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THERMAL RADIO EMISSION FROM RADIATIVE SHOCKS IN COLLIDING WIND BINARIES

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RESUMEN

Presentamos un modelo semi-analítico para calcular la emisión térmica en radio continuo proveniente de choques radiativos en binarias con colisión de vientos. Considerando una aproximación de cáscara delgada, calculamos la contribución de la región de colisión de vientos a la emisión térmica total en sistemas cercanos. Investigamos la dependencia del espectro total con la separación de las estrellas. Adicionalmente, señalamos la importancia de tener en cuenta esta contribución con el fin de interpretar correctamente las observaciones y los parámetros derivados de éstas.

ABSTRACT

We present a semi-analytic model for computing the thermal radio continuum emission from radiative shocks within colliding wind binaries. Assuming a thin shell approximation, we calculate the contribution of the wind collision region (WCR) to the total thermal emission for close binaries. We investigate the effect of the binary separation on the total spectrum. In addition, we point out the relevance of taking into account this contribution for the correct interpretation of the observations, and the accuracy of parameters derived from them.

Key Words: binaries: close — radio continuum: stars — stars: winds, outflows

1. INTRODUCTION

Stellar winds from hot massive stars, OB and Wolf-Rayet (WR) type stars, emit free-free thermal emission detectable at radio frequencies. For a steady, isothermal, and radially symmetric wind, the radio spectrum is characterized by a spectral index, $\alpha \sim 0.6$ ($S_\nu \propto \nu^\alpha$; Wright & Barlow 1975). However, deviations from these assumptions, may alter the value of α (Leitherer & Robert 1991; González & Cantó 2008). In binary systems, the WCR, resulted from the stellar wind interaction between the stars may also change its radio spectrum (Eichler & Usov 1993). The binary influence over the spectrum has been inferred from negative spectral indices, which are explained as the result of a non-thermal contribution from the WCR (WR 147; Contreras & Rodríguez 1999).

Theoretical studies suggest that the thermal emission from a WCR might have an important contribution to the total emission (see Stevens 1995), being even more important for close systems (Pittard et al. 2006). Pittard et al. (2006) analyzed the thermal emission from an adiabatic WCR, and found that the hot gas within it remains optically thin, with a thermal component of emission with a spectral index ~ -0.1. Recently, Pittard (2010) studied the emission from radiative shocks in O+O type systems. They found that the thermal emission from the material within this kind of shocks remains optically thick with spectral indices up to ~ 1.5 for frequencies ~ 50 GHz. Such steep tendency for the spectral index was reported for WR systems in Montes et al. (2009), which suggest that a thermal component from a radiative WCR could also be taking place in WR stars.

2. THE THERMAL RADIO SPECTRA OF BINARY SYSTEMS

Using the formalism developed by Cantó, Raga, & Wilkin (1996) and Cantó, Raga, & González (2005) we obtain semi-analytic solutions (Montes et al. 2011) from which the free-free thermal emission arising from the interaction region, and its dependence with the stellar wind parameters, can be obtained.

In Figure 1, we consider two symmetric and stationary outflows separated by a distance D. Assuming a thin shell approximation (radiative shocks), it can be seen that the radius of the layer $R(\theta) = D \sin\theta_1 \csc(\theta + \theta_1)$. In addition, the stagnation

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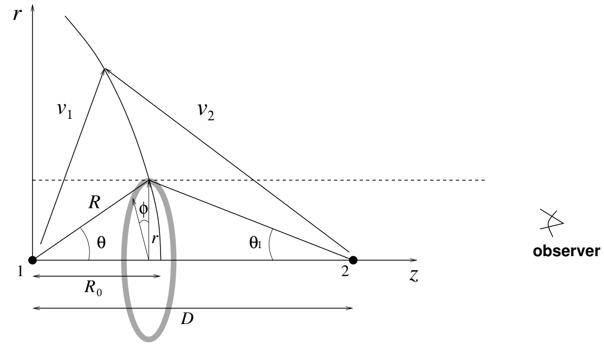

Fig. 1. Schematic diagram showing the interaction of two symmetric winds with velocities v_1 and v_2, and mass loss rates $\dot{m}_1$ and $\dot{m}_2$. The dotted line represent the line of sight from the observer through the stellar winds, which intersects the thin shell at the impact parameter r.

