Metallicity Determination of M Dwarfs from High-resolution IR Spectra

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Abstract.
In this work we determined the metallicity of two M dwarfs, both in close binary systems with an F/G dwarf companion. The spectroscopic analysis is based on high-resolution spectra taken in the J band with the CRIRES spectrograph. Due to the use of infrared wavelength a good continuum placement can be achieved and a reliable abundance analysis performed. Our preliminary results show that our derived metallicities of the M dwarfs are in good agreement with both the metallicities of their F/G dwarf companions as well as with literature values - demonstrating that the method gives reliable metallicities for M dwarfs.

1. Introduction

M dwarfs are the most numerous type of Main Sequence stars in our Galaxy, and accurate knowledge of their composition is essential for advancing the understanding of e.g. planet formation, galactic evolution and the initial/present mass function. However, due to their intrinsic faintness and low surface temperature M dwarfs are a spectroscopic challenge. For a long time the majority of high-resolution spectroscopic instruments were only working in the optical, and in that wavelength region the spectrum of an M dwarf is covered with a forest of millions of molecules lines making a good continuum placement nearly impossible. In the infrared the situation is highly improved. The density of stellar molecular lines is limited, reducing the blending with atomic lines and allowing an accurate continuum placement. This gives a great improvement in the reliability of the abundance determination for M dwarfs.

2. Analysis

Spectra were obtained with the CRIRES spectrograph at the ESO-VLT. The observations cover four wavelength intervals in the J band (1100-1400 nm) with a slit width of 0.4" giving a resolving power of $R \sim 50000$. Binary systems were chosen since the companions should have the same metallicity, and since the warmer companion has a less complex spectrum it can be used as a reliability check of the abundance determination. In the work by Önehag et al. 2012 three M dwarfs in binaries with K dwarfs were analyzed, while in this work we analyzed M dwarfs with F/G dwarf companions. Besides increasing the sample of M dwarfs analyzed with high-resolution spectroscopy we can also try to see if there are any spectral-type dependent systematic errors in the analysis of the solar-type dwarfs.

The choice of the J band was motivated by the reduced number of molecular lines in the infrared and further by the presence of sufficient numbers of good atomic lines for abundance analysis. The spectral analysis was done with the software package *Spectroscopy Made Easy* (*SME*) (Valenti & Piskunov 1996), by fitting synthetic spectra computed on the fly, with free parameters including [Fe/H], T_{eff}, *logg*, vsini, micro- and macroturbulence. We used MARCS model atmospheres (Gustafsson et al. 2008), and the atomic data were taken from Vienna Atomic Line Database, VALD3 (Kupka et al. 2000; Heiter et al. 2008) together with some additional atomic data from Meléndez & Barbuy 1999 and a line list of FeH calculated by Bertrand Plez (private communication, 2012). For the F/G dwarfs the values of T_{eff} and *logg* were adopted to be an average of available literature values. For the M dwarfs an initial T_{eff} value was taken from the lookup table based on spectral type by Boyajian et al. 2012 and *logg* was calculated from the *logg* - $M_\star$ relation established by Bean et al. 2006. The effective temperatures of the M dwarfs was adjusted with the help of FeH line strengths and the surface gravities with help of KI lines and the wings of strong lines available in the spectra. To determine the metallicity we let the metallicity, micro- and macroturbulence parameters vary simultaneously in SME, in search for the best fit by χ^2 minimization.

3. Results

The results from our preliminary abundance analysis are promising. For the binary HIP12048 the metallicity determined for the M dwarf is 0.16 ± 0.10, while for the G dwarf [Fe/H] = 0.14 ± 0.02. For the system GJ527 the metallicity of the M dwarf was determined to 0.32 ± 0.12 and for the F dwarf to 0.29 ± 0.03. Part of the spectrum of the two M dwarfs is shown in Figure 1 and 2. The T_{eff} and *logg* values used are shown in Table 1. The metallicities derived from the secondaries and primaries are in good agreement with each other, giving a confirmation that using high-resolution spectroscopy in the infrared is a reliable method to determine the metallicity of M dwarfs. Also looking at literature values from previous studies we find a good agreement between the metallicities we derived and those previously found by other authors (note that metallicity determinations have previously only been done based on optical spectra for the warmer F/G dwarf). The average of the literature values for HIP12048 A is [Fe/H] = 0.13 dex with $\sigma = 0.05$, and for GJ527 A [Fe/H] = 0.30 dex with $\sigma = 0.08$.

