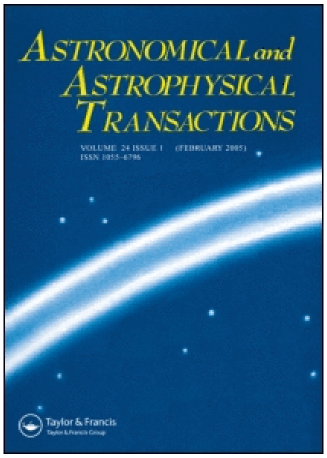

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INFLUENCE OF RED DWARF COMPONENT ACTIVITY ON ACCRETION IN CLOSE BINARY SYSTEMS

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Active late type stars lose mass as due to the effect of magnetic instabilities in their corona connected to flares. The phenomenon is similar to what happens in the Sun, but with greates intensity, with the stellar wind reaching $M \sim 10^{-11} M_{\odot}$ yr^{-1}. In later spectral types the effect is suspected to be more discontinuous and dominated by coronal mass ejections (CMEs): transient events of gas expulsion due to large-scale reconnection of the magnetic field. CMEs from active red dwarfs have been detected in the last few years. In these transient events up to 10^{16} g of gas are expelled on time-scales of some minutes. Some observations suggest that such events can support a mass loss rate from the active star $M \sim 10^{-11} M_{\odot}$ yr^{-1}, similar to the above case. We investigate the possibility that interaction between the expelled gas and the accretion pattern around the compact object in Cataclysmic variables (CVs) and low-mass X-ray binaries (LMXBs) gives rise to observable energy release. We estimate that in some cases this may be true: short-time-scale variability (seconds to minutes) in optical, UV, X-rays can be observed, wich luminosities of the order 10^{32}–10^{35} erg s^{-1}. The kind of emission will depend on the place at which the interaction takes place: the surface of the central object, accretion columns, accretion disk. We also speculate on the possibility that particularly strong CMEs or an increase in the CME production rate may, by positive feedback effect due to increased irradiation of the surface of the red dwarf, give rise to some mass transfer instability.

KEY WORDS Red dwarfs, activity, coronal mass ejection, close binary system

1 INTRODUCTION

Magnetic activity is present in a large number of low-mass, main-sequence stars (spectral type F or later), with characteristics similar to the Sun. As a consequence these stars, as for the Sun, lose mass in the form of a variable stellar wind. In the later spectral types (red dwarfs) the activity and the mass-loss rate appear to be very, large with respect to the solar case, by a factor $\sim 10^3$, reaching $M \sim$

$2 \times 10^{-11} M_\odot$ yr^{-1} (Badalyan and Livshits, 1992; Katsova, 1993). As we know from the Sun, the mass loss can be produced by regions of open or closed field lines, consisting of streamers and coronal mass ejections (CMEs), respectively. Both phenomena are related in a complicated way to flare activity.

CMEs are the most relevant transient event of mass loss in the Sun. They are apparently produced by large-scale magnetic field instabilities in corona. A CME appears as a bubble of coronal material with dimensions some fraction of the solar surface and mass $M \simeq 2 \times 10^{14}$–$2 \times 10^{16}$ g, leaving the Sun with a velocity $v \simeq 3 \times 10^8$ cm s^{-1}. The instantaneous mass-loss rate during a CME corresponds to $M \sim 10^{-13}$–$10^{-11} M_\odot$ yr^{-1} (Wagner, 1984). Observations of similar events in red dwarfs are recent and have been reported by Houdebine *et al.* (1990, 1993) and Mullan *et al.* (1989). It can be deduced that, as for the case of flare energy, CMEs are more powerful, with a velocity up to 3×10^8 cm s^{-1} and an instantaneous mass-loss rate which can reach $M \sim 10^{-8} M_\odot$ yr^{-1}. In both cases (Sun and red dwarfs) it can be inferred that the plasma bubbles expand with a speed $v \sim 10^7$ cm s^{-1} (Wagner, 1984; Houdebine *et al.*, 1990).

Red dwarfs are the less evolved component in cataclysmic variables (CVs) and low mass X-ray binaries (LMXBs). The presence of magnetic activity in this case has not yet been established. It is observed in some CVs in which the normal component is slightly underfilling its Roche lobe and in which the accretion luminosity is low, but not in Roche lobe filling objects, where optical and X-ray flares are difficult to detect because of the relatively high emission from the accretion pattern. Anyway, flares from the red component in Algol systems (Roche lobe filling) indicate that this geometry is not disturbing for magnetic activity (Shore, 1992).

