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Mass Loss History of the AGB star, R Cas

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Abstract. We report here on the discovery of an extended far-infrared shell around the AGB star, R Cassiopeia, made by *AKARI* and *Spitzer*. The extended, cold circumstellar shell of R Cas spans nearly $3'$ and is probably shaped by interaction with the interstellar medium. This report is one of several studies of well-resolved mass loss histories of AGB stars under *AKARI* and *Spitzer* observing programs labeled “Excavating Mass Loss History in Extended Dust Shells of Evolved Stars (MLHES)”.

1. Introduction

Deutsch (1956) discussed the existence of blueshifted circumstellar cores in the spectrum of the red supergiant star α Her, constituting direct evidence for high rates of mass loss. Since that time, numerous observations have elucidated the magnitude and ubiquity of mass loss across the upper right side of the Hertzsprung-Russell diagram. The high rates of mass loss among AGB stars rival evolutionary timescales, affecting stellar evolutionary tracks substantially. Therefore, the high rates of mass loss deserve careful determination. These facts have befuddled theorists, who are struggling with the basic challenge of how to lift so much mass away from the gravitational hold of the star.

During the 1980's, observations with the *Infrared Astronomical Satellite* (*IRAS*) demonstrated that extended infrared shells of evolved stars - the anticipated effect of continuous dusty mass loss (e.g. Stencel, Pesce, & Hagen Bauer 1988; Young, Phillips, & Knapp 1993a,b) - were present. During the 1990's, the *Infrared Space Observatory* and ground-based infrared work began to refine those results (e.g. Izumiura et al. 1997; Meixner et al. 1999), indicating variations in the mass loss rate over time and resulting in shells and structure as might be predicted in stellar evolution calculations for AGB stars (e.g. Iben 1995). This decade, we are fortunate to have higher resolution and sensitivity instruments like the *AKARI Infrared Astronomy Satellite* (*AKARI*: Murakami et al. 2007) and the *Spitzer Space Telescope* (*Spitzer*: Werner et al. 2004) that can more carefully map the mass loss history of evolved stars.

This report is the first of several studies of well-resolved mass loss histories of AGB stars under *AKARI* and *Spitzer* observing programs labeled "Excavating Mass Loss History in Extended Dust Shells of Evolved Stars (MLHES)". In this contribution, we will explore whether the detection of an extended ($\sim 3'$ radius) dust shell around the oxygen-rich AGB star, R Cas, can be interpreted in terms of thermal pulses, in order to constrain mass loss histories from this evolved star. In parallel with the mass loss history of evolved stars, evidence for the interaction of circumstellar and interstellar medium (ISM) is growing, with new observations of bow shocks around R Hya (Ueta et al. 2006) and Mira (Martin et al. 2007; Ueta 2008), plus theoretical considerations of the phenomena (Villaver, García-Segura, & Manchado 2003; Wareing et al. 2007). Because nature is intrinsically complicated, we will examine evidence for both mass loss history and interaction with the ISM in the case of the extended infrared shell of R Cas.

2. R Cas: the Star and its Circumstellar Shell

The Mira type variable, R Cas (HD224490), is an oxygen-rich star with a period of 431 days and estimated mass loss rate of 10^{-7} $M_\odot$ yr^{-1}. This star shows an extended circumstellar shell originally detected by *IRAS* at 60μm, having angular extent at least 4.′3 (Young, Phillips, & Knapp 1993a), or 2.′8 (Bauer & Stencel 1994) using careful deconvolution of the point-spread-function (PSF). The linear extent of the shell depends on the distance determination.

We observed R Cas in the four bands at 65, 90, 140 and 160μm using the Far-Infrared Surveyor (FIS: Kawada et al. 2007) on-board *AKARI* on 2007 January 16 as part of the MLHES Mission Program (PI: I. Yamamura). Observations were made with the FIS01 (compact source photometry) scan mode, in which two strips of forward and backward scans (at 0.5s reset rate) were done with a $70''$ spacing.

R Cas was also observed at 70μm using MIPS aboard *Spitzer* on 2008 February 18 as part of the Cycle 4 GO project, *Spitzer*-MLHES (PID 40092, PI: T. Ueta). We mapped a $15' \times 20'$ region with a series of exposures in photometry/fixed-cluster-offset mode, while avoiding the central star that is brighter than the saturation limit of the MIPS arrays.

3. Preliminary Results and Discussion

Figure 1 shows a *Spitzer* image at 70μm (top left) and *AKARI* images at 90 and 140μm (top middle and right, respectively). These far-infrared images show the extended circumstellar shell around R Cas, which is roughly circular of radius 140 to $165''$. The shell's emission structure consists of the relatively flat "plateau" region on the west side (of surface brightness $\sim$ 15 to 20 MJy sr^{-1} at 65 to 90μm and $<$ 10 MJy sr^{-1} at 140μm) and the region of higher surface brightness (emission core) on the east side around the central star. We immediately see that the extended shell is off-centered, i.e., position of the central star does not coincide with the geometric center of the extended circular shell.

