The hidden transition from AGB to post-AGB stars as observed by AKARI

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Abstract: When stars leave the asymptotic giant branch (AGB), they enter the post-AGB stage and are just about to become visible as a planetary nebula (PN). At this stage, their circumstellar shell has lost spherical symmetry and the infrared spectrum of their dusty envelope has changed drastically.

We investigate six sources selected as candidates for stars experiencing the hidden transition from AGB to post-AGB stars. All six sources exhibit oxygen-rich chemistry and were selected by their position in the IRAS two-colour diagram. Three of which still evolve on the AGB, while the other three have already entered the post-AGB stage. Observational data contain AKARI/IRC infrared spectra in the range of 2.1-25.5 µm with data gaps at 4.9-5.4 µm and 12.1-18.7 µm. The 1D radiation transfer code DUSTY was used to apply model fits.

All spectra show a strong 10 µm absorption feature of amorphous silicates indicating the oxygen-rich nature of the sources. Features of crystalline silicates, however, are absent. Beside amorphous silicates DUSTY model calculations require a certain amount of amorphous carbon dust to be present in the circumstellar shells of all investigated AGB as well as post-AGB sources. While the fraction of amorphous carbon does not exceed 15% for DUSTY AGB models, an inner shell composed of pure amorphous carbon dust surrounded by an outer shell of mixed chemistry had to be assumed for DUSTY post-AGB models.

The transition of oxygen-rich and carbon-rich AGB stars to the post-AGB stage may no longer be considered to proceed separately, since oxygen-rich AGB stars can still be converted to carbon stars during the very final phase of AGB evolution.

Keywords: AGB and post-AGB stars, stellar evolution, circumstellar matter, infrared spectra

1. Introduction

When intermediate mass stars experience their final nuclear burning stage, they have reached the asymptotic giant branch (AGB) in the Hertzsprung-Russell diagram (HRD). Here they lose a major part of its mass and exhibit much higher luminosities than their main-sequence progenitors. It is the mass-loss process, which leads to the formation of stellar winds causing the total obscuration of the central star (at least for M > 3 M⊙) in the optical wavelength range. For an astronomically short while, the star is observable only in the infrared, since a circumstellar envelope (CSE) consisting of the recently ejected matter absorbs all the optical radiation emerging from the star and reemits it at longer wavelengths. The composition of this recently ejected matter made up of gas and dust sensitively depends on the C/O ratio of the CSE. Originally, the abundance of oxygen in an AGB CSE exceeds the abundance of carbon, so that dust, which is able to form in this relatively cool and dense environment, primarily consists of amorphous silicates. This is due to the fact that, under the assumption of a local thermodynamical equilibrium (LTE), the less abundant species is completely locked in the CO molecule, since this atomic compound has the highest binding energy in an LTE environment (e.g. Salpeter, 1974).

When the star has lost its entire stellar envelope, the mass-loss process stops and the star reappears in the optical.

As a star evolves along the AGB, it is supposed to move from the lower left to the upper right part of the IRAS two-colour diagram (see Fig.1) as dynamical pulsations start and the star becomes variable. The meaning of the labelled regions is described by van der Veen & Habing (1988). Sources located in region IV are supposed to experience the hidden transition from AGB to post-AGB stars. Our sample (see Tab.1) consists of three oxygen-rich AGB stars, of which two (IRAS 11549-6225 and IRAS 18432-0149) are located in region IV of the two-colour diagram, which is most probably the region, where AGB evolution ends. Both of them show a high variability index indicating that dynamical pulsations have not stopped, yet. The variability index of IRAS 14104-5819 is low, however, this index...
source is located in region IIIb, where regular AGB stars are expected to be found. All three sample sources show double-peaked OH maser emission and no optical counterpart.

The three post-AGB stars of our sample have moved a bit further along the proposed evolutionary track in the two-colour diagram. For none of them an optical counterpart was detected, so that their low variability index (if observed) indicates that dynamical pulsations have recently stopped. IRAS 18450-0148 and 19134+2131 belong to a small group of objects referred to as the “water fountains” (Likkil et al., 1992). High-velocity H$_2$O masers of roughly 100 km/s, originating from an environment of high temperatures and hydrogen densities, were detected from radio observations of these sources (Imai et al. (2002); Imai et al. (2004)), implying that they must be located in the collimated bipolar outflows of a post-AGB star. For IRAS 20266+3856 maser emission was detected only from the OH molecule showing a regular double-peaked maser spectrum.

3. AKARI observations

The observations with the AKARI satellite (Murakami et al., 2007) were made between May 10, 2006 and May 17, 2007. We used the Infrared Camera (IRC) (Onaka et al., 2007) with the spectroscopic observation mode AOT04. Long and short exposed spectroscopic observations were obtained with the dispersion elements NP (1.8-5.2 µm), SG1 (5.4-8.4 µm), SG2 (7.5-12.9 µm), and in two cases LG2 (17.5-25.7 µm). The dispersion varied from 0.06 µm/pix at 3.5 µm to 0.175 µm/pix at 25 µm. The data reduction was made with the IRC Spectroscopy Toolkit Version 20080528 (Ohyama et al., 2007). For all sources except for IRAS 19134+2131 and IRAS 20266+3856, where spectroscopic data could be obtained only from the MIR-S channel, we encountered saturation effects in the long exposures of one or more dispersion elements. In such cases we extracted the spectra from the short exposures. If the calibration was considered unreliable, we removed data at the edges of the dispersion element wavelength ranges. Finally we shifted the flux calibration of the different wavelength ranges relative to the SG1 spectrum. The resulting spectra are plotted in Fig. 2 and 3. Note that the wavelength range 13-18 µm was not covered by AKARI due to a malfunction of the LG1 dispersion element.

