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The progress in the study of post-AGB stars

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Abstract. Post-AGB stars represent a crucial phase in the evolution of low and intermediate stars where rapid change in the surface composition of the star and its circumstellar envelope takes place. We summarize recent developments and observational properties of various subgroups identified within this class of objects. We also summarize the impact of recent ground-based and space surveys on our understanding of these fascinating objects.

Keywords : stars: post-AGB – stars: evolution – stars: abundances

1. Introduction

The post-AGB stars (hereinafter PAGB stars) are excellent probes to study stellar and galactic evolution due to their diagnostic properties in the study of rapid morphological and chemical changes taking place at late stages of evolution of low and intermediate mass stars (approximate mass range 0.8 to $8M_{\odot}$). At AGB phase the star has hydrogen and helium shells atop the electron-degenerate C,O core (O,Ne and Mg core for the super AGB stars) and successive thermonuclear pulses cause convective mixing events providing rich environments for nuclear processing. The extensive nucleosynthesis at AGB and mixing processes (dredge-ups) change the surface composition of the star over a short time (a few thousand years) and synthesized elements are ejected to interstellar medium (ISM) through strong mass-loss preceding the post-AGB phase. AGB stars are therefore major contributors of C,N,F,Al,Na and s-process elements to ISM and hence play a crucial role in the chemical evolution of galaxies. Very comprehensive models following these pulses in detail have been developed (see Herwig 2005 for a review of AGB models).

The model calculations show that AGB evolution is strongly affected by the mass

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and metallicity of the progenitors. The low mass stars ($M < 1.8\ M_\odot$) may not undergo sufficient number of thermal pulses at AGB and subsequent dredge up and hence remain O-rich (C/O ratio < 1). The intermediate mass stars in mass range 2-4 $M_\odot$ would experience third dredge up (TDU) where the products of helium burning as well as s-process elements are transported to the outer envelope and these objects become carbon stars with C/O > 1. The classical post-AGB stars like HD 56126 confirming these predictions are generally found in the thick disk of our Galaxy and they make a very small fraction of the known post-AGB stars. An unpublished compilation of these objects (Sumangala Rao, Giridhar & Lambert 2011) show that most of these objects do not show indication of binarities. On the other hand for higher mass stars ($M > 4M_\odot$), the bases of convective envelopes reach temperature hot enough ($T > 2 \times 10^7$K) to cause proton capture nucleosynthesis to occur there. This is called hot bottom burning (HBB) as explained in Lattanzio et al. (1996) and Lattanzio & Wood (2004). The carbon produced by helium burning would be quickly converted to nitrogen and hence C/O ratio will not exceed unity. These relatively massive objects also do not become carbon stars but would have enhanced nitrogen. Lithium production (transient) has also been predicted in these models based upon HBB. At lower metallicities the minimum mass needed to activate HBB, number of thermal pulses needed to produce carbon stars and high dredge up efficiency are attained at relatively lower masses.

2. Detection and classification of post-AGB stars

Surveys such as IRAS, GLMP, ISO, Spitzer and AKARI have been very productive in identifying and classifying these objects. Due to the intersection of evolutionary tracks with Pop II instability strip, variable stars such as RV Tau stars, Pop II Cepheids and SRD variables also harbour PAGBs (Giridhar et al. 2005; Maas, Giridhar & Lambert 2007). The Torún catalogue of Galactic post-AGB and related objects (Szczerba et al. 2007) is an on-line catalogue being regularly updated.

2.1 Classical (optically bright) post-AGB stars

This group contains low metallicity stars of F-G spectral type and high galactic latitude distribution. Their Spectral Energy Distribution (SED) shows characteristic double-peak components. The optical peak arises due to the central star while IR peak is caused by the dust grain in the circumstellar envelope. The chemical composition studies show that they come in two flavours. Carbon-rich PAGBs showing s-process enhancement caused by sufficient number of thermal pulses and efficient dredge-up. The Oxygen-rich PAGB share the spectral type and SED shape except s-process enhancement (termed "have not" in the review paper by van Winckel 2003).

