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A new high-precision [Fe/H] calibration for M dwarfs in the visible: a tool to explore the star-planet connection.

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Abstract

We present a new metallicity calibration for M dwarfs using a 22 star sample from X-SHOOTER spectra. We achieve a precision of 0.05 dex for [Fe/H] and intend to use it to study the planet-metallicity relation of M dwarfs, as well as to constrain evolutionary and transit light curve models in order to obtain more precise values of stellar and planetary mass and radius.

1. Introduction

Determining the metallicity of M dwarfs is of prime importance for galactic, stellar and planetary sciences. The very-low-mass M dwarfs are small, cool and faint, but they dominate the Galaxy by number, and even by total mass. Any realistic model of the Galaxy therefore needs an excellent description of this faint component. M dwarf metallicities have also become relevant in the context of planet formation around very low mass stars. One robust result of the exoplanet searches is that G and K stars which host giant planets are on average more metal rich than the bulk of the solar neighborhood population [7], a result that extends to the low-mass M dwarfs [5].

The available photometric calibrations [4] are limited in precision ($\sim$ 0.2 dex) and no consensus has been reached on the true zero point of the different scales. Resolving and rooting the individual lines and molecular bands that are the most sensitive to metallicity can improve dramatically the precision of the photometric calibrations, as shown in works using low resolution infrared spectra [6, 3].

Recently we have established a spectroscopic calibration using high-resolution HARPS spectra and achieved a [Fe/H] calibration with a precision of $\pm$ 0.08 dex [5]. However, this calibration is indirect, based on a photometric calibration [4], and thus limited in accuracy. Here we present a new metallicity calibration based on X-SHOOTER M dwarf spectra in the visible region, where the [Fe/H] values are anchored on high-precision values from FGK primaries.

2. Method and Results

The method is based on the measurement of 'peak-to-peak' equivalent widths (EW) of lines and features from moderate resolution (R $\sim$ 10.000) M dwarf spectra taken with the X-SHOOTER spectrograph [8]. The M dwarf stars are secondaries in FGK+M binary systems, where their [Fe/H] is assumed to be the same as the primary star. The metallicity of the primary star is measured using established high-resolution spectroscopic methods [7].

From our 22 star sample we first measure 'peak-to-peak' equivalent widths of 2134 lines/features in the 560-1020 nm spectral region. Here we consider features as blended lines. We define the 'peak-to-peak' equivalent widths as

$$W = \sum \frac{F_{pp} - F_\lambda}{F_{pp}} \Delta\lambda, \qquad (1)$$

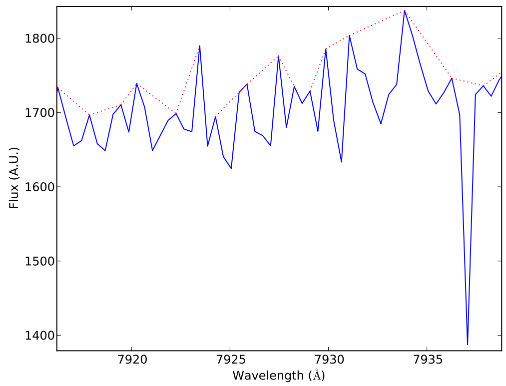

Figure 1: Small region of the Gl 105B spectra illustrating the 'peak to peak' equivalent width line measurement. The red dotted line represents the 'peak-to-peak' flux.

where F_{pp} is the value of the flux between the peaks of the line/feature at each integration step and F_λ the flux of the line/feature. The measurement of the EWs is illustrated in Fig. 1, where the 'peak-to-peak' flux correspond to the red dotted lines, and the blue line is the flux of the reference spectra. We rejected lines/features with EW < 6 mÅ and very steep lines/features.

We then calculate a linear fit of the EWs with the metallicity (taken from the primaries) and effective temperature (taken from [1]), using a least squares approach. For each EW i and for each star m we have,

$$W_{i,m} = \alpha_i [Fe/H]_m^T + \beta_i T_{eff\,m}^T + \gamma_i, \qquad (2)$$

where $W_{i,m}$ is a $i \times m$ matrix containing the EWs, and both $[Fe/H]_m$, and $T_{eff\,m}$ are $1 \times m$ vectors. The α and the β are the coefficients related to metallicity and effective temperature, respectively, while γ is an independent coefficient.

Finally, we use a weighted least squares approach and invert Eq. 2, recovering one value of metallicity and effective temperature for each star. We get a dispersion of metallicity of 0.05 dex, as illustrated in Fig. 2. The details of this technique are described in detail in the Appendix of [5].

We plan to use this new high-precision calibration to constrain evolutionary and transit light curve models [e.g. 2] in order to obtain more precise values of stellar and planetary mass and radius. We also aim to explore the [Fe/H]-planet relation, in order to confirm the giant planet-metallicity correlation as well as to test if the relation between Neptunian planets and metallicity is flat or if there is an anti-correlation, as studied by [5].

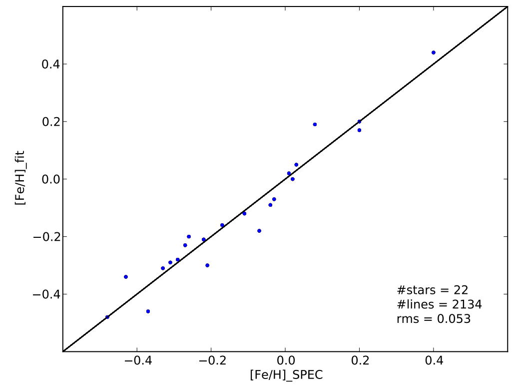

Figure 2: [Fe/H] obtained with our technique as a function of the spectroscopic [Fe/H] from the FGK primaries.

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