ANISOTROPIC STELLAR WIND IN CLOSE BINARIES WITH NON–RELATIVISTIC COMPONENTS: OBSERVATIONAL EVIDENCES AND THEORETICAL IMPLICATIONS

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ABSTRACT. Some of the most important issues of anisotropic stellar wind research in close binaries with non-relativistic components, basically Algol-type stars, serpentides and early-type contact systems are briefly discussed with an emphasis on the problems of origin of anisotropy, morphology of gas, observable effects of wind upon spectra and light curves, the angular momentum loss and the evolutionary consequences.

Key words: Stars: Close Binaries; Anisotropic Stellar Wind.

1. Introduction

During the last 10-15 years the problem of anisotropic stellar wind in close binaries has received a considerable attention both from the observers and theoreticians. The underlying reasons for that are multifold but actually are self-explanatory. Firstly, there is a plentiful evidence suggesting that early-type MS stars and supergiants of all spectral classes lose mass at a rate $\dot{M} = 10^{-6} - 10^{-4} M_{\odot}$ per year. For typical velocities of expansion $v_{esc} = 10^2 - 10^3$ km·s^{-1} and characteristic size of the orbit $a \sim 10^{12} - 10^{13}$cm this would mean optical depths of circumbinary gas of order $\tau \sim 0.1 - 1.0$, quite sufficient to influence both continuum and the line spectra of a binary system. In case of an optically thick stellar wind the accretion luminosities may be comparable to the intrinsic luminosities of the accreting star and thus may significantly alter the picture based upon assumptions of conventional theories. Secondly, morphology and dynamics of an ambient gas is governed by the interaction of gas (often in transonic flow) with the components and the consequences of it are often observed. Besides, the importance of studying various aspects of stellar wind problem is underscored by the fact that stable accretion discs cannot be formed in many cases whereas stellar wind is present practically in all binaries. Last but not least, it has been indicated that for the components of spectral type later than F5 with the convective envelopes magnetic stellar wind appears to be a very effective mechanism of redistributing the angular momentum and thus drastically changing the orbital elements which in its turn will have profound consequences for the future evolutionary status of a binary (this is especially valid for contact systems, both early-type and W UMa type stars).

In sum stellar wind permeats practically all important aspects of astrophysical research of close binary systems. But its full role in shaping the overall picture of the observed phenomena in these systems and the underlying processes are far from being fully understood. Here we give just a sketchy review of some of the key issues of anisotropic stellar wind problems:

a) anisotropy, colliding winds, morphology and clumpy structure,

b) the effect of wind upon the spectra and the light curves,
c) angular momentum loss and evolutionary consequences.

2. Anisotropy, Interacting Winds, Morphology

Anisotropy of stellar wind stems from the very binary nature of the system even if the wind is associated just with one of the components and is virtually absent for a companion star. Anisotropy is caused by the displacement of a sonic point induced by the periodically varying gravitational attraction of a companion star (Friend and Castor 1982, Hadrava 1985) or may be induced radiatively (Basko and Sunyaev 1973; Modisette and Kondo 1980). Recently we have derived a fairly simple expression for an estimate of the relative displacement of a sonic point (Pustylnik 1994) valid for a radially expanding wind in an adiabatic case

$$\frac{\Delta r_s}{r_s} \simeq \frac{1}{4} f(r_s)\, q\, r_s^2\, \frac{u_e^2}{u_s^2}\,, \qquad (1)$$

where $\Delta r_s/r_s$ is the relative displacement of a sonic point (in comparison with a single star), q is the mass ratio, u_e is the escape velocity from a binary system and u_s is sonic velocity whereas $f(r_s, q) \sim 1$ is an elementary function, r_s is expressed in units of the semi-major axis. Thus, it follows from (1) that the relative displacement is of order of $10^{-3} - 10^{-2}$ of a stellar radius which is comparable to the scale of the chromosphere. Since the mass loss rate $\dot{M} = 4\pi \rho_s u_s r_s^2$ depends primarily on the density of gas ρ which is very sensitive to the depth in the chromosphere (u_s scales as the square root of a temperature but the accompanying changes with the depth would be much smaller) the net result should be higher mass flux in the directions pointing to the companion star.

