Astron. Astrophys. 326, 655–661 (1997)

ASTRONOMY
AND
ASTROPHYSICS

On the nature of the Am phenomenon or on a stabilization and the tidal mixing in binaries

II. Metallicity and pseudo-synchronization

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Received 4 July 1996 / Accepted 12 May 1997

Abstract. We reveal sufficient evidences that for Am binaries the metallicity might depend on their orbital periods, $P_{\rm orb}$, rather than on $v\sin i$. In particular, δm_1 index seems to decrease with increasing orbital period up to at least $P_{\rm orb} \approx 50^d$, probably even up to $P_{\rm orb} \approx 200^d$. This gives further support to our "tidal mixing + stabilization" hypothesis formulated in Part I.

Moreover, while the most metallic Am stars seem to have rather large periods the slowest rotators are found to exhibit substantially shorter $P_{\rm orb}$. A questioning eye is thus cast on the generally adopted view that Am peculiarity is caused by a suppressed rotationally induced mixing in slowly rotating 'single' stars.

The observed anticorrelation between rotation and metallicity may have also other than the 'textbook' explanation, namely being the result of the correlation between metallicity and orbital period, as the majority of Am binaries are possibly synchronized.

We further argue that there is a tendency in Am binaries towards pseudo-synchronization up to $P_{\rm orb} \approx 35^d$. This has, however, no serious impact on our conclusions from Part I; on the contrary, they still hold even if this effect is taken into account.

Key words: stars: chemically peculiar – binaries: close – turbulence – diffusion – hydrodynamics

1. Introduction

Pursuing further the pioneering ideas of Abt (Abt 1961, 1965, Abt & Bidelman 1969, Abt & Levy 1985), we have recently pointed out (Budaj 1994b, 1996 - henceforth referred to as Part I, Iliev et al. 1997) that the physical characteristics of Am stars acquired a new dimension – dependence on the orbital period and eccentricity. We especially have in mind a conspicuous $180 - 800^d$ gap in their orbital period distribution (OPD), the sensitivity of the maximum rotation rate on $P_{\rm orb}$, as well as the finding that the abundance anomalies seems to be larger for long periods and high eccentricities. In order to account for these features we, at the same time, invoked a new mechanism, that of tidal mixing (Budaj 1994a, 1996), whose disturbing effects on the separation of chemical elements have a tendency to weaken with increasing $P_{\rm orb}$. In addition, the presence of another wide-range (up to $P_{\rm orb} \approx 180^d$) stabilization mechanism, suppressing the mixing processes - so that the diffusion can give rise to the abundance anomalies, was suggested to explain the above-mentioned period gap. The retardation mechanism of Tassoul & Tassoul (1992), stretching to large orbital periods, was found to fit remarkably well into this pattern.

It is rather interesting to observe that alongside Am binaries it is also Ap ones that seem to reveal similar characteristics (Budaj 1995, Budaj et al. 1997). Indeed, there are some indications of the existence of a similar gap in orbital periods of Ap's around $P_{\rm orb} \approx 3\times10^2$ days. This gap, in addition, also seems to be a break point in the trend of increasing peculiarity towards larger $P_{\rm orb}$, as a slight correlation with $P_{\rm orb}$ of both the $\Delta(V_1 - G)$ photometric index and the magnetic field strength seen on the left (i.e. short) period side of the gap seems to be absent on the other side. Both the quantities also tend to decrease with an increasing eccentricity.

As for metallicity in Am stars, it has extensively and thoroughly been studied only in connection with rotation. The favoured view (e.g. Smith 1971, Kodaira 1975, Hauck 1978, Kitamura & Kondo 1978, Hauck & Curchod 1980) is its continuous diminishing with increasing $v\sin i$. The most elaborated findings of Burkhart (1979) indicate that this decrease is not smooth, but exhibits an apparent jump at $v\sin i$ = 55 km s^{-1}. Theory, on the other hand, tells us a different story as the meridional circulation is demonstrated to have a little influence on a separation of chemical elements other than He (Charbonneau & Michaud 1991).

