ON SUDDEN PERIOD CHANGES IN CONTACT BINARIES

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ABSTRACT

We propose that sudden period jumps in contact binaries can be caused by the action of a third companion in a highly eccentric orbit of small periastron distance. Time jumps as observed are easily reproduced for a wide range in mass of the third body but observations may restrict the possible mass range to less than a few times 0.1 $M_\odot$.

INTRODUCTION

Contact binaries of solar type may exhibit rather sudden changes in their periods (e.g. Kreiner 1977) which are usually interpreted in terms of mass transfer within the system or away from it (e.g. Van't Veer 1979).

We here argue that it is, at least, physically possible to produce similar period changes through the action of a third companion orbiting around the binary in a highly eccentric orbit of small periastron distance. The effect of this is different from that of a remote companion in an orbit of low eccentricity which may cause a light-time effect as in, for example, AK Herculis (Schmidt and Herczeg 1959). A third body in an orbit of intermediate eccentricity has been suggested by Mazeh and Shaham (1976) to produce a long term variability in binary stars. In our case, however, we examine what usually is termed a close passage during which one may transfer energy away from or into the binar depending on the conditions of the close passage.

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NUMERICAL COMPUTATIONS AND RESULTS

Our numerical integration program is a modified version of a regularized N-body program by Peters (1968, 1969).

The masses of the binary members are in all cases $M_1 = 1\ M_\odot$ and $M_2 = 0.5\ M_\odot$ with radius $R_1 = R_2 = 0.005$ a.u. They are initially in circular orbits with mutual distances of $2R_1$, i.e. they are just in contact. The companion is given an orbital period of 6.5 years in all cases. We have computed a comparatively large number of cases for masses of the third body $M_3 = 1\ M_\odot$ and $0.1\ M_\odot$ and fewer cases for $M_3 = 0.01\ M_\odot$.

For a fixed value of M_3 the energy transfer (period change) increases with decreasing periastron distance q. The dependence on the phase angle of the binary also becomes more marked at smaller q. At a sufficiently small q the third body will in most cases be thrown into a hyperbolic orbit and disappear from the system. In Fig. 1 we show for $M_3 = 1$ and $0.1\ M_\odot$ the fractional change of the binary period $\Delta P/P$ as function of its phase angle for different values of q.

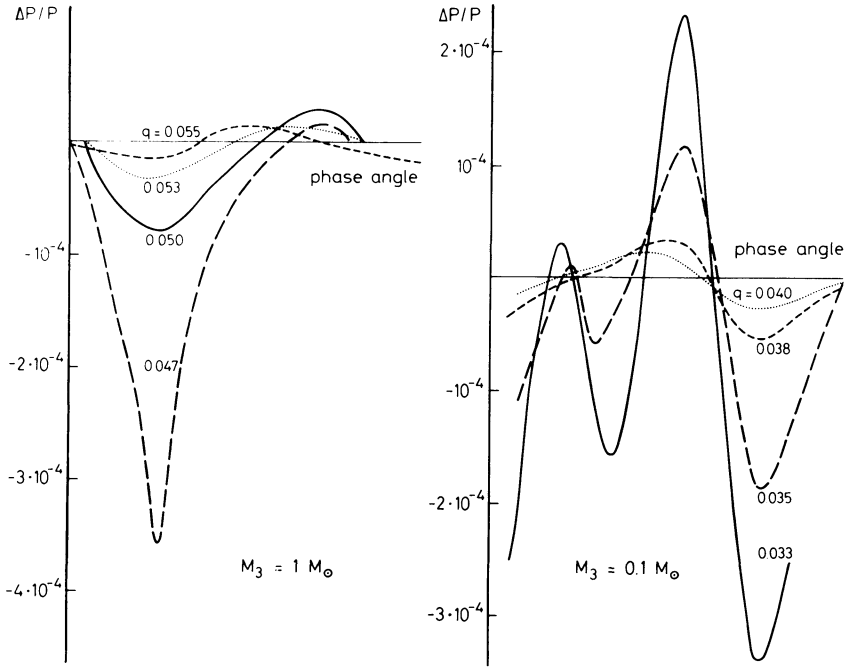

Fig. 2. The period changes as function of the binary phase angle for different periastron distances q.

