IRAS 17423−1755 (HEN 3−1475) REVISITED: AN O–RICH HIGH–MASS POST–ASYMPTOTIC GIANT BRANCH STAR

M. Manteiga

Departamento de Ciencias de la Navegación y de la Tierra. Universidade da Coruña.
Paseo de Ronda 51, E-15011 A Coruña, Spain
manteiga@udc.es

D. A. García-Hernández

Instituto de Astrofísica de Canarias (IAC), Vía Lactea s/n, E-38200 La Laguna, Tenerife, Spain

A. Ulla

Departamento de Física Aplicada. Campus Lagoas-Marcosen de. Universidade de Vigo.
E-36310 Vigo, Pontevedra, Spain

A. Manchado

Instituto de Astrofísica de Canarias (IAC), Vía Lactea s/n, E-38200 La Laguna, Tenerife, Spain

P. García-Lario

Herschel Science Centre. European Space Astronomy Centre (ESAC)/ European Space Agency (ESA). Villafranca del Castillo. Apartado de Correos 78. E-28080 Madrid, Spain

ABSTRACT

The high-resolution (∼600) Spitzer/IRS spectrum of the bipolar proto planetary nebula (PN) IRAS 17423−1755 is presented in order to clarify the dominant chemistry (C-rich versus O-rich) of its circumstellar envelope as well as to constrain its evolutionary stage. The high quality Spitzer/IRS spectrum shows
weak 9.7 \( \mu m \) absorption from amorphous silicates. This confirms for the first time the O-rich nature of IRAS 17423−1755 in contradiction to a previous C-rich classification, which was based on the wrong identification of the strong 3.1 \( \mu m \) absorption feature seen in the Infrared Space Observatory (ISO) spectrum as due to acetylene \((C_2H_2)\). The high-resolution Spitzer/IRS spectrum displays a complete lack of C-rich mid-IR features such as molecular absorption features (e.g., 13.7 \( \mu m \) \( C_2H_2 \), 14.0 \( \mu m \) HCN, etc.) or the classical polycyclic aromatic hydrocarbon infrared emission bands. Thus, the strong 3.1 \( \mu m \) absorption band toward IRAS 17423−1755 has to be identified as water ice. In addition, an [NeII] nebular emission line at 12.8 \( \mu m \) is clearly detected, indicating that the ionization of its central region may be already started. The spectral energy distribution in the infrared (\( \sim 2−200 \mu m \)) and other observational properties of IRAS 17423−1755 are discussed in comparison with the similar post-asymptotic giant branch (AGB) objects IRAS 19343+2926 and IRAS 17393−2727. We conclude that IRAS 17423−1755 is an O-rich high-mass post-AGB object that represents a link between OH/IR stars with extreme outflows and highly bipolar PN.

**Subject headings:** circumstellar matter–planetary nebulae: general – stars: AGB and post-AGB –stars: individual (IRAS 17423−1755, stars: infrared radiation)

### 1. Introduction

IRAS 17423−1755 (Hen 3−1475) was first suggested by Parthasarathy & Pottasch (1989) as a possible member of the transition phase from the asymptotic giant branch (AGB) to the planetary nebula (PN) stage due to its unusual IRAS colors. The high values of the [NII]/H\(\alpha\) ratios in the outflowing material detected by Riera et al. (1995) and the low luminosity deduced for the central star allowed them to confirm the classification of this object as an evolved star. **Hubble Space Telescope (HST)** and **Very Large Array (VLA)** observations by Bobrowsky et al. (1995) showed the presence of both OH maser emission and highly collimated ionized outflows like those detected in OH/IR stars or very young PN.

