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Short-period RS CVn and W UMa binaries: how are they related?

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Abstract

Two groups of late-type very close main sequence binaries, the so-called short-period RS Canum Venaticorum (RS CVn) and W Ursae Majoris (W UMa) systems, are important for the understanding of the structure and evolutionary consequencies of angular momentum loss (AML) resulting from magnetic stellar winds of fast rotating solar type stars. The components of RS CVn stars are close to their Roche lobes, but still detached, whereas W UMa binaries are contact systems; both are rotating fast. One of the crucial problems is trying to answer the question if there is a dynamical relation between the two types of binaries in the sense that, as a consequence of the AML, the orbit of the detached sytems will shrink, so that both components come in contact and produce a W UMa type binary. We discuss the relation between wind and starspots and the dependance of AML on the latitude of these spots. No obvious conclusion is possible concerning the shrinking of the orbit of RS CVn binaries. We show that other possibilities for orbits of detached systems with magnetic activity also exist.

1. Introduction

Magnetic activity is a well-known phenomenon observed at the surface of late spectral type, fast rotating single stars and close binary components. It may be visible in the spectrum in a very extended range of wavelengths (as also observed in the Sun), and in the variation of the total light emitted by the visible rotating hemispheres of these stars.

In the present discussion we will consider more specifically the magnetic activity of the well-defined group of eclipsing W Ursae Majoris (W UMa) late-type contact binaries, and the close, but not in contact, group of short period RS Canum Venaticorum (RS CVn) systems. The presence of magnetic activity is one of the main characteristics of both groups. This activity is visible in the spectrum, changing with the phase of the eclipses, and from the comparaison of light curves representing different cycles of the rotation of the same system. As for the Sun, this activity is certainly related with the existence of a convective zone, and depends on the rapid rotation of the tidally coupled components which rotate with a period generally shorter than one day (see for ex. [1]).

It is expected that this magnetic activity is at the origin of stellar winds, and hence, of mass loss from the components. This mass loss is accompanied by angular momentum loss (AML) from the system, and responsible for slow evolutionary changes invisible on a human time-scale [2]. The AML is related to the mass loss by a quantity called the *Alfven radius*, r_{A}, which defines the corotation distance of the outflowing charged particles trapped by magnetic fields of the system. In order to give information about the AML, this corotation distance should be measured perpendicularly to the rotation axis of the system.

We know indeed, from measurements of single stars in galactic clusters of known age, that the angular momentum (spin) decreases with age (see for ex. [3],[4]). This is expected as the result of the action of any non-polar outflow of mass, even when no magnetic fields are present. The problem is completely different for binary systems, for the simple reason that two types of angular momentum are present, the orbital angular momentum and the spin of the components. The orbital angular momentum is one or two orders of magnitude higher than the spin, depending on the mass ratio of the two components and the orbital radius.

For the time being we know nothing about the initial orbital parameters of the binary systems. Or formulated in a different way, it is impossible to make any statement about the period distribution of close binaries immediately after their formation. Nevertheless, it is a commonly accepted hypothesis that W UMa binaries are the evolutionary result of angular momentum losing detached but close progenitors, and that the evolution of W UMa stars is, in its turn, also controlled by AML [5-16].

In the following pages we will try to give a brief analysis of the question of dynamical evolution of close binaries starting with a formulation of the angular momentum problem. We will also consider recent observational results concerning the magnetic activity of these binaries.

2. Angular momentum and angular momentum loss (AML)

We first consider the orbital angular momentum J_o of a binary system given by the well-known expression derived from the Kepler motion of the two components around their center of mass, supposed to be circular for this group with very close components,

$$J_o = G^{\frac{2}{3}}(2\pi)^{-\frac{1}{3}}P^{\frac{1}{3}}m_1 m_2 m^{-\frac{1}{3}} \tag{1}$$

where $m = m_1 + m_2$ is the sum of the masses of the two components, G the gravitational constant, and P the period of the system. For every system with known period and masses, this quantity can be computed with a precision depending mainly on the validity of the estimation of the masses, which are less well known than the orbital period.