The aim of the present paper is three-fold. First, we will reinvestigate the problem of metallicity in Am's in a more complex view, considering its intimate links with orbital periods, rotation as well as OPD. This will be followed by a thorough

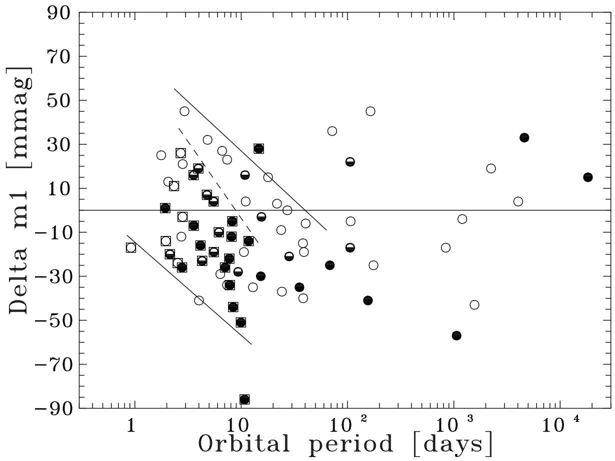

Fig. 1. δm_1 versus $P_{\rm orb}$. The notation is as follows: full circles – $v \sin i \leq 20$ km s^{-1}, semi-full circles – $20 < v \sin i < 40$ km s^{-1}, open circles – the rest or unknown $v \sin i$, squares – 'possible' synchronized binaries, solid lines – the boundary of δm_1 for all binaries of the sample, and dashed line – the upper boundary of δm_1 for 'possible' synchronized binaries.

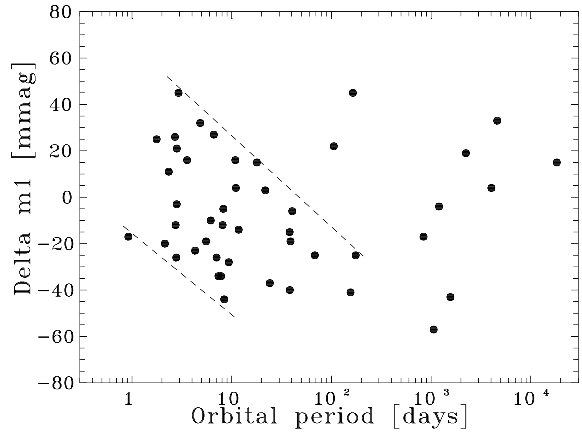

Fig. 2. δm_1 versus $P_{\rm orb}$, with double-lined binaries excluded; dashes give the limiting values of metallicity of Am stars at a certain orbital period (see the text)

inspection to the role of pseudo-synchronization in Am phenomena. Finally, we will address the issue of related lithium abundance anomalies in Am and other binaries.

2. Sample stars

The sample stars used in this analysis are the same as in Part I, which the interested reader can consult for more details. The data are taken, under some constraints, from Seggewiss (1993), and are based on The Eighth Catalogue of Orbital Elements of Spectroscopic Binary Systems (Batten et al. 1989) and, as far as δm_1 is concerned, on the catalogue of Philip et al. (1976). In Table I we list the supplemented information to Table I of Part I, which is relevant to this Part.

3. Metallicity versus orbital period

Following, among others, Burkhart (1979) we also adopt δm_1 as a reliable metallicity parameter. This parameter shows us the difference in m_0 (a dereddened m_1 index in the uvby photometry) between an Am star and a normal star of the same β index, i.e. $\delta m_1 \equiv m_{\rm zams} - m_0$. The smaller is δm_1 the larger is metallicity, as found by Barry (1970), Smith (1971), Crawford (1975), Berthet (1990) or Smalley & Dworetsky (1993).

Fig. 1 illustrates a δm_1 versus $P_{\rm orb}$ plot for our sample. Despite a remarkably large scatter around the zero value, we still clearly see an apparent decrease of this index (especially as for its upper boundary) with increasing $P_{\rm orb}$, up to at least $P_{\rm orb} \approx 50^d$. However, the decline of its lower boundary does not seem so smooth; there is an indication (as already mentioned in Part I) of a possible jump at about 7^d, as all but one binaries with $\delta m_1 < -0.03$ exhibit the orbital periods exceeding the latter value. However, this general tendency of the index δm_1 to diminish as $P_{\rm orb}$ gets greater cannot be ascribed to the effects of a decreasing rotation due to synchronization; really, although the averaged $v \sin i$ can be traced to decrease with $P_{\rm orb}$ up to $P_{\rm orb} \approx 8^d$, then it turns growing up to $P_{\rm orb} \approx 30^d$ (see Fig. 3), this having no serious response on δm_1, which still goes on decreasing. With a view of eliminating a possible influence of a secondary companion of an Am star on the photometric index, we give in Fig. 2 the same plot but for the sample with double lined binaries excluded; [1] the decreasing behaviour is also well pronounced, being almost linear on this scale and seemingly extending to the whole 'stabilized' region ($P_{\rm orb} < 200^d$). There are just two long period binaries there, HD 138213 and HD 183007, which do not obey the favoured behaviour. However, notice that having almost circular orbits both stars are rather exceptional cases for their orbital periods. The stars lying beyond the gap and having very large periods $P_{\rm orb} > 800^d$ do not seem to conform to the above mentioned trend; on the contrary, they might even obey an opposite tendency.