**HST** images revealed a rich and complex morphological structure in the circumstellar material (see Section 4 for details). The outflow is collimated in bipolar jets along several condensations of shock-excited gas that extend about 11 arcsec. The lobes show expansion velocities of about 425 km s\(^{-1}\) and a high velocity jet (\(\sim 900 \) km s\(^{-1}\)) in the inner part of the lobes (Riera et al. 1995). The nebula displays a remarkable point symmetry that has been interpreted as due to the precession of a central binary system that undergoes episodic events of mass loss. Bobrowsky et al. (1995) proposed that the expanding shell has
a torus-like structure where the OH emission originates in a high density region, where H$_2$O is dissociated and further collimated in the observed jets. Additionally, Sánchez-Contreras & Sahai (2001) found evidences of ultrafast winds (up to 2300 km s$^{-1}$) highly collimated and located close to the central star which could be a relatively young post-AGB outflow not strongly altered by interaction with the AGB.

Stars at the end of the AGB phase are characterized by severe mass loss ($10^{-8}$ to $10^{-4}$ M$_\odot$ yr$^{-1}$), which results in the formation of circumstellar envelopes (Herwig 2005). The spherical symmetry of the envelopes of AGB stars is translated into a variety of shapes in the PN phase by a mechanism or mechanisms not as yet well understood. There is increasing evidence that at least in some instances the shaping starts at the end of the AGB phase (van Winckel 2003). IRAS 17423–1755 is a spectacular example that may represent a link between OH/IR stars with extreme outflows and highly bipolar PN.

The spectral energy distribution (SED) of extreme (e.g., highly embedded) OH/IR AGB stars is characterized by the presence of strong and broad amorphous silicate absorption features at 9.7 and 18 $\mu$m together with crystalline silicate absorption/emission features from 10 to 45 $\mu$m (Sylvester et al. 1999; García-Hernández et al. 2007). At the end of the AGB phase, the crystalline silicate features become dominant and can be observed in more evolved O-rich PN (Molster et al. 2001). Comparison of the Infrared Space Observatory (ISO) observations of O-rich dust shells surrounding evolved stars with laboratory data suggested the presence of several families of crystalline silicates, such as olivines and pyroxenes, and marked the beginning of an emerging discipline: the mineralogy of stellar and other astronomical (i.e., cometary) dust shells. Water ice features at 3.1, 43, and 62 $\mu$m have been additionally observed in heavily obscured and extremely bipolar sources such as the post-AGB star IRAS 19343+2926 (or M1–92, see e.g. Dijkstra et al. 2006 and references therein).

Gauba & Parthasarathy (2004) studied the ISO spectra of seven hot post-AGB stars including IRAS 17423–1755. DUSTY models (Ivezić & Elitzur 1997) were fitted to optical, near- and far-infrared (IRAS and ISO) photometry in order to reconstruct the SEDs and to derive physical parameters such as dust temperatures, mass loss rates, angular radii and the inner boundary of the dust envelopes. For the particular case of IRAS 17423–1755 they considered a combination of silicates and carbon in the circumstellar environment. They reported the presence of a broad absorption feature at 3.1 $\mu$m that they identified as due to the presence of C$_2$H$_2$ and/or HCN in the circumstellar envelope. This identification led these authors to infer a C-rich chemistry for the shell. More recently, Cerrigone et al. (2009) presented observations of a sample of 26 hot post-AGB stars with the Infrared Array Camera and the Infrared Spectrograph (IRS) on board the Spitzer Space Telescope. These observations were analyzed together with Two Micron All Sky Survey, IRAS and radio
centimeter data in order to model the SEDs of the targets. Cerrigone et al. (2009) classified IRAS 17423−1755 as a C-rich star on the basis of the Gauba & Parthasarathy (2004) report of the C$_2$H$_2$ feature at 3.1 µm and in the absence of a strong 9.7 µm amorphous silicate absorption/emission feature in their low-resolution (R~64–128) Spitzer spectrum. However, they pointed out that the expected polycyclic aromatic hydrocarbon (PAH) features in the 5–12 µm region are not detected. It is to be noted here that weak and narrow molecular absorptions from C-based molecules such as 13.7 µm C$_2$H$_2$, 14.0 µm HCN, etc., are difficult to detect at the low resolution of their Spitzer spectrum. The detection of these C-rich molecular absorptions - typical of C-rich AGB/post-AGB stars - requires in most of the cases higher resolution observations such as those provided by the high-resolution modes of Spitzer (R~600) and ISO (R~1000) (see e.g., Cernicharo et al. (1999, 2001); García-Hernández et al. (2009)).

