Statistical analysis of the influence of binarity on the Ap phenomenon. Progress report

J. Budaj[1], V.G. Elkin[2], I.I. Romanyuk[2], G.A. Wade[3], J. Ziznovsky[1], J. Zverko[1]

[1] Astronomical Institute, Slovak Academy of Sciences, 05960 Tatranska Lomnica, The Slovac Republic
[2] Special Astrophysical Observatory of the Russian AS, Nizhnij Arkhyz 357147, Russia
[3] Astronomy department, Univ. of Western Ontario, London, Ontario, Canada N6A 3K7

Abstract. We support and deepen our recent findings that a gap at about $3 \cdot 10^2$ days occurs in the orbital period distribution (OPD) of Ap binaries and that this inconspicuous feature becomes, at the same time, a breaking point in an increasing behaviour of λ5200 depression as well as magnetic filed strength with orbital period, P^{orb}. Both latter quantities are uncovered to exhibit even much more pronounced decline with the eccentricity of the orbit but only if the stars on the short period side of the gap are considered. The other stars rather obey the reversed rule. It is also pointed to a controversial fact that although the Ap phenomenon is getting on well at circular orbits, on the other hand, there are a number of high eccentric orbits still at rather short periods ($P^{orb} > 5^d$).

The main lesson to be learned from this contribution is that the physical characteristics of the Ap binaries including their magnetism are governed by the stellar binarity.

1 Motivation

The backbone of the research of CP stars is their modern classification scheme by Preston (1974). He clearly distinguished a non-magnetic sequence of CP1 and CP3 (Am and HgMn) stars as well as a magnetic sequence of CP2 (Ap) and some CP4 (He-weak) stars. Table 1 summarizes the well-known basic facts about the most populated CP1 and CP2 groups along with the physical processes invoked for their explanation. While, at present, we have at hand some explanation of the origin of abundance anomalies or slow rotation of these stars it is not the case of their magnetic fields and binarity both of which are often referred among the primordial causes of CP peculiarity. However, no account for CP stars in their totality can be final, which leaves these mentioned distinguishing characteristics completely disregarded. The apparently reversed appearances of magnetic fields and binarity in Am and Ap stars suggest close relation of these quantities, which, if confirmed, might push our understanding of CP phenomenon much deeper.

2 Introduction

First indication of Babcock (1958) stimulated Abt and Snowden (1973) to the pioneering and still fundamental work favouring a connection between magnetism and binarity. Magnetic Ap stars turned out to rarely occur in binaries while non-magnetic Am stars are dominantly short-period ones. Later on Gerbaldi et al. (1985) extending the study of Floquet (1983) confirmed the lower frequency of binaries among hot Ap (37%) stars but not for cool Ap stars (46%) when comparing to

Table 1: A summary of some basic CP distinguishing characteristics and the potential causes of theirs.

characteristics	Ap	Am	We have at hand ...
abundance anomalies	Yes	Yes	diffusion, conv. zones, winds, mag. fields, slow rotation
slow rotation	Yes	Yes	rot. induced mixing, binarity
mag. fields	Yes	No	NO IDEA
binarity	No	Yes	

the expected standard value of 47% on the main sequence (Jaschek and Gomez, 1970). They even first pointed out that the $\Delta(V_1 - G)$ photometric index reaches the highest values for low eccentricities of the orbits if long periods $P_{orb} < 200^d$ are excluded. This was, however, built only on two points at low eccentricities. Recently, North (1994) obtained again a much lower percentage of cool Ap stars among binaries — 19% which is close to that of Abt and Snowden (1973). Further studies of Seggewiss (1981, 1993), Gerbaldi et al. (1985) and Lebedev (1987) confirmed the lack of short periods, the lack of circular orbits, lower SB2/SB1 ratio and Lebedev also found a predominance of orbits with smaller amplitudes of radial velocities as well as no correlation between inclinations of rotation and orbital axes in Ap binaries. All this rouses our suspicion, supporting again completely reversed binary characteristics of Am and Ap stars, on an interplay of stellar binarity and magnetism.

