A Massive Star Odyssey, from Main Sequence to Supernova
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Radio emission models of colliding-wind binary systems

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Abstract. We present preliminary calculations of the spatial distribution of the radio emission from a WR+OB colliding wind system, based on high-resolution hydrodynamical simulations and solutions to the radiative transfer equation. We account for both thermal and non-thermal radio emission, under the assumption of equipartition between magnetic and relativistic particle energy densities, and that the latter is a simple fraction of the thermal particle energy density. These calculations provide the foundation for modeling high resolution radio images and light curves of colliding-wind systems like WR 140, WR 146 and WR 147.

1. Introduction

Observations of some early-type stars reveal them to be sources of both thermal and non-thermal (NT) radio emission, of which the latter is commonly attributed to synchrotron emission from relativistic electrons accelerated in shocks by the first order Fermi process. For single stars, shocks arise due to wind instabilities (*e.g.*, Lucy & White 1980), while for massive binary systems stationary shocks occur where the winds of the two stars collide (Eichler & Usov 1993).

Spatially resolved observations of the WR+OB binary systems WR 146 (Dougherty *et al.* 1996, 2000) and WR 147 (Moran *et al.* 1989; Churchwell *et al.* 1992; Williams *et al.* 1997; Watson *et al.* 2002) provide direct evidence that the wind-wind collision region is the origin of the NT emission. In both these cases, the thermal emission is coincident with the position of the WR star, while the NT emission arises between the binary components at a position consistent with the presssure balance of the stellar winds. There is also strong evidence that all early-type stars that exhibit NT emission are binaries (van der Hucht *et al.* 1992; Dougherty & Williams 2000).

While some simple modeling of radiometry exists in the literature (usually assuming that point-like NT emission is absorbed by a sperically symmetric stellar wind envelope), no attempts have been made to construct synthetic radio images based on more complex density/temperature distributions. In making the first steps towards addressing this situation, we have calculated the free-free

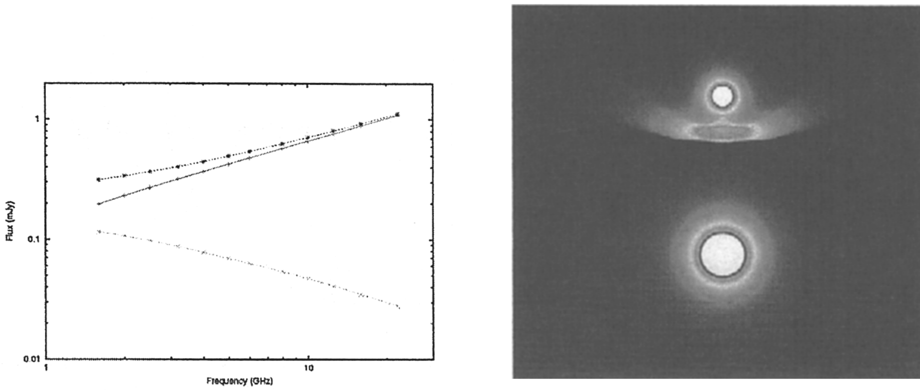

Figure 1. *Left:* Synthetic spectra from a WR+OB binary model: non-thermal flux (bottom), f-f flux (middle), total flux (top). *Right:* Synthetic intensity distribution at 5 GHz (FoV = 250×225 mas); $i = 0°$ was assumed.

and synchrotron emission arising from hydrodynamic models of an early-type binary system. We use standard expressions to calculate both types of emission, with the additional assumptions of (*i*) equipartition between the energy density of the nonthermal particles (U_{rel}) and the magnetic fields (U_B), and (*ii*) that both U_{rel} and U_B are proportional to the thermal energy density, U_{th}.

2. Results and future work

Fig. 1 shows results from a model with $\dot{M}_{\rm WR} = 2\times10^{-5}\,{\rm M_\odot\,yr^{-1}}$, $\dot{M}_{\rm O} = 2\times10^{-6}\,{\rm M_\odot\,yr^{-1}}$, $v_{\infty,{\rm WR}} = v_{\infty,{\rm O}} = 2000\,{\rm km\,s^{-1}}$, and $D_{\rm sep} = 2\times10^{15}$ cm, which are typical of a long-period WR+O binary. The NT emission from the colliding winds shock is clearly obvious. Our preliminary results indicate that both the inclination angle and the size of the optically thick region of the stellar winds relative to the stellar separation determine the amount of non-thermal flux that is visible. An examination of the combination of these two effects will lead to a better understanding of the radio light curve of objects such as WR 140, and we will also attempt to model the spatial distribution of radio emission from very wide WR+OB binaries such as WR 146 and WR 147.

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