CIRCUMSTELLAR MATERIAL IN CATACLYSMIC BINARIES

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ABSTRACT

This semi-review will concentrate primarily on geometric and photometric parameters of rotating gaseous disks in cataclysmic binaries. Dimensions, or more precisely - the outer radius of the disk can be estimated from three types of data: (a) From the analysis of eclipses of the hot spot, by assuming that its "radius-vector" is identical with the outer radius of the disk. (b) From the analysis of the eclipses of the disk itself. (c) From the radial velocity data giving the rotational velocity of the disk and the orbital velocity(ies) of the component(s). The resulting radius, corresponding to the peaks of the double emission lines, is not identical but presumably quite close to the outer radius of the disk. From a more detailed analysis of the disk's eclipse one can also obtain an information concerning the surface brightness distribution across the disk.

1. VARIABLE DIMENSIONS OF DISKS

Nearly all systems with sufficiently extensive coverage of their photometric behaviour show variable dimensions of their disks. The best studied cases are: U Gem (Smak 1971) in which the variations are related to the dwarf nova outburst cycle; Z Cha (Fabian, Pringle, Whelan, and Bailey 1978, Smak 1979a) in which two series of data (Warner 1974 and Bailey 1979) give different geometric parameters but with no obvious relation - so far - to its outburst or super-outburst cycles; RW Tri (Walker 1963, Winkler 1977, Smak 1979c) in which large and irregular variations occur on a time scale of days and longer. Three other systems with variable shapes of their eclipse curves, certainly due to variable parameters of their disks, are: UX UMa, DQ Her, and EM Cyg. In addition there is a very special case of HT Cas for which recent photometry by Patterson (1979) indicates that its disk is a transient feature: the hot spot in this system, while present between the outbursts, became undetectable following an outburst.

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2. MINIMUM AND MAXIMUM DIMENSIONS OF DISKS

In all studied cases the outer radii of disks (or minimum radii in cases of variable dimensions) are larger than the minimum theoretical radii defined by the angular momentum carried by the stream coming from the secondary component. This implies that an angular momentum transfer mechanism(s) must operate in those disks either on a stationary basis or at least occasionally to redistribute the angular momentum. Only in the case of HT Cas the radius of its transient disk is nearly equal to the angular momentum radius and it may mean that in this case the angular momentum exchange mechanism is rather ineffective.

Turning to the largest observed radii we find the situation somewhat confusing. If we consider only five systems for which the evidence comes from the eclipse analysis, i.e. U Gem, Z Cha, RW Tri, HT Cas, and WZ Sge (Fabian, Lin, Papaloizou, Pringle, and Whelan 1978, Smak 1979b), we find that the outer radii are smaller than the largest non-intersecting orbits calculated within the three-body problem (Paczyński 1977, Smak 1976). Only in U Gem at outburst the disk is somewhat larger but even then it does not exceed the stability limit (Piotrowski and Ziołkowski 1970).

A different picture is obtained for three other systems: Z Cam (Robinson 1973a, 1973b, 1976), EM Cyg (Robinson 1974, 1976), and SS Cyg (Walker and Chincarini 1968, Robinson 1976) for which evidence comes from the radial velocity data. All three are double-line spectroscopic binaries with mass ratios near 1 and in all cases the rotational velocities of their disks imply radii comparable to or even larger than the Roche lobe. In all three cases the lines are not clearly double and therefore the resulting radii should be taken with caution.

3. SURFACE BRIGHTNESS DISTRIBUTION

In the case of two dwarf novae: U Gem (Smak 1971) and Z Cha (Smak 1979a) there is photometric evidence that the outer parts of their disks are brighter than the inner ones. On the other hand, in the case of one nova - DQ Her (Cherepashchuk 1979), and one nova-like - RW Tri (Ivanon 1969), the results of eclipse analysis indicate an increase of the surface brightness towards the center of the disk. This difference may imply that while the accretion does indeed operate in novae and nova-like systems, it does not take place between the outbursts of dwarf novae. Supporting this is a recent result by Kiplinger (1979) who finds that the spectral energy distribution of SS Cyg between the outbursts cannot be described by a steady-state accretion model.

4. RING/TORUS-LIKE DISK IN U GEM

Madej and Paczyński (1977) and Paczyński (1978) proposed a ring- or torus-like model for the disk in U Gem, in which no viscosity and accretion takes place between the outbursts. The only major effect of the exchange of the angular momentum is due to the fact that the incoming stream carries less angular momentum that that of the torus. Outbursts are due to an instability leading to a sudden accretion of the part of material stored in the torus onto the white dwarf (cf. Osaki 1974, Smak 1976).

With the parameters available for U Gem it is possible to test how self-consistent such a torus-like model is. If we identify the radius of the torus with the outer radius of the disk, we know that it shrinks between the outbursts from 0.38 to 0.34 in dimensionless units (Smak 1971). If this variation is exclusively due to the material supplied by the stream, we can calculate how much of the lower angular momentum material in the torus is needed to account for the observed decrease of the radius. We obtain that the total amount of mass added to the torus between the outbursts is about 1/7 of the amount present immediately after the outburst.

The amount of energy radiated by the torus-like disk between the outbursts, as being due to the decreasing mechanical energy, can be expressed in terms of the total amount of mass stored in the torus and its initial and final radii. Likewise, the amount of energy radiated by the hot spot between the outbursts is a function of the impact parameters and the total amount of material being supplied to the disk. The ratio of these two is equal to the ratio of luminosities of the disk and of the spot. With the 1/7 value obtained above we get that the disk/spot luminosity ratio should be about 3/2 in remarkable agreement with photometric data (Smak 1971, Table 3). True, it is not clear how much this agreement would be spoiled by applying appropriate bolometric corrections.

It has been pointed out earlier (Osaki 1974, Smak 1976) that the amount of energy released during a sudden accretion of the material supplied by the stream and stored between the outburst in the disk, is sufficient to explain the outbursts of U Gem. We can also consider the angular momentum balance. We assume that the 1/7 of the amount of mass available in the torus will be accreted. Its angular momentum must be added to the remaining 6/7. As a result we find that the radius of the torus should increase up to about 0.45. Again, this is consistent with the observational evidence (Smak 1971): during the outburst we indeed observe an expansion of the disk and 3-5 days after maximum we still have $r = 0.41$. It can only be added that the initial fast contraction of the disk, immediately after the outburst, may be partly due to tidal effects which should be particularly effective in the case of very large disks.

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