In connection with this Budaj (1994, 1996a,b) showed already that the physical characteristics of Am binaries gained a new dimension — the dependence on the orbital period of the binary. Their orbital periods were splitted by a 180 - 800^d unpopulated gap into two areas (see also Abt, 1965). The gap seemed to be also a break in the smooth decreasing behaviour of δm_1 index towards larger orbital periods (i.e. increasing of metallicity) for $P_{orb} < 180^d$ because such a behaviour did not continue on the other side of the gap. In his subsequent analysis of Ap binaries (Budaj, 1995) he points to the presence of an analogous period gap, to a possible analogous dependence of $\Delta(V_1 - G)$ index and magnetic field strength on the orbital period (like δm_1 in Am's) as well as to the fact that both quantities were seeming to decrease with eccentricity. This analysis was based on Seggewiss (1993) data who considers just the Ap binaries listed in the Eighth Catalogue of Orbital Elements of SB Systems (Batten et al., 1989) i.e. on the best available critical source of orbital parameters. Nevertheless, a more complete list of Ap binaries can be derived from the catalogue of Ap stars by Renson et al. (1991).

In the following we aim at rerevision of the above analysis using the latter source of data which is intended to be a starting point of a more detailed study (in progress) of the interplay between stellar magnetism and binarity. A more complex research should not disregard an investigation of possible:

- anomalies in orbital parameters, mass ratio and ages,
- dependence of Ap peculiarity on orbital parameters,
- as well as that of rotational characteristics including differential rotation,
- influence of circularization, synchronization as well as pseudo-synchronization mechanism on the Ap phenomenon and so on ...

Thus, a lot of work is ahead and we will try to address, at least, partially to some of these points below.

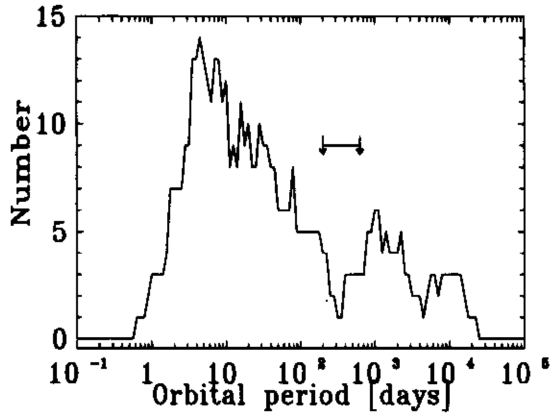

Figure 1: OPD of 50 BpAp binaries. Arrows indicate the width of the smoothing window.

3 Sample stars

Most of the data analyzed here are extracted from the database of Renson et al. (1991) apart from the mean effective magnetic field. This was taken from Glagolevskij et al. (1986). The following rules were obeyed to avoid any ambiguity when compiling the sample of stars: we carefully selected all the binary components of Si, Sr, Cr or Eu peculiarity within B5-F5 spectral type along with a few binaries of mixed peculiarity (Si, Sr, Cr or Eu accompanied by e.g. He-w, Hg or Mn) if the latter exhibited also either light-spectral variations or detected magnetic field. For suspected triple systems we left out the orbital periods of third bodies. All these were then complemented by the recent data from North (1994) and Wade et al. (1996). Due to the scarcity of data it probably does not make a sense to distinguish between cool and hot CP2's, at present, but although the resulting sample is a little inhomogeneous the great majority of objects are within B9-A1 spectral types. The total number of Ap binaries included is thus 50.

