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Atomical abundances of iron and magnesium on red dwarfs in the solar neighborhood

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Abstract. We present the application of the spectral synthesis method to obtain chemical abundances of 178 red dwarfs in the solar neighborhood. We show a routine that identifies exoplanets in the literature that orbit a given list of stars; through this, we use the planetary mass obtained from the NASA Exoplanet Archive and the metallicity obtained by the group through spectral indices to obtain a relationship between them.

Resumo. Apresentamos a aplicação do método de síntese espectral para obtenção de abundâncias químicas de 178 anãs vermelhas da vizinhança solar. Mostramos uma rotina que identifica na literatura exoplanetas que orbitam uma dada lista de estrelas; através disso, usamos a massa planetária obtida no NASA Exoplanet Archive e a metalicidade obtida pelo grupo através de índices espectrais para obter uma relação entre elas.

Keywords. Star abundances – Atomic data – line identification

1. Introduction

Red dwarfs are cold, low-mass stars with weak intrinsic brightness and a complex spectrum that span the late K classes and the entire M spectral class. They are numerous in our Galaxy, representing about 70% of stars (Bochansky et al. 2010) and each is estimated to have at least 3 planets (Tuomi et al. 2019). Finally, because they have highly convective core and envelope, they can live up to trillions of years.

Such facts demonstrate the importance of these stars for exoplanetology, astrobiology and for the understanding of the chemical evolution of the Galaxy. However, due to their weak intrinsic brightness and complex spectrum, compared to the main spectral classes, these stars have been little studied over the years. Therefore, they have an outdated census and are not well known in terms of their fundamental parameters, such as metallicity and effective temperature. Even red dwarfs with confirmed exoplanets are poorly known: more than 60% of exoplanets lack the metallicity of your evaluated star (Figure 1).

In this sense, appears the work of Costa-Almeida et al. 2021, who observed 178 red dwarfs from the solar neighborhood, using the Coude Spectrograph, from the Pico dos Dias Observatory (OPD), in order to improve the knowledge of red dwarfs. The spectral index method was used to obtain the effective temperatures and metallicities for these 178 stars, the authors obtained a good agreement with the other data in the literature, but, even so, there is room for improvement, mainly in the metallicity issue.

At this point, this work arises, with the objective of improving metallicities, obtaining atomic abundances of magnesium and, also, derivate the surface gravity through the Ca II Triplet for these 178 stars, using the spectral synthesis method.

Furthermore, a secondary objective that emerged as the work progressed was to find a relationship between the metallicity of red dwarf star systems and the planetary mass of these systems, see, e.g., Adibekyan 2019. Using data from the literature, we will know which red dwarfs from the sample of 178 have exoplanets discovered orbiting them, the total mass of these planets and we will relate them to the metallicity of the systems, obtained both by spectral indices first and, in the future, by spectral synthesis. With this, we will compare the relationship of the two methods and see which ones have more statistical relevance and greater similarity with the results already defined in the literature.

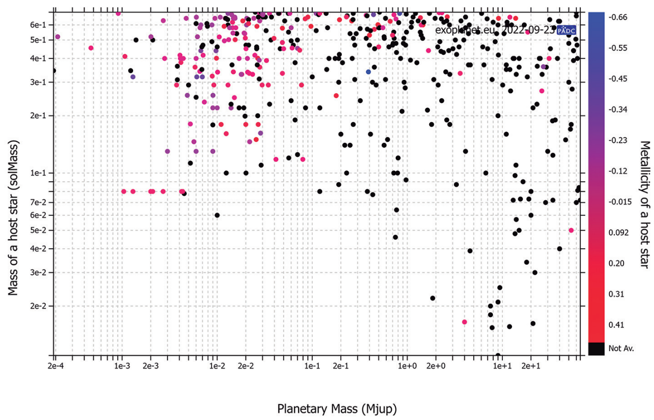

Figure 1. Exoplanets detected around M dwarfs. The abscissa represents the mass of the planet in Jupiter mass and the ordinate represents the mass of the host star in solar mass. The color bar represents the metallicity of the host star, where the black dots signify the absence of the parameter value. Data taken from Exoplanet.eu, on 22/09/2022.

2. Methodology and Application

Traditionally, the most used method to obtain stellar atomic abundances is using equivalent widths. However, in complex spectra with several molecular bands (lowered continuous) and/or low S/N, we rarely find individualized spectral lines, making this method inefficient. In these cases, one of the possible solutions is to obtain abundance through spectral synthesis.

This method consists of measuring abundance based on atmospheric models and lists of previously known atomic and molecular transitions. With this, a synthetic spectrum is created that, by changing the abundance of the model elements, adjusts to the spectrum observed in its spectral lines and continuum.

