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X-RAY EMISSION FROM INTERSTELLAR BUBBLES AROUND WOLF-RAYET STARS

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RESUMEN

Estudiamos la evolución del medio interestelar y circunestelar en torno a una estrella de alta masa ($M = 40\ M_\odot$) mediante simulaciones radiativo-hidrodinámicas. Los parámetros del viento estelar y la tasa de fotones ionizantes varían en el tiempo según la fase evolutiva de la estrella central. Comparamos nuestros resultados con las observaciones en rayos X hacia algunas burbujas alrededor de estrellas Wolf-Rayet.

ABSTRACT

We study the evolution of the interstellar and circumstellar media around a massive star ($M = 40\ M_\odot$) through radiative-hydrodynamic simulations. The parameters for the stellar wind and ionizing photon rate vary in time depending on the evolutionary phase of the central star. We compare our results with X-ray observations of wind-blown bubbles around Wolf-Rayet stars.

Key Words: ISM: bubbles — ISM: kinematics and dynamics — stars: massive — stars: mass-loss

1. INTRODUCTION

There are around 200 Wolf-Rayet (WR) stars in our Galaxy, and only two of them have nebulae detected in diffuse X-rays: S 308 and NGC 6888 (Bochkarev 1988; Wrigge et al. 1994; Wrigge 1999; Chu et al. 2003; Wrigge et al. 2005). Both of these WR bubbles present limb-brightened X-ray morphologies and spectra dominated by gas at $T \sim 10^6$ K, with an external optical counterpart. The lack of soft X-ray emission in other WR wind-blown bubbles could be due to the strong absorption by neutral hydrogen along the line of sight, or because the X-ray emission corresponds to a short-lived phase in the evolution of the nebula (Toalá & Arthur 2011).

Here we investigate, by means of radiation-hydrodynamical simulations, the possible structures that can form around a star of initial mass 40 $M_\odot$ due to the interaction of its stellar wind and ionizing photons with the surrounding medium. We take into account the full time evolution of the stellar parameters as input to our models and, in addition to calculating the hydrodynamics of the bubble, we also simulate the resultant soft X-ray emission.

2. THE MODELS

We model the evolution of the interstellar and circumstellar medium around a star of initial mass 40 $M_\odot$ from the beginning of the main sequence through the WR stage. We compare results from two different publicly available stellar evolution models: MM2003 (Meynet & Maeder 2003) and STARS (Eldridge et al. 2006). The variation of the stellar mass-loss rate with time is taken directly from these models, while the stellar wind velocities are calculated using the stellar parameters (e.g., Vink et al. 2001; Nugis & Lamers 2000), and the ionizing photon rates are obtained from the appropriate stellar atmosphere models distributed with the Starburst 99 code (Leitherer et al. 1999). We consider MM2003 models both with and without stellar rotation.

Full details of the radiation-hydrodynamics numerical scheme can be found in Toalá & Arthur (2011).

3. RESULTS

In Figure 1 we present grayscale images of the ionized density and temperature in the circumstellar medium around the 40 $M_\odot$ star stellar models from STARS and MM2003 (with and without rotation) when the WR wind is interacting with the slow wind from the previous red supergiant (RSG) phase. The main difference between the STARS and MM2003 models is that in the former, the WR wind interacts with RSG material located mainly close to the star (∼2 pc) and the swept-up shell soon breaks up into clumps due to instabilities. In the MM2003 models, the RSG material is mainly located in a dense shell further from the star (∼6 pc) and so at the time shown in Figure 1, the swept-up shell has not yet broken up into clumps.