The matter expelled by the red dwarf during a CME usually has a typical velocity larger that the escape velocity of the star (some times 10^7 cm s^{-1}) and the orbital velocity of the binary (of the same order). Thus the plasma bubble leaves the red dwarf following approximately a straight line. If the geometry is favourable, it will interact with the compact object, giving rise to a release of energy. In these systems we can hypothesize, by consequence, a secondary, variable stream of accretion on to the compact object, not connected to the transfer via the accretion disk. The aim of this work is to estimate the energy emission during the interaction between the plasma bubble and compact object and to discuss the possibility of its detection.

2 EMISSION NEARBY THE COMPACT OBJECT

2.1 Parameters

We consider two limiting but realistic cases. In the first, the gas bubble expelled during the CME reaches the compact object with a low density due to its low velocity and the large distance between the components. The second case has opposite characteristics and the final density is higher.

Model parameters are: v_T transfer velocity, d distance between components, $n_i n_f$ initial and final gas number densities, $R_i R_f$ initial and final bubble radii,

M_B blob mass, t_T transfer time between the two components, t_I interaction time between gas and compact object or accretion disk.

Case 1:

$$\begin{aligned} v_T &= 5 \times 10^7 \text{ cm s}^{-1},\ d = 5 \times 10^{16} \text{ cm}, n_i = 10^{15} \text{ cm}^{-3},\ R_i = 3 \times 10^8 \text{ cm}, \\ M_B &\simeq 3 \times 10^{16} \text{ g},\ R_f \simeq 10^{11} \text{ cm},\ t_T \simeq 10^4 \text{ s}. \end{aligned}$$

Case 2:

$$\begin{aligned} v_T &= 2 \times 10^8 \text{ cm } s^{-1},\ d = 6 \times 10^{10} \text{ cm}, n_i = 10^{13} \text{ cm}^{-3},\ R_i = 3 \times 10^9 \text{ cm}, \\ M_B &\simeq 10^{18} \text{ g},\ n_f \simeq 10^{12} \text{ cm}^{-3},\ R_f \simeq 6 \times 10^9 \text{ cm},\ t_T \simeq 300 \text{ s}. \end{aligned}$$

In both cases the gas expansion velocity will be $v_E = 10^7$ cm s^{-1}. For the mass of the compact object we assume $1 M_\odot$ both for a white dwarf (WD) or a neutron star (NS). The radius of the WD will be 5×10^8 cm, the radius of the NS 10^6 cm.

Our calculations are only order of magnitude estimates. We do not go into the detail of the accretion process.

2.2 Probability of the Interaction

Our parameters permit us to calculate the accretion radius around the compact object, when the gas bubble is directed towards it. In the two cases we have:

$$(1)\ r_{\text{accr}} \simeq 6 \times 10^{10} \text{ cm}, \quad (2)\ r_{\text{accr}} \simeq 2 \times 10^9 \text{ cm}.$$

In both cases it is smaller that the final dimension of the bubble. As a general picture we can imagine that part of the gas will be accreted by the compact object and part will interact with the accretion disk. The bubble will be ejected by the red dwarf in any direction and will interact with the companion if it transits the companion's accretion radius.

We can deduce an estimate for the probability of interaction, by the ratio between the cross-section of the bubble and the surface of the sphere with radius d. We have:

$$(1)\ P \simeq 10^{-2}, \quad (2)\ P \simeq 8 \times 10^{-3}.$$

This is the fraction of CMEs that will reach the companion and maybe signal the event with a burst of energy. We do not know the frequency of CMEs on red dwarfs. On the Sun this is 0.74 d^{-1} (Wagner, 1984) and we take this value (as usual) as a minimum remembering that the level of activity scales by a factor 10^3 between the two groups. From Wagner we also know that the percentage of flares related CMEs is about 10–15%. So some fraction of the observed events will be preceded by a flare on the red dwarf. The temporal separation between the two events will be of the order of t_T, shown above.

2.3 Calculations

Let us now consider the different kinds of compact object and estimate the intensity and energy of the emitted luminosity.

We begin with WD and NS. For the amount of luminosity we consider $L = GM_x M/R_x$, with M estimated as flux through the accretion radius. We obtain:

$$(1)\ M \simeq 3 \times 10^{13}\ \mathrm{g\,s^{-1}}, \quad (2)\ M \simeq 4 \times 10^{15}\ \mathrm{g\,s^{-1}}.$$

Then we calculate blackbody temperature for accretion on to a WD surface and kinetic temperature for accretion on to a NS and for the shock in the accretion column of a magnetized WD.

