
Excavating Mass Loss History in Extended Dust Shells of Evolved Stars: the AKARI MLHES Mission Program

Toshiya Ueta¹, Hideyuki Izumiura², Issei Yamamura³, Osamu Hashimoto⁴, Mikako Matsuura^{5,6}, Takashi Miyata⁷, Yoshikazu Nakada⁷, Yoshifusa Ita⁶, Noriyuki Matsunaga⁸, Toshihiko Tanabé⁷, Hinako Fukushi⁷, and Takashi Tsuji⁷

¹ Department of Physics and Astronomy, University of Denver, Denver, CO 80112, U.S.A. tueta@du.edu

² Okayama Astrophysical Observatory, Asakuchi, Okayama, 719-0232, Japan

³ Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Sagami-hara, Kanagawa, 229-8510, Japan

⁴ Gunma Astronomical Observatory, Agatsuma, Gunma, 377-0702, Japan

⁵ National Astronomical Observatory of Japan, Mitaka, Tokyo, 181-8588, Japan

⁶ Department of Physics and Astronomy, UCL, London WC1E 6BT, U.K.

⁷ Institute of Astronomy, University of Tokyo, Mitaka, Tokyo, 181-0015, Japan

⁸ Department of Astronomy, Kyoto University, Sakyo, Kyoto, 606-8502, Japan

Summary. Using the Japanese IR Astronomy Satellite, *AKARI*, we have performed a far-IR imaging survey of extended cold dust shells aiming to understand the history of mass loss as a function of time during the late stages of stellar evolution. In this contribution, we present a brief overview of the MLHES Mission Program of the *AKARI* Astronomy Satellite and its preliminary results.

Key words: circumstellar matter – infrared: stars – stars: AGB and post-AGB – stars: mass loss stars: winds, outflows

1 Far-IR Observations of Evolved Star Dust Shells

Low to intermediate mass ($0.8 - 8 M_{\odot}$) stars experience copious mass loss at the rate of $10^{-7} - 10^{-4} M_{\odot} \text{ yr}^{-1}$ during the asymptotic giant branch (AGB) phase [8, 9]. The ejected matter forms a circumstellar envelope (CSE), which is originally spherically symmetric [14]. When mass loss is terminated at the end of the AGB phase, the CSEs become detached and coast away from the central star. A number of imaging surveys of post-AGB shells both in the optical (probing reflection nebulae) and mid-IR (probing thermal dust emission) have concluded that the CSEs must have already developed the axisymmetric CSE structure by the end of the AGB phase [1, 15, 19, 21, 22, 23].

To fully understand mass loss, thorough investigations of the history of AGB mass loss must be done using far-IR emission of cold dust as the primary tracer.

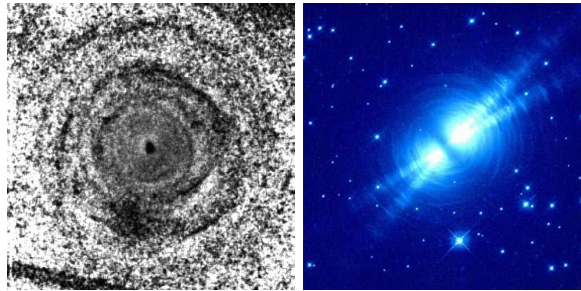


Fig. 1. Left: Ground-based composite $B+V$ image of the $131'' \times 131''$ field around a carbon-star IRC+10216 with an average radial profile subtracted, showing concentric shells resulting from rather spherical AGB mass loss [14]. **Right:** HST V (WFPC2/F606W) image of the $74'' \times 74''$ field around the Egg Nebula, a post-AGB object, displaying the already fully-developed bipolar structure [18].

