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The TGAS HR diagram of S-type stars

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Abstract. S-type stars are late-type giants enhanced with s-process elements originating either from nucleosynthesis during the Asymptotic Giant Branch (AGB) or from a pollution by a binary companion. The former are called intrinsic S stars, and the latter extrinsic S stars. The atmospheric parameters of S stars are more numerous than those of M-type giants (C/O ratio and s-process abundances affect the thermal structure and spectral synthesis), and hence they are more difficult to derive. Nevertheless, high-resolution spectroscopic data of S stars combined with the TGAS (Tycho-Gaia Astrometric solution) parallaxes were used to derive effective temperatures, surface gravities, and luminosities. These parameters allow to locate the intrinsic and extrinsic S stars in the Hertzsprung-Russell diagram.

Keywords. S stars, AGB stars, TGAS, HR diagram

1. Introduction

S stars are late-type giants showing ZrO molecular bands along with TiO bands as the most characteristic distinctive spectral features (Merrill 1922). The C/O ratio of S stars ranges from 0.5 to 1 suggesting that they are transition objects between M-type giants (C/O ~ 0.5) and carbon stars (C/O > 1) on the Asymptotic Giant Branch (AGB) (Iben and Renzini 1983). Their spectra show signatures of overabundances in s-process elements (Smith and Lambert 1990).

The evolutionary status of S stars as AGB stars was challenged when Tc lines (an s-process element with no stable long-lived isotope) were reported as missing in some S stars (Merrill 1952; Smith and Lambert 1986; Jorissen *et al.* 1993). This puzzle regarding the evolutionary status of S stars was solved when it was perceived that the Tc-poor S stars belong to binary systems (Smith and Lambert 1986; Jorissen *et al.* 1993). S stars may therefore be classified into two different classes: Tc-rich as intrinsic S stars that are genuine thermally-pulsing AGB (TP-AGB) stars and Tc-poor as extrinsic S stars that owe their s-process element overabundances to a mass transfer from a former AGB companion which is now a white dwarf. They are the cooler analogues of barium stars.

The thermal structure of the atmospheres of S stars depends on effective temperature ($T_{\rm eff}$), surface gravity (log g), [Fe/H], C/O as well as [s/Fe] (s-process element abundances). The abundance analysis of S stars requires a reliable determination of all these stellar atmosphere parameters.

† This work has made use of data from the European Space Agency (ESA) mission *Gaia* (https://www.cosmos.esa.int/gaia), processed by the *Gaia* Data Processing and Analysis Consortium (DPAC, https://www.cosmos.esa.int/web/gaia/dpac/consortium). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the *Gaia* Multilateral Agreement.

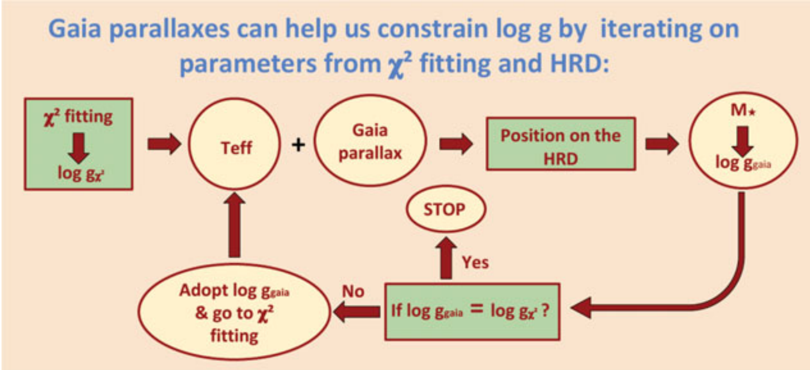

Figure 1. Algorithm adopted to constrain log g, comparing the location of the stars in the HR diagram with the evolutionary tracks from the STAREVOL code.

2. Stellar sample and parameter determination

Our sample consists of S stars from the General Catalog of S stars (Stephenson 1984) with $V \leqslant 11$ and $\delta \geqslant -30°$, thus observable with HERMES (High Efficiency and Resolution Mercator Echelle Spectrograph, mounted on the 1.2m Mercator Telescope at the Roque de Los Muchachos Observatory, La Palma; Raskin *et al.* 2011). Furthermore, a condition is imposed on the TGAS parallaxes (Gaia Collaboration 2016), considering only those stars with a small error on the parallax ($\sigma_{\varpi} \leqslant 0.3\varpi$). With these conditions, the sample amounts to 18 S stars.