The controversial origin of the mid- to far-IR features in IRAS 17423−1755 merits a re-analysis of the dust features observed in the high-resolution and higher quality Spitzer spectrum. In Section 2 we present the new Spitzer observations together with the construction of the overall SED of the nebula as observed by both Spitzer and ISO, while in Section 3 the evidence for an O-rich chemistry is analyzed and discussed. The evolutionary stage of IRAS 17423−1755 is discussed, including our new results, in Section 4 while a summary of our main conclusions is presented in Section 5.

2. **Spitzer and ISO observations of IRAS 17423−1755**

High-resolution (R~600) Spitzer/IRS spectra of IRAS 17423−1755 are now available in the Spitzer public database. Short-high (SH: 9.9-19.6 µm) and Long-high (LH: 18.7-37.2 µm) observations were obtained on 2009 April 21 under the General Observer Program #50777 (P.I.: B. McCollum). A typical signal-to-noise ratio (S/N) higher than 50 was easily reached by using just three cycles of 6 s for both SH and LH modules. However, the S/N is much lower for wavelengths longer than 34 µm - the red end of the LH module that is affected by a strong noise level. The post-bcd products (one spectrum for each nod position) automatically reduced by the IRS Custom Extractor (SPICE) were retrieved from the Spitzer database. The automatic data reduction includes the extraction from the 2-dimensional images as well as the wavelength and flux calibration. The Spitzer-contributed software SMART (Higdon et al. 2004) was used for cleaning residual bad pixels, spurious jumps and glitches and for smoothing and merging. The short-low (SL: 5.2-14.5 µm) Spitzer spectrum reported by Cerrigone et al. (2009) was also retrieved from the Spitzer database. We found a good match (≤5%) between the SL and SH module spectra. However, the absolute flux level of
the LH module spectra was found to be $\sim 8\%$ higher than the SH module spectra. Thus, we scaled the LH observations to the SH ones in order to obtain the final high-resolution Spitzer spectrum of IRAS 17423$-$1755. The good match between the Spitzer/IRS SL and the SH spectra is illustrated in Figure 1. For comparison, we also retrieved from the Spitzer database the high-resolution Spitzer observations of the similar post-AGB stars IRAS 19343$+$2926 and IRAS 17393$-$2727 (an OH/IR massive post-AGB already reported by García-Hernández et al. (2007)).

The full range ISO SWS+LWS spectrum of IRAS 17423$-$1755 was obtained in 1997 March as part of the open-time program PGARCIA.PN on spectroscopy of proto-PN candidates. Both SWS and LWS spectra were taken in the full scan AOT1 mode (de Graauw et al. 1996) at speed 1. The data were processed using the standard Interactive Analysis Software, version 7.0 of the SWS and LWS off-line processing system at the Max Planck Institute for Extraterrestrial Astronomy (Garching, Germany); see García-Lario et al. (1999) for more details on the reduction procedure. All detector signals were inspected for spurious features, which were removed. No fringes were seen in the ISO spectrum of this source. There is good agreement between our SWS spectrum and IRAS low resolution overlap region, and a good match between the SWS and LWS spectra. The 3.1 $\mu$m absorption band can be clearly observed in SWS AOT Band 1D. No firm conclusions can be drawn concerning the presence of any other solid-state dust feature because of the strong noise level in the ISO spectrum. The contribution from Galactic cirrus emission was estimated by IRSKY at the Galactic coordinates of the nebula. It was fitted by polynomials and subtracted from the resulting ISO spectra. The final spectrum was transformed to standard FITS format and the subsequent processing and analysis was performed using IRAF routines.