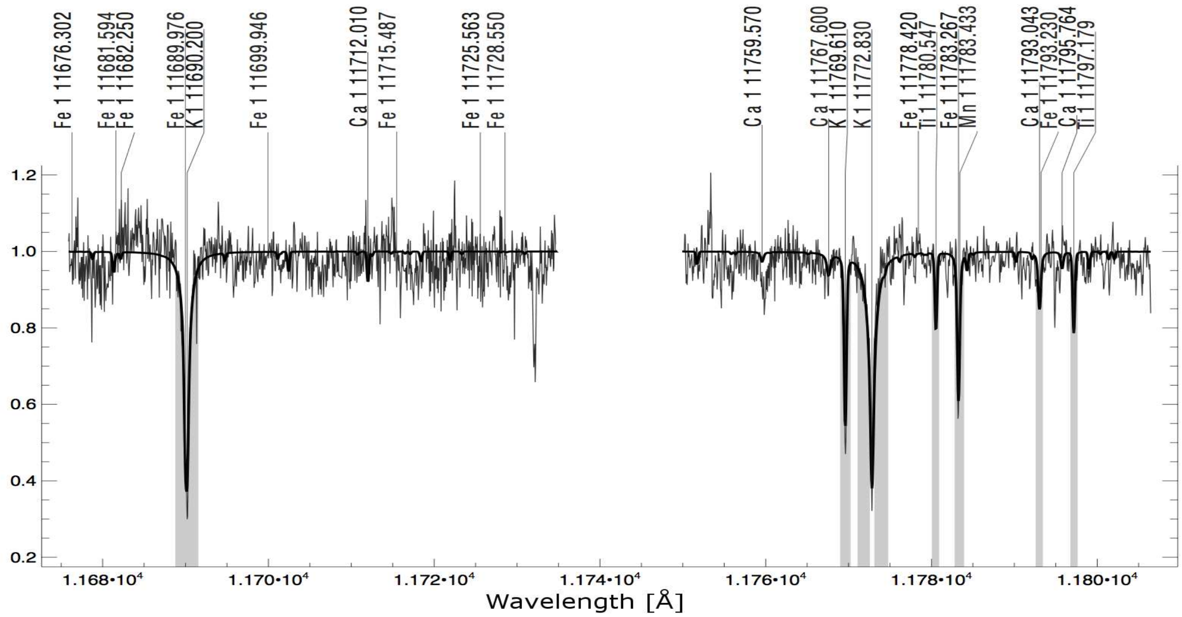

Figure .1: Two of the eight observed wavelength intervals of M dwarf HIP12048 B. The thicker black line shows the best-fit synthetic spectrum with [Fe/H] = 0.16, and the mask used for the metallicity determination is marked with grey. Several spectral lines are labelled with element symbol, ionization stage, and wavelength in Å.

4. Conclusions and Outlook

The analysis of these two binary systems, together with the results from Önehag et al. 2012, shows that high resolution spectroscopy in the infrared can provide improved metallicity determination for M dwarfs. Our results show good agreement between the binary components, as well as with previous optical studies of the warmer companions. Using the same observational and analyzing strategy the study will next be extended to a sample of additionally 22 single M dwarfs, to provide accurate determined metallicities of M dwarfs in a large span of $T_{\rm eff}$ and metallicity. The aim is to derive an accurate relationship between photometric color and metallicity, covering most M dwarf subtypes and a metallicity span from approximately −0.7 to +0.7 dex. With this relationship one can then use a larger sample of M dwarfs observed only photometrically to statistically investigate a possible planet host - metallicity connection. To include these cooler and faint stars is also expected to further constrain planet formation theory.

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