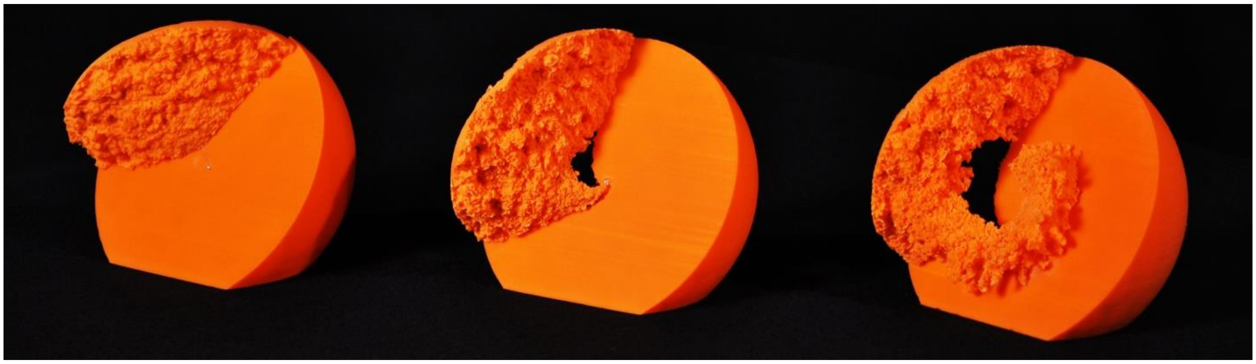

Eta Carinae's Colliding Stellar Winds

3D Printing Guide

Low Mass-Loss Rate Version

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Eta Carinae is the most luminous and massive stellar system within 10,000 light-years. It contains two stars with masses 90 and 30 times greater than the Sun's, whose eccentric orbits bring them unusually close every 5.5 years. At closest approach (called periastron) these monster stars are only about 140 million miles (225 million kilometers) apart, or about the average distance between Mars and the Sun. Both stars are so bright they produce powerful mass outflows called stellar winds that interact in complex ways, especially near periastron.

This package contains 3D models derived from simulations performed on the Pleiades supercomputer at NASA's Ames Research Center in Moffett Field, California, and reported in Madura et al. (2015)[1] (see e.g., this NASA press release). When the smaller star swings around the more massive primary at periastron, its faster wind carves out a spiral cavity within the dense outflow of the primary star. To better visualize the details of this interaction, Madura converted the computer simulations to 3D digital models and made solid versions using a consumer-grade 3D printer (Makerbot Replicator 2X).

This package contains the 3D model files as well as instructions for printing and assembling them. The files were derived from the 3D Smoothed Particle Hydrodynamics simulations of Madura et al. (2013)[2] that assume a primary star mass-loss rate of 2.4×10^{-4} solar masses per year. In each model the scale is 1 mm ≈ 1.4 AU ≈ 2.09×10^{8} km. The dimensions in the table below represent the length, width, and height of each printed part in their default orientation.

There are three complete models, each corresponding to a specific orbital phase. Each model consists of two parts. The top part is the isolated surface of the wind-wind collision region, while the bottom part is a slice along the orbital plane showing the dense primary wind and the cavity carved within it by the companion star's wind. The orbital phases included are apastron (when the stars are farthest apart and the geometry of the wind collision region is simplest), periastron (when the stars are closest together), and phase 1.045 (3 months after periastron).

In the orbital plane, there is a small hemispherical indentation and narrow trench at the center of each 'PrimaryWind' component. The hemispherical indentation marks the location of the larger primary star, while the trench indicates the direction to the smaller companion star. Small arts-and-crafts beads, connected by a thin metal pin, can be used to represent the two stars, with the length of the connecting pin to scale with the stellar separation. The 'stars' can then be glued to the model (Figure 1). Pins 21 mm, 1.1 mm, and 5 mm in length should be used to connect the stars at apastron, periastron, and phase 1.045, respectively.

To make the stars more visible at the model scale, we suggest using a 1.4 mm diameter bead for the primary star and a 0.7 mm diameter bead for the companion. These sizes correspond to scaled radii equivalent to 210 and 105 solar radii for the primary and companion, respectively, which are 3.5 times larger than the stellar radii used in the SPH simulation. The top and bottom of each model can be connected by pushing 10 mm long pins into each piece (see Figure 2).

The 3D models were successfully printed using a dual-extrusion 3D printer (MakerBot Replicator 2X), with one nozzle containing the print material (e.g., ABS or PLA) and the other dissolvable support material (e.g., HIPS). This greatly increases the chances of a successful print. We have not attempted to print on a single-extrusion 3D printer. Our successful prints used a 0.1 mm layer height and a 10% density hexagonal infill. Print times per model piece ranged from 10 to 32 hours.

References:

1. Madura, T. I.; Clementel, N.; Gull, T. R.; Kruip, C. J. H.; Paardekooper, J.-P. 2015, *3D Printing Meets Computational Astrophysics: Deciphering the Structure of η Carinae's Inner Colliding Winds*, Monthly Notices of the Royal Astronomical Society, 449, 3780

2. Madura, T. I.; Gull, T. R.; Okazaki, A. T.; Russell, C. M. P.; Owocki, S. P.; Groh, J. H.; Corcoran, M. F.; Hamaguchi, K.; Teodoro, M. 2013, *Constraints on Decreases in η Carinae's Mass Loss from 3D Hydrodynamic Simulations of its Binary Colliding Winds*, Monthly Notices of the Royal Astronomical Society, 436, 3820

