AKARI/IRC observations of heavily obscured oxygen-rich AGB and post-AGB stars

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Abstract. We present AKARI/IRC observations of a sample of six extremely red IRAS sources, of which three are variable OH/IR stars and the rest are early post-AGB stars. The OH/IR stars show a red continuum with the expected strong 10 µm silicate absorption feature, while the post-AGB stars show an even redder continuum accompanied with a comparably weak silicate absorption. We modelled the spectral energy distributions with DUSTY. While for the OH/IR stars a reasonable fit can be obtained with almost pure silicate dust, the post-AGB stars require a mixture of silicate and carbon-rich dust. We assume that in the latter objects the inner dust shell is carbon-rich, while the outer shells are still oxygen-rich.

1. Introduction

During the latest phases of stellar evolution on the Asymptotic Giant Branch (AGB), stars experience high mass loss rates of up to $10^{-4} \ M_\odot$/yr and form dense optically thick circumstellar envelopes (CSE) made up of dust and gas. The stars are pulsating as Mira variables but with much longer periods. They are completely obscured and discovered by OH maser or infrared surveys as OH/IR stars or ”extreme” carbon stars. At the tip of the AGB, when except of the core mass, all mass has been lost, pulsation ceases and the remnant CSE dissipates into the interstellar medium. The departure from the AGB occurs, while the stars (the remnant cores) are still completely hidden.

We observed six oxygen-rich candidates selected on the base of their maser properties and their IRAS infrared colors, to study details of the AGB - post-AGB transition phase. All stars selected have OH or H\textsubscript{2}O masers. Three stars (IRAS 11549−6225, 14104−5819, OH 30.7+0.4) are pulsating variables still on the AGB, while the others (OH 31.0+0.0, IRAS 19134+2131, OH 77.9+0.2) are post-AGB candidates.

2. Observations and data reduction

The AKARI [Murakami et al. 2007] observations were made between 2006-10-05 and 2007-05-17. We used the Infrared Camera (IRC) (Onaka et al. 2007) with the spectroscopic observation mode AOT 04. We obtained long and short exposed spectroscopic observations of dispersion elements NP, SG1 and 2, and in
one case LG2. The data reduction was made with the IRC Spectroscopy Toolkit Version 20080528 (Ohyama et al. 2007). For some sources we encountered saturation effects, so that the short exposures were used. The spectra extracted by the pipeline from the calibrated images are shown in Figures 1 and 2. We found that the calibration was unreliable at the edges of each band and we confined therefore the nominal wavelength ranges: NP (2.1–4.9\,\mu m), SG1 (5.4–8.0\,\mu m), SG2 (8.0–12.1\,\mu m) and LG2 (18.7–25.5\,\mu m). A residual calibration error between the spectra of dispersion elements NP and SG1 was found, probably because of insufficient sky background removal in the crowded fields. The NP wavelength range was therefore scaled to match the SG1 range. Additional Spitzer spectra were taken by us under the GO program #30258 (García-Hernández et al., these proceedings). We use data from these spectra to cover the 13–18\,\mu m range.

All six sources, AGB as well as post-AGB stars, show a clearly visible 10\,\mu m-feature of amorphous silicates, which are expected to be the major dust component of O-rich circumstellar shells. The mid-infrared continua of the post-AGB stars are much redder than those of the AGB stars, indicating the presence of a more obscured shell. None of them was found on the NP images at $\lambda < 5\,\mu m$. Surprisingly, their 10\,\mu m-feature is weaker than for the AGB stars.