Another post-AGB nebula sharing some observational properties with IRAS 17423$-$1755 is IRAS 19343$+$2926 (M1$-$92), the Minkowski Footprint (Eiroa et al. 1983). Both nebulae display similar morphological properties (bipolarity), a comparable effective temperature for the central (B-type) star, host an OH maser and also present analogous infrared spectral distributions (see also Section 4). In order to compare their infrared properties, we have extracted the ISO spectra for this source from the archive and performed a similar SWS+LWS reduction procedure as in the case of IRAS 17423$-$1755. The ISO spectrum of IRAS 19343$+$2926 is of much higher quality than that of IRAS 17423$-$1755. Indeed, Kraemer et al. (2002) have previously classified the ISO spectra of IRAS 17423$-$1755 and IRAS 19343$+$2926 with the classes 5.F: and 5.SA, respectively. This means that both spectra have red continua with the ISO spectrum of IRAS 17423$-$1755 displaying no strong features superimposed on the SED, and the ISO spectrum of IRAS 19343$+$2926 displaying a clear 10 $\mu$m silicate absorption feature and classified as an O-rich source. Objects in class 5.SA often also possess water ice, CO and CO$_2$ features. Additionally, the IRS spectrum of the
post-AGB star IRAS 17393−2727 (García-Hernández et al. 2007), will also be considered for comparison with IRAS 17423−1755.

We have constructed the SEDs of IRAS 17423−1755 and IRAS 19343+2926 in the spectral region from 2 to ∼180 µm by using the IRS Spitzer data in the interval from 5 to 34 µm and ISO SWS and LWS in the remaining range. The ISO data were smoothed to the resolution of Spitzer (R∼600) and scaled to the Spitzer fluxes by using maximum scaling factors of ∼20 %. The resulting SEDs for both objects are shown in Figure 2.

The overall SEDs of IRAS 17423−1755 and IRAS 19343+2926 peak between 40 and 60 µm. Notably, the absorption feature in the 2.5-3.5 µm region appears strong in both objects, together with [CII] in emission at 158 µm; however, this latter feature might be Galactic residual background emission.

The ∼2−180 µm SEDs in Figure 2 display a very cold bimodal continuum that can be interpreted in terms of thermal emission from the dust. Obviously, it would correspond to several wavelength-dependent dust emissivities with a certain range of dust temperatures, but we found that two main components of the nebular dust, cold (strong) and hot (weaker), could roughly reproduce the general trend of the observed overall energy distribution. We performed a multiple blackbody fitting using the IRAF routine NLFIT on the $F_\lambda$ over $\lambda$ spectrum and obtained blackbody temperatures of 120 K and 965 K for IRAS 17423−1755 (in agreement with the values reported in Gauba & Parthasarathy (2004)) and temperatures of 120 K and 965 K in the case of IRAS 17423−1755. The fitted blackbody curves are shown in the $F_\nu$ over $\lambda$ spectra of Figure 2, where we also detail the fitting in the region of the 3.1 µm absorption feature. Bunzel et al. (2009) have recently reported difficulties in modeling the SEDs of heavily obscured O-rich post-AGB stars by using a more sophisticated radiation transfer code for dusty environments such as DUSTY. They needed to add amorphous carbon dust in their DUSTY models in order to reproduce both the observed red continua and the apparently weak 10 µm amorphous silicate absorption.\footnote{This problem has also been found by Cerrigone et al. (2009) and Gauba & Parthasarathy (2004), who also needed to introduce amorphous carbon grains to reproduce the observed SED of IRAS 17423−1755. This fact probably led these authors to identify the strong 3.1 µm absorption band as due to C2H2.} It is to be noted here that the inclusion of amorphous carbon grains in the DUSTY models of O-rich post-AGB stars does not necessarily mean that these sources are C-rich; their infrared spectra show O-rich dust features only. Other more unusual O-rich dust species with optical properties similar to those of the amorphous carbon grains could be present in the circumstellar shells of heavily obscured O-rich post-AGB stars (see Section 4), also giving a good fit to the observed SEDs of these stars (R. Szczerba 2009, private communication). These difficulties prevent us from...
proceeding further with this modeling, as the thermal continuum around 3 \( \mu m \) was found to provide an adequate reference for the optical depth of the observed feature and we are mainly interested in the analysis of the dust features present in the new high-resolution \textit{Spitzer} spectrum.