To speak in more objective terms, we will calculate Pearson's linear (r_l) as well as Spearman's rank order (r_s) correlation coefficients for the data in Fig.1, together with their two-sided significances or p-values (p_l, p_s, see Press et al. 1986). The latter simply represents the probability of the occurrence of a better correlation coefficient (i.e. its larger absolute value) than that found here (Table 2) under the assumption that the quantities δm_1 and $\log P_{\rm orb}$ do not correlate at all. Generally – but it depends on one's 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 that although the correlation coefficients are not large the anticorrelation between δm_1 and $\log P_{\rm orb}$ is significant for $\log P_{\rm orb} < 50^d$ but not for the sample as a whole.

[1] The double lined binaries considered here are those denoted by "d" in Table 1, Part I. In these binaries the lines of the secondary are definitely seen so that its orbit can be determined.

Table 1. Our sample stars - the additional information to Table I of Part I ($P_{\rm orb}$ and $P_{\rm p}$ are in days, δm_1 in mmag, $v_{\rm ps}$ in km s^{-1})

HD	$P_{\rm orb}$	e	δm_1	$P_{\rm p}$	$v_{\rm ps}$	note:	HD	$P_{\rm orb}$	e	δm_1	$P_{\rm p}$	$v_{\rm ps}$	note:
204038	0.79	0.12		.62	246.	s,p	23631	7.35	0.03		6.92	22.	s,p
21912	0.92	0.00	-17	.92	165.	s,p	125335	7.37	0.20	-34	4.81	32.	
106112	1.27	0.00		1.27	120.	s,p	182490	7.39	0.00	23	7.39	21.	
1826	1.43	0.02		1.37	111.		79193	7.75	0.09	-22	6.44	24.	s,p
178661	1.54	0.00		1.54	99.		209625	7.83	0.05	-34	7.08	21.	s,p
209147	1.60	0.00		1.60	95.		184552	8.12	0.14	-12	6.07	25.	s,p
23848	1.77	0.09	25	1.47	103.	p	17581	8.25	0.23	-5	5.03	30.	s,p
93075	1.81	0.00		1.81	84.	s,p	27749	8.42	0.00	-44	8.42	18.	s,p
125337	1.93	0.10	1	1.57	97.	s,p	205234	8.44	0.00		8.44	18.	
4058	1.96	0.00	-14	1.96	77.	s,p	144426	8.86	0.38		3.68	41.	p
113158	2.0	0.30		1.03	148.	s,p	82191	9.01	0.01		8.83	17.	
156965	2.06	0.00	13	2.06	74.		40536	9.36	0.16	-28	6.69	23.	
27628	2.14	0.04	-20	1.97	77.	s,p	44691	9.95	0.08	-51	8.45	18.	s,p
213534	2.34	0.02	11	2.25	68.	s,p	92139/40	10.21	0.51		2.85	53.	s,p
190786	2.35	0.30		1.21	126.	s,p	6619	10.62	0.22	-19	6.62	23.	
46052	2.53	0.00	-24	2.53	60.	s,p	179950	10.78	0.47	-86	3.43	44.	s,p
206155	2.63	0.00		2.63	58.	s,p	198391	10.88	0.39	16	4.40	35.	
110326	2.70	0.05	26	2.44	62.	s,p	196544	11.04	0.23	4	6.73	23.	
40372	2.74	0.02	-12	2.63	58.		861	11.22	0.22		7.00	22.	
18597	2.78	0.00		2.78	55.		18778	11.67	0.29		6.15	25.	
102660	2.78	0.02	-26	2.67	57.	s,p	108642	11.78	0.06	-14	10.43	15.	s,p
139319	2.81	0.02	-3	2.70	56.	s,p	73619	12.91	0.20	-35	8.43	18.	
162132	2.82	0.00	21	2.82	54.		171653	14.35	0.21		9.16	17.	
75737	2.90	0.00		2.90	52.	s,p	171978B	14.67	0.21	28	9.36	16.	s,p
39220	2.93	0.00	45	2.93	52.		12869	15.29	0.61	-30	2.93	52.	p
60178	2.93	0.00		2.93	52.	s,p	23277	15.51	0.22	-3	9.67	16.	
219815	3.22	0.03		3.03	50.		36412	16.79	0.12		13.10	12.	
112014	3.29	0.04		3.03	50.	s,p	20320	17.93	0.14	15	13.39	11.	
128661	3.33	0.14		2.49	61.		204188	21.72	0.00	3	21.72	7.	
149420	3.39	0.03		3.19	48.	s,p	155375	23.25	0.43		8.37	18.	
211433	3.57	0.01		3.50	43.		42954	23.81	0.74	-9	2.39	63.	p
29140	3.57	0.00	16	3.57	43.	s,p	216608A	24.16	0.20	-37	15.78	10.	
