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The optically bright post-AGB population of the LMC

Els van Aarle[1], Hans van Winckel[1], Tom Lloyd Evans[2] and Peter R. Wood[3]

[1]Instituut voor Sterrenkunde, Celestijnenlaan 200D BUS 2401, 3001 Leuven, Belgium
email: els.vanaarle@ster.kuleuven.be, hans.vanwinckel@ster.kuleuven.be

[2]School of Physics & Astronomy, University of St Andrews,
North Haugh, St Andrews KY16 9SS, Scotland, UK
email: thhle@st-andrews.ac.uk

[3]Mount Stromlo Observatory, Cotter Road, Weston Creek, ACT 2611, Australia
email: wood@mso.anu.edu.au

Abstract. The detected variety in chemistry and circumstellar shell morphology of the limited sample of Galactic post-AGB stars is so large, that there is no consensus yet on how individual objects are linked by evolutionary channels. The evaluation is complicated by the fact that the distances and hence luminosities of these objects are poorly known. In this contribution we report on our project to overcome this problem by focusing on a significant sample of post-AGB stars with known distances: those in the LMC. Via cross-correlation of the infrared SAGE-SPITZER catalogue with optical catalogues we selected a sample of 322 LMC post-AGB candidates based on their position in the various colour-colour diagrams. We determined the fundamental properties of 82 of them, using low resolution optical spectra that we obtained at *Siding Spring* and *SAAO*. We selected a subsample to be studied at high spectral resolution in order to obtain accurate abundances of a wide range of species. This will allow us to connect the theoretical predictions with the obtained surface chemistry at a given luminosity and metallicity. By this, we want to constrain important structure parameters of the evolutionary models. Preliminary results of the selection process are presented.

Keywords. stars: AGB and post-AGB, circumstellar matter, stars: evolution, Hertzsprung-Russell diagram, galaxies: individual (LMC), Magellanic Clouds

1. Introduction

Post-AGB stars are stars of low and intermediate mass that evolve rapidly from the Asymptotic Giant Branch (AGB) towards the Planetary Nebula (PN) phase before cooling down as a white dwarf. The evolutionary stage of these objects is still badly understood. In the Galactic sample, the post-AGB stars display for instance a much broader chemical diversity than can be predicted based on the theoretical evolutionary models: stars with similar global properties can show completely different photospheric abundance patterns (see Van Winckel 2003 and references therein). The connection between the initial metallicity and the occurrence of a third dredge-up also remains unclear. Furthermore, the very different circumstellar geometries and kinematics of post-AGB outflows can not be explained yet (see Balick & Frank (2002); Sahai *et al.* (2007), and references therein). The fact that all these questions remain unresolved, is a consequence of the lack of fundamental insight in how the internal structural evolution leads to the chemical enrichment of the stellar surface as well as of the poor understanding of the physical processes that are responsible for the high, often collimated, mass-loss rates that we observe. In addition to gaining insight in their own evolutionary phase, studying post-AGB stars can also help us to better understand the AGB evolution as well as the PNe physics (e.g., Van Winckel 2003; Hrivnak 2003; García Lario 2006). Thanks to the broad spectral range of their electromagnetic spectrum, a simultaneous study of the stellar photosphere and the circumstellar environnement is possible: the central star is responsible for the UV- and optical emission while the cool circumstellar envelope radiates in the infrared.

Resolving the mysteries of post-AGB stars is, however, rather difficult since this evolutionary phase is relatively short. Hence, not many post-AGB stars are known and detailed studies of individual objects prevail in the literature (for a list of post-AGB stars in the Galaxy, see Szczerba *et al.* 2007). Moreover, the poorly constrained distances of the Galactic sample prevent good theoretical diagnostics. The main goal of our project is therefore to study a significant sample of post-AGB stars with a known distance and hence luminosity: those in the LMC. We first discuss the selection of our sample and go into detail on some preliminary results. We end with conclusions and a short description of the future plans.