3. Discussion

3.1. O-rich chemistry

The most interesting and well-defined feature in the \textit{ISO} spectrum of IRAS 17423–1755 is a clear absorption band at 3.1 \( \mu m \), which we identify for the first time as water ice (see below) present in the dust grains of the circumstellar material. Similar detections are not very numerous, the comparison object being IRAS 19343+2926, a bipolar post-AGB star with an O-rich composition, another case that has also been observed with \textit{ISO}. The identification of this 3.1 \( \mu m \) absorption feature as C₂H₂ by Gauba & Parthasarathy (2004) is erroneous, as the new high-resolution \textit{Spitzer}/IRS spectrum confirms. Figure 3 displays the SED of IRAS 17423–1755 from 2 to \( \sim \)16 \( \mu m \) together with the comparison O-rich post-AGB stars IRAS 19343+2926 and IRAS 17393–2727. No other feature characteristic of a C-rich chemistry (e.g., SiC, PAHs, C₂H₂, HCN) in the circumstellar envelope can be found in the observed \textit{Spitzer} spectrum. In particular, there is no indication of the presence of C₂H₂ absorption at 13.7 \( \mu m \) and the key point here is that the C₂H₂ ro-vibrational lines at \( \sim \)3 and 14 \( \mu m \) are of similar strength (\( \sim \)20 \% from the continuum; see e.g., Cernicharo et al. (1999)). Thus, if the 3.1 \( \mu m \) absorption feature is due to C₂H₂, then the C₂H₂ 13.7 \( \mu m \) feature should be detected in the high-resolution \textit{Spitzer} spectrum presented here. The non-detection of this feature, or even the other small hydrocarbons detected in C-rich post-AGB stars (Cernicharo et al. 1999, 2001) supports our identification of the 3.1 \( \mu m \) absorption band with water ice.

\textit{Spitzer}/IRS SL and SH spectra of IRAS 17423–1755 reveal for the first time a mid-IR feature that was not evident in the low S/N \textit{ISO} spectrum (Kraemer et al. 2002; Gauba & Parthasarathy 2004) and that was not recognized by Cerrigone et al. (2009) in their IRS/SL spectrum. A weak and broad 9.7 \( \mu m \) absorption from amorphous silicates (O-rich) is present. This is shown in Figure 3, in comparison with the other well known O-rich post-AGB stars IRAS 17393–2727 and IRAS 19343+2926.

García-Hernández et al. (2007) discussed the presence of crystalline silicates in the \textit{Spitzer}/IRS spectrum of IRAS 17393–2727. They reported the presence of several weak crystalline silicate emission features in the 27-31 \( \mu m \) region, and crystalline silicate absorption features at shorter wavelengths. In particular, an absorption feature at 15.4 \( \mu m \) can be clearly
observed in the IRS spectrum of this star presented in Figure 3. Such crystalline silicate absorption/emission features cannot be claimed for definitely in either IRAS 17423−1755 or IRAS 19343+2926 at the S/N level of our Spitzer/IRS spectra. It is worth noticing here that these weak crystalline silicate features have been observed in the circumstellar envelopes of O-rich evolved stars with a variety of strengths and at slightly different wavelengths from source to source, depending on the specific chemical composition and the size and density of the dust grains in the circumstellar envelope (García-Hernández et al. 2007).

Our identification at 3.1 $\mu$m of water ice and the weak 9.7 $\mu$m amorphous silicates absorption permit us to infer for the first time an O-rich chemistry for the circumstellar envelope around IRAS 17423−1755. Figure 3 shows that a notable similarity exists between the infrared spectra of the O-rich post-AGB star IRAS 19343+2926 and that of IRAS 17423−1755. In addition, [NeII] nebular emission at 12.8 $\mu$m is also detected for the three objects shown in this figure, suggesting that the ionization of the circumstellar material may have already started in these evolved stars.

### 3.2. Water ice in highly embedded evolved stars

The conditions for condensation and properties of amorphous and crystalline H$_2$O ice in astrophysical environments have been extensively reviewed by several authors (Leger et al. 1979, 1983; Baratta et al. 1991; Kouchi et al. 1994; Smith et al. 1994). Different forms of water ice can be observed, depending mainly on temperature, pressure and the mechanisms of deposition. For typical low pressure conditions present in the circumstellar envelopes, temperatures higher than 150–170 K produce hexagonal ice, which remains stable during further cooling. If deposition takes place at lower temperatures (between 110 and 130 K) cubic ice is formed, while at temperatures lower than 100–130 K the resulting ice is amorphous (Baratta et al. 1991; Kouchi et al. 1994).