4. Infrared spectra and DUSTY models

For all six sources of our sample we found a prominent 10 µm absorption feature, indicating the oxygen-rich nature of the sources. While the three AGB stars show a certain amount of near-infrared flux, all three post-AGB stars are totally obscured in the near-infrared region. Their spectra could not be found on NP spectroscopic images. The 10 µm absorption feature of the latter ones seems to be located on the ascending blue part of the Planck curve, while for the three regular AGB stars, the 10 µm absorption feature is located close to the maximum. This is already an indication of the relatively cool dust around the post-AGB sources compared to the higher dust temperatures at the inner CSE boundary of the regular AGB stars. For applying DUSTY model calculations to fit the spectra of the regular AGB stars, the influence of all model parameters was tested. Initial parameter values were taken from the literature. These were varied until a ‘standard model’ was found, in which all parameters with a relatively small influence on the model spectrum were fixed to values, which provide the best fit for all three sources. As a result of our obtained standard model, the temperature of the central star was set to $T_*$ = 2500 K, the dust temperature on the inner boundary of the dust shell was set to $T_{\text{dust}} = 1000 K$, a single dust grain size distribution of $a = 0.27$ µm was used and the density profile was calculated via an analytical radiatively driven winds solution, which is implemented in DUSTY and applies a full hydrodynamics calculation in a spherical symmetry. The only variable parameters in our AGB models are the optical depth at 10 µm and the composition of the dust. The optical depth was varied until a good fit for the 10 µm absorption feature was obtained. However, with a pure-silicate dust composition no good fit could be obtained. Thus, an admixture of the most common dust for C-rich AGB CSEs, amorphous carbon dust, was added and increased until a good fit was obtained. AKARI/IRC spectra

![Image](image_url)
as well as obtained final DUSTY models for all three AGB stars of our sample are displayed in Fig. 2. Derived values of the varied model parameters are given in Tab. 2.

Using our standard model, no good fit for the spectra of the three post-AGB stars of our sample was found. Even under the assumption of very low dust temperatures, the extreme redness of the spectra could not be explained. To reproduce this redness, another type of model had to be invented. Thus, we applied model calculations for an inner C-rich shell with standard-model parameters, consisting purely of amorphous carbon dust, and used the resulting model spectrum as an input to an outer shell of mixed chemistry modelled in slab geometry. In this configuration the model mimics a carbon star seen through a screen consisting of a mixed dust composition. AKARI/IRC spectra as well as obtained final DUSTY models for all three post-AGB stars of our sample are displayed in Fig. 3. Derived values of the varied model parameters are given in Tab. 3. The temperature for the outer shell is much lower than for the inner one, since its distance to the central radiation source is much larger and its density has decreased due to expansion of the shell. It is conspicuous that the outer shell still seems to contain more C-rich than O-rich material.

5. Implications on the final stage of AGB evolution

Model calculations presented in the previous section suggest a certain amount of carbonaceous dust grains to be present in all of the observed sources. This is an astonishing result, since O-rich and C-rich AGB stars were up to now believed to evolve separately from that moment on the AGB, when a thermal pulse makes the C/O ratio of the stellar envelope exceed unity. Our model calculations, requiring the inner CSE layers of O-rich post-AGB stars to consist of C-rich dust, indicate that, even if the O-rich chemistry survives all thermal pulses at the end of AGB evolution, a significant amount of carbonaceous dust grains forms in the inner CSE. The origin of this C-rich dust is so far unknown. In the following, we describe two scenarios we consider to explain this C-rich inner shell.

The first scenario (see Fig.4) is a cessation of the hot bottom burning (HBB) at the end of AGB evolution. HBB prevents massive AGB stars, which are all O-rich, from being converted to carbon stars. Their convective envelope penetrates the hydrogen-burning shell, so that C-rich material, which was dredged up into the envelope during a thermal pulse, is being converted into nitrogen via the CNO cycle. Thus, the abundance of carbon in the stellar envelope is prevented from outnumbering the abundance of oxygen. However, as the star evolves along the AGB, it loses huge parts of its stellar envelope, what leads to a decrease in temperature at the bottom of the envelope, where HBB takes place. This might cause the HBB to stop at some point, when the convection zone is no longer able to penetrate the hydrogen-burning shell. Subsequent final thermal pulses would now be able to change the chemistry of the remaining stellar envelope and C-rich dust could...
be produced after the next mass ejection. If this happens just before the convective envelope is totally lost and AGB evolution ends, the inner part of the remnant CSE would be C-rich, while the outer parts are still O-rich.

The second scenario (see Fig. 5) is that the CSE of a massive AGB star initially remains O-rich after the whole stellar envelope was released. A subsequent ejection of the remnant hydrogen- and helium-burning shells as well as the intershell zone, might form the inner part of the CSE, which would then be made up of C-rich material. For a short period of time the star will resemble our model made up of an inner C-rich shell and an outer O-rich (or mixed) shell.

These two scenarios would cause the formation of a geometrically thin C-rich layer at the inner edge of the outflowing remnant CSE. Although the inner C-rich shell might be thin compared to the outer O-rich shell, it dramatically affects the spectral energy distribution of the star, since its density is much higher than that of the dissipated outer shell.

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References


