A Massive Star Odyssey, from Main Sequence to Supernova
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Grain formation in post-shocked wind collisions of massive binary systems

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Abstract. Massive binary star systems are not uncommon, and neither the supersonic collision of their winds. In the present work we study these shocks and the further consequences on wind structure. The post-shock gas is a warm and high-density environment, which allows dust to form and grow. We show that this growth is fast, of just a few hours. An application to η Car shows that, probably, the decline of X-rays fluxes observed in its light curve is the consequence of its high absorption in periodic dust formation events, at periastron passage.

1. Introduction

Many massive binary systems are known, and almost all present high-energy fluxes, not originated in the stars, but around them, indicating the presence of colliding winds. The source of observed high X-ray fluxes should be a hot and dense gas, generated by shocks around these objects (Zhekov & Skinner 2000). At high temperature and density, free-free emission in X-rays becomes highly important (Usov 1992; Ishibashi *et al.* 1999). X-ray emissions associated with interacting winds were observed on many objects (Williams *et al.* 1990; Corcoran *et al.* 2001; Thaller *et al.* 2001). Grains also may be formed and grow on post-shocked gases (*e.g.*, Williams *et al.* 1987, 1990; Monnier *et al.* 2001; Williams *et al.* and Tuthill *et al.* in these Proceedings), when the heated gas loses high amount of energy, mainly by *Bremsstrahlung*, cools and becomes denser. Recent observations in the IR supply this idea, showing episodic dust formation events in these regions (Williams *et al.* 1990; Marchenko *et al.* 1999; Harries *et al.* 2000). Some binary systems present, periodically, a sudden decrease of X-ray emission (Ishibashi *et al.* 1999). A fast dust formation and growth event in these regions due to the shocked winds might provoke a considerable increase in extinction explaining these features of the light curves. This could cause the temporary reduction on X-rays and UV fluxes, which may increase *a posteriori* with the evaporation of the particles, or even by the expansion of the dust shell.

2. Model and results: an application to η Carinae

The model assumes the colliding winds of two massive stars A and B, which have mass loss rates $\dot{M}_{\rm A}$ and $\dot{M}_{\rm B}$, and wind velocities $v_{\rm A}$ and $v_{\rm B}$, respectively, orbiting each other with period P, eccentricity e and separation D at *periastron.*

We divide the shock evolution in four parts: (*i*) the instantaneous collision, neglecting radiative losses; (*ii*) the gas cooling at post-shock; (*iii*) the formation of dust and its growth; and (*iv*) the evolution of the dust shell, and its consequence to the light curve observed. The basic physics of the shock is very well known, and described by the hydrodynamics equations of mass continuity, fluid momentum and energy. The growth and evaporation rates of the dust particles are given by the classic nucleation theory.

η Car is a super massive star, supposed to be a LBV class star, and also is supposed to have a companion, probably a massive WR or OB star (Damineli *et al.* 2000). The system total mass, inferred by luminosity, is $\sim 120\,\mathrm{M}_\odot$. η Car A is responsible for major of this mass and η Car B should have typical WR stellar winds, $\dot{M}_\mathrm{B} \approx 10^{-5}\,\mathrm{M}_\odot\,\mathrm{yr}^{-1}$ and $v_\mathrm{B}^\infty \approx 3\times10^3\,\mathrm{km\,s}^{-1}$. Observations indicate that η Car A should have $\dot{M}_\mathrm{A} \approx 10^{-3}\,\mathrm{M}_\odot\,\mathrm{yr}^{-1}$ and $v_\mathrm{A}^\infty \approx 500\,\mathrm{km\,s}^{-1}$ (Hillier *et al.* 2001; Damineli *et al.* 2000). For the above parameters and $\dot{M} = 5\times10^{-4}\,\mathrm{M}_\odot\,\mathrm{yr}^{-1}$ and $e \simeq 0.8$, it was possible to reproduce its observed light curve.

3. Conclusions

In this work we present a model for colliding winds, where we determined the changes in physical parameters, like density, temperature and pressure in the post-shock. This gas, cooled and denser after shock, can be the site for grains formation. The model was applied to η Car which could explain: (*i*) the rapid decline on fluxes observed periodically; and (*ii*) the slight decrease in opacity considering the expansion of the dust with the wind. This model agrees better with observations for $e \simeq 0.8$, and a mass loss rate of the primary star of about $3\text{-}5\times10^{-4}\,\mathrm{M}_\odot\,\mathrm{yr}^{-1}$.

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