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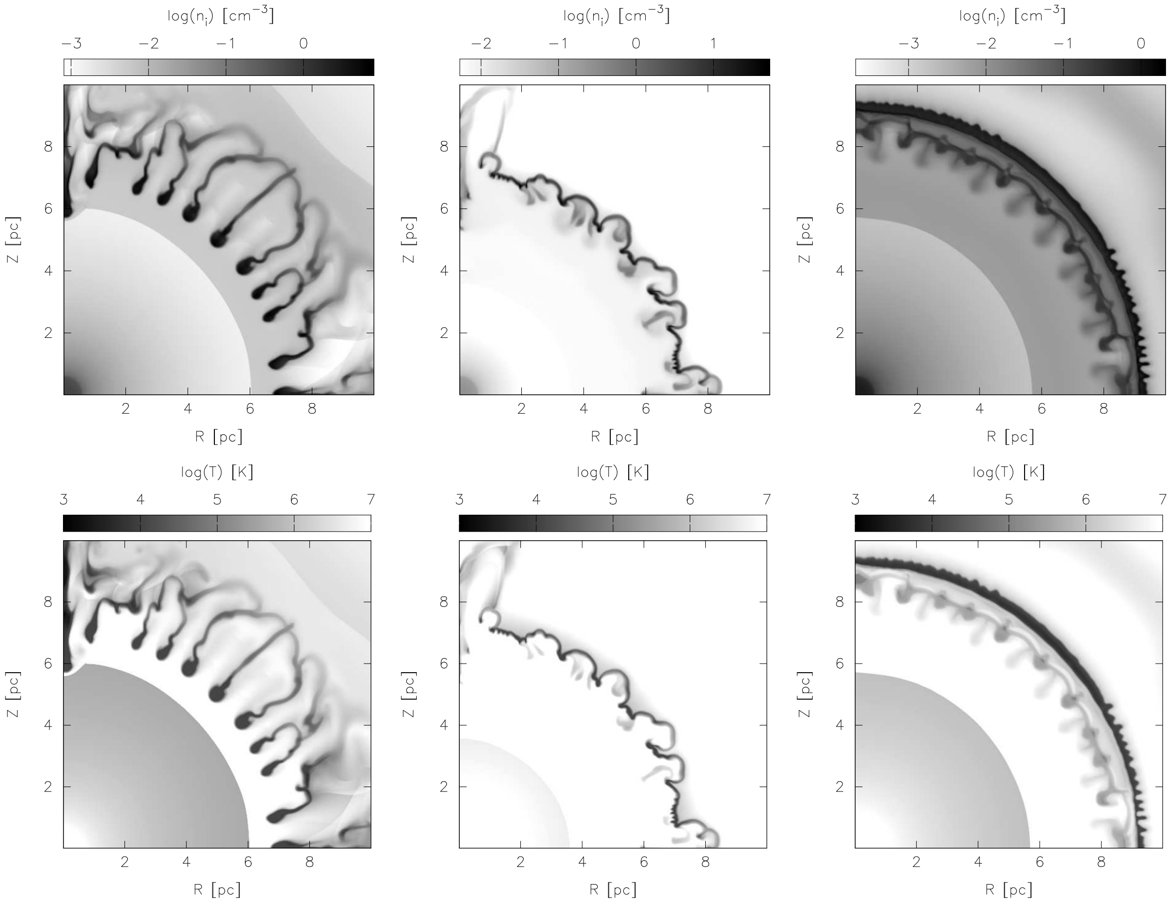

Fig. 1. Density and temperature during the interaction of the fast WR wind with the slow, dense RSG wind for the 40 $M_\odot$ STARS and MM2003 models. Top panels: ionized number density, bottom panels: temperature. Left: STARS model 151,600 yrs after the onset of the WR stage, middle: MM2003 model without rotation 33,250 yrs after the onset of the WR stage, and right: MM2003 model with rotation 15,080 yrs after the onset of the WR stage.

The structures resulting from the STARS model do not produce much gas at $T \sim 10^6$ K, and we obtain very low soft X-ray luminosities ($< 10^{32}$ erg s^{-1}). This could explain why RCW 58 was not detected by *XMM-Newton* (Gosset et al. 2005; Toalá & Arthur 2011). On the other hand, the MM2003 models produce structures morphologically similar to the WR bubbles S 308 and NGC 6888, with optical emission (photoionized gas) external to the hot, X-ray-emitting gas. The observationally derived soft (0.25–1.5 keV) X-ray luminosity for S 308 is 5×10^{33} erg s^{-1} (Toalá et al. 2011, in preparation), while that of NGC 6888 is $\sim3\times10^{34}$ erg s^{-1} in the energy band 0.4–2.4 keV (Wrigge et al. 2005). Our MM2003 simulations lead to soft X-ray luminosities in the range 10^{33}–10^{34} erg s^{-1} but only for a short period of time ($< 50,000$ yrs) while the wind-wind interaction is taking place.

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