# Spitzer/IRS survey of heavily obscured planetary nebula precursors

D. A. García-Hernández[1], J. V. Perea-Calderón[2], D. Engels[3], and P. García-Lario[4]

[1] W. J. McDonald Observatory. The University of Texas at Austin. 1 University Station, C1400. Austin, TX 78712−0259, USA agarcia@astro.as.utexas.edu
[2] European Space Astronomy Centre, INSA S. A., P.O. Box 78, 28691 Villanueva de la Cañada, Madrid, Spain Jose.Perea@sciops.esa.int
[3] Hamburger Sternwarte, Universität Hamburg, Gojenbergsweg 112, 21029 Hamburg, Germany dengels@hs.uni-hamburg.de
[4] Herschel Science Centre. European Space Astronomy Centre, Research and Scientific Support Department of ESA. P.O. Box 78, 28691 Villanueva de la Cañada, Madrid, Spain Pedro.Garcia-Lario@sciops.esa.int

**Summary.** We present the first results of a Spitzer/IRS survey carried out on a large sample (∼80) of galactic IRAS sources recently identified by us as heavily obscured planetary nebula (PN) precursors based on their characteristic IRAS colors. Most of them are invisible in the optical and extremely bright in the infrared, but very little is known from the spectroscopic point of view. Here we present the qualitative analysis of the Spitzer/IRS spectra (∼5−37 $\mu$m) obtained for 41 sources in our sample. We have determined the dominant chemistry of the circumstellar shells (O-rich vs. C-rich) as well as the nature of the dust grains (amorphous vs. crystalline) for most of the stars in this subsample (41). We identify heavily obscured PN precursors (both with C-rich and O-rich dust shells) at the precise evolutionary stage where the transition from amorphous (aliphatic) to crystalline (aromatic) dust structure is taking place, as well as a new young infrared PN. Our observations constitute an important step forward in improving our understanding of the crucial processes occurring during the "hidden phase" of the AGB to PN evolution.

**Key words:** stars: AGB and post-AGB; circumstellar matter; dust, extinction; planetary nebulae: general; infrared: stars

## 1 Motivation

Low- and intermediate-mass (1–8 $M_\odot$) stars end their evolution on the Asymptotic Giant Branch (AGB) with a strong increase of the mass loss rate, which leads to the formation of a circumstellar envelope of dust and gas. The actual departure from the AGB usually occurs while the circumstellar shell is optically thick and the stars are only detectable at infrared wavelengths. The high mass loss rates then drop rapidly and the circumstellar shell moves outwards. Later in the post-AGB phase the central star reappears again, while the diluted remnant shell remains detectable as a far-infrared excess in the spectral energy distribution (SED).

Current observational knowledge on the post-AGB phase is based on the discovery of about hundred post-AGB stars in the last 20 years. They were mostly found as optically bright stars having an infrared excess in the IRAS bands and presenting therefore a characteristic double-peaked SED ([9, 10] and references therein). However, these post-AGB stars may be representative only of the low-mass (1–2 $M_{\odot}$) population of these stars in the Galaxy, as their high-latitude galactic distribution seems to confirm. Since low-mass post-AGB stars are expected to evolve more slowly, they are more easily detectable in optical surveys. When they reappear in the optical, they usually still show an intermediate spectral type in their way to become hot central stars of Planetary Nebulae (PNe). In the most extreme cases, these low mass stars may never experience a phase of total obscuration. In contrast, higher mass AGB stars (above 2 $M_{\odot}$), which are expected to evolve very fast[5], may have systematically escaped detection in past optical surveys. Post-AGB transition times are for them too short to dilute the remnant shell significantly and they may remain hidden during the whole AGB-PN transition. At present, very little is known about this population of more massive, heavily obscured planetary nebula precursors.

