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 along a position angle of $\sim 170°$, and the visibilities in the J-, H-, and K-bands are 0.97 ± 0.06, 0.78 ± 0.06, and 0.61 ± 0.03, respectively. The visibilities obtained with IOTA, as well as speckle visibilities with baselines of 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 J- and H-band visibilities can be fitted with these models, which have a temperature of 950 – 1100 K and an inner boundary of 60 – 80 $R_\star$. However, the K-band visibilities predicted by the models are about 10% smaller than the visibility obtained with IOTA. Given the simplifications adopted in our models and the complex nature of the object, this can nevertheless 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.

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 1934, O'Keefe 1939). 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 1986, 1988, Feast 1996), or very close to the photosphere, $\sim 2R_\star$ (Payne-Gaposchkin 1963).

Ohnaka et al. (2001, 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. Paper I shows that the SED and visibility observed at near-maximum light can be fitted with simple optically thin dust shell 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 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 the Infrared Optical Telescope Array (IOTA) in the J-, H-, and K-bands. We show simultaneous fits of the observed J-, H-, and K-band visibilities and SED using 2-component models and discuss possible interpretations of the observed data.

2. IOTA observations

The data presented here were obtained at IOTA, a Michelson stellar interferometer located on Mt. Hopkins, Arizona (see, e.g. Traub 1998). We used IOTA in the two-telescope mode. Details of our beam combiner are described in Weigelt et al. (2002).

Table 1 summarizes our R CrB observations. We used a baseline length of 21 m. 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 visibilities measured with IOTA are 0.97 ± 0.06, 0.78 ± 0.06, and 0.61 ± 0.03 in the J-, H-, and K-band, respectively.

Table 1: IOTA observations of R CrB. $B_{\rm p}$: projected baseline, $N_{\rm T}$: number of interferograms acquired for the target, $N_{\rm R}$: number of interferograms acquired for the reference star, T: exposure time of each frame

Date	V (mag)	$B_{\rm p}$	$N_{\rm T}$	$N_{\rm R}$	T(ms)
2001 Jun. 05	6	21.18 m	7700	5000	300

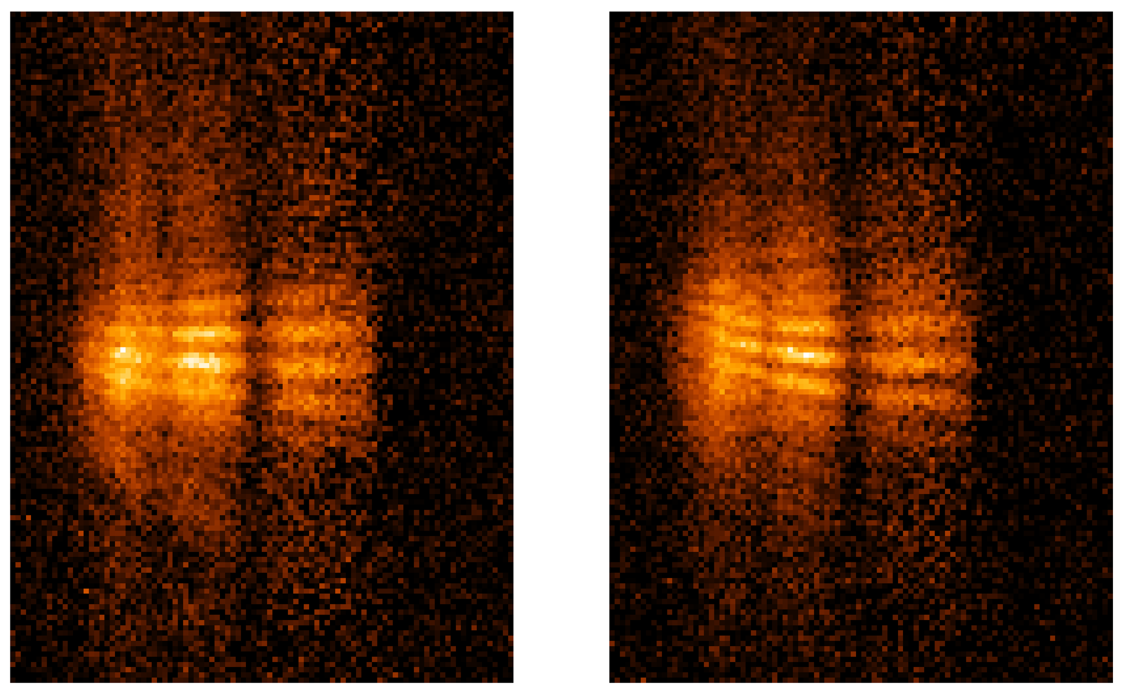

Fig. 1: Interferograms of R CrB. The fringes are spectrally dispersed in the horizontal direction, covering 1 to 2.3 μm from left to right in each panel

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. (1987) (AC2 sample), Rouleau & Martin (1991) (AC1 sample), and Colangeli et al. (1995) (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 JHK-band visibilities obtained with IOTA, as well as by speckle interferometry in 1996 (Paper I), and predictions from models with 3 different opacities of amorphous carbon. All three models predict that R CrB is unresolved in the J-band with the baseline we used, which is consistent with our observations with IOTA. The predicted visibilities are somewhat higher in the H-band, but the agreement should be regarded as fair, given the error bars of the observation, as well as the simplifications adopted in our models.

