Characterising early-M dwarfs from high-resolution optical spectra

J. Maldonado, L. Affer, G. Micela,
and the GAPS team

INAF - Osservatorio Astronomico di Palermo,
Piazza Parlamento 1, 90134 Palermo, Italy
jmaldonado@astropa.inaf.it

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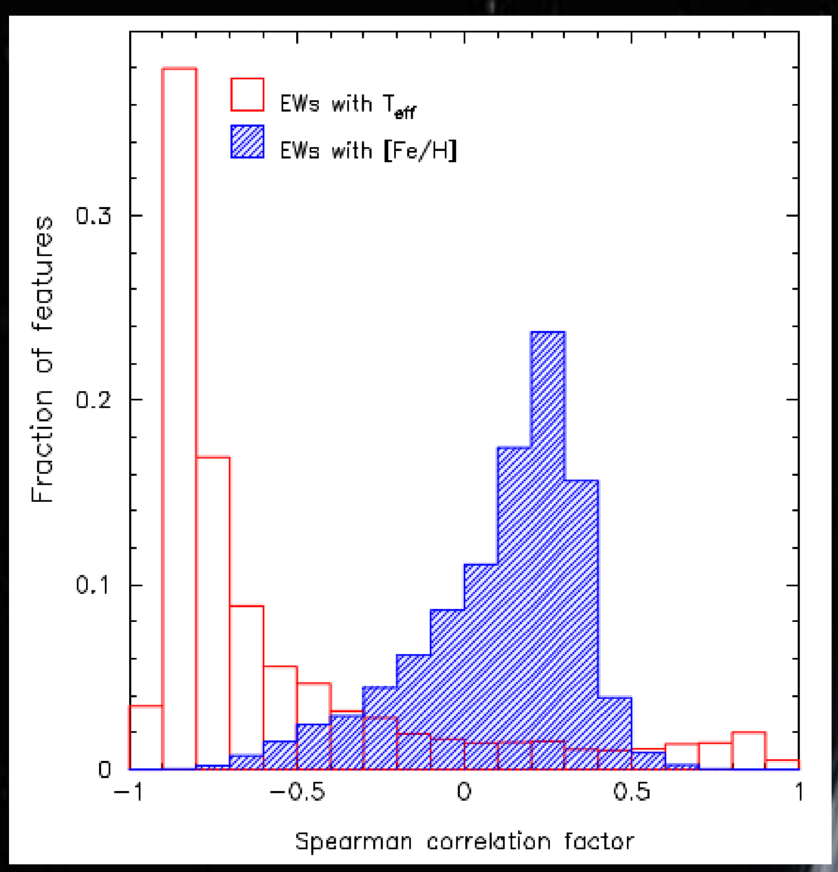
The discovery and characterisation of small, rocky planets with the potential capability of hosting life is one of the major scientific endeavours of modern Science. While most of the planets discovered so far have been found orbiting around solar-type stars, low-mass stars have recently been recognised as a "shortcut" to glance into an exo-life laboratory. The radial velocity searches currently ongoing with HARPS at La Silla and HARPS-N at the Telescopio Nazionale Galileo within the framework of the Global Architecture of Planetary Systems project (GAPS) are producing a large quantity of high-resolution and high signal-to-noise ratio spectra of the targets that are being monitored. In this contribution we present empirical relationships to determine stellar parameters for early-M dwarfs (spectral types M0-M4.5) using the same spectra that are used for the radial velocity determinations. Our methodology consists in the use of ratios of pseudo-equivalent widths of spectral features as a temperature diagnostic. Empirical calibrations for the spectral type are also provided. Combinations of features and ratios are used to derive calibrations for the stellar metallicity. We also provide our own empirical calibrations for stellar mass, radius, and surface gravity.