3. Modelling the spectral energy distributions

To characterize the obtained SEDs we applied model calculations using DUSTY, which is a 1D-radiation transport code for dusty environments (Ivezić et al. 1999). DUSTY simulates a radiating source inside of a dust shell both in spherical and planar geometry. To be able to compare the models between the different
stars and to order them by their evolutionary stage, we fixed as much model parameters as possible. Suh (1999) proposed to use the optical depth as the only variable parameter, assuming that the progress on the AGB evolutionary track depends only on the amount of mass it has recently lost. We found that with this assumption it is not possible to model the transition from AGB to post-AGB. Apparently also the dust chemistry is changing during the transition. Therefore, as a second parameter the chemical composition of the dust had to be changed as well. All other parameters were fixed and set to the following values to create a 'standard model': Effective temperature $T_{\text{eff}} = 2500$ K, dust condensation temperature $T_d = 1000$ K, a single grain size of 0.27 $\mu$m, and a density distribution obtained from the hydrodynamic calculation option given in the code. The optical constants of the dust were taken from Suh (1999) for amorphous silicates and from Suh (2000) for amorphous carbon dust.

| Source          | Class. | $\tau_{10\mu m}$ | $\tau_{10\mu m}$ | $\tau_{10\mu m}$ | $\eta_{\text{sil}}$ | $\eta_{C}$ | $T_{\text{outer}}$ |
|-----------------|--------|------------------|------------------|------------------|---------------------|-----------|------------------|
| IRAS 14104−5819 | AGB    | 9                | —                | —                | 90                  | 10        | —                |
| IRAS 11549−6225 | AGB    | 16               | —                | —                | 86                  | 14        | —                |
| OH 30.7+0.4     | AGB    | 18               | —                | —                | 97                  | 03        | —                |
| OH 77.9+0.2     | post-AGB | —               | 0.3              | 4                | 26                  | 74        | 160              |
| IRAS 19134+2131 | post-AGB | —               | 1                | 5                | 37                  | 63        | 200              |
| OH 31.0+0.0     | post-AGB | —               | 5                | 5                | 40                  | 60        | 140              |

Table 1. Varied model parameters for investigated AGB and post-AGB stars

For the three AGB stars we created a silicate-only DUSTY model varying the optical depth until the best fit was obtained for the strength of the 10$\mu$m-feature and for the continuum. The remaining differences between observed SED and model fit were reduced by adding amorphous carbon dust and readjusting the optical depth. Figure 1 shows the final fits of the three AGB stars. Table 1 (Class: AGB) gives the associated model parameters.

For the three post-AGB stars we assumed that the mass loss has recently decreased strongly and that the inner part of the shell is composed of amorphous carbon. A second outer shell was assumed to contain a mixture of amorphous silicate and carbon grains. The inner shell was modelled as a spherical shell, with an inner dust condensation temperature of 1000 K and a density distribution derived from hydrodynamical calculation. The output spectrum was used as input to the outer shell modelled in slab geometry. In this configuration the model mimics a carbon star seen through a screen containing silicate dust.

Table 1 (Class: post-AGB) gives for the best fits the values of the model parameters varied. $\tau_{10\mu m}$ gives the optical depths of the inner C-rich shell and the outer slab of mixed chemistry. $T_{\text{outer}}$ is the temperature at the inner border of the slab. $\eta_{\text{sil}}$ and $\eta_{C}$ are the fractions of silicate and amorphous carbon dust. Figure 2 shows the final fits of the post-AGB stars.

4. Discussion

The AKARI spectra clearly show that the mid-infrared spectra of stars departing from the AGB are much redder than those of pulsating OH/IR stars. This is
Figure 2. AKARI spectra (black) with DUSTY model fits (red) for the post-AGB stars. The 13–18\(\mu\)m gaps were filled with Spitzer spectra (blue). The spectrum of OH 77.9+0.2 is contaminated for \(\lambda < 6\mu m\).

not unexpected as the post-AGB stars should be surrounded by a remnant shell representing for a given mass the highest mass loss rate achievable on the AGB. Using pure silicate dust, high optical depths are needed to fit the red continua of the post-AGB stars. Such models, however, predict a much stronger 10\(\mu\)m absorption feature than observed. By assuming that the red continuum is made by carbon-rich dust and the 10\(\mu\)m absorption is due to additional silicate-rich dust in the outer shell, a reasonable fit can be found.

As all the post-AGB stars still host masers in an oxygen-rich environment, the conversion of the inner shell chemistry cannot have happened more than a few thousand years ago. All stars must have experienced the conversion into a carbon star, while they were losing the last amounts of matter of their envelopes before exposing their cores.

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