The Lives and Death-Throes of Massive Stars
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X-rays from colliding winds in massive binaries

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Abstract. In a massive binary, the strong shock between the stellar winds may lead to the generation of bright X-ray emission. While this phenomenon was detected decades ago, the detailed study of this emission was only made possible by the current generation of X-ray observatories. Through dedicated monitoring and observations at high resolution, unprecedented information was revealed, putting strong constraints on the amount and structure of stellar mass-loss.

Keywords. X-rays: stars – stars: early-type – stars: winds – stars: binaries

Stellar winds are expected to collide in a strong shock if their sources, massive stars, are sufficiently close to each other, as occurs in multiple systems. This shocked plasma should not escape detection as its signature could appear anywhere throughout the electromagnetic spectrum, e.g., hard X-ray emission, non-thermal radio or gamma-ray emissions, or optical Hα emissions. In the X-ray domain in particular, massive stars display intrinsic X-ray luminosities following $L_X \sim 10^{-7} L_{BOL}$: any additional phenomenon, such as colliding winds, should produce a departure from this relation. The first X-ray observations of massive stars with Einstein or ROSAT seemed to support this scenario, but larger surveys with the more sensivitive XMM and Chandra observatories demonstrated that only few O+OB systems are overluminous and harder - the models were thus predicting too large X-ray luminosities. The situation is clearly different for systems comprising WRs or LBVs, where binaries truly are more luminous than single objects. Here we summarize the results of the recent sensitive studies of X-ray bright colliding-wind binaries - for a full review, see Rauw & Nazé (2016).

Since other phenomena may also produce overluminosities and hard X-rays (e.g. magnetically confined winds), the smoking gun for identifying colliding wind emission rather relies on the presence of recurrent variations linked to the orbital period. Two broad categories can be defined. The first one concerns the detection of changing absorption. Indeed, when the two winds have different densities, a modulation in the soft band will be detected as the line-of-sight towards the collision alternatively crosses each wind. This effect is particularly strong in asymmetrical cases, i.e., WR+OB systems. For example, large increases in the observed emission of γ^2 Vel or V444 Cyg are detected when the collision is seen through the O-star wind. Such changes can be used to constrain the opening angle of the collision cone or the wind densities. Another possibility to get an absorption modulation occurs in eccentric systems: as the collision zone plunges into the densest regions of the wind, the absorption increases, lowering the soft X-ray flux observed at Earth (see e.g. the cases of WR22, WR25, or WR140).

The second category only concerns eccentric systems: the changing separation is then the source of additional variability, as it directly impacts on the collision strength (which can be directly probed using the hard X-ray emission). For adiabatic collisions, one expects $L_X \propto 1/D$ where D is the orbital separation (i.e. emission should be maximum at periastron). This is observed for several systems (Cyg OB2 #9, 9 Sgr, WR25) but strong deviations from this relation are also seen and some remain unexplained: the emission in WR140 varies less than from a $1/D$ scaling while the emission even appears constant in the case of WR22 and γ^2 Vel despite their large eccentricities. For radiative collisions, one expects $L_X \propto v^2$ (i.e. minimum at periastron if the winds are still accelerating), but again it is not always clearly detected. Note that some collision may change their nature along the orbit. Such transitions between adiabatic and radiative types are especially prone to occur near periastron, and it can be easily detected by a deviation from the $1/D$ relation at that phase (as seen e.g. for Cyg OB2 #9 or 9 Sgr). The influence of the radiative braking (a slowing of the stellar wind of one star by the UV emission of its companion) plays a crucial role in this context.

The sensitivity of current X-ray observatories, coupled to dedicated, dense monitorings, revealed additional things. For example, since colliding wind emission should mostly arise close to the stagnation point, i.e. the location along the line-of-centers where wind momenta equilibrate, eclipses of the emitting zone by the stellar bodies are expected to occur when the inclination is high - and this was observed for V444 Cyg. Also, for close binaries, the orbital velocities are non-negligible compared to the wind velocities, so that Coriolis deflections of the collision zone are expected - and this leads to lightcurve asymmetries as detected in V444 Cyg. Moreover, when the secondary wind is very weak, it may not be able to maintain a stable collision zone against the primary wind, leading to a crash or collapse of the collision at (or close to) the secondary photosphere. In close and circular systems, this may occur all the time (e.g. the case of CPD −41°7742); in eccentric systems, this may occur only at periastron (as e.g. for WR140 or WR21a). Finally, detailed hydrodynamic simulations revealed that the emission from the shocked plasma in eccentric systems does not react instantly to the changing conditions, i.e. it has a "memory" hence the variations recorded on the way towards periastron will be different from those after periastron, even at similar separations - and this hysteresis effect has now been detected in several systems.

High resolution X-ray spectroscopy brings the most stringent constraints, and it has become available in the last two decades but only for the brightest objects: only a handful colliding-wind binaries could be observed (WR48a, WR140, WR147, θ Mus, γ^2 Vel, HD166734). These data first confirmed the origin of X-rays in a collision distant from the photosphere, thanks to the detection of strong f lines in He-like triplets. They also revealed the presence of cool gas through the detection of radiative recombination continua and brought some information on the shock cone geometry thanks to the analysis of line shifts and widths. Obviously, these pioneering datasets have demonstrated the potential of such observations.

The future of colliding wind studies appears twofold. On the one hand, it is crucial to continue observations with the aim of filling the parameter space: studying other binary configurations to probe other collision regimes appears important, as surprises (i.e. deviations from expectations) have been numerous in this field; probing systems with different metallicities are also required, to check our understanding with totally different wind strengths. On the other hand, monitoring the line profiles at high resolution and high sensivity for many systems is the logical next step, as such observations will provide the most stringent constraints on the geometry and properties of the interaction zone - but it will have to await the advent of a new generation of spectrometers, like the forthcoming XIFU onboard Athena.

Reference

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