Why Galaxies Care About AGB Stars:
A Continuing Challenge through Cosmic Time
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AGB stars in *Gaia* DR2

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Abstract. *Gaia* Data Release 2 (DR2; April 25, 2018) provides astrometric and photometric data for more than a billion stars - among them many AGB stars. As part of DR2 the light curves of several hundreds of thousand variable stars, including many long-period variable (LPV) candidates, are made available. The publication of the light curves and LPV-specific attributes in addition to the standard DR2 products offers a unique opportunity to study AGB stars. In this contribution, we present the first results for AGB stars based on the analysis of the *Gaia* data performed after their release. As an immediate result of the *Gaia* DR2 LPV database we introduce a new photometric index capable of efficiently distinguishing AGB stars of different masses and chemical properties.

Keywords. stars: variability, stars: evolution, stars: AGB and post-AGB

1. Introduction

The *Gaia* all-sky survey is expected to add a major contribution to the study of the populations of long-period variables (LPVs) during its five-year nominal mission plus extensions, in particular by covering Galactic field and halo stars. These groups of stars can only be studied (Trabucchi *et al.* 2017) in a way comparable to the major Magellanic Cloud surveys done in the past (Ita *et al.* 2004, Soszinski *et al.* 2009) if the distance is obtained for the stars. Furthermore, the high level of completeness of LPVs expected from the *Gaia* survey will offer the opportunity to study, among other subjects, the frequencies of various groups of LPVs in the extended solar neighbourhood and other parts of the Galaxy. Thus, the *Gaia* database of LPVs will be unique and will provide a major step forward in understanding these variables.

Gaia Data Release 2 (DR2, *Gaia* Collaboration 2018) offers the first opportunity to provide a *Gaia* catalogue of LPV candidates to the scientific community. In this conference paper we present an overview on the first *Gaia* catalogue of LPVs published in DR2. Using this catalogue we developed a new photometric index capable of effectively distinguishing stars of various masses and chemistry on the AGB.

2. The *Gaia* DR2 catalogue of LPVs

This catalogue is described in detail in Mowlavi *et al.* (2018). We have put the priority to ensure an as-low-as-possible level of contamination, without targeting completeness.

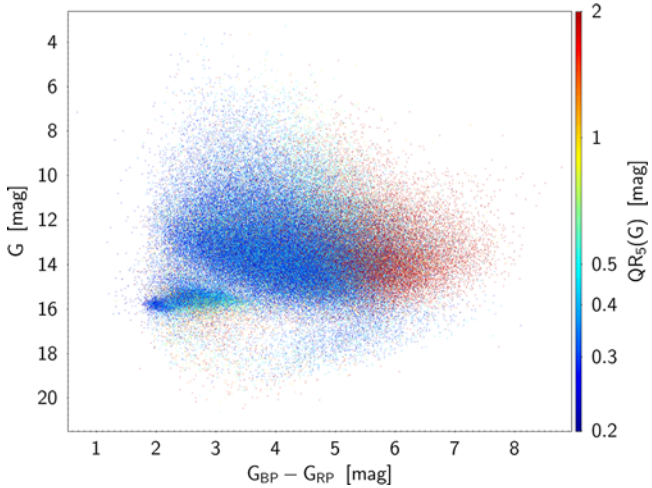

Figure 1. Colour-magnitude diagram of all LPV candidates published in *Gaia* DR2, with the 5–95% quantile range QR_5 of the cleaned G time-series shown in colour according to the colour scale drawn on the right of the figure. The clump observed around $G \simeq 15.6$ mag contains stars from the Magellanic Clouds, while the Sagittarius dwarf galaxy appears around $G \simeq 14.7$ mag.

Knowing that LPVs have periods that can exceed 1000 days, and given the limited 22-month coverage of DR2 combined with the temporal sparsity of *Gaia* measurements due to the spacecraft's scanning law, this first *Gaia* catalogue of LPV candidates is incomplete. We have limited the catalogue to Mira and semi-regular variables (SRVs) with variability amplitudes larger than 0.2 mag in the *Gaia* G-band. Small amplitude red giant variables, detected as a large group in the OGLE database, were excluded at this stage.

The catalogue contains 151 761 candidates. Already at this preliminary stage, the catalogue thus contains about twice the number of LPVs with amplitudes larger than 0.2 mag known before DR2. This shows the great potential of *Gaia* for the detection and characterisation of an even larger set of LPVs in future data releases.