Contents of LowMdotSTLFiles.zip

File	Description and Dimensions in mm (*L* × *W* × *H*)
README_LowMdot.pdf	This file
ApastronLowMdotPrimaryWind.stl	The dense primary wind and cavity carved by the secondary star at apastron. 144.81 × 107.84 × 107.62
ApastronLowMdotWWCR.stl	The dense wind-wind collision surface at apastron. 154.85 × 31.47 × 77.69
PeriastronLowMdotPrimaryWind.stl	The dense primary wind and cavity carved by the secondary star at periastron. 127.29 × 115.74 × 134.07
PeriastronLowMdotWWCR.stl	The wind-wind collision surface at periastron. 155.04 × 32.18 × 77.11
Phase1p045LowMdotPrimaryWind.stl	The dense primary wind and cavity carved by the secondary star 3 months after periastron (phase 1.045). 125.86 × 115.86 × 137.59
Phase1p045LowMdotWWCR.stl	The wind-wind collision surface at 3 months after periastron (phase 1.045). 154.77 × 75.84 × 77.51

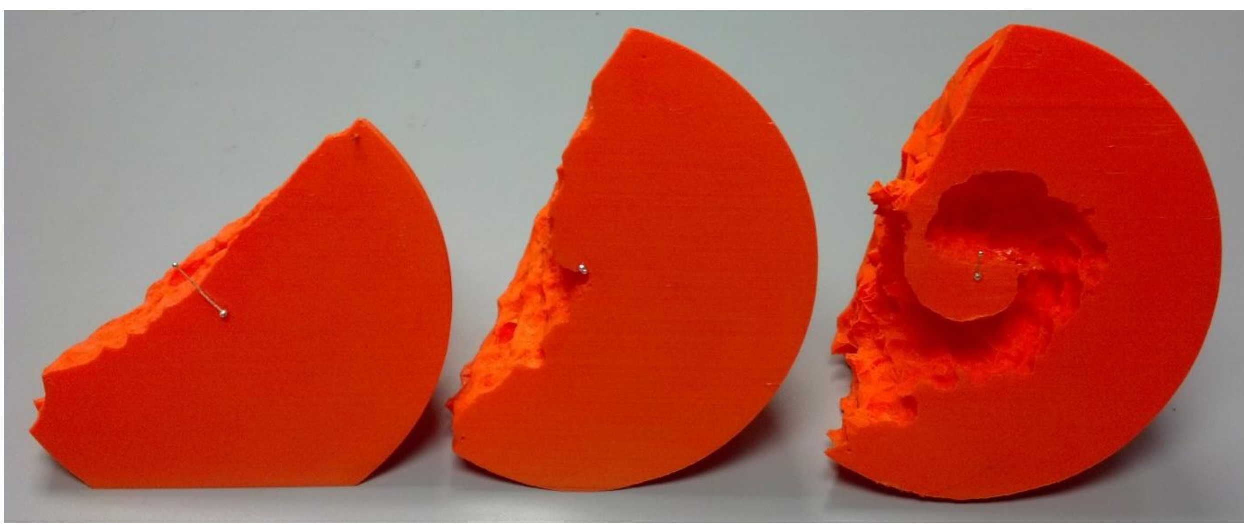

Figure 1. Example showing the beads representing the stars attached to each 3D print model listed in the above table. Orbital phases are, from left to right, apastron, periastron, and 1.045.

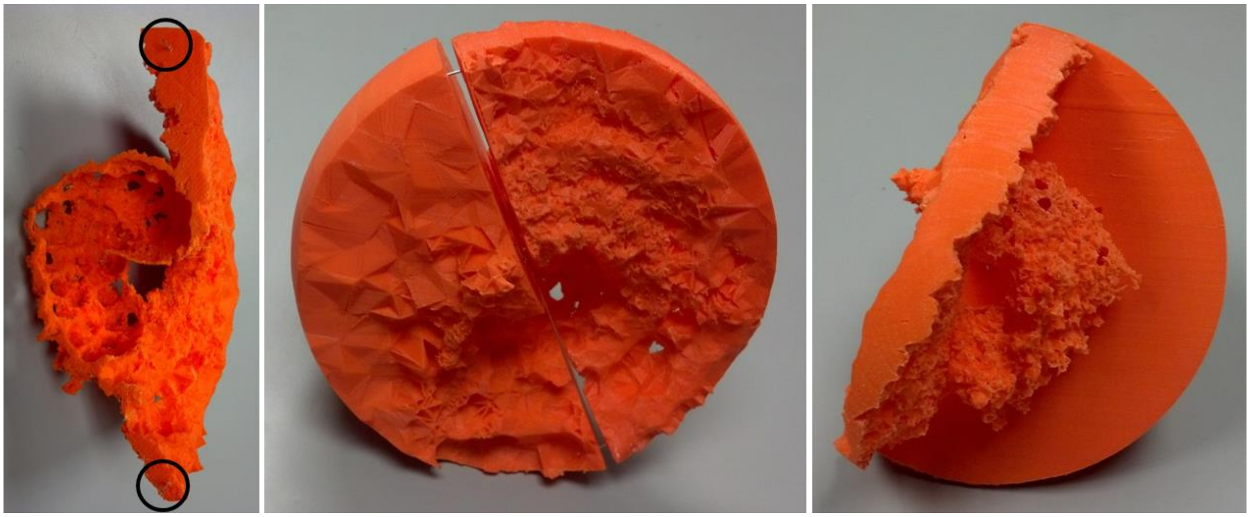

Figure 2. Example showing the placement of the metal pins (circled in the first panel) used to connect the two component pieces of the 3D print model at orbital phase 1.045.