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K-band spectroscopic metallicities and temperatures of M-dwarf stars

Bárbara Rojas-Ayala[a]

Department of Astrophysics, American Museum of Natural History, Central Park West at 79th Street, New York, NY 10024, USA

Abstract. I present the metallicity and effective temperature techniques developed for M dwarf stars by Rojas-Ayala et al. (2010, 2012). These techniques are based on absorption features present in the modest resolution K-band spectra (R ∼2700) of M dwarfs and have been calibrated using FGK+M dwarf pairs and synthetic atmosphere models. The H_2O-K2 index seems to overestimate the effective temperatures of M dwarfs when compared to interferometric measurements. The metallicity distribution of the M dwarf host candidates by the Kepler Mission hints that jovian-size planets form preferentially around solar and super-solar metallicity environments, while small rocky planet host exhibit a wide range of metallicities, just like in their solar-type counterparts.

1. INTRODUCTION

M-dwarf stars hold the key to understand the formation of planets, stars and the Milky Way. They are the most numerous stars in the Galaxy, their lifetimes are longer than the Hubble time, and they are the hosts of some of the most interesting planetary systems discovered to date. However, due to their intrinsic faintness and complex spectra, their fundamental properties have been hard to unravel. Here, I present the metallicity and effective temperature techniques based on the strength of the Ca I triplet and the Na I doublet, and water absorption present in the K-band spectra of M dwarfs developed by Rojas-Ayala et al. [1, 2].

2. K-BAND EFFECTIVE TEMPERATURES

The infrared spectrum of M dwarfs is predominately dominated by water opacity. The depressions due to water absorption from 2.07 μm to 2.38 μm increase with decreasing spectral type deforming the overall shape of the spectra of M dwarfs. Rojas-Ayala et al. [2] defined a water index, the H_2O-K2 index, which measures the deformation of the spectra due to water absorption using portions of the K-band spectra of M dwarfs almost free of atomic features. Smaller values of the H_2O-K2 index correspond to greater amounts of H_2O opacity. Rojas-Ayala et al.[2] calibrated the H_2O-K2 index as an effective temperature indicator using the BT-Settl-2010 spectral models [3], which is metallicity and gravity insensitive for $3000 < T_{\rm eff} < 3800$ K.

Ten of the M dwarfs in [2] have interferometric angular diameters by Boyajian et al. [4]. Boyajian et al. [4] used their trigonometric parallax values and literature photometry to calculate their bolometric fluxes and physical diameters, which allows the determination of their effective temperatures as well. For half of these sample, the agreement between the effective temperatures estimated by the H_2O-K2

[a]e-mail: babs@amnh.org

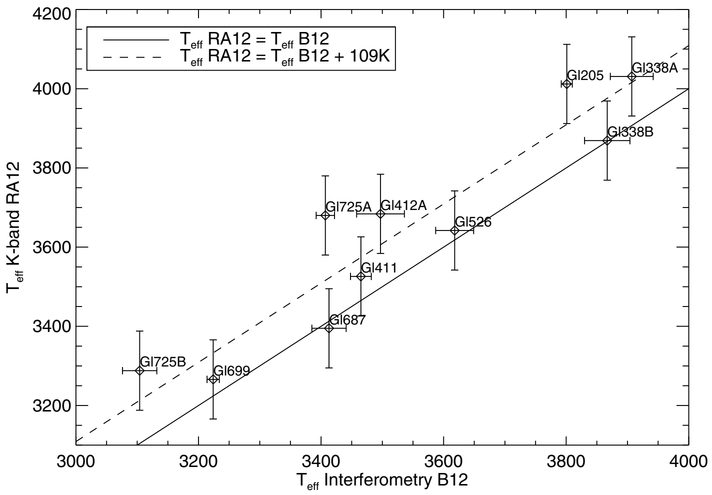

Figure 1. M dwarfs with interferometric measurements by Boyajian et al. (2012) in Rojas-Ayala et al (2012). The H_2O-K2 technique overestimates the interferometric temperatures in average by ∼109 K.

and interferometric techniques is quite good, with the H_2O-K2 technique providing slightly higher $T_{\rm eff}$ for the stars ($\Delta T_{\rm eff} < 61$ K). However, for the other half of the sample, the disagreement is higher than 120 K, with Gl 724A having the largest difference: $\Delta T_{\rm eff} = 276$ K. If all the sample is considered, the H_2O-K2 technique overestimates the interferometric temperatures in average by ∼109 K (Fig. 1).

