IOTA observation of the circumstellar envelope of R CrB

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ABSTRACT

We report the first long-baseline interferometric observations of R CrB. The observations were carried out at the Infrared Optical Telescope Array (IOTA), using our new JHK beam combiner which enables us to record fringes simultaneously in the J-, H-, and K-bands. The circumstellar envelope of R CrB is resolved at a baseline of 21 m, and the K-band visibility is derived to be 0.61 ± 0.03 along a position angle of $\sim 170°$. The visibility obtained with IOTA, as well as speckle visibilities with baselines up to 6 m and the spectral energy distribution (SED), are fitted with 2-component models consisting of the central star and an optically thin dust shell. The K-band visibilities predicted by the models are about 10% smaller than the visibility obtained with IOTA. However, given the simplifications adopted in our models and the complex nature of the object, this can be regarded as rough agreement. As a hypothesis to explain the small discrepancy, we propose that there might be a group of newly formed dust clouds, which might appear as a third visibility component.

Keywords: long-baseline interferometry, near-infrared, circumstellar matter, mass-loss, individual star (R CrB)

1. INTRODUCTION

R Coronae Borealis (R CrB) stars are characterized by irregular sudden declines in their visual light curves as deep as $\Delta V \sim 8$. They are believed to undergo ejections of dust clouds in random directions, and when a dust cloud happens to form toward the line of sight, a sudden deep decline can be observed (Loreta,[1] O'Keefe[2]). However, the effective temperatures of R CrB stars are as high as 7000 K, and therefore, the mechanism of dust formation in such a hostile environment is still little understood. In particular, the location of dust formation is controversial; far from the star, $\sim 20R_\star$ (e.g. Fadeyev,[3] ,[4] Feast[5]), or very close to the photosphere, $\sim 2R_\star$ (Payne-Gaposchkin[6]). The evolutionary status of R CrB stars also remains a mystery. Their atmospheres are hydrogen-deficient and carbon-rich (e.g. Asplund et al.[7]), suggesting that they are at the post-asymptotic giant branch (post-AGB). However, there is no theory of stellar evolution which is successful in reproducing the observed properties of R CrB stars (see, e.g. Clayton[8] for review).

Ohnaka et al.[9](hereafter Paper I) presented speckle interferometric observations with the 6 m telescope at the Special Astrophysical Observatory in Russia. With a spatial resolution of 75 mas, the circumstellar envelope around R CrB was resolved for the first time at near maximum light, as well as at minimum light . In Paper I, we used simple optically thin dust shell models for the simultaneous fit of the observed spectral energy distributions (SEDs) and the visibilities. It was shown that the SED and visibility observed at near maximum light can be fitted with such simple models, and the inner radius of the dust shell was derived to be $\sim 80\ R_\star$ (19 mas) with a temperature of ~ 900 K. The simultaneous fit of the SED and visibility observed at minimum light implied

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Table 1. IOTA observations for R CrB. B_p: projected baseline, N_T: number of interferograms acquired for the target, N_R: number of interferograms acquired for the reference star, T: exposure time of each frame

	2001 Jun. 05
JD	2452067
V (mag)	6
B_p	21.18 m
Reference star	HD 143393, HR 5877
N_T	7700
N_R	5000
T(ms)	300

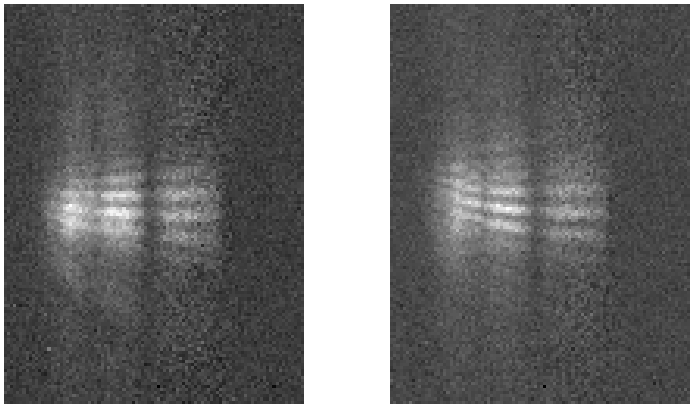

Figure 1. Interferograms of R CrB after sky subtraction. The fringes are spectrally dispersed in the horizontal direction, covering from 1 to 2.3 μm from left to right in each panel.

the presence of a newly formed dust cloud close to the central star, but the spatial resolution was insufficient to draw a clear conclusion about the presence of additional dust clouds.

Long-baseline interferometry provides a unique opportunity to investigate the circumstellar environment of R CrB stars with higher spatial resolution. In this paper, we report the results of observations of R CrB with Infrared Optical Telescope Array (IOTA) in the J-, H-, and K-bands. We show simultaneous fits of the observed K-band visibility and SED using 2-component models and discuss possible interpretations of the observed data. The J- and H-band observations, together with a more detailed modeling, are reported in Ohnaka et al.[10]

2. IOTA OBSERVATIONS

The data presented here were obtained at IOTA, a Michelson stellar interferometer located on Mt. Hopkins, Arizona (see, e.g. Traub[11]). We used IOTA in the two-telescope mode. A pair of 45 cm telescopes collect starlight and collimate it into a pair of 4.5 cm beams, which are sent to the evacuated delay line tubes. The outcoming beams are filtered through dichroics, which feed visible light onto star tracker CCDs and infrared light into our beam combiner. Details of our beam combiner are described in Ref. 12.

