Spectroscopic and photometric characterization of evolved stars with substellar companions

Camila Zuloaga (1,2), Emiliano Jofré (1,2), Romina Petrucci (1,2), Eder Martioli (3)

(1) Observatorio Astronómico, Universidad Nacional de Córdoba (OAC-UNC), Argentina, (2) Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Argentina, (3) Laboratório Nacional de Astrofísica (LNA), Brasil

Introduction

It is now widely accepted that **FGK main-sequence (MS) stars with giant planets are more metal-rich than those without planets** (e.g., Fisher & Valenti 2005), a result known as the **planet-metallicity correlation** (PMC). On the contrary, studies conducted on red giant stars with planets show that they do not follow the same trend observed in main sequence stars (e.g., Jofré et al., 2015a), and more recently, it's been suggested that the PMC does not seem to be present in solar-type MS stars hosting brown dwarfs (BDs, e.g., Maldonado et al., 2017). This would suggest that brown dwarfs could form by processes that don't depend on the metallicity of the star, such as gravitational instability mechanism. However, in **evolved red giants (RGs)**, whose MS progenitors are dwarfs more massive than FGK stars, **the role of metallicity in the formation of BDs is not well studied.** Furthermore, detailed spectroscopic analysis of evolved stars has allowed the **identification of several RGs with chemical anomalies in several elements**, which may be caused by external contamination events (e.g., Jofré et al., 2015a).

Additionally, the analysis of high-precision Kepler photometric data has shown that **a large number of evolved stars exhibit not only flares but also periodic modulation produced by cold spots** (e.g., Gaulme et al., 2020). However, **little is known about this type of activity in RGs with BDs**.

In this context, we present a **detailed spectroscopic and photometric analysis of a small sample of RGs hosting substellar objects from high-resolution Gemini spectra and high-precision photometric data from the TESS space mission.**

Observations

We performed spectroscopic observations of a small sample of RGs with BDs that were obtained with **GRACES instrument** (Chene et al., 2014) at 8.1 m **North Gemini telescope**. The spectra reach a resolution of R~68000 between 400 and 1000 nm, and signal-to-noise ratio S/N ~ 320.

The photometric data of the same red giants were obtained from the **TESS mission** (Ricker et al., 2015). All available two-minute cadence light curves were extracted and normalised using Lightkurve package (Lightkurve Collaboration 2018). These were determined using Pre-search Data Conditioning Simple Aperture Photometry (PDCSAP) and processed by the "Science Processing Operations Center" pipeline (SPOC; Jenkins et al., 2016).

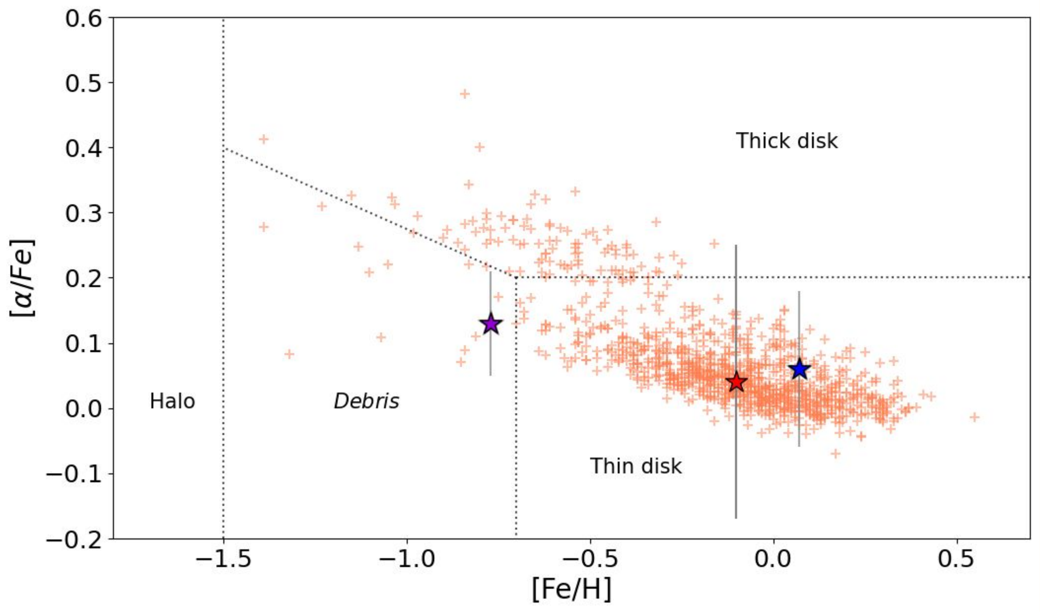

Figure 1 [Fe/H] vs. [α/Fe] for the HARPS GTO stars (Adibekyan et al. 2011; orange crosses). The blue, red, and violet stars represent the location of the three RGs studied in this work. The black dashed lines delineate different components of the Milky Way according to Navarro et al. (2011).

