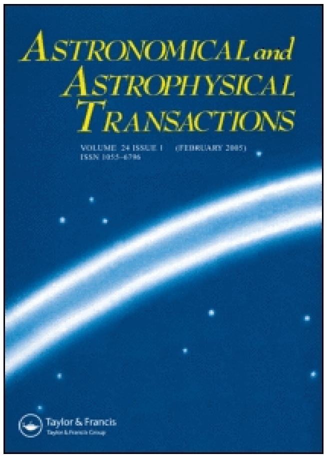

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CORONAL MASS EJECTIONS AND MASS TRANSFER IN ALGOL-TYPE BINARIES AND RELATED OBJECTS

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We give a critical assessment of the observational data on flare activity in Algol-type binaries. Special attention is given to the evaluation of the possible accretion component from Roche lobe filling secondaries. A simplified model of a radially expanding stellar wind in a binary system is presented. We investigate the anisotropy effect which is due to the displacement of a sonic point caused by the gravitational field of the companion star. We estimate the X-ray flux for Algol caused by accretion upon the primary component and find satisfactory agreement with X-ray Ginga data for mass transfer rate $\dot{M} = 0.4 \div 2.0 \times 10^{-11} M_{\odot}$ yr^{-1}. Detailed data in X-ray, radio and optical regions are prerequisite before estimates of comparable accuracy will be feasible for other interacting close binaries.

KEY WORDS **Stellar wind, accretion, flare activity**

1 INTRODUCTION

Recent X-ray and microwave observations of Algol-type semidetached binaries (see, for instance Umana *et al.*, 1991); Stern *et al.*, 1994; Singh *et al.*, 1995, and references therein) reveal the occurence of apparently permanent flare activity in these interacting systems which is associated with the extended coronae surrounding the secondaries filling in their respective Roche lobes. Contrary to what we have learned from ground-based data and what is expected from the evolutionary scenarios for these systems the filling in of the Roche lobe and the accompanying mass outflow do not seem to be the dominant factor in shaping light variability and spectral characteristics for both these spectral windows, at least not for the limited number of binaries (predominantly Algol itself) studied so far. It is noteworthy that there is a striking similarity between the Algol-type systems and RS CVn type objects both in X-ray and radio flux values, the characteristic temperature of the coronal plasma. Remarkably, the coronal activity indicators do not seem to reveal a correlation with the Roche lobe filling factor in the case of RS CVn systems for which representative samples (136 objects) have been recently studied using *ROSAT* data (Dempsey *et al.*, 1993). At the same time several lines of reasoning summarized below suggest that mass transfer and accretion upon the primary component may be one of the important factors behind the observed flare activity in Algols.

(1) A study of the coronal X-ray emission from five short-period Algol binaries based on *ASCA* and *ROSAT* data (see Singh *et al.*, 1995) indicates the presence of circumstellar or circumbinary absorbing matter following from the line of sight N_H column density estimates to the target binaries.

(2) The estimates of the accretion temperature are at least in qualitative agreement with the data for the low-temperature component for two-component plasma models both for *Ginga* (Stern *et al.*, 1992) and *ASCA* data (Singh *et al.*, 1995).

(3) The X-ray light curve of Algol during the flare reveals a shallow secondary minimum during which a mass-losing late-type component is eclipsed (see Antunes *et al.*, 1994).

(4) Of all five studied objects β Per, U Cep, δ Lib, RZ Cas and TW Dra, U Cep is the only system exhibiting a variable contribution from low-temperature component and just in this case the mass loss reaches $\dot{M} \simeq 10^{-6} M_{\odot}$ yr^{-1}.

To this one may add that despite the close similarity in the absolute orbital elements and the spectral types of both components in the abovementioned five Algol-type binaries the temporal behaviour of the X-ray emission in individual systems is diverse. It is tempting to conjecture that this may be due to the fact that during the limited time interval of monitoring these specific Algol-type binaries have been caught during the different episodes of the mass outburst. Up to now no detailed model has been proposed to account for the interaction between the corona of the Roche lobe filling component and the primary. Stern *et al.* (1992) argue that solar type coronal mass ejections but scaled up by three to four of magnitude may be responsible for feeding up the transient accretion disk in Algol while Beskin and Minarini (1995) studying the influence of the red dwarf activity on accretion in LMXB discuss the possible consequences of interaction between the magnetized bubbles of CME and the accretion disks surrounding the primaries.

In view of all the abovementioned it will be helpful to estimate the potential contribution of accretion into the X-ray luminosity of the late-type components in Algol-type binaries.

