DIAMETER MEASUREMENTS AND IMAGING OF MIRA VARIABLES

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Abstract

This paper describes the study of pulsation effects in the extended atmosphere and close circumstellar environment of o Cet obtained at the Harvard-Smithsonian Center for Astrophysics using high-angular resolution speckle techniques.

Mira (o Cet) is the prototype of a class of highly variable giant stars on the asymptotic branch of the H-R diagram. They are rapidly losing large quantities of their mass as they head toward their final state as planetary nebulae or white dwarfs. Observations of Mira-type variables obtained using photometric, spectroscopic, polarimetric, and other techniques show regular variation with a period of several hundred days attributed to a pulsation process. Although the mechanism of mass loss in these stars is not well understood, there is strong observational evidence that stellar pulsation has an essential role.

A typical Mira star has a tenuous atmosphere that has expanded to several hundred solar radii and is strongly affected by the propagation of shock waves created near the stellar photosphere as a result of the pulsation. Because of the extended atmosphere, it is difficult to determine a photospheric diameter for Mira-type variables, a crucial parameter for establishing the effective temperature scale (Ridgway and Joyce 1980) and the mode of pulsation (Ostlie and Cox 1986). In recent years it has became clear that a detailed modeling of Miras' atmospheres is necessary for an accurate determination of the photospheric diameter. Key parameters that must be measured include the diameter and the brightness distribution across the stellar disk as a function of wavelength. Due to the degrading effects of atmospheric turbulence, the diameter and the brightness distribution cannot be measured from direct images of Miras. For example, the closest and largest Mira, o Cet, has an angular size less than one tenth of an arc second, while the atmospheric blurring is rarely better than one arc second.

At the Harvard-Smithsonian Center for Astrophysics, we have developed detectors and algorithms for recovering very high resolution images from seeing-degraded images using a technique called speckle imaging (Nisenson 1988). Long sequences of short-exposure images are recorded with a photon counting detector at the focus of the telescope. These data are combined by averaging out the effects of the atmosphere, and they yield power spectra and reconstructed images with greatly enhanced resolution.

Since 1983, we have carried out speckle interferometry observations of o Cet with large aperture telescopes (2-4 m) at different phases of several pulsation cycles (Karovska *et al.* 1986; Karovska *et al.* 1989a). Observations were obtained using narrow-bandpass filters (FWHM = 10 nm) in spectral regions between 450 nm and 850 nm, in the continuum and in the strong molecular spectral features. Assuming that the star is spherically symmetric, we measured the angular diameter by fitting to the observed power spectra model functions corresponding to several different brightness distributions

on the stellar disk. The procedure is described by Koechlin (1988) and Karovska *et al.* (1989b). Assuming a model profile, we determined angular diameters at several wavelengths with an accuracy better than 3%, and, for data recorded with very good seeing conditions (less than one arc second), better than 1%. Diameter measurements are model dependent and vary by more than 30% for a given data set. For example, from the observations obtained near the light maximum in November 1988 at 530 nm, we measured 67 ± 1 mas diameter (mas = milli-arc second = 0.001 arc second) for o Cet assuming uniform brightness disk. For a fully limb-darkened model, the calculated disk diameter increases by approximately 15%. We also estimated o Cet's diameter using a model profile showing strong limb-brightening, calculated by Beach *et al.* (1988) for a typical Mira in the spectral region around 550 nm at light maximum. By fitting this model profile to our data we calculate a 45 mas photospheric diameter. For a given model profile, diameters measured using observations obtained in different spectral regions at the same epoch differ by up to 40%. The measurements obtained at the same wavelength at different pulsation phases also show large differences. For this reason it is necessary to explore the variation of the diameter as a function of pulsation phase for at least one pulsation cycle.

Our observations of o Cet obtained at four different epochs show direct evidence that the atmosphere of this star departs substantially from spherical symmetry. High angular resolution speckle images showing strong asymmetry were obtained in several different wavelengths at pulsation phases 0.4 (November 1983), 0.7 (December 1986), 0.9 (December 1987), and 1.1 (November 1988). The asymmetry is clearly visible in the images of o Cet and was not seen in the images of comparison stars recorded before and after o Cet. Figure 1 displays the reconstructed images of o Cet and the comparison star obtained from the data recorded in December 1987 at 775 nm.

The degree of asymmetry (the ratio of major to minor axis) varies with wavelength (by 10%-30%), and the position angle of the major axis of the asymmetry is consistent with the position angle of polarization measured at these three epochs (Boyle *et al.* 1986; Kemp 1986; Boyle 1988). Polarimetric observations have detected linear polarization from a number of other Mira-type variables (including o Cet), indicating a departure from spherical symmetry (Boyle *et al.* 1986). The cause of the observed asymmetries has not yet been determined but plausible mechanisms have been discussed by Willson and Bowen (1988), and they include instabilities in the pulsating atmospheres, non-radial pulsation, large scale convective motions,and the presence of stellar or non-stellar companions.

