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ISO Observations of AGB Stars in the Small Magellanic Cloud

J.A.D.L. Blommaert

ISO Data Centre, Astrophysics Division of ESA, Villafranca, PO Box 50727, E-28080 Madrid, Spain

M.A.T. Groenewegen

Max-Planck-Institut für Astrophysik, Garching, Germany

M.R. Cioni, H.J. Habing

Sterrewacht Leiden, Leiden, The Netherlands

J.Th. van Loon

Astronomisch Instituut, Univ. van Amsterdam, The Netherlands

N.R. Trams

ESTEC, Astrophysics Division of ESA, Noordwijk, The Netherlands

Abstract. We used ISOCAM and ISOPHOT to observe the spectral energy distribution between 3.6 and 60 μm of AGB stars in the Small Magellanic Cloud detected by IRAS. CAM-CVF spectra are made which enable us to establish the carbon- or oxygen-rich nature of the stars.

We are in the process of analysing this data using a radiative transfer model. This will provide us with accurate determinations of luminosity and mass loss rate. Combining the results on the SMC, LMC and Galaxy we hope to address the open question of the metallicity dependencies of the mass loss rate. This in turn is important in the ejection of matter by AGB stars into the interstellar medium.

1. Introduction

Searches for Asymptotic Giant Branch (AGB) stars in the Magellanic Clouds (MCs) have been made using optical spectroscopic surveys, photometric surveys using V and I Schmidt plates and optical surveys for Long Period Variables (LPVs). However, these surveys missed the red dust-enshrouded OH/IR stars and infrared carbon stars in the MCs, very luminous examples of which did turn up in the IRAS point source catalog. Over the last few years near-infrared (NIR) studies have been initiated to study IRAS sources in the MCs (e.g. Reid et al. 1990; Wood et al. 1992; Zijlstra et al. 1996; Loup et al. 1997; Tanabé et al. 1997; van Loon et al. 1997, 1998). Still, most work until now focussed on the Large Magellanic Cloud.

As the metallicity difference between the SMC and our Galaxy is much larger than that between the LMC and our Galaxy, the SMC AGB stars are interesting in the study of the influence of metallicity on AGB evolution. As an example of this, Groenewegen et al. (1995) compared the spectral energy distribution and 8-13 μm spectra of an AGB star of comparable pulsation period in the Galaxy, LMC and SMC and showed that the dust optical depth of the LMC star was two-thirds of that of the Galactic one, but that of the SMC star was only one-fifteenth.

Recently, Groenewegen & Blommaert (1998) presented the result of NIR ground-based observations of 31 candidate AGB stars in the direction of the SMC, selected from the IRAS Faint Source Catalog to have the colours and flux-levels expected for AGB stars at the distance of the SMC. Previous work on potential AGB stars among IRAS sources in the SMC was rather limited (Whitelock et al. 1989; Wood et al. 1992; Zijlstra et al. 1996).

2. ISO observations

As a next step, we used the Infrared Space Observatory for follow-up work. The ISO observations include: (1) small rasters (FOV = $2' \times 2'$) in the ISOCAM LW2 (6.7μm) and LW10 (12μm) filters (to check possible confusion with other red sources), (2) staring ISOCAM observations in the SW1 (3.6μm), LW1 (4.5μm), LW2, LW7 (9.6μm) and LW10 filters, (3) ISOPHOT observations at 25 and 60 μm, (4) ISOCAM-CVF ($7 - 14\mu$m) spectroscopic observations.

Analysis of this data is still in progress, and we report only some initial results (previously, we reported on the status of this project as of 1997 at the "ISO's view on stellar evolution" conference, Blommaert et al. 1998).

3. Results

Outcome of the 21 raster images: Almost all NIR sources correspond to the IRAS source. In other words, at the centre of the raster (i.e. the NIR position) we find a red object with a flux density at 12 μm within a factor of 3 of the IRAS flux (allowing for variability of the AGB stars (maximum factor ≈ 2.5) and the uncertainty in the measurements). No other red source of similar 12 μm flux-densities is found in the raster. Only in 3 cases (14% of the sample) we find a source in the centre of the ISOCAM 12 μm raster image which is much weaker than the IRAS flux. Only in 1 of the 3 we see that the IRAS coordinates differ considerably with the NIR ones ($41''$), so that part of the IRAS error ellipse may fall out of the raster. In the two other cases it is not clear whether extreme variability or simply the fact that we had a spurious source in the IRAS Faint Source Catalog is the cause of the discrepancy.

