Unveiling the abundance signature of M dwarf stars with planets

COOL STARS 20.5
... virtually cool

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Our understanding of which stellar properties influence planet formation is still largely biased towards main-sequence, solar-type stars. While low-mass stars (M dwarfs) have been recognised as promising targets in the search for small, rocky planets, detailed chemical studies of large samples of M dwarfs with planets are still missing. This is because the accurate determination of the stellar parameters and abundances of M dwarfs is a difficult task. To overcome this difficulty we developed a methodology to determine stellar abundances of elements other than iron for M dwarf stars from high-resolution, optical spectra. Our methodology is based on the use of principal component analysis and sparse Bayesian's methods. We made use of a set of M dwarfs orbiting around an FGK primary with known abundances to train our methods. In this contribution we applied our methods to derive stellar metallicities and abundances of a large sample of M dwarfs observed within the framework of current radial velocity surveys.

M dwarf abundances: methodology

In order to derive the stellar abundances of M dwarfs we applied the Principal Component Analysis technique to a set of high-resolution, optical spectra of selected M dwarfs in common proper-motion pairs orbiting around solar-type stars. We then used sparse Bayesian learning algorithms (automatic relevance determination regression) to find a relationship between the principal components and the stellar abundances measured in the primaries.

We apply our methods to a list of late-K and M dwarf stars observed within the framework of radial-velocity surveys. To test the reliability of our methods we compare the [X/H] versus [Fe/H] trends derived from our M dwarfs with those known for FGK stars, as it is reasonable to expect similar trends for both types of stars. We found a good agreement for most of the elements (Fig. 1)

