THE O-RICH AGB SEQUENCE

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Abstract: One of the most fundamental questions that still remains open in the understanding of AGB stellar evolution is the interpretation of the well defined area occupied by oxygen-rich AGB stars in the IRAS two-colour diagram [12]–[25] vs. [25]–[60]. We have interpreted the sequence in terms of evolutionary stage and/or progenitor mass with the help of a recently studied very large sample of O-rich AGB stars (≈450 objects).

1 Introduction

Oxygen-rich AGB stars occupy a well defined area in the IRAS two-colour diagram [12]–[25] vs [25]–[60] (see Figure 1). In 1987 [1] interpreted for the first time the IRAS colours for O-rich AGB stars with increasing mass loss. The solid line in Figure 1 corresponds to the sequence of colours predicted by Bedijn which we have named the 'O-rich AGB sequence'.

It has been shown by several authors (e.g. [1, 2]) that the 'O-rich AGB sequence' reflects the increase of optical thickness of the circumstellar envelope (CSE), the objects with the thinnest CSE (O-rich AGB stars with bright optical counterparts) being placed in the bluest part of the sequence and those with the thickest CSE (O-rich AGB stars without optical counterparts) in the reddest part of this sequence.

However, this increase can be interpreted in two different ways: i) **evolutionary sequence** (e.g. [3]) with the mass-loss rate increasing with time: every star would start the AGB phase at the blue end of this sequence ([12]–[25] ≈ -1; thin CSE), and would later move while increasing its mass-loss rate until reaching the red extreme ([12]–[25] ≈ 1.5; thick CSE) at the end of the AGB; ii) **mass sequence**

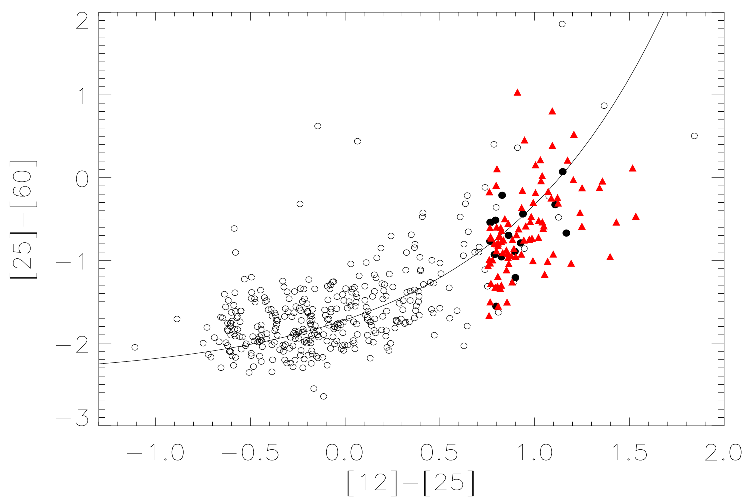

Figure 1: The position of the AGB stars in the sample in the IRAS two-colour diagram (open circles for the 'Arecibo sample'; filled triangles for the 'GLMP sample'; filled circles for the few objects in common). The solid line is the 'O-rich AGB sequence' (see text).

(e.g. [4, 5]): their different location would be just a consequence of their different initial mass, which would determine the mass-loss rate (assumed to be constant) experienced during the AGB phase. A third interpretation of the 'O-rich AGB sequence' was proposed by [6, 7], which is a combination of the previous ones: all O-rich AGB stars would move towards redder colours as they increase their mass-loss rate (and with it, the optical depth of their CSE), but only the more massive stars would be able to reach the reddest end of the sequence.

2 The sample

Recently, we have published the result of a large scale near-infrared photometric survey of two different samples of O-rich AGB stars [8, 9]: the 'Arecibo sample' (363) and the 'GLMP sample' (94). In total we compiled 457 stars providing a good coverage of the 'O-rich AGB sequence' (Figure 1). These two samples are complementary: the 'Arecibo sample' is mainly formed by objects from the blue part of the sequence, with a small contribution from very red sources, while the 'GLMP sample' contains exclusively sources in the redder part of the sequence.

Now we use this unique sample of O-rich AGB stars to improve our knowledge on the main properties of the stars populating the 'O-rich AGB sequence' and derive our own conclusions.

