Contrib. Astron. Obs. Skalnaté Pleso **38**, 129 – 134, (2008)

Am stars in binary systems

I.Kh. Iliev[1] **and J. Budaj**[2]

[1] *Institute of Astronomy, NAO Rozhen, Sofia, Bulgaria*

[2] *Astronomical Institute, Tatranská Lomnica 05960, Slovakia, budaj@ta3.sk*

Received: November 28, 2007; Accepted: January 9, 2008

Abstract. It is argued that apart from the well known dependence of the Am phenomenon on mass, age (effective temperature, gravity) and rotation there is also a complex dependence on the orbital parameters in binary systems. This is why the generally accepted scenario in which the Am star's rotation plays a unique role needs to be revisited, the strong correlations between the rotation, orbital period and eccentricity need to be properly addressed, and tidal effects should be taken into account. Recent observations of Am stars in binary systems are reviewed.

Key words: stars: chemically peculiar – stars: binaries: general – stars: abundances

1. Introduction, general context and the standard scenario

The chemically peculiar (CP) stars form a well know group of anomalous stars on the upper main sequence (see e.g. Romanyuk, 2007; Wahlgren, 2004 for the most recent reviews). It is generally accepted that the slow rotation of these stars is the primordial cause of the Am and Ap peculiarity. Slow rotation translates into weak rotationally induced mixing and stable atmospheres void of disturbing turbulence. Then radiatively driven microscopic diffusion takes over and drives a vertical or horizontal stratification of chemical elements, leading to the observed abundance anomalies. At low effective temperature the CP phenomenon disappears due to the deep convection zones; at high temperatures it vanishes because of the strong stellar winds. Large scale magnetic fields, if present, can strongly affect the diffusion and thus the observed abundance anomalies, and differentiate between the magnetic Ap and nonmagnetic Am stars. Slow rotation is due to magnetic braking in single magnetic stars, or to tidal synchronization in binary stars.

With this picture in mind one can explain many of the fundamental observed properties of Am stars:

– the slow rotation with a cutoff of about $100\,\mathrm{km\,s^{-1}}$;

– abundance anomalies decreasing with increasing rotational velocity;

– the high fraction of close binaries in Am stars;

– the absence of Am binaries with very short orbital periods ($P_{\rm orb} < 1.2$ days, such systems rotate above the $100\,{\rm km\,s^{-1}}$ cutoff due to the spin-orbit synchronization and, thus, the abundance anomalies disappear).

2. The problems with the generally accepted scenario

Nevertheless, there are inconsistencies and potential problems with the above mentioned standard picture in which rotation and diffusion play a unique role. The picture invokes tidal braking, synchronization, and circularization, but ignores tidal effects on the stellar magneto-hydrodynamics and mixing. It assumes that Am stars rotate as single stars while most of them are close binaries. Could it be that the Am anomalies depend primarily on the orbital period or eccentricity which, in close binaries, strongly correlate with the rotation, and it is for this reason that we observe a correlation of peculiarity with the rotation? Could it be that the correlation of Am anomalies with the rotation and the rotation cutoff velocity are not due to rotationally induced mixing, but due to tidal mixing which might depend on the degree of the pseudo-synchronization and thus on the rotation? Could it be that the absence of short period Am binaries is not due to their high rotation but due to the enhanced mixing and flows in the strongly irradiated, tidally distorted star with its surface approaching the Roche lobe? To our knowledge nobody has ruled out such options so far.

There are other problems which are difficult to explain within the standard picture. Budaj (1996, 1999), Feňovčík *et al.* (2004, and references therein) studied the Am and Ap anomalies as a function of rotation and orbital elements. They found evidences that the properties of Am and Ap binaries depend on their orbital elements (some of them were questioned by Noels *et al.*, 2004). It was suggested that the tidal effects in binary systems and a complex interplay between the binarity, rotation and magnetism play crucial role in driving the CP phenomenon and are more 'far-reaching' than originally though.

There is clear evidence of enhanced Li abundances in the cool late type dwarfs and giants in close binaries, indicating very different mixing in the envelopes of a tidally locked star than in a single star (Spite *et al.*, 1994; Costa *et al.*, 2002).

