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Isotopic ratios of C, O and light element abundances in AGB stars undergoing Hot Bottom Burning

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Abstract. We present preliminary results of an on going project aimed to study CNO isotopic ratio variations that are expected to arise from third dredge-up and hot-bottom burning in highly evolved intermediate-mass (M$\geq$ 4 M$_\odot$) AGB stars. We perform an abundance analysis from high resolution near infrared spectra of Galactic O-rich (and a few C-rich) AGB stars. Stars are selected according to different observational properties considered as a proxy of a large stellar mass. Abundances of Li, F, Na, Mg and Al, elements which may be altered by the operation of hot bottom burning, are also derived. We compare the abundance results with predictions from state-of-the-art intermediate-mass AGB models.

Key words. Stars: abundances – Stars: AGB – Stars: nucleosynthesis

1. Introduction

It is widely accepted for some time that intermediate-mass AGB stars ($\geq$ 4 M$_\odot$) develop deep convective envelopes with very high temperatures at the base (T$_{BCE}$ $>$ 40 $\times$ 10^6 K), allowing for nuclear burning (Scalo, Despain, & Ulrich 1975). This temperature is high enough for activation of the CNO cycle. Because the convective envelopes of AGB stars are well mixed, this hot bottom burning (HBB) can dramatically alter the surface composition. During HBB the CN cycle comes quickly into equilibrium, as a consequence ^{12}C is substantially depleted (which prevents the formation of a carbon star); ^{15}N and ^{18}O are also destroyed to produce ^{14}N; ^{13}C and ^{17}O are mildly enhanced whereas ^{19}F is destroyed. If T$_{BCE}$ exceeds $\sim$ 70 $\times$ 10^6 K, the Ne-Na and Ma-Al chains can be also activated producing some ^{23}Na and ^{24}Mg depletions together with ^{25,26}Mg and ^{27}Al enhancements (e.g. Karakas & Lattanzio 2014). In addition, the production of ^{7}Li is also thought to occur in HBB through the Cameron-Fowler mechanism (Cameron & Fowler 1971). In fact, the Li enhancements found in luminous O-rich AGB stars in the Magellanic Clouds and the Galaxy are still the most compelling observational evidence that HBB is occurring in intermediate-mass AGB stars (Smith, & Lambert 1990; Plez, Smith, & Lambert 1993; García-Hernández et al. 2007). Note, however, that the enhancement in this element is predicted to exist during a limited period of time during the AGB phase, and that Li can be produced by other mechanisms not necessarily linked to HBB (Ventura 2000; Palmerini et al. 2011). Thus, Li abundances have to be interpreted as an indirect (average) evidence of the HBB operation.

Excluding Li abundances, few additional observational evidence exist on HBB: MacSaveney et al. (2007) derived large N enhancements and C deficiencies in two luminous O-rich stars in the LMC, while Justtamont et al. (2015) recently report the absence of $H_2^{18}O$ lines in several extreme galactic OH/IR stars implying very large $^{16}O/^{18}O$ ratios. These findings are compatible with the operation of HBB, but the lack of further observational constrains difficult the modeling of HBB. Indeed theoretical predictions are extremely sensitive to the adopted stellar mass-loss rate, treatment of the convection and mixing (instantaneous-, diffusion-, advection-like etc), and thermonuclear reaction rates. In consequence, the exact stellar mass range where HBB migth take place and its dependence on the stellar metallicity, mass-loss etc, is basically unknown (see e.g. Karakas & Lattanzio 2014). The aim of this study is to put some light in this issue by deriving CNO isotopic ratios and light element abundances (Li, F, Na, Al) is a sample of (presumed) intermediate-mass Galactic AGB stars.

2. The stellar sample

In our study the stellar mass is a critical parameter as we should include in the sample only stars massive enough to undergoing HBB ($\geq 4\ M_\odot$), at least theoretically. In the Galaxy, only for a few field AGB stars, their luminosities (distances) are known accurately enough to determine the masses. Isochrone fitting to color-magnitude diagrams of Galactic globular clusters reveals that stars now in the AGB phase are not massive enough to undergoing HBB. Thus, we have to rely on indirect properties which are commonly used as proxies of stellar mass. Namely, we selected long period (log P> 2.5), large amplitude variables (up to 8-10 mag in the V band) O-rich (and a few C-rich) AGB stars. Studies of AGB in the Magellanic Clouds indicate that there is a positive correlation between stellar mass and period (e.g. Whitelock 2012). Many of the selected stars are well known OH/IR stars, which distribution on the galactic disk corresponds to a massive population (Baud & Habing 1983). Furthermore, a correlation exists between the OH maser expansion velocities of these stars and their Galactic latitude in the sense that high expansion velocity ($v_{exp} > 6$ km s^{-1}) stars statistically are found at very low latitude. IRAS colors were used also in the selection of the targets since redder colors can be interpreted as the consequence of a more massive population of AGB stars since in principle they should be able to develop thicker circumstellar envelopes even at a relatively early stage in their AGB evolution. Together with these criteria, stars showing s-element enhancements were preferably chosen since this is a clear indication of thermally pulsing AGB stars undergoing TDU episodes. Using at least one of the above selection criteria, we finally selected a sample of about 50 Galactic AGB stars, most of them are included in the studies by Little, Little-Marenin, & Bauer (1987) and García-Hernández et al. (2007).