Non-magnetized WD:

$$(1)\ L \simeq 10^{31}\ \mathrm{erg\ s^{-1}}, \quad T_{\mathrm{BB}} \simeq 10^{4}\ \mathrm{K},$$
$$(2)\ L \simeq 10^{33}\ \mathrm{erg\ s^{-1}}, \quad T_{\mathrm{BB}} \simeq 4 \times 10^{4}\ \mathrm{K}.$$

Non-magnetized NS:

$$(1)\ L \simeq 4 \times 10^{33}\ \mathrm{erg\,s^{-1}}, \quad (2)\ L \simeq 6 \times 10^{35}\ \mathrm{erg\,s^{-1}},$$
$$T_{\mathrm{KIN}} \simeq 5 \times 10^{11}\ \mathrm{K}.$$

For a magnetized NS the estimates will be the same. For a magnetized WD the luminosity will be the same, but from the shock we will obtain a kinetic temperature $T_{\mathrm{KIN}} \simeq 2 \times 10^{9}$ K.

It is possible to see that in a non-magnetized WD the energy will be emitted in the optical-UV, in the other cases in X-rays. The estimated intensities are of the order or larger than typical CV or LMXB luminosities in the same ranges and so we may suppose that the phenomenon we are considering may be the cause of some bursts from these objects.

2.4 Accretion on to a Black Hole

If the accreting object is a black hole, the problem is to obtain a relatively high efficiency of conversion of gravitational energy to photons, in an accretion pattern which is quasi-spherical. This question has been analysed by a number of authors; we take the model by Mézsáros (1975) because it has the highest efficiency, remembering that the values we show must be regarded as upper limits. In this model the black hole has $M_x = 10 M_{\odot}$, the mass accretion rates will then be:

$$(1)\ M \simeq 3 \times 10^{15}\ \mathrm{g\,s^{-1}}, \quad (2)\ M \simeq 4 \times 10^{17}\ \mathrm{g\,s^{-1}}.$$

From Mézsáros' calculations we obtain in the optical:

$$(1)\ L \sim 3 \times 10^{36}\ \mathrm{erg\,s^{-1}}, \quad (2)\ L \simeq 2 \times 10^{38}\ \mathrm{erg\,s^{-1}}$$

by synchrotron. In X-rays:

$$(1)\ L \sim 10^{30}\ \mathrm{erg\,s^{-1}}, \quad (2)\ L \sim 10^{37}\ \mathrm{erg\,s^{-1}}$$

by bremsstrahlung. In this case too, the luminosities are observable.

2.5 Emission from the Disk

For interaction with the accretion disk, we take into account the two possibilities of thermalization of a bubble's kinetic energy by interaction with the disk itself and non-thermal emission by interaction with the disk's coronal magnetic field. However, the gas density and thermal energy density of the disk (Shakura and Sunyaev, 1973) are too high with respect to the bubble and its kinetic energy, to obtain any variation of energy emission from them.

If the disk is surrouded by a magnetically active corona, the interaction takes place via reconnection of bubble and corona magnetic field lines. CMEs seem to carry with them an ordered magnetic field, which can reconnect with disk's field with good efficiency. The kinetic energy density in the bubble, in our highest density case (case 2) is $E_{\mathrm{KIN}} \simeq 2 \times 10^4$ erg cm^{-3}. This corresponds to a magnetic energy density due to a field $B \sim 10^3$ G. Reconnection will then take place at an energetic level similar to flaring on the Sun. The emitted radiation on the Sun is up to 10^{29} erg s^{-1} in the optical and 10^{27} erg s^{-1} in X-rays: quite low for our purposes. However, the development of a model of this interaction could, by comparison with X-ray variability observations, act as a test for the presence of a magnetic corona above accretion disks.

2.6 Will We Observe It?

We have estimated that the release of energy by the interaction between the gas bubbles expelled during a CME on the red dwarf component and the accretion pattern in CVs and LMXBs can be observed as a burst in the optical or X-rays. The duration of such a burst depends on the bubble's dimension and its velocity. In our cases we obtain:

$$(1)\, t_I \simeq 2 \times 10^3\,\mathrm{s}, \quad (2)\, t_I \simeq 30\,\mathrm{s}.$$

In general it will be of the order of 1 min up to some 10s of minutes. If the CME is related to flare activity on the red dwarf, it seems possible to observe a flare event anticipating the burst. The temporal distance is of the order of t_T.

We asked ourselves whether such X-ray bursts could, by irradiation of the companion, induce some instability in the mass transfer. The duration of the irradiation is too short to induce any change in the stars's convective envelope (Gontikakis and Hameury, 1993) and any increase of mass loss through the Lagrangian point. The X-rays from the compact object thermalize in the red dwarf's photosphere. The possibility is that this may induce by some mechanism an increase in coronal particle kinetic energy. This may produce an increase in magnetic activity (Badalyan and Livshits, 1992) and maybe render more effective transient events of mass loss.

Finally, we did not consider AM Her systems. In these binaries the two components are surrounded by a common magnetosphere. The dynamics of bubbles are controlled by the magnetic field lines and maybe also small-scale phenomena can produce a mass-loss event which can be directly carried to the WD. Our simple model can not be applied to these objects and their analysis requires further investigations.

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