136403	3.58	0.09	-7	2.98	51.	s,p	104671	24.48	0.61		4.70	32.	p
26591	3.66	0.00		3.66	41.	s,p	148367	27.22	0.74	0	2.74	56.	p
161321	3.90	0.00		3.90	39.	s,p	41357	28.28	0.56	-21	6.61	23.	
40183	3.96	0.00	19	3.96	38.	s,p	434	34.26	0.41		13.08	12.	
193637	4.01	0.00	-41	4.01	38.		8374	35.37	0.63	-35	6.24	24.	p
12881	4.12	0.00		4.12	37.	s,p	30050	37.28	0.36		16.37	9.	
85040	4.15	0.00	-16	4.15	37.	s,p	159560	38.13	0.04	-15	35.17	4.	
28204	4.20	0.00		4.20	36.	s,p	110951	38.32	0.07	-40	33.22	5.	
174343/4	4.24	0.00		4.24	36.		29479	38.95	0.15	-19	28.46	5.	
71973	4.29	0.11		3.42	44.	s,p	96528	40.45	0.10	-6	32.93	5.	
173648	4.30	0.01	-23	4.21	36.	s,p	108651	68.29	0.36	-25	29.98	5.	
193857	4.34	0.05		3.92	39.		107259	71.9	0.34	36	33.30	5.	
40932	4.45	0.00		4.45	34.	s,p	138213	105.95	0.00	22	105.95	1.	
4161	4.47	0.00		4.47	34.	s,p	42083	106.0	0.63	-17	18.69	8.	
173654	4.77	0.02	7	4.58	33.	s,p	11636	107.0	0.90	-5	2.45	62.	
56429	4.80	0.00		4.80	32.		33254	155.83	0.67	-41	22.86	7.	
114519	4.80	0.00		4.80	32.		183007	164.64	0.12	45	128.43	1.	
120955B	4.84	0.05	32	4.37	35.		116657	175.55	0.46	-25	57.65	3.	
112486A	5.13	0.00		5.13	30.	s,p	209790	810.9	0.46		266.31	1.	
162656	5.45	0.45		1.85	82.	p	195725	840.6	0.03	-17	791.28	0.	
168913	5.51	0.00	4	5.51	28.	s,p	78362/3	1062.4	0.48	-57	327.46	0.	
20210	5.54	0.03	-19	5.21	29.	s,p	17094	1202.2	0.46	-4	394.81	0.	
93903	6.17	0.00	-10	6.17	25.	s,p	198743	1566.0	0.23	-43	954.06	0.	
206546	6.37	0.00	-29	6.37	24.		56986	2238.6	0.35	19	1009.67	0.	
103578	6.63	0.02	27	6.37	24.		27176	4035.	0.34	4	1868.99	0.	
30453	7.05	0.03	-26	6.64	23.	s,p	47105	4613.66	0.90	33	105.84	1.	
275604	7.16	0.21		4.57	33.		48915	18277.	0.59	15	3805.24	0.	
109510	7.34	0.21		4.69	32.	s,p							

Note: s - 'possible' synchronization; p - 'possible' pseudo-synchronization; $v_{\rm ps}$ - the theoretical pseudo-synchronization velocity and $P_{\rm p}$ - the instantaneous orbital period at periastron for $M_{\rm s}$ = $0.5M$, M = $2M_{\odot}$, R = $3R_{\odot}$

Nevertheless, the problems should always be seen in their interplay, which we attempted to do in Fig. 3. There the mean δm_1 values of Fig.1, accompanied by a shifted mean $v \sin i$ and a scaled OPD given in Part I, are plotted versus $P_{\rm orb}$. It is worth noticing the occurrence of two pronounced depressions in the functional dependences; the one is connected with rotation, filling the interval $2-20^d$ and corresponding to the main maximum in OPD, and the other with metallicity, being shifted, with respect to the previous one, towards longer periods and spreading within a $5-60^d$ interval. Also, the above mentioned decrease of the upper boundary of δm_1 up to at least 50 days seems to exactly correspond to a small questionable drop in the OPD. At the same time we may also find some dependence of δm_1 on $v \sin i$. This is already indicated in Fig. 1 (where we use different symbols to distinguish between different projected rotational velocities). However, more encouraging evidence comes out of the fact that the upper boundary line of δm_1 index for the 'possibly' synchronized stars (see Part I for the definition) has a steeper slope than that characterizing the whole sample,