In order to obtain measurements that can provide a better understanding of the structure of Mira's atmosphere, we plan to obtain precise diameter measurements and high resolution images of o Cet and other Miras using narrow bandpass (1- 10 nm) filters in spectral regions that include the continuum, the absorption minima of strong molecular spectral features, and the emission lines. Future speckle observations will be carried out in coordination with multi-technique ground-based and space observations at different epochs of several consecutive pulsation cycles. An international campaign for coordinated observations of several Mira-type variables (including o Cet) is being organized.

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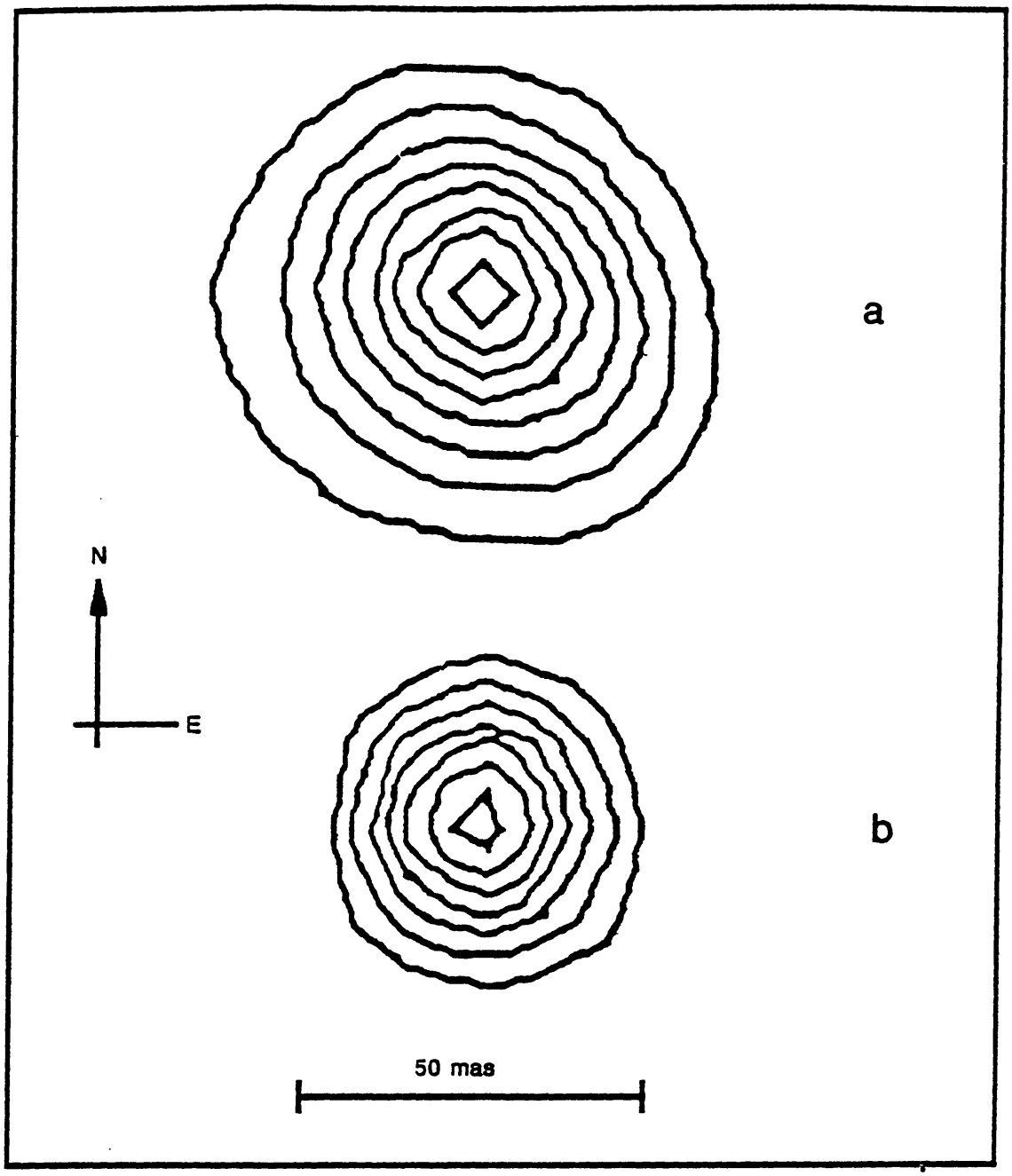

Figure 1. Reconstructed images of o Cet (a) and the comparison star (b) in December 1987 at 775 nm.