The study of the hidden post-AGB phase is in particular relevant for stellar evolution models, because fundamental evolutionary processes take apparently place while stars are in this short evolutionary phase. Radical changes in the dominant chemistry of the central star can take place very late in the AGB as a consequence of the dredge-up of processed material to the stellar surface. In some cases this chemical transition occurs only at the very end of the AGB during the last few thermal pulses when the star is already completely invisible in the optical, or even in the early post-AGB phase. A feature which is also generally observed in the few transition sources studied with ISO is a radical change in the dust grain internal structure which seems to turn from amorphous (aliphatic) to crystalline (aromatic) as a consequence of physical processes which are not yet well understood [5]. In addition, it is also well known that fast bipolar outflows can develop during this short transition phase modifying the overall morphology of the resulting PN. In order to understand the whole transition process for the complete mass-range of former AGB stars, we have started a Spitzer program devoted to characterize the infrared properties of the galactic population of heavily obscured transition sources (AGB-PN) not previously studied. Here we present the first results and a qualitative analysis of the Spitzer/IRS spectra (e.g. dominant chemistry, dust composition, identification of new young PNe and peculiar sources) for 41 heavily obscured planetary nebula precursors.

## 2 The sample of heavily obscured PN precursors

We compiled a comprehensive list of galactic heavily obscured IRAS sources with infrared colors (as quoted in the IRAS Point Source Catalogue) similar to those of known post-AGB stars and PNe from the GLMP catalogue [4], and thus, identified by us as heavily obscured planetary nebula precursors. The target list represents

[5] The transition time required for an AGB star to become a PN depends mainly on the progenitor mass, ranging from a few hundred yrs for the most massive ($M>4$ $M_{\odot}$) progenitors, to several thousand yrs for lower mass progenitors (e.g. [2])

a complete flux-limited sample of ∼80 hidden post-AGB candidates. The size of the sample is largely determined by our goal to be as unbiased as possible by the selection and to ensure that it covers the transition phase uniformly for the full range of AGB progenitor masses involved.

The sources in our sample do not show any optical counterpart and many of them are also obscured at near infrared wavelengths. Most of them have never been observed before in the infrared domain with spectroscopic techniques. Our sample is composed by ∼40 non-variable OH/IR stars (i.e. most-probably O-rich) and ∼40 non-variable sources of previously unknown chemistry (in some cases OH maser detection was tried and it was not successful; a fraction could be heavily obscured C-rich post-AGB stars). The non-variability status for these sources is deduced from the IRAS variability index and suggests that they have already departed from the AGB phase. For comparison purposes, we also included a few known young PNe and variable thermally pulsing (TP) AGB stars completing a final sample of 88 sources.

Here we present the first results of our Spitzer program for 41 heavily obscured PN precursors in our sample. This subsample contains 9 non-variable OH/IR stars, 28 sources of previously unknown chemistry, one young PNe and 3 variable OH/IR stars (i.e. TP-AGB stars).

## 3 The Spitzer observations and data reduction

The Spitzer/IRS spectra of the 41 sources in our sample presented here were taken between August 2006 and May 2007, in the 5.2−37.2 $\mu$m range, using, when possible, the Short-Low (64<R<128 SL; 5.2−14.5 $\mu$m), Short-High (SH; 9.9−19.6 $\mu$m) and Long-High (LH; 18.7−37.2 $\mu$m) modules (R∼600). Actually, most of the sources are found to be very bright sources for a sensitive instrument like IRS onboard Spitzer, with their SEDs peaking in the 25−40 $\mu$m range. Thus, we achieved a S/N larger than 50 for the 41 sources in the sample over the whole spectral range with just 2 cycles of 6 s in each of the three modules SL, SH, and LH.

We started our analysis from the co-added 2-D flat-fielded images (one for each nod position) resulting from the Spitzer Science Center (SSC) data reduction pipeline version 15.0. First, we used the *irsclean* software package available from the SSC website to clean our images for bad pixels. Then, the spectra for each nod position were extracted from the 2-D images, wavelength and flux calibrated using the Spitzer IRS Custom Extractor (SPICE) with a point source aperture. For the low resolution module SL the two nod positions were previously differenced in order to subtract the sky background. The 1-D spectra were cleaned for bad points, spurious jumps and glitches, smoothed and merged into one final spectrum per module for each source using the Spitzer contributed software SMART[6]. In general, we found a good match between the different nod position spectra except for wavelengths longer than 31−34 $\mu$m and these noisy areas at the red end of the LH module were excluded from our analysis.