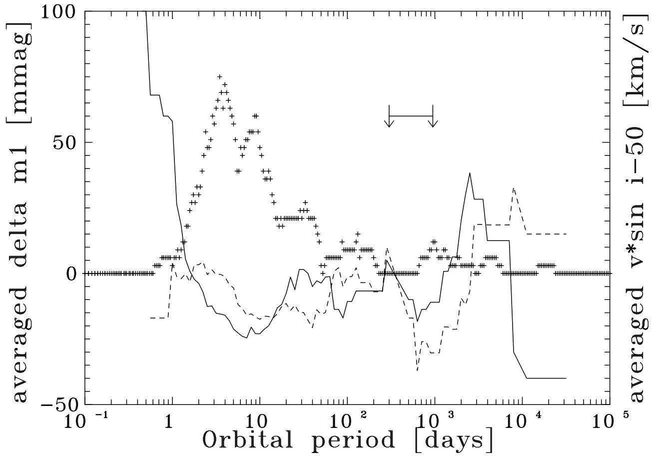

Fig. 3. A more complex look at the behaviour of the physical characteristics of Am binaries versus $P_{\rm orb}$: solid curve – the value of $v \sin i$ adopted from Part I, shifted by – 50 km s^{-1} and averaged over an 0.5 wide interval (in log $P_{\rm orb}$) and plotted with a step of 0.05 ; dashed curve – δm_1 averaged over the same interval and plotted with the same step; crosses – a sketch of the Am OPD taken from Part I and scaled by a factor of 3 . The arrows indicate the width of the window used when computing averages.

Table 2. Correlation coefficients for the relation between δm_1 and log $P_{\rm orb}$ from Fig.1, together with corresponding significances

	$P_{\rm orb} < 50^d$	$P_{\rm orb} < 200^d$	all $P_{\rm orb}$
r_l	-0.28	-0.10	0.008
p_l	0.038	0.44	0.95
r_s	-0.28	-0.18	-0.10
p_s	0.035	0.16	0.40

as well as from the tendency to a small maximum at 20^d in the behaviour of the averaged δm_1 (Fig. 3).

4. Interpretation and discussion

4.1. Metallicity

Let us start with discussing Fig. 1. The large scatter around the zero value indicates that either δm_1 is not so tight a metallicity parameter for Am binaries, or metallicity is not, in fact, their typical distinguishing characteristic. Nevertheless, there are statistically significant indications that *metallicity increases with increasing* $P_{\rm orb}$ up to at least $P_{\rm orb} \approx 50^d$, or that it acquires its peak values at substantially larger $P_{\rm orb}$ than is the minimum of the mean projected rotational velocities. This, however, cannot be understood in the framework of a generally accepted picture of converting normal stars to Am ones (Charbonneau & Michaud 1991). The latter considers a lowered rotationally induced mixing in slowly rotating single stars as a principal agent responsible for the Am peculiarity and can thus only predict an anticorrelation (either weak or none) of metallicity and rotation. In spite of the fact that there is a slight dependence of δm_1 on $v \sin i$ at a certain fixed period, it seems that the anticorrelation between rotation and metallicity as thought so far might originate from a correlation between metallicity and orbital period, because many Am binaries are 'possibly' synchronized. It also remains to be checked as to what extent is this possible weak dependence of δm_1 on rotation associated, when disregarding the dependence on $P_{\rm orb}$ (or at certain $P_{\rm orb}$), with real metallicities affected by e.g. meridional circulation, whether it may also be due to the tidal mixing (because it still depends on rotation through $P_{\rm o-r}$ in Eq.1), or we simply deal with apparent rotation effects (e.g. Collins & Sonneborn 1977).

However, the most exciting fact is an indication that the area of decreasing δm_1 index might extend from the short orbital periods up to the gap in the OPD (Fig.2). This is supported by our abundance analysis (Iliev & Budaj 1996, Iliev et al. 1997) of three long period Am binaries, as well as by the findings of Burkhart & Coupry (1989, 1993) for 16 Ori (all stars having $50^d < P_{\rm orb} < 200^d$) uncovering great abundance anomalies of Li and Ca/Fe in them. This cannot be a mere coincidence because such a gap and such a behaviour of the peculiarity seem to be present also in physical characteristics of Ap binaries. It rather means that this gap might represent some qualitative change in the physical processes playing the crucial role in both Ap and Am binaries. Anyway, regardless of the fact whether metallicity increases up to 50 or 200 days, it supports our hypothesis about the stabilization mechanism extending up to the corresponding $P_{\rm orb}$. This is because once we admit tidal mixing without stabilization, the metallicity and its anomaly should increase with $P_{\rm orb}$ up to an infinite separation of binary components and approach the status of single stars, which is apparently not observed in Figs. 1-2.

