THE IMPRINT OF MASSIVE STELLAR EVOLUTION ON CIRCUMSTELLAR GAS

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Abstract. We follow the interaction of massive stars with their circumstellar media over their entire lifetimes by combining several numerical models. We use a stellar evolution model for 35 and 60 $M_\odot$ stars (Langer *et al.* in preparation) as inner boundary conditions for one- and two-dimensional gas dynamical models of the circumstellar medium using ZEUS (Stone & Norman 1992). In this poster, we focus on circumstellar evolution during the Luminous Blue Variable (LBV) and Wolf-Rayet (WR) stages.

Key words: : stars: evolution – Wolf-Rayet – LBV – circumstellar gas

60 $M_\odot$ model. In this model, the LBV has four well-defined periods of mass loss after exhaustion of H in the core. The first period creates an expanding shell, driven by the ram pressure of a cold, dense, hypersonic wind. The termination shock of the wind is radiative, so this shell is momentum conserving. This first shell becomes unstable when the ram pressure of the wind drops below the thermal pressure of the surrounding, fossil, main sequence (MS) bubble. When this occurs the hot gas filling the MS bubble flows in, collapsing towards the LBV star at later times. This shell is probably unobservable, with a final radius of 10 pc. Mass lost during the second and third periods expands into the previous atmosphere. Shells are not formed during these periods, but the circumstellar density is enhanced. During the fourth period, mass is lost with higher velocity, sweeping up the gas from the second and third events into an expanding ($\sim$ 300 $\mathrm{km\,s^{-1}}$), highly unstable shell. This shell is driven by a hypersonic, cold wind, which drives instabilities with short angular wavelength. Bow shocks and Mach cones form around every clump resulting in a highly filamentary shell. A run at twice the numerical resolution shows similar morphology. After the four periods of extreme mass loss, there is a transition to a fast wind, monotonically increasing in velocity and decreasing in density over time. This wind passes through a termination shock and drives an almost energy conserving bubble into the mass already lost, sweeping it up at high velocity ($\sim$ 1100 $\mathrm{km\,s^{-1}}$) (Fig. 1) resembling the *HST* image of η Carinae (however, η Carinae is a more massive star).

35 $M_\odot$ model. The development of this model agrees well with the Three-Wind Model discussed by García-Segura & Mac Low (1993). After the star

K. A. van der Hucht and P. M. Williams (eds.), Wolf-Rayet Stars: Binaries, Colliding Winds, Evolution, 72–73.

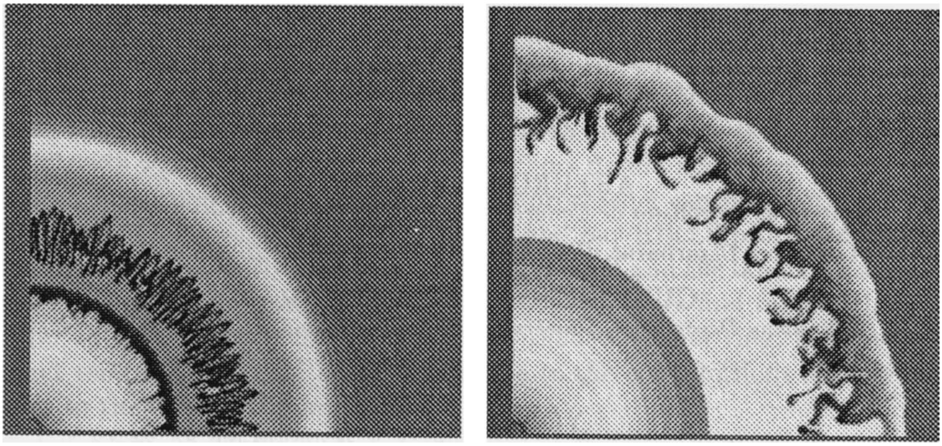

Fig. 1. Logarithm of density during the LBV phase for the 60 $M_\odot$ model, before and after the collision of the inner, faster shell with the fragmented shell produced during the fourth period of extreme mass loss. The grey scale ranges from 2×10^{-26} g cm^{-3} (gray background) to 4×10^{-26} g cm^{-3} (white) to 3×10^{-22} g cm^{-3} (black). The background is set to gray for greater clarity. The time between the two frames shown is 1700 yr. The grid size is 3 pc.

reaches the end of the MS, an almost steady, red supergiant (RSG) wind expands into the MS bubble, until the ram pressure of the RSG wind balances the thermal pressure of the MS bubble. A dynamically stable shell of compressed RSG wind is formed at this point. After the RSG phase, the fast wind of the WR phase turns on almost instantaneously, sweeping up a shell of RSG wind. This shell is unstable to Rayleigh-Taylor (from the increasing mechanical luminosity) and Vishniac (1983) instabilities. Eventually, the swept-up shell breaks through into the MS bubble.

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