4 Orbital periods and eccentricities

Let us start with the orbital period distribution (OPD) of Ap binaries. It is displayed in Fig. 1 and represents the number of periods falling within 0.5 wide intervals (in $\log P_{orb}$) plotted versus their centers. A gap at $3 \cdot 10^2$ days is not much pronounced but is still the most apparent feature of this distribution which supports our earlier findings. There is just one star, the well-known Ap binary HD 9996, within $160\text{-}630^d$ interval. While the mentioned period gap is a common feature of Ap and Am binaries the distributions of eccentricities seem rather different. The eccentricities of magnetic stars (Fig. 2) do not seem to be effectively circularized and high eccentric orbits are present at the orbital periods as short as 5 days comparing to about 9 days in Am's (Budaj, unpublished) or to normal binaries (see e.g. Gerbaldi et al., 1985). Thus the lack of circular orbits is not probably only due to missing short period binaries but rather there is not enough time for the circulation mechanism, or Ap binaries themselves are selected by the nature to have such eccentricities for some reason.

5 $\Delta(V_1 - G)$ versus orbital period and eccentricity

One can study another important characteristic of Ap stars, $\Delta(V_1\text{-}G)$ photometric index, measuring the λ5200 depression. The larger is the above index the more pronounced is this Ap anomaly. We

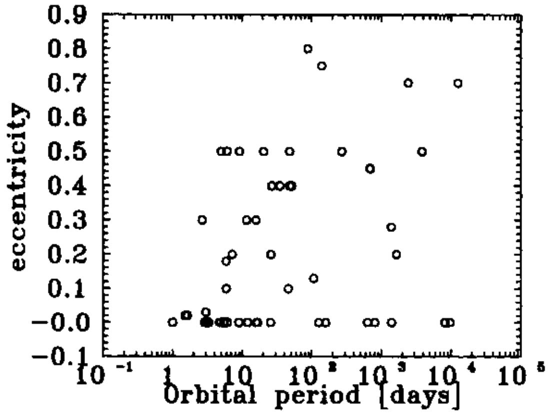

Figure 2: Eccentricity versus orbital period.

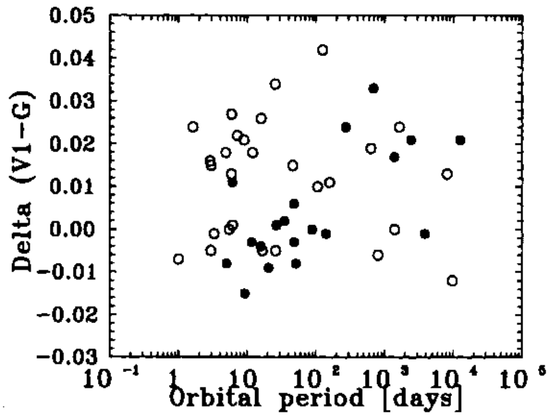

Figure 3: $\Delta(V_1 - G)$ versus $P_{\rm orb}$ for BpAp binaries.

start with plotting this quantity versus orbital period as seen in Fig. 3. One might feel a tendency of increasing Ap peculiarity with P_{orb} spreading from short periods up to the period gap while it looks reversed on its opposite side. Unfortunately, this behaviour is not very convincing but resemble very much that of δm_1 index in Am binaries (Budaj, 1996b) which emphasizes significance of this feature. To speak in more objective terms, we have calculated Pearson's linear (r_l) as well as Spearman's rank order (r_s) correlation coefficients together with their two-sided significances or p-values (p_l, p_s, see Press et al., 1986 for further details). The latter simply represents the probability of appearance of a better correlation coefficient than that found here under the assumption that the quantities $\Delta(V_1 - G)$ and $\log P_{orb}$ do not correlate at all (the so-called null hypothesis). Generally — but it depends on your choice or degree of pessimism — a p-value less than about 0.05 is accepted as a serious support for the presence of the correlation. We see from Table 2, column 2, that neither the correlation coefficients on the left side of the period gap are large nor their significances can favour a correlation. However, this is not a full story and not a reason for giving up. A possible correlation might be easily smoothed by some other mechanism and, in connection with this, please, note a remarkable fact that high eccentric orbits ($e > 0.2$) clearly occupy the bottom of Fig. 3 for $P_{orb} < 160^d$ emphasizing, at the same time, possible P_{orb} dependence. On the long period side of the gap, however, the opposite seems true.