The stellar parameters are derived using the MARCS grid of atmospheric models for S stars (Van Eck *et al.* 2017) containing more than 3500 models covering the parameter space in $T_{\rm eff}$, log g, [Fe/H], C/O and [s/Fe] ratios. The comparison between observed and synthetic spectra is then performed by a χ^2-fitting procedure, summing over all spectral pixels in spectral bands approximately 200 Å wide. The model with the lowest χ^2 value is chosen as the best fitting model.

The distance and luminosity of these stars are derived from the TGAS parallaxes. Comparison between the positions of the stars in the HR diagram constructed from TGAS parallaxes with the evolutionary tracks from the STAREVOL code (Siess and Arnould 2008) yields the mass, hence the surface gravity of our stars (log $g_{\rm Gaia}$). Because log $g_{\rm Gaia}$ and log g derived from the χ^2 fitting do not always agree, we derive a new surface gravity estimate as explained in Figure 1. This iteration on the stellar parameters ensures that the adopted log g is consistent with the TGAS parallaxes.

3. HR diagram of S stars

The temperatures obtained after constraining log g with the TGAS parallaxes lead to the HR diagram of S stars presented in Figure 2. Intrinsic S stars are cool and luminous objects likely on the TP-AGB in the HR diagram. On the other hand, the extrinsic S stars are hotter and intrinsically fainter on the early AGB or red giant branch (RGB) except for HD 150922 and HD 191226 which seem more evolved in the 4-6 $M_\odot$ range. Also, the intrinsic S star on the 1 $M_\odot$ track is intriguing because the third dredge-up is expected to occur only for masses larger than 1.3 $M_\odot$ according to stellar evolution predictions (Karakas and Lugaro 2016). Nevertheless, the occurrence of the third dredge-up for low mass stars (<1.3 $M_\odot$) was also found in low-luminosity s-process-rich post-AGB stars (De Smedt *et al.* 2015). The evolutionary tracks have a strong metallicity dependence, impacting on the mass determination. Spectral analysis to constrain [Fe/H] is ongoing.

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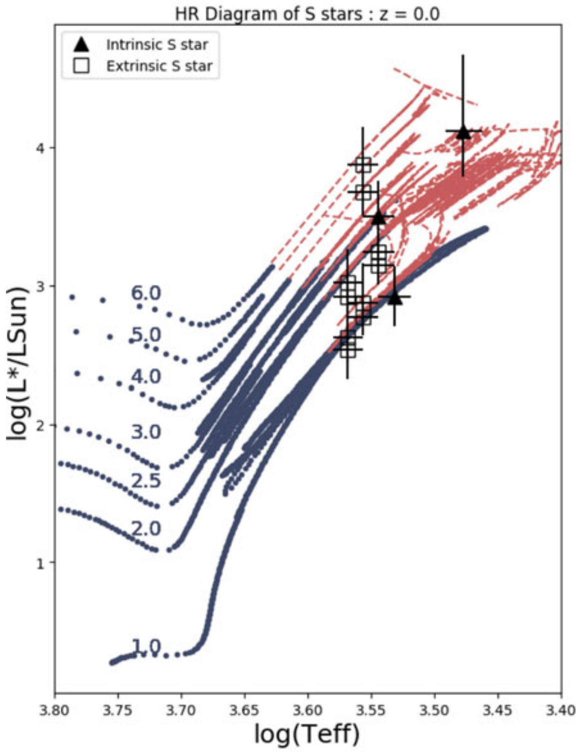

Figure 2. HR diagram of S stars with STAREVOL evolutionary tracks for [Fe/H] = 0.00. The dark blue dotted tracks represent pre-AGB phases and the pink dashed tracks represent the AGB phase.

4. Conclusion

The S stars set strong constraints on mixing and nucleosynthesis processes in AGB stars. However, it is difficult to probe the onset of third dredge-up with TGAS data since there are only 3 intrinsic S stars (identified from the analysis of their Tc lines) as yet. This is due to the limitations of Gaia DR1 on red sources which put a bias against the very evolved and red intrinsic S stars.

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