3. Analysis and results

Stellar spectra were obtained at the 3.5 m TNG telescope using the echelle spectrograph GIANO. This spectrograph provides the HJK near-infrared bands in only one shot with a resolving power R$\sim$ 45000. Despite the gaps between orders, the wavelength coverage includes the main CO molecular bands in the K-band where $^{12,13}C^{16,17,18}O$ features can be identified. These bands, together with a few OH and CN lines in the 1.5 and 2.3 μm region (see e.g. MacSaveney et al. 2007) allows the determination of the carbon, nitrogen and oxygen absolute abundances, which are critical for the computation of the synthetic spectrum. Some Na, Al, Mg and HF lines, spread out in the wavelength region covered, were used to derive the abundances of these light elements (see e.g. MacSaveney et al. 2007; Abia et al. 2010),

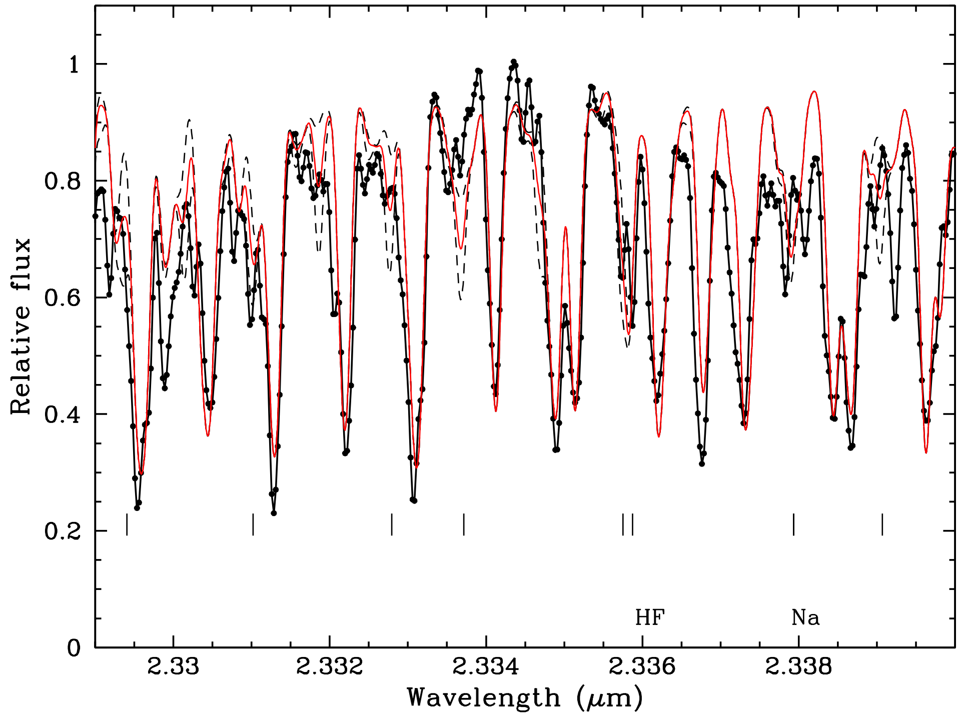

Fig. 1. Comparison between the observed (black line with circles) spectrum of the O-rich AGB star YZ Peg in the 2.3 μm region with theoretical spectra computed for different $^{16}O/^{17}O$ ratios: best fit (red line) and with $^{16}O/^{17}O$= 300, and no ^{17}O (dashed lines), respectively. Some $^{12}C^{17}O$ features are marked together with the HF and NaI lines at λ2.33583 and λ2.33789 μm, respectively.

Table 1. Abundances for the AGB stars in this study

Star	C/O	$^{12}C/^{13}C$	$^{14}N/^{15}N$	$^{16}O/^{17}O$	$^{16}O/^{18}O$	Lights	HBB
WX Cyg	1.01	4	10	463	610	Li↑	No
YZ Peg	0.77	40	–	570	560	solar	No
V1415 Aql	0.30	20	–	> 600	> 1000	solar	?
V1416 Aql	0.90	> 35	–	800	400 – 700	F↓	No
V697 Her	0.45	30	–	–	> 1000	Li↑	?

while Li abundances were taken from the literature. Synthetic spectra in LTE were computed with the Turbospectrum code (Plez 2012) using MARCS spherical atmosphere models with different C/O ratios (Gustasson et al. 2008; Van Eck et al. 2017). The effective temperature for our stars range 2600-3300 K. We adopted a gravity log g= 0.0 and solar metallicity for all the stars. The microturbulence parameter estimated was ξ = 2 – 5 km s^{-1}. Theoretical spectra were convolved with a Gaussian function to mimic the instrumental profile, which includes a macroturbulence parameter typically 9 – 12 km s^{-1}. Figure 1 shows the comparison between the observed and theoretical spectra for one of the O-rich stars in the present analysis (YZ Peg) in the spectral region where the $^{16}O/^{17}O$ ratio is derived. Fluorine and sodium abundances can be estimated also from this spectral region (see marked features in the figure). Table 1 shows the final CNO isotopic ratios derived in the stars analyzed up to date. The nitrogen isotopic ratio is only derived in the carbon star WX Cyg using CN lines from an independent spectrum in the 8000 Å region. The CN features present in the HJK-bands are not sensitive enough to variations in this ratio, thus unfortunately this ratio cannot be derived in our stars. The column with the header *Lights* indicates the most significant abundance figures found in a particular star concerning Li, F, Na, Mg, and Al (in this case Li enhancement or fluorine depletion). When *solar* is quoted, this means that the abundances derived of these elements are compatible with a solar ([X/H]$\simeq$ 0.0) value. Last column in the table indicates whether the abundances and isotopic ratios derived are consistent with theoretical predictions if HBB is at work. From the table, only V1415 Aql and V697 Her show isotopic ratios compatible with expectations; in particular because their ^{12}C and $^{17,18}O$ depletions. Obviously, the analysis of the remaining stars in the sample will provide us a clear picture on the operation of HBB and its consequences on the surface abundances of AGB stars. Stay tuned.

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