This motivates a search for eccentricity dependence. Corresponding situation is illustrated in

Table 2: Correlation coefficients for the relation between $\Delta(V_1 - G)$ versus $\log P_{orb}$ ($P_{orb} < 160^d$) and eccentricity together with corresponding significances.

$\Delta(V_1 - G) \times \log P_{orb}$			$\Delta(V_1 - G) \times e$	
	Fig. 3	Fig. 5	$P_{orb} < 160^d$	$P_{orb} > 160^d$
r_l	0.03	0.43	-0.49	0.52
p_l	0.87	0.011	0.003	0.08
r_s	-0.05	0.33	-0.64	0.34
p_s	0.80	0.050	$4\,10^{-5}$	0.28

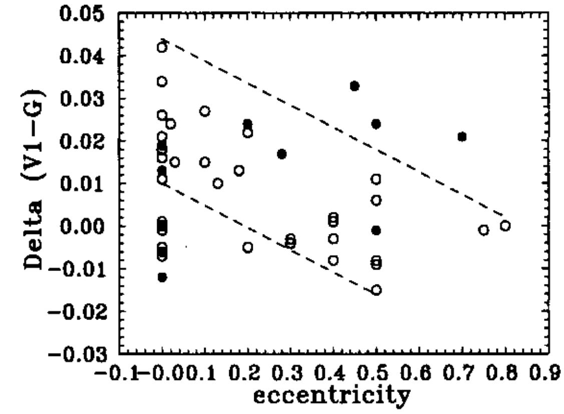

Figure 4: $\Delta(V_1 - G)$ versus eccentricity of the orbit.

Fig. 4 and does not look very promising again. Fortunately, we know now that the stars occupying different sites of the period gap should be distinguished from one another. Performing the task we see that the situation has changed immediately. While the stars, coming from the left hand side of the period gap, exhibit apparent and significant anticorrelation with eccentricity, the stars from the other hand side of the gap seem to behave just opposite. For corresponding statistics check e columns 4-5 of Table 2. This allows us to calibrate the dependence of $\Delta(V_1 - G)$ on eccentricity and consequently to remove it when studying other effects. As a preliminary approximation from the sketched boundary lines in Fig. 4 we accepted:

$$\frac{\partial \Delta(V_1 - G)}{\partial e} = -0.052 \qquad (1)$$

and calculated $\Delta(V_1 - G)_{e=0}$ values which are referred to zero eccentricity.

$$\Delta(V_1 - G)_{e=0} = \Delta(V_1 - G) + 0.052e. \qquad (2)$$

We take a benefit from this and jump in feet back to Fig. 3 where we studied the P_{orb} dependence. Once $\Delta(V_1 - G)$ is replaced by $\Delta(V_1 - G)_{e=0}$ on the left side of the period gap one can realize immediately (Fig.5) that a significant correlation with P_{orb} is emerging (see column 3, Table 2).

6 Magnetic field versus orbital period and eccentricity

The situation is now ripe for reinvestigation of the interplay between magnetic field and binarity. Effects similar to those uncovered above might be expected here because there is a sort of corre-

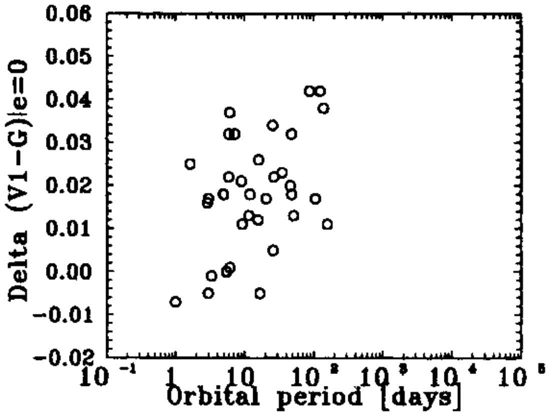

Figure 5: $\Delta(V_1 - G)_{e=0}$ versus $P_{\rm orb}$ with the eccetricity dependence removed for $P_{\rm orb} < 160^d$.

