The effects of binarity in driving CP phenomena

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Abstract. A lot of evidence has recently accumulated that physical characteristics of CP stars (δm_1, Ca/Fe ratio, Li abundance, distribution of orbital periods, $v \sin i$, $\Delta(V1-G)$, magnetic field) depend on orbital period or eccentricity. Consequently, the "tidal mixing + stabilization" hypothesis has been formulated to account for such features and the "binarity $\times$ magnetism" hypothesis of Abt & Snowden (1973) was reanalyzed. We conclude that all mentioned characteristics and properties of CP stars, including even CP star magnetism, may be affected or governed by binarity.

1. Motivation or "binarity $\times$ magnetism" hypothesis

The backbone of the current research of CP stars is their modern classification scheme by Preston (1974). He clearly distinguished a non-magnetic sequence of Am and HgMn stars as well as a magnetic sequence of Ap and some He-weak stars. While, at present, we have at hand some explanation of most of the CP star distinguishing characteristics like the origin of abundance anomalies and slow rotation of these stars, this is not the case of their magnetism and binarity. Both of these phenomena are often referred to as primordial reasons for CP peculiarity in the corresponding area of the HR diagram. Nevertheless, it is slow rotation which is generally accepted as a more direct reason for the CP phenomenon and which is closely related to the primordial causes, namely, being a result of tidal or magnetic breaking mechanisms (Abt 1965, 1979, Wolff 1983). The reason for these primordial causes is however not very clear, and this is just what we aim to touch in these studies. The pioneering works of Abt (1961) and Abt & Snowden (1973) completed and reanalyzed e.g. by Abt (1965), Floquet (1983), Abt & Levy (1985), Gerbaldi et al.(1985), Lebedev (1987), Seggewiss (1993), North (1994), North at al. (1998) and many others revealed that the frequency of occurrence among binaries is much higher for Am than for Ap stars, short period orbits are much more frequent in Am than in Ap ones and the N(SB2)/N(SB1) ratio is higher in Am's than in Ap's. The reversed appearances of magnetism and binarity in Am and Ap stars suggest a possible relationship between these fundamental CP characteristics and we will handle such an idea as a "binarity $\times$ magnetism" hypothesis. It was first suggested by Abt & Snowden (1973). Guided by such motivations we searched (e.g. Budaj 1995, 1996, 1997a, 1997b, Budaj et al. 1997, Iliev et al. 1998) for the various possible imprints of a stellar companion on the CP star.

Contrib. Astron. Obs. Skalnaté Pleso **27**, (1998), 218– 222.

2. Imprint 1: orbital periods of Am and Ap binaries

The orbital period distribution (OPD) of Am's was compared with that of corresponding normal binaries. It seems that:
– Am binaries do not have orbital periods less than $\approx 1.2^d$, except for a few stars, which is not the case of normal ones (also e.g. North et al. 1998).
But the most interesting puzzle is:
– a gap in the OPD of Am's between 180 and 800 days [1],
– which center is replaced by a peak in the OPD of normal stars (5 of them).
– Such a dip (160 – 600 days) was also found in the OPD of Ap binaries.

3. Imprint 2: rotation of Am binaries

Based on the current view on Am stars, one would expect a horizontal dividing line at about $\approx 100\ \mathrm{km\,s^{-1}}$ which would separate Am from normal stars in a plot of equatorial rotation velocity versus P_{orb}. We analyzed the $v \sin i$ versus P_{orb} dependence for Am binaries and the most interesting results are:
– there is an apparent area of synchronization at the short periods;
– the maximum rotational velocity allowed for an Am star, V_{max}, is not a constant but an increasing function of P_{orb} in the range $4^d < P_{orb} < 20^d$;
– only for the longer periods ($P_{orb} > 20^d$), V_{max} acquires a constant value of about $75\ \mathrm{km\,s^{-1}}$;

4. Imprint 3: metallicity and lithium in Am binaries

We accepted the δm_1 index, Ca/Fe ratio (ratio of the equivalent width of Ca I 6717 and Fe I 6678 lines) and Li abundance as the metallicity or peculiarity indicators. The smaller the δm_1 or Ca/Fe, the larger the metallicity or peculiarity. It turned out that:
– the δm_1 index decreases with the orbital period at least up to $P_{orb} \approx 50^d$ and probably up to $P_{orb} \approx 200^d$;
– the Ca/Fe ratio exhibits a similar tendency, but it is not well defined due to the rather small number of stars;
– the lithium abundance may also decrease with P_{orb} but, like in the case of Ca/Fe, it is not well defined.
The dependence on eccentricity seems even more pronounced because:
– the Ca/Fe ratio decreases with eccentricity;
– the Li abundance decreases with eccentricity;
– δm_1 decreases with eccentricity (mainly in the interval $10^d < P_{orb} < 180^d$).
Moreover, the δm_1 index exhibits a very interesting behaviour in the diagram

[1] Abt (1965) already noticed the dip near 100 days in the OPD of Am's. But, at that time, he could only conclude that it "may not be real" and it has not been mentioned any longer.

