Optical spectroscopy of post-AGB stars

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Summary. A review of the main results obtained in the last few years on post-AGB stars with optical spectroscopy techniques is here presented. The connection of the physical and chemical properties observed in the optical spectra of these sources with the morphological features detected in high spatial resolution images is discussed. Among others, the spectral signatures attributed to the effect of binarity, progenitor star mass and metallicity are analysed in connection with the asymmetric morphologies observed in planetary nebulae.

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

1 Introduction

Post-Asymptotic Giant Branch (post-AGB) stars may hold the key for understanding the dramatic morphological and chemical changes which take place at the latest stages of stellar evolution in low- and intermediate mass (0.8–8 $M_\odot$) stars.

From the spectroscopic point of view post-AGB stars are ideal probes to test and study stellar nucleosynthesis, as they are much easier to study than their precursors, the AGB stars, and provide more complete information on a wide number of atomic species. But, is there any correlation between the physical and chemical properties derived from the spectroscopic observations and the observed morphology?

Unfortunately, the answer to this question is difficult to obtain, as the analysis is hampered by two main observational problems. First, there is a limited number of galactic sources to study: just a few hundred in the most recent compilation made by Szczerba et al. (2007) in 'The Toruń Catalogue of Galactic post-AGB and related objects'. In addition, there is a strong observational bias towards optically bright ('classical') post-AGB stars (García-Lario, 2006) and a general lack of information from those strongly obscured in the optical ('IRAS selected' post-AGB stars), whose study is in some cases limited to infrared and radio wavelengths.

To overcome these difficulties, a considerable effort has been made in the last few years to enlarge the sample of post-AGB stars with available optical spectroscopy and to extend the analysis to the most reddened sources.

Optical spectrocopy provides information on fundamental physical parameters of the stellar photosphere (log T_{eff}, log g); from which masses and metallicities can be inferred. In addition, detailed chemical abundances can be derived for a large number of atomic species. In particular, the abundances of CNO and s-process elements provide essential information on the activation and efficiency of some nuclear processes taking place in these stars, such as the third dredge-up, or hot bottom burning. In this respect, extending the statistics to the unexplored regions of the parameter space of masses and metallicities may be crucial to understand the influence of these physical parameters in the generation and development of the asymmetric morphologies observed.

2 Recent progress

2.1 Spectroscopic surveys and catalogues

An important progress was made in this area with the publication of an atlas of low-resolution spectra of an infrared (IRAS) selected sample of 124 post-AGB stars and pre-PNe (Figure 1) by Suárez et al. (2006). As a result of this study, which includes many new identifications, a flatter distribution of spectral types was obtained compared to previous studies reported in the literature, the larger proportion of late-type stars found probably reflecting the youth of the new sources observed.

Evidence for two different mass populations was also presented in this work, with the 'classical' optically bright stars showing a galactic distribution corresponding to lower progenitor masses, while obscured post-AGB stars appear more concentrated towards the galactic plane suggesting higher progenitor masses (Figure 2).

Using similar criteria, the identification of an additional group of 10 post-AGB candidates was also reported by Pereira & Miranda (2007).

Regarding catalogues, the *Toruń Catalogue of Galactic post-AGB and related objects* was made available on-line by Szczerba et al. (2007), containing optical and infrared photometry, infrared spectroscopy and spectral type information, and links to finding charts and bibliography for 326 very likely post-AGB stars.

Complementary to this, stellar parameters and chemical abundances derived from high-resolution optical spectroscopy of 125 sources identified as post-AGB stars or related objects in the literature were also compiled by Stasińska et al. (2006).

2.2 Analysis of individual stars

An increasing number of individual sources have been studied in the last few years by various research groups using high spectral resolution techniques. Detailed chemical abundance analysis are now available for e.g. IRAS 06530−0213, IRAS 08143−4406 (Reyniers et al. 2004); IRAS 19386+0155 (Pereira et al. 2004); IRAS 13266−5551, IRAS 17311−4924 (Sarkar et al. 2005); IRAS 05381+1012 (Pereira & Roig 2006); IRAS 08281−4850 or IRAS 14325−6428 (Reyniers et al. 2007), revealing a wide variety of photospheric properties, although most of the sources studied are found to be strongly carbon and s-process enriched, metal poor stars.

