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DUST FORMATION EVENTS IN COLLIDING WINDS: AN APPLICATION TO ETA CAR

D. Falceta-Gonçalves,[1] V. Jatenco-Pereira,[1] and Z. Abraham[1]

Recent IR observations indicate that many massive binary systems present dust formation episodes in regions close to the stars during the periastron passage. These systems are known to be high-energy sources, and it is believed that wind collisions are the origin of the emission. In this work we show that wind collisions not only increase the X-ray emission but also allow dust formation. As an application we study η Car, which presents, near periastron, an increase in the X-ray emission followed by a sudden decrease that lasts for about a month. We reproduce this feature calculating the optical depth due to dust formation along the orbital period.

Individual massive stars emit, in general, about $10^{33}\,\mathrm{erg\,s^{-1}}$ in X-rays, but binary systems are known to emit roughly 100 times more in this band. This discrepancy indicates that a large amount of this energy comes from a non-stellar source. Usov (1992) developed an X-ray emission model for colliding winds in massive binary systems in which the gas becomes denser and hotter (about $10^8\,\mathrm{K}$) in the shocked region, increasing the free-free emission in the X-ray band. However, some systems, such as η Car, present anomalous light curves, with sudden decreases in flux, which rises again after some period of low emission (Ishibashi et al. 1999). Many massive binary systems also present high IR emission (e.g., Monnier, Tuthill, & Danchi 2001), which is associated with dust formed close to the stars mainly during the periastron passage.

Shocks between winds will be occurring during the whole orbital period, but near periastron they will be stronger. The resulting hot and dense shocked gas will emit large amounts of energy, cooling on a short time scale ($\sim$ few hours) from $10^8\,\mathrm{K}$ to just $10^4\,\mathrm{K}$. As the gas cools it also becomes denser, generating an optically thick screen to the ionizing photons around the system. The neutral region behind the screen becomes even cooler ($\sim 10^3\,\mathrm{K}$). At this temperature and density dust may form and grow quickly, increasing the high-energy absorption.

We applied the wind collision model to the η Car binary system, assuming stellar parameters for η Car given by Corcoran et al. (2001) and a WR as the companion star, with stellar parameters given by e.g., Lamers (2001). At periastron the dense region reaches approximately $10^{13}\,\mathrm{cm}$, while the ionized part only reaches 10^9 cm. The temperature of the neutral region varies between $\sim 1800\,\mathrm{K}$, at the boundary with the ionized region, to $\sim 100\,\mathrm{K}$ at the external radius. Graphite dust grains grow to an equilibrium size of $0.1\,\mu\mathrm{m}$ in about 5 hours. The optical depth in the 2 to 10 keV band is given by $\tau_X \simeq 10^3\,\dot{M}_{-3}\,v_{100}\,R$, where $\dot{M}_{-3}$ is the mass-loss rate in units of $10^{-3}\,M_\odot\,\mathrm{yr}^{-1}$, v_{100} is the velocity in units of $100\,\mathrm{km\ s^{-1}}$, and R is the periastron binary separation in AU. This allows a great decrease in the observable X-ray flux. Assuming an eccentricity for the system of $e = 0.8$ and a mass-loss rate of $\dot{M} = 3 \times 10^{-4}\,M_\odot\,\mathrm{yr}^{-1}$, we could reproduce the strong X-ray flux absorption near periastron passage. The later increase in X-ray emission is simply due to expansion of the dust cloud. This model is also in agreement with recent observations of several massive binary systems, such as WR 137, WR 134, WR 125, and WR 140 (Williams, Kidger, & van der Hucht 2001; Kwok, Volk, & Bideldman 1997; Monnier et al. 2001).

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[1]Instituto de Astronomia, Geofísica e Ciências Atmosféricas, Universidade de São Paulo, Rua do Matão, 1226, 05508-090 São Paulo, Brazil (diego@astro.iag.usp.br).