THE EVOLUTION OF CONTACT BINARIES

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Abstract. Asymmetric light curves and period changes of contact binaries can be explained by large-scale prominence activity. From the mass outflow accompanying this activity the mean lifetime of a contact binary is estimated as 5×10^7 yr. From the lifetimes of contact binaries and normal solar type dwarfs on the one hand and the proportion of the former among the latter in equal volumes of space on the other hand, it is concluded that (almost) all solar type dwarfs were contact binaries at the beginning of their main sequence life.

1. Prominence Activity

All solar type (F5-G5) contact binaries show irregularly varying light curves which suggest intense activity on the stellar surfaces. The presence of a convective surface layer favours the development of large prominences, which are perhaps some orders of magnitude stronger than those visible on the solar disk. For example a large prominence covering 4% of a solar type ($T_{\text{eff}} = 5600$ K) visible hemisphere and a temperature of 7500 K will produce a change in magnitude of $\Delta m = 0.05$ mag. Changes up to 0.1 mag are currently reported for well observed light curves of solar type W UMa stars. On the other hand the velocities of escape are significantly smaller than for the Sun. They depend, for a system with a primary component of known mass, on the mass ratio of the two components and are a function of the location on the star. They are higher in the polar than in the equatorial regions, where the lowest velocity of escape is found in the neighbourhood of the Second Lagrangian point L_2, on the outer side of the secondary component. For example the velocities of escape for a binary just in contact with $m_1 = 1.5\ m_\odot$ and a mass ratio $q = 0.4$ are 400, 220 and 300 km s^{-1} at the points L_1, L_2 and L_3 respectively. The velocities observed for the solar prominences vary from some hundreds to 1000 km s^{-1}. So it is reasonable to admit that large quantities of mass will escape from the system. In this respect it is interesting to note that one prominence per year lasting one or two days with a continuous outflow of 10% of its material is sufficient to produce a mass loss of $10^{-7}\ M_\odot$ per year.

Assuming a homogeneous distribution of the prominences in the equatorial regions, and taking into account the considerations given above, the mass flow leaving the components will be mainly generated at the points L_2 and L_3, with a preponderance for L_2, especially when the mass ratio is small. Ejections from L_1 are also possible, but its rate depends on the velocity distribution of the prominences, which is unknown.

Computations of the angular momentum, carried away by the ejected mass Δm, show that for synchronised systems the parameters P (period), a (radius of the circular orbit) and q (mass ratio m_2/m_1) must generally vary after each ejection. The sign of the variations Δa, ΔP and Δq depends on the location of the prominence on the surface, and its value depends on Δm, the parameters of the system and the magnetic field. Mass transfer from one component to the other is also possible, and the irregular period changes of most solar type W UMa stars confirm that a great variety of mass displacements can occur. On a longer time scale however, we expect that most of the mass will be

P. Eggleton et al. (eds.), Structure and Evolution of Close Binary Systems, 343–346.

ejected through the points with the lowest velocity of escape. A sequence of observations, much longer than those actually available is necessary to confirm these theoretical predictions. Detailed computations show that in synchronised systems with dominating orbital angular momentum ($q > 0.08$ approximately), a preponderant ejection from L_2 must cause a decrease of the parameters P, a and q. The decrease of a is accompanied by a shrinking of the equipotential surfaces. This effect will stimulate new ejections and keep up the process of outflow. This process will be stopped when a mass ratio near 0.08 is reached. In this stage the total angular momentum of a synchronised contact binary has reached a minimum value, and the synchronisation will break down if at this stage large mass ejections from L_2 or L_3 carry away much angular momentum. On the other hand the velocity of escape at L_2 has become approximately 100 km s^{-1}, and even a moderate prominence activity is sufficient for mass ejections at this point. A further decrease of the mass ratio will rapidly lower the velocity of escape from L_2, and we now probably enter the final phase of binary life which actually escapes the possibilities of observational detection.

2. Mean Lifetime of Contact Binaries

Following this dynamical evolutionary scheme it is clear that the life of a contact binary must be rather short, although we do not know the final physical processes. The shortness of its life is confirmed by studies on period changes which suggest lifetimes not exceeding 10^8 yr. In conclusion from the dynamical and observational considerations given above, we can say that solar type contact binaries are rather short lived systems, which show an intense prominence-like activity at their surface. This activity, combined with the low velocity of escape, is the main cause of the intermittent ejections of stellar material which gradually reduce the mass ratio of the binary. After about 5×10^7 yr reckoned from the beginning of the contact phase, the binary has become a single star with a part of the ejected material orbiting around it, and another part having escaped from the system.