In the circumstellar envelopes of evolved stars water ice can condense forming icy mantles on dust grains which have previously condensed while the gas cooled down in the expanding envelopes. In O-rich envelopes all the carbon atoms are thought to be locked in CO molecules and the remaining O atoms are supposed to form H$_2$O aggregates. Determining the occurrence and characterization of water ice features is interesting because ice in these mantles can provide important diagnostics of the physical conditions in circumstellar envelopes. Water ice has been observed in a significant sample of AGB stars - in particular in OH/IR stars - some post-AGB stars and a few PN (Omont et al. 1990; Eiroa & Hodapp 1989; Hoogzaad et al. 2002; Molster et al. 2001). The specific conditions for the formation of water ice in circumstellar envelopes around evolved stars have been discussed and modeled.
by Dijkstra et al. (2003, 2006), who also studied the trends that can be observed in the 3, 43 and 62 μm water ice features during the stellar evolution from the AGB to the PN phase.

According to Dijkstra et al. (2006) it continues to be a puzzle why some stars form water ice and not others. One clue these authors found might be the fact that the strength of the 3, 43 and 62 μm water ice features increases with the increasing initial mass of the star. Their model calculations suggest that water ice features will be too weak to be detectable for stars with zero age main sequence (ZAMS) masses lower than 5 M⊙; the water ice features completely disappear for initial masses lower than ~3 M⊙. A high mass loss rate also favors the detectability of the water ice features, as well as large values of the mass loss rate to luminosity ratio. The absence of a strong interstellar UV radiation field also preserves ices, as well as the presence of a high density region that can provide shielding from an energetic radiation field.

Both crystalline and amorphous water ice can form in circumstellar envelopes. The models developed by Dijkstra et al. (2006) show that the shape of the spectral features is very sensitive to the type of water ice aggregate formed. The 3.1 μm crystalline water ice absorption feature is characterized by a sharp core with two unequally strong shoulders. On the other hand, the amorphous water ice absorption feature is broader, with no substructures, and displaced to shorter wavelengths. In the 30–100 μm region crystalline water ice shows two prominent and very broad emission features near 43 and 62 μm. In the case of amorphous water ice, these latter features are undetectable because they are broad and show almost no contrast with the dust continuum.

Figure 4 details the 3.1 μm water ice band in IRAS 17423−1755 and in IRAS 19343+2926. In both cases the band presents a sharp profile and shows the characteristic shoulders on both sides of the central core, indicating that most of the water ice formed must be crystalline. This is demonstrated by the good match that can be appreciated among the observed profiles and the model displayed in the figure, calculated for crystalline water ice deposited at a dust excitation temperature of 150 K by Smith et al. (1989).

Additionally, the ISO spectrum of IRAS 19343+2926 shows the presence of the water ice bands at 62 and 43 μm (Dijkstra et al. 2006), confirming the crystalline nature of the water ice in this star. The presence of these latter features cannot be excluded in the case of IRAS 17423−1755 because of the poor quality of the ISO LWS spectrum (see Figure 2). A much higher S/N spectrum would be needed in order to confirm/discard the detection of the crystalline water ice features at the longer wavelengths. The water ice features are providing us with valuable information for interpreting the precise evolutionary stage of these nebulae. This point will be addressed in Section 4 together with the analysis of other observational properties such as the nebular morphology and the presence of amorphous silicates.
4. Evolutionary stage

The available *HST* optical images for IRAS 17423$-1755$ (Bobrowsky et al. 1995) and IRAS 19343$+2926$ (Trammell & Goodrich 1996) were retrieved from the *HST* archive in order to compare the morphological properties of both objects. These optical images are presented in Figure 5, together with the *HST* image of IRAS 17393$-2727$ (unpublished), showing that strong and highly collimated bipolar outflows are observed in the three objects. Note that bipolar morphologies are mainly found among type I PN, which are expected to be the descendants of the evolution of the more massive AGB/post-AGB stars (Corradi & Schwarz 1995).

