AKARI and Spitzer observations of heavily obscured C-rich AGB/post-AGB stars

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Abstract. We present AKARI/IRC and Spitzer/IRS observations of a selected sample of galactic IRAS sources considered to be heavily obscured AGB/post-AGB stars based on their characteristic IRAS colours. All of them are completely invisible in the optical range but extremely bright in the infrared. Based on AKARI and Spitzer spectroscopy and using DUSTY we are able to determine the dominant chemistry of their circumstellar shells as well as the properties of the dust grains contained in these shells. Most of the sources are found to be C-rich (being the reddest C-rich stars observed so far). We find only molecular absorptions (and no PAH features) such as acetylene (C₂H₂) at 13.7 µm, indicative of an early post-AGB stage. We shortly discuss our findings in the context of stellar evolution during the hidden “transition phase” from AGB stars to Planetary Nebulae.

1. Motivation

Stars with low- and intermediate main-sequence masses (1–8 M☉) evolve along the Asymptotic Giant Branch (AGB) just before they become Planetary Nebulae (PNe). At the end of the AGB phase, these stars experience thermal pulses (TP) and strong mass loss (up to 10⁻⁴–10⁻⁵ M☉yr⁻¹). As a consequence of the strong mass loss, the more massive AGB stars (M>3 M☉) experience a hidden “transition phase” (AGB => PN), in which the surrounding circumstellar envelope (CSE) of dust and gas is optically thick, making these stars completely undetectable in the optical domain but very bright in the IR. Thus, the departure from the AGB occurs while these stars are still heavily obscured by their thick CSEs. In addition, a fraction of this heavily obscured AGB population will be converted into C-rich stars (M<4–5 M☉ at z=0), when the 3rd dredge-up is able to bring freshly produced material to the stellar surface. More massive AGB stars (M>4–5 M☉) will evolve as O-rich (the so-called OH/IR stars) because of the “Hot Bottom Burning” activation, which prevents the carbon star formation (e.g. García-Hernández et al. 2007).

From the observational point of view, TP-AGB stars are found as Mira-like variables with periods of up to 2000 days in the case of OH/IR stars (Jiménez-Esteban et al. 2006) and up to 900 days in the case of “extreme” carbon stars (Kerschbaum et al. 2006). The strong mass loss and pulsation cease when the AGB phase is terminated, and early post-AGB stars are characterized by their
non-variability status. Candidate post-AGB stars can be easily identified by their characteristic IRAS colours and the IRAS two-colour diagram (see Fig.1) is a powerful tool to discriminate between these candidate post-AGB stars and other types of astronomical sources. Thus, heavily obscured post-AGB stars display IRAS \((25–12) \geq 0.0\) (those regions marked as IIIb, IV and V in Fig.1). The obscured “non-variable OH/IR stars” have been positively identified as O-rich post-AGB stars (e.g. Engels 2002). This study was prompted by the remarkable fact that a positive identification for the obscured C-rich post-AGB candidates is still lacking.

![Figure 1](image)

Figure 1. IRAS two-colour diagram displaying the “infrared carbon stars” compiled from the literature by Chen & Shan (2007) (red open circles), the compilation of “extreme carbon stars” from Chen & Shan (2008) (blue crosses), our heavily obscured C-rich AGB/post-AGB stars (magenta squares), and the sample of obscured OH/IR sources (green open triangles) observed also by us with AKARI (Bunzel et al., these proceedings).

2. The sample and infrared observations

Our sample is composed of 5 extremely red IRAS sources identified as candidate post-AGB stars with no optical counterpart taken from the so-called GLMP catalogue (see e.g. García-Lario et al. 1997). These sources were of unknown chemistry and with no detection of OH maser emission, and thus they were expected to be heavily obscured C-rich stars. We observed our sample stars by using the IRC and IRS spectrographs onboard AKARI and Spitzer satellites, respectively.