The tidal mechanism for slowing down the rotation of an Am star is not well understood at present. There are two very different theories for the tidal synchronization and circularization: the dynamical tide theory of Zahn (1977), and the hydrodynamical mechanism of Tassoul and Tassoul (1992). The first mechanism can synchronize the spin of stars with radiative envelopes for orbital periods up to a few days. The latter is much more efficient and could reduce the stellar rotation in systems with orbital periods of as much as 100 days.

Spin-orbit synchronization was typically observed in A V type binaries for orbital period of a few days. There is a tendency for pseudo-synchronization of Am binaries for orbital periods up to 30 days (Budaj, 1996). However, recently

Abt and Boonyarak (2004) concluded that in B - A IV or V binaries with periods as long as about 500 days, the rotational velocities of the primaries are reduced relative to the primaries in wider binaries and single stars, due to tidal effects. Abt (2005) showed that binaries with B0 - F0 IV or V primaries and intermediate orbital periods (10 -100 days) lack highly eccentric orbits, and that there is a tendency for circularization for periods up to about 1000 days.

Thus, there is no reason to believe that magneto-hydrodynamics in a member of the close binary is the same as in the single star. Consequently, the observed properties of Am stars mentioned in the previous section cannot be considered as a proof of this standard text book explanation of the Am phenomenon and need to be revisited. Apart from the obvious dependence of the Am phenomenon on the mass, age (effective temperature, gravity) and rotation, the dependence on the orbital elements also has to be studied and the strong correlations between the rotation, orbital period and eccentricity need to be properly addressed and understood.

3. Am stars in binary systems

A more detailed study of Am stars in binary systems, involving the abundance analysis, determination of the orbital parameters, masses, radii, rotation, ages, and studies of synchronization and circularization, is thus very important. Recently, there have been a number of such studies.

Budaj and Iliev (2003) studied three A-type binaries and concluded that HD 33254 is pronounced Am star, HD 198391 is extremely sharp-lined hot Am star, and HD 178449 is not Am star and that there is a faint sharp-lined secondary spectrum. The original orbit based on the photographic data turned out to be wrong.

Iliev *et al.* (2004) observed a few dozen SB1 Am binaries to search for SB2 systems. They detected the secondary spectra and estimated mass ratios in HD 434, HD 861, HD 108642, and HD 216608. In the last star they in fact observed three spectra and concluded that the previous orbit based on photographic data was misinterpreted and wrongly assigned to the visual A component of the system.

Carquillat *et al.* (2004) determined the orbit of 10 new Am binaries.

Lacy *et al.* (2004) studied the detached SB2 Am eclipsing binary star V885 Cyg and determined masses, radii and effective temperatures. The orbit is circular with a period of 1.69 days, and the observed rotational velocities are synchronous with the orbital motion for both components. The age of this system would seem to favor the hydrodynamic damping mechanism of Tassoul and Tassoul.

Mikulášek *et al.* (2004) confirmed a mild Am-peculiarity of both components of the double-lined spectroscopic eclipsing binary HR 6611 with a nearly circular orbit and revealed slightly asynchronous rotation of the primary star.

North and Debernardi (2004) studied the e versus $P_{\rm orb}$ dependence and orbital period distribution of Am binaries, and concluded that there are two populations of Am stars: systems with $P_{\rm orb} < 30$ days, which owe their slow rotation to tidal effects, and systems with $P_{\rm orb} > 30$ days (or single stars), for which tides are not effective.

Feňovčík *et al.* (2004) studied Fe and Ca abundances in Am binaries as a function of the rotation, eccentricity, orbital period, and effective temperature. They found that for orbital periods between 10 and 200 days the abundance anomalies depend on the effective temperature, anti-correlate with the rotation, and correlate with the eccentricity.

Kaye *et al.* (2004) discovered that the SB2 binary HD 221866 is an Am (metallic-line A-type) star with an orbital period of 135 days. The authors determined the basic physical and orbital parameters of both components. They have similar masses, temperatures and radii but the primary is the Am star, whereas the secondary appears to be a normal early F-type dwarf. However, the secondary has a lower $v \sin i = 14\,{\rm km\,s^{-1}}$ than the primary $v \sin i = 19\,{\rm km\,s^{-1}}$.

Vuissoz and Debernardi (2004) studied the distribution of mass ratio, q, in Am binaries and found that it is centered on $q = 0.56$.