2 ANISOTROPIC STELLAR WIND IN A BINARY SYSTEM

We present here a simplified model of anisotropic radially expanding stellar wind in a moderately close binary system where stellar wind from one component overwhelms the wind from the companion star. Without going into details of the accretion process we estimate an X-ray flux component resulting from mass transfer in Algol-type binaries. Our purpose is to estimate the effects of anisotropy due to the displacement of a sonic point caused by the gravitational attraction of a companion star. In the next paragraph we apply our model to estimate the X-ray flux using the combined optical and radio data for Algol itself.

For a stationary flow ignoring the Coriolis forces due to stellar rotation the equation of motion of gas and the equation of continuity are as follows

$$(\mathbf{u}\nabla)\mathbf{u} + \nabla\Phi + \frac{1}{\rho}\nabla P = 0, \tag{1}$$

$$\nabla(\rho\mathbf{u}) = 0. \tag{2}$$

Here $\mathbf{u}$ is velocity of gas, ρ and P are, respectively, the local density of matter and the pressure exerted by both gas and radiation, Φ is gravitational potential. Equation (1) is a good approximation provided that $u_s/u_{\rm orb} \ll 1$ where u_s is the local sound velocity and $u_{\rm orb}$ is the velocity of orbital motion. We shall treat here an idealized case of radial expansion of gas from one component star.

In this case equation (2) reduces to the conservation of mass flux (mass flow rate per unit solid angle) along the streamline, i.e.

$$J = \rho u R^2 = \text{const}, \tag{3}$$

and equation (1) reduces to

$$u\frac{du}{dR} = -\frac{1}{\rho}\frac{dP}{dR} - \frac{d\Phi}{dR}. \tag{4}$$

Introducing the gravitational potential of the Roche model, using equation (3) and the relation between the gas pressure and the density of matter valid for ideal gas $P = u_s^2 n$ one obtains

$$\frac{1}{2}\left(1 - \frac{u_s^2}{u^2}\right)\frac{du^2}{dR} = \frac{2}{R}u_s^2 - \frac{du_s^2}{dR} - \frac{d\Phi}{dR}, \tag{5}$$

where u_s is the local sound velocity.

At the sonic point the following set of equations should be fulfilled

$$R = R_s, \quad u = u_s, \tag{6a}$$

$$\frac{2}{R_s}u_s^2 - \frac{2k}{m}\frac{dT}{dR}\bigg|_s - \frac{d\Phi}{dR}\bigg|_s = 0. \tag{6b}$$

Turning back now to the condition of conservation of mass flux J, we should expect as well for an evaporative wind (Hadrava, 1987)