Also remarkable in this field is the publication by Klochkova et al. (2007) of an atlas containing ∼1500 spectral lines/features identified in HD 56126, the 'canonical'

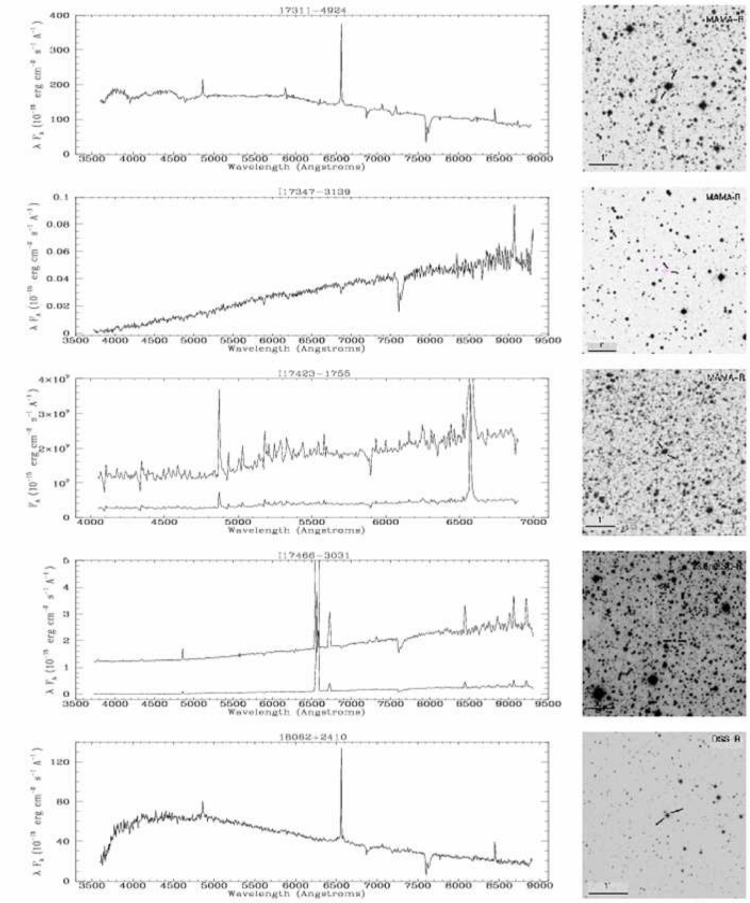

Fig. 1. Sample spectra and associated finding charts, taken from the spectroscopic atlas of 'IRAS selected' post-AGB stars compiled by Suárez et al. (2006)

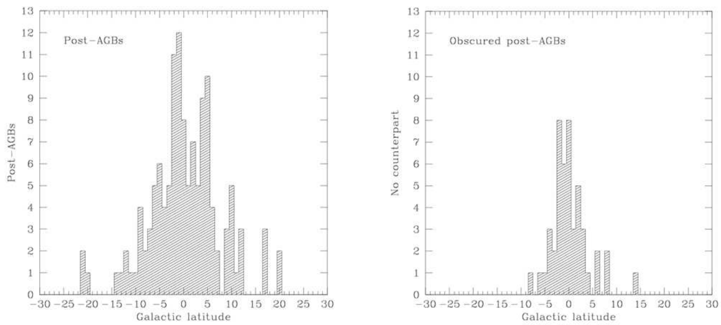

Fig. 2. 'Classical' (left) and 'obscured' (right) post-AGB stars show a distinct galactic distribution (Suárez et al. 2006)

post-AGB star. HD 56126 is a low-metallicity ([Fe/H]=−1.0) F5Iab-type star with a strong excess of carbon and s-process elements located at high galactic latitude showing the characteristic double-peaked spectral energy distribution and a strong, yet unidentified, 21 μm feature at infrared wavelengths observed in other C-rich galactic post-AGB stars. This star, as many others in this particular transition phase, shows a variable and complex Hα profile, interpreted as shock waves estimulating mass outflow (Figure 3).

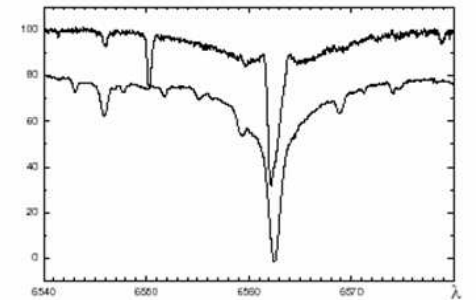

Fig. 3. Variable Hα emission observed towards HD 56126, the 'prototypical' post-AGB star (Klochkova et al. 2007)

2.3 Diffuse Interstellar Bands

A byproduct of the spectroscopic analysis of optically bright post-AGB stars is the identification and study of the observed *Diffuse Interstellar Bands* or *DIBs*, usually attributed to carbonaceous compounds. A recent systematic study performed by Luna et al. (2008) on a sample of reddened post-AGB stars shows, however, that these features do not seem to form in the circumstellar envelopes of these stars, but they have always an interstellar origin, no matter the dominant chemistry of the circumstellar shell (O-rich or C-rich) or the spectral type of the central star considered (Figure 4).

