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*Letter to the Editor: first results from ISO*

# A detached dust shell surrounding the J-type carbon star Y Canum Venaticorum

**H. Izumiura**[1], **O. Hashimoto**[2], **K. Kawara**[3,4], **I. Yamamura**[5,6], **and L. B. F. M. Waters**[7,6]

[1] Okayama Astrophysical Observatory, National Astronomical Observatory, Kamogata, Asakuchi, Okayama 719-02, Japan
[2] Department of Applied Physics, Seikei University, 3 Kichijojikita, Musashino, Tokyo 180, Japan
[3] Institute of Space and Astronautical Science, 3-1-1 Yoshinodai, Sagamihara, Kanagawa 229, Japan
[4] ISO Science Operations Centre, Astrophysics Division of ESA, Villafranca, 28080 Madrid, Spain
[5] Institute of Astronomy, Faculty of Science, The University of Tokyo, 2-21-1 Osawa, Mitaka, Tokyo 181, Japan
[6] SRON Laboratory for Space Research Groningen, P.O. Box 800, NL-9700 AV Groningen, The Netherlands
[7] Astronomical Institute , University of Amsterdam, Kruislaan 403, NL-1098 SJ Amsterdam, The Netherlands

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**Abstract.** This paper reports the first clear detection of a detached dust shell surrounding the prototypical J-type carbon star Y CVn in 90 $\mu$m and 160 $\mu$m maps taken with the ISO/ISOPHOT[1]. The projected inner radius of the shell is $180''$–$190''$, corresponding to (6.4–7.1) $10^{17}$ cm at a distance of 250 pc. The shell thickness is obtained to be (2–5) $10^{17}$ cm. The mass-loss rate at the formation of the shell is estimated to be in the range (7–20) $10^{-6}$ $M_{\odot}$ yr$^{-1}$, about two orders of magnitude higher than the present-day mass-loss rate derived from CO gas observations. The obtained mass in the shell is (4–14) $10^{-2}$ $M_{\odot}$. It is concluded that the mass-loss rate decreased by two orders of magnitude on a short time scale 1.4 $10^4$ years ago assuming an average shell expansion velocity of 15 km s$^{-1}$, and that Y CVn has been staying at the low mass-loss state. The duration of the previous higher mass-loss phase would be at most 2 $10^4$ years even if the asymmetry in the shell geometry is taken into account. The evolutionary status of Y CVn is also discussed.

**Key words:** Stars: carbon – Stars: evolution – Stars: imaging – Stars: individual: Y CVn – Stars: mass-loss – Stars: AGB and post-AGB – Dust

## 1. Introduction

Very extended dust shells around luminous red stars were noticed soon after the launch of the InfraRed Astronomical Satellite (IRAS). Hacking et al. (1985) noted that there were significant number of asymptotic giant branch (AGB) stars resolved by the IRAS beam at either 60 $\mu$m or 100 $\mu$m. Because such extended shells around AGB stars are the direct products of stellar mass-loss, they must contain key information on the late stages of the evolution of low- and intermediate-mass stars. In particular those of carbon stars are of great interest since a significant fraction of cool carbon stars show large far-infrared excess emission presumably due to a detached, cold dust shell (cf. Willems & de Jong 1988). The detached shells might have been produced by the interruption of a high mass-loss phase or by an episodic high mass-loss. Such a change of mass-loss configuration is probably related to the thermal pulse on the AGB (Vassiliadis & Wood 1993; Blöcker 1995), or possibly to the He core-flash just after the termination of the red-giant branch (RGB) (Dominy 1984). High resolution IRAS (HIRAS) images (Bontekoe et al. 1994) of U Hya obtained by Waters et al. (1994) indeed show a detached, geometrically thin dust shell, the age of which (12,000 years) is compatible with the interpulse period for intermediate-mass stars. Furthermore, Izumiura et al. (1996) have discovered that U Ant is surrounded by two dust shells in the HIRAS images, the outer one of which is clearly detached. The inner one is also found to be detached through model analysis, which is reinforced by the detached CO gas shell (Olofsson et al. 1996). They conclude that the two shells could have formed through