Moreover, the pronounced upper boundaries of the behaviour of δm_1 index in Figs. 1 and 2, indicate that there should be no preferred dependence of metallicity of Am stars on e.g. their age and the latter would thus reached its 'current status' relatively quickly. In general, we cannot, however, exclude that the favored behaviour of metallicity is affected by evolutionary effects (see e.g. Alecian 1996). It may well be the case that long period Am binaries are in fact more evolved, especially when taking into account that the assumed stabilization mechanism establishes itself more slowly at larger $P_{\rm orb}$.

The above described behaviour of metallicity can well be qualitatively embraced by introducing the tidally induced turbulent motions which act to eliminate the abundance anomalies. Following Part I, our empirical approach to this process of tidal mixing (in the region where the stabilization is suspected, $P_{\rm orb} < 200^d$), characterized by the turbulent diffusion coefficient, $D_{\rm T}$, would imply:

$$D_{\rm T} = \alpha \left(\frac{4\pi^2}{G} \frac{1}{M + M_{\rm s}} \frac{M_{\rm s}}{M} \right)^{\beta} R^{2+3\beta} \frac{1}{P_{\rm orb}^{2\beta}} \frac{1}{P_{\rm o-r}} \quad (1)$$

with

$$P_{\rm o-r} = P_{\rm orb} P_{\rm rot} / (P_{\rm orb} - P_{\rm rot}) \quad (2)$$

where M and $M_{\rm s}$ are, respectively, the masses of a CP star and its companion, G is the gravitational constant, R stands for the CP star radius and $P_{\rm rot}$ for its rotation period. The value of $D_{\rm T}$

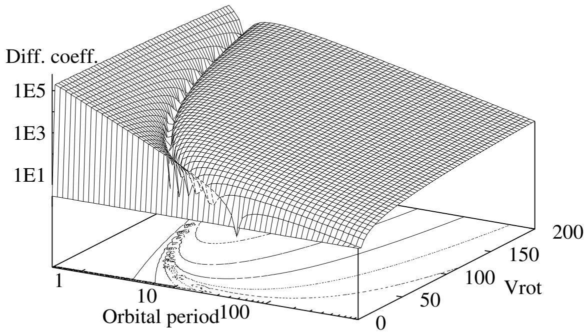

Fig. 4. The turbulent diffusion coefficient [cm^2 s^{-1}] as a function of $P_{\rm orb}$ [days] and the equatorial rotation velocity [km s^{-1}] as given by Eq. (1) for $R = 3R_\odot$, $M_s = 0.5M$, $M = 2M_\odot$. The iso-lines are also drawn at the bottom.

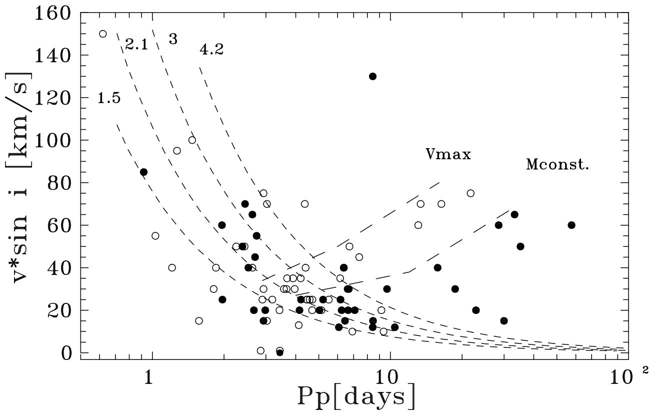

Fig. 5. $v \sin i$ as a function of the instantaneous periastron orbital period, $P_{\rm p}$. The notation is: full circles – $\delta m_1 \leq 0.00$, open circles – $\delta m_1 > 0.00$ or unknown, $V_{\rm max}$ – the curve of maximum rotation velocity, $M_{\rm const}$ – the curve of constant metallicity, short dashes – curves of theoretical pseudo-synchronization corresponding to $R = 1.5, 2.1, 3.0, 4.2R_\odot$.

for $R = 3R_\odot$, $M_s = 0.5M$, $M = 2M_\odot$ and the parameters $\alpha = 3.36\,10^{-13}$, $\beta = 0.5$, derived in Part I, is plotted in Fig.4. Such a behaviour of turbulence is really a very promising feature. It (1) weakens with $P_{\rm orb}$; (2) declines with the rotation velocity when approaching the synchronization from above so that also a few high metallic Am stars found at $P_{\rm orb} < 3^d$ (see Fig.5) can be accounted for by high degree of synchronism; and (3) its iso-lines follow those shown in Fig.4 of Part I, or those of Fig.5 here.