Methodology

Stellar parameters and chemical abundances determination: Atmospheric parameters —temperature (Teff), surface gravity (log g), metallicity ([Fe/H]), and microturbulent velocity (vt)— were derived from the equivalent widths of iron lines by imposing spectroscopic equilibrium conditions (e.g., Jofré et al., 2020). Also, we estimated chemical abundances of 18 species (Li, O, Na, Mg, Al, Si, Ca, Sc I, Sc II, Ti I, Ti II, V, Cr I, Cr II, Mn, Co, Ni, Zn) in addition to Fe, from equivalent widths, using the q2 code (Ramírez et al., 2014).

Searching for periodic photometric variability: Lomb-Scargle (LS; Scargle 1982, VanderPlas, 2018) periodogram was used to search for a rotational period due to cold spots on the TESS light curves using Astropy package (Astropy Collaboration 2022). As maximum and minimum frequencies, we used the inverse of twice the cadence of the data and the inverse of the duration of a half-sector observation, respectively. The resulting periods were then evaluated according to most of the criteria defined by Petrucci et al. (2024) to confirm the astrophysical origin of the signals detected.

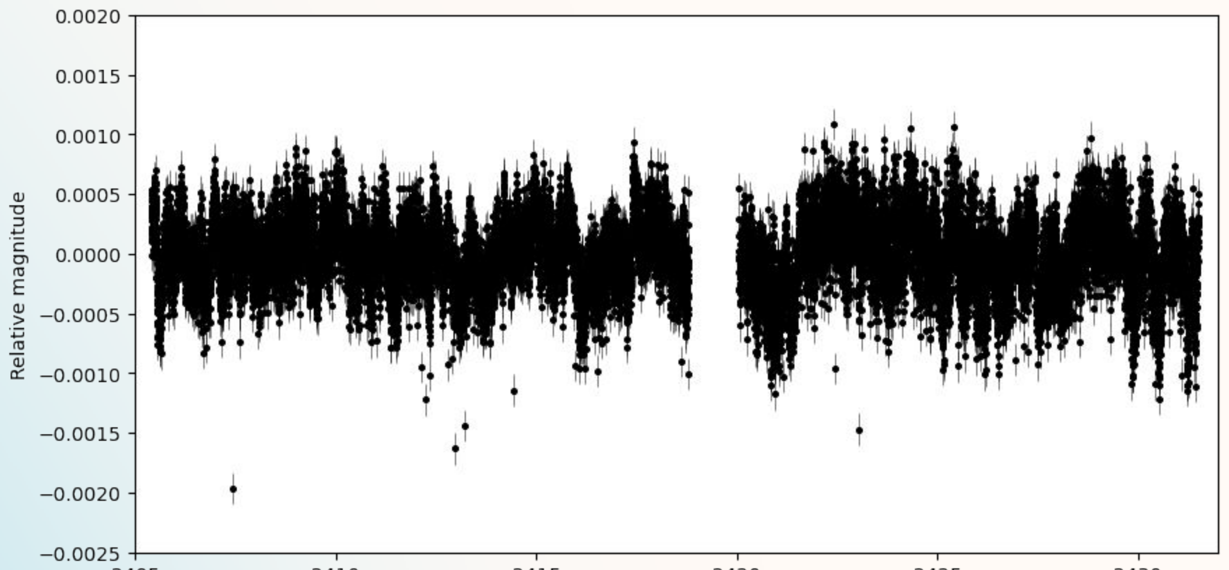

Figure 2 Extract of the TESS light curve obtained for one of the RGs of the sample, corresponding to sectors 40 and 41.