METHODOLOGY

We have developed a technique to calibrate empirical relationships to determine stellar parameters of early M dwarfs by using ratios of pseudo-equivalent widths (hereafter EW) of features and combinations of pseudo equivalent widths and ratios. A feature can be a line or a blend of lines. Pseudo-equivalent widths are defined as the traditional equivalent widths, but measured to the value of the flux between the peaks of the feature at each wavelength (Neves et al. 2014).



A total of 4229 features were identified. In 43% of the features the EW shows a high anticorrelation with T_{eff}, while only a relatively small fraction (~3%) shows a significant positive correlation (Fig. 1). The correlation between [Fe/H] and EWs is generally less significant with a clear peak at +0.25 dex (Fig. 1).

Fig. 1. Spearman correlation factor distribution of the EWs with [Fe/H] (blue) and with T_{eff} (red).

EFFECTIVE TEMPERATURE

We have identified and calibrated 112 temperature sensitive ratios of features using as calibrators a sample of early M-dwarfs with angular sizes obtained with long-baseline interferometry from Boyajian et al. 2012 (BO12) and von Braun et al. 2014 (vB14). The revised temperature scale by Mann et al. (2013) and Newton et al. (2015) was taken into account. Typical uncertainties in our derived T_{eff} are of about 70 K.

Some examples of the obtained fits are given in Fig. 2 (left). The ratios have been fitted to different functional forms: Hoerl function $ab^{r}\times r^{c}$; modified Hoerl function $ab^{1/r}\times r^{c}$; power-law $a\times r^{b}$; exponential $a\times b^{r}$; and logarithmic $a+b\ln(r)$.