$v \sin i$ versus P_{orb} or $v \sin i$ versus instantaneous orbital period at periastron:
– the curve of constant metallicity, $M_{const.}$, is a function of P_{orb} and is parallel to the V_{max} curve!

5. Imprint 4: the $\lambda 5200$ depression and magnetic fields in Ap binaries

We studied the $\Delta(V1-G)$ index which is related to the $\lambda 5200$ depression and mean effective magnetic field, $< B_e >$ (e.g. Glagolevskij et al. 1986). The larger the $\Delta(V1-G)$ index, the more pronounced the depression. We have succeeded in disentangling the e and P_{orb} dependences and discovered that:
– both $\Delta(V1-G)$ and $< B_e >$ decrease with eccentricity if $P_{\rm orb} < 160^d$ [2];
– both parameters also very probably increase with P_{orb} if $P_{\rm orb} < 160^d$, while the trend seems opposite at the larger P_{orb} beyond the period gap.

6. Discussion, interpretation and disentangling

It is hardly possible to explain most of the above-mentioned points in the framework of current views on CP stars, i.e. as a result of slow rotation and magnetism in the corresponding area of the HR diagram, reducing the role of binarity effects just to slowing down the rotation. In the following we briefly summarize our interpretation of the above points.

We showed that the lower boundary of about $P_{\rm orb} \approx 1.2^d$ in the OPD of Am's corresponded to the semidetached systems with the Am stars radii $R = 3R_\odot$. One cannot, however, exclude that the Am phenomenon is disturbed slightly before the Roche lobe is filled in what would then result in a little lower radii of Am stars. Consequently, the Am stars' rotation in this area of synchronization could be limited by its orbital period (at some fixed stellar radius) rather than by the generally accepted critical rotation velocity of about 100 km s^{-1}.

We argue that a decrease of δm_1, Ca/Fe, or Li abundance (i.e. increase of peculiarity) with $P_{\rm orb}$ could be explained by the hypothesis on "tidal mixing + stabilization". We propose the mechanism of tidal mixing which acts to smooth the chemical anomalies built by diffusion. It gets more intensive when the components are closer and weakens when (pseudo-)synchronization is approached. The fact that the increase of peculiarity is observed only in a limited range of orbital periods (up to $P_{orb} \approx 50^d$ or $P_{orb} \approx 200^d$) gives rise to the idea of some kind of stabilization mechanism within this range. The latter arises because, without some "stabilization", the peculiarity or chemical anomalies should progressively increase with P_{orb} up to infinite P_{orb} and, at the same time, approach the status of "single" stars, which is not observed.

[2] A decrease of $\Delta(V1-G)$ with eccentricity was already indicated by Gerbaldi et al. (1985).

The behaviour of the V_{max} curve, which is not a constant but a function of P_{orb}, sheds more light on the well known overlap in rotation velocities of normal and Am stars for $40 < v < 100$ km s^{-1} (Abt & Hudson 1971) or the deficiency of normal stars for $P_{orb} > 2.5^d$ (Abt & Bidelman 1969) because it intersects the $R = 2.1\,R_{\odot}$ synchronization curve at $v = 35$ km s^{-1} and $P_{orb} = 3^d$. The parallel behaviour of the $M_{const.}$ and V_{max} curves is hardly an accident but it is rather a natural consequence of the idea that each curve corresponds to different intensity of turbulence in the v versus P_{orb} diagram.

The fact that there is a peak in normal stars within the period gap in Am's supports the presence of the mentioned gap. [3] Thus, three independent samples (Am, Ap, normal A4-F1) indicate that there might be some breaking point in the (magneto)hydrodynamics of an AV-type binary at the orbital period of several hundred days. We suggest the "tidal mixing + stabilization" hypothesis to account for this gap and propose that there is a peak in the turbulence within the period gap so that the He superficial convection zone cannot disappear due to He settling. This could result in the observed pattern of all three samples.