When mass is lost by one of the (or both) components, m_1 or (and) m_2, and of course m, will change by a certain amount Δm in a certain lapse of time Δt. The mass loss parameters $\frac{dm_1}{dt} = \dot{m}_1$ and $\frac{dm_2}{dt} = \dot{m}_2$ can be related to the changes of the period P and the orbital angular momentum J_o by differentiation of Eq.(1) with respect to time. This gives

$$\dot{J}_o = \frac{\partial J_o}{\partial P}\dot{P} + \frac{\partial J_o}{\partial m_1}\dot{m}_1 + \frac{\partial J_o}{\partial m_2}\dot{m}_2, \tag{2}$$

and hence

$$\dot{J}_o = J_o \left\{ \frac{1}{3P}\dot{P} + (\frac{1}{m_1} - \frac{1}{3m})\dot{m}_1 + (\frac{1}{m_2} - \frac{1}{3m})\dot{m}_2 \right\}. \tag{3}$$

The next step will be to derive an equation for the angular momentum taken away by the stellar wind. The important, and poorly known, parameter, directly related to the AML connected with this wind, is the so called corotation distance or Alfven radius $r_{\rm A}$, measured perpendicularly to the rotation axis of the binary system. Following the well-known relation expressing the angular momentum loss ΔJ_w taken away by the wind in a time interval Δt,

$$\Delta J_w = 2\pi \Delta m_i r_{\rm A}^2 P^{-1}, \tag{4}$$

where m_i can be m_1 or m_2 according to the location of the outflow. This expression is valid during the limited period of time when the mass flow $\dot{m}$ can be considered as constant. In principle, we should take for the period P a mean value $P + \frac{1}{2}\Delta P$, taking into account the variation of P between the beginning and the end of the mass flow. However the changes of P are sufficiently small to neglect this variation. We may now write for the variation with time

$$\dot{J}_w = 2\pi \dot{m}_i r_{\rm A}^2 P^{-1}. \tag{5}$$

Eqs.(3) and (5) define the same quantity and lead to a relation between $P, m_1, m_2, \dot{P}$, $\dot{m}_1, \dot{m}_2$ and $r_{\rm A}$. Hence for a system with known P, m_1 and m_2 we can relate the mass loss and the period change with the corotation radius.

Especially for a given amount of mass loss it will be interesting to compute the period changes for different possible corotation distances. Clearly this distance strongly depends on the angle of outflow of the mass, and hence of the polar distance of the starspot, when we consider starspots as the location of the outflow.

In the next Section we will consider this question more closely and discuss different solutions of the formulation obtained by Eqs.(3) and (5) in order to obtain some insight in the problem of the orbital evolution of the RS CVn type binaries.

3. Are the orbits of short-period RS CVn binaries always shrinking?

Eqs.(3) and (5), derived in the preceding Section, express the AML connected with the change of the parameters of the system and the angular momentum taken away by the stellar wind, respectively. Equating the two expressions we find for mass loss from the primary component

$$r_{\mathrm{A}}^2 \dot{m}_1 = \frac{1}{2\pi} J_o P \left\{ \frac{1}{3P} \dot{P} + (\frac{1}{m_1} - \frac{1}{3m}) \dot{m}_1 \right\}. \tag{6}$$

Clearly, a similar formula is valid with m_2 in stead of m_1 when mass is lost from the secondary companion.

So we now have a simple relation between the known parameters P, m_1, m and J_o, and the unknowns $r_{\mathrm{A}}, \dot{m}_1$ and $\dot{P}$. This means that we can immediately evaluate the case for which no period change will occur, $\dot{P} = 0$, giving for the corotation distance

$$r_{\mathrm{A}}^2 = \frac{1}{2\pi} J_o P (\frac{1}{m_1} - \frac{1}{3m}), \tag{7}$$

which we call the critical Alfven distance r_{Ac}. The computation is very easy and for the simple case of a binary with $m_1 = m_2 = m_\odot$ and $P = 1d$ we find $r_{\mathrm{Ac}} = 2.38\,10^{11} cm = 3.41 r_\odot$. This means a few solar radii for a system with two components of one solar mass each and a period of one day! It is interesting to compare this quantity with the dimensions of the system. The orbital radius can be directly obtained with Kepler's 3rd law

$$a = G^{\frac{1}{3}} (2\pi)^{-\frac{2}{3}} P^{\frac{2}{3}} m^{\frac{1}{3}}, \tag{8}$$

giving, for the system defined above, in a circular orbit an orbital distance $a = 3.70\,10^{11} cm$ $= 5.28 r_\odot$. This result means that the critical Alfven radius and the orbital dimension are about the same. Similar computations can be made for different binaries with unequal components. However, the important conclusion remains the same: the period variation after mass loss can be positive or negative depending on the corotation distance with respect to the axis of rotation of the binary.

Going back to Eq.(6) we note indeed that $\dot{P} < 0$ (shrinking of the orbit) will be obtained for corotation distances greater than the critical value corresponding to the parameters of the system. This statement is independant of the mass ratio of the system for in Eq.(6) we always have $\dot{m}_1 < 0$ and $\frac{1}{m_1} - \frac{1}{3m} > 0$.

