

ANGULAR MOMENTUM EVOLUTION OF INTERACTING BINARY STAR SYSTEMS

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Abstract:

The orbital angular momentum distribution of interacting binary star systems and the important role of mass loss and the Alfvén radius in effective spin down and orbital shrinkage (and thus in the orbital angular momentum evolution) of these systems are reviewed.

1. Definitions

The spin angular momentum H_s of a star with mass M , radius R , and spin period P_s :

$$(1) \quad H_s = k^2 R^2 M P_s^{-1}$$

where k is the gyration constant varying between 0.07 and 0.15 depending on the density distribution inside the star

The orbital angular momentum H_o of an interacting binary system with component masses $m_{1,2}$ and orbital period P_{orb} , is given by

$$(2) \quad H_o = \left(\frac{G}{2\pi} \right)^{1/3} \frac{m_1 m_2}{(m_1 + m_2)^{1/3}} P_{orb}^{1/3}$$

where G is the universal gravity constant.

2. The angular momentum loss (AML) and slow-down of a single star.

The H of a star is lost by stellar winds.. However for cool stars with convective envelopes ($m \leq 1.6 m_\odot$), the mass loss through the stellar wind occurs not from the photospheric surface but from the top of closed magnetic loops (Alfvén radius). If H of a cool star with toroidal magnetic loops differentiated with respect to P_s and m , respectively, on the surface,

and on the Alfven radius of the star by considering that the stellar wind leaves the star at Alfven radius, we obtain

$$(3) \quad \frac{dH}{dt} = k^2 R_A^2 P_s^{-1} \frac{dM}{dt} = -k^2 R^2 M P_s^{-2} \frac{dP}{dt}$$

which reveals the magnetic braking law of single cool stars as

$$(4) \quad \frac{dP}{dt} = \left(\frac{R_A}{R} \right)^2 \frac{P}{M} \frac{dM}{dt}$$

as noted first by Schatzman (1959), Kraft (1965), and Mestel (1968). It is known that the R_A is an order of magnitude larger than R in Eq.(3) and Eq.(4). Therefore (due to the large R_A) a relatively small amount of mass loss becomes sufficient to spin down the cool stars. Such efficient spin-down was first observed by Skumenich (1972) in cool stars, and by Uesugi and Fukuda(1982) in different spectral-type field stars.

3. AM evolution of RS CVn systems into contact binaries.

In RS CVn type binaries with late type (mostly G or K) evolved components it is expected that the enhanced AML from the component stars is fed by H_o by the process of tidal friction so that a strong braking torque on the individual components causes the binary orbit to shrink, and eventually spiraling into forming a contact binary system (see e.g. Van't Veer 1993, and Guinan and Bradstreet 1988). In order to understand the process , Demircan (1999) formed the H_o - P_{orb} diagram of 40 well known RS CVn systems. He derived the semi-empirical relation

$$(5) \quad \frac{dM}{dt} = 0.068 \frac{m_1 m_2}{(m_1 + m_2)^{1/3}} P^{-2/3} \frac{dP}{dt}$$

between the wind driven mass loss and the orbital period decrease of these systems, where the masses are in scalar unit and the orbital period in days. The time scale for the RS CVn systems to evolve into contact binaries is estimated by integrating Eq.(5) between t_o and t :

$$(6) \quad t(yr) \cong \frac{0.204}{\dot{M}} \frac{m_1 m_2}{(m_1 + m_2)^{1/3}} (P_o - P_t)^{1/3}$$

where P_t is the orbital period at a given age t after t_0 . Note that for $t > t_0$ the P_t is always smaller than P_0 . The \dot{M} in Eq.(6) is the mass loss (in m_\odot / yr) from the system. Demircan's (1999) example of the orbital period evolution of the system RT And for five different assumed initial periods P_0 obtained by using Eq.(6) is reproduced in Fig 1., where \dot{M} was assumed to be $10^{-10} m_\odot / yr$.

Fig.1. confirms that it would take a few billion years for the RS CVn systems to evolve into contact configuration by the considered process (see also Guinan and Bradstreet 1988).

4. AM evolution of massive binaries

The magnetic braking process is not present for stars with radiative envelopes. These stars are generally more massive than $1.6 m_\odot$. However, it is well known that they also spin-down effectively (cf. Uesugi and Fukuda, 1982) due to probably higher rate of stellar wind flow, and probably large (comparable with the Alfvén radius) co-rotating distance of the wind material. The massive components in a close binary systems can not spin down due to strong tidal forces, but the total AML is driven from the orbit by a process of tidal friction, so that the binary orbits must shrink just as in the case of binaries with cool components.

5. Discussion

The well known spin-down of single stars due to AML requires the orbital shrinkage (period decrease) in close binary star systems. Thus, we expect the AM evolution of close binary systems towards smaller orbits. For this process to be effective, the spin orbit coupling ($P_s \cong P_{orb}$) is the necessary condition. Thus, the relatively longer period ($P_0 \geq 10d$) binaries are not expected to evolve into shorter period systems. On the other hand, the more massive component of a short period binary may fill its Roche lobe and start transferring mass to the other component, while the system is evolving towards shorter periods under the wind driven mass loss and spin-orbit coupling mechanism. When Roche lobe overflow starts, then the control in AM evolution of the binary is dominated by the mass transfer and

until mass-ratio reversal, the orbital period should decrease, but during the second stage after mass ratio reversal, it is expected to increase.

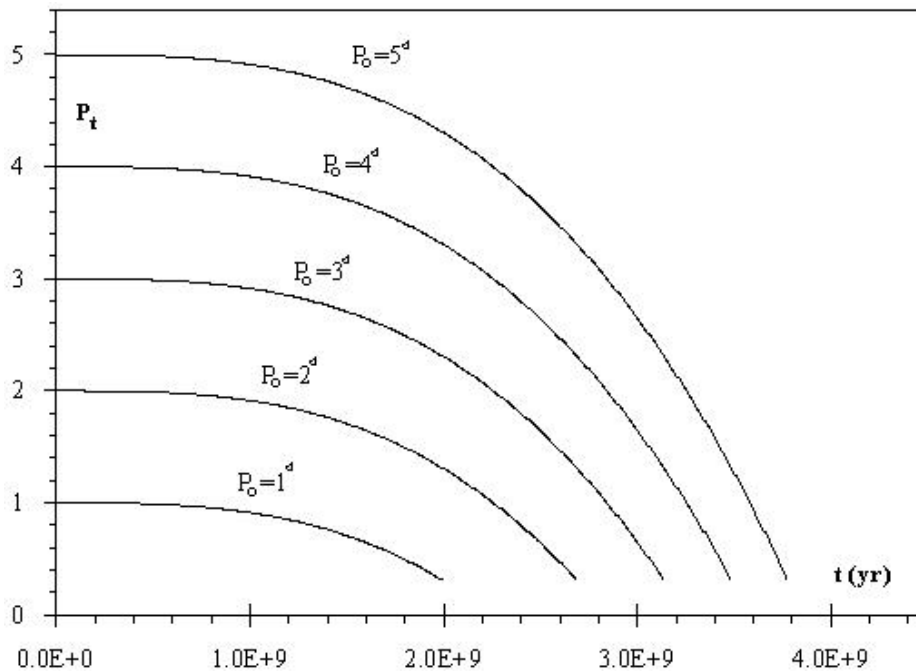


Fig.1. Dynamical evolution of the system RT And from detached to contact stage, for five different initial orbital periods P_o (extracted from Demircan 1999).

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