

# Anyone out there? Galactic Halo Post-AGB stars

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**Abstract.** We present results of a survey of post-asymptotic giant branch stars (post-AGBs) at high galactic latitude. To date, few post-AGB stars are known throughout the Galaxy and the number of known members of the older populations like the galactic halo is even smaller. This study looks at the number of post-AGB stars which are produced using different synthetic population methods and compare the results with observations. The resulting synthetic populations are compared to observational results from a complete and studied subsample from the photographic Palomar-Green (PG) survey (with high resolution spectroscopic follow-up for post-AGB candidates) and the SDSS spectroscopic database. The results show only two candidate post-AGB stars in a complete subsample of the PG survey spanning  $4200 \text{ deg}^2$  and one in the SDSS database. We discuss and explore any observational biases which may cause the result. If found to be truly representative of the halo population, one can expect the majority of Population II stars to fail to ascend the AGB and evolve through other evolutionary channels such as the extended horizontal branch.

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## INTRODUCTION

In the standard scenario, all low and intermediate mass stars should evolve up the asymptotic giant branch (AGB) and enter the white dwarf cooling sequence as post-AGB stars. It is known that extreme horizontal branch (EHB) stars become white dwarfs without an AGB/post-AGB phase but their numbers are estimated to be low [ $\sim 1\%$ , 1, 2, 3]. The number of known PNe and post-AGB stars in the galactic halo is quite small. The Torun catalogue [4] is the most complete compilation of known post-AGB stars. However, most of the objects included in this catalogue were detected due to their IR excess including all of the IRAS objects from [5]. This can be expected to introduce a bias in favour of higher mass pop. I post-AGB stars with dense envelopes. Only 20 objects in the catalogue are possible or probable pop. II stars.

Higher mass post-AGB stars have suffered from strong mass loss and are evolving quickly. As a result they can remain enshrouded in their circumstellar envelope during most of this phase. Extinction makes the star difficult to detect in the optical, but they are easily found by the IR surveys mentioned above. Low mass post-AGB stars (of pop. II) experience relatively small mass loss and evolve slowly. As a result little or no IR excess is expected, but the stellar radiation is essentially unabsorbed.

Classifying post-AGB stars is difficult as some types of object have a similar appearance. Examples include, horizontal branch stars (HB), extreme HB (EHB), post-EHB (pEHB) and hot, massive MS stars. Accurate parameters and sometimes only detailed chemical abundance analyses tells them apart from post-AGB stars. However, the number of stars contaminating the post-AGB region is expected to be small and our findings can only

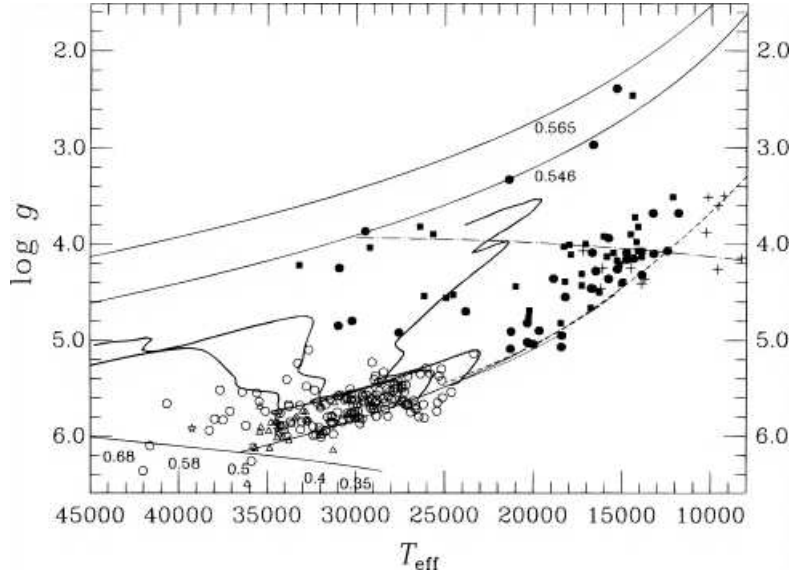
increase the number of objects found in the post-AGB region.