In the next Section we will consider the observational information that can help us to better understand the question of the period variation of RS CVn binaries and some numerical results concerning the relation between $\dot{m}_1$ and $\dot{P}$. We should not forget, however, that there will always be a delay between the mass loss and the period change. This delay is dictated by the tidal torque strenghened by the unknown torque resulting from the magnetic coupling between the two components.

4. How to learn more?

From Eq.(7) we know that for the standard binary system defined in the preceding Section the critical corotation distance is $r_{\mathrm{Ac}} = 3.41 r_\odot$. In reality, nothing is known about the structure and intensity of the magnetic field between and around the components.

From the solar, slow rotating, single star example we know that stellar winds are related to the magnetic activity on the surface and phenomena in the corona. The solar wind may be trapped up to one to several tens of solar radii out of the equatorial region. This is a very effective configuration for the braking of single star rotation and even a much smaller corotation distance will be able to do this work in a less efficient way.

For the active solar type eclipsing close binaries we only have information about the size and position of dark starspots from analysis of the light curves and simultaneous spectral observations. This so-called Doppler imaging technique has been developed during the last two decades (see for ex. [17,18]). It soon became clear that from light curve analysis alone it was difficult to extract enough information to adequately constrain the spot solution [19,20], unless long term and frequent observations are available, as for ex. for the late-type giant RS CVn type binary HK Lacertae [21].

The same can be said for W UMa binaries, and the interesting polar spot solution for V743 Sgr [22] from photometric data alone needs to be confirmed by an spectroscopic analysis. Maceroni et al. [23] did not detect polar spots, according to an application of Doppler imaging, on the W UMa systems AE Phe and YY Eri. The uniqueness of photometric solutions is difficult to reach with the present photometric precision [24]. Many people were also influenced by the solar paradigm telling us that sunspots are confined to an area extending to approximately 30^o degrees at both sides of the equator.

Doppler imaging measurements showed that equatorial spots also occur on fast rotating solar type stars and evolved and unevolved close components of RS CVn type binaries. However, it soon became evident that big sub-polar spots also often appear. From observations covering a sufficient number of years it is even possible to follow the motion of spots, and it seems well established now that equatorial spots drift up towards the pole.

The polar spot question has been discussed by sceptical, prudent and enthusiast colleagues at several international meetings [20][25-28]. Moreover, the theoretical study of magnetic flux tubes in the outer convection zone of rapidly rotating cool stars offered a better understanding of the dynamics of the problem [29-32].

We are sure now that the polar spots really exist, not only on rapidly rotating solar-type single stars or sub-giant binary components, but also on short period "precursors" of W UMa binaries (see for ex. [33]). So we again ask the question: *what is the AML resulting from mass loss occurring near to the pole?* It all depends on the distance of corotation with respect to the axis of rotation of the system. For small distances we can imagine that the dynamical evolution of the orbit is slow and irregular, but in fact we do not know how to formulate the restoration of synchronization after a mass loss event. What is the time needed for this process with respect to the time scale of mass loss, and what is the proportion of the orbital angular momentum and spin taken away by winds originating from the components at high latitudes?

In a recent study ([34], see also [35]) it was possible to estimate, from the relation between the mass ratio and the total mass of W UMa binaries, a probable value for the corotation distance of 2 to 3 solar radii. If this value would be confirmed for short period RS CVn binaries, we would have to face the unexpected situation that no evident evolutionary relation can exist, at least from AML, between the two types of active systems. However, contact binaries really exist and it is not evident how they can be formed directly during the stages of star formation, and how exactly they will reach a final single star stage [36]. Finally, most of them are old, as we know from their velocity distribution [37], and from the observational result that those detected in clusters are mainly members of very old galactic clusters. This indication is also confirmed by the detection of contact binaries in the direction of the galactic bulge (Rucinski 1997). So, real zero age Main Sequence W UMa binaries probably do not exist, in contrast with what I was thinking more than 20 years ago [38]. Finally we should also note that the stellar expansion during the core hydrogen-burning phase may help the components of originally detached binaries to reach contact.

5. Conclusions

The role of magnetic activity, and the AML connected with it, in the long-term behavior of the orbital parameters of RS CVn and W UMa binaries is not clear. Polar spots are currently observed on the short period late-type precursors of W UMa contact binaries. According to our present knowledge, we can only guess the structure of the magnetic fields and the intensity of the stellar winds related with these fields.

In this contribution it is suggested, that the shrinking of the orbits of these late-type close binaries, now commonly believed, is not at all a general rule. This fact should be taken into account in all speculations concerning the origin and evolution of W UMa stars.

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