The transition from AGB to post-AGB evolution as observed by AKARI and Spitzer

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Abstract. The AKARI and Spitzer satellites provided an unique opportunity to observe a variety of stars, which are considered as departing from the Asymptotic Giant Branch (AGB) and have started their post-AGB evolution recently. Most of these stars are absent optically and are bright in the mid-IR wavelength range. Spectra of close to 200 objects have been obtained. For all of them the 1–60\,µm spectral energy distribution has been constructed using photometric data from various surveys. We report here on the results of Spitzer observations of 88 IRAS selected post-AGB candidates and discuss them in comparison to the results of the AKARI observations of post-AGB candidates reported elsewhere in these proceedings. The dust compositions can be divided broadly in oxygen- and carbon-rich types, but a variety of intermediate types have been found. Among the oxygen-rich stars amorphous dust prevails, but a few sources show emission features from crystalline dust. The spectra from carbon-rich shells may be completely featureless, may show emission features from PAHs or a molecular absorption line from C\textsubscript{2}H\textsubscript{2}. We found also sources with a neon emission line at 12.8\,µm. More than a third of all sources show a near-infrared excess at λ < 5\,µm and almost all of them show evidence of C-rich dust in their shells. We postulate that the emerging post-AGB wind after the end of AGB evolution contains always carbon-rich dust irrespective of the chemistry of the former AGB star.

1. The hidden phase of post-AGB evolution

At the end of the stellar evolution on the Asymptotic Giant Branch (AGB) stars loose copious amounts of mass, which build up a circumstellar dust and gas shell hiding the star from optical view almost completely. Stars departing from the AGB and evolving towards the Planetary Nebula (PN) phase are therefore difficult to observe optically. It was found that a number of Proto-Planetary Nebulae (cf. in CRL 2688; Sahai et al.\textsuperscript{1998}) show high velocity bipolar outflows which are connected to a fast, axially-symmetric wind, which is taking the place of the much slower, spherically-symmetric wind operating on the AGB. The physical mechanism responsible for the change of the spherically-symmetric to an axially-symmetric, or in some cases point-symmetric wind is strongly debated. Observations of masers in transition objects often reveal that this morphological change takes place at a very early stage in the post-AGB phase (Sahai et al.\textsuperscript{1999}; Zijlstra et al.\textsuperscript{2001}), while the star is still heavily obscured in the optical range.
Non-variable OH/IR stars (Engels 2002) and IRAS selected infrared sources with extreme red colors (Suárez et al. 2006) are candidates for such hidden post-AGB stars. Their study has made progress only in the last decade due to the improved observation capabilities in the infrared at $\lambda > 5\mu m$ by space-based observatories. In the mid-infrared the emission emerges from the circumstellar envelopes (CSE) and their gas and dust composition has to be used to infer on the evolutionary state of the underlying star and the mass loss process.

The spectroscopic observations with ISO showed that strong changes occur in the infrared SEDs during total obscuration (García-Lario & Perea Calderón 2003). In the case of the C-rich AGB stars the molecular $\text{C}_2\text{H}_2$ absorption and the amorphous SiC emission feature at 11.3$\mu m$ suddenly disappear and become substituted by a broad plateau of emission from 11 to 15$\mu m$ due to hydrogenated PAHs. These are later replaced by de-hydrogenated, narrow PAH features at 3.3, 6.2, 7.7, 8.6 and 11.3$\mu m$, which are also observed in more evolved C-rich PNe. In O-rich AGB stars the strong silicate absorption features at 9.7 and 18$\mu m$ disappear and are replaced by several prominent crystalline silicate emission features in the 10 − 40$\mu m$ wavelength range. A mixed chemistry is found also in a few sources, but it is not clear whether it is associated to late thermal pulses at the end of the AGB phase and/or to the preservation of O-rich material in long-lived circumstellar disks. Globally considered, there seems to be a continuous evolution from an amorphous (aliphatic) to crystalline (aromatic) organization of molecules in the dust grains both in the C-rich and the O-rich sequence, which is still unexplained (García-Lario 2006).