The AKARI/IRC observations were carried out from 2006-12-08 until 2007-08-14. We obtained long and short spectroscopic exposures by using the observation mode AOT04 for different dispersion elements (NP, SG1, SG2), which give a spectral resolution between 50 and 140 and an almost complete coverage from 1.8 to 12.9 \(\mu m\) (in one case we used LG2 that covers the 17.5–25.7 \(\mu m\) region). The data reduction was done with the IRC Spectroscopy Toolkit Version 20080528. A few sources were reduced by applying the short exposure mode of the data reduction pipeline, since all long exposure frames were saturated.
The Spitzer spectral data were taken with IRS under a General Observer program (#30258, PI, P. García-Lario). Spitzer/IRS spectra of our sample stars were obtained by using the Short-High (SH: 9.9–19.6 \(\mu\)m; R~600) module. The Spitzer spectra were reduced with the help of the Spitzer IRS Custom Extractor (SPICE) and SMART (see e.g. García-Hernández et al. 2009, in press).

3. SEDs and DUSTY modelling

Spectral energy distributions (SEDs) of all 5 sources were constructed with the reduced AKARI/IRC and Spitzer/IRS spectra (see Fig. 2). For all sources (except IRAS15408) we obtained almost featureless spectra (e.g. typical of carbonaceous grains) with a weak 9–12 \(\mu\)m depression (which might be attributed to small amounts of SiC or amorphous silicates) and acetylene (C\(_2\)H\(_2\) at 13.7 \(\mu\)m) absorptions (Fig. 2). IRAS15408 is a particular case and it shows the 10 \(\mu\)m absorption feature of amorphous silicates (O-rich) and no C\(_2\)H\(_2\) absorption.

We have determined the dominant chemistry and the properties of the dust grains present in the CSE by fitting DUSTY models (Ivezić & Elitzur 1995) to the observed SEDs. The best fits obtained are shown in Fig. 2 and the derived model parameters from DUSTY are summarized in Table 1. Our modelling confirms the C-rich nature of 4 out of 5 sample stars, containing > 80% of carbonaceous dust. The only exception is IRAS15408 for which we found almost half amorphous silicate and half amorphous carbon dust.

\[^1\] We fixed the temperature of the central star (T\(_{\text{eff}}\)=2500 K), the condensation temperature of the dust (T\(_{\text{dust}}\)=1000 K), and the grain size (a=0.27 \(\mu\)m) because the spectral shapes of the models are not very sensitive to variations of these parameters.
Table 1. Derived model parameters (optical depth at 10 μm and abundances of amorphous carbon, amorphous silicates and SiC) from DUSTY.

| IRAS name  | τ(10μm) | Abundances |
|------------|---------|------------|
|            |         | n_C [%]    | n_sil [%] | n_SiC [%] |
| 09024–5019 | 7       | 90         | 5         | 5         |
| 10194–5625 | 9       | 90         | 5         | 5         |
| 11544–6408 | 6       | 86         | 7         | 7         |
| 13404–6059 | 10      | 80         | 15        | 5         |
| 15408–5657 | 8       | 48         | 52        | 0         |

4. Discussion

It is not completely clear, if these heavily obscured C-rich stars are still pulsating on the AGB or if they have already departed from the AGB, being the C-rich counterparts of the heavily obscured “non-variable OH/IR stars” (O-rich post-AGB stars). The only variability information comes from the IRAS variability index and with the exception of IRAS09024 (with a high 99% probability for variability), all sources are probably not large amplitude variables (with <20% probability for variability), and thus we identify them as heavily obscured C-rich post-AGB stars.

From Fig.1, it is obvious that these sources are the reddest AGB/post-AGB stars studied so far (being even redder than the “extreme” carbon stars previously known). Interestingly, IRAS09024 (probably the unique AGB star in our sample) shows the strongest C_2H_2 absorption (Fig.2). C_2H_2 and other carbon-based molecules are believed to be the building blocks of more complex molecules such as PAHs (e.g. Sloan et al. 2009), which are seen in more evolved (and less obscured) C-rich post-AGB stars and PNe of our Galaxy. Thus, the detection of C_2H_2 in our “non-variable extreme carbon stars” is indicative of an early post-AGB stage because PAHs have not formed yet. We are probably witnessing the evolution of the more massive and obscured C-rich AGB/post-AGB stars of our Galaxy.

Acknowledgments. This research is based on observations with AKARI and Spitzer, a JAXA project with the participation of ESA and a NASA’s Great Observatories Program, respectively.

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