[6] SMART was developed by the IRS Team at Cornell University and is available through the Spitzer Science Center at Caltech.

# 4 Results

## 4.1 Dominant chemistry

From the reduced 1D Spitzer/IRS spectra we are able to determine the dominant chemistry (O-rich or C-rich) of the circumstellar shell for most of the 41 sources analyzed here. Some sources show featureless spectra, making very difficult to determine the dominant chemistry of the dust shell from the present observations.

The variety of solid state features (e.g. amorphous silicates, crystalline silicates, PAHs, SiC, etc.) found in the observed spectra is amazing. We found that 6 of the non-variable OH/IR stars show strong O-rich solid state features, as expected from the presence of OH maser emission from their circumstellar shells, while 3 OH/IR stars show featureless spectra. Among the sources in our sample with previously unknown chemistry we find 8 O-rich, 9 C-rich, 8 featureless, a new young IR PN (see Section 4.4) and two bad pointings. Finally, the 3 variable OH/IR stars are O-rich and the previously known young PN shows nebular emission lines, as expected.

The most important result is that we find some stars showing very clearly the precise moment of transition from amorphous (aliphatic) to crystalline (aromatic) dust features. In addition, this is observed in both chemical branches (O-rich and C-rich, see Section 4.5). We also identify a new young PN which is a possible double-dust chemistry (C-rich and O-rich) PN.

## 4.2 O-rich PN precursors

Among the sources clearly identified by us as O-rich PN precursors we find very different strengths of the broad amorphous silicate absorptions at 9.7 and 18 $\mu$m (Figure 1). In addition, the crystalline silicate features at wavelengths longer than 15−20 $\mu$m, generally attributed to olivine and pyroxenes with various mixtures of Mg and Fe (e.g. [7]), are seen (either in absorption or in emission depending on the optical depth of the dust shell at different wavelengths) emerging from the underlying continuum. The crystalline silicate features are detected with a variety of strengths and at slightly different wavelengths from star to star. Interestingly, it seems that the crystalline silicate features are more clearly seen while the broad amorphous silicate absorptions decrease in strength and the complete SED seems to be cooler (Figure 1).

## 4.3 C-rich PN precursors

The C-rich sources identified in our sample display a variety of carbon-based solid state features too (Figure 2). Emission bumps at 11−15 and 15−20 $\mu$m and sometimes strong broad emission features centered at 21, 26 and 30 $\mu$m are seen in some sample stars. In addition, a few sample sources also show the "classical" set of unidentified infrared (UIR) features at 6.2, 7.7, 8.6 and 11.3 $\mu$m and that are generally attributed to PAHs. As in the case of the O-rich sources, it seems that the 11−15 and 15−20 $\mu$m emission bumps disappear while the PAH features emerge at shorter wavelengths (Figure 2).

On the other hand, we found 5 C-rich sources displaying $C_2H_2$ absorption at 13.7 $\mu$m and other molecular absorptions from carbon-based molecules such as HCN,

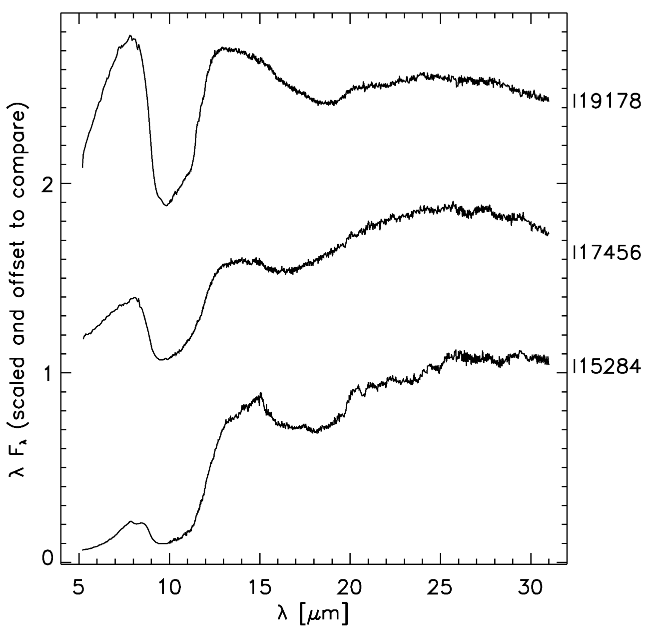


**Fig. 1.** Spitzer/IRS spectra of some O-rich PN precursors in our sample. The spectra are shown (from top to bottom) according to the decreasing strength of the amorphous silicate absorption features at 9.7 and 18 $\mu$m. The crystalline silicate features are detected as sharp peak features that appear either in absorption or in emission at wavelengths longer than 15−20 $\mu$m (see text).