Such extended CSEs of evolved stars were indeed detected by *IRAS* [4, 7, 20, 27, 28] and highly-processed *IRAS* data revealed the CSE structures [6, 12, 25]. Subsequent *ISO* studies confirmed the existence of large AGB CSEs [5, 10, 11]. New opportunities with *Spitzer* have recently yielded the CSE images of evolved stars, notably leading to the first detection of the interface between the AGB wind and ISM [24]. Here, we present preliminary results from the latest large-scale (> 100 objects) far-IR imaging survey entitled “Excavating Mass Loss History in Extended Dust Shells of Evolved Stars (MLHES)” carried out with the *AKARI* Astronomy Satellite.

2 AKARI Astronomy Satellite

AKARI (formerly known as *ASTRO-F*) is the first Japanese satellite dedicated to IR astronomy [16]. The primary objective of the satellite is to create second-generation all-sky IR catalogs at better spatial resolution and for wider spectral coverage than *IRAS* [2]. The satellite is equipped with a 68.5 cm cryogenically-cooled telescope with two focal-plane instruments, the Infrared Camera (IRC) covering $1.8 - 26.5 \mu\text{m}$ in nine bands [17] and the Far-IR Surveyor (FIS) covering $50 - 180 \mu\text{m}$ in four bands [13]. *AKARI* was launched on 2006 February 21 (UT) by the Japan Aerospace Exploration Agency (JAXA). Science operation of *AKARI*, consisting of large-area surveys (LSs), mission programs (MPs) and open-time (OT) programs, began on 2006 May 8. The all-sky survey was prioritized during Phase 1, which lasted until 2006 November 10, and most of the MP and OT programs were executed during Phase 2, which commenced on 2006 November 11. *AKARI*'s cold campaign has come to an end on 2007 August 26 when the cryogen was exhausted.

3 The MLHES Mission Program

The MLHES MP aims at tracing the history of mass loss imprinted in the density structure of very extended, cold dust shells surrounding evolved stars by performing

a far-IR imaging survey of these CSEs. With each pointed FIS scan, we obtain a roughly $10' \times 20'$ map of extended CSEs by detecting thermal emission arising from cool dust grains in these CSEs. From these far-IR surface brightness maps, we can reconstruct the history of mass loss over the course of the latest stages of stellar evolution. By studying these maps from more than 100 objects, we can systematically examine the mass-loss history during the last $10^4 - 10^5$ yr with a time resolution of 10^3 yr.

Based on our coherent FIS data set, we will examine (1) how stellar properties would influence the history of mass, (2) how the rate of mass loss varies and (3) how and when the non-spherical shell structure development really begins. We also perform a mid-IR imaging with IRC for some selected objects to examine the physical conditions of the inner regions of the CSEs via warmer dust in these shells. This additional information will greatly contribute to our subsequent detailed modeling efforts to understand the structure and dust-heating energetics in these CSEs.

4 Preliminary Results

Under the MLHES MP *AKARI* made 149 pointed observations, of which 144 are FIS scan maps and five are IRC maps. Approximately 40% of the sources appear to show some kind of extension while about 20% appear as point sources. The rest seems marginally extended. Further diagnostics of the point-spread-function needs to be performed before we can conclude whether or not these sources are truly extended.

There seem to be four types of extension among those appear extended. The first type shows a round but clumpy CSE, in which the central star seems located off-center. Y CVn (Fig. 2, top left) is a C-rich, SRb variable whose CSE has already been seen by *ISO* [10]. V Tel (Fig. 2, right) is an O-rich, SRb variable. *AKARI* detected the CSE for the first time at far-IR, signifying the fact that O-rich AGB stars can also sustain significant mass loss that results in the CSE, contrary to a recent study implying that O-rich AGB stars would not drive dust grains as effectively as C-rich AGB stars [26]. The second type displays a round CSE with the central star in the middle. In U Hya we have clearly captured the detached shell (Fig. 2, bottom left). The third type exhibits elongated CSEs as in RZ Sgr, an SRb type S-star (Fig. 2, bottom right). The fourth type is an arc-like shell (not presented here).