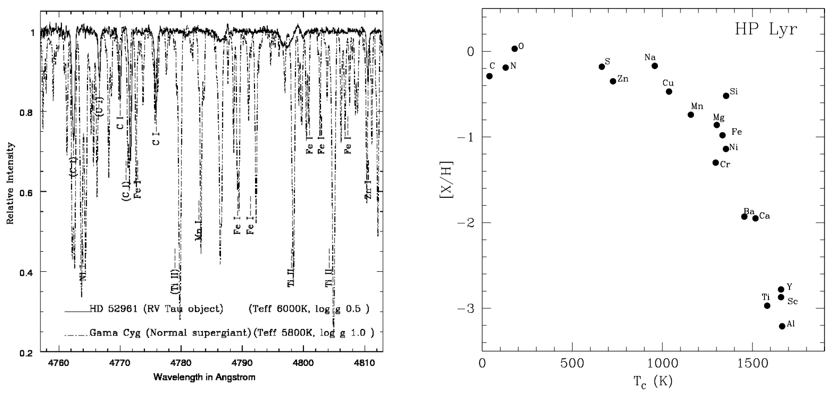

Figure 1. The left panel shows the spectrum of HD 52961 compared with a standard star of very similar temperature and gravity. The dependence of elemental depletion on T_C is illustrated in the right panel for HP Lyr.

2.2 Heavily obscured post-AGB stars

Their central stars are generally B type indicating a fast PAGB evolution of massive progenitors. The SED contains a hot dust component indicating recent or on-going mass-loss. Nearly half members do not show any optical counterpart at all. Most of these sources are found to be O-rich which may be attributed to hot bottom burning (HBB) proposed by Lattanzio et al. (1996). They are found mostly in the galactic plane suggesting massive population.

2.3 Post-AGB stars masquerading as metal-poor stars

Their spectra resemble those of metal-deficient stars due to systematic depletion of condensable elements observed initially for HR 4049, BD+39^{o}4926, HD 52961 and several others (see De Ruyter et al. 2006 for a full compilation). The abundance pattern shows strong dependence on the predicted condensation temperature T_C for low pressure gas of solar composition. Hence, elements like Al, Ca, Ti and Sc with the higher T_C (1500 to 1600K) are significantly depleted while the elements with low T_C (like S, Zn) are not affected. In Fig. 1 we have compared the spectrum of HD 52961 with a normal star of similar temperature and gravity. One can see the absence of lines of elements with large T_C while those of low T_C such as C and Zn are present. In the right panel we have plotted the derived [X/H] as function of T_C for HP Lyr because for this RV Tau star the abundance analysis covers large number of elements. It is obvious from the figure that the elements with large T_C are systematically depleted while those with lower T_C are much less affected

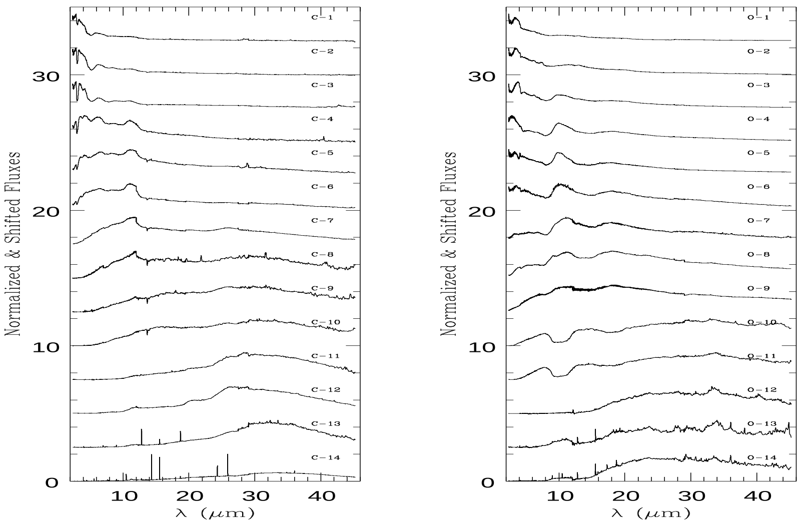

Figure 2. The evolutionary sequence as inferred from the IR spectra. The left panel shows C-rich sources and the right O-rich ones (Figure courtesy P. Garcia-Lario, reproduced from proc. IAUS, 234, 397 eds M. J. Barlow & R. H. Méndez, by permission of Cambridge Univ Press)