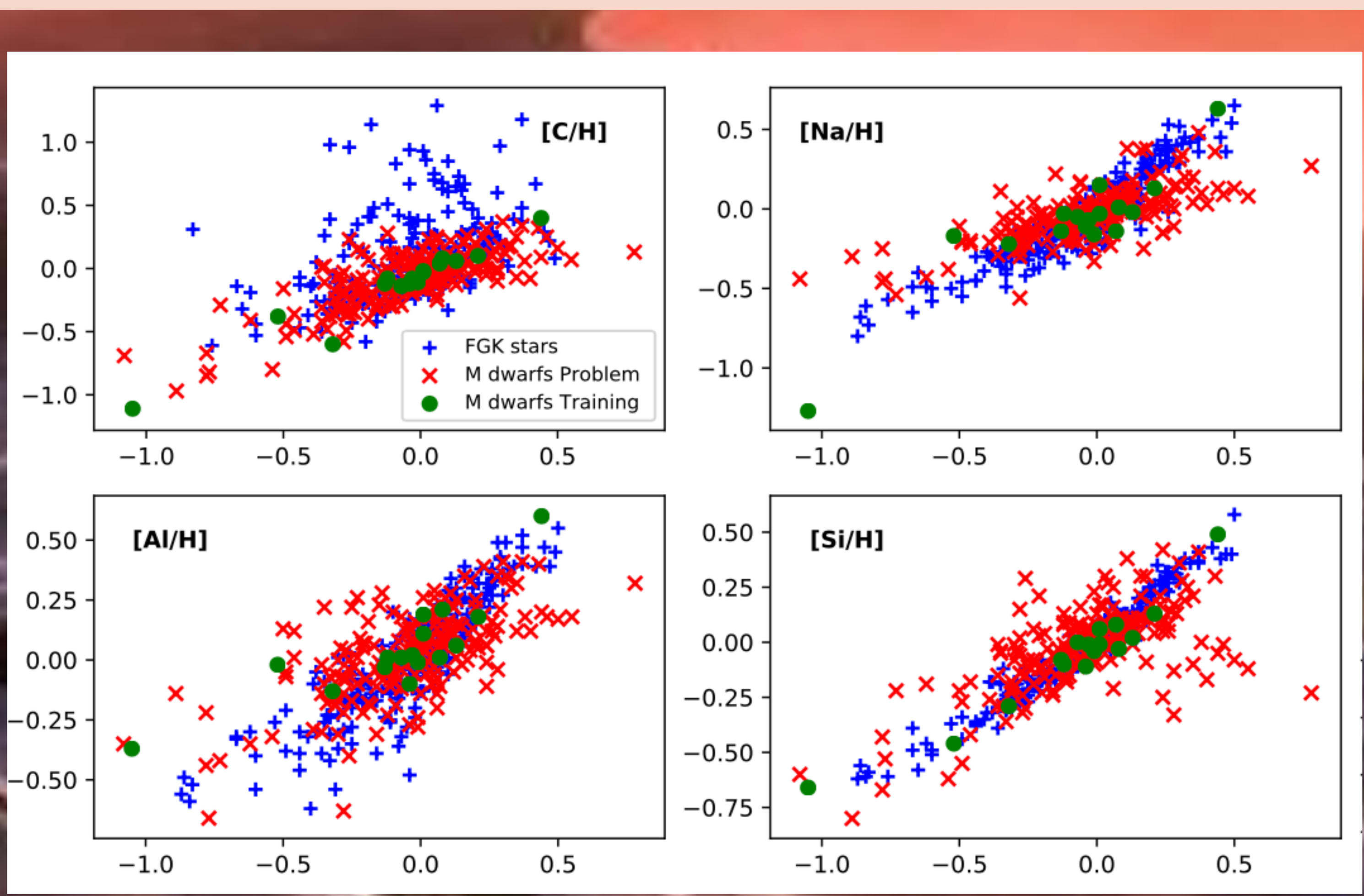

Fig. 1. Some examples of [X/H] versus [Fe/H] for FGK stars (blue plus symbols), the M dwarf training stars (green circles), and our sample of "problem" M stars (red crosses).

In addition, we performed a cross-validation of the technique, using it to derive the stellar abundances of a sample of FGK stars using similar spectra and exactly the same procedure that was used for the M dwarfs. For most elements the agreement between the PCA-derived abundances and those measured using the usual curve of growth approach is better than 0.10/0.15 dex (Fig. 2).

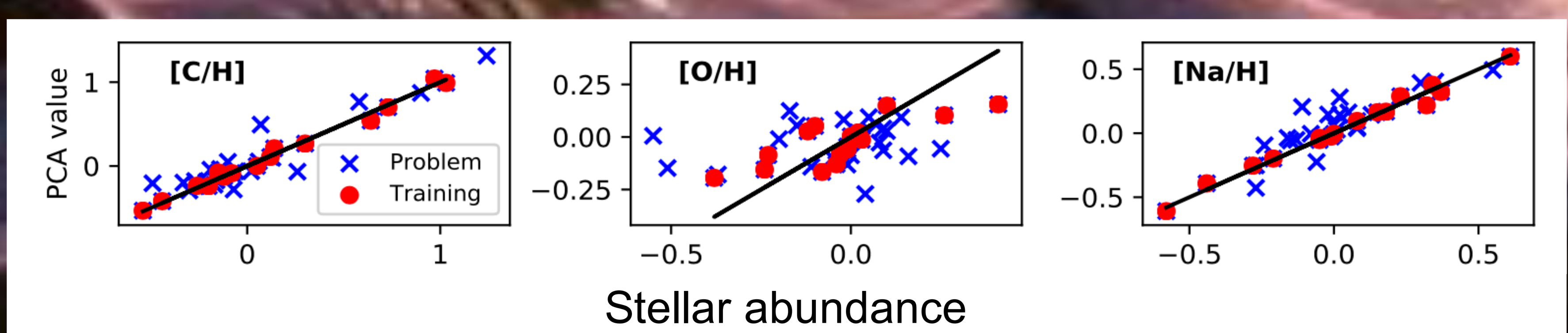

Fig. 2. Some examples of PCA-derived abundances versus stellar abundances for our sample of FGK stars from one of the performed simulations. The training dataset is shown as red circles while problem stars are shown as blue crosses.

The planet – stellar metallicity – stellar mass correlation

We tested the planet occurrence around M dwarfs as a function of the stellar metallicity and mass (Fig. 3). We used a Bayesian framework to fit the planetary frequency to a function of the form:

$$f(M,F) = CM^{\alpha}10^{\beta F}$$

where M is the stellar mass and F is the stellar metallicity.