$C_4H_2$ and $C_6H_2$ and that are known to be the building blocks of more complex molecules such as PAHs. Interestingly, benzene ($C_6H_6$) is clearly detected in one of the sample stars. Only two other detections of benzene by [3] in CRL 618 -tentative- and [1] in SMP LMC 11 have been reported. Thus, our detection of benzene represents the first clear detection of this molecule in post-AGB stars of our Galaxy (García-Hernández et al., in preparation).

### 4.4 Young PNe

After the inspection of our Spitzer/IRS spectra we found two young PNe (I14079 and I19176) as indicated by the detection of nebular emission lines (e.g., [Ar II], [Ar III], [Ne II], [S III], etc.) overimposed to the dust continuum (Figure 3). I14079 is a poorly known young and dusty PN. We find that it is O-rich showing amorphous silicate emission at 9.7 $\mu$m together with crystalline silicates emission at longer wavelengths. However, we identify for the first time to I19176 as a new young infrared PN with a possible double-dust chemistry (O-rich and C-rich). I19176 display crystalline silicates in emission in the 9−13 $\mu$m spectral range (and also at longer wavelengths) together with an intriguing 6.3 $\mu$m emission feature. We note that a 6.4 $\mu$m feature

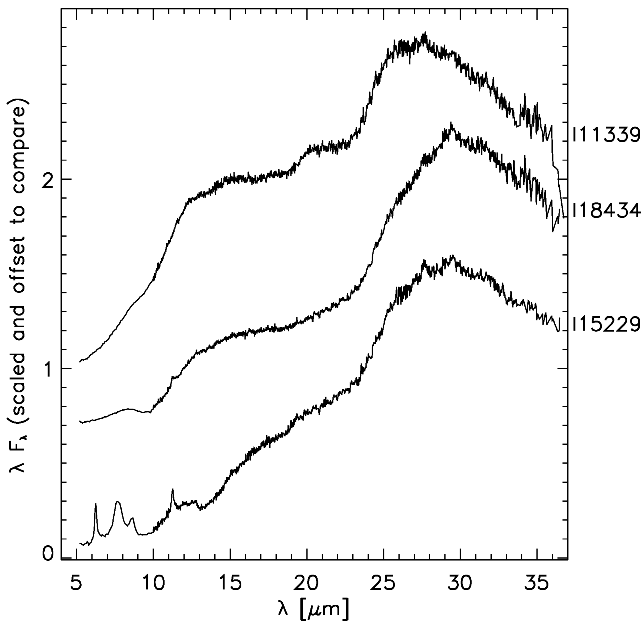


**Fig. 2.** Spitzer/IRS spectra of some C-rich PN precursors in our sample. The spectra are shown (from top to bottom) according to the decreasing strength of the 11−15 and 15−20 $\mu$m emission bumps (see text).

has been attributed to C-C stretch transitions in extremely H-deficient carbonaceous grains (e.g., Abell 78; [6]).

### 4.5 O-rich and C-rich transition sources

The most surprising result has been the first detection of heavily obscured O-rich PN precursors showing the evolution of the dust features at the precise moment when the transition from amorphous to crystalline dust structure is taking place. At present, two O-rich PN precursors have been identified out of the 41 sources analyzed. In these peculiar sources, the crystalline silicate features are detected in emission inside the broad amorphous silicate absorptions at 9.7 and 18 $\mu$m. A more detailed analysis of these unique post-AGB stars will be presented in a forthcoming paper (García-Hernández et al., in preparation).