4.2. Pseudo-synchronization

In connection with the above-mentioned increase of metallicity up to $P_{\rm orb} \approx 50^d$ which coincides with a drop in the OPD diagram (Fig. 3), with the mentioned stabilization mechanism as well as with a possible impact on our previous conclusions concerning the Am star rotation (Sect.4 and 5.2 of Part I) etc., the effects of a possible synchronization at periastra for eccentric orbits deserve particular attention (Harmanec, private communication). It has recently been studied in the early type normal stars (Giuricin et al. 1984, Harmanec 1988, Claret et al. 1995) but not in connection with Am phenomena.

To begin with we will consider the most uncertain parameter $M_{\rm s}$ to be equal to $0.5M$. This allows us to express the total mass and its uncertainty $M_{\rm s} + M = 1.5M \pm 0.5M$. Consequently, fixing the orbital period and $M = 2M_\odot$, the third Kepler law can give us the value of semimajor axis, a, with reliable precision of the order of $\delta a/a = \frac{1}{3}\delta(M + M_{\rm s})/(M + M_{\rm s})$ i.e. of about $\pm 10\%$. Using the expressions for periastron distance, q, and orbital velocity at periastron, $v_{\rm p}$:

$$q = a(1 - e), \qquad v_{\rm p} = \frac{2\pi a}{P_{\rm orb}}\sqrt{\frac{1 + e}{1 - e}} \tag{3}$$

one might define the instantaneous "periastron orbital period", $P_{\rm p}$, and the theoretical pseudo-synchronization velocity, $v_{\rm ps}$:

$$P_{\rm p} = \frac{2\pi q}{v_{\rm p}}, \qquad v_{\rm ps} = \frac{R}{q} v_{\rm p} \tag{4}$$

having the relative uncertainty $\delta P_{\rm p}/P_{\rm p} = 2\delta a/a$ i.e. of about $\pm 20\%$, if $P_{\rm orb}$, e and M are fixed. The stars with $v \sin i$ smaller than $v_{\rm ps}$ (for $R = 3R_\odot$) will be treated as "possibly pseudo-synchronized," and are denoted by "p" in Table 1. From this table as well as from Table I of Part I, both ordered in $P_{\rm orb}$, it is also evident that while the region of "possible synchronization" ends at about 15 days, that of "possible pseudo-synchronization" extends up to 35 days. Thus, it might reflect a plateau in OPD within this interval of $P_{\rm orb}$. We cannot even exclude that some stars such as HD 108651 or HD 11636, with rather high $P_{\rm orb} = 68^d$ and $P_{\rm orb} = 107^d$, respectively, are also pseudo-synchronized. Nevertheless, there are far more stars within $10^d < P_{\rm orb} < 200^d$ that are certainly not pseudo-synchronized and we can conclude that within this interval the pseudo-synchronization is not a necessary condition for the star to become an Am as well as for its peculiarity to be pronounced. The later fact follows from Fig.5, which is an analog to Fig.4 of Part I (using just $P_{\rm p}$ instead of $P_{\rm orb}$), where the pronounced metallic stars with $\delta m_1 \leq 0.00$ are given a special mark to distinguish them from the rest. It is very interesting to observe also here the same effects as in the $v \sin i \times P_{\rm orb}$ plot. In particular, it is worth noticing the very existence and similarity in the shape of the curve of "maximum rotation velocity" and that of "constant metallicity," which are both increasing functions of $P_{\rm orb}$ with "parallel" behaviour. Although this supports the conclusions from Sect.5.2 of Part I, it emerges here in a non-trivial way because we hit upon the further dimension of the problem - the eccentricity effects - which are outside the scope of this paper. Finally, also the apparent concentration of the stars between the $R = 3R_\odot$ and $R = 2.1R_\odot$ pseudo-synchronization curves indicates that our previous accounts concerning the Am star radii and the degree of (pseudo-) synchronization do not need any special modification.

