Unraveling the planet metallicity correlation in evolved stars

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Twenty years after the discovery of the first exoplanets, most of our current knowledge on planet formation is still based on observations of main-sequence stars, in particular, the correlation between the metallicity of the star and the presence of giant planets. Last years have been fruitful in discovering a wide variety of planets around evolved stars opening for the first time the possibility of testing planet formation in a very different environment. Although several attempts to study the properties of evolved stars with planets have been made, they are mainly based on small or inhomogeneous samples. In this contribution we present the results of a high-resolution spectroscopic survey which includes, to our best knowledge, the best combination so far between homogeneous analysis and sample size.

Notation: GWPs (giants with planets) / GWOPs (giants without planets) / SGWPs (subgiants with planets) / SGWOPs (subgiants without planets) / LMWPS (late main-sequence with planets) / MSWPs (main-sequence with planets) / Purple colours: GWPs and $M_* > 1.5\ M_{Sun}$ (GWPs below $1.5\ M_{Sun}$ remain in blue) / Filled symbols: planet hosts

Observations, sample, and analysis

Our sample contains 142 evolved stars from which 70 are known to host at least one planetary companion. High-resolution spectra of the stars were obtained at La Palma observatory (Canary Islands, Spain) using the HERMES spectrograph at the MERCATOR telescope and the FIES instrument at the NOT telescope.

The basic stellar parameters Teff, logg, microturbulent velocity and [Fe/H] are determined using the code TGVIT (Takeda et al. 2005) which is based on iron-ionization and excitation conditions. Chemical abundances of individual elements (Na, Mg, Al, Si, Ca, Sc, Ti, Mn, Cr, V, Co, Ni, Zn) are obtained by using the WIDTH9 program (Castelli 2005) together with ATLAS9 plane-parallel LTE model atmospheres (Kurucz 1993).

Metallicity distribution of the different stellar samples

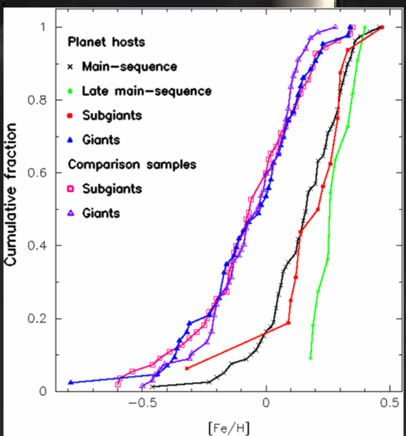

Fig. 1. Histogram of cumulative frequencies for the different samples studied in this work.

The cumulative [Fe/H] distribution of all samples is shown in Fig. 1. The main results are:

- GWPs show a similar behaviour than GWOPs
- The [Fe/H] distribution of SGWPs is shifted towards higher metallicities with respect to the SGWOPs
- SGWOPs behave as giants
- SGWPs show a similar [Fe/H] distribution than main-sequence planet hosts

The metal rich nature of the planet hosts stars tend to dissapear as the star evolves

Given that the stellar mass is the parameter that changes the most between giants and MS samples the data has been examined for correlations between mass and metallicity. The results are shown in Fig. 2.

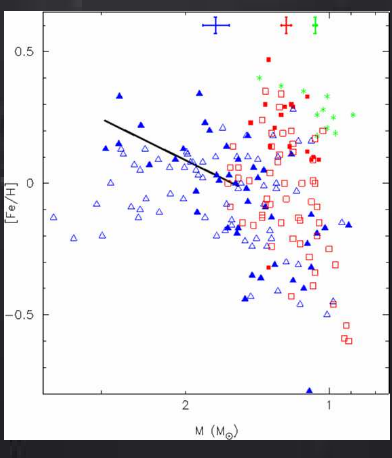

Fig. 2. [Fe/H] as a function of the stellar mass.

Giants $M_* < 1.5\ M_{Sun}$

- GWPs/GWOPs are well mixed covering the whole range of [Fe/H]
- GWPs and GWOPs show similar abundance patterns in all the considered elements

Giants $M_* > 1.5\ M_{Sun}$

- Lower scatter in the [Fe/H] axis, GWPs located on the metal-rich part of the plot
- GWPs/GWOPs show differences in some elements like Na, Co, Ni

Can massive proto-planetary disks explain the observed trends ?

- Recent simulations of planet formation have shown that a high-mass protoplanetary disk might compensate a low-metallicity environment, allowing the formation of giant planets even around low-metallicity stars.

✗ But the sample of GWPs in the mass-domain $M < 1.5\ M_{Sun}$ show a similar mass-range than the SGWPs, where we do see the metal-enrichment signature.

Can the [Fe/H] signature be erased as the star evolves ?

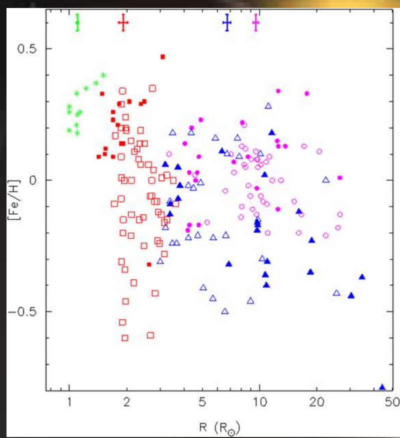

Fig. 3. [Fe/H] as a function of the stellar radius.

✗ In this scenario, SGWPs should show lower metallicities than MSWPs, however we find the opposite (see Fig. 1)

✗ There is no physical reason why the metal-rich nature of the star would be lost due to convection only for giants with $M_* < 1.5\ M_{Sun}$, remaining for giants with $M_* > 1.5\ M_{Sun}$

✗ No obvious difference between giants below/above $1.5\ M_{Sun}$ in the [Fe/H]-radius diagram (Fig. 3)

Is our sample biased ?

✗ Giants with $M_* < 1.5\ M_{Sun}$ show a similar age distribution than subgiants and main-sequence hosts (Fig. 4), ruling out galactic radial mixing as a possible explanation of their metallicity distribution

✗ No bias that could affect the metallicity distribution of low-mass giant stars has been identified

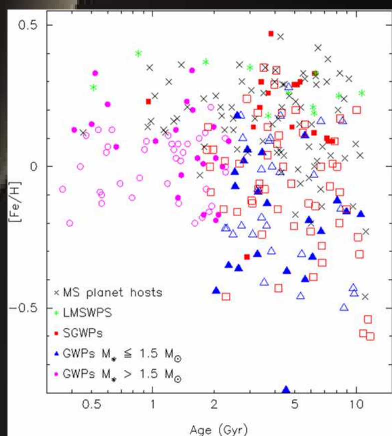

Fig. 4. [Fe/H] as a function of the stellar age.

The metallicity distribution of planet hosting subgiant and giant stars with $M_* > 1.5\ M_{Sun}$ fits well in current core-accretion models. The fact that giant planet hosts with masses below $1.5\ M_{Sun}$ do not show metal-enrichment is difficult to explain.

Reference: Maldonado et al. 2013, A&A 554, A84

Background image: The planetary system of HD 69830 (Credits: ESO)