Bull. Spec. Astrophys. Obs., 1996, 39, 59–61

Diffraction-limited images of the Mira-type variable R Cas

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Received November 29, 1995; accepted December 1, 1995.

Abstract. We present the first diffraction–limited speckle masking observations of the long–period variable star R Cas with the 6 m SAO telescope. At 700 nm wavelength the resolution of the reconstructed images is $\lambda/D = 25$ milliarcsec (mas). Speckle interferograms were recorded through interference filters with centre wavelength/bandwidth of 714 nm/6 nm (strong TiO absorption band) and 700 nm/6 nm (moderate TiO absorption). The two reconstructed images show that the average 700 nm diameter of R Cas is 37 ± 2 mas, while the average 714 nm diameter is 50 ± 3 mas. Both images show the elliptical shape with an axis ratio of about 0.8.

Key words: interferometry – stellar atmosphere – long period variables

1. Mira–type variables project with the 6 m telescope

In our Mira–type star project we plan to investigate with the 6 m telescope the surface structure and to measure angular diameters of several long–period variables as a function of wavelength. Mira stars show substantial variations of angular size with wavelength which are related to TiO molecula opacity (Labeyrie et al., 1977; Bonneau et al., 1982). Continuum and TiO band observations with suitable interference filters yield important information on the atmospheric structure and hence on the physical processes involved. Studies of the exploratory models of Bessell et al. (1989) and recent models of Bessell et al. (1995) show that the monochromatic radii observed in suitably chosen filters and at selected phases are an extremely sensitive diagnostic tool for investigating the structure of Mira photospheres. Accurate monochromatic radius measurements combined with colour and line profile observations may pin down the photospheric parameters and discriminate between different pulsation models (e.g. pulsation mode; pulsation constant; deviations from equilibrium, cf. Beach et al., 1988; Bessell et al., 1989). The goal of our program is to provide the basic observations for modelling the photospheric structure of Mira variables which so far have yet been susceptible to quantitative analysis (cf. Scholz, 1992; Bessell et al., 1995).

2. Observations and results

R Cas (HD224490, $4^m_.7 - 13^m_.5$, M6e – M10e, 23:58+51:23 (2000.0)) is a cool giant star with large–amplitude magnitude variations over a period of about 430 days. It is one of the best Mira candidates for interferometric study with the 6 m telescope because of its high declination and relatively high brightness. The star can be followed at different phases of its pulsation cycle.

The R Cas data were obtained with the 6 m telescope on September 20, 1994 (light curve phase 0.9) under the 1–1.5 arcsec seeing conditions. Two speckle data sets were recorded through interference filters Fig.1(a) with centre wavelength 700 nm, and (b) with centre wavelength 714 nm (TiO absorption band). In both cases the bandwidth was 6 nm, and the exposure time per image was 10 ms. The speckle raw data were recorded with the speckle camera described by Baier and Weigelt (1983). The new detector used was an image intensifier (gain 500 000) coupled optically to fast CCD camera (512 × 512 pixels, frame rate 4 images per second, digital correlated double sampling). A system of Digital Signal Processors was used for real time speckle interferometry and for fast simultaneous data storage on four Exabyte streamers.

Images with diffraction–limited resolution and high dynamic range were reconstructed by the speckle masking method (Weigelt, 1977; Lohmann et al., 1983; Hofmann and Weigelt, 1986). The first processing step in speckle masking is the calculation of the ensemble average 4–dimensional bispectrum

Table 1: *Uniform–disk diameters of R Cas at two wavelengths*

Filter $\lambda/\Delta\lambda$(nm)	Diameter (mas)	Direction
700/6	37 ± 2	azimuth average
714/6	50 ± 3	
700/6	32 ± 2	short axis
714/6	43 ± 4	
700/6	40 ± 3	long axis
714/6	57 ± 5	

$< I^{(3)}(u,\nu) >$ of all 2–dimensional speckle interferograms $i(x)$:

$$< I^{(3)}(u,\nu) > = < I(u)I(\nu)I(-u,-\nu) >,$$

where $I(u)$ is the Fourier transform of $i(x)$, and x, u, and ν are 2–dimensional image space and Fourier space coordinates, respectively. The 4–dimensional bispectrum of each frame of R Cas consisted of $37 \cdot 10^6$ elements with maximum length of bispectrum vectors: u =45 pixels, ν = 100 pixels. After compensation of photon bias terms and the atmospheric transfer function (we used an unresolved star as a reference source) a true diffraction–limited image was reconstructed.

The first diffraction–limited reconstruction of R Cas with 25 mas resolution is shown in Fig.1. The top image is the reconstruction of R Cas at 714 nm (strong TiO absorption band), the middle one is the R Cas image at 700 nm (moderate absorption), and the reconstruction of an unresolved reference star is at the bottom. At both wavelengths this Mira variable is resolved with the 6 m telescope.

The diameters of R Cas were derived by using a uniform–disk model. The results are given in Table 1. The reconstruction shows that the average size of R Cas is about 1.34 times larger in the TiO absorption band than at 700 nm. Both images are slightly elongated with the ratio between the short–axis and long–axis diameter of about 0.8. Therefore, Table 1 includes three different pairs of measurements. Fig.2 shows intensity cuts through the centre of each of the two R Cas reconstructions and the reconstruction of the unresolved star at the three position angles: (a) PA = 240°(long axis), (b) PA = 150°(short), and (c) PA = 195°. One of the possible explanations for the image departure from spherical symmetry could be the existence of hot regions on the disk of R Cas caused by giant convective cells. Similar asymmetry with axis ratio of 0.8 – 0.9 was found recently in diffraction-limited images of o Cet (Karovska et al., 1991). For a better understanding of the cause of the observed asymmetries in the atmospheres of Mira–type variables, changes of their geometry must