2. Selection of the sample

The post-AGB stars we observe in the Galaxy can be roughly divided into two different classes according to the shape of their SED. The most well known of these types has a double peaked SED in which the peak at longer wavelengths corresponds to the emission of a detached shell of expanding and cooling dust. If the optical depth in the line of sight is not too large, the central star is visible at shorter wavelengths. The second type of SED shows a broad infrared excess, which indicates that there is still hot dust in the system. These SED's are indicative of a disc rather than an expanding envelope (De Ruyter *et al.* 2006) and recent interferometric results show that the dusty discs are very compact and likely very stable (e.g., Deroo *et al.* 2006; Gielen *et al.* 2008).

For the selection of our sample, we made use of the magnitudes provided in the point source catalogue of the SAGE-SPITZER LMC survey (Meixner *et al.* 2006). Our initial selection criteria to look for optically bright post-AGB stars included a flux limit of $F(24) < 1\,\mathrm{Jy}$, with $F(24)$ the flux at 24 μm, to avoid the majority of the supergiants. To avoid the bulk of the young stellar objects, we imposed that $2\,\mathrm{mJy} < F(24)$. The existence of the two types of SED's is reflected in the other criteria we chose. To detect post-AGB stars with a freely expanding, detached dust shell, we focused on the presence of cool dust in the system and therefore imposed that $F(24) > F(8)$. The selection criterion for disc sources was inspired by the Galactic sample for which we folded the SEDs with the filter transmission curves of *Spitzer*. We also looked for the presence of cool dust, but we made the criterion less strong: $F(24) > 0.5 \times F(8)$. Furthermore we imposed a $J - K < 1.0$ mag as an additional criterion. This has the advantage that it also helps to avoid the bulk of the M-type stars.

On their poster for this conference, Toshiya Ueta and collaborators (see Ueta *et al.* these proceedings) used similar criteria based on SAGE colours, to select post-AGB stars in the LMC. The main difference between our method and theirs is that we focus on optically bright post-AGB stars while they include also the obscured ones in their criteria. This is justified by the different goals we aim at: they plan to make a list of all post-AGB stars of the LMC while we are selecting a range of stars to study in more detail.

430 objects fulfill our colour and magnitude conditions. We then correlated the positions with three optical catalogues: Massey's catalogue of the UBVR CCD survey of the

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Magellanic clouds (Massey 2002) which gave 68 matches, the Guide Star Catalog, Version 2.3.2 (2006) which resulted in 313 matches and the LMC stellar catalog of Zaritsky *et al.* (2004) which gave 275 matches. The total sample at this point contained 381 stars. A search on SIMBAD allowed to remove the stars that are known not to be post-AGB stars and this resulted in a final sample of 322 stars.

To characterise the sample more, we obtained low-resolution optical spectra (∼ 3.7 Å) at the *Siding Spring Observatory* in Australia or at *SAAO* for 82 of the 322 stars so far. The spectra were reduced using IRAF and following the standard recipies for long-slit spectral reduction. The main goal of this, is to determine the spectral type of the different objects and to examine their membership of the LMC. We detected all spectral types from O to M with number density peaks around B and M. About one third of the post-AGB candidates show emission lines, which might indicate the presence of hot circumstellar gas (and dust).