Here we describe the results of systematic searches for high galactic latitude post-AGB stars facilitating optical and UV data. Results are compared with expectations based on the standard scenarios and we discuss the implications.

## POST-AGB STARS IN HIGH GALACTIC LATITUDE SURVEYS

**Sloan Digital Sky Survey (SDSS):** SDSS performed an imaging survey of 12,000 square degrees of the northern sky, mostly with  $|b| > 10^\circ$ . An extensive spectroscopic database of over 1.6 million objects followed-up is available. In a brute force approach to identify post-AGB stars in SDSS we carried out Balmer line fitting of all objects bluer than  $g' - r' < 0.0$ . Quasars and other extra galactic objects were identified and discarded.  $T_{\text{eff}}$  and  $\log g$  of the remaining objects were compared with post-AGB tracks. In the end **only one** star remained with parameters compatible with a post-AGB nature. This is obviously at odds with any plausible estimate of post-AGB numbers. However, one has to have in mind possible biases in the selection of SDSS targets for follow-up. Such biases include some objects saturating, photometry not being unique and post-AGBs are low priority for follow-up. Some post-AGB objects are known in the SDSS survey area [4] but were not included in the spectroscopic database. This is likely due to one of the reasons mentioned above.

**Palomar-Green (PG) Catalogue:** In an effort to double check the completely unexpected outcome of our search of the SDSS database, we studied findings from the PG survey. This is a 10,714 square degrees photographic survey of UV-excess objects of high galactic latitude [6]. 1874 objects were selected for low resolution spectroscopic follow-up based upon the criteria  $U - B < -0.46$  and given a spectral classification. Due to the low resolution of the spectra the classifications were quite broad or mistakenly labelled HBB, sd, sdB and sdBO which with higher resolution follow-up later determined to be post-AGB, HBB, pHBB, pEHB, and pop. I and II main sequence stars. Saffer et al. [7] carried out intermediate resolution follow-up of a collection of stars categorised as above and the resulting  $T_{\text{eff}}\text{-}\log g$  diagram is shown in Fig. 1. The interesting objects for our study are the ten post-AGB candidates which are found near the [8] post-AGB tracks. However, also apparent from the other tracks are the ambiguity of the candidates with the hotter objects possible post-EHBs and other potential pop. I MS stars. Therefore, to confidently classify the different types, high resolution spectroscopy is required to determine chemical composition. In an effort to contain a complete sample for their study and prioritise objects for follow-up observations, [7] selected three fields (see Fig. 2) and a brightness limit  $B_{\text{PG}} < 14.7$ . Only three of the ten post-AGB candidates fulfill the criteria, PG1212+369, PG1243+275 and PG2120+062. The high resolution spectroscopy revealed that PG1212+369 had a close secondary component which it had probably interacted with, ruling it out as a post-AGB candidate [9]. PG1243+275 is metal-poor and its abundance makes it a strong post-AGB candidate. PG2120+062 was confirmed as a post-AGB star through its CNO depletion. Further details of the object can be found in [10]. Thus only two post-AGBs observed within the 4200 deg<sup>2</sup> region of sky followed-up for the complete sample. The position of all the candidates in the  $T_{\text{eff}}\text{-}\log g$  diagram suggests that they are low mass ( $M < 0.55M_\odot$ ). This is in agreement with observed mass



**FIGURE 1.** The  $T_{\text{eff}}$ - $\log g$  diagram of the followed-up PG region. This table is Fig. 5 in Saffer et al. (1997). The solid symbols are halo B-type star candidates and the squares are the complete sample (details in this and their paper). The evolutionary tracks from low to high gravity are firstly, the two solid lines are the post-AGB tracks of Schönberner (1983) for the stated masses. The dash-dot line is the pop. I ZAMS, the various dashed, dotted and undulating curves are HB and post-HB tracks with the solid He ZAMS at the bottom.

distributions for similar WD populations [11, 12].