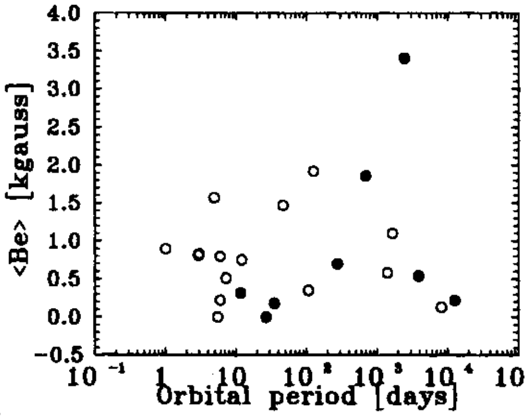

Figure 6: Mean effective magnetic field $< B_e >$ as a function of $P_{\rm orb}$ of BpAp binaries.

lation between λ5200 depression and magnetic field strength (Hauck, 1975; North, 1980; Cramer and Maeder, 1980; Hauck and North, 1982; Lebedev, 1988; Romanyuk 1986; Glagolevskij, 1994). Unfortunately, the magnetic observations are still rather rare among Ap binaries although most of them are rather bright stars. In the following we accept the mean effective magnetic field, $< B_e >$, (see Glagolevskij et al., 1986) as a magnetism parameter. Really, the behaviour of $< B_e >$ versus P_{orb} (Fig. 6) seems analogous to that of Fig. 3 including the behaviour of high eccentric orbits ($e > 0.2$) which imply lower (higher) field on the left (right) side of the period gap. However, also here, this P_{orb} dependence is not significant when speaking strictly in terms of statistics (see column 2, Table 3) and we proceed to inspect the eccentricity dependence in Fig. 7. Guided by the $\Delta(V_1 - G)$ scenario we distinguished stars on different sides of the period gap and the originally unpromising picture turned clear right away. The significant decline of $< B_e >$ with eccentricity for $P_{orb} < 160^d$ has emerged accompanied with just the opposite tendency for $P_{orb} > 160^d$ (see columns 4, 5 of Table 3). If one estimates from the last picture (dashed line)

$$\frac{\partial < B_e >}{\partial e} = -4.5 \qquad (3)$$

and allows for it when studying P_{orb} dependence, then the latter becomes much more pronounced (Fig. 8) and significant (column 3 of Table 3).

Table 3: Correlation coefficients for the $< B_e >$ versus $\log P_{\rm orb}$ ($P_{\rm orb} < 160^d$) and eccentricity together with corresponding significances.

	$< B_e > \times \log P_{\rm orb}$		$< B_e > \times e$	
	Fig. 6	Fig. 8	$P_{\rm orb} < 160^d$	$P_{\rm orb} > 160^d$
r_l	0.12	0.50	-0.55	0.44
p_l	0.67	0.06	0.03	0.27
r_s	-0.14	0.55	-0.77	0.17
p_s	0.62	0.03	$8\,10^{-4}$	0.69

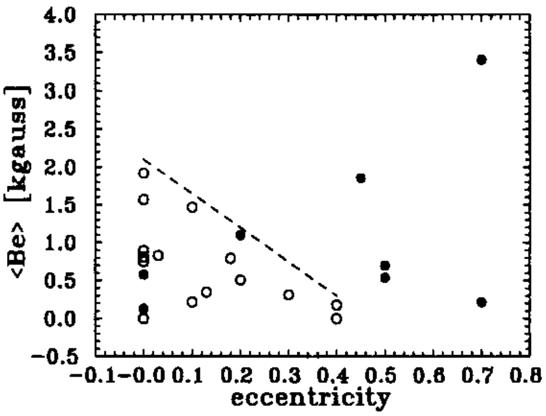

Figure 7: $< B_e >$ as a function of eccentricity of the orbit.

