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# Am stars in binary systems

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**Abstract.** It is argued that apart from the well known dependence of the Am phenomenon on the 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 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 taken into account. Recent observations of Am stars in binary systems are reviewed.

**Key words:** CP stars – Am stars – double stars – chemical abundances

## 1. Introduction, general context and the standard scenario

Chemically peculiar (CP) stars is 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 the low 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 and observed abundance anomalies. At low effective temperatures CP phenomenon disappears due to the deep convection zones, at hotter temperatures it is because of the strong stellar winds. Large scale magnetic fields, if present, can strongly affect the diffusion, observed abundance anomalies, and differentiate between the magnetic Ap and nonmagnetic Am stars. Slow rotation is due to the magnetic breaking in single magnetic stars or 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 the cutoff of about 100 km/s;
- abundance anomalies decreasing with the rotational velocity;
- high fraction of close binaries in Am stars;
- absence of Am binaries with very short orbital periods ($P_{orb} < 1.2$ days, such systems rotate above the 100 km/s 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 breaking, synchronization, 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 this is why we observe a correlation with the rotation? Could it be that the correlation of Am anomalies with the rotation and the rotation cutoff velocity are not due to the rotationally induced mixing but due to the 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 the surface approaching the Roche lobe? To our knowledge nobody has ruled out such options so far.

There are more problems which is 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 a clear evidence of the 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 of slowing down the rotation of an Am star is not well understood so far. 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 & Tassoul (1992). The first mechamism 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 up to orbital periods of 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 & Boonyarak (2004) concluded that in BA 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 which is due to tidal effects. Abt (2005) found out that binaries with B0-F0 IV or V primaries with 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 the 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 has to be studied also and the strong correlations between the rotation, orbital period and eccentricity need to be properly addressed and taken into account.

## 3. Am stars in binary systems

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

Budaj & Iliev (2003) studied three A-type binaries and concluded that HD33254 is pronounced Am star, HD198391 is extremely sharp-lined hot Am star, and HD178449 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 hunting for the SB2 systems. They detected the secondary spectra and estimated mass ratios in HD434, HD861, HD108642, and HD216608. 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 the period 1.69 days, 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 formalism of Tassoul & Tassoul.

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

North & Debernardi (2004) studied $e$ versus $P_{orb}$ dependence, and orbital period distribution of Am binaries and concluded that there are two populations of Am stars. Systems with $P_{orb} < 30$ days owe their slow rotation to tidal effects and systems with $P_{orb} > 30$ 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 10-200 days the abundance anomalies depend on the effective temperature, anti-correlate with the rotation, and correlate with the eccentricity.

Kaye et al. (2004) found out that the SB2 binary, HD 221866, is an Am (metallic-line A-type) star with the 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, it is the secondary which has lower vsini=14km/s than the primary vsini=19km/s.

Vuissoz & 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 a spectroscopic triple system DG Leo. The inner binary consists of two Am components, at least one of which is not yet rotating synchronously though the orbit is a circular one.

Southworth et al. (2005) analysed eclipsing Am binary WW Aur and determined precise masses, radii and temperatures of both components and they are similar to each other. Orbit has a period of about 2.5 days. Synchronized rotation is 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 the Zahn tidal theories.

Iliev et al. (2006) studied 6 A-type binaries and concluded that HD861, 29479, 108561 are typical Am stars, HD20320 is a mild Am star, and HD18778 turned out not to be an Am star in spite of very low vsini=27 km/s. On the contrary, HD96528 with vsini=85 km/s is a mild Am star. The orbit of HD29479 based on the photographic data is wrong.

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

Carquillat & 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 $\lambda$ Vir and determined precise masses, orbit and physical properties. The masses and temperatures of both components are very similar but projected rotational velocities differ by a factor of 3-4. The orbit has a very small but nonzero eccentricity, 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 & Unsuree (2007), Ryabchikova (2005) found a 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.

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