$$J \sim \exp\frac{-\Phi_s}{kT_s}. \tag{7}$$

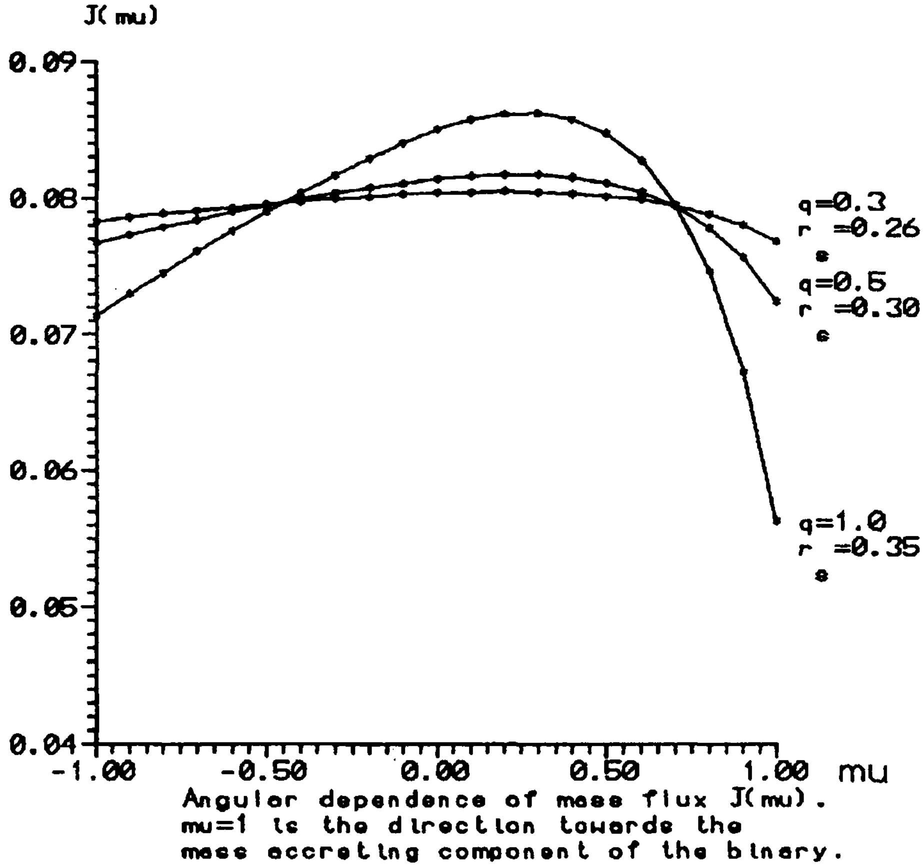

Figure 1 Angular dependence of mass flux $J(\mu)$ for several values of the mass ratio q, the radius r_s is close to the critical Roche radius, $\mu = 1$ is the direction towards the mass accreting component of the binary.

It follows from equation (6b) T_s must be direction-dependent, or in other words, equation (7) quantitatively describes anisotropy which is due to the influence of the companion star. We may estimate the rate of anisotropy by assuming that

$$T_s = T_{s0} + \left(\frac{dT}{dr}\right)_s \Delta r_s, \tag{8}$$

where the displacement of a sonic point Δr_s is caused by the gravitational attraction of the companion star (for more details see Pustylnik, 1994, 1995).

Thus combining equation (3) and equations (7) and (8) we have the condition of the mass flux conservation in the form

$$J = \rho v r^2 = B J_0 F, \tag{9}$$

where $J_0 = \rho_0 v_0 r_{s0}^2$ and the total mass loss equals $\dot{M} = 2\pi \int_{-1}^{+1} J d\mu = 4\pi J_0$.

Function F is given by

$$F = \exp - \left[\frac{\Phi_s}{kT_{s0}} \left(1 + \frac{d \ln T}{dr} \bigg|_{s0} \Delta r_s^0 \right)^{-1} \right], \tag{10}$$

and it can be easily calculated if we insert the explicit expression for gravitational potential for the Roche model into equation (6b). By T_{s0} in equation (10) we denote an average temperature which is fixed by simply postulating that kinetic energy of a gas particle plus specific enthalpy should be equal to the difference between the potentials at the surface of the mass-losing component and Roche critical potential.

Normalization constant B is defined by subsequent formula

$$B = \frac{1}{2\pi} \frac{1}{\int_{-1}^{1} F d\mu}. \tag{11}$$

Figure 1 demonstrates the angular dependence of the mass flux $J(\mu)$ for several values of the mass ratio q. Note that the rate of anisotropy increases with increasing q and that maximum of $J(\mu)$ falls upon the value of $\mu = 0.5$ which is due to the influence of the term responsible for the centrifugal force. Since our calculations are based on the assumption of a radially expanding wind the position of maximum of $J(\mu)$ distribution is relevant only to our specific model. The rate of anisotropy is sensitive to the ratio u_s/u_e (where u_s is local sonic velocity and u_e is the escape velocity) and the scaleheight of thermal drop off (or the displacement Δr_s of a sonic point).

We mention here in passing that different ad hoc flux tube approximations have been introduced in a number of papers, among others by Modisette and Kondo (1980), Haisch *et al.* (1980) and Kopp and Holzer (1976). From all the abovementioned it is clear that equations (9) and (10) may be regarded as equations of a flux-tube based upon very simple but physically justified assumptions.

3 EVALUATION OF MASS TRANSFER RATE IN ALGOL

We may use now equation (6b) and equations (8)–(11) of the preceding section and with the known observed parameters of Algol we estimate the mass transfer rate due to accretion upon the B8 primary component. The thermal (free–free) radioflux for a single star losing matter through an isotropic stellar wind is given by a subsequent expression (Panagia and Felli, 1975)

$$\begin{aligned} S_\nu &= 5.12 \left(\frac{\nu}{10\,\mathrm{GHz}} \right)^{0.6} \left(\frac{T_e}{10^4\,K} \right)^{0.1} \left(\frac{\dot{M}}{10^{-5} M_\odot\,\mathrm{yr}^{-1}} \right)^{4/3} \\ &\times \left(\frac{\overline{m}}{1.2} \right)^{-4/3} \left(\frac{u_{\mathrm{esc}}}{10^3\,\mathrm{km\,s^{-1}}} \right)^{-4/3} \overline{Z}^{2/3} \left(\frac{d}{\mathrm{kpc}} \right)^{-2} \mathrm{mJy}. \end{aligned} \tag{12}$$