2.4 Massive precursors of post-AGB stars

High resolution optical spectroscopy was used to identify some of the most massive precursors of post-AGB stars among a sample of galactic *OH/IR stars*, extremely reddened O-rich AGB stars displaying OH maser emission (García-Hernández et al. 2006, 2007; Figure 5). Their masses were inferred from the combination of theoretical models with the detection of strong lithium and rubidium overabundances in their optical spectra. In particular, the strong lithium abundance can be interpreted as an indicator of hot bottom burning (activated only for M $\geq$ 3–3.5 M$_\odot$ at galactic metallicities). On the other hand, the Rb overabundance confirms that the ^{22}Ne neutron source is dominant in these sources (and not the usual ^{13}C), something which is only predicted to occur in the most massive AGB stars (M$\geq$4 M$_\odot$).

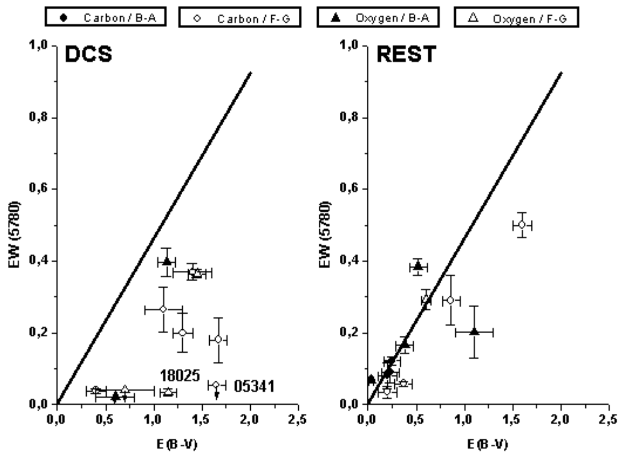

Fig. 4. Diffuse bands, like the one at 5780 Å shown here, are extremely weak or absent in post-AGB stars dominated by circumstellar reddening (left) compared to those post-AGB stars in which interstellar extinction is the dominant contributor to the observed reddening (right) - (Luna et al. 2008)

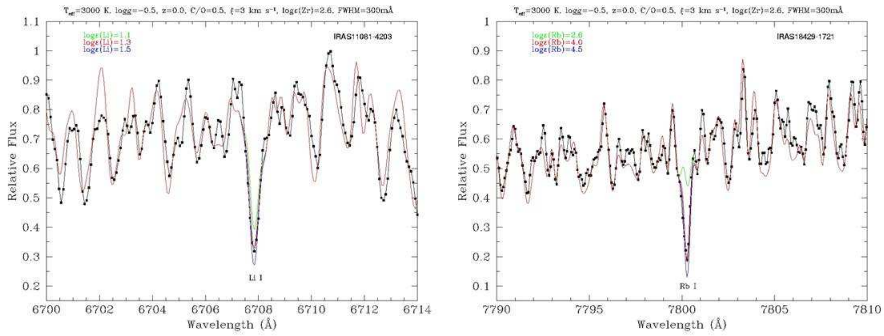

Fig. 5. High resolution spectroscopy of massive AGB stars, showing strong Li I 6707 Å and Rb I 7800 Å lines, indicators of hot bottom burning and of the activation of the ^{22}Ne neutron source, respectively (García-Hernández et al. 2006, 2007)

2.5 Binary post-AGB stars

Another area where a lot of progress has been made is in the identification of binary post-AGB stars. These stars show depletion of refractory elements which get locked in dust grains formed in long-lived, circumbinary Keplerian disks (Maas et al. 2005; de Ruyter et al. 2006), which are easy to identify in the infrared because of their strong crystalline silicate emission (Gielen et al. 2007). In addition, radial velocity variations of spectral lines with a period of a few hundred days can also be interpreted as the signature of binarity (van Winckel et al. 1995), and this has been used to confirm the binary nature of some stars, like HR 4049, HD 44179, HD 52961, HD 46703 or BD +39 4926.

3 Post-AGB galactic populations and their connection with observed morphologies

Thick disk post-AGB stars: 'Classical' post-AGB stars belong to this galactic population. They usually show simultaneously bright optical counterparts affected by little or only moderate reddening and a considerable excess at infrared wavelengthes, presenting therefore a characteristic double-peaked spectral energy distribution. These stars, however, may be representative only of the slowly evolving low-mass population of post-AGB stars in the Galaxy, with progenitor masses in the 1.0 – 2.0 $M_\odot$ range. They usually are carbon and s-process enriched, consistent with an efficient dredge-up of processed material, as predicted by nucleosynthesis models for these mildly metal-deficient ([Fe/H]= -0.5 to -1.0) stars. Many of them are strong 21 μm emitters as well. Observations with HST reveal aspherical shapes in scattered light in most cases, but very rarely strong bipolar morphologies (Ueta et al. 2000; Meixner et al. 2002).