*Send offprint requests to*: H. Izumiura, izumiura@oao.nao.ac.jp

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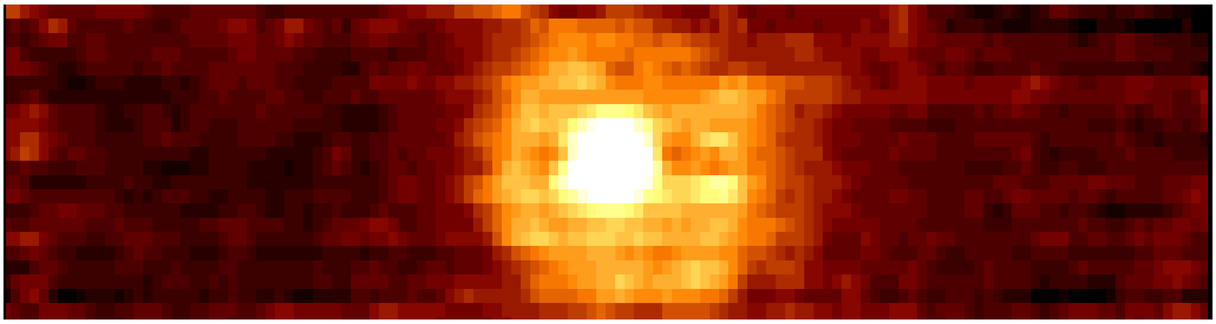

**Fig. 1.** 90 $\mu$m image of Y CVn taken with PHT-C100 array detector and C90 filter displayed in linear brightness scale.

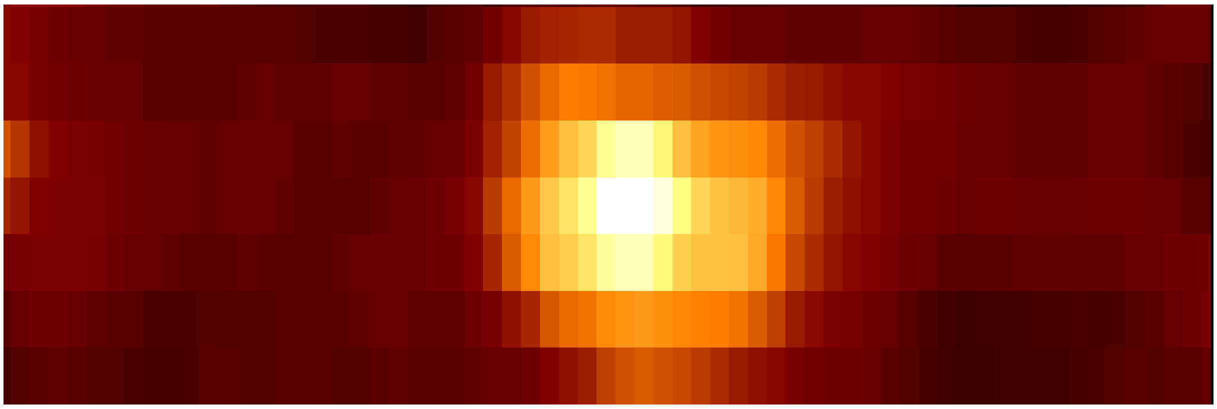

**Fig. 2.** 160 $\mu$m image of Y CVn taken with PHT-C200 array detector and C160 filter displayed in linear brightness scale.

two consecutive thermal pulses 3,000 and 17,000 years ago. Far-infrared observations with high spatial resolution have been proved to be a powerful means to study the mass-loss history of carbon stars on time scales longer than $10^4$ years. Such studies, however, require observations in space, and have been restricted to those of the IRAS database.

The ISOPHOT photo-polarimeter (Lemke et al. 1996) on board the Infrared Space Observatory (ISO) (Kessler et al. 1996) is suited for that purpose. Indeed our guaranteed-time program is now being executed using ISOPHOT to examine the mass-loss history of both Oxygen-rich AGB stars and carbon stars by mapping their dust shells in the far-infrared. This paper reports the first results of our first program star, Y Canum Venaticorum (Y CVn), which is the brightest J-type cool carbon star in the optical. J-type stars are cool carbon stars with a low $^{12}C/^{13}C$ carbon isotopic ratio in the atmosphere, whose evolutionary status is still unclear compared to typical N-type carbon stars (cf. Lambert et al. 1986). The ISOPHOT observations have revealed a definitely detached dust shell surrounding Y CVn, implying that the mass-loss rate was considerably higher in the past and declined on a short time scale.