The models by Dijkstra et al. (2006) discussed in Section 3.2 have shown that the conditions for the formation and prevalence of crystalline water ices, like those observed in IRAS 17423$-1755$ and IRAS 19343$+2926$, would imply high initial masses (at least higher than $\sim3\,M_\odot$) for the central star and the probable presence of high density structures such as a dusty disk or torus, which could completely obscure the central star in the optical/near-IR wavelength range. The existence of such dusty disk/torus structures is confirmed in the optical images of both objects. García-Hernández et al. (2007) have proposed that heavily obscured high-mass precursors of PN like IRAS 17393$-2727$ may be already developing strong bipolar outflows, and it is likely that a thick circumstellar disk/torus - where the crystallization of water ice could take place - is surrounding the central post-AGB star. The presence of a highly collimated bipolar outflow as well as a thick circumstellar disk/torus that completely obscures the central source in IRAS 17393$-2727$ is now confirmed by the available *HST* images shown in Figure 5.

Sylvester et al. (1999) used the *ISO* spectra of a sample of OH/IR stars to analyze the IR characteristics of their circumstellar dust. They found that the optical depth of the $\sim10$ and $18\,\mu m$ amorphous silicate features increases with increasing mass loss rate during the AGB.\(^2\) The same results were found by Dijkstra et al. (2006), who modeled the evolution of the 2–200 $\mu m$ SED for a $5\,M_\odot$ (ZAMS) star evolving from the early AGB until the early PN stage. At the end of the AGB, the circumstellar envelope detaches from the star, becoming optically thin and causing the amorphous silicate features to disappear. This infrared evolutionary sequence from the AGB to the PN stage has been observationally confirmed by García-Hernández et al. (2007) using *Spitzer* spectra of massive O-rich AGB/post-AGB stars. Regarding the evolutionary state of IRAS 17423$-1755$, it is likely that this star is more evolved than IRAS 19343$+2926$ because the amorphous silicate absorption and the water ice

\(^2\)Note that it is believed that the mass-loss rate increases during the AGB phase (van der Veen & Habing 1988)
band are weaker (Dijkstra et al. 2006). IRAS 17393–2727 could be the least evolved object of the three because it has no optical/near-IR counterpart (the central star is not detected even in the K-band). However, in the case of IRAS 19343+2926 and IRAS 17423–1755, the central star has already reappeared in the optical/near-IR range. The presence of [NeII] nebular emission could provide evidence on the onset of the circumstellar envelope ionization, although shock excitation in the high velocity outflows cannot be excluded.

The SED of IRAS 17423–1755 is similar to those of extreme OH/IR AGB stars, which exhibit absorption features from amorphous silicates together with crystalline silicate features that alternate between emission and absorption depending on the specific physical and chemical properties of the circumstellar dust grains (Sylvester et al. 1999). We think that the presence of crystalline silicates in the 13-35 \( \mu \)m region in IRAS 17423–1755 and IRAS 19343+2926 cannot be excluded but that higher S/N spectra would be needed in order to confirm or discard such a presence.

In summary, the bipolar morphology, the detection of OH maser emission and crystalline water ice as well as the 9.7 \( \mu \)m absorption from amorphous silicates present in the Spitzer spectrum indicate that IRAS 17423–1755 is a massive O-rich post-AGB star similar to IRAS 19343+2926 and IRAS 17393–2727. The three sources represent a link between massive OH/IR AGB stars and bipolar type I PN.

5. Conclusions

An O-rich chemistry for the circumstellar envelope around the post-AGB object IRAS 17423–1755 is here confirmed, despite a previous classification as C-rich. This result is based on the detection of a weak and broad 9.7 \( \mu \)m amorphous silicate absorption in the high-resolution Spitzer/IRS spectrum. The complete lack of C-rich mid-IR features (in particular \( \text{C}_2\text{H}_2 \) at 13.7 \( \mu \)m) supports our identification of the strong 3.1 \( \mu \)m absorption band seen in the ISO spectrum as due to water ice as well as our O-rich classification for IRAS 17423–1755.