Here $\overline{m}$ is the mean molecular weight, $\overline{Z}$ is an average ionic charge and the remaining notation is self-explanatory. Using recent very precise determination of Algol's parallax $0\overset{''}{.}0343 \pm 0\overset{''}{.}00085$ (Gatewood *et al.*, 1995) and assuming S_ν equal to radioflux of non-flaring component $S_\nu = 50$ mJy ($\nu = 2695$ MgHz) (Woodworth and Hughes, 1976) and taking u_{esc} equal to $u_e = \sqrt{2G(M_1 + M_2)/a}$ which gives $u_e = 350$ km s^{-1} for the Algol system we obtain $\dot{M} = 2 \times 10^{-7} M_\odot \overline{m} \sqrt{Z}$ yr^{-1}. This is certainly an upper limit estimate because it is generally believed now that the predominant source of radiation measured in the cm wavelength range is of synchrotron nature. Richards (1992) finds that $10^{-11} M_\odot \leq \dot{M} \leq 10^{-10} M_\odot$ yr^{-1}. This estimate follows from the mass of localized H II region indentified by spectroscopic observations made by Richards and also from considerations which presume equipartition between the magnetic field strength and the kinetic energy of the gas stream at the inner Lagrangian point (Bolton, 1989). Another independent estimate of $\dot{M}$ comes from the analysis of the optical light curves of Algol which yields $10^{-10} M_\odot \leq \dot{M} \leq 5 \times 10^{-10} M_\odot$ yr^{-1} (for more details see Pustylnik, 1994). Again this is only an upper limit estimate. The third and actually the most straightforward way to estimate mass loss rate $\dot{M}$ is to analyse observations of period changes which for Algol have a record of over 300 years. Paradoxically though this classical approach is the least reliable method of evaluation $\dot{M}$. If we assume a simple mass loss (no mass transfer, no angular momentum loss) then for $\Delta P/P \simeq 10^{-9}$ (Söderhjelm, 1980) this results in $\dot{M} \simeq 2 \times 10^{-8} M_\odot$ yr^{-1}. However, this seems to be a gross overestimation because it is generally believed now that due to the presence of magnetic field ($B \simeq 100$ G) connected with the Roche lobe filling secondary component period variations are caused basically by the angular momentum loss from the orbital motion (Tout and Hall, 1991; Yungelson *et al.*, 1989; Bolton, 1989). Summing up the above-given arguments we take $\dot{M} \simeq 1 \div 5 \times 10^{-10} M_\odot$ yr^{-1} as the most reliable upper limit estimate of mass loss rate from Algol. Integrating now equation (9) for the mass flux $J(\mu)$ over μ we find (using the data of Richards, 1992, for R_{aacr}) the following estimate for accretion rate $\dot{M}_{accr} \simeq 0.4 \div 2.0 \times 10^{-11} M_\odot$ yr^{-1}. We find for Algol $T_{accr} \simeq 2.8 \times 10^6$ K. According to calculations of Lubow and Shu (1975) (see also Ulrich and Burger, 1976) the effective crossection of the gas stream can be approximated as

$$S_{str} = 6.9 \times 10^{-5} \frac{T_4 r_2^3}{\overline{m} M_2}, \tag{13}$$

where S_{str} is expressed in units of solar surface, T_4 is the temperature in units of 10^4 K, $\overline{m}$ is again the mean molecular weight and r_2, M_2 are also expressed in solar units. Thus we find from equation (13) $S_{str} \simeq 1 \div 3 \times 10^{20}$ cm^2. Actually this estimate practically coincides with a simple evaluation of a thermal drop-off scale of the stream width $H/R \simeq u_s^2/u_e^2$ in our notation (see, for instance, Pringle, 1985). If we take this estimate close enough to the first Lagrangian point then the value of H/R is fully determined by the ratio $G(M_1 + M_2)kT$ and geometry of the Roche model (see also Meyer and Hoffmeister, 1983). We intentionally emphasize this point since both the emission measure and X-ray luminosity scale with H^3. Taking now our above-derived value of M_{accr} and taking into account that gas is fully ionized in the stream we find for the average electron density $n_e \simeq 1 \div 3 \times 10^{10}$ cm^{-3} magnitude estimate it is worth mentioning that it agrees satisfactorily with the value found from the analysis of *Ginga* data on X-ray flare. This last figure is translated into the emission measure *EM* for the accretion region

$$\int n_e^2 dV \simeq 1 \div 5 \times 10^{52} \text{ cm}^{-3}.$$

We take the emissivity function for optically thin gas for the X-ray range considered ($1.2 \div 18$ KeV) from Mewe *et al.* (1986)

$$P_c(\lambda, T) = 2.051 \times 10^{-22}\, n_e^2\, G_c \lambda^{-2}\, T^{-1/2} \exp\left[-143.9/(\lambda T)\right], \tag{14}$$

