Why Galaxies Care About AGB Stars:
A Continuing Challenge through Cosmic Time
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The composition of Barium stars and the s-process in AGB stars

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Abstract. Using abundances from the available largest, homogeneous sample of high resolution Barium (Ba) star spectra we calculated the ratios of different hs-like to ls-like elemental ratios and compared to different AGB nucleosynthesis models. The Ba star data show an incontestable increase of the hs-type/ls-type element ratio (for example, [Ce/Y]) with decreasing metallicity. This trend in the Ba star observations is predicted by low mass, non-rotating AGB models where ^{13}C is the main neutron source and is in agreement with Kepler asteroseismology observations.

Keywords. stars: abundances, nuclear reactions, nucleosynthesis, abundances, stars: AGB and post-AGB

1. Introduction

Barium stars are chemically peculiar giants and dwarfs with spectral classes from G to K. These stars are in binary systems where the primary star (a former AGB, now a white dwarf) polluted the companion with *s*-process enhanced material. Since these elements were synthesised during the TP-AGB evolutionary phase, Ba stars can be used to probe AGB *s*-process nucleosynthesis. The temperatures of Ba stars (from over 4000K up to 6500K) are higher than those of late AGB stars ($\simeq$ 3000–4000K), meaning that their spectra is easier to model because of the absence of molecular features in their spectra. Another advantage of using Ba stars instead of AGBs is that many dynamical processes can be present in the atmospheres of AGB stars (such as pulsations, mass loss, and also dust formation) which makes the modelling more complicated (Abia *et al.* 2002, Pérez-Mesa *et al.* 2017).

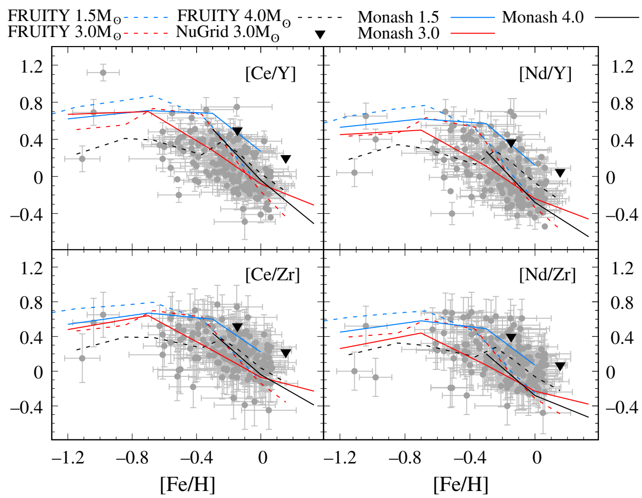

Figure 1. Final surface abundances of different AGB nucleosynthesis models compared to the available hs-like to ls-like elemental ratios for the Ba star sample of de Castro *et al.* (2016). Monash label indicates the models from Karakas & Lugaro (2016) and Fishlock *et al.* (2014), while FRUITY stands for models from Cristallo *et al.* (2015). We show also 3 $M_\odot$ type He07 models from Battino *et al.* (2016) for comparison. The dots without error bars represent stars where at least one of the elements have less than three lines. All the models shown here are in the mass range of Ba stars and have [s/Fe] ⩾ 0.25 dex.

The efficiency of the *s*-process has been measured using the abundances of the ls (light-*s*) and hs (heavy-*s*) indexes, taken as the average of different elements belonging to the first (Sr, Y, Zr) and second (Ba, La, Ce, Nd, Sm) *s*-process peaks, respectively. However, the availability and accuracy of the abundances of these elements vary in different studies. Using the largest set of homogeneous observational data of Ba stars published by de Castro *et al.* (2016) we are moving forward from the use of ls and hs to directly use the available elements.