4.3. Lithium in binaries

The extensive observations of Li in Am stars by Burkhart & Coupry (1993) uncovered the Li abundance to be almost equal to the cosmic value, or just in a weak deficit, of about 0.5 dex, when compared to the normal stars – the only exception being an extremely Li-deficient star HD 33254 (16 Ori) which is, however, a well known long period binary. On the other hand, so far the most elaborated calculations of Richer & Michaud (1993) imply that a Li cloud is formed under the upper convection zone of stars situated around the Li gap. The observed Li anomaly of 16 Ori finds, however, a nice explanation within the framework of tidal mixing+stabilization hypothesis, because a majority of Am stars are supposed to be short period binaries where tidal mixing might wipe out Li clouds, which is not the case of 16 Ori. This is a motivation for farther study of Li in other long period Am binaries and Iliev et.al 1997 have already reported a discovery of another candidate for Li-deficient long period binary HD 116657.

One might propose another scenario considering the above-mentioned stabilization only. If the latter is considered as some suppression of the differential rotation accompanied by the turbulence - which is the main agent responsible for an Li depletion - it will result in preservation of the Li content in such stabilized binaries. This concept is not new by any means. It was favoured in connection with the known synchronization mechanisms by Soderblom et al. (1990), Thorburn et al. (1993), Zahn (1994)... Guided by this scenario one should just expect the Li preservation within a wider range of $P_{\rm orb}$ as e.g. indicated by Spite et al. (1994). However, this applies to normal stars rather than to Am's, as the diffusion can mask the effect in the latter.

Let us mention also the RS CVn-type stars, which might also exhibit a sign of similar tidal effects. It was very exciting for us indeed to find out that their amplitudes of light variation (Rodonò 1995) increase with $P_{\rm orb}$ up to 10^2 days like $\Delta(V_1-G)$ and magnetism of Ap binaries (or δm_1 in Am's) or decreases with increasing eccentricity also like the peculiarity of Ap's.

5. Conclusions

We have demonstrated that there exist a variety of arguments speaking strongly in favour of the model presented in Part I, which views the interplay between tidal mixing and some sort of stabilization as being of fundamental importance in explaining the nature of Am stars, and which naturally leads to the dependence of their physical properties on orbital parameters. In particular, we argue that:

- there are statistically significant indications concerning the increase of metallicity with $P_{\rm orb}$ up to at least $P_{\rm orb} \approx 50^d$, but probably even up to $P_{\rm orb} \approx 200^d$, which would coincide with the area to the left from the period gap. This favours the idea of tidal mixing;
- since this trend does not prolongate to infinity and is not seen beyond 50 days, or beyond the period gap, this gives a support to the hypothesis of some sort of stabilization up to the corresponding $P_{\rm orb}$;
- slow rotators exhibit substantially shorter orbital periods when compared with those at which metallicity acquires its peak values. This poses a serious problem for the standard model;
- the pseudo-synchronization, if taken into account, supports our findings from Sect.4 and 5.2 of Part I concerning the existence and shape of the $V_{\rm max}$ and $M_{\rm const}$ curves as well as the Am star radii, or the degree of (pseudo-)synchronization.

These arguments acquire a firmer footing when complemented by the statistical analysis of a sample of **Ap binaries** (Budaj 1995, Budaj et. al 1997), indicating:

- the presence of a similar period gap;
- similar behaviour of both $\Delta(V_1 - G)$ and magnetic field strength, pointing out to an increasing peculiarity with $P_{\rm orb}$ on the left side of the period gap as well as to its dependence on the eccentricity of the orbit;

As a by-product, the frequently observed anticorrelation between rotation and metallicity, standing in contrast with currently favoured theoretical models, might here be accounted for as due to the correlation between metallicity and orbital period, as many Am binaries are regarded as possibly synchronized.

It is also worth mentioning possible implications of this scenario on the problem of stellar lithium abundances as we might expect an increasing Li deficit with $P_{\rm orb}$ in both chemically peculiar Am and normal binaries.

Further support is thus provided to the idea that no account of Am binaries in their totality can be final which reduces the role of tidal effects just to slowing down the rotation of "a single star" below 100 km s^{-1}.

Acknowledgements. I would like to thank Dr. W. Seggewiss for kindly providing me with his sample stars data. I am indebted to Drs. P. Harmanec and J. Zverko, as well as to the referee Prof. Zahn, for their critical comments on this paper. I am also grateful to Dr. M. Saniga who helped me to improve the layout of the paper and to Dr. Komžík for his care about the computer facilities at our institute. This work was supported by the grants Nos. 1002/95 and 4175/97 of The Scientific Grant Agency VEGA.

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