3 Luminosity, distance and galactic height

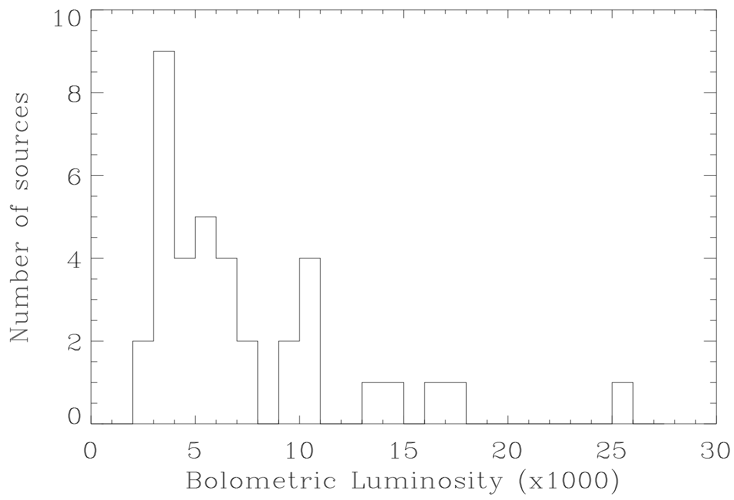

Figure 2: Absolute bolometric luminosity in thousands of $L_{\odot}$ of the O-rich AGB stars belonging to the Galactic Bulge population.

For all objects in the sample we have collected: J (1.25 μm), H (1.65 μm) and K (2.2 μm) photometric data from our own observations or from the 2MASS Point Source Catalogue (PSC); A (8.28 μm), C (12.13 μm), D (14.65 μm) and E (21.3 μm) flux densities from the MSX6C PSC; and 12, 25, 60 and 100 μm photometry from the IRAS PSC. Based on these data we have constructed their *Spectral Energy Distributions* from the near- to the far-infrared domain, and estimated the bolometric flux by integrating, and extrapolating toward both shorter and longer wavelengths. Although the error in the extrapolation towards both the blue and the red ends of the SEDs could be large, this only affects a minority of sources. This means that, in most cases, the main source of uncertainty has been their intrinsic variability. Adding up the two effects, the typical uncertainty is $\approx 40\%$.

The absolute luminosity of O-rich AGB stars is still subject to debate since different authors provide a different estimation of the mean luminosity of stars in this short transition phase. Also, one of the main problems to deal with when determining the absolute bolometric luminosity of O-rich AGB stars, as it also happens with PNe, is the determination of the distance.

In order to avoid or at least diminish the effect of this uncertainty we have selected 41 sources detected in the direction of the Galactic Bulge and assumed a common distance to all these sources equivalent to the generally assumed distance to the Galactic Center of ≈ 8 kpc [10]. Figure 2 shows the distribution of the absolute luminosities. Although a wide range of luminosities was found, however, the distribution is strongly peaked around $3\,500\,L_{\odot}$. This maximum is in good agreement with those found by other authors using different O-rich AGB star samples in the Galactic Bulge with very different (bluer) colours [11, 12, 13, 14, 15, 16] or using O-rich AGB star samples located in different parts of the Galaxy (solar neighborhood) [17].

Thus, we conclude that the luminosity function may be similar throughout the Galaxy and not very dependent on the colours of the star selected. Therefore, we estimated the galactic height for the rest of O-rich AGB stars by simply assuming a common and constant luminosity (L) of $3\,500\,L_{\odot}$ for all of them, as a first approximation to their real luminosity.

4 Interpretation of the O-rich AGB sequence

The IRAS two-colour diagram [12]–[25] vs. [25]–[60] has been proved to be an efficient and simple tool for discussing the properties of AGB stars. However, none of the two IRAS colours [12]–[25] or [25]–[60], alone considered, are adequate to describe the full range of positions covered by the 'O-rich AGB sequence' in this diagram.

In order to have a good descriptor for the whole 'O-rich AGB sequence', we have defined the λ parameter as the distance covered along the sequence, taking as starting point the position corresponding to the bluest object in the sample. This way each star in the sample has been assigned a λ value which corresponds to the nearest point in the 'O-rich AGB sequence'. Thus, low values of λ correspond with objects situated in the blue part of the sequence and high values with those situated in the redder part of it.

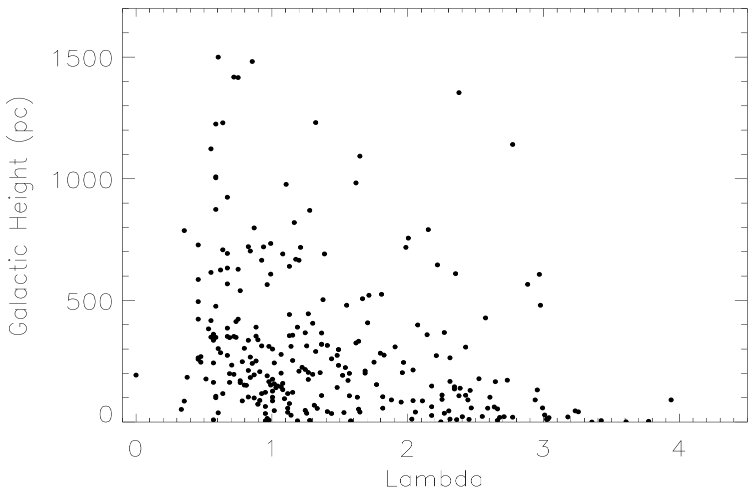

Figure 3: Galactic height (in absolute value) distribution as a function of λ derived for all disk sources in the sample ($L = 3\,500\,L_\odot$ assumed).