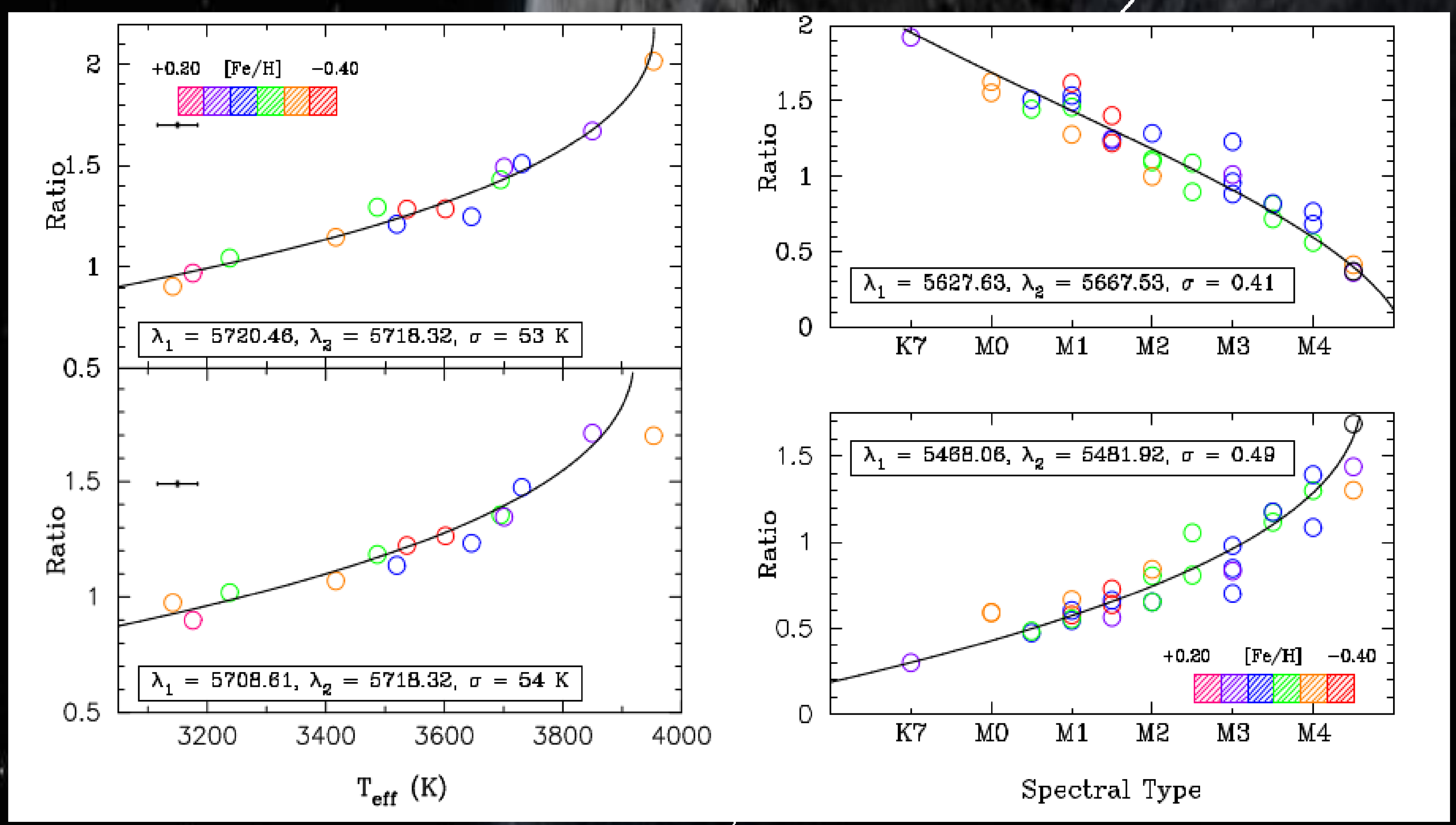


Fig 2. Left: Examples of some features identified to be sensitive to T_{eff} in early-M dwarfs. Right: Spectral type as a function of two different spectral-type sensitive ratios. Stars are plotted using different colours according to their metallicity.

SPECTRAL TYPES

In a similar way, we identified 82 spectral-type sensitive ratios with a standard deviation lower than 0.5 spectral subtypes (Fig. 2, right). In this case, we use as reference 33 stars from the compilations by Kirkpatric et al. (1991) and Henry et al. (1994).

METALLICITY

For [Fe/H] we searched for empirical relationships as a function of features and ratios of features with the analytical form:

$$[Fe/H]=(A\times EW)+(B\times r)+c$$

(where r is a temperature-sensitive ratio of features, and A, B, C independent coefficients).

A total of 696 calibrations with standard deviation values between 0.07 and 0.10 dex were identified.

MASS, RADIUS, SURFACE GRAVITY

We made use of our temperature and metallicity values to search for empirical relationships with the stellar evolutionary parameters.
First, we derived our own mass-radius relationship (combining data from BO12, vB14 with data from low-mass eclipsing binaries by Hartman et al. (2014)):

$$R=0.0753+0.7009M+0.2356M^{2}$$

Where masses were computed from near-IR photometry (Henry & Mc Carthy 1993). Finally, logg values were obtained using the derived masses and radius.

Our derived relationships (Fig. 3) are the following:

$$M=-171.616+0.139T_{eff}-3.776\times10^{-5}T_{eff}^{2}+3.419\times10^{-9}T_{eff}^{3}+0.382[Fe/H]$$

$$R=-159.857+0.130T_{eff}-3.534\times10^{-5}T_{eff}^{2}+3.208\times10^{-9}T_{eff}^{3}+0.347[Fe/H]$$

$$\log g=174.462-0.138T_{eff}+3.728\times10^{-5}T_{eff}^{2}-3.376\times10^{-9}T_{eff}^{3}-0.332[Fe/H]$$