Geometry of wind is either incorporated with the aid of ad hoc stream tubes (Modisette and Kondo 1980, Haisch et al. 1980 , Kopp and Holzer 1976) or for a simple model of evaporative stellar wind by fixing the ratio of gravitational potential of a binary to the total energy of a gas particle (Pustylnik 1994). Even in this latter relatively simple case geometry of wind is strongly dependant on the temperature T_{gas}. For hot gas $T_{gas} \geq 10^6\,K$ the wind may be nearly isotropical, whereas for $T_{gas} \simeq 10^4\,K$ transonic flow is realized,i.e. the shocks and the clumpy structure will be the inevitable consequences . In the intermediate case $T_{gas} \simeq 10^5 K$ conical shape should be a good approximation, the angle subtended by the cone being determined roughly by the cros-section of the critical Roche lobe of an accreting star. In the case of accretion from stellar wind (Kolychalov and Sunyaev 1979) one should expect to find some consequences of interaction between the gas flow and the disk and indeed in some interacting binary systems these effects have been observed (for instance in UW CMa, Eaton 1979).

Modelling of colliding wind structure and dynamics has become one of the most topical problems in stellar astrophysics during the last 10-15 years. Originally it has been worked out and applied to symbiotic stars ,novae and binaries with Wolf-Rayet type components (this topic is beyond the scope of the present report and will not be elaborated here). But more recently modelling of colliding winds proved to be a promising approach to investigation of classical interacting systems as well - serpentides, early-type contact binaries (Gies and Wiggs 1991, 1992; Luo, McCray and Low 1991; Stevens, Blondin and Pollack 1992; Kallrath 1991 and references therein). Despite of the high degree of sophistication and complicated mathematical technique the input physics is still fairly simple one (isothermal or adiabatic gas, two-dimensional models), the treatment of interaction of the winds is confined to the consequences at the impact front of the winds where dynamical pressures of the winds are equal, whereas effects of anisotropy pertinent to the binary nature and mentioned above are neglected. The most immediate effects of colliding winds from the observational aspect are formation of bow shocks around the mass accreting star, generation of significant X-ray emission (Cherepashchuk 1976) and the dependence of P Cyg type line profiles on the orientation in respect to a bow shock, line profile changes with the phase of the orbital period.

3. The Effect of Wind upon the Light Curves and Spectra of Close Binaries

There are multiple manifestations of the influence of stellar wind upon the light curves and spectra of the Algol-type stars,serpentides and early-type contact binaries. Thus, Plavec (1989) who has made a comparative analysis of UV emission lines of C IV, N V, C III, Si IV, Al III etc for 10 Algols and 6 serpentides finds no significant differences between them and concludes that these lines are formed in the wind basically due to scattering processes. The effects of wind are invariably found for the well studied interacting systems if sufficient temporal, spatial and spectral resolution is achieved. Thus Eaton (1978) from analysis of OAO-2 UV light curves of a bright early-type contact binary UW CMa finds the evidence for an expanding region of low continuum optical depth or in other words, anisotropic stellar wind from Of component producing small dips in the UV light curves during the secondary minimum. Short time variations in the intensity of stellar wind have been found from high resolution spectrum of another early type contact system SV Cen (Drechsel et al. 1982), where mass loss is of order $10^{-4}\,\dot{M}_{\odot}$/year according to the same authors. Analysis of UV resonance lines and $H\alpha$ as well as He I λ 6678 in AO Cas (Gies and Wiggs 1991) suggests that stellar wind is concentrated towards the mass accreting component, emission in $H\alpha$ originates predominantly on the hemisphere of accreting star facing the mass losing component. Similarly P Cyg type profile variations with the phase of orbital period have been detected in HD 47129 (Sahade and Brandi 1991), V 444 Cyg (Short and Brown 1988), γ Vel (Brandi, Ferrer and Sahade 1991). According to Karetnikov and Glazunova (1985), Karetnikov and Menchenkova (1987) who studied spectroscopically early-type binary systems V 367 Cyg, V 448 Cyg (by all evidence, an intermediate type of objects between serpentides and early-type contact binaries) practically all absorption lines observed in the visible range of their spectra are formed in a common envelope. A new technique has been proposed to assess the rate of mass loss (or at least to set an upper limit) directly from the light curves based on an assumption of optically thin wind from one component (Pustylnik 1994). It has been applied to an early-type system SZ Cam (Pustylnik and Polushina 1994) and an estimate $\dot{M} \simeq 5 \cdot 10^{-7} M_{\odot}$/year has been found as an average for about 50 years. Optically thick stellar wind may be unstrumental in explaining many puzzling features of the early-type contact binaries (small changes of the amplitudes of radial velocities, phase dependant estimates of spectral and luminosity types, as well as luminosity and radii excesses for the secondaries etc).