However, the predicted K-band visibilities for our IOTA measurement are lower than the one observed. The predicted visibilities at the observed spatial frequency range from 0.41 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 $\sim 10\%$. In particular, the model with the dust opacity obtained by Rouleau & Martin (1991) 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.

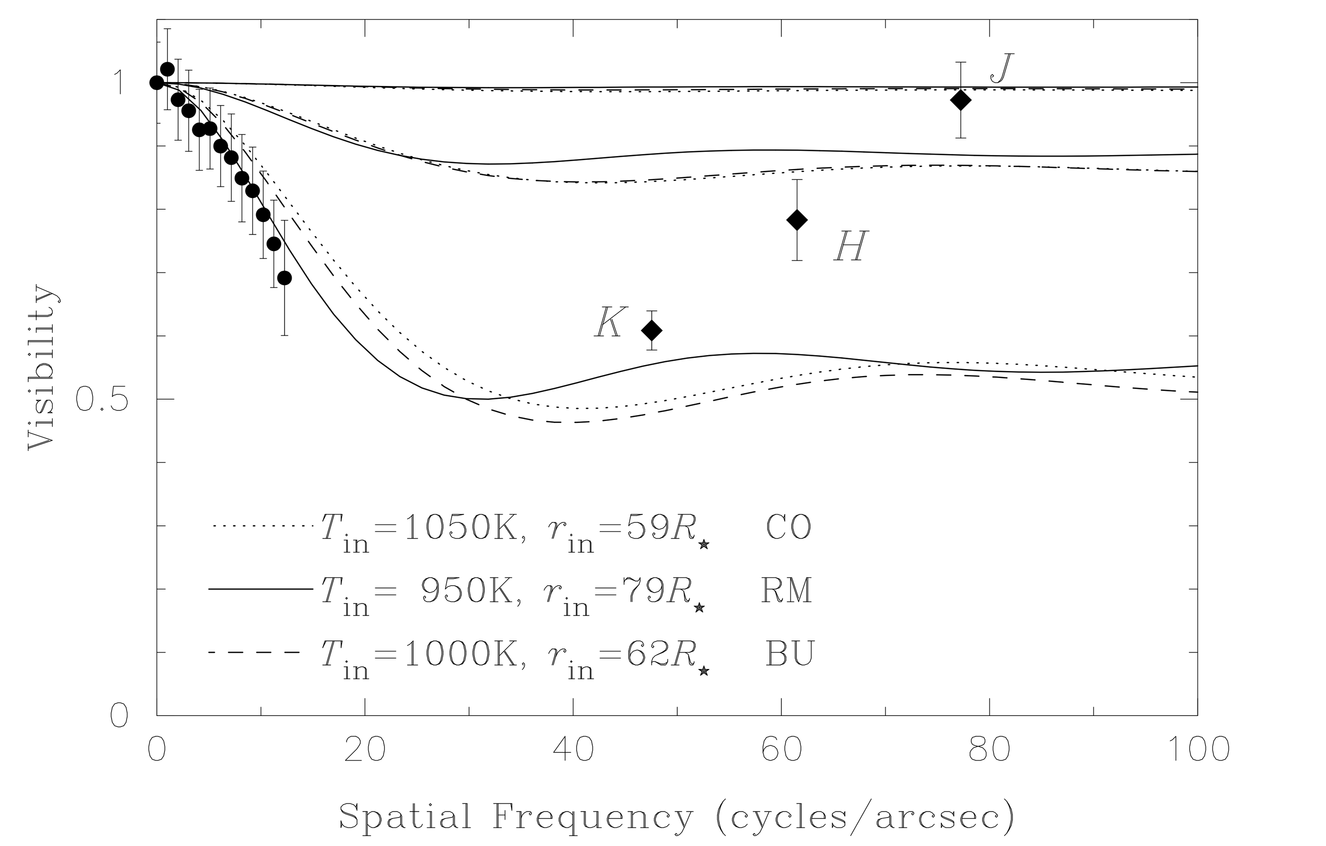

Fig. 2: The filled diamond represents the JHK-band visibilities observed with IOTA along P.A. $\sim 170°$. The visibility obtained at near-maximum light in 1996 is represented by filled circles. Model predictions with different dust opacities are represented by 3 curves. RM: Rouleau & Martin (1991), CO: Colangeli et al. (1995), BU: Bussoletti et al. (1987)

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.

5. Conclusion

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 JHK-band visibilities. However, there are still discrepancies between the observations and the model predictions. Further tests of models by obtaining more visibility points are indispensable for a better understanding of the circumstellar environment of R CrB.

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