SECULAR MASS LOSS FROM CATACLYSMIC VARIABLES

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1. Introduction

The mass loss from cataclysmic binaries seems an important and worth studying phenomenon for a number of reasons. It is probably enough to mention only two of them:

(a) Whenever we can directly observe the ejected material, determine its amount and the rate of mass loss, as well as its chemical composition (this being the case of the expanding envelopes of novae), we are getting a good insight into the basic physical mechanisms responsible for the observed phenomena.

(b) The mass loss (together with the mass transfer) and the loss of the orbital angular momentum are related directly to the dynamical evolution of a binary system and - indirectly - to the evolution of its components.

The subject of mass loss from cataclysmic binaries has been discussed in several original and review papers (cf., e.g., the latest excellent review by Robinson (1976)). For that reason, and due to the time limit imposed on the present review, I shall limit myself to a brief summary of the direct observational data, followed by a general discussion of the theoretical problems.

2. Direct Observational Evidence

There is a wealth of observational material, including results based on spectroscopy or direct photography, concerning the mass loss from classical novae during their outburets. This topic has been extensively covered in many books and review articles. It has also been already discussed earlier during this Colloguium. It will be enough therefore to quote - for comparison with other objects - that the amount of mass ejected during a single outburst is between 10^{-3} and $10^{-5}\ \mathfrak{M}\odot$. Then, if we assume that all novae are recurrent, with the recurrence intervals of the order of 10^{4} years (or so), we get an upper limit to the duration of the nova stage between 10^{7} and 10^{9} years. This may seem rather long but there might be some other mechanisms that terminate the nova performance much sooner.

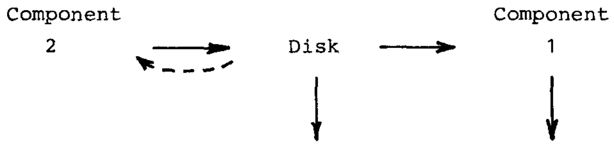
In the case of recurrent novae the only single piece of evidence available is that for the 1958 outburst of RS Oph for which Pottasch (1967) determined the mass of the expanding envelope to be $5\mathrm{x}10^{-6}\ \mathfrak{M}\odot$. The outbursts of RS Oph repeat - on the average - every 30 years. This implies that the mass transfer rate between the outbursts, necessary to provide enough material for the next outburst, must be at least $1.5\mathrm{x}10^{-7}\ \mathfrak{M}\odot$ /year. This is significantly larger than the mass transfer rates reported for other types of cataclysmic binaries (see below).

The evidence for dwarf novae is also very limited and rests entirely on the detection by Robinson (1973) of the stationary emission components in the spectrum of Z Cam. Robinson interpreted them in terms of a mass outflow with a velocity of about 280 km/s and at a rate of $2\mathrm{x}10^{-9}\ \mathfrak{M}\odot$ /year, comparable to the mass transfer rate in this system. According to Warner (1974) this mass loss is likely to occur only during the outbursts, at a rate of the order of $10^{-9}\ \mathfrak{M}\odot$ per outburst, well below direct spectroscopic detectability.

So far, there is no convincing observational evidence of any significant mass outflow from any type of cataclysmic binaries outside of their major outbursts.

3. Mass Transfer, Accretion and Mass Loss

The mass loss from cataclysmic binaries is closely related to the mass transfer between the components. In general, the situation can be described within the following scheme:



Let us discuss briefly different processes, as marked with individual arrows in this scheme.

As it is now well established, the mass transfer is due to the fact that the secondary component fills-up its Roche lobe and looses material through the inner Lagrangian point. To account for this phenomenon and, particularly, for the observed rates, it is commonly accepted that the mass loosing secondary is unstable on a thermal time scale. However, since so little is known about their past evolutionary history and their present structure, our understanding of this point is only qualitative. Neverheless it is worth to remember that the already existing data on the rates of mass transfer will eventually provide an important check point for a future complete theory.

As it is also well known, the material streaming out from the secondary is temporarily stored in a disk rotating around the primary component. And only after getting rid of the excess angular momentum it eventually may (but not necessarily all of it) reach the primary, compact component.