## SYNTHETIC POPULATION PREDICTIONS

We generate a synthetic post-AGB galactic population using an adaptation of the WD Monte Carlo simulation of [13]. The simulation uses the galactic model structure of [14] to randomly assign locations of a large number of stars based on observed densities. Depending on population membership each star is given a metallicity, an initial mass and kinematical properties. Number densities of the three populations (thin disc, thick disc and halo) are calibrated with the local population based on the Supernova Type Ia Survey [SPY, 11, 15]. The evolution of each individual star up to the post-AGB phase is determined from the Padova evolutionary tracks [16] and refs. therein. The tracks give a metallicity range of  $Z=0.0001-0.1$  corresponding to a  $[\text{Fe}/\text{H}]$  of  $-2.3$  to  $0.95$ . This fully covers the range from observed populations which are reproduced in the simulation. All stars which are not old enough to have evolved to the tip of the AGB are discarded. The evolution of the remaining stars is followed through the post-AGB phase and the WD cooling sequence. We performed simulations using various mass and metallicity post-AGB tracks of [8], [17], [18], [19] and [20] to compute  $T_{\text{eff}}$  and  $\log g$ . The masses range from  $0.524-0.943M_{\odot}$  and metallicities  $Z=0.0005$  to  $0.04$  (equivalent to  $[\text{Fe}/\text{H}]=-1.6$  to  $0.3$ ). All post-AGB tracks used for our analysis see the star leave the AGB as hydrogen-burners. He-burners evolve slower and thus would produce an even higher number of observable stars. The higher mass post-AGB stars evolve much

**TABLE 1.** Simulated post-AGB population for various models in the region of the Saffer et al. (1997) complete sample.

Post-AGB Mass $M_{\odot}$	MS Mass $M_{\odot}$	MS Met. (Z)	N <sup>o</sup> thin disc	N <sup>o</sup> thick disc	N <sup>o</sup> halo	Total	Grid Ref.
0.524	1.00	0.021	11 ± 2	36 ± 4	160 ± 9	208 ± 10	[19]
0.546	0.80	0.021	13 ± 3	28 ± 4	59 ± 5	99 ± 8	[8]
0.565	1.00	0.021	0 ± 1	1 ± 1	13 ± 3	15 ± 3	[8]
0.605	3.00	0.021	0 ± 0	0 ± 1	16 ± 3	16 ± 3	[19]
0.569	1.00	0.016	1 ± 1	3 ± 1	97 ± 7	100 ± 7	[17]
0.597	1.50	0.016	1 ± 1	1 ± 1	32 ± 4	34 ± 4	[17]
0.633	2.00	0.016	0 ± 0	0 ± 0	9 ± 2	9 ± 2	[17]
0.530	1.20	0.008	1 ± 1	1 ± 1	34 ± 4	36 ± 4	[20]
0.531	1.00	0.004 <sup>α</sup>	0 ± 1	2 ± 1	37 ± 4	40 ± 4	[20]
0.533	1.20	0.004	1 ± 1	2 ± 1	35 ± 4	37 ± 4	[20]
0.623	1.50	0.001	0 ± 0	2 ± 1	35 ± 4	37 ± 4	[17]
0.663	2.00	0.001	0 ± 0	0 ± 0	6 ± 2	7 ± 2	[17]
0.534	1.00	0.0005 <sup>α</sup>	1 ± 1	2 ± 1	36 ± 4	39 ± 4	[20]
0.599	2.00	0.0005 <sup>α</sup>	0 ± 0	0 ± 0	3 ± 1	3 ± 1	[20]
Observed	–	–	0	0	2(?)	2	

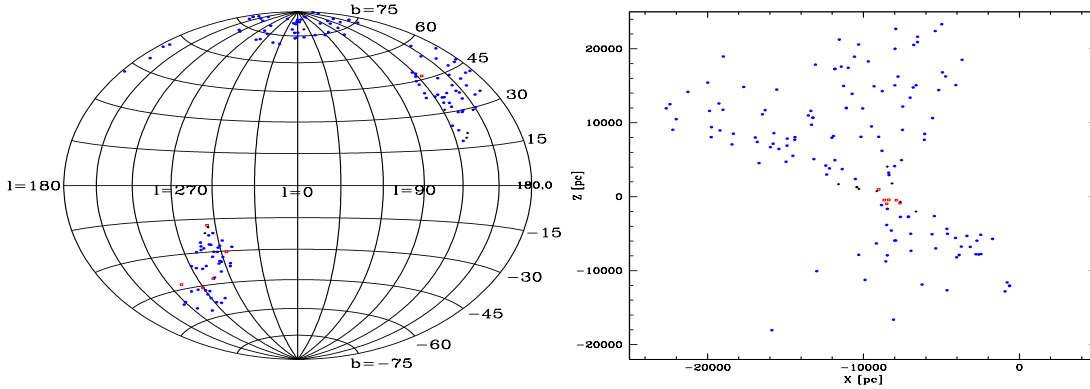
α indicates an α-enhanced initial composition.