To perform the synthesis it is necessary to use softwares that can compute the strength of the spectral lines in certain regions and create the synthetic spectrum. The software chosen for this project was the MOOG (Sneden 1973), through the open-source distribution that uses Python libraries, PyMOOGi. To create the synthetic spectrum, it is necessary to insert an atmospheres model and a list of atomic lines: the initial model for the tests was generated using Kurucz's grid of atmospheric models (Kuruckz 1993); while the list of lines was compiled through VALD (Vienna Atomic Line Database), from 8800 Å to 8830 Å, where the main spectral lines are located, being Mg I 8806 Å and Fe I 8824 Å (Figure 2).

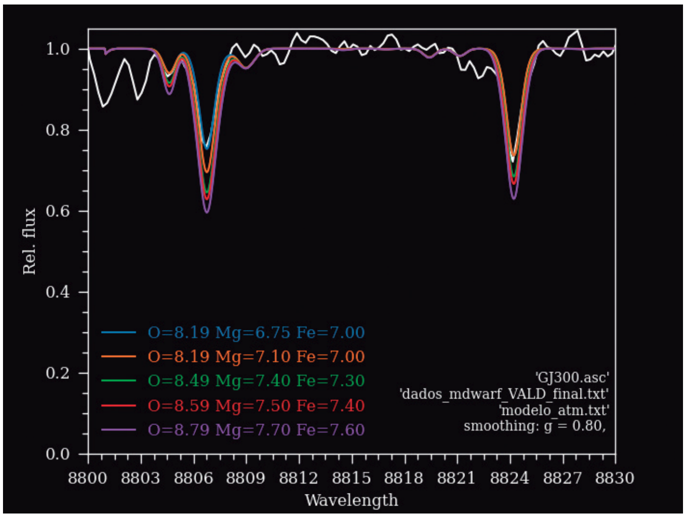

Figure 2. Example of spectral synthesis of the M dwarf GJ300, from 8800 Å to 8830 Å. The first major spectral line is the Mg I 8806 Å and the other is the Fe I 8824 Å. The white line represents the observed spectra, while the other lines represent several synthetic spectra, each with a certain atomic abundance of elements. In this case, we vary the abundances of oxygen, magnesium and iron in the synthetic spectra.

To evaluate the mass of planetary systems and the metallicity of the stars present in our sample, a Python routine was developed. This routine identifies whether there are exoplanets in the stars of our sample and, if so, how many are present in each star, for this purpose, the *astroquery* library of Python was used. From this, another routine creates a relationship between the metallicity obtained by Costa-Almeida et al. 2021, using spectral indices, and the sum of minimum planetary masses, using data from SIMBAD and the NASA Explanet Archive.

3. Preliminary Results and Future Perspectives

At the moment, we have not yet obtained any concrete results with the spectral synthesis, only the learning of the tool and the testing of functionality of PyMOOGi. The next step is to start checking which more intense atomic and/or molecular lines still need to be added to the line list, and then perform the complete synthesis in the spectra in this region from 8800 Å to 8830 Å and some other.

Regarding the relationship between the metallicity of the host stars and the planetary masses, we identified that the routine is functional and can be used by anyone who has a sample of stars and wants to verify which of the stars have an exoplanet orbiting around it. In the future, the routine will be available on GitHub.

To assess this relationship, we made a histogram of the metallicity of the stars with and without exoplanets in our sample (Figure 3), in which we applied the KS statistical test (Kolmogorov-Smirnov), whose result was that there is no statistical difference between the populations.

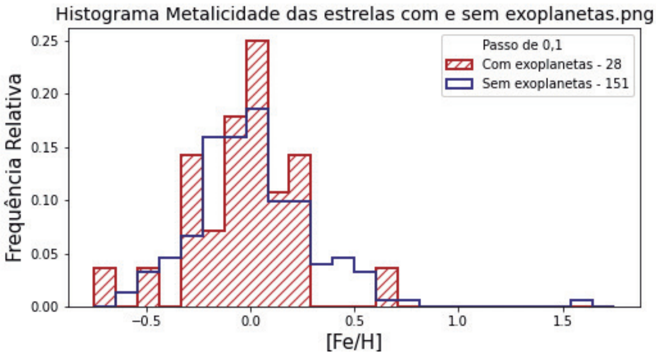

Figure 3. Histogram of metallicity of stars with and without exoplanets. The abscissa represents metallicity and the ordinate represents relative frequency. There are, in all, 28 stars with exoplanets, red line, and 151 without exoplanets, blue line.

This result may indicate that the metallicity of stars with or without exoplanets varies very little or that the metallicity error hides some tendency in these populations. Finally, further evaluations should be made at the end of the spectral synthesis in the sample of stars, comparing the results with the metallicity of the stars in each of the methods.

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