4. Angular Momentum Loss and Evolutionary Consequences

During the last decade it became clear that angular momentum loss through the stellar magnetic wind plays a crucial role in the evolutionary history of different type close binaries and can successfully explain transition of a binary from detached to a semi-detached state and from the latter to the contact stage (see, for instance, Yungelson, Tutukov and Fedorova 1989; Vilhu 1982; Iben and Tutukov 1984). With the aid of magnetic field embedded in the flow it is easy to understand at least in qualitative terms subkeplerian velocities, supersonic turbulence and high temperature regions in circumstellar material (Bolton 1989). Quite recently Tout and Hall (1991) have presented arguments in favour of the idea that at least in some cases (for the conservative case B mass transfer when mass losing component is in a giant stage with a deep convective zone) the time scale for the angular momentum loss may be shorter than the nuclear time scale for a component nearly filling in its respective critical Roche lobe. Thus they suggest that namely angular momentum loss may be the driving mechanism behind mass transfer proccess.

In this way comparable estimates for the mass transfer and mass loss rates find an interpretation. This picture also reasonably agrees with the radiodata for some Algol-type and RS CVn type systems (Owen and Gibson 1978) as well as with the alternating decreases and increases of the orbital period found in many systems (Hall and Kreiner 1980).

One of still unresolved problems of the theoretical treatment of stellar wind during the critical stages of stellar evolution is of fundamental nature. Namely, the mass transfer process has been invariably treated as the filling in of the critical Roche lobe,whereas both mass loss and mass transfer occur even when a star is far from reaching its critical Roche surface. Besides, a simple picture of the Roche equilibrium model may loose its validity during the short-lived dynamical stages of evolution.

References

Basko M.M., Sunayev R.A.: 1973, *Ap.Space Sci.*, **23**, 117.

Bolton C.I.: 1989, *in: Algols, IAU Coll.* **107**, ed. A.Batten, Kluwer, Dordrecht, 311.

Brandi E.I., Ferrer O.E., Sahade J.: 1991, *Ap.J.*, **340**, 1091.

Cherepashchuck A.M.: 1976, *Pis'ma v Astron. Zhurn.* **2**, 138.

Drechsel H., Rahe J., Wargau W., Wolf B.: 1982, *As.Ap.* **110**, 246.

Eaton J.A.: 1978, *Ap.J.*, **220**, 578.

Friend D.B., Castor J.I.: 1982, *Ap.J.*, **261**, 293.

Gies D.R., Wiggs M.S.: 1991, *Ap.J.*, **375**, 321.

Gies D.R., Wiggs M.S.: 1992, *Ap.J.*, **396**, 238.

Hadrava P.P.: 1987, *Publ. Astron. Inst. Czechoslovak.*, **70**, 263.

Haisch B.M., Linsky J.L., Basri G.S.: 1980, *Ap.J.*, **235**, 519.

Hall D.S., Kreiner J.M.: 1980, *Acta Astr.*, **30**, 387.

Iben I., Tutukov A.V.: 1984, *Ap.J.* **284**, 719.

Kallrath J.: 1991, *M.N.R.A.S.,* **248**, 653.

Karetnikov V.G., Glazunova L.V.: 1985, *Astron. Zhurn.*, **62**, 938.

Karetnikov V.G., Menchenkova E.V.: 1987, *Astron. Zhurn.*, **64**, 367.

Kolychalov P.I., Sunyaev R.A.: 1979, *Pis'ma v Astron. Zhurn.* **5**, No.7, 338.

Kopp R.A., Holzer T.E.: 1976, *Solar Phys.,* **46**, 43.

Luo I.R., Mc Cray J.M. Low A.M.I.: 1991, *Ap.J.*, **362**, 267.

Modisette J., Kondo Y.: 1980, *Ap.J.*, **240**, 180.

Owen F.N., Gibson D.M.: 1978, *A.J.*, **83**, 1488.

Plavec M.J.: 1989, In: *Algols, IAU Coll.* **107**, ed. A.Batten, Kluwer, Dordrecht, 95.

Polushina T.S., Pustylnik I.: 1994, *As. Ap. Transactions,* **5**, 303.

Pustylnik I. : 1994, *As. Ap. Transactions,* **5**, 287.

Sahade J., Brandi E.: 1991, *Ap.J.*, **379**, 706.

Shore S.N., Brown D.N.: 1988, *Ap.J.*, **334**, 1021.

Stevens I.R., Blondin J.M., Pollack A.M.I.: 1992, *Ap.J.*, **386**, 265.

Tout C.A., Hall D.S.: 1991, *M.N.R.A.S.,* **253**, 9.

Vilhu O.: 1982, *As.Ap.*, **109**, 17.

Yungelson L.R., Tutukov A.V., Fedorova A.V.: 1989, in: *Algols, IAU Coll.* **107**, ed. A.Batten, Kluwer, Dordrecht, 141.