IRAS 17423–1755, IRAS 19343+2926 and IRAS 17393–2727 present clear evidences of the presence of a circumstellar disk or torus, where the conditions would be very similar to those found in less evolved and more embedded OH/IR stars. A recent strong mass-loss event has been reported in the case of IRAS 19343+2926 (Alcolea et al. 2007), which would favor this scenario. Water ice and crystalline silicates would preferentially form in the outer region of the inner torus, where low temperature conditions and shielding from the central star would allow a favorable rate of crystallization to take place. Both in IRAS 17423–1755
and IRAS 19343+2926, the ice band at 3.1 µm is sharp and presents substructures, and comparison with models of water ice growth around evolved stars (Smith et al. 1989; Dijkstra et al. 2006) allows us to confirm that the ice is mostly in a crystalline state.

The morphological properties, detection of OH maser emission, and the Spitzer/IRS spectra observed in IRAS 17423–1755 are similar to those of the O-rich post-AGB stars IRAS 19343+2926 and IRAS 17393–2727, allowing us to interpret the evolutionary stage of IRAS 17423–1755 as belonging to an intermediate stage between those OH/IR stars with extreme outflows and highly bipolar type I PN.

M. M. and A. U. acknowledge financial support from the Spanish Ministry of Science and Innovation (MICINN) through grant AYA 2009-14648-02 and from the Xunta de Galicia through grants INCITE09 E1R312096ES and INCITE09 312191PR, all of them partially supported by E.U. FEDER funds. D. A. G. H. and A. M. acknowledge support for this work provided by the MICINN under the 2008 Juan de La Cierva Program and under grant AYA-2007-64748. This work is based on spectra obtained with ISO, an ESA project with instruments funded by ESA Member States (especially the PI countries: France, Germany, The Netherlands and the UK) and with participation of ISAS and NASA; and Spitzer, a NASA’s Great Observatories Program.

REFERENCES


Fig. 1.— Overlap region between the Spitzer/IRS SL spectrum and SH of IRAS 17423−1755 showing the agreement between both spectra (≤5%).
Fig. 2.— SED from \( \sim 2 \) to \( 180 \) \( \mu \text{m} \) for IRAS 17423–1755 and IRAS 19343+2926. The SEDs were constructed by combining Spitzer and ISO data (see the text for details). The blackbody curves fitted to the spectra of both stars are also shown, corresponding to dust temperatures of 120 K and 965 K for IRAS 17423–1755, and 107 K and 800 K for IRAS 19343+2926. The spectral region around \( 3 \) \( \mu \text{m} \) is detailed in the small window.
Fig. 3.— *Spitzer/IRS* and *ISO SWS* spectra from ~2 to 16 μm for IRAS 17423−1755 in comparison with those of the O-rich post-AGB stars IRAS 19343+2926 and IRAS 17393−2727. This figure illustrates the presence of the broad 9.7 μm absorption from amorphous silicates (O-rich) and the absence of C$_2$H$_2$ absorption at 13.7 μm. [NeII] 12.8 μm nebular emission is clearly detected in the three sources.
Fig. 4.— Observed profile of the 3.1 microns water ice feature (continuum divided) in IRAS 17423–1755 and IRAS 19343+2926 and the theoretical profile derived by Smith et al. 1989 for crystalline water ice-coated silicate grains at 150 K.
Fig. 5.— Optical HST images retrieved from the HST archive for the O-rich post-AGB stars IRAS 17393–2727 (left panel, unpublished), IRAS 19343+2926 (middle panel, original images reported by Trammell & Goodrich(1996)) and IRAS 17423–1755 (right panel; original images reported by Bobrowsky et al. 1995). North is up and east to the left; axes are in arcsecs. The optical filters (F606W, F547M, F555W) are indicated in each panel. The images are shown on a logarithmic scale. Note the strong and highly collimated bipolar outflows seen in the three objects.