The estimated sensitivities of the MLHES data based on the standard deviation in the background sky are roughly 0.1 (0.08) and 0.6 (0.4) MJy sr⁻¹ for the WIDE-S and WIDE-L band, respectively, at the 15 (8) arcsec s⁻¹ scan speed. These values are roughly a factor of several better than results obtained in similar observations done by *Spitzer* [3]. These values and the image quality are critical to observationally establish the history of AGB mass loss, and we will improve them as we continue to characterize the detector performance and instrumental effects.

In Table 1, we summarize how much mass loss history we can learn for these sources in the case of a 15 km s⁻¹ wind given the detected CSE size. One of the main objectives of the MLHES project is to derive the rate of mass loss as a function of time, $\dot{M}(t)$, and possibly as a function of projected position, $\dot{M}(r, \theta; t)$, based on a statistically significant data set, which will serve as the direct observational constraints. By confronting theoretical models with our observational constraints, we will be able to test proposed mechanisms of dusty mass loss that take place along

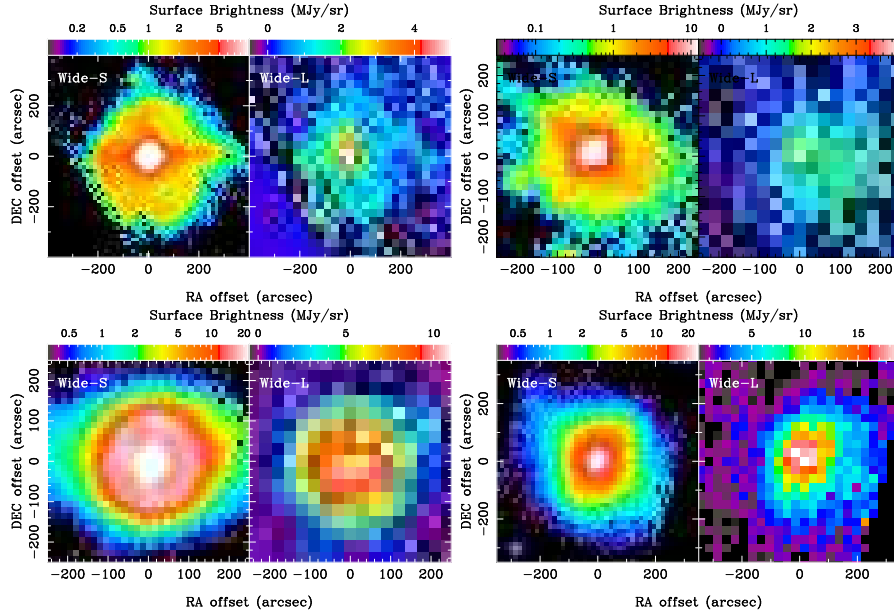


Fig. 2. WIDE-S ($90 \mu\text{m}$, left) and WIDE-L ($140 \mu\text{m}$, right) images of the CSEs. **Top Left:** Y CVn, showing a clumpy CSE ($\sim 300''$ radius) with the off-center C-rich star. **Top Right:** V Tel, showing a clumpy CSE ($\sim 200''$ radius) with the O-rich central star in the middle. **Bottom Left:** U Hya, showing a *detached* round shell ($\sim 100''$ radius). **Bottom Right:** RZ Sgr (O-rich S-star), showing an elongated extension. Tickmarks are RA and DEC offsets with respect to the central star in arcsec. The wedges on the top show surface brightnesses in MJy sr^{-1} .

the AGB phase.

Table 1. Detected CSE Size and 15 km s^{-1} Wind Crossing Time

Source	Type	Radius (arcsec)	Distance (pc)	Wind Crossing Time (yr)	Time Resolution (yr)
Y CVn	C(SRb)	200	218	14000	1000
V Tel	O(SRb)	200	309	20000	1500
U Hya	C(SRb)	100	162	5100	770
RZ Sgr	O(SRb)	150	388	18000	1800

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