Our results are consistent with a planet–metallicity correlation for gas-giant planets. We also find a strong dependence of the gas-giant planet frequency on the stellar mass.

M dwarfs hosting low-mass planets do not seem to follow the planet–metallicity correlation. We also find that the frequency of low-mass planets does not depend on the mass of the stellar host.

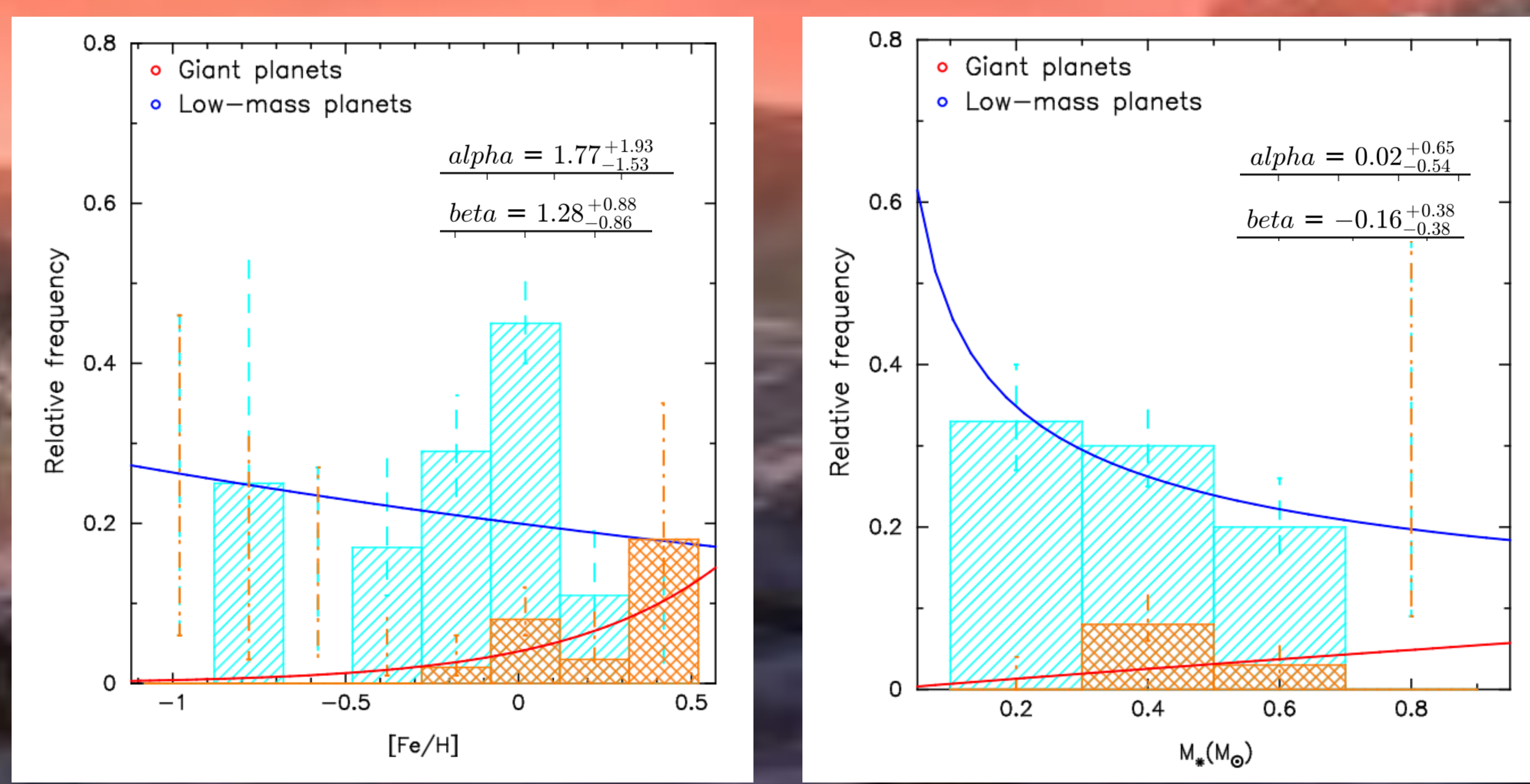

Fig. 3. Fraction of gas-giant planets (light orange) and low-mass planets (light blue) as a function of the stellar [Fe/H] (left) and stellar mass (right). The best bin fitting is shown in red for gas-giant planets and in blue for low-mass planets.