Figure 1 shows the content of the catalogue in a colour-magnitude diagram. The colours extend from $G_{\rm BP} - G_{\rm RP} \simeq 2$ mag to $\sim$8 mag for the reddest LPV candidates. This spread in $G_{\rm BP} - G_{\rm RP}$ largely originates from extinction due to interstellar and/or circumstellar dust. The spread in G magnitudes, on the other hand, is largely due to distance effects. However, among these reddest stars in our sample we also find the large amplitude, Mira-like variables, which constitute about 20% of our catalogue. The LPV candidates from the Magellanic Clouds at $15 \lesssim G$ [mag] $\lesssim 16$ and $1.8 \lesssim (G_{\rm BP} - G_{\rm RP})$ [mag] $\lesssim 3.5$ clearly stand out. The tail of faint outliers visible below the main bulk of the distribution is a result of the magnitude threshold in $G_{\rm BP}$.

The *Gaia* DR2 database includes multi-epoch observations of each object covering a time span of up to 22 months. The resulting light curves in G, $G_{\rm BP}$, and $G_{\rm RP}$ can be extracted from the database as described in Mowlavi *et al.* (2018). In the course of the evaluation of the data, the light curves and derived quantities were compared with ground based observations from various surveys, showing satisfactory agreement.

Finally, the DR2 catalogue of LPVs gives bolometric corrections for all objects included based on their $G_{\rm BP} - G_{\rm RP}$ colour. We note, however, that in DR2 no discrimination was made between O-rich and C-rich stars. Therefore, this difference is not taken into account in the current data release. It has to be mentioned further that the parallaxes have to be seen as preliminary at the moment. Major improvements in these aspects are expected for the forthcoming data release 3.

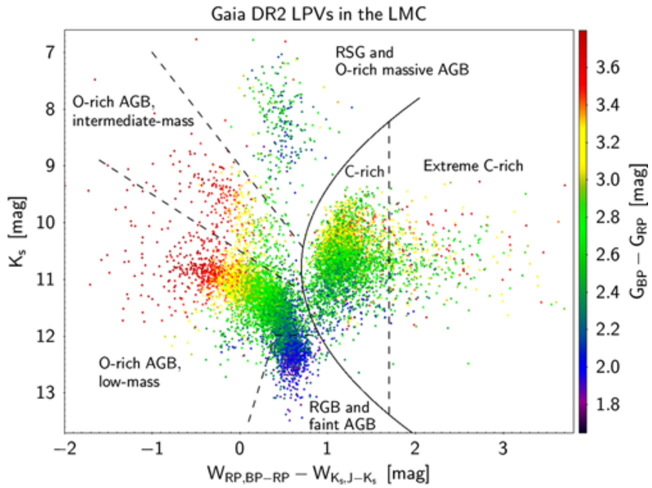

Figure 2. $W_{RP,BP-RP} - W_{K_s,J-K_s}$ versus K_s diagram of*Gaia* DR2 LPVs in the LMC. The markers are coloured with $BP - RP$ according to the colour-scale shown on the right of the figure. The solid line delineates O-rich (left of the line) and C-rich (right of the line) stars, and dashed lines delineate sub-groups as indicated in the figure.

3. A new method to identify subclasses among AGB stars

Large photometric surveys formed the base for fundamental steps forward in our understanding of the AGB evolution. With the *Gaia* catalogue we now have a deep, all-sky survey at hand. Here we report on a first result derived from this dataset, namely the development of a new photometric index useful for the distinction of AGB stars according to their mass and their evolutionary status. This distinction is challenging because the upper giant branch represents a mixture of objects of various masses and evolutionary stages.

As a starting point we selected LPVs belonging to the LMC in terms of sky positions, proper motions, and parallaxes ($\varpi < 0.5$ mas). All data were taken from the *Gaia* catalogue of LPVs described above. Their variability supported their identification as AGB stars. The sample was then cross-matched with the 2MASS catalogue. This allowed the construction of a combination of two Wesenheit functions, namely one using *Gaia* $G_{\rm BP}$ and $G_{\rm RP}$ photometry, and one using 2MASS J and K_s photometry. The final photometric index is of the form

$$W_{RP,BP-RP} - W_{K_s,J-K_s} = G_{\rm RP} - 1.3 \times (G_{\rm BP} - G_{\rm RP}) - K_s + 0.686 \times (J - K_s). \quad (3.1)$$

This index is thus a combination of three colours. It turns out to be very useful because of its different sensitivity to temperature changes for O-rich and C-rich stars. Details are described in Lebzelter *et al.* (2018). In Fig. 2 we plotted this index against K_s. Note that this is not a colour-magnitude diagram in the classical sense since the hottest stars are found in the centre of the x-axis, while cooler stars are found on the left side (if O-rich) or right side (if C-rich) of the diagram.