Yushchenko *et al.* (2004) carried an abundance analysis for both components of the SB2 star HD 153720. Both components are Am stars and have similar temperatures and projected rotation velocities.

Frémat *et al.* (2005) analyzed the spectroscopic triple system DG Leo. The inner binary consists of two Am components, at least one of which is not yet rotating synchronously even though the orbit is a circular one.

Southworth *et al.* (2005) analysed the eclipsing Am binary WW Aur and determined precise masses, radii and temperatures of both components, and found that they are similar to each other. The orbit has a period of about 2.5 days. Synchronized rotation is found, in agreement with the theory of Tassoul but not with that of Zahn. The circular orbit of WW Aur is in conflict with the circularization time-scales of both the Tassoul and Zahn tidal theories.

Iliev *et al.* (2006) studied 6 A-type binaries and concluded that HD 861, HD 29479 and HD 108561 are typical Am stars, HD 20320 is a mild Am star, and HD 18778 turned out not to be an Am star in spite of very low $v \sin i = 27\,{\rm km\,s^{-1}}$. On the contrary, HD 96528, with $v \sin i = 85\,{\rm km\,s^{-1}}$ is a mild Am star. The orbit of HD 29479 based on the photographic data is wrong.

Fekel *et al.* (2006) analyzed HR 1613, which is a slowly rotating A type binary in a nearly circular orbit, with an orbital period of 8.1 days, $v \sin i = 11\,{\rm km\,s^{-1}}$ and an equatorial rotational velocity of $30\,{\rm km\,s^{-1}}$ or less, but without apparent Am anomalies. This is difficult to explain withing the standard model, but might be understood with the conclusion of Feňovčík *et al.* (2004) that the Am phenomenon is more pronounced in systems with eccentric orbits. On the contrary, θ And ($v \sin i = 93\,{\rm km\,s^{-1}}$, Kocer *et al.* 2003) seems to be an Am star.

Carquillat and Prieur (2007) determined the orbital elements of 8 Am binaries, and present statistical properties of the orbital parameters of the spectroscopic binaries with an Am primary.

Zhao *et al.* (2007) carried out a comprehensive analysis of λ Vir and determined precise masses, orbital and physical properties. The masses and temperatures of both components are very similar, but the projected rotational velocities differ by a factor of 3 - 4. The orbit has a very small but nonzero eccentricity, an orbital period of 206 days, and nonsynchronous rotation of both components. The authors argue that this is in agreement with the tidal theory of Zahn (1977).

Fossati *et al.* (2007), Adelman and Unsuree (2007), and Ryabchikova (2005) found good agreement of the Am abundance anomalies with the prediction of the diffusion theory.

Burkhart *et al.* (2005) found no abundance trend for Al, Si, S, and Fe during the Main Sequence evolution of Am stars.

4. Conclusion

A more complex and detailed study of Am stars in binary systems can shed more light on the fundamental questions of the origin and nature of the CP stars as well as on the interior hydrodynamics in binary systems.

Acknowledgements. II acknowledges the partial support from the Bulgarian NSF under grant F-1403/2004. JB acknowledges grant VEGA 2/6036/6. The research leading to these results has received funding from the European Community's Seven Framework Programme (FP7/2007-2013) under grant agreement No. MIRG-CT-2007-200297.

References

Abt, H.A., Boonyarak, C.: 2004, *Astrophys. J.* **616**, 562

Abt, H.A.: 2005, *Astrophys. J.* **629**, 507

Adelman, S.J., Unsuree, N.: 2007, *Baltic Astronomy* **16**, 183

Budaj, J.: 1996, *Astron. Astrophys.* **313**, 523

Budaj, J.: 1999, *Mon. Not. R. Astron. Soc.* **310**, 419

Budaj, J., Iliev, I.Kh.: 2003, *Mon. Not. R. Astron. Soc.* **346**, 27

Burkhart, C., Coupry, M.F., Faraggiana, R., Gerbaldi, M.: 2005, *Astron. Astrophys.* **429**, 1043

Carquillat, J.-M., Prieur, J.-L., Ginestet, N., Oblak, E., Kurpinska-Winiarska, M.: 2004, *Mon. Not. R. Astron. Soc.* **352**, 708