2. AKARI and Spitzer observations of hidden post-AGB stars

The AKARI satellite (Murakami et al. 2007) and the Spitzer Space Telescope (Werner et al. 2004) offered the possibility to extend the ISO observations to larger and better selected samples of hidden post-AGB stars. Observations between 2 and 26$\mu m$ were possible with the Infrared Camera (IRC) (Onaka et al. 2007) on board of AKARI, and in the range $5 < \lambda < 37\mu m$ with the InfraRed Spectrograph (IRS) (Houck et al. 2004) on board of Spitzer. A first sample studied consisted of obscured OH/IR sources with associated radio continuum emission. The Spitzer spectra allowed a re-classification of the sources in AGB stars and post-AGB stars close to the formation of PNs (García-Hernández et al. 2007). The new samples observed, consisted of extremely red IRAS sources from the GLMP catalog (García-Lario 1992), and of OH/IR stars selected on the base of their appearance in the Spitzer GLIMPSE survey. The 2MASS and GLIMPSE surveys were used to identify OH/IR stars with near-infrared excesses indicative for a post-AGB nature of these sources (Engels 2007).

2.1. AKARI observations of OH/IR stars and extreme carbon stars

The SEDs of obscured variable OH/IR stars peak in the wavelength range 5 − 30$\mu m$ and show a strong 10$\mu m$ and a weaker 18$\mu m$ absorption feature. These SEDs can be modeled in detail using cold dust opacity functions of amorphous silicates (Suh & Kim 2002). This is confirmed by the results we obtained from the modeling of the AKARI spectra of the infrared sources classified as AGB stars (Bunzel et al., these proceedings). The carbon-rich cousins of OH/IR stars
are the 'extreme carbon stars' (extreme in terms of infrared color). The dust features seen in their SEDs are usually weak, but they often show a molecular absorption line at 13.7\,\mu m attributed to C$_2$H$_2$. The extreme carbon stars are rarer than OH/IR stars and harder to classify because of the lack of prominent dust features and radio maser emission. Before AKARI, the most extreme carbon stars were studied by Volk et al. (2000), who modeled the SEDs successfully with amorphous carbon dust. They found the evolutionary status compatible with the end phase of AGB evolution. The extreme carbon stars, we identified among the infrared sources observed with AKARI, are the reddest found so far. The spectra of all of them (except IRAS 15408-5657) could be modeled with amorphous carbon dust ($\eta_C > 80\%$), with minor contributions of SiC and silicates. Because of a low IRAS variability index we suspect that part of them could have started post-AGB evolution already (García-Hernández et al., these proceedings).

IRAS 15408-5657 is a peculiar source, in the sense that its silicate absorption features are too weak for its red continuum. The model SED required a mixture of carbon and silicate dust in almost equal parts to obtain the appropriate strength of the silicate band. Its low IRAS variability index makes it a post-AGB candidate. It is unlikely that both dust species spatially coexist, because the underabundant atomic species (C or O) should be locked in CO, and would not be available for dust formation (Ivezić & Elitzur 1995). Thus, the mixed chemistry may indicate the presence of two shells, an inner shell with C-rich dust and an outer one with O-rich dust.
Figure 2. Spitzer 5 $< \lambda < 20\mu m$ spectra of IRAS 18470+0015 (a) and IRAS 11444-6150 (b). Symbols as in Fig. 1. Arrows denote upper limits. IRAS 18470+0015 shows weak features of crystalline silicate dust. All three objects of this type have OH masers. IRAS 11444-6150 is a carbon-rich post-AGB star with a spectrum classified as 'featureless'.

