ROTATION IN CLOSE BINARY STARS

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In binary stars of short period, axial rotation of the components tends to be synchronized with the orbital revolution. Rotation of B and A stars is therefore slowed down, while for the later-type stars, it is accelerated. This latter fact probably contributes to the phenomenon of the RS CVn stars. Notable deviations from synchronism among short-period systems are probably related to mass transfer between the components.

Binary stars play a double role in astrophysics. On the one hand, they reveal properties and structures that would otherwise be almost unobservable, and therefore help considerably to undertand the character and evolution of single stars. On the other hand, they create objects and phenomena that otherwise would not exist at all, thereby actually creating more problems than they help to solve. I think that the first aspect makes the binary stars extremely useful; the other aspect makes them extremely exciting and interesting. This dual role also appears in connection with rotation. The "revealing" property is best documented by the fact that the phenomenon of stellar rotation was discovered in binary stars, through the "rotation effect" distorting the radial velocity curve of an eclipsed star. A more recent example is the probable identification of a star considerably flattened and distorted by differential rotation, in agreement with the theoretical models advanced by Bodenheimer and Ostriker (1970). The star is the secondary component of BM Orionis, which is the faintest of the four stars forming the famous Orion Trapezium. BM Orionis was once suspected of harboring a black hole, since during the apparently total eclipse of the primary B3 star, is spectrum remained visible and no other spectrum could be detected (Doremus, 1970). A higher dispersion of our Lick spectra permitted us (Popper and Plavec, 1976) to detect weak lines of the secondary star, which is most likely a late A giant still contracting to the main sequence. The flat bottom of the light curve at the primary eclipse is best explained by a model first suggested by Hall (1971), involving a disk-shaped, differentially rotating star. It would be difficult to recognize the shape of such a star if it were not member of an eclipsing system.

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SYNCHRONISM OF ROTATION AND REVOLUTION

Let us now discuss effects caused by a star's membership in a close binary system. In general, its axial rotation may be very profoundly affected. There exists a very pronounced trend toward synchronization of axial rotation with orbital revolution, i.e. both periods tend to be equal.

The angular velocity of axial rotation reaches its maximum near the spectral type A5 and falls off rapidly on both sides, so that the G0 V and O5 V stars have about the same average period of rotation (McNally, 1965), namely between 4 and 5 days. Note that the Sun is an unusually slow rotator. For main-sequence A stars, the typical period of rotation is less than one day, and for B stars, less than 2 days. On the contrary, the majority of close binary stars containing these components have periods between 2 and 5 days. As a consequence of synchronism, binary star components of spectral types B and A will tend to be slowed down in their axial rotation. Figure 1 shows the effect very clearly.

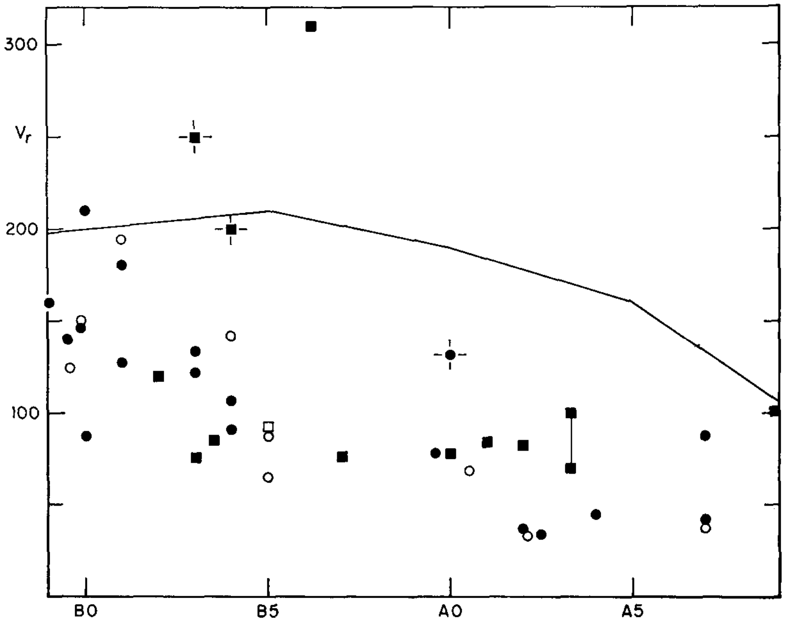

Fig. 1. Linear velocity of rotation V_r (km/s) is plotted against spectral type. Full symbols represent primary (more massive) components, open symbols are secondary components. Circles mean detached systems, squares semidetached systems. *(The Figure is from p. 135 of "Stellar Rotation", ed. Slettebak, Reidel Publishing Company, 1970)* 70.)