Figure 3 shows the distance to the galactic plane ($|z|$) as a function of the λ, excluding the galactic bulge subsample. We have found a very clear trend in the sense that sources with low values of λ have been found to show a wider distribution in galactic height, whereas sources associated to large values of λ have been found much more concentrated towards the Galactic Plane. This implies that the redder part of the 'O-rich AGB sequence' must be populated mainly with objects of higher mass. Note that assuming a different luminosity would just change the scale of the y-axis.

The expansion velocity (v_{exp}) of the CSE has been proposed to be correlated with the progenitor mass [18, 7]. v_{exp} was derived for the stars in our sample from the OH maser measurements. Figure 4 shows that there is also a very clear correlation between z and v_{exp} in the sense that there is a deficit of stars with high v_{exp} at high z. In addition, among the sources with low z most of them have high v_{exp}. This means that the objects with high v_{exp} in mean must have higher progenitor masses than those with low v_{exp}.

In Figure 5 we show that sources with high v_{exp} are found in all areas of the 'O-rich AGB sequence', while those with low v_{exp} are almost only associated to

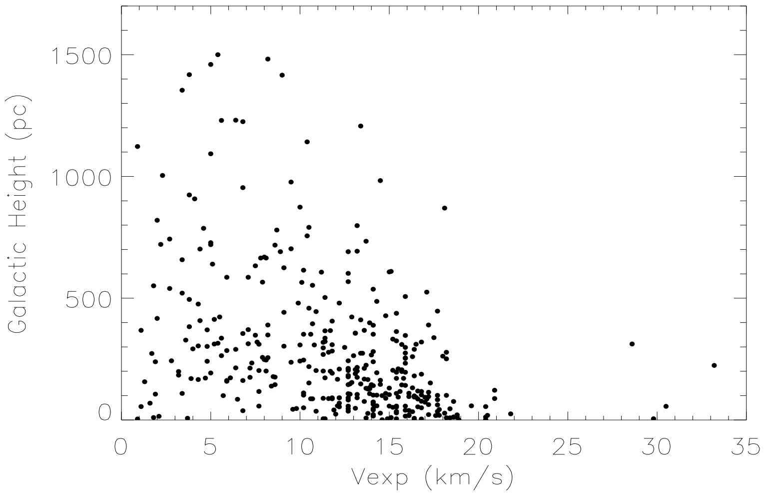

Figure 4: Galactic height (in absolute value) distribution as a function of v_{exp} for all disk sources in the sample ($L = 3\,500\,L_{\odot}$ assumed).

low values of λ.

We conclude that the red part of the 'O-rich AGB sequence' (high λ) is mainly populated by sources with higher progenitor mass. In contrast, the blue part of the 'O-rich AGB sequence' is populated by a combination of O-rich AGB stars of low and high progenitor mass. Since objects with low progenitor mass are almost not found at high values of λ, they must abandon the AGB phase without reaching the red end of the 'O-rich AGB sequence'.

The above results are only consistent with an evolutionary scenario in which **all O-rich AGB stars would start the AGB phase, independent of their progenitor mass, in the bluer part of the O-rich AGB sequence and then they would evolve toward redder colours, although only the more massive stars would reach the very end of the sequence**.

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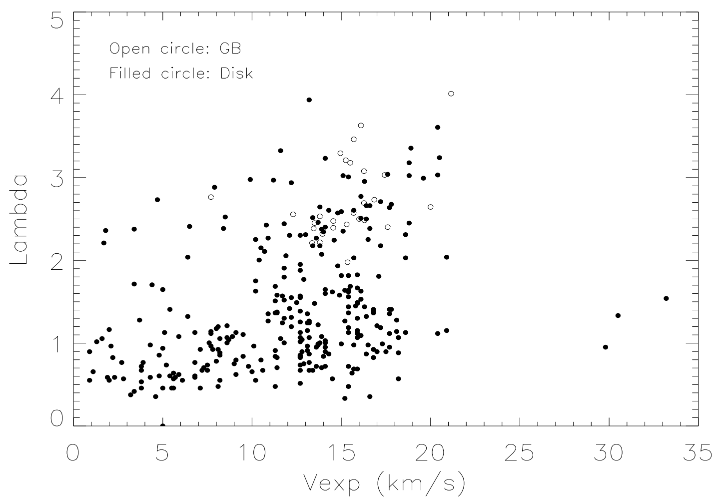

Figure 5: v_{exp} distribution as a function of the λ parameter for all sources in the sample, including those of the Galactic Bulge.

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