Finally, our findings that the degree of peculiarity in Ap's depend on orbital elements strongly supports the "binarity $\times$ magnetism" hypothesis and we can conclude that magnetism, as a necessary condition for Ap phenomena, is (1) affected by binarity or (2) the opposite. In fact, this second possibility cannot be definitely excluded based on the above arguments (including those mentioned in Sect. 1) only. Abt & Snowden (1973) preferred just this possibility and suggest e.g. that "for those Ap stars having strong magnetic field, the formation of binaries with separation $10^6 - 10^9$ km is inhibited ...". Nevertheless, the second possibility seems to be more complicated and thus more unlikely in the light of our recent findings, due to a rather complex behaviour of Ap peculiarity with respect to orbital elements. Thus, we favor the idea that binarity "governs" the magnetism. At present it is not very clear what could be the reason of such an interplay but one can speculate that (pseudo-)synchronization might play an important role. Generally, the shorter the orbital period, the higher the degree of (pseudo-)synchronization and the binary components tend to rotate as rigid bodies. One can expect that this will suppress the differential stellar rotation, which is thought to drive the magnetism, at least in the case of the Sun. It could then result in a deficit of short periods or an increase of peculiarity with P_{orb} or low frequency of occurrence or low SB2/SB1 ratio in Ap binaries. Even the decrease of their peculiarity with eccentricity could be understood because highly eccentric orbits have higher velocities at periastra than circular ones, thus also a higher degree of pseudo-synchronization. Also it would not be very surprising to observe just the opposite behaviour, i.e. more pronounced anomalies at larger eccentricities or relative enhancement of short period orbits (except for $P_{orb} < 1.2^d$) in non-magnetic Am binaries. Nevertheless, the latter facts could

[3] One could estimate its significance to $1/2^5$ as there are 5 normal stars. The gap in Ap's is also significant approximately at the level of 2σ.

also be explained outside the scope of the "binarity × magnetism" hypothesis as a consequence of the mentioned "tidal mixing + stabilization" hypothesis, since tidal mixing should weaken as pseudo-synchronization approached.

To conclude, there is for the first time reliable observational evidence (except for synchronization and circularization) that the hydrodynamics or magneto-hydrodynamics of a "detached binary" component is affected by its companion in a surprisingly broad interval of orbital elements .

Acknowledgements. I thank the editors for carefull proofreading the contribution. This work has been supported by the VEGA Grant No. 4175.

References

Abt, H.A.: 1961, *Astrophys. J., Suppl. Ser.* **6**, 37
Abt, H.A.: 1965, *Astrophys. J., Suppl. Ser.* **11**, 429
Abt, H.A.: 1979, *Astrophys. J.* **230**, 485
Abt, H.A., Bidelman, W.P.: 1969, *Astrophys. J.* **158**, 1091
Abt, H.A., Hudson, K.I.: 1971, *Astrophys. J.* **163**, 333
Abt, H.A., Snowden, M.S.: 1973, *Astrophys. J., Suppl. Ser.* **25**, 137
Abt, H.A., Levy, S. G.: 1985, *Astrophys. J., Suppl. Ser.* **59**, 229
Budaj, J.: 1995, in *Stellar Surface Structure - Poster Proceedings, IAU Symp. 176*, ed.: K.G. Strassmeier, Institut für Astronomie, Universität Wien, 147
Budaj, J.: 1996, *Astron. Astrophys.* **313**, 523
Budaj, J.: 1997a, *Astron. Astrophys.* **326**, 655
Budaj, J.: 1997b, *Ph.D. thesis, submitted* ,
Budaj, J., Elkin, V.G., Romanyuk, I.I., Wade, G.A., Žižňovský, J., Zverko, J.: 1997, in *Stellar Magnetic Fields*, eds.: Yu.V. Glagolevskij and I.I. Romanyuk, SAO, Moscow, 176
Floquet, M.: 1983, *Les journées de Strasbourg, Véme Réunion, Observatoire de Strasbourg* , 83
Gerbaldi, M., Floquet, M., Hauck, B.: 1985, *Astron. Astrophys.* **146**, 341
Glagolevskij, Yu.V., Romanyuk, I.I., Chunakova, N.M., Shtol, V.G.: 1986, *Izv. SAO* **23**, 37
Iliev, I. Kh., Budaj, J., Zverko, J., Barzova, I.S., Žižňovský, J.: 1998, *Astron. Astrophys., Suppl. Ser.* **128**, 497
Lebedev, V.S.: 1987, *Izv. SAO* **25**, 41
North, P.: 1994, in *Proc. of the 25th workshop and meeting of EWG on CP stars*, eds.: I. Jankovics and I.J. Vincze, Gothard Astrophys. Obs., Szombathely, 3
North, P., Ginestet, N., Carquillat, J.-M., Carrier, F., Udry, S., 1998, these proceedings
Preston, G.W.: 1974, *Ann. Rev. Astron. Astrophys.* **12**, 257
Seggewiss W.: 1993, in *Peculiar Versus Normal Phenomena in A-type and Related Stars*, ed.: M.M. Dworetsky et al., A.S.P.C.S. Vol.44, San Francisco, 137
Wolff, S.C.: 1983, *The A-type Stars: problems and perspectives, NASA SP-463*, CNRS, NASA, Paris, Washington, D.C.