## 2. The observations and results

Mapping observations of Y CVn were made using the ISOPHOT imaging photo-polarimeter as the first target of our guaranteed time observing program on 25 April 1996 (UT). We obtained a $8'.3 \times 34'.8$ map with PHT-C100 detector array of $43''.5$ square pixel through C90 filter centered at 95.1 $\mu$m and a $10'.5 \times 35'.5$ map with PHT-C200 detector array of $89''.4$ square pixel through C160 filter centered at 174.0 $\mu$m using AOT PHT32. This AOT is used for multi-filter mapping with high spatial resolution by oversampling using the focal plane chopper. The chopping direction is parallel to the spacecraft Y-axis, which was along the position angle of 66° at the observations. The maps are extended along this direction (see Figures 3 and 4; hereafter the horizontal and vertical directions in the maps are called the x- and y-directions, respectively), hence, along north-east (left-side in the maps) to south-west direction on the sky. The oversampling factor was 3 in the x-direction for both maps and was 3/2 and 1 in the y-direction for the 90 $\mu$m and 160 $\mu$m maps, respectively. Resulting spatial sampling intervals are $15''$ and $30''$ in the x-direction, and $22''.5$ and $90''$ in the y-direction, for the 90 $\mu$m and 160 $\mu$m maps, respectively. Mapping center was located at $\alpha = 12^{\mathrm{h}}45^{\mathrm{m}}07\overset{\mathrm{s}}{.}8$ and $\delta = 45°26'24\overset{''}{.}0$ (J2000). Each mapping took nearly one hour.

The raw data were reduced taking standard procedures using PIA[2] at the ISO Science Operations Center in Spain. Flat fielding and the absolute flux calibration were done with the latest version of the calibration file available at early June 1996. The uncertainty in the absolute flux calibration is estimated to be 50–100 % in both maps. Background subtraction was done by fitting a plane to the neighborhood of the star using NOAO IRAF. The resulting ISOPHOT images of Y CVn at 90 $\mu$m and 160 $\mu$m are shown in Figures 1 and 2, respectively. The pixel sizes are $15'' \times 22\overset{''}{.}5$ and $30'' \times 90''$ in Figures 1 and 2, respectively.

The images show that Y CVn is surrounded by extended emission almost circularly distributed about the star, and that the emission is clearly resolved into its structure. The extension of the emission is about $8'$ in diameter in either image, which is in good agreement with the extended emission component seen in the one-dimensional IRAS survey scan data of Y CVn at 60 and 100 $\mu$m (cf. Young et al. 1993). The size of the extended emission at 90 $\mu$m being almost the same as that at 160 $\mu$m also indicates that the emission is not an artifact due to the diffraction pattern but indeed comes from the dust shell of Y CVn.

The 90 $\mu$m and 160 $\mu$m surface brightness profiles are shown along the x-direction crossing the central star in Figures 3 and 4, respectively. The 90 $\mu$m data clearly show a local maximum at about $190''$ at either side of the star, evidencing a clearly resolved, detached dust shell. The spatial resolution at 160 $\mu$m is insufficient to give such a local maximum but the profile indeed has a shoulder at around $190''$, which is consistent with the 90 $\mu$m data.

It should be noted that the dust shell has asymmetries in the structure. The star is not located exactly at the center of the extended emission and the brightness of the shell is lower in the top-right (west) part. These features are found in both the 90 $\mu$m and the 160 $\mu$m images but the origin is not clear yet. Although the detector memory effect and detector drifts cannot be ruled out, they are of great interest for further investigations.

The brightness profiles in Figures 3 and 4 are analysed, using a spherical, detached dust shell model (Izumiura et al. 1996). In the model, the outflow velocity is constant at 15 km s$^{-1}$, which is higher than the present-day CO gas outflow velocity ($\sim$ 9 km s$^{-1}$). It is chosen because the outflow velocities in extended, detached CO gas shells are much higher than those of the present-day, and are around 15 km s$^{-1}$ (cf. Olofsson et al. 1996). A mass density distribution proportional to $r^{-2}$ is assumed, where $r$ is the distance from the center. The grain opacity is set proportional to $\nu^{\alpha}$, where $\nu$ denotes frequency, with 150 cm$^2$ g$^{-1}$ at 60 $\mu$m and the gas-to-dust mass ratio of $4.5\,10^{-3}$ is adopted (Jura 1986), which corresponds to carbon-rich chemistry. The grain temperature is determined with the use of thermal equilibrium calculation assuming a blackbody central star. The effective temperature is set as 2460 K (Groenewegen et al. 1992), and the luminosity as 7050 $L_{\odot}$ (Frogel, Persson & Cohen 1980). A distance of 250 pc (Groenewegen et al. 1992) is adopted. Though the exact detector response function against a point source has not been published yet, the gaussian convolving beams with FWHMs of $65''$ and $120''$ at 90 $\mu$m and 160 $\mu$m, respectively, are introduced to the model as they give the best fit

