Why Galaxies Care About AGB Stars:
A Continuing Challenge through Cosmic Time
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S-process Elements in Binary Central Stars of Planetary Nebulae

Lisa Löbling[1,2] and Henri Boffin[1]

[1]European Southern Observatory,
Karl-Schwarzschild-Str. 2, 85748 Garching bei München, Germany
email: lloebling@eso.org

[2]Institute for Astronomy and Astrophysics, Kepler Center for Astro and Particle Physics,
Eberhard Karls University, Sand 1, 72076 Tübingen, Germany

Abstract. Low- and intermediate-mass stars experience a phase of carbon enrichment and slow neutron-capture nucleosynthesis (s-process) on the asymptotic giant branch. An interesting element is the radioactive technetium, whose presence is a clear indication that nucleosynthesis happened recently. Analysing the element abundances not only in the hot evolved stars at the center of planetary nebulae helps to derive constraints for the evolution of these stars. Doing so also in their companions if they are in a binary, provides information on the mass-transfer history.

Keywords. planetary nebulae: individual: Hen 2−39 – stars: abundances – stars: evolution – AGB and post-AGB stars – chemically peculiar stars: barium-stars

1. Introduction

Barium (Ba) stars are polluted with asymptotic giant branch (AGB) nucleosynthesis products like carbon (C) and s-process elements from an evolved companion via (wind-)Roche-lobe overflow (RLOF, Jones & Boffin 2017). Hen 2−39 hosts a binary with a red giant companion dominating in the visible. Miszalski *et al.* (2013) determined an enrichment in C and Ba placing this star in the small group of five known Ba central stars of planetary nebulae (Ba-CSPNe).

Technetium (Tc), the lightest element without stable isotopes, is found in evolved stars and must be synthesised in late stages of stellar evolution, since the half-life of ^{99}Tc of 210 000 years is much shorter than the time spent as a giant. The analysis of the Tc surface abundance of the Ba-CSPN may provide the mass-transfer link between the binary components. Taking into account typical post-AGB ages of CSPNe of some 10^3 years (Miller Bertolami 2016) and the short duration of dynamical mass transfer of only hundreds of years (Iben & Livio 1993), a large fraction of the transferred ^{99}Tc must still be present in the stellar atmosphere.

2. Analysis and Results

Observations, Analysis Techniques, and Atomic Data. We analysed optical spectra obtained with the Ultraviolet and Visual Echelle Spectrograph (UVES) at the Very Large Telescope (VLT). For synthetic spectra, we used SPECTRUM (Gray & Corbally 1994) based on ATLAS9 (Castelli & Kurucz 2003) model atmospheres. Tc data was taken from the atomic spectra database of the National Institute of Standards and Technology (NIST) and from Palmeri *et al.* (2007).

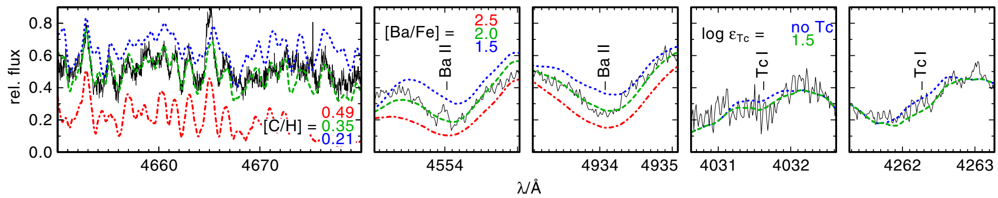

Figure 1. Observation (solid line) compared to model spectra for regions of absorption due to C with [C/H] = 0.49, 0.35, 0.21 dex (red dash-dotted, green dashed, blue dotted), Ba with [Ba/Fe] = 2.0, 1.5, 1.0 dex, and Tc with $\log \epsilon_{\mathrm{Tc}} = 1.5$ (green dashed) and without Tc (blue dotted).

Fundamental Parameters. We determined $T_{\mathrm{eff}} = (4260 \pm 170)$ K from characteristic lines of Fe I, Fe II, Ti I, Ti II, Sc I, and Sc II. The surface gravity $\log g$ could not be constrained by a fit of these lines and a spectroscopic determination is hampered by uncertain values for the distance and brightness. Thus, we adopted a typical value of $\log(\mathrm{g/cm/s^2})$ = 2.5 for the giant. This approach seems reasonable since a change of $\Delta \log g = 0.5$ does barely affect the derived abundance values compared to the statistical error limits.

Element Abundances. The region of strong C_2 absorption (4650 - 4737 Å) yields [C/H] = 0.35 ± 0.02 dex (Fig. 1). Using Ba II λλ 4554.0, 4934.1, 5853,7, 6141.7, 6496.9 Å, we determined [Ba/Fe] = 2.0 ± 0.3 dex (Fig. 1). Absorption features at Tc I λλ 4031.6, 4095.7, 4238.2, 4262.3, 4297.1 Å appear in the computed spectra but cannot be identified in the observation. We found an upper abundance limit of $\log \epsilon_{\mathrm{Tc}} = 1.5$ ($\log \varepsilon_{\mathrm{X}}$ are normalized to $\log \sum \mu_{\mathrm{X}} \varepsilon_{\mathrm{X}} = 12$, Fig. 1).

Comparison with AGB Models and Mass-Transfer History. We compared the determined abundances to the yields of nucleosynthesis models from Karakas *et al.* (2018) with a metallicity of $Z = 0.0028$. With the observed and calculated enrichment factors for C, we get $\Delta M_2 / M_{2,\mathrm{env}} = 0.4$ for the envelope $M_{2,\mathrm{env}}$ and the accreted mass ΔM_2. To reproduce the observed Ba enrichment, the required [Ba/Fe] = 2.5 dex for the donor is only almost reached for the model with an initial mass of 2.5 $M_{\odot}$. Assuming this mass for the AGB star, the companion should have $M_{\mathrm{ini}} = 1.5$ - 1.9 $M_{\odot}$ to be a red giant, which would have a convective envelope of about 1.2 - 1.6 $M_{\odot}$. Thus, it needs to have accreted 0.46 - 0.64 $M_{\odot}$ which equals the amount of mass lost by the AGB star in the last thermal pulse demanding quasi-conservative mass transfer. Model calculations of Iaconi *et al.* (2017) support that this can be obtained in RLOF. Alternatively, a quasi-conservative wind-RLOF (e.g., Chen *et al.* 2017) may be possible.

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