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Chemical anomalies in solar twins

Pollution from a former Asymptotic Giant Branch companion

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Abstract. The analysis of the chemical composition of solar twins reveals that some stars are chemically anomalous. The observed anomalies are enhancements in heavy elements produced by the slow neutron-capture process (s-process). Such a signature is characteristic of mass transfer from an Asymptotic Giant Branch (AGB) star. The excess in s-process elements is evidence that these stars may have been polluted by material ejected from a AGB companion with initial mass of $\sim 3M_{\odot}$, which is now a white dwarf (WD). We suggest that HIP 67620 and HIP 64150 are blue stragglers who likely experienced mass transfer with a former AGB.

Resumo. A análise da composição química de estrelas revelou que algumas gêmeas solares são quimicamente anomalas. Excessos nas abundâncias de elementos pesados produzidos pelo processo lento de captura de nêutrons (processo-s) é assinatura característica da transferência de massa de uma estrela do Ramo Assintótico de Gigantes (AGB). Os elementos do processo-s são evidências de que estas estrelas podem ser poluídas pelo material ejetado por companheira AGB com massa inicial de $\sim 3M_{\odot}$, que agora é uma estrela anã branca. Sugerimos que HIP 67620 e HIP 64150 são *blue stragglers* que sofreram transferência de massa de uma AGB.

Keywords. Stars: white dwarf — (Stars:) solar type — (Stars:) blue straggler

1. Introduction

The search for planets around solar twins by our group SAMPA using ESO's HARPS spectrograph yielded high resolution and high signal-to-noise spectra. The analysis of the chemical composition of our sample revels that some stars are chemically anomalous, besides showing high rotation and chromospheric activity (dos Santos et al., 2017). These chemical signatures are observed as characteristic of nucleosynthesis from an AGB companion star. The composition of the solar analogues suggests that mass was transferred to the main sequence star during the super winds phase when the AGB star was experiencing thermal pulses. The mass transfer resulted in the solar-type's atmosphere being polluted with the products of the slow-neutron capture process (s-process; Desidera, D'Orazi & Lugaro, 2016).

The solar twins HIP 67620 and HIP 64150 show enhanced abundances of s-process elements (Spina et al., 2018). Therefore they could be blue stragglers who likely experienced mass transfer with a former AGB companion (Schirbel et al., 2015). Blue stragglers are objects bluer than main sequence turn off point, so they look younger than stars in a cluster. Binary field stars also can be rejuvenated by mass accretion from a companion, which also results in an increase in the rotational velocity and chromospheric activity (Zurlo et al., 2013).

The mass ejected by slow winds from an AGB star can be extended up to separation larger than several hundreds of solar radii (Zurlo et al., 2013). Therefore, despite the distance of tens of astronomical units between the stars, the winds ejected matter that was accreted and diluted in the convective zone of the solar twin atmosphere. We do not know the sort of mass transfer that occurred but it is likely to be wind accretion. As a result the star spin-up and it may also explain the observed beryllium depletion in these binary systems (Desidera, D'Orazi & Lugaro, 2016).

2. Previous work

Creep et al. (2013) observed the nearby Sun-like star HIP 64150 using high-contrast imaging with the Keck telescope in the J and K bands and they discovered a faint companion star. The only self-consistent interpretation of photometric and dynamical measurements point towards a white dwarf (WD) companion. The constrain of the effective temperature, mass and cooling age from Spectral Energy Distribution (SED) are different and disagree for all fitted theoretical models. Furthermore, there is an apparent conflict with the age of the primary star.

Matthews et al. (2014) took photometric observations including L band $(3,7\mu m)$ measurements using the Large Binocular Telescope. Astrometry for a WD companion to HIP 64150 in terms of angular separation reveal systemic orbital motion and our Gemini data follows the trend. They modeled the star photometry using atmospheric compositions of pure hydrogen or pure helium. The synthetic flux of the best-fitted model revealed that the optical region differs significantly for predicted SED, therefore measurements in this region are important.

Bacchus et al. (2017) presented the first near infrared spectrum of the faint WD companion of HIP 64150. The SED fitted to the data were computed for hydrogen pure or helium pure atmospheres. They showed two broad results: an extremely cool, low mass, H atmosphere WD or an unusually high mass, hot WD with a third brown dwarf companion. Therefore, further analysis are needed to unveil the nature of the HIP 64150 system.

The probability distribution of the companion mass for the HIP 64150 was computed by dos Santos et al. (2017), it is consistent with the Creep et al. (2013) analysis that combined radial velocities and imaging data indicating a $0.26M_{\odot}$ minimum mass. The value obtained by Matthews et al. (2014) using SED fitting for the HIP 64150 WD companion was $0.54M_{\odot}$. The predicted WD mass for a star that experienced thermal pulses and it produced s-process elements is above $0.51M_{\odot}$ (Kong et al., 2018).