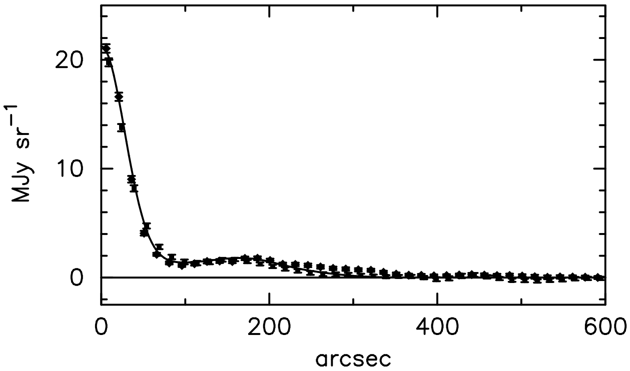


**Fig. 3.** Observed (symbols) and model (line) brightness profiles at 90 $\mu$m. Squares and diamonds express the data points in the north-east and the south-west parts, respectively (see text). The observed profile is presented so that the central stellar component appears symmetric. Only statistical error is shown. Model parameters are given in the text.

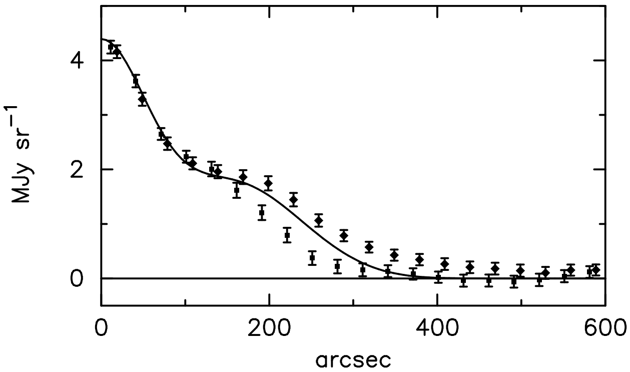


**Fig. 4.** Same as in Figure 3 but at 160 $\mu$m.

[2] PIA (PHT Interactive Analysis software) is a joint development by the ESA Astrophysical Division and the ISOPHOT consortium led by the Max Planck Institute for Astronomy (MPIA), Heidelberg

to the central stellar component. The model does not include the relative response function across the photometric band and the spectrum is assumed to be monochromatic within the band. It should be reminded in the following results that the absolute calibration still carries an uncertainty of 50–100 %, which makes the obtained quantities somewhat uncertain.

One of the best fit models is shown as solid line in Figures 3 and 4, where the shell inner radius, shell thickness, and mass-loss rate are $6.4\,10^{17}$ cm, $5.0\,10^{17}$ cm, and $7.4\,10^{-6}$ $M_\odot$ $yr^{-1}$, respectively. The robust numbers one can obtain at this preliminary stage of the flux calibration is the inner radius and thickness of the detached shell. These are given as $R_{inner}$=(6.4–7.1) $10^{17}$(D/250) cm and $\Delta$R=(2–5) $10^{17}$(D/250) cm, respectively, for the mean brightness profile of the north-east and the south-west parts, where $D$ denotes the distance to the star in parsec. The asymmetry of the shell results in the uncertainty of $\Delta$R. If we treat the two parts separately, we obtain the minimum thickness of about $1\,10^{17}$ cm in the north-east part, and the maximum one of about $10\,10^{17}$ cm in the south-west part. The latter one places the upper limit of the shell thickness, which corresponds to an expansion time of $2\,10^4$ years for the assumed expansion velocity. The mass-loss rate and the total mass in the shell are estimated to be in the range (7–20) $10^{-6}$ $M_\odot$ $yr^{-1}$ and (4–14) $10^{-2}$ $M_\odot$, respectively, for any reasonable fittings to the present data. The power-index of the dust opacity law $\alpha$ is determined to be 0.83 from the simultaneous fittings of the data at the two wavelength bands. This number is not very plausible physically. It is likely due to the flux calibration error in the 90 $\mu$m data, which is inferred through comparison of the ISO images with the IRAS 100 $\mu$m data, while the absolute calibration is probably working fairly well at 160 $\mu$m. Scaling up by a factor of 1.8 seems to be necessary for the obtained 90 $\mu$m stellar flux density of 2.4 Jy to match the 100 $\mu$m IRAS flux density of 7.8 Jy in the IRAS Point Source Catalog (IRAS Science Working Group 1988), where the stellar contribution is estimated to be 4.3 Jy. This scaling of the 90 $\mu$m data results in the power index of the dust opacity law to become 1.0, which is physically more favorable. Even in that case, it is found that the mass-loss rate and mass in the shell change only slightly and the above whole arguments hold.