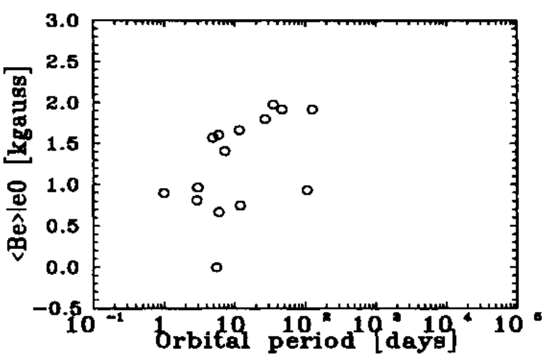

Figure 8: $< B_e >_{e=0}$ versus $P_{\rm orb}$. The same as in Fig. 6 but with the eccentricity dependence removed for $P_{\rm orb} < 160^d$.

7 Brief discussion

One can suggest a very natural empirical explanation which could qualitatively catch both P_{orb} as well as eccentricity dependences on both sides of the period gap. Namely all this might be a manifestation of one dependence on periastrum distance which would proclaim a growing peculiarity (with the distance) up to the period gap and a sinking one behind it. Unfortunately, it is not so promising quantitatively as the scatter in $\Delta(V_1 - G)$ seems large enough to be straightened by this effect.

Further accounts on the very pronounced behaviour of peculiarity, on e.g. eccentricity, might put some constraints also on further processes proposed in Ap stars. If there really are such strict eccentricity dependences as seen in Figs. 4 and 7, this would imply that e.g. evolutionary (Glagolevskij, 1996) or rotation velocity effects (Landstreet et al., 1975; Borra and Landstreet, 1980; Hauck and North, 1982) are not strong enough to smooth it and that binarity effects are at least as important as the previous ones.

The controversial fact that (1) although the Ap phenomenon is more pronounced at low eccentricities but such orbits are lacking as well as that (2) there is an apparent deficiency of short periods and that (3) rotational and orbital axes are not parallel and that (4) SB2/SB1 ratio is pretty low indicate that *an Ap star may endure just limited "working hours" of tidal effects of certain intensity or is not allowed to develop under such conditions.* The mentioned conditions in a binary can well be characterized by the orbital parameters, mass ratio and age of binary systems. It might be then an attractive idea that even typical "non-binary" stars (in parenthesis as it is always relative what is a non-binary), such as Ap stars, could be understood as in the framework of binaries when we ascribe to them some special-limiting binarity parameters.

Finally, we would like to stress that very similar and analogous features to those mentioned above are found in Am binaries as well. Thus both samples exhibit the same sign, probably, of the same not well-known puzzling processes acting on large distances between the companions. Perhaps Tassoul & Tassoul (1992) retardation-synchronization mechanism or empirical tidal mixing + stabilization hypothesis of Budaj (1996a) can shed more light on this interesting problem in the future.

8 Conclusion

Let us stop at this point and summarize the main results rather then pursue the above ideas deeper. We confirmed on a more elaborated statistical backgroud and larger sample the finding of Budaj (1995) that the physical characteristics of Ap binaries depend on orbital parameters. Namely both $\Delta(V_1 - G)$ and $< B_e >$ increase with orbital period on the short period side of the period gap while the opposite seems true on the other long period side. Both quantities exhibit even much more pronounced decline with eccentricity but also only if the stars with $P_{orb} < 160^d$ are considered. The rest rather obey the reversed rule. This emphasizes the occurrence of the period gap itself ascribing to it, at the same time, the role of a breaking point in the behaviour of fundamental Ap characteristics.