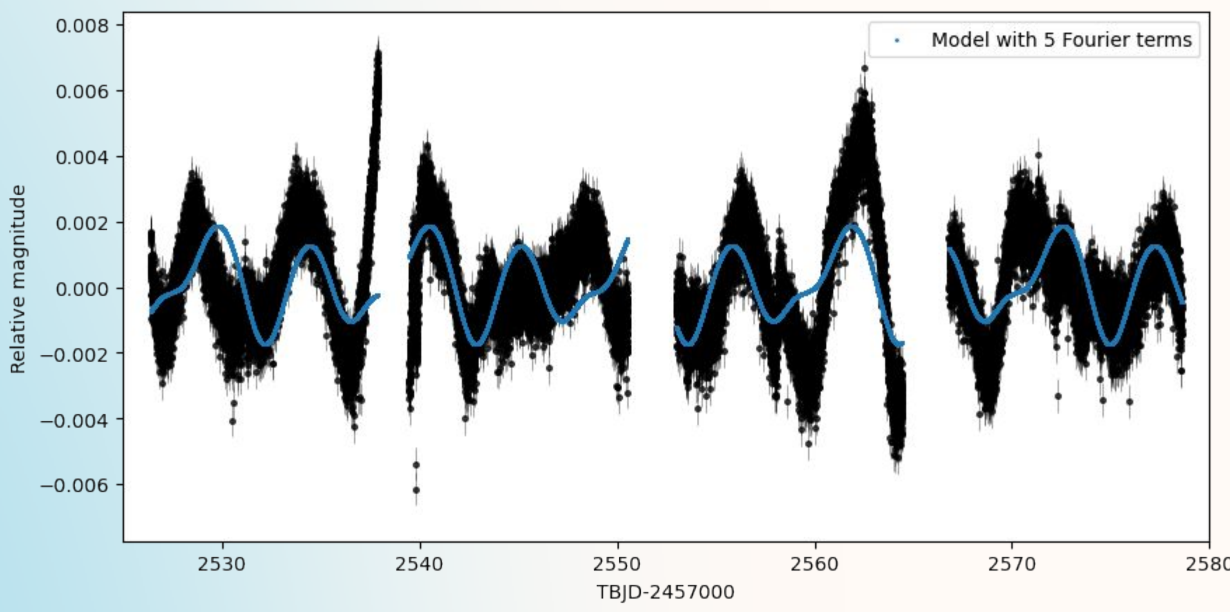

Figure 3 Extract of the TESS light curve of one of the RGs of the sample corresponding to sectors 45 and 46 (black dots) together with the model with 5 Fourier terms found through the DF method (solid blue line).

Results and discussion

Searching for chemical anomalies: Figure 1 shows the location of the three RGs studied in this work in the in [α/Fe]-[Fe/H] plane, along with a sample of stars from the HARPS GTO program (Adibekyan et al., 2012a). According to the classification given by Navarro et al. (2011), two of them are located in the thin-disk stars region, while the other is located in a region called Debris. This zone is formed by high-metallicity and alpha-poor halo stars. Moreover, this region would be composed of the remnants of dwarf galaxies accreted by the Milky Way.

Searching for periodic photometric variability: Figure 2 shows an extract of the TESS light curve obtained for one of the RGs studied in the work. The execution of the periodogram in its light curve did not yield any frequency or period that satisfied most of the conditions mentioned in Petrucci et al. (2024). In the case of the second one, using the method of Fourier Decomposition (DF; Deb & Singh, 2009), we fitted a model consisting in 5 Fourier terms (Figure 3; blue line), and detected a period of P = 10.7 ± 1.04 days. Also, we found that the light curve of this RG has similarities with pulsating OSARGs (OGLE Small Amplitude Red Giants), a type of pulsating star defined by the OGLE catalogue (Wray et al., 2004). Finally, we did not analyze the photometric data of the last RG of the sample because it is saturated in the TESS field, which requires a more complex analysis of its light curves.

Metallicity in red giants with BDs: To analyze the metallicity of giants with BDs (GWBDs) we constructed a sample of 8 GWBDs, including the values found for two of the RGs in the sample that belong to the thin disk, and the GWBD from the work of Maldonado et al. (2017). Comparing the average metallicity of this GWBD sample ([Fe/H] = -0.09 ± 0.19 dex) with the literature samples of giants with and without planets, our results suggest that GWBD are not metal-rich, implying that GWBD do not follow de PMC.

