Observations and Modeling of the Nonuniform Dust Outflow around Red Supergiant NML Cygni

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Abstract. We present recent work by the Infrared Spatial Interferometry (ISI) group at the University of California at Berkeley. New 11 μm interferometric measurements have been combined with published data to place strong constraints on self-consistent, radiative transfer models of the dust shell around NML Cygni. Details can be found in Monnier et al. (1997). A spherically symmetric, maximum entropy fit to the mid-infrared data suggests the presence of 2 distinct dust shells, one ~ 100 mas and the other ~ 350 mas from the star. These radii of mid-infrared emission coincide approximately with the locations of the H_2O maser shells observed by Richards, Yates, & Cohen (1996). The radial distributions of the 11 μm radiation for various dust-shell models are plotted in Figure 1, with the corresponding physical parameters appearing in Table 1. In addition, a variety of published optical constants for astronomical silicates were tested during the modeling process, and those of Ossenkopf, Henning, & Mathis (1992) proved most successful at reproducing the observed broadband spectrum and 9.7 μm silicate feature. New observations reported also include multiple 8-13 μm spectra taken from 1994-1995 and N-band (10.2 μm) photometry from 1980-1992.

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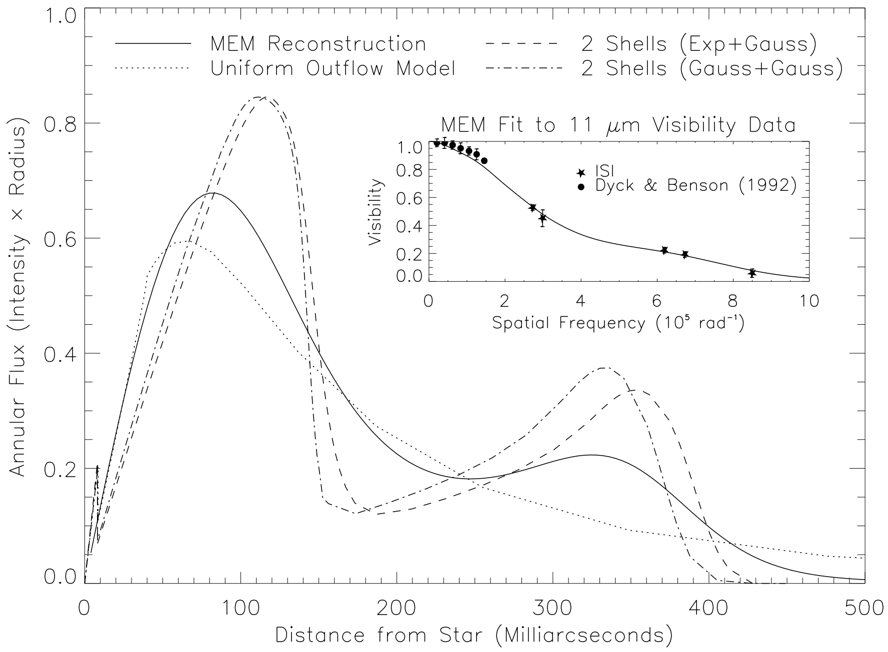

Figure 1. Maximum entropy method (MEM) and model reconstructions of NML Cygni's dust shell at 11 μm. The MEM fit to the visibility data appears in the inset plot. The lack of emission at large scales, indicated by the relatively high visibility at low spatial frequency, forces one to consider two-shell models for the dust density distribution.

Table 1. Model Parameters

Model Description	R_* (mas)	T_* (K)	Shell One Parameters	Shell Two Parameters	Comments
Single Shell: Uniform Outflow	8.6	2500	$\rho \propto r^{-2}$ $R_{\rm inner} = 40$ mas $\tau_{11} = 2.4$		Fits 11 μm visibility. Poor fit to 4.8 μm speckle data and broadband spectrum.
Single Shell: Geometrically Thin	8.6	2500	$\rho \propto r^{-5}$ $R_{\rm inner} = 110$ mas $\tau_{11} = 1.93$		Fits all data except for long-baseline 11 μm interferometry
Double Shell: Exponential & Gaussian	8.2	2500	$\rho \propto e^{-(r-R_1)/l}$ R_1 =120 mas $l = 10$ mas $\tau_{11} = 1.8$	$\rho \propto e^{-\left[\frac{(r-R_2)}{\sigma_2}\right]^2}$ R_2 =370 mas $\sigma_2 = 20$ mas $\tau_{11} = 0.34$	Fits all data except spectrum below 2 μm
Double Shell: Gaussian & Gaussian	8.2	2500	$\rho \propto e^{-\left[\frac{(r-R_1)}{\sigma_1}\right]^2}$ R_1 =125 mas $\sigma_1 = 10$ mas $\tau_{11} = 2.0$	$\rho \propto e^{-\left[\frac{(r-R_2)}{\sigma_2}\right]^2}$ R_2 =350 mas $\sigma_2 = 20$ mas $\tau_{11} = 0.33$	Fits all data except spectrum below 2 μm