As q decreases the probability for obtaining a negative $\Delta P/P$ far exceeds that of obtaining a positive $\Delta P/P$. Such a situation is evidently unstable and the orbital evolution of M_3 would be toward a progressively smaller period of the binary and a correspondingly longer period of M_3 with its eventual escape from the system. We note that as the periastron distance q increases the probability of positive and negative period jumps becomes practically equal when the relative period jumps decrease below 10^{-5} which is in the region which Kreiner (1977) finds for the observed period jumps in W UMa binaries. If the period jumps are caused by close passages of a third body it is essential that the observed jumps corresponds to periastron distances giving about equal probabilities for positive and negative ΔP to ensure the stability of M_3 over a prolonged period of time.

We have calculated a sufficient number of passages for $M_3 = 0.01\ M_\odot$ to find at what values of q the period jumps of the binary becomes of the order of those observed. This happens for $q \lesssim 0.035$ a.u. Extrapolating our results for $M_3 = 1$, 0.1 and 0.01 $M_\odot$ toward lower masses indicates that the required period jumps can be the result of close passages of a third body of mass as low as $M_3 \sim 10^{-4}\ M_\odot$ if the periastron distance is small enough.

Some restrictions on the mass of the third body may be set. $M_3 \sim 1\ M_\odot$ are unlikely mainly because such stars, of the same magnitude as the binary members, should be directly observable. There should also in most cases be an observable light-time effect. With $M_3 \sim 0.1\ M_\odot$ the light of M_3 is so weak as to escape detection and the maximum light-time effect (for a period of 6.5 years) is now ~ 5 min. Due to orientation effects the apparent light-time may escape detection.

CONSEQUENCES OF PERIOD JUMPS

The action of the third body which may cause a change in the orbital period of the binary - and the third body - also influences on the binary orbit to make it slightly elliptical. Further, the intrinsic rotation of the binary members are not influenced noticeably by the close passage whence the binary is brought out of synchronization. Such changes in the binary orbit and rotation may have a profound influence on the characteristics of the binary. One effect will be that some sort of pumping action is set up in the contact region as this is stretched and compressed during the noncircular motion of the binary. When $|\Delta P/P| \sim 10^{-5}$ the difference between maximum and minimum distance between the binary members is $\Delta R \lesssim 1.5\ 10^3$ km resulting from a binary orbit eccentricity of e ~ 0.001. This will most certainly generate surface waves which may have an observable influence on the light curve of the binary and may also possibly trigger mass transfers from one binary member to the other.

The lack of synchronization will cause the contact point to "slip" and move over the surface of the binaries. We have found that this motion of the atmosphere of the one binary relative to the other is too slow to give rise to any of the familiar drift instabilities (e.g. Hasegawa 1975). There may, however, be another effect of the non-synchronization which can result in a rather violent instability. Assuming that the stars have magnetic fields this is dragged along by the contact point as it moves over the surface. A deformation of the field results and a neutral sheet is formed along the line traced out by the contact region. An acceleration of surface plasma may eventually take place and may be visualized as a "snapping back" of field lines. This is essentially the same mechanism as suggested by Parker (1963) to accelerate matter in solar flares.

All these effects, which may well be induced by close passages of a third body, act to disturb the system and may possibly also lead to disturbances in the light-curves of the binary.