For several sources with silicate absorption features observed by Bunzel et al. with AKARI we had indications for their post-AGB nature beforehand. Either due to the presence of bipolar high-velocity outflows traced by the H$_2$O masers (IRAS 19134+2131, Imai et al. 2004; OH 31.0+0.0 = W43A, Imai et al. 2002), or due to the presence of a near-infrared excess. As for IRAS 15408-5657 the SEDs of these sources could not be modeled by pure amorphous silicate dust, but required a model, where the inner carbon-rich shell is viewed through an outer shell containing 20-40% silicate dust. The results for these post-AGB stars and for IRAS 15408-5657 indicate that for oxygen-rich AGB stars the departure from the AGB marks also a change in dust chemistry. Carbon-rich dust forms in the inner shell, while the silicate-rich dust shell formed on the AGB expands outwards.

2.2. Spitzer observations of the GLMP sample of post-AGB stars

A preliminary evaluation of the Spitzer spectra in the 5 – 20$\mu$m range and the 1 – 60$\mu$m SEDs of 88 IRAS sources from the GLMP catalog confirm the AKARI results and show that the mid-IR spectra are even more diversified than expected. Judged from the IRAS variability index almost all these sources have a chance of $< 50\%$ to be variable and are therefore currently post-AGB stars. Based on the spectra and the 1 – 60$\mu$m SEDs they can be divided into several groups:

- About 45% have strong silicate absorption features and are heavily obscured in the near-infrared. These are former O-rich AGB stars, where the remnant AGB shell dominate the mid-IR spectra.

- Another 15% show the combination of a very red continuum longward of $\lambda = 5\mu m$ and a weak silicate absorption. About two-third of them have a near-infrared excess at $\lambda < 5\mu m$ as it is exemplified in IRAS 18355–0712
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(Fig. 1). These sources are similar to the AKARI observed post-AGB stars, which required a mixed chemistry to model their SEDs.

- Three sources show evidence for the presence of crystalline silicate dust judged from sharp absorption features in the 10µm region. All of them are OH/IR stars with a relatively blue continuum (see Fig. 2a).

- Another 20% show featureless spectra (see IRAS 11444-6150 in Fig. 2b), spectra with C$_2$H$_2$ absorption at 13.7µm or weak carbon dust features. Almost half of them show a near-infrared excess as in IRAS 18355−0712. These objects are probably post-AGB carbon stars with varying degrees of optical depths of their remnant AGB shells and where the objects with a near-infrared excess are the more evolved.

- The remaining objects have (in part strong) near-infrared excesses and show a variety of carbon dust features in their spectra. An example is IRAS 19176+1251, which shows strong PAH features and in addition a NeII 12.8µm emission line, coming probably from material shocked by the stellar wind (Fig. 3). These objects are considered as the most advanced in their post-AGB evolution.

3. Conclusions

Post-AGB evolution starts when almost the complete stellar envelope has been lost by the stellar wind, and the stars are still hidden by their circumstellar envelope. Such stars do not show the AGB typical long-period variability anymore.
The AKARI and Spitzer spectra of such hidden post-AGB stars indicate that the inner part of the CSEs contains carbon-rich dust formed in the post-AGB wind irrespective of the chemistry of the star on the AGB. The silicate absorption features seen in many of the sources may originate from the outer CSE, which is composed mainly by dust of the remnant AGB shell. These conclusions can be probed in those stars, where the remnant AGB shell has been diluted far enough, that observations of the warm dust near the star are possible. Spectroscopy in the $2 - 5 \mu m$ range using the IRC during the AKARI warm phase will therefore be made, to search for C-rich matter in the inner dust shell of those post-AGB stars showing the $10 \mu m$ silicate absorption and a strong near-infrared excess.

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**Question by T. Onaka:** Is there any signature of C-rich material in the NIR spectra of mixed chemistry objects?

**Answer:** Not yet. Only with GLIMPSE covering the $3 < \lambda < 8 \mu m$ wavelength range it was possible to verify that the 2MASS counterparts found for hidden post-AGB stars at $< 3 \mu m$ are not field stars. Objects with confirmed near-infrared excess are currently observed by AKARI between 2 and 5\(\mu m\).

**Question by T. Onaka:** Do silicate dust grains have to have lower temperatures than carbonaceous dust in the outer shell?

**Answer:** This cannot be answered on the base of our DUSTY-based models.