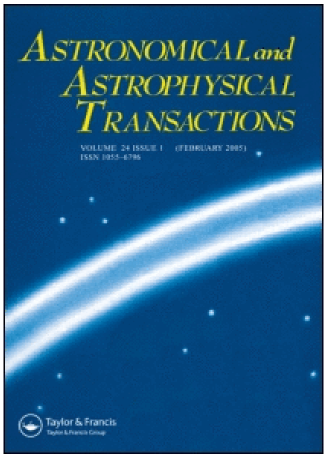

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X-ray properties of early-type binaries: theory versus observations

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X-ray properties of early-type binaries: theory versus observations

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Early-type binary stars are expected to be more luminous and hard X-ray sources than single stars are. However, recent observational studies show that, *on average*, the X-ray properties of single and binary early-type stars are not very different. We review these studies and discuss a possible explanation for this discrepancy.

Keywords: Close binary stars; Hot stars; Stellar winds; X-ray properties;Wind–wind collision

1. Introduction

Massive hot luminous stars of types OB and WR have strong supersonic, radiatively driven winds. It has long been known [1, 2] that both single and binary early-type stars are X-ray emitters. X-ray emission of single stars is attributed to the internal instability of their winds (see, for example, [3–5]). Model computations predict shock velocity jumps that reach a few hundred kilometres per second, implying post-shock temperatures of a few megakelvins. In the case of early-type binaries, collision of the individual stellar winds should lead to the formation of strong shock fronts in which the kinetic energy of the winds is converted into high-temperature gas. The velocity jump in this case is defined by the wind flow velocity (greater than $1000\,\mathrm{km\,s^{-1}}$) and so the resulting plasma temperature can be very high (above 10 MK). Thus, early-type binaries should be more luminous and hard X-ray sources than single stars are. This idea was first put forward in [6, 7]. According to the simple analytical treatment of wind–wind collision [8], the X-ray luminosity of an early-type binary should be higher by an order of magnitude than that of a single star.

However, subsequent X-ray observations with various space observatories (Einstein, ROSAT, ASCA, XMM-Newton and Chandra) have revealed a more complex picture. In this paper we review the key observational facts about the X-ray properties of early-type stars and current models and discuss possible ways to resolve existing discrepancies.

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2. Observational X-ray properites of early-type stars

Let us summarize the key properties of X-ray radiation from early-type stars. Observations with X-ray satellites indicate that single hot luminous stars have rather soft thermal X-ray spectra (see, for example, [2, 9–11]). Another well-known property of the X-ray emission of early-type stars is that their observed intrinsic (*i.e.* corrected for the interstellar absorption) X-ray luminosity is proportional to the bolometric luminosity $L_X \approx 10^{-7} L_{bol}$. It could be expected that, in the $L_X - L_{bol}$ plane, binary stars would be clearly separated from single stars, owing to their increased X-ray luminosity. However, various studies have shown that this is not the case. In figure 1 taken from [9], the $L_X - L_{bol}$ relation is shown for binary and single stars located in the Carina OB1 association. As seen from the figure, there is no clear distinction between binary and single O-type stars in the $L_X - L_{bol}$ plane. The lines show the best-fit linear relations between $\log_{10} L_X$ and $\log_{10} L_{bol}$ which include single and binary O stars. Similar results were obtained in [11]. Note that some binary