quicker to hotter temperatures and so will spend less time on the top of the H-R diagram and resulting in less post-AGB stars at a given time. The final post-AGB population is normalised to the local WD population as described in [13].

**Simulation of the Complete PG Subsample:** We simulated the [7] sample of post-AGB candidates by selecting the stars from the same fields applying the same brightness limit ( $B_{PG} < 14.7$ ) as those for the complete sample defined in [7]. We applied a temperature criterion of 14,000–34,000K. This was defined at the low end due to the PG  $U - B$  cutoff criteria and the photometric uncertainty attached to this, and the top end by the hottest found post-AGB candidate in their sample. These criteria are conservative and can be interpreted as a lower limit on the number of stars which should be observed in that survey.

## THE RESULTS

The resulting post-AGB numbers differ greatly from one track to another and there is a general trend with mass and metallicity. Fig. 2 shows a simulated post-AGB population, within the brightness and positional criteria set out, assuming a mass of  $0.546M_{\odot}$ . We run the simulation for each post-AGB evolutionary track we have obtained and summarise the most relevant tracks in Tab. 1. The masses stated are the final post-AGB/WD and the initial ZAMS in their respective papers. The metallicities are the initial compositions of the stars on the MS. The numbers for each population and the total are given. The reference for the model used is stated in the final column. The original simulation contains a multiple of the evolved stars present in our galaxy. A normalisation factor is calculated and a random set of stars selected for the multi-Galaxy. This way 100 synthetic representations of the Galaxy are produced.



**FIGURE 2.** *Left:* An Aitoff-Hammer projection of the post-AGB population from the three selected complete regions in galactic coordinates. This example is for a  $0.546M_{\odot}$  assumed post-AGB mass. The red, square, open symbols represent thin disc post-AGBs, the black, filled, diamonds the thick disc and the blue filled circles the halo. *Right:* A spatial coordinate projection of the post-AGB population. Note the galactic centre is at vector  $[X,Z]=(0,0)$  and the objects converge to our Sun's position in the galaxy at approximately  $[X,Z]=(8500,0)$ .

## CONCLUSION

The observed PG subsample of [7] implies that there are very few post-AGBs in the halo and the ones that exist have low masses ( $M < 0.55M_{\odot}$ ). The masses are very much in agreement with halo WD mass distributions both within the Milky Way and other galaxies [11, 12]. However, our synthetic galactic model shows that the lower the mass of the central star (and progenitor) the slower the evolution and the number of stars meeting our brightness and temperature criteria will increase. This is displayed in Fig. 16 of [20]. In the same figure, a small metallicity effect can be seen and this is reflected in our numbers but this is fairly small effect at sub-solar metallicities. Our results suggest, as the observational fields are complete, the evolutionary paths or timescales for the majority of halo stars differ from the theory. Increasing the central star evolutionary speed across the HR diagram would bring the observed and theoretical populations in agreement, however, a PN would be a likely result. Even fewer PN are known in the halo than post-AGBs ruling out that option. An alternative solution is that the majority of evolved stars in the halo do not ascend the AGB. Obviously, this would reduce the expected number of post-AGB stars and would also be consistent with the HB post-AGB ratio observed in the [7] sample. A similar HB to post-AGB ratio is observed in M32 by [21]. Brown et al. [21] propose that this is unlikely due to an increase in evolutionary speed or circumstellar absorption. The post-AGB population may not be observed as they do not exist. Instead of ascending the AGB, the pop. II halo stars would evolve via the EHB and straight on to the WD cooling track. If this is the case for all such populations then there would be implications for subsequent galactic evolution.

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