Table 1 summarizes our R CrB observations. We used a baseline length of 21 m (north-south orientation). R CrB was at maximum light and had a visual magnitude of approximately 6. Figure 1 shows two examples of the interferograms obtained for R CrB. The visibility was derived by calculating the ensemble average power spectra in each spectral channel and then taking the sum of them. The K-band visibility measured with IOTA is 0.61 ± 0.03 at a spatial frequency of 47.6 cycles/arcsec and P.A. $\sim 170°$ (see Fig. 2).

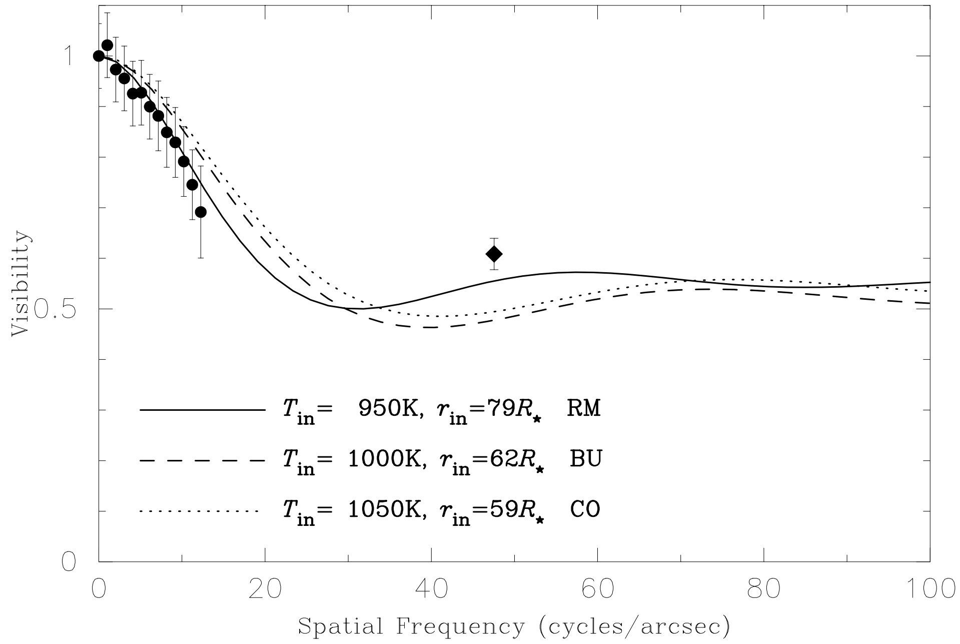

Figure 2. The filled diamond represents the K-band visibility observed with IOTA along P.A. ∼ 170°. The visibility obtained at near maximum light in 1996 is represented by filled circles. Model predictions with different dust opacities are represented by 3 curves. RM: Rouleau & Martin,[14] CO: Colangeli et al.,[15] BU: Bussoletti et al.[13]

3. MODEL FIT

We fit the observed visibilities and SED simultaneously using 2-component models consisting of the central star and an optically thin dust shell, as adopted in Paper I. Since the details of our models are described in Paper I, we only summarize the assumptions used in our models. We assume an optically thin dust shell with an inner radius $r_{\rm in}$ and outer radius $r_{\rm out}$, and with density proportional to r^{-2}. An effective temperature of 6750 K and a radius of 70 $R_\odot$ are adopted for the central star. We use three different opacity data for amorphous carbon published by Bussoletti et al.[13] (AC2 sample), Rouleau & Martin[14] (AC1 sample), and Colangeli et al.[15] (ACAR sample). The temperature distribution in the shell is calculated from the thermal balance equation for an optically thin dust shell.

We found that the observed SED, which was obtained on 2001 June 10 with the 1.22 m telescope at the Crimean Laboratory of the Sternberg Astronomical Institute, can be fitted with models whose inner radius is 60 – 80 $R_\star$ and inner boundary temperatures 950 – 1050 K. The visibility function, which directly reflects the spatial extent of the shell, enables us to examine the validity of the models described above. Figure 2 shows a comparison between the K-band visibility obtained with IOTA, as well as by speckle interferometry in 1996 (Ohnaka et al.[9]), and predictions from models with 3 different opacities of amorphous carbon. It reveals that the models can reproduce the low frequency part of the observed visibilities very well, but the predicted K-band visibilities for our IOTA measurement tend to be lower than the one observed. The predicted visibilities at the observed spatial frequency range from 0.45 to 0.54, depending on the dust opacities adopted in the models. Given the complex nature of the circumstellar environment of R CrB on the one hand, and the simplifications adopted in our models on the other hand, it is difficult to draw a definitive conclusion about this discrepancy of ∼ 10%. In particular, the model with the dust opacity obtained by Rouleau & Martin[14] predicts a K-band visibility in rough agreement with that observed. It may be due to slight deviation from spherical symmetry and/or the presence of clumps, which are plausible for R CrB.

Alternatively, this discrepancy can be interpreted as an indication of an additional component, which is more compact than the optically thin dust shell. For example, it is also possible that there is a group of hot dust clouds close to the star, and that we can detect only its global extent, not individual clouds. This point will be discussed in detail in our forthcoming paper.

4. CONCLUDING REMARKS

The first long-baseline interferometric observations of R CrB have been performed at IOTA, using our new JHK beam combiner, which enables us to record interferograms simultaneously in the J-, H-, and K-bands. The visibilities predicted by simple optically thin dust shell models are in rough agreement with the observed K-band visibility. However, there are still discrepancies between the observations and model predictions. Further tests of models by J- and H-band visibilities are indispensable for obtaining a better understanding of the circumstellar environment of R CrB, and will be published in a forthcoming paper.

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