Carquillat, J.-M., Prieur, J.-L.: 2007, *Mon. Not. R. Astron. Soc.* **380**, 1064

Costa, J.M., da Silva, L., do Nascimento, J.D., Jr., De Medeiros, J.R.: 2002, *Astron. Astrophys.* **382**, 1016

Fekel, F.C., Williamson, M., Buggs, C., Onuoha, G., Smith, B.: 2006, *Astron. J.* **132**, 1490

Feňovčík, M., Budaj, J., Iliev, I.Kh., Richards, M.T., Barzova, I.: 2004, in *The A-star Puzzle, IAU Symp.* 224, eds.: J. Zverko, J., Žižňovský, S.J. Adelman and W.W. Weiss, Cambridge University Press, Cambridge, 749

Fossati, L., Bagnulo, S., Monier, R., Khan, S.A., Kochukhov, O., Landstreet, J., Wade, G., Weiss, W.: 2007, *Astron. Astrophys.* **476**, 911

Frémat, Y., Lampens, P., Hensberge, H.: 2005, *Mon. Not. R. Astron. Soc.* **356**, 545

Iliev, I.Kh., Budaj, J., Feňovčík, M., Stateva, I., Richards, M.T.: 2006, *Mon. Not. R. Astron. Soc.* **370**, 819

Kaye, A.B., Gray, R.O., Griffin, R.F.: 2004, *Publ. Astron. Soc. Pac.* **116**, 558

Kocer, D., Adelman, S.J., Caliskan, H., Gulliver, A.F., Gokmen Tektunali, H.: 2003, *Astron. Astrophys.* **406**, 975

Lacy, C.H.S., Vaz, L.P.R., Claret, A., Sabby, J.A.: 2004, *Astron. J.* **128**, 1324

Mikulášek, Z., Zverko, J., Romanyuk, I.I., Žižňovský, J., Elkin, V.G., Kudryavtsev, D.O.: 2004, in *Magnetic Stars*, eds.: Yu. Glagolevskij, D. Kudryavtsev and I. Romanyuk, SAO RAS, Nizhnij Arkhyz, 191

Noels, A., Montalbán, J., Maceroni, C.: 2004, in *The A-star Puzzle, IAU Symp.* 224, eds.: J. Zverko, J. Žižňovský, S.J. Adelman and W.W. Weiss, Cambridge University Press, Cambridge, 47

North, P., Debernardi, Y.: 2004, in *Spectroscopically and Spatially Resolving the Components of the Close Binary Stars*, eds.: R.W. Hilditch, H. Hensberge and K. Pavlovski, Astron. Soc. Pacific, San Franisco, 297

Romanyuk, I.I.: 2007, *Astrophysical Bulletin* **62**, 62

Ryabchikova, T.A.: 2005, *Astronomy Letters* **31**, 388

Southworth, J., Smalley, B., Maxted, P.F.L., Claret, A., Etzel, P.B.: 2005, *Mon. Not. R. Astron. Soc.* **363**, 529

Spite, M., Pasquini, L., Spite, F.: 1994, *Astron. Astrophys.* **290**, 217

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

Vuissoz, C., Debernardi, Y.: 2004, in *Spectroscopically and Spatially Resolving the Components of the Close Binary Stars*, eds.: R.W. Hilditch, H. Hensberge and K. Pavlovski, Astron. Soc. Pacific, San Franisco, 320

Wahlgren, G.M.: 2004, in *The A-star Puzzle, IAU Symp.* 224, eds.: J. Zverko, J., Žižňovský, S.J. Adelman and W.W. Weiss, Cambridge University Press, Cambridge, 291

Yushchenko, A.V., Gopka, V.F., Khokhlova, V.L., Lambert, D.L., Kim, C., Kang, Y.W.: 2004, *Astron. Astrophys.* **425**, 171

Zahn, J.-P.: 1977, *Astron. Astrophys.* **57**, 383

Zhao, M., Monnier, J.D., Torres, G., Boden, A.F., Claret, A., Millan-Gabet, R., Pedretti, E., Berger, J.-P., Traub, W.A., Schloerb, F.P., Carleton, N.P., Kern, P., Lacasse, M.G., Malbet, F., Perraut, K.: 2007, *Astrophys. J.* **659**, 626