where $P_c(\lambda, T)$ is in units of (erg cm^{-3} s^{-1}), λ is expressed in cm and T in 10^6 K. According to Mewe *et al.* (1986), the total Gaunt factor (the sum from free–free, bound–free and two photon emission contributions) is practically independent of λ for the energy range considered. Thus we assumed an average value of G_c taken from the graphical data of the just quoted paper. Now, combining this with our estimate of the emission measure for an accretion region we obtain finally for the X-ray luminosity $L_x \simeq 0.4 \div 2 \times 10^{30}$ erg s^{-1} (which is nearly by an order of magnitude lower than an earlier estimate of Harnden *et al.* (1977). Our upper limit estimate relates to a higher value of $T_{\text{accr}} = 6 \times 10^6$ K and it reflects an uncertainty in the impact velocity for the stream. We arrive at a lower value for L_x because our mass transfer rate is correspondingly roughly one order of magnitude lower than that used in the paper of Harnden *et al.* (1977).

Unfortunately, the lack of observational data of a comparable accuracy and amount for other Algol-type binaries precludes the application of the above-described method for the derivation and estimation of the X-ray accretion component flux.

In sum, we find no contradiction with the results of the analysis of X-ray *Ginga* Algol observations by Stern *et al.* (1992) who set a 10–20% upper limit for the eclipsed flux fraction during the two eclipses. As mentioned above, the effective area of accretion shock region must be by at least two orders of magnitude lower then the eclipsed region.

References

Antunes, A., Nagase, F., and White,N. E. (1994) *Astrophys. J.* **436**, L83.

Beskin, G. and Minarini, R. (1995) In *Flares and Flashes: View from the Ground and Space*, G. Greiner, H. Duerbeck, R. Gershberg (eds.), Kluwer Academic Publishers, p. 195.

Bolton, C. T. (1989) In *Algols*, Kluwer Academic Publishers, p. 311.

Dempsey, R. C., Linsky, J. L., Scmitt, J. H. M. M., and Fleming, T. A. (1993) *Astrophys. J. Suppl.* **86**, 599.

Gatewood, G., de Jonge, J. K., and Heintz, W. D. (1995) *Astron. J.* **109**, 434.

Hadrava, P. P. (1987) *Publ. Astron. Inst. Czech.* **70**, 263.

Haisch, B. M., Linsky, J. L., and Basri, G. S. (1980) *Astrophys. J.* **235**, 519.

Harnden, Jr. F. R., Fabricant, D., Topka, K., Flannery, B., Tucker, W. H., and Gorenstein, P. (1977) *Astrophys. J.* **214**, 418.

Kopp, R. A. and Holzer, T. E. (1976) *Sol. Phys.* **46**, 43.
Lubow, S. H. and Shu, F. H. (1975) *Astrophys. J.* **198**, 383.
Mewe, R., Lemen, J. R., and van den Oord, G. H. J. (1986) *Astron. Astrophys. Suppl. Ser.* **65**, 511.
Meyer, F. and Hoffmeister, E. (1983) *Astron. Asrtophys.* **121**, 29.
Modisette, J. and Kondo, Y. (1980) *Astrophys. J.* **240**, 180.
Panagia, N. and Felli, M. (1975) *Astron. Astrophys.* **39**, 1.
Pringle, J. E. (1985) In *Interacting Binary Stars*, J. E. Pringle and R. A. Wade (eds.), Cmabridge University Press, p. 3.
Pustylnik, I. (1994) *Astron. Astrophys. Trans.* **5**, 287.
Pustulnik, I. (1995) *Balt. Astron.* **4**, 64.
Richards, M. (1992) *Astrophys. J.* **387**, 328.
Singh, K. P., Drake, S. A., and White, N. E. (1995) *Astrophys. J.* **445**, 840.
Sõderhjelm, S. (1980) *Astron. Astrophys.* **89**, 100.
Stern, R. A., Uchida, Y., Tsunata, S., and Nagase, F. (1992) *Astrophys. J.* **400**, 321.
Tout, C. A. and Hall, D. S. (1991) *Mon. Not. R. Astron. Ser.* **253**, 9.
Ulrich, R. K. and Burger, H. L. (1976) *Astrophys. J.* **206**, 509.
Umana, G., Catalano, S., and Rodono, M. (1991) *Astron. Astrophys.* **249**, 217.
Yungelson, L. R., Tutukov, A. V., and Fedorova, A. V. (1989) In *Algols*, Kluwer Academic Publishers, p. 141.
Woodworth, A. W. and Hughes, V. A. (1976) *Mon. Not. R. Astron. Ser.* **175**, 177.