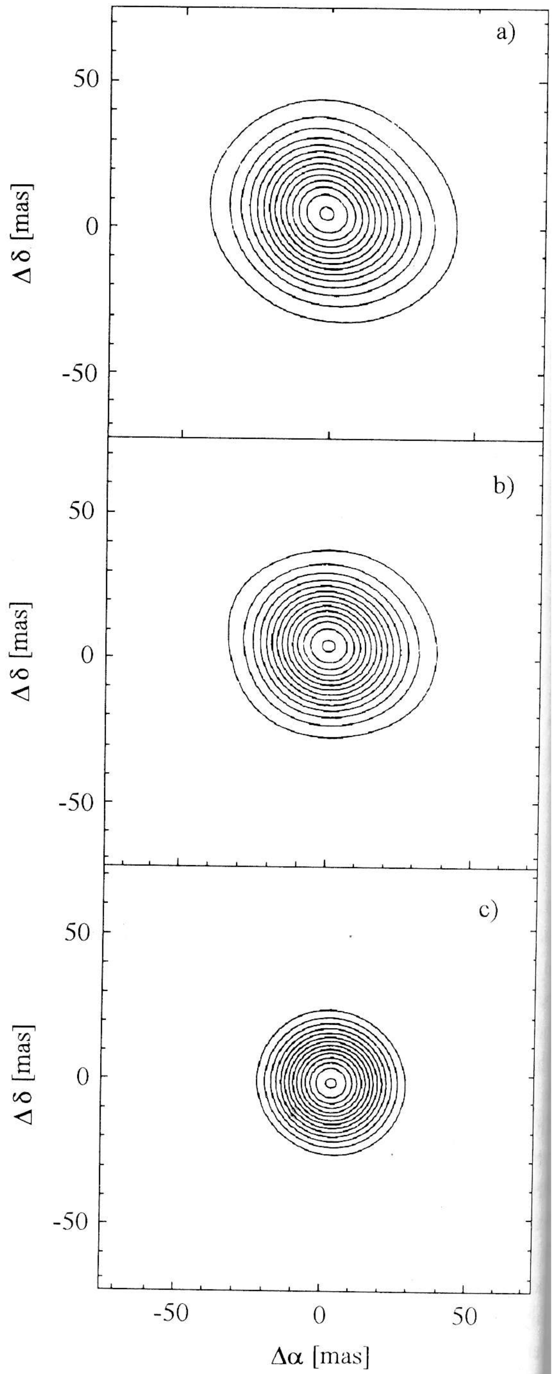

Figure 1: *Contour plots of the diffraction-limited reconstructions of R Cas (top) at 714 nm, (middle) at 700 nm; (bottom) contour plot of a reconstructed unresolved star. In each panel the contour levels are plotted from 0-100 % of the peak intensity in steps of 7% and the axes are labelled in mas. North is at the top and east to the left.*

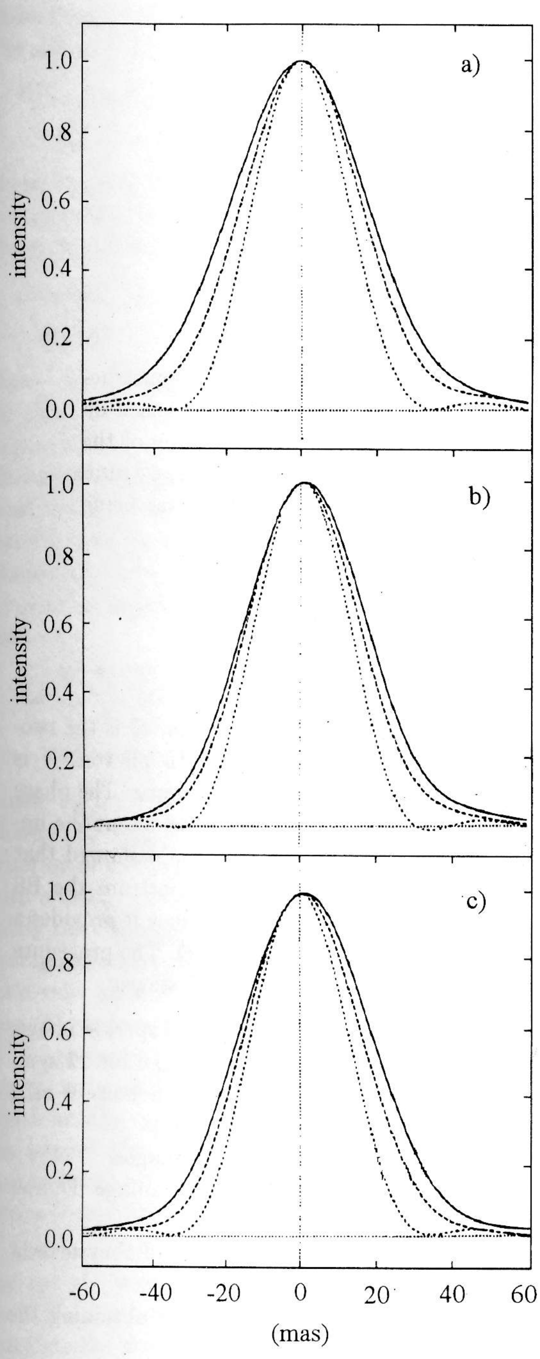

Figure 2: *Intensity cuts through the center of the 714 nm (solid line) and 700 nm reconstructions (dashed line) and an unresolved star (dotted line) at 3 different position angles (top)* 240°, *(middle)* 150°, *and (bottom)* 195°.

be studied over different phases, and from cycle to cycle.

This work has been supported in part by the Russian State Scientific Program "Astronomy".

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