3. SEDs

To determine the luminosities of our sample, we developped a method based on a Monte Carlo simulation to minimise simultaneously for the total reddening as wel as for the effective temperature of the star. First, we determined separately the best atmosphere model to be used for each star. We allowed a small range in temperatures, constrained by the spectral type which we deduced from the low-resolution optical spectra. The effective temperatures of all models used in the routine range from 3000 up to 10 000 K in steps of 250 K, from 10 000 up to 13 000 K in steps of 500 K, from 13 000 to 35 000 K in steps of 1000 K and from 35 000 up to 50 000 K in steps of 2500 K. Log g is not a free parameter since only one model was used for each temperature. For atmosphere models with effective temperatures higher than or equal to 3500 K, we used Kurucz models with a metallicity of −0.3. For the range of $T_{\rm eff}$ from 3000 to 3250 K we used MARCS-models with metallicity −1.0. A lower limit of 0.04 was imposed for the value of $E(B-V)$ to correct for the interstellar extinction. By use of the Monte Carlo Method with 150 steps and a Gaussian distribution of the errors on the photometric points, the best model for each star is determined minimising the χ^2 between the rescaled atmosphere model and the deredded photometric data used only up to 25 000 Å. The spectra were left out of this process since the uncertainties on the calculated flux remain too large. If other photometric data are available, the magnitudes from the Guide Star Catalogue were not involved in the procedure since they differ significantly from those in the other two catalogues.

The model that was most frequently found as a solution is used to determine the values and errors of the other free parameters. In this second step of our minimisation procedure we computed these different values, again by rescaling the atmosphere model and dereddening the photometry up to 25 000 Å with a lower limit of 0.04 for the value of $E(B-V)$. The final solution is calculated by the Monte Carlo Method with 150 steps and the error deduced is the standard deviation of all physically sound solutions: if a reasonable amount (2/5) of other solutions existed, the ones where $E(B-V)$ equalled 0.04 were deleted. The luminosity was calculated then by integration under the final atmosphere model.

This minimisation procedure gives very decent results (see Fig. 1 for some examples), except for spectral types O and B, since there is a lack of photometry at wavelengths lower than 3600 Å, where still a significant part of the luminosity is radiated. The calculated luminosities remain, however, very sensitive to changes of the atmosphere model, the

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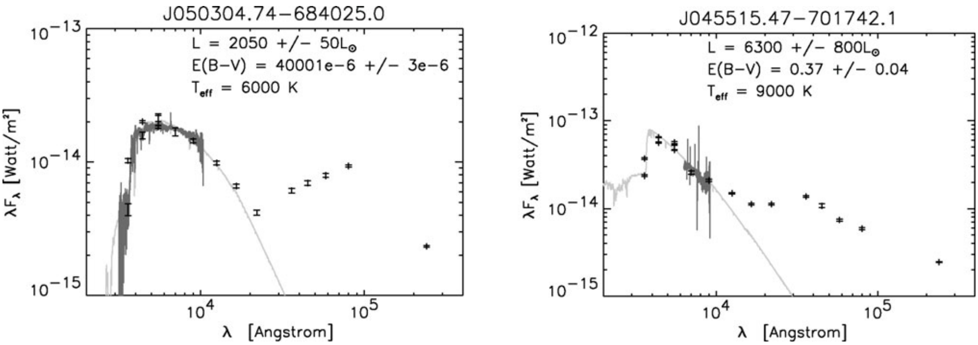

Figure 1. Some examples of the SED's we computed. The figure on the left corresponds to a post-AGB candidate with a freely expanding, detached shell, while the one on the right has a disc.

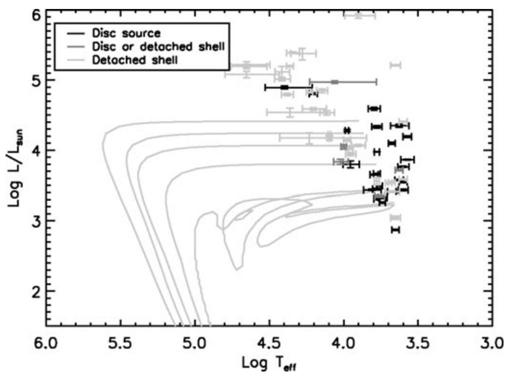

Figure 2. The position in the HR diagram of the post-AGB candidates for which we already obtained a low resolution optical spectrum. The evolutionary tracks are from Blöcker (1995) and correspond to stars with an initial mass of 1, 3, 4, 5 and 7 $M_{\odot}$.

value of $E(B-V)$ and variability of the photometry. Based on the info in the SED, the low resolution optical spectra and our colour selection criteria, we found that 60 of the 82 observed stars remain good post-AGB candidates. 30 have a freely expanding, detached shell and 25 are disc sources. The remaining five could be either.

