The Structure of the Homunculus: I. Shape and Latitude Dependence from H$_2$ and [Fe II] Velocity Maps of Eta Carinae

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High resolution long-slit spectra obtained with the Phoenix spectrograph on Gemini South provide our most accurate probe of the three dimensional structure of the Homunculus Nebula around η~Carinae. The new near-infrared spectra dramatically confirm the double-shell structure inferred previously from thermal dust emission, resolving the nebula into a very thin outer shell seen in H$_2$ λ21218, and a warmer, thicker inner layer seen in [Fe~{\sc ii}] λ16435. The remarkably thin and uniform H$_2$ skin has ΔR/R of only a few per cent at the poles, hinting that the most important mass loss during the 19th century eruption may have had a very short duration of $\la$5 yr. H$_2$ emission traces the majority of the more than 10 M$_{\odot}$ of material in the nebula, and has an average density of order $n_H\ga$10$^{6.5}$ cm^{-3}. This emission, in turn, yields our first definitive picture of the exact shape of the nebula, plus a distance of 2350$\pm$50 pc and an inclination angle of $\sim$41\arcdeg\ (the polar axis is tilted 49\arcdeg\ from the plane of the sky). The distribution of the H$_2$ emission provides the first measure of the latitude dependence of the speed, mass loss, and kinetic energy associated with η~Car's 19th century explosion. Almost 75\% of the total mass and more than 90\% of the kinetic energy in the ejecta were released at high latitudes between 45\arcdeg\ and the polar axis. This rules out a model for the bipolar shape wherein an otherwise spherical explosion was pinched at the waist by a circumstellar torus. Also, the ejecta could not have been deflected toward polar trajectories by a companion star, since the kinetic energy of the polar ejecta is greater than the binding energy of the putative binary system. Instead, most of the mass appears to have been directed poleward by the explosion itself --- or the star failed to launch material from low latitudes, which would have important consequences for the angular momentum evolution of the star. In any case, comparing H$_2$ and [Fe~{\sc ii}] emission resolves some puzzles about structure noted in previous studies. H$_2$ emission also provides our first reliable picture of the critical innermost waist of the Homunculus, yielding clues to the observed morphology of the core and the more extended equatorial debris.

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