The various branches in Fig. 2 can be associated with various mass ranges with very little ambiguity. This fact allows the use of this diagram to separate AGB stars according to this parameter and to compare predictions from models with observed populations for studying both stellar evolution and the star formation history. In Fig. 3, the high diagnostic capability of the new diagram is corroborated with the help of state-of-the-art stellar evolution models (`PARSEC` and `COLIBRI` – see Marigo *et al.* 2017 for details).

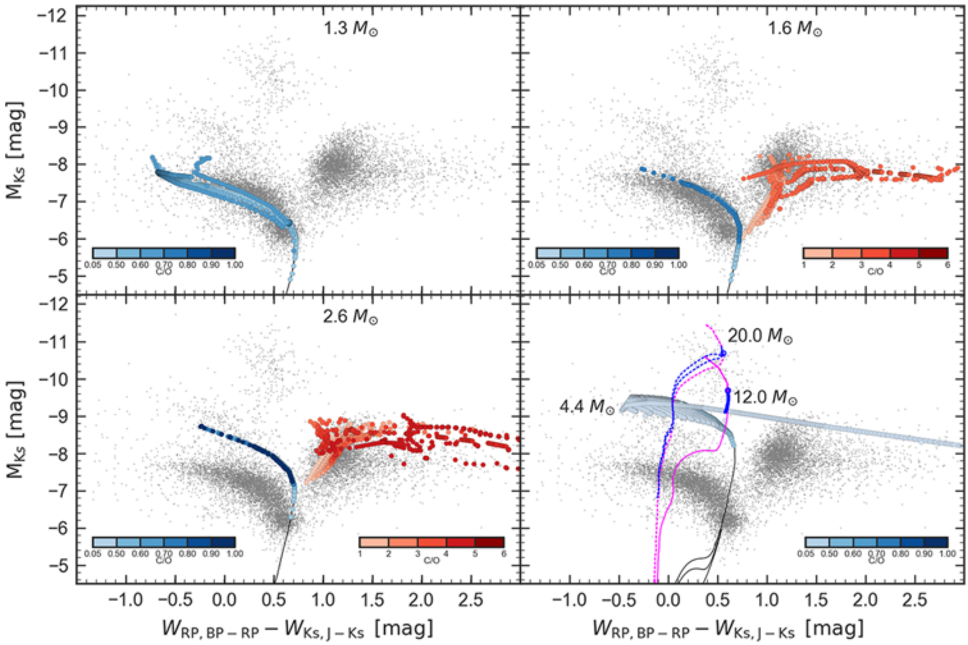

Figure 3. Location of stellar evolutionary tracks computed with the PARSEC and COLIBRI codes for a few selected values of the initial mass (as indicated). The initial metallicity is $Z = 0.006$ for the tracks with $M_i = 1.3$, 1.6, 2.6, and 4.4 $M_\odot$, and Z = 0.008 for the massive ones with $M_i = 12$ $M_\odot$ (solid line) and 20 $M_\odot$ (dashed line). The TP-AGB phase is color-coded according to the surface C/O ratio, while the previous evolution is shown with a black line.

4. Conclusions

The first *Gaia* catalogue of LPVs provides the scientific community with a photometric and astrometric database greatly expanding the known number of AGB variables with amplitudes >0.2 mag. While the quality of the results is going to be highly improved in future *Gaia* data releases, this data set already allowed the construction of a new photometric index that is very efficient for identifying AGB stars according to their mass and C or M star status. Further investigation of this index is currently under way.

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Discussion

Menzies: Can you indicate how the distribution of points would change in $(W_{\rm RP} - W_{K_s})$ vs. K_s diagram for a metallicity much less than for the LMC?

Lebzelter: We did some first tests for the *Gaia* sample of the SMC and Sgr DSph. The structure we see in the $(W_{RP,BP-RP} - W_{K_s,J-K_s})$ vs. K_s diagram is the same, but the distribution of stars within the diagram is different.