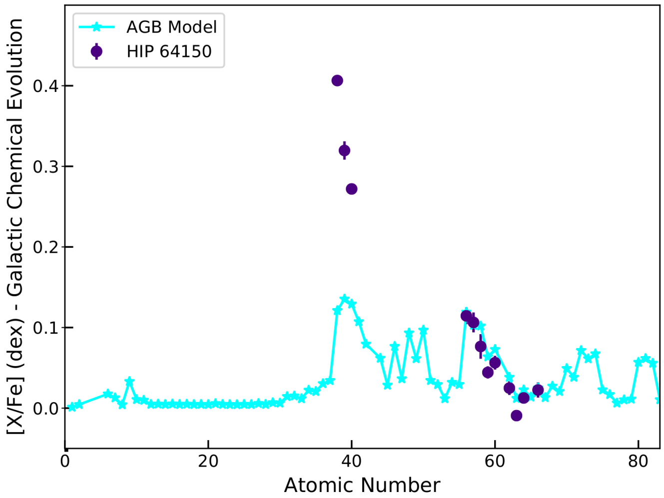

Figure 1. Abundance of neutron-capture elements as a function of atomic number. We subtracted the effects of the chemical evolution of the Galaxy, therefore the observed enrichment is likely due to a former AGB companion. There are not a good match for the light n-cpature elements though. The cyan curve corresponds to model after all thermal pulses from a $3.25 M_{\odot}$ AGB progenitor and the points are HIP 64150.

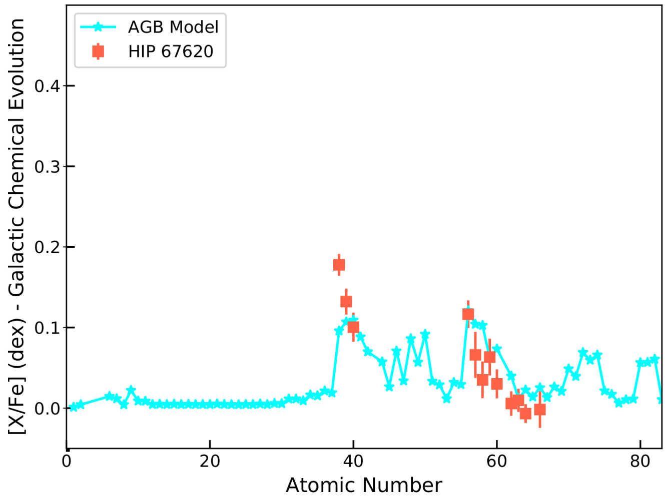

Figure 2. Same as Fig. 1 for a $2.75 M_{\odot}$ model and HIP 67620.

There are no previous studies of HIP 67620, but the radial velocities and the orbital solutions are evidence for a binary or multiple system likely with a WD companion. Further evidence of this are the anomalous [Y/Mg] abundance and heavy neutron-capture elements found by our group (Tucci-Maia et al., 2016).

3. Method

The abundances obtained for the anomalous solar twins were subtracted from the Galaxy's chemical evolution pattern of neutron-capture elements, fitted by Spina et al. (2018), to determine the excess in abundances at a given age. The values are close to zero in normal solar twins, but for the two anomalous stars there is an excess for elements produced by the slow process of neutron-capture that could be evidence for pollution by material ejected from a AGB companion, now a WD star.

To analyze the measurements we computed the nucleosynthesis models of AGB stars using the *Stromlo* code, that produces a rich region with ^{13}C pockets needed to activate the main source of neutrons by the $^{13}C(\alpha, n)^{16}O$ reaction. ^{13}C pockets are only included in models with mass up to $5 M_{\odot}$; more massive models are predicted not to form ^{13}C pockets for reasons discussed in Karakas & Lugaro (2016). Without ^{13}C pockets AGB models do not form s-process elements in the quantities observed in real AGB stars. For this reason, some form of extra mixing is required in AGB models in order to achieve a ^{13}C-rich region, where neutrons can be released. For details of the method used in the Stromlo models we refer to Karakas & Lugaro (2016).

These models calculated the evolution of the star from the main sequence to the tip of the AGB, and through all thermal pulses and mixing events (Karakas & Lugaro, 2016). Uncertain mass loss prescriptions determines the final stellar mass and the resulting initial-final mass relation. From these models the ejected yields can be calculated. The pollution from the AGB star to the solar twin was modeled by considering that a fraction of ejected the yields from the evolved star was accreted and diluted in the convective zone of the solar twin star.

4. Results and conclusion

The best fit to the solar twins HIP 64150 (Fig. 1) and HIP 67620 (Fig. 2) indicated reasonable agreement to the strontium and barium peak, for AGB progenitors what were $3.25 M_{\odot}$ and $2.75 M_{\odot}$, respectively. The mass estimate of the WD progenitor is needed to infer the total mass loss and to verify what is the best available parameterization in stellar evolutionary models. These analyses are important to determine the parameters of the binary systems and it can provide a rigorous test on the isochronal ages.

The excess in s-process elements is evidence that these solar twin stars may have been polluted by material ejected from a AGB companion with initial mass of $\sim 3 M_{\odot}$, now a WD star. Furthermore, this mechanism is relevant to determine the age of the primary star by comparison with the WD age added to the age of its progenitor, to obtain the total age of the system.

We were awarded with photometric and spectroscopic observations using the coronographic method in the near infra-red - YJHKs to observe the companion star of the HIP 67620 using the Gemini South Telescope with the GPI instrument. There are also public data from the SPHERE/VLT to the HIP 64150 (Claudi et al., 2016). Future work will be to use a SED to infer the temperature, gravity, cooling time and mass from WDs cooling models, then we intend to find an initial to final mass relation to identify the mass loss and stellar parameters. Furthermore, this method is relevant to determine the age of the primary star (solar twin) by comparison with the WD age added to the age of its progenitor, to obtain the total age of the system.

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