If the diagram in Figure 1 were continued to later spectral types, we would see that the broken line representing the average rotational velocity for single stars would fall below the observed rotational vel-

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ocities of binary star components. The average single star velocity is 12 km/s for a G0 V star and less for later types, while in the subgiants of the semidetached systems, like U Cep and U Sge, we observe rotational velocities 50 - 80 km/s. Thus for the late-type components of binary stars, synchronism means an accelerated rotation forced upon the star. It is very well possible that the peculiar properties of the binary stars of the RS CVn type are to a large degree due to this effect.

Synchronism operates in full only in systems in which the components are close to each other. Considerable effort has been made to establish the limits (Plaut, 1959; Olson, 1968; Plavec, 1970; Levato, 1974). Plaut suggested that the limit is about 10 days. I found that a reliable limiting period is 4 days, while beyond this limit the observational material was too incomplete to permit a meaningful evaluation. I also argued that the orbital period is not the most appropriate parameter: a pair of O5 stars revolving in a period of 4 days is nearly in contact, while two G0 dwarfs with the same period are well detached. Synchronization is no doubt mainly due to tidal forces, which strongly depend on the ratio of the radius to the separation. Levato attempted to take this fact partially into account by separating binaries into groups according to spectral types (this is possible, since in detached main sequence systems, both components typically have similar masses and spectral types). He finds that the limiting period for full synchronism is shortest at about A5 V, namely about 2 days; at B2 V, it is 4-8 days, and among F stars, 10-14 days. There always exists a gray zone in which both synchronized and non-synchronized pairs occur.

It is not surprising that among the later-type stars, the limiting period for synchronism is longer. Tidal forces are very efficient when acting upon convective envelopes. What is rather surprising is the considerable degree of synchronism found in early-type components with radiative envelopes. In 1970, I suggested that their synchronization may have largely been determined in the pre-main-sequence stages. However, Levato (1976) finds that binaries evolved beyond the main sequence tend to be more synchronized. Zahn (1966) suggested that the tidal forces may induce a small surface convective zone. After all, we know nothing about the distribution of angular momentum inside the components!

DEVIATIONS FROM SYNCHRONISM AND MASS TRANSFER

In my 1970 paper, I showed a diagram of the observed rotational velocity vs. the synchronized values. Within observational uncertainties, for systems with short periods, the synchronization is well established. There are, however, a few nonconformists, which can be seen in Fig. 1 as well. I will now adopt the attitude of the medical profession, ignore the normal cases, concentrate on the pathological ones, and prefer those that promise a rich reward.

Not interesting are deviations in wide detached systems such as the primary in Alpha CrB, represented in Fig. 1 by the point at A0

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and V_r=132 km/s. The synchronized velocity would be only 9 km/s, but synchronism cannot be expected with a period of 17.4 days and with a G dwarf secondary. Still, the observed velocity is well below normal for an A0 V star.

Definitely significant is the asynchronism of the primary B6:V star in U Cephei. A system with only 2.5 days period should be synchronized; however, instead of rotating at the synchronous velocity of 60 km/s, the star spins at 260 - 310 km/s, according to several estimates. The G8 III secondary of U Cep fills its critical Roche lobe and loses mass, which according to the theory by Lubow and Shu (1975) flows to the primary and impacts on it directly with a speed of 720 km/s, of which the tangential component is 270 km/s. I think that the near agreement with the observed spin is not accidental; rather, I suggest that the star's accelerated rotation is due to the mass transfer. The impacting stream will penetrate to a depth at which its ram pressure is balanced by the pressure inside the star. Ulrich and Burger (1976) calculate that if the mass transfer rate is 3 x 10^{-9} solar masses per year, the stream will be stopped at the photosphere. Because in U Cep the rate is higher, the stream penetrates the subphotospheric layers.

Observing the far ultraviolet spectra of interacting binaries with the IUE satellite, R.H. Koch and myself discovered recently strong emission lines of highly ionized atoms (C IV, N V, Si IV) and hot continua in seven binaries of longer period (W Ser, SX Cas, V 367 Cyg, W Cru, RX Cas, AR Pav, and Beta Lyr). We believe that these phenomena are related to rapid mass transfer. In such systems of longer period (13 days and more), the accreting material does not impact on the accreting star directly, but forms a disk. Viscosity in the disk eventually transfers mass to the star. A transition zone forms at the star's surface as the material transits from a Keplerian orbit. An accelerated rotation probably results again; indeed, the star may be at the verge of instability.

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