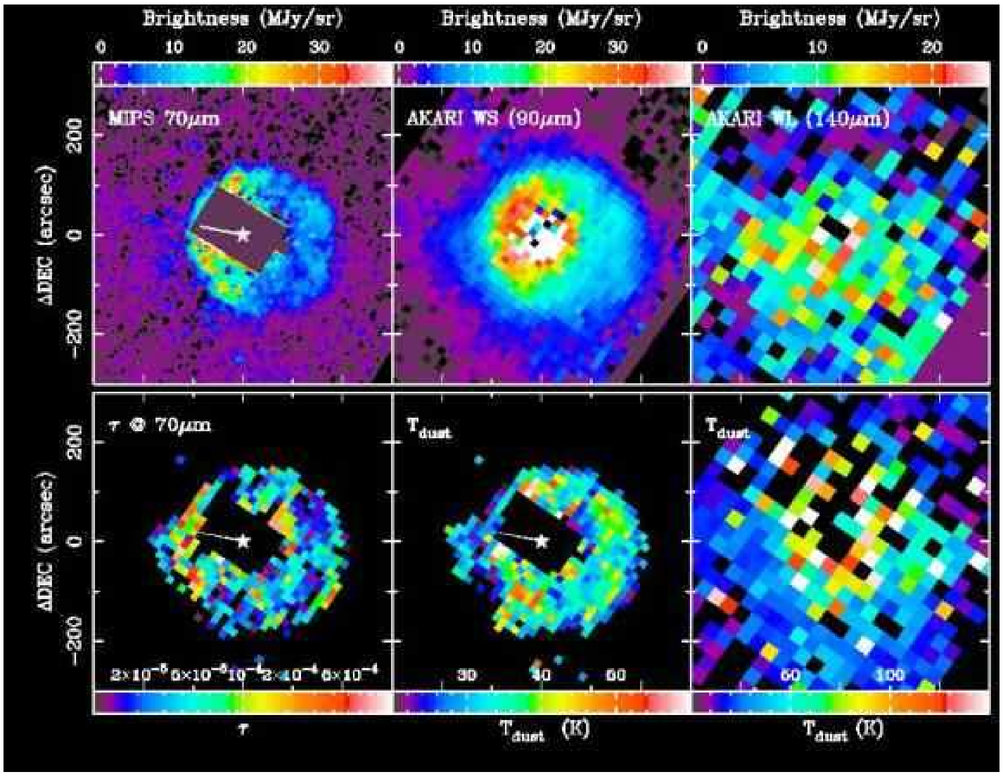

Figure 1. R Cas images in the far-infrared and derived quantities. [Top] *Spitzer* 70μm (PSF subtracted, left) and *AKARI* 90μm (WIDE-S, middle) and 140μm (WIDE-L, right) maps. [Bottom] Optical depth map at 70μm (left) and dust temperature maps derived from *Spitzer* and AKARI 90μm map (middle) and from AKARI 90 and 140μm maps (right). The line emanating from the central star's position indicates the direction of the star's proper motion. The color image is available from the version on arXiv.

Also, there appears to be an enhancement of the surface brightness along the periphery of the shell (especially recognizable in the *Spitzer* 70μm and the dust temperature maps). This density enhancement may be due to a fast low density wind shock-merging with a slower, high density wind which was caused during an era of higher/enhanced mass loss, as has been hydrodynamically predicted (e.g. Steffen, Szczerba, & Schönberner 1998).

Hipparcos measured the proper motion of $(\mu_\alpha, \mu_\delta) = (85.5 \pm 0.8, 17.5 \pm 0.7)$ mas yr^{-1} (van Leeuwen 2007). This translates to the position angle of $78.^\circ4 \pm 0.^\circ7$ east of north, which is indicated as a line drawn from the position of the star in Figure 1. This direction agrees remarkably well with the direction along which there is a positive gradient of surface brightness. In other words, the brighter surface brightness in the eastern edge of the shell appears to arise from interactions between AGB winds and the ISM, where a bow shock is expected as discovered around another AGB star, R Hya (Ueta et al. 2006).

The shape of the circumstellar shell was fit by an ellipse. The best-fit semi-major axis and eccentricity pair, (a, ϵ), is $a = 33.6$ pix $= 165''.3$ and $\epsilon = 0.3$: indeed, the R Cas shell is not quite circular in projection. According to the best-fit ellipse, the distance from the ellipse center to one of the foci is $c = a \times \epsilon = 9.9$ pix $= 48''.8$. This means that the central star is $48''.8$ displaced from the ellipse center over the course of the shell expansion. At the preferred distance for R Cas, 176 pc, the semi-major and semi-minor axes correspond to 0.12 to 0.14 pc. At the measured CO expansion rate of 12 km s^{-1} (Bujarrabal, Fuente, & Omont 1994), a crossing time of the shell is therefore roughly 10^4 years.

If the elongation of the R Cas shell is solely due to the motion of the central star with respect to the shell (in an otherwise stationary local environment), the star must have been moving roughly at 5 mas yr^{-1}, which is much smaller than the observed motion of 86.5 mas yr^{-1}. Thus, the shaping of the shell is NOT self-inflicted as in interactions between fast and slow AGB winds expected in the AGB shells (Steffen, Szczerba, & Schönberner 1998). Rather, the shall shaping appears to be a result of interactions between AGB winds emanating from the moving star AND the ISM flow local to R Cas. As shown by Ueta et al. (2009) in this volume, one can deduce the direction of the ISM flow local to R Cas given the direction of the proper motion by fitting the shell/bow structure in the leading, brighter eastern edge. While similar analyses would allow probing of the 3-D dynamics of the ISM local to these wind-ISM interacting shells, these shells do not preserve mass loss history beyond the wind crossing time of the shell. In the case of R Cas, mass loss history can be probed only up to 10^4 yr ago from the internal structure of the shell.

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