Acknowledgements. This work was supported by the VEGA grant No. 1002. Part of this work was done during a stay of J.B. at the SAO and he acknowledges the invitation of Dr. Yu. Balega and the support of Dr. Yu. Glagolevskij as well as the hospitality of all SAO people.

References

Abt H.A.: 1965, Astrophys. J. Suppl. Ser., **11**, 429.
Abt H.A., Snowden M.S.: 1973, Astrophys. J. Suppl. Ser., **25**, 137.
Babcock H.W.: 1958, Astrophys. J. Suppl. Ser., **3**, 141.

Batten A.H., Fletcher J.M., MacCarthy D.G.: 1989, Eigth Catalogue of Orbital Elements of SB Systems, Publ. Dominion Astrophys. Obs., 17.

Borra E.F., Landstreet J.D.: 1980, Astrophys. J. Suppl. Ser., 42, 421.

Budaj J.: 1994, poster at 22-nd General Assembly Meeting, The Hague.

Budaj J.: 1995, in: Strassmeier K.G. (ed.), "Stellar Surface Structure — Poster Proceedings from IAU Symp.", 176, 147.

Budaj J.: 1996a, Astron. Astrophys., (in press).

Budaj J.: 1996b, Astron. Astrophys., (in press).

Cramer N., Maeder A.: 1980, Astron. Astrophys. Suppl. Ser., 41, 111.

Floquet M.: 1983, in: "Les journees de Strasbourg", Verne Reunion, Observatoire de Strasbourg, 83.

Gerbaldi M., Floquet M., Hauck B.: 1985, Astron. Astrophys., 146, 341.

Glagolevskij Yu.V.: 1994, in: Zverko J. and Ziznovsky J. (eds.), "CP and magnetic stars", Astronomical Institute, Tatranska Lomnica, Slovakia, 102.

Glagolevskij Yu.V.: 1996, in this proceedings.

Glagolevskij Yu.V., Romanyuk I.I., Chunakova N.M., Shtol' V.G.: 1986, Astrofiz. Issled. (Izv. SAO), 23, 37.

Hauck B.: 1975, in: W.W.Weiss, H. Jenkner, H.J. Wood (eds.), "Physics of Ap Stars", Vienna, 365.

Hauck B., North P.: 1982, Astron. Astrophys., 114, 23.

Jaschek C, Gomez A.E.: 1970, Publ. Astr. Soc. Pacific, 82, 809.

Landstreet J.D., Borra E.F., Angel J.R.P., Illing R.M.E.: 1975, Astrophys. J., 201, 624.

Lebedev VS.: 1988, Ph. D. thesis.

Lebedev V.S.: 1987, Astrofiz. Issled., (Izv. SAO), 25, 41.

North P.: 1980, Astron. Astrophys., 82, 230.

North P.: 1994, in: "Proceedings from the 25th workshop and meeting of European working group on CP stars", 3.

Press W.H., Flannery B.P., Teukolsky S.A., Vetterling W.T.: 1986, Numerical Recipes, Cambridge Univ. Press, Cambridge.

Preston G.W.: 1974, Annu. Rev. Astron. Astrophys., 12, 257.

Renson P., Kobi D., North P.: 1991, Astron. Astrophys. Suppl. Ser., 89, 61.

Romanyuk I.I.: 1986, Ph.D. thesis.

Seggewiss W.: 1981, in: "Les etoiles de composition chimique anormale du debut de la sequence principale", Inst. d'Astrophysique, Univ. de Liege, 183.

Seggewiss W.: 1993, in: Dworetsky M.M., Castelli F., Faraggiana R. (eds.), "Peculiar Versus Normal Phenomena in A-type and Related Stars", A.S.P.C.S., 44, San Francisco, 137.

Tassoul J.L., Tassoul M.: 1992, Astrophys. J., 395, 259.

Wade G.A., North P., Mathys G., Hubrig S.: 1996, Astron. Astrophys., (in press).