A model involving circumbinary disks proposed by De Ruyter et al. (2006) is gaining acceptance with a large binary frequency among dusty PAGBs (van Winckel 2007). These authors found clear evidence for stable circumbinary disks through their modeling of broad band SED characteristics of a large sample of such objects. They found a dust-excess starting near sublimation temperature irrespective of the effective temperature of the star. For this geometry to sustain, atleast a part of the dust must be gravitationally bound since any typical AGB outflow velocity would bring the dust to cooler regions within years. The dust emission is resolved in Red Rectangle and disc structure is visible (Cohen et al. 2004). Deroo et al. (2007) conducted high spatial resolution *N*-band interferometry for SX Cen and HD 52961 and estimated the diameters of dust emissions 11 mas and 35 mas respectively. From study of orbital parameters for the well-studied objects, these authors suggest that these orbits are too compact for sizes of PAGB stars. It is highly improbable that these stars have evolved as single PAGB stars; a strong interaction phase while the star was in giant stage is required to explain the present configuration.

3. Evolution of circumstellar envelopes

The identifications of IR features are summarized in García-Lario (2006). The spectra of C-rich PAGB show many dust features including those at 3.3, 6.2, 7.7, 8.6 and 11.3 μm generally attributed to poly aromatic hydrocarbons (PAH)s. Hydrogenated PAH cause features at 11- 15 μm region (Hony, van Kerckhoven & Peeters 2001) and large compounds at 15-21 μm (van Kerckhoven, Hony, Peeters 2000). The 21 μm feature has been attributed to TiC nanocrystals (van Helden, Tielens & van Heijnshergen 2000), TiC interacting with fullerenes (Kimura, Nuth & Ferguson 2005) or doped SiC grains (Jiang, Zhang & Li 2005). The 30 μm feature associated with MgS (Hony, Waters & Tielens 2002) is now believed to be mixture of two different features centered at 26 and 33 μm. The O-rich PAGB have strong broad features of silicates at 9.7 and 18μm. Also seen are narrower emissions due to crystalline silicate at 19.8, 23.5, 27.5, 33.5, 40.8, 43.3 and 60 μm and water ice at 3.1, 43 & 62 μm.

Using ISO spectra of large number of AGB-PN sources García-Lario and Perea Calderón (2003) have proposed an evolution scheme which takes into account the gas-phase molecular bands seen in the extended atmospheres of AGB, solid state features detected in circumstellar shells surrounding the transition objects and nebular emission lines seen in PNe over the 2-45 μm range along with the shape of underlying infrared continuum.

The evolutionary sequence is illustrated for both C-rich and O-rich sources in Fig. 2. The increasing mass-loss rate at AGB could be seen through increasing strength of dust emission features. Increase of optical thickness in the circumstellar shells of AGB stars at the end of AGB phase could be inferred as these emission features turn into absorption as the envelope becomes optically thick. At the end of AGB when mass-loss has suddenly stopped; the gradual cooling of circumstellar envelope results in shifting of the peak of IR emission to longer wavelengths. The change in dust grain properties from amorphous to crystalline for O-rich chemistry and aliphatic to aromatic for C-rich chemistry takes place. Consequently, strong crystalline silicate features for O-rich stars and PAHs and other aromatic C-rich compounds for C-rich case are seen. More recently, the IR features of C_{60} at 7.0, 17.4 and 18.9 μm are detected in the Spitzer/IRS spectrum of IRAS 01005+7910 by Zhang & Kwok(2011).

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