Galactic halo post-AGB stars: an old population of very low mass post-AGB stars with optically bright and unusually hot spectral types is also found at very high galactic latitudes. These stars may have never experienced a phase of total obscuration during their previous evolution. Usually they are C-poor and non-s-process enriched (no or little dredge-up), and show very low metallicities ([Fe/H] ≤ -1.0). Observations with HST reveal only slight departures from the round morphology in scattered light and little reddening in the optical. Most of them were not detected by IRAS and may never develop an observable PN (progenitor masses below 1.0 $M_\odot$).

Thin disk post-AGB stars: many of the post-AGB stars belonging to this population escaped from detection in previous surveys as they frequently show extremely reddened counterparts in the early post-AGB phase. They have only been recognised as such in recent surveys based on their strong infrared excess and characteristic IRAS colours. Contrary to their thick disk analogues, these stars are in most cases O-rich and non-s-process enriched, which may be the consequence of a not so efficient third dredge-up in the previous AGB phase at solar metallicities. With masses above 2 $M_\odot$, some of them still display OH maser emission as well as CO molecular emission, indicative of a massive molecular envelope. Their more massive precursors may belong to the group of fast evolving, hot bottom burning OH/IR stars showing strong Li and Rb overabundances, with progenitor masses exceeding the 3.0 – 3.5 $M_\odot$ range. Many of them, recently observed with HST (Sahai et al. 2007) display a strong bipolar morphology and dusty toroidal waists, and in many cases shocked excited H_2 emission as well (García-Hernández et al. 2002).

In the most extreme cases (progenitor masses above 4 $M_\odot$), post-AGB stars may remain completely hidden at optical wavelengths during their whole evolution from the AGB to the PN stage. As a consequence, these fast evolving sources would produce infrared PNe, never detectable at optical wavelengths. At present, very litle is known about this population of more massive, heavily obscured PN precursors, but some candidates have already been identified with the help of Spitzer spectroscopy (García-Hernández et al., in preparation). Interestingly, all of them for which HST observations are available, show very strong bipolar morphologies (Figure 6).

The nucleosynthesis pattern observed in galactic post-AGB stars is the consequence of the chemical branching experienced by their progenitor stars at the end of the AGB as a consequence of nuclear processes already mentioned, mainly the third

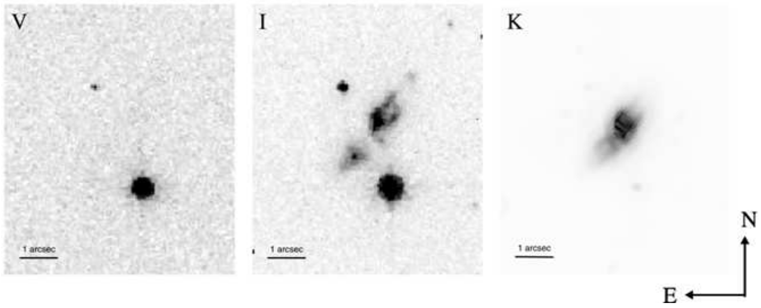

Fig. 6. Some of the most extremely reddened post-AGB stars are completely invisible in the optical domain; many of them show a strong bipolar morphology when observed with HST, like IRAS 17347−3739, shown in the figure.

dredge-up and hot bottom burning. However, this branching is strongly dependent on the metallicity of the progenitor star, e.g. at low metallicities the third dredge-up is more efficient, while hot bottom burning becomes activated at a lower mass limit.

The result expected from this evolution is that low-mass AGB stars, classical Miras with progenitor masses in the 1.0 – 2 $M_\odot$ range, will become either O-rich or C-rich type II PNe at the end of their evolution depending on the metallicity environmemt in which they were formed, while those AGB stars with higher progenitor masses $\geq$3.0 – 3.5 $M_\odot$ will eventually become high-mass O-rich (but also N-rich) type I PNe.

4 Concluding remarks

Recent spectroscopic observations of post-AGB stars suggest that this class of astronomical sources is chemically much more diverse than initially thought. Although mass is confirmed to be the main driver of the diversity observed, metallicity plays a crucial role as well and it is a necessary ingredient which needs to be considered to fully understand and interpret the wide variety of spectroscopic properties and morphologies observed in PNe.

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