There are two ways of estimating the rate at which the material is transferred from the secondary component to the disk. The first method makes use of the hot spot. If all kinetic energy carried by the stream were released within the hot spot and if we had an estimate of its bolometric luminosity, then we would get directly the value of $\dot{\mathfrak{M}}$. Since, however, only part of available energy goes into the luminosity of the spot (and we do not know what fraction) and also, since we do not yet know the bolometric corrections, our estimates can only provde a lower limit to $\dot{\mathfrak{M}}$. The other method makes use of the observed rates (or lack) of period variations. These, when interpreted in terms of the simplest model: conservation of mass and of the orbital angular momentum of the system, are directly related to the mass transfer rate. In the case of systems with $q < 1$ (and increasing periods) the possible existence of those other effects implies that our estimates can only provide an upper limit to the rate of mass transfer. It is interesting to see how well these lower and upper limits agree, at least in the case of the two best studied systems, namely U Gem (from Smak (1976), with an additional assumption that $L_s > 5L_2$, and period variation data from Arnold et al. (1976) and WZ Sge (from Robinson et al. (1977)):

$$\text{U Gem:} \quad 0.8\text{x}10^{-8} < \dot{\mathfrak{M}} < 2.4\text{x}10^{-8}\ \mathfrak{M}_\odot\ /\text{year},$$

$$\text{WZ Sge:} \quad 0.8\text{x}10^{-10} < \dot{\mathfrak{M}} < 1.8\text{x}10^{-10}\ \mathfrak{M}_\odot\ /\text{year}.$$

Period variations in other systems imply mass transfer rates roughly similar to that for U Gem (Pringle 1975). As noticed by Robinson et al. (1977) the mass transfer rate in WZ Sge is much faster than that resulting from gravitational radiation effects alone. Therefore they conclude that the mass and orbital momentum loss from this system is the dominant mechanism. This must be even more true in the case of other systems with longer periods.

The accretion of material from the disk onto the surface of the primary component requires that there is an efficient mechanism to transfer the momentum accross the disk. Whatever the nature and details of such a mechanism are, it also requires that there are ways of removing the excess angular momentum from the outer parts of the disk. Two types of mechanism are considered in this context. Papaloizou and Pringle (1977) have recently demonstrated that the action of tidal torques on the disk might be effective in transferring the momentum back to orbital momentum. Such a mechanism requires no, and results in little or no mass loss and momentum loss from the system. Secondly, it is felt that such a mechanism can operate efficiently on relatively longer time scales: it can play an essential role in the case of a stationary accretion, but not in the case of a sudden accretion, as proposed for the U Gem type outbursts (Smak 1971, Osaki 1974).

The other promissing mechanism is that of mass outflow from the outer parts of the disk followed by the mass and momentum loss from the system. Various aspects of this mechanism have been discussed in a number of papers (e.g. Bielicki et al. (1974), Lin and Pringle (1976), Lin (1977)). As compared with the tidal mechanism, the mass outflow can operate not only in a stationary regime but also in the case of any non-stationary phenomena.

In order to see what are the consequences of a sudden transfer of angular momentum to the outer portions of the disk, I performed a series of particle-trajectories calculations, based on a purely formal assumption that a particle (or mass element) moving around the primary component on a periodic, quasi-circular orbit is suddenly accelerated and its velocity is increased by a certain fraction. The calculations have been done for the specific case of the outer parts of the disk in U Gem and their results can be summarized as follows. When the increase in velocity amounts to about 10 percent of its original value, then there will be an outflow of particles from a large area on the circumference of the disk to the secondary component. When the increase in velocity is about 15 percent, then - in addition to the outflow to the secondary component - there is an outflow of material from the binary system either to infinity, or at least to large distances where it can form an outer ring rotating around the system.

Finally, we should turn to the case of a direct mass loss from the primary component which is an essential feature of the nova type outbursts. In the simplest case of an isotropic, sudden mass loss, the angular momentum loss and the period variations can be simply related to the amount of ejected mass. In fact, however, the situation is far more complex. In particular, one should remember about the modifications to be introduced due to the existence of the disk in which a non-negligible amount of mass and momentum can stored prior to the outburst.

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DISCUSSION of paper by SMAK:

BIANCHINI: As absolute magnitudes of old novae roughly range from +2 to +9, do you think that this is due to the different brightness of the disks or to some contribution from the secondary?

SMAK: One has to look at the spectra, and - of course - there are cases like T CrB or GK Per where the secondary dominates; often the high luminosity of the system is due to the giant nature of this secondary. So to say something about the disks one has to compare those novae and those dwarf novae in which the secondary does not contribute any significant fraction of light. Now, to answer your question : in the case of novae, the wide range is obviously due to both factors (i.e., secondaries and disks).

WOLF: You mentioned that classical novae have bright disks. A bright disk is not indicated in the case of Nova Cyg 1975. Its prenova object in the visual was extremely faint, probably fainter than $M\sim9$.

SMAK: I agree that Nova Cyg 1975 was unusual.