3. K-BAND METALLICITIES

Using FGK + M binary systems, Rojas-Ayala et al. [1, 2] demonstrated that the strength of the Ca I triplet and the Na I doublet, and water absorption in the K-band differentiate metal-rich and metal-poor M-dwarf stars. The strength of this technique is that it only requires K-band modest resolution (∼ 2700) spectra to provide metallicities with σ([M/H])∼ 0.1 dex. Using this technique, Rojas-Ayala et al. [2] estimated the metallicities of 133 nearby M dwarf stars and confirmed that the ground-based discovered jovian M-dwarf planet hosts were more metal-rich than neptune and super Earth M-dwarf planet hosts, which is in agreement with the metallicity distribution of their FGK counterparts.

The K-band [M/H] technique was applied to cool stars in the 2011 Kepler Object of Interest (KOI) list [5], by Muirhead et al. [6]. The sample was observed with the same instrument used to develop the metallicity technique [7]. Muirhead et al. [6] estimated the stellar radii of the host candidates and the sizes of their planet candidates using their K-band [M/H] and $T_{\rm eff}$ values and evolutionary models [8],. The distribution of the metallicities of the KOI M-dwarf host candidates is shown in Fig. 2. The sample was divided according to the largest planetary candidate in the systems. The few M dwarfs with planets larger than 5.5 $R_\oplus$ ("Jupiters") exhibit [M/H] values higher than -0.13 dex, while the systems with planets smaller than 5.5 $R_\oplus$ ("Neptunes" and "Earths") only, exhibit a wide range of metallicities from −0.37 dex to +0.4 dex. This result is in agreement with the one found by Buchhave et al. [9] for a subsample of solar-type stars in the KOI sample.

4. DISCUSSION AND FUTURE WORK

The determination of M dwarf metallicities and temperatures is relevant to stellar astrophysics and planetary formation. The K-band techniques by Rojas-Ayala et al. [1, 2] have been useful to constrain the physical parameters of M dwarf stars and their planetary systems [6, 10], and provide an alternative

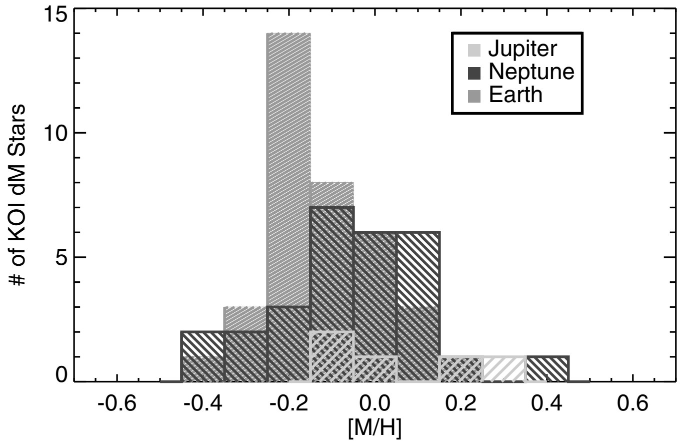

Figure 2. Metallicity distribution of M dwarf planet host candidates in the KOI sample. The sample was divided according to the largest planet candidate in the system. The median values for the distribution of jupiter, neptune, and earth host candidates are +0.02, −0.05, and −0.12 dex, respectively.

to optical techniques. During 2012, three other spectroscopic techniques to estimate the metallicities of M dwarfs have been developed using the near infrared wavelengths [11–13], along with two optical techniques [14, 15]. Two of these techniques have confirmed that the K-band Na I doublet and the Ca I triplet seem to be the best features for the estimation of M dwarf metallicities in the near infrared at modest resolution [12, 13].

Longer wavelengths can also provide metallicity information for M dwarfs. A new technique based on a color-color diagram, including WISE magnitudes, can produce [Fe/H] estimates for M dwarfs accurate to RMSE = 0.17 dex, without the need of parallaxes like previous photometric calibrations (Rojas-Ayala et al. in prep [16]).

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