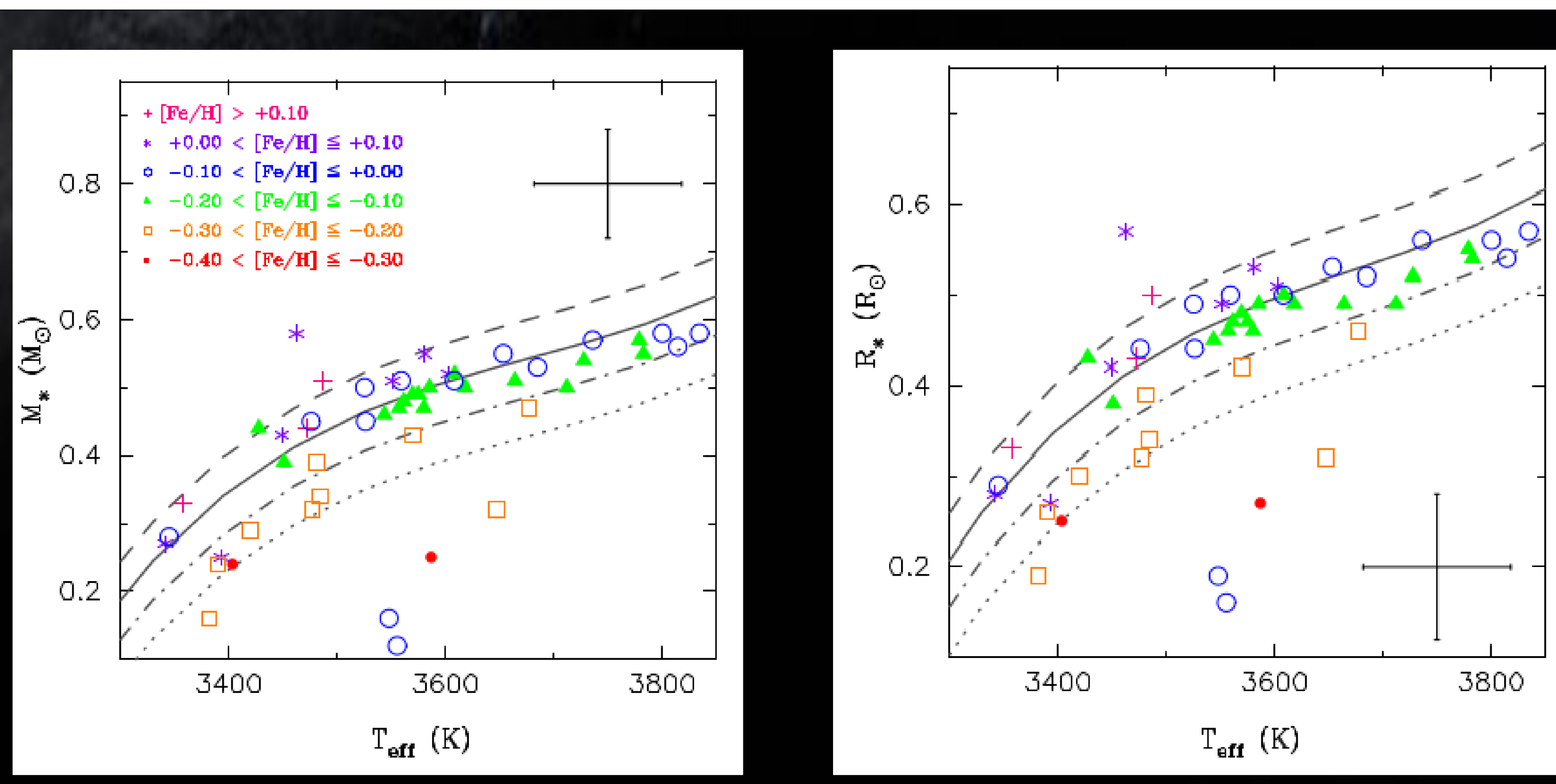


Fig. 3. Stellar mass (left), and radius (right) as a function of the effective temperature. Several fits for fixed metallicity values are plotted.

Although HARPS/HARPS-N optical spectra were used for this work, a similar methodology can be used for other instruments/spectral range.

TO KNOW MORE

Maldonado et al. 2015, A&A, 577, A132
http://www.astropa.inaf.it/~jmaldonado/Msdlines.html
http://www.oact.inaf.it/exoit/EXO-IT/Projects/Entries/2011/12/27_GAPS.html