3. Remnants of Contact Binaries

The question of the final stage of a contact binary, and the results of the preceding paragraph merit some reflection. From a more general point of view the final single star stage seems quite reasonable, for it is no more necessary to look for special classes of stars (dwarf novae, detached binaries or others), supposed to be the descendants of contact binaries. The final product of a W UMa type star has always been an intriguing problem because of their great number, but it has become a real Gordian knot since we made a new statistical study on the frequency of contact binaries among F5 to G5 stars (Van't Veer, 1975a). We found that in equal volumes of space in the neighbourhood of the Sun there is at least one contact binary for 100 main sequence stars of the same spectral type. Taking into account: (1) this high proportion of contact binaries, (2) the lifetimes of normal F-G dwarfs (5×10^9 yr), (3) the lifetimes of contact binaries (5×10^7 yr), we can easily understand that there must be as many endproducts from contact binaries as normal main sequence stars. So it is tempting to identify the former with the latter. This new result confirms the preceeding one, and it permits us to be still more affirmative: All or nearly all mainsequence stars of solar type are the endproducts of contact binaries.

4. Origin of Contact Binaries

In order to produce such a great number, and perhaps the totality, of solar type main sequence stars from contact binaries, we must look for a general formation process taking place at the beginning of main sequence life. There is no doubt, if our reasoning is correct, that the fission process of the Jeans-Roxburgh type is the only one, actually, which may account for all the observed phenomena. Roxburgh (1966) showed that the fission process may become operative, at the end of the pre-main sequence contraction phase, for stars with masses ranging from 0.8 to 4 solar masses.

5. Conclusions

We conclude with some short comments.

(1) Huang (1966) suggested that contact binaries can be formed from detached binaries by magnetic braking. We think that a relatively small number of contact binaries can indeed be formed in this way. It probably explains some more exceptional cases like the B and A type contact binaries and those observed in old galactic clusters.

(2) All contact binaries formed by the fission process must be very young stars, and they must be therefore abundantly present in very young galactic clusters. A systematic search for W UMa stars in these clusters can provide us with a crucial test for the validity of our conclusions. The small cluster Coll 359 containing 8 W UMa stars may be a typical case. On the other hand we have good reasons to believe that young galactic clusters show a preferential orientation of the spin of their members (Van't Veer, 1975b). For the detection of W UMa stars we need a favorable general orientation of the spin.

(3) At the beginning of this paper we tried to show that much mass is blown away from the components, because of prominence activity. The specific angular momentum of this material depends on the velocity and the location of outflow and the intensity of the magnetic fields. There is no doubt that the particles which do not leave the system can possess sufficient angular momentum to occupy Keplerian orbits extending to Plutonian distances.

References

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DISCUSSION

Vilhu: Your proposal includes big mass loss from the system on a short time scale. I wonder whether it can be observed (high dispersion infrared etc.); maybe our dwarfs do not sufficiently excite the possible circumstellar matter around the system. Have you any estimates about this?

Van't Veer: I hope that high dispersion image-tube observations can be made soon to detect the presence of circumstellar matter.

Geyer: Dr Van't Veer has underestimated the light curve changes of contact binaries. A co-worker, Mr Hoffmann, has evidence that in a certain W UMa system the minima have interchanged in depth within 7 yr, which corresponds to changes of about 0.2. In addition I would like to make a second comment concerning the evolutionary time scale of contact binaries: we should look for the frequency of eclipsing binaries in very old stellar aggregates like globular clusters in that part of the HRD where the cluster stars are still close to the main sequence. If W UMa systems are not found, we would know that the evolutionary time scale for them is less than 10^{10} yr. Unfortunately a variable star search has not yet been done for such faint stars in globular clusters.

Wood: Is it not true that your arguments concerning mass loss and period change would apply equally well to systems in which only one component fills its lobe? I made a study many years ago in which it was found that in all systems showing sudden period changes, at least one component filled the critical lobe, and that the changes could be explained by the expulsion of 10^{-7} solar masses. It is interesting to note that the paper was criticized on the grounds that no star could ever lose mass.

Fracastoro: The contribution of prominences to the solar light is indeed negligible. That is why I am observing Algol with an interference filter centred at Hα. In spite of being a semi-detached system an activity of solar type is certainly present. However, no major effects have been observed yet.

Editors: During the presentation of the above paper controversy arose concerning the age and lifetime of W UMa stars. The Chairman invited the 'experts' in the subject to give their estimates of the lifetimes in the W UMa stage of evolution. Eight estimates were made by, in alphabetical order, Flannery, Hazlehurst, Moss, Ŗucinski, Van't Veer, Vilhu, Webbink and Whelan which were well distributed in the range 5×10^7 to 5×10^9 yr and indicate the wide spectrum of opinion.