Outcome of the staring observations and modelling: In total 13 sources were observed. Four sources are oxygen-rich (showing silicate features). They have high luminosities ($L_* > 20\,000\ L_\odot$), of which 2 are near or above the limit of

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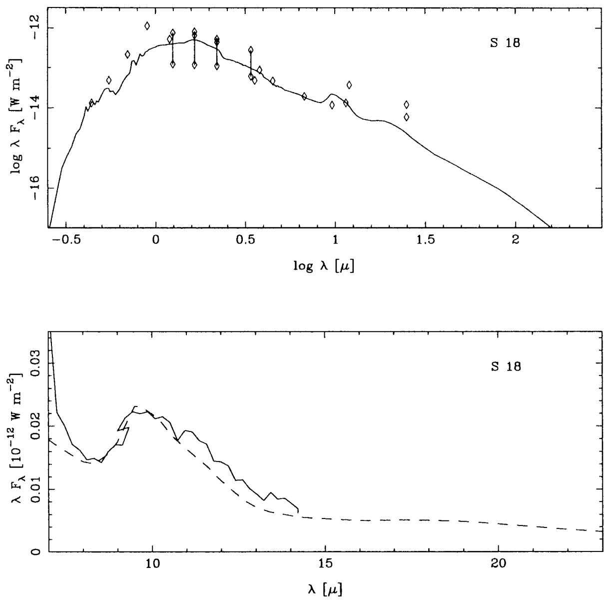

Figure 1. Model fit to the SED and CAM-CVF spectra of one of the oxygen-rich sources. Luminosity and mass-loss rate are 65 600 $L_\odot$ and 3×10^{-8} $M_\odot\, yr^{-1}$.

AGB stars ($L_* > 55\,000$ $L_\odot$). $\dot{M}$ ranges from 10^{-8} to 10^{-6} $M_\odot\, yr^{-1}$. See Fig. 1 for an example.

Six sources are carbon-rich. Five have relatively low luminosities ($L_* \leq$ 10 000 $L_\odot$). One source has a luminosity of $\approx$ 20 000 $L_\odot$. All suffer extreme high mass-loss rates ($\dot{M} \geq 10^{-5} M_\odot\, yr^{-1}$, assuming a (Galactic) dust/gas ratio of 1/200). This is quite remarkable because first, one would assume that the metallicities are lower in the SMC and thus the dust to gas ratio may even be much lower than assumed here. This would further increase the resulting mass-loss rate. And second, we find evidence here that relatively low mass stars ($\approx 1.5 M_\odot$) also reach high mass-loss rates in excess of 10^{-5} $M_\odot\, yr^{-1}$. Third, *no* high luminosity carbon-rich sources above 20 000 $L_\odot$ like those in the LMC were found (van Loon et al. 1997, 1998).

Three sources do not fall in either of the above categories: IRAS 00369−7419 has been classified as a C-rich post-AGB star (Whitelock et al. 1989). IRAS 00535−7219 is classified as a symbiotic star. The third object, IRAS 00492−7408, has been extensively observed with ISO. Groenewegen & Blommaert (1998) could not detect a NIR counterpart of this source. ISO observations confirm that the source is extremely red and was easily detectable up to 100 μm. The source was also monitored over a time range of almost 600 days with ISOCAM at 6.7 and 12 μm. These measurements did not show any evidence of variability. Also the IRAS 12 μm flux corresponds well to the ISOCAM one. The CAM-CVF spectrum between 5 and 17μm shows no spectral features. Together with the

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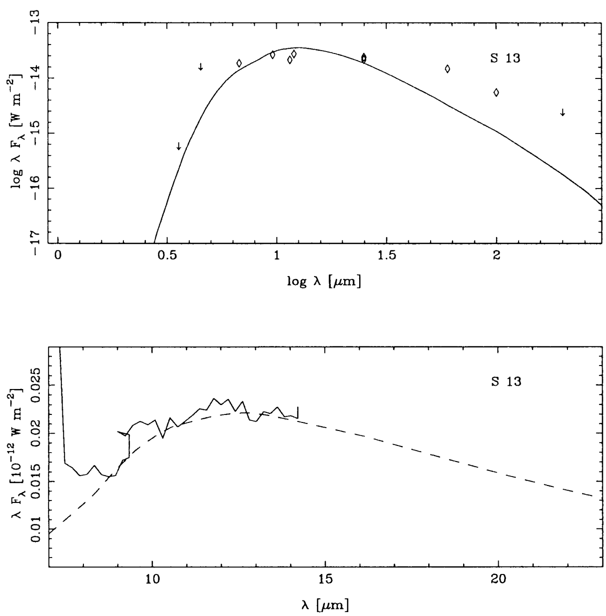

Figure 2. Model fit to the mid-IR and CAM-CVF spectra of the unusual object IRAS 00492−7408 (see text).

SED, a model is plotted for a 5 300 $L_\odot$ star with $\dot{M} = 8 \times 10^{-5} M_\odot\,yr^{-1}$ and 100% amorphous carbon dust (Fig. 2). The model is fine up to the mid-IR but is clearly deviant at longer wavelengths. The nature of the source remains unclear. A possibility is a nature similar to HD 101584. This object is interpreted as a post-AGB star of intermediate mass with a nearby companion that affects the stellar wind (Bakker et al. 1996). HD 101584 shares the featureless, non-variable and very red spectrum with IRAS 00492−7408. Optical spectra taken of some optically visible sources near the ISOCAM position may help us to identify it.

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Discussion

Cannon: Can you give a simple explanation of the physics behind your derivation of mass-loss rates?

Groenewegen: The fundamental quantity derived from the dust radiative transfer model is the optical depth. The conversion from optical depth to a mass-loss rate requires information or assumptions on the opacity of the dust, the dust-to-gas ratio and the expansion velocity of the circumstellar shell.

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