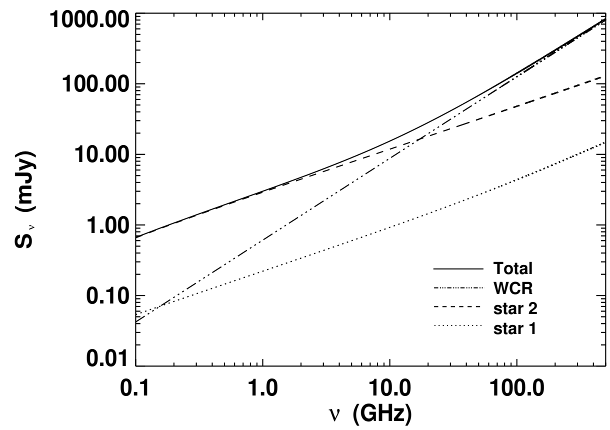

Fig. 2. Predicted thermal radio spectrum from a binary system with $\beta = 0.25$, $D = 4$ AU, $v_1 = v_2 = 10^3$ km s^{-1}, $\dot{M}_1 = 1.25\times10^{-5}\ M_\odot$ yr^{-1}, and $\dot{M}_2 = 5\times10^{-5}\ M_\odot$ yr^{-1}.

point radius is $R_0 = \beta^{1/2}D/(1+\beta^{1/2})$, where $\beta = (\dot{m}_1\, v_1)/(\dot{m}_2\, v_2)$.

These assumptions allow us to find an expression for the radio continuum flux from a system located at a distance L from the observer,

$$S_\nu = 2\pi B_\nu \left(\frac{R_0}{L}\right)^2 \int_0^{\tilde{r}(\theta_\infty)} [1-\mathrm{e}^{-\tau(\theta,\theta_1)}]\, \tilde{r}\, d\tilde{r}, \quad (1)$$

where $\tau(\theta,\theta_1) = \tau_{\rm WCR}(\theta,\theta_1) + \tau_{w,1}(\theta) + \tau_{w,2}(\theta)$ is the total optical depth along the line of sight, $B_\nu = 2kT\nu^2/c^2$ (being k the Boltzmann's constant, and c the light speed) is the Planck function in the Rayleigh-Jeans approximation, and $\tilde{r}(\theta_\infty)$ is the impact parameter at the asymptotic angle θ_∞ of the thin shell, which corresponds to $R \to \infty$.

In Figure 2 we show the total thermal spectrum from a binary system with typical WR+O type star parameters. The shock emission remains optically thick with $\alpha_{\rm WCR} \sim 1.1$, and the stellar wind components shows the expected $\alpha \sim 0.6$ behavior. At low frequencies, the total spectrum approaches the emission from the strongest wind, and, at higher frequencies, the flux density is dominated by the shocked layer. Therefore, the impact of the WCR over the total spectrum is seen as an excess of emission at high frequencies (with respect to that expected for a single stellar wind spectrum). Furthermore, it can be shown that the flux density from the WCR increase with the binary separation D (Montes et al. 2011), which is in contrast with the D^{-1} dependence for adiabatic shocks (Pittard et al. 2006).

3. CONCLUSIONS

For close systems where the non-thermal emission is expected to be absorbed, this model shows that the thermal contribution from a radiative WCR may also impact the total radio spectrum. Such impact is expected to be detected as an excess of emission at high frequencies (>50 GHz). Thus, our model predicts steep spectral indices, similar to those observed for some WR and O type stars. This extra contribution must be taking into account in order to avoid a possible overestimation for mass loss rates determined from radio observations. Furthermore, the contribution from the WCR is expected to be modulated by the orbital motion, resulting in a variable thermal contribution. Therefore, observational studies to identify a modulated thermal excess of emission, might represent a new method to unveil close binary systems from high frequency radio observations.

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