In Fig. 2 we show the position in the HR diagram of all post-AGB candidates with a low resolution optical spectrum. The different candidates show a large spread in luminosities and represent therefore a wide range of different initial masses. This is very interesting in the light of the final goal of our project. By allowing a broader range in temperatures in our minimisation procedure, we could calculate an approximation to the luminosity of the objects without low resolution optical spectrum. The HR diagram of these objects is shown in Fig. 3. We notice that many sources, mainly the ones with a freely expanding, detached shell, have a low luminosity. Disc candidates show, on average, a lower effective temperature than the other objects. As less massive stars evolve slower, the expected bias towards lower mass objects is also observed.

4. Conclusions and future plans

Since other types of stars like YSOs or supergiants show similar colours as post-AGB stars, the low resolution optical spectra are needed for a full characterisation of the

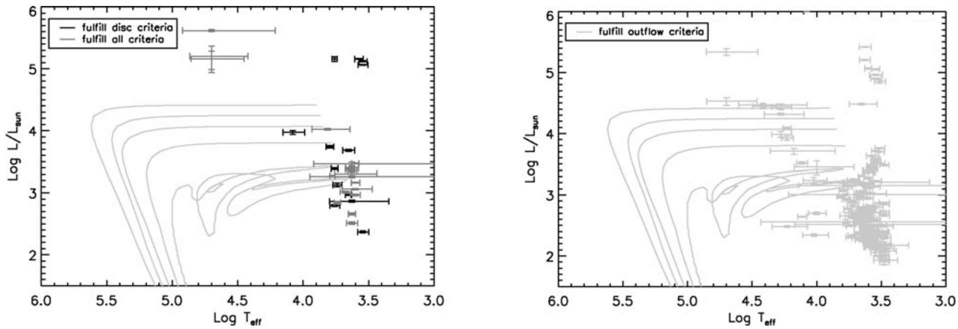

Figure 3. HR diagram containing the 260 post-AGB candidates for which we have not obtained low resolution optical spectra yet. The evolutionary tracks are from Blöcker (1995) and correspond to stars with an initial mass of 1, 3, 4, 5 and 7 $M_{\odot}$.

objects. This is why only 75% of the stars of our initial sample could still be considered to be post-AGB candidates, based on the information from the spectra. This rather high percentage does emphasize the efficiency of our selection criteria.

So far, we have a good sample of post-AGB candidates with a freely expanding, detached shell for which we already have low resolution optical spectra. Since this sample shows a rather large spread in luminosities, it will be very interesting to analyse it further in the light of the chemical evolution of post-AGB stars. Our initial sample also contains an extensive number of post-AGB candidates with expanding dust with a rather low luminosity. Obtaining low resolution optical spectra of these sources will form an interesting extension to the existing group of objects and give us an even broader look on post-AGB evolution. Also in the LMC, like in our Galaxy, there is a significant number of post-AGB candidates which seem to harbor a disc.

The uncertainty on the luminosities we computed based on these SEDs remains, however, large. The values are sensitive to changes of the atmosphere model, the value of $E(B-V)$ and variability of the photometry.

During next LMC observing season, we want to obtain low-resolution optical spectra for all objects of the extensive sample of post-AGB stars with a freely expanding, detached shell and a rather low luminosity. These objects can form an interesting extension of the existing sample. Furthermore, we plan to investigate the sample for which we already have low resolution spectra in more detail. For this, we were awared telescope time to obtain high-quality, high-resolution optical spectra of a small sample of representative candidate post-AGB stars. These spectra will allow us to study the chemical abundance patterns in detail. The ultimate goal is to confront the atmospheric enrichement distributions, with evolutionary model predictions. This will allow us to investigate the occurence of a third dredge up as a function of the stellar mass and metallicity.

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