THE DUST ENVELOPE OF IRC +10216

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ABSTRACT. Infrared speckle measurements and photometry are used to assess the shape and thickness of the dust shell of the carbon rich Mira variable IRC +10216. A spherically symmetric radiative transfer model has been developed to approximate the physical parameters.

The carbon rich Mira variable IRC +10216 has been the subject of numerous observational studies. This work has mapped in some detail the characteristics of the spectrum and the spatial intensity distribution. However, the characteristics of the star and surrounding dust shell may not for the most part be inferred directly from the observational material. A modeling process must be applied to deduce the stellar parameters of astrophysical interest. With the aid of numerical radiative models for the dust envelope, the observational material suffices to specify within narrow ranges the principal model parameters.

IRC +10216 is a Mira type variable with a period of ≈ 640 days. The bolometric flux varies by a factor of ≈ 4 during the Mira cycle. The color temperature (based on K-L color) varies concurrently over the approximate range 530-575K (R. Joyce, private communication). The Mira periodicity is superimposed on a longer term secular decrease in mean luminosity of approximately 0.02 mag/year.

Spatial measurements by IR interferometry and lunar occultation show that the apparent angular size of IRC +10216 depends on position angle, wavelength, and phase. The time-averaged angular size in the E-W direction, defined by the half-intensity radius of the one-dimensional image, increases from ≈ 0.15 arcsec at $2\mu m$ to ≈ 0.4 arcsec at $11\mu m$. The variation with phase is not well determined observationally, but is probably ≈ ±20%.

The N-S dimension is greater than the E-W dimension by a factor ranging from ≈ 1.5x at $2\mu m$ to ≈ 1.2x at $5\mu m$. However, the N-S shape is more complex at some epochs and a single parameter description of the shape is inadequate.

The apparent bipolar geometry suggests that the E-W spatial data is more

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suitable to describe the typical source dimension than either the N-S data or a mean, since the N-S extension may be the result of rather narrow polar 'windows' in the shell structure. For purposes of a model analysis, we attempt to characterize the situation near a typical recent maximum, since the most complete data are available for this phase. The situation at other phases can then be estimated by scaling the model parameters.

The models are spherically symmetric, with a sharp inner boundary where dust formation is assumed to occur, and an outer boundary sufficiently large to play no role in the analysis. The major grain constitituent is amorphous carbon. SiC grains are included as a secondary component to reproduce the $11\mu m$ SiC emission feature, but do not play a significant role in the analysis. The radiation transport and radiative equilibrium equations are solved by a partial linearization procedure to determine the dust temperature. The emergent intensity distribution is compared with observational data.

As is well known, it is possible to reproduce a given shell spectrum and size with a large range of model parameters. In the case or IRC +10216, however, the data strongly constrain the choice of parameters because of two additional pieces of information. The variation of diameter with wavelength constrains both the stellar temperature and the radial density law. And the observed stellar flux fraction at mid-IR wavelengths fixes the integrated dust extinction.

It was not possible to match all observed characteristics within observational uncertainty with any combination of parameters. This suggests that the assumption of spherical symmetry is not adequate to fully describe the source. However, it was possible to fit the observations well enough to conclude that the model parameters are probably a good approximation to the actual source characteristics. The central result is that the inner boundary of the dust shell is at approximately $5R_\star$.

Interestingly, the dust density distribution in the inner regions of the shell is strongly constrained by the wavelength dependence of the angular diameter. If we assume that the dust density distribution is $\propto r^{-2.0}$ for $r \geq 12R_\star$, then the distribution at smaller radii is $\propto r^{-2.3}$. Two arguments would suggest that the density distribution should vary as a higher power of r in the inner shell. First, the dust is thought to accelerate after formation as a result of radiation pressure. Second, molecular spectra show that the gas reaches a terminal velocity of approximately $14\frac{km}{sec}$.

The relatively shallow observed dependence of density on radius suggests that the acceleration of the dust occurs within a very narrow radial distance at the inner boundary of the dust shell, and that outside this 'impulsive' acceleration region, the acceleration continues at a relatively mild rate, $v \propto r^{0.3}$. This is consistent with the analysis of high resolution molecular line profiles, which have a 'plateau' in the velocity curve at approximately $9\frac{km}{sec}$ in the inner shell (Keady et al 1986). Additional details of the results of the shell modeling will be published elsewhere (Ridgway and Keady 1981, 1986).

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