## 3. Discussion

The present-day mass-loss rate derived from the CO observations is about $10^{-7}$ $M_\odot$ $yr^{-1}$ (e.g. Olofsson et al. 1993), which is about two orders of magnitude smaller than the one obtained for the detached dust shell. These observations imply that the mass-loss rate decreased by about two orders of magnitude over the last 14,000 (D/250)(15/$V_{av}$) years, where $D$ and $V_{av}$ denote the distance to the star in parsec and the average shell expansion velocity in km $s^{-1}$, respectively. The mass-loss rate probably declined in a short time considering the clear brightness maximum in the brightness distribution (Figure 3).

Similar variation in mass-loss occurred in U Hya (Waters et al. 1994) and U Ant (Izumiura et al. 1996). U Hya shows Tc absorption line which indicates a recent third dredge-up due to a thermal pulse (Little, Little-Marenin, & Bauer 1987). Other s-process elements are also enriched in this star (Utsumi 1985). The mass-loss change in U Hya that took place 12,000 years ago may be related to a thermal pulse event. Despite the lack of information on the s-process enhancements U Ant is also thought to have experienced thermal pulses recently since it has been found to show two detached dust shells which formed 3,000 and 17,000 years ago. Relating them with two consecutive thermal pulses satisfies both theoretical and observational requirements simultaneously (Izumiura et al. 1996). In terms of mass-loss behavior Y CVn resembles to U Hya and U Ant which are believed to be on the AGB, although it is not clear yet if the same mechanism is responsible for the production of the detached shells in these three stars.

Y CVn does not show the Tc absorption line (Little, Little-Marenin, & Bauer 1987). Utsumi (1985) has proved no enhancements in s-process elements in Y CVn. With these observations one may put Y CVn not on the AGB but on the RGB or the He core-burning stage after the helium core-flash (cf. Dominy 1984). Lambert et al. (1986) have found, however, that the CNO abundances of J-type carbon stars including Y CVn are distinct from those of R-type carbon stars reported by Dominy (1984), while both groups lack the s-process enhancements. They have concluded that J-type stars are not evolved R-type stars.

The present day mass-loss rate of Y CVn is also rather large compared to those of RGB stars and of R-type carbon stars. The high mass-loss phase of a considerable duration found in this study probably precludes the possibility that Y CVn is a low- or intermediate-mass star on the RGB or the He core-burning stage as far as Y CVn was born as a single star in the Galaxy.

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## References

Blöcker, T : 1995, A&A 297, 727
Bontekoe,Tj.R., Koper, E., Kester, D.J.M.: 1994, A&A 284, 1037
Dominy, J. F.: 1984, ApJS 55, 27
Frogel, J. A., Persson, S. E., Cohen, J. G.: 1980, ApJ 239, 495
Groenewegen, M.A.T., de Jong, T., van der Bliek, N.S., Slijkhuis, S., Willems, F.J.: 1992, A&A 253, 150
Hacking, P., Beichman, C., Chester, T., Neugebauer, G., Emerson, J.,: 1985, PASP, 97, 616
Izumiura, H., Waters, L. B. F. M., de Jong, T., Loup, C., Bontekoe, Tj. R., Kester, D. J. M.: 1996, A&A, in press

Joint IRAS Science Working Group, 1988, IRAS catalogs and atlases, The Point Source Catalog (PSC), US Government Printing Office, Washington
Jura, M.: 1986, ApJ 303, 327
Lambert, D. L., Gustafsson, B., Eriksson, K., Hinkle, K. H.: 1986, ApJS 62, 373
Kessler, M. F., et al. : 1996, A&A, this volume
Lemke, D., et al. : 1996, A&A, this volume
Little, S. J., Little-Marenin, I. R., Bauer, W. H.: 1987, AJ 94, 981
Olofsson, H., Eriksson, K., Gustafsson, B., Carlstöm, U.: 1993, ApJS 87, 267
Olofsson, H., Bergman, P., Eriksson, K., Gustafsson, B.: 1996, A&A, 311, 587
Utsumi, K.: 1985, Abundance Analysis of Cool Carbon Stars. In: Jaschek, M., Keenan, P. C. (eds.) Cool Stars with Excesses of Heavy Elements. Reidel, Dordrecht, p.243
Vassiliadis, E., Wood, P.R.: 1993, ApJ 413, 641
Waters, L.B.F.M., Loup, C., Kester, D.J.M., Bontekoe, Tj.R., de Jong, T.: 1994, A&A 281, L1
Willems, F. J., de Jong, T.: 1988, A&A 196, 173
Young, K., Phillips, T. G., Knapp, G. R.: 1993, ApJS 86, 517

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