For other elements besides iron, we show, for the first time, that there are no differences in the abundance distributions of stars with and without planets (Fig. 4).

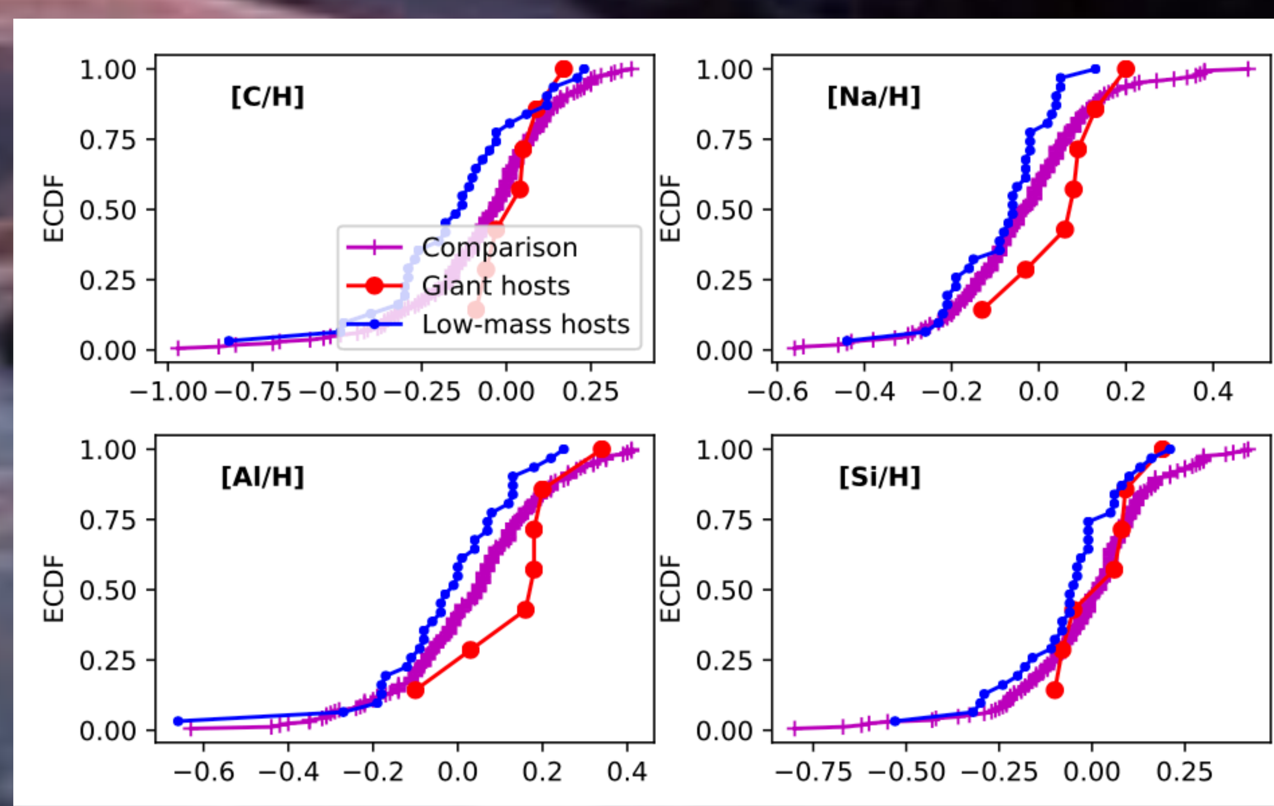

Fig. 4. Examples of the [X/H] cumulative fraction of low-mass-planet hosts (blue), gas-giant-planet hosts (red), and comparison M dwarfs (purple).

To know more

Maldonado et al. A&A 644, A68 (2020)
Our codes are publicly available, scan the code to use them!

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