Blitz Model for the Eruptions of Eta Carinae

Nathan Smith, Joyce A. Guzik, Henny J.G.L.M. Lamers,
Joseph P. Cassinelli, and Roberta M. Humphreys

Boston U., Los Alamos, Utrecht U., U. Wisconsin and U. Minnesota

Abstract. Following the "Great Eruption" of 1843, η Carinae underwent a second major eruption around 1890. We suggest a preliminary working model developed during this meeting (in one night, hence the term "Blitz") that attempts to explain the temporal development of the 19th century eruptions of η Car, as well as the formation of the Homunculus nebula (note that we are not offering an explanation for the *cause* of the Great Eruption!). The essence of the model is that after the Great Eruption ends, the star's extended outer envelope re-adjusts itself on a thermal time scale. This re-adjustment allows envelope material to crash back onto the surface of the star, inducing the second eruption in 1890.

We begin with the pre-eruption rotating star near the Eddington limit. We will approximate the geometry of the star by an extended envelope and a dense "core" (not necessarily the nulear burning core; just some region that does not experience significant structural changes during the eruption). The star's rotating envelope is in quasi-hydrostatic equilibrium modified by centrifugal forces, where the density decreases with increasing distance from the equatorial plane (see Fig. 1a). We assume that *something* deep within the star triggers the Great Eruption and causes an increase in energy output from the core, pushing the star beyond the Eddington limit. Humphreys (these proceedings) has shown that giant eruptions show a marked increase in bolometric luminosity. The increased energy output from the core may induce pulsations in the envelope that will help drive material off the surface of the star. These pulsations will travel through the envelope at the local sound speed $c_s^2 = \gamma P \rho^{-1}$. Because there is a stronger density gradient in the poleward direction than in the equatorial direction, the trajectory of radial pulsations will curve poleward, driving mass loss preferentially from the polar regions of the star (Fig 1b). The ejecta expand to form the bipolar lobes of the Homunculus.

After the Great Eruption ends, energy output from the core returns to "normal". At this point, the star's distorted envelope is drastically out of any sort of equilibrium. Most of the mass in the polar regions of the envelope has been "scooped out" by the Great Eruption, leaving something like a toroidal structure around the star. The remaining envelope mass is probably several times greater than the mass in the polar lobes ($2M_\odot$), since most of the material in the pre-eruption envelope was concentrated toward the equatorial plane. If we assume that this distorted envelope has 10 - $15M_\odot$, it will re-adjust itself on a Kelvin-Helmholtz timescale of about 30 - 45 yrs (for $5 \times 10^6 L_\odot, 100 M_\odot, 200 R_\odot$). As this distorted envelope re-adjusts itself, material from the extended regions in the equatorial plane crashes back onto the core (Fig 1c). The potential energy of this infalling material is transferred into kinetic energy for a small portion of the mass ($0.5 M_\odot$), which is ejected from the star at high velocities in a process analogous to the core bounce in a supernova explosion. The residual angular momentum in the outer regions of the rotating envelope will cause the collapsing envelope to rotate rapidly, which may confine the mass ejection primarily to the equatorial plane and may leave a disk around the post-eruption star (Fig 1d).

This model differs from previous models for the formation of the Homunculus in that the bipolar lobes are *not* wind blown bubbles. The axisymmetric geometry of the Homunculus is the direct result of an explosion on the surface of a rotating star. The clumps and knots in the nebula are linearly expanding shrapnel from the explosion, rather than structures that form from gas dynamic instabilities. Some of the presently observed equatorial ejecta would have originated during the 1890 erutpion. This model is appealing because it requires only a rotating luminous star to reproduce the bipolarity and equatorial spray in the nebula; it does not rely on magnetic fields or a binary scenario. It also gives a possible explanation for the second eruption seen in 1890, which may be a common feature seen in the lightcurves of other giant eruptions (Humphreys, these proceedings).

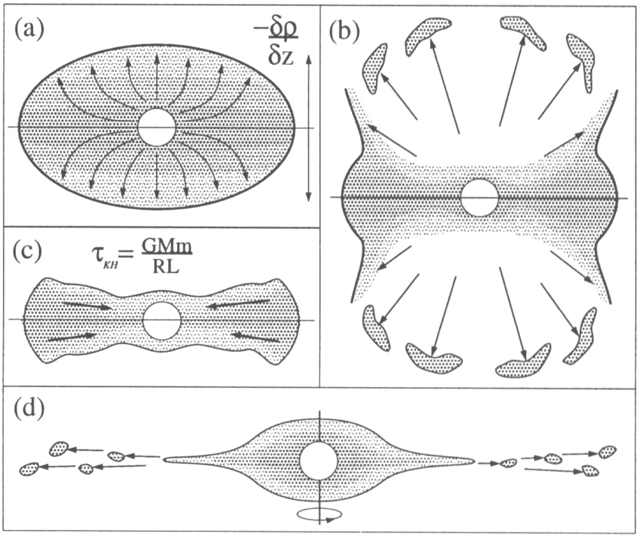

Fig. 1. (a) Pre-eruption rotating star with poleward density gradient. (b) The Great Eruption ejects shrapnel from the poles of the star. (c) The post-eruption stellar envelope re-adjusts itself on a K-H timescale of 30 – 45 years. (d) During the 1890 eruption, the rapidly rotating envelope ejects mass primarily in the equatorial plane.