a gradual change of peculiarity, rotational velocity or magnetic field strength during the main sequence life time.

The main theoretical reason for studying CP stars in clusters is the introduction of the parameter <u>time</u> in the empirical data set for these stars. Presently, simple, undisputable correlations with stellar age are not established. This may be due to several reasons. Firstly, it might be interpreted as evidence that the characteristic time scales of the involved processes are short i.e. the star reaches the main sequence as a full-grown peculiar star. In this case, by studying main sequence stars nothing can be learned about the order in which the different peculiarities develop (magnetic field decay or built-up, rotational braking, overabundances, spots...). Secondly, it might be interpreted as evidence that stellar individuality destroys any clear-cut correlation with age, although all physical processes involved are likely to be time-dependent. Among the factors that could be considered to produce this individuality are the star's environment and its chemical maturity which may be function of initial conditions and the way the interaction with the environment occurred. As a result, star-to-star, and thus also cluster-to-cluster differences can be expected. Such systematic difference on the level of clusters is claimed by Abt (1979) for the Am stars at a 85% confidence level.

With this in mind, Abt and Cardona (1983) considered an alternative approach. Instead of studying clusters, they determine the frequency of CP secondaries in binaries with O5-A1 main sequence primaries and secondaries in the absolute magnitude range of CP stars. The motive is that most field stars are escapees from the gradual desintegration of clusters, so that the condition of averaging out over many clusters is better fulfilled and the influence of stellar individuality is minimized. Although constrained by low number statistics, and by the fact that for the primaries only an upper limit of their age is known, the evidence is interpreted as support for an enhancement of the frequency of CP stars with time.

The conflicting conclusions of recent investigations clearly show that the situation is more complicated than perhaps hoped for originally. Much more empirical data and a more general approach, including other parameters than time, seem to be needed.

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Discussion appears after the following paper.

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