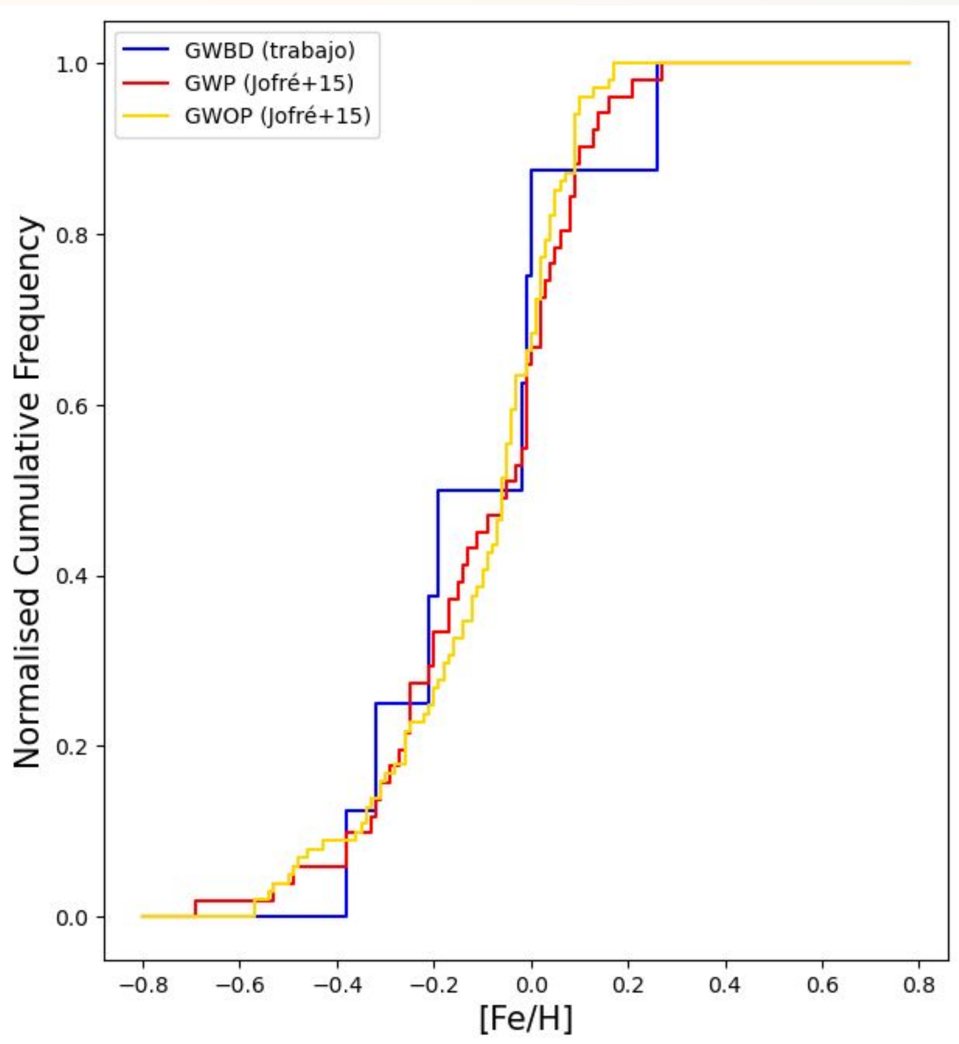

Figure 4 Cumulative frequency distribution of [Fe/H] for the GWBD (blue) compared to GWP (giants with planets, red) and GWOP (giants without planets, yellow) from Jofré et al. 2015b.

Future work

This work is part of the author's PhD thesis. Future plans include extending the detailed spectroscopic and photometric analysis to a larger sample of GWBDs, determining lithium and other elemental abundances through spectral synthesis, and applying advanced tools, such as the Period04 software, for the detection of multiperiodic variability, among other ongoing studies.

References

Adibekyan V. Z., et al., 2012a, A&A, 543, A89

Astropy Collaboration et al., 2022, ApJ, 935, 167

Chene, A., Padzer, J., Barrick, G. et al. 2014, Proc. SPIE, 9151 ,47

Deb S., Singh H. P., 2009, A&A, 507, 1729

Jenkins J. M., et al., 2016, in Chiozzi G., Guzman J. C., eds, Society of Photo-Optical Instrumentation

Jofré E., et al., 2015a, A&A, 574, A50

Lightkurve Collaboration et al., 2018, Lightkurve: Kepler and TESS time series analysis in Python, Astrophysics Source Code Library

Maldonado J., Villaver E., 2017, A&A, 602, A38

Navarro J. F., et al., 2011, MNRAS, 412, 1203

Petrucci R. P., et al., 2024, MNRAS, 527, 8290

Ramírez I., et al., 2014, A&A, 572, A48

Ricker G. R., et al., 2015, Journal of Astronomical Telescopes, Instruments, and Systems, 1, 014003

Scargle J. D., 1982, ApJ, 263, 835

VanderPlas J. T., 2018, ApJS, 236, 16

Wray J. J., et al., 2004, MNRAS, 349, 1059