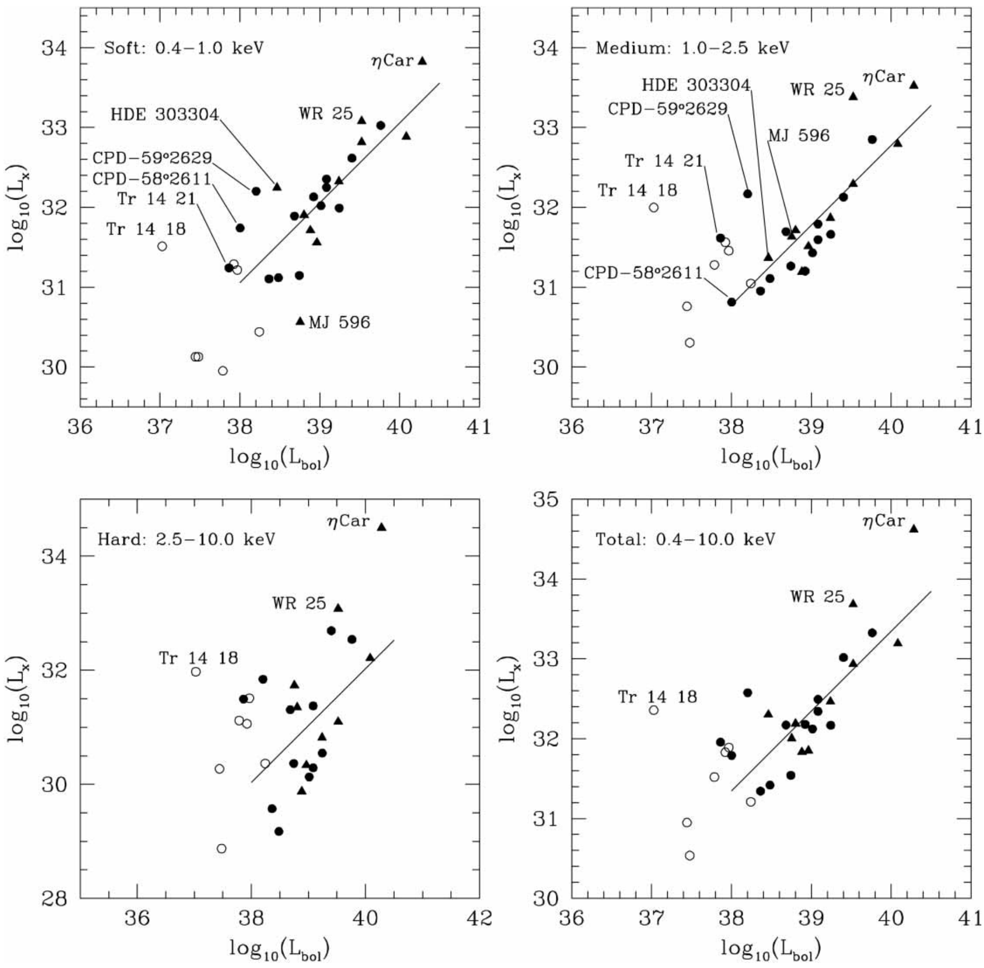

Figure 1. L_X versus L_{bol} for early-type stars in the Carina Nebula in different energy bands. Presumably single O-type stars are indicated as full solid circles, and binary stars as full triangles. B-type stars are indicated as open circles. The demarcation line between O- and B-type stars is located at about 10^{38} erg s^{-1}. Marked stars are excluded from the fits for various reasons.

stars are indeed bright and hard X-ray sources, in agreement with the qualitative picture outlined above (see, for example, [12]). On the other hand, there are a number of known early-type binaries which do not show a significant X-ray excess nor particularly hard X-ray spectra.

3. Models of wind–wind collision and the importance of mutual radiative inhibition

Efforts to develop dynamic simulations of colliding winds have been quite successful with respect to the adiabatic shocks formed in low-density winds of *wide* binary systems [13, 14]. Such simulations, however, encounter severe difficulties in resolving the extensive structure of unstable radiative shocks characteristic of high densities at the interaction front in *close* binary systems. Antokhin *et al.* [15] suggested a steady-state method for computing X-ray emission in this case. Irrespective of the method used to compute the X-ray emission of binary stars, the existing models produce very bright and hard X-ray sources. Yet, as shown above, the X-ray properties of single and binary hot stars are not very different *on average*. There must exist some mechanism which ‘dumps’ the X-ray production in a large fraction of early-type binary systems.

Let us recall that the main source of energy which heats the gas to X-ray temperatures is the kinetic energy of the winds. An important factor not accounted for in the current wind interaction models is the mutual radiative influence of the stars on the winds of other stars. Indeed, most of the current models deal only with the structure of the shocks assuming a simple kinematic model for the individual winds outside the collision zone. The wind kinematics are assumed to be the same as in the case of an isolated undisturbed single wind.

Theoretical studies of wind–wind collision mechanisms [4, 16] suggest that either the so-called radiative braking or radiative inhibition may significantly slow down the winds of the binary components. In both cases the underlying physical mechanism is the same, namely that the radiation force of a star accelerates its own wind and *decelerates* the wind of the component. Radiative braking may occur in wide binaries where one wind dominates the other. In this case the collision zone is located very close to the weaker star. The radiation density of this star in the vicinity of the collision zone is much higher than the radiation density of the brighter component. The radiation of the weak component suddenly slows down the incoming dominating wind just before the collision (hence the term ‘braking’). In close binaries with more or less similar winds the influence may be mutual and so both winds are slowed down right from their base at the stellar surfaces. Estimates show that wind velocities in the vicinity of the collision zone may decrease by some 50% [17]. Recall that the temperature of the heated gas just behind the shock is proportional to the square of the wind velocity. Thus radiative inhibition may greatly reduce the X-ray luminosity of the system and the hardness of its X-ray spectrum.

4. Conclusions

X-ray observations of single and binary early-type stars show that, while X-rays of some binaries are brighter and harder than those of single stars (as expected from simple qualitative analysis), *on average* the X-ray properties of large samples of single and binary O stars do not differ very much. What could be the mechanism that ‘dumps’ the X-ray production in a large fraction of binary early-type systems? Mutual radiative inhibition of the binary components may be the answer to this question.

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