2. Data sample

The largest, self-consistent determination of *s*-process element abundances in Ba giants with masses from 1 to 6 $M_\odot$ was published by de Castro *et al.* (2016). In this study a star was considered as Ba star if the limit of [s/Fe] ⩾ 0.25 was reached. This values was calculated as the arithmetic mean of [La/Fe], [Ce/Fe], [Nd/Fe], [Y/Fe] and [Zr/Fe]. Using this homogeneous sample (169 Ba stars in total) we calculated proper errors for the first time for different hs-like to ls-like elemental ratios for each individual star (Cseh *et al.* submitted) instead of using an average value and typical error for the [hs/ls] ratio.

3. Results and conclusions

All of the four calculated combination of hs-to-ls elemental ratios ([Ce/Y], [Ce/Zr], [Nd/Y], [Nd/Zr]) and the calculated error bars based on the sample of de Castro *et al.* (2016) were compared to different AGB nucleosynthesis models. A spread of about a factor of 3 is apparent in the data, indicating that other effects may be present, such as variations in the initial mass of the AGB, magnetic field or rotation.

The four available elemental ratios show a clear increasing trend with decreasing metallicity and are in agreement with the model predictions. All of the models shown in Fig. 1 are the final surface abundances and have [s/Fe] ⩾ 0.25, the same limit as was used for the Ba stars. This value is reached after the first few thermal pulses in the most cases,

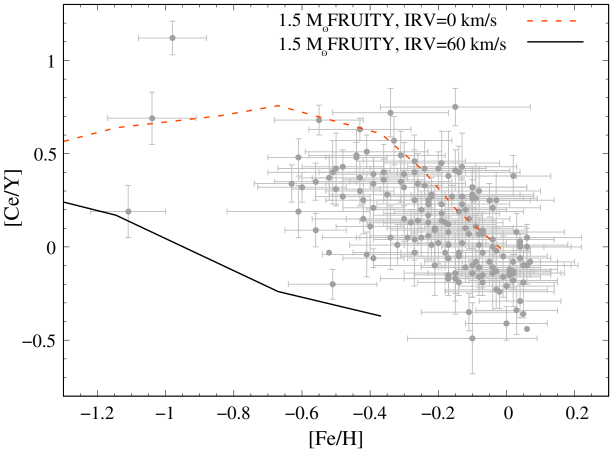

Figure 2. Comparison for [Ce/Y] between the Ba stars and the 1.5 M$_\odot$ rotating and non-rotating (IRV = initial rotational velocity) FRUITY models (Cristallo *et al.* 2015, Piersanti, Cristallo & Staniero 2013). The dots without error bars represent stars for which there are less than 3 lines for one of the elements. All the models shown here have [s/Fe] $\geqslant$ 0.25 dex.

indicating that a Ba star could formed even if the mass transfer occured before the AGB reached the last thermal pulse.

The 1.5 M$_\odot$ rotating models with initial rotational velocity of 60 km/s (Piersanti, Cristallo & Staniero (2013)), producing enough *s*-process elements ([s/Fe] $\geqslant$ 0.25), are shown with their non-rotating counterparts in Fig. 2. The production of [Ce/Y] in the rotating models is much lower than those observed in Ba stars, indicating that strong mixing within the ^{13}C pocket of their AGB companions should not occur. Kepler asteroseismology observations of the cores of red giant stars and of white dwarfs (the ancestors and the progeny of AGB stars, respectively) show low core rotational velocities (Hermes *et al.* 2017), which is in agreement with the independent results from the Ba star data. This points out the need for the existence of a mechanism for angular momentum transport in giant stars, but without mixing the chemical species.

4. Future work

We will continue the analysis of this set of Ba star data with other elements (C, O, and further heavy elements) and compare with other Ba star observations. The possible effect of dilution after the mass-transfer was also not taken into account here. Furthermore, we are planning to compare the observations of different other *s*-process enhanced stars (C, CEMP-, CH- and post-AGB stars) with the Ba star sample in order to identify the signature of other effects (such as the *i*-process).

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