Our infrared spectra also show the transition from aliphatic to aromatic dust structures in C-rich environments. Two C-rich PN precursors in our sample show the broad carbon-based emission feature (SiC?) at 11.3 $\mu$m together with molecular absorption of $C_2H_2$ at 13.7 $\mu$m. In addition, one of these stars displays also PAHs and the broad 26 and 30 $\mu$m emission features. The latter has been previously observed in a few galactic and Magellanic Cloud post-AGB stars (e.g. MSX SMC 029; [8]).

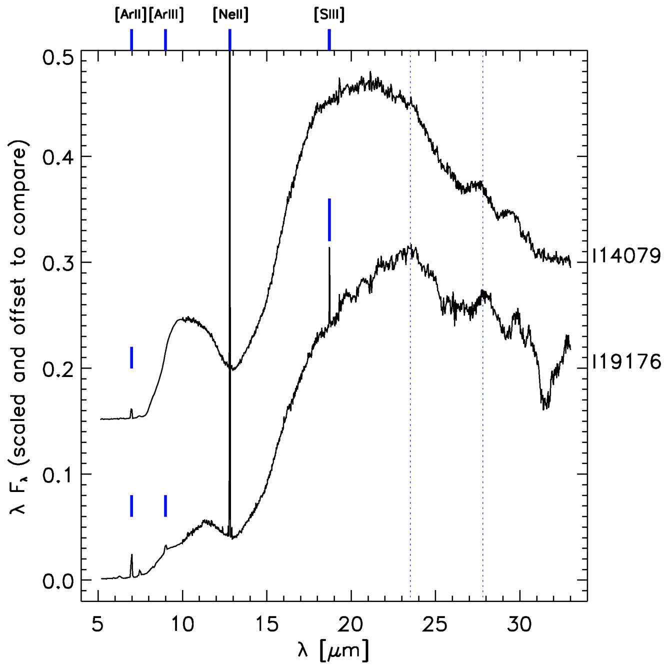


**Fig. 3.** Spitzer/IRS spectra of the young PNe I14079 and I19176. The positions of nebular emission lines and crystalline silicate features are indicated.

## 5 Concluding remarks

At present, 41 Spitzer/IRS spectra of heavily obscured planetary nebula precursors not previously studied have been qualitatively analyzed. In summary, we found that most of the non-variable OH/IR stars are O-rich but both C-rich and O-rich sources are found among the post-AGB stars of previously unknown chemistry. A new young infrared PN has also been identified in our sample. The infrared spectra shows a variety of dust compositions with amorphous (aliphatic) and crystalline (aromatic) structures in both O-rich and C-rich environments. We identify for the first time O-rich PN precursors where the transition from amorphous to crystalline dust structure is taking place (García-Hernández et al., in preparation). Finally, we also report the first clear detection of benzene ($C_6H_6$) in galactic post-AGB stars

*Acknowledgement.* This work is based on observations made with the Spitzer Space Telescope, which is operated by the Jet Propulsion Laboratory, California Institute of Technology under a contract with NASA. DAGH acknowledges support for this work provided by NASA through an award (#30258) issued by JPL/Caltech.

## References


1. J. Bernard-Salas, E. Peeters, G. C. Sloan et al: ApJ. **652**, L29 (2006)
2. T. Blöcker: A&A.**299**, 755 (1995)
3. J. Cernicharo, A. M. Heras, A. G. G. M. Tielens et al: ApJ. **546**, L123 (2001)
4. P. García-Lario, A. Manchado, W. Pych, S. R. Pottasch: A&AS. **126**, 479 (1997)
5. P. García-Lario and J. V. Perea Calderón. in *Exploiting the ISO Data Archive. Infrared Astronomy in the Internet Age*, p. 97 (2003)
6. J. P. Harrington, N. J. Lame, K. J. Borkowski et al: ApJ. **501**, L123 (1998)
7. C. Koike, A. Tsuchiyama, H. Shibai et al: 2000, A&A. **363**, 1115 (2000)
8. K. E. Kraemer, G. C. Sloan, J. Bernard-Salas et al: ApJ. **652**, L25 (2006)
9. S. R. Pottasch, R. Olling, C. Bignell, A. A. Zijlstra: A&A.**205**, 248 (1988)
10. H. van Winckel: ARA&A. **41**, 391 (2003)