FORMATION AND STABILITY OF THE SYSTEMS

Three body systems as the ones we have envisaged with their high eccentricity may seem rather exceptional in view of our statistics on multiple systems. We can of course not exclude the possibility that the chances for the formation of such systems are so small as to be of no practical interest. However, we would like to suggest some possible ways of forming these systems. It is well known from numerical simulations of the evolution of stellar clusters that close passages between the members of the cluster have a profound effect on its evolution. This leads, among else, to the ejection of stars from the cluster. In small clusters with an initial number of stars of the order of 10 most cluster members are ejected and the eventual result is one double - or triple - system with some other stars in wide orbits (Van Albada 1968). Wielen (1967) has studied larger systems and finds the same general results but with the formation of several double - or triple - systems as the final state of the cluster. We here argue that if a close binary was member of such a cluster and experienced one or more close encounters with other cluster members it could possibly aquire one or more companions with the required highly eccentric orbits. This could happen both if it had its own "planetary" system which was strongly disturbed during the close passage of another star or possibly also through capture of "planets" from other cluster members during their close passages. If the presence of planetary systems are a common feature around stars it may be that highly eccentric orbits are not uncommon due to reasons given above.

DISCUSSION

The periastron distance q which is required to obtain time jumps in the interval $10^{-5} \gtrsim |\Delta P/P| \gtrsim 10^{-6}$ varies from grazing encounters up to several tens of stellar radiae depending on the third body mass. A large q results in a smaller period jump than observed. We cannot, however, exclude the possibility that a passage resulting in a small direct period jump creates disturbances which in turn trigger mass transfer events leading to larger changes in the binary periods. We are unable to specify beyond what periastron distances the binary will be unaffected by a close passage of a third body.

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COMMENTS FOLLOWING HAVNES

Guinan: Many of the brighter W UMa-type systems appear to have companions moving in rather wide orbits and with orbital periods of 30 years or greater. Examples are VW Cep, i Boo, W UMa, and AM Leo. These companions have orbits that appear to be too wide and have periods too long to produce the observed short term changes in periods. In addition would not the presence of an interacting third component produce more or less periodic changes in the orbital period of the W UMa system?

Havnes: It is true that the companions you mention cannot produce the period changes I have considered. This requires much larger eccentricities (and shorter periods). If the period changes were solely produced during the close passages of a third body, the interval between each period jump could change quite a bit if $M_3 \lesssim 0.01M_\odot$. This is because a transfer of energy to/from the binary from/to the third body has an effect on the orbit of M_3 which increases as the mass of M_3 decreases. However, if such large changes in the M_3 orbit took place, I think one could get problems with its orbital stability. For this reason somewhat larger M_3 may be required, in which case the intervals between the periastron passages would be practically constant. Unequal intervals between the period jumps could still result, as there is always the possibility that the effect of one passage can be too small to be detected. Another possibility is the presence of several "planets" in eccentric oribits; this may, however, encounter problems when it comes to the formation of such systems.

In my opinion the best thing, both from stability and formational considerations, would be if a third body generally produced smaller period changes than what one apparently observes and that these act as disturbances of the binary, which in turn experiences larger period jumps as it attempts to restore synchronization (through mass transfer?).

Shu: I would like to support the general philosophy that one should be careful not to interpret every period change as a mass transfer event. Such effects may arise for reasons that have nothing to do with binary evolution. You give one example; Doug Hall gave another yesterday on the basis of magnetic activity. Indeed, mass loss need not even be involved in the magnetic activity. Very minor changes of stellar structure associated with a magnetic cycle may give rise to period changes of the observed magnitude.

Rucinski: As a comment to Dr. Shu's remark I would like to point out that the intervals of period constancy as inferred from the O-C diagrams (5-15 years typically) might roughly correspond to the time scales of magnetic-field structure reorganization as observed in solar-type phenomena.

Geyer: In a recent paper by me (Astrophys. Space Sci., 48, 137, 1977) I gave a few other causes which give rise to erratic "period changes" which have nothing to do with mass loss or mass exchange in a binary system. For example if there is a non-symmetric brightness distribution which is slowly changing by itself, this gives rise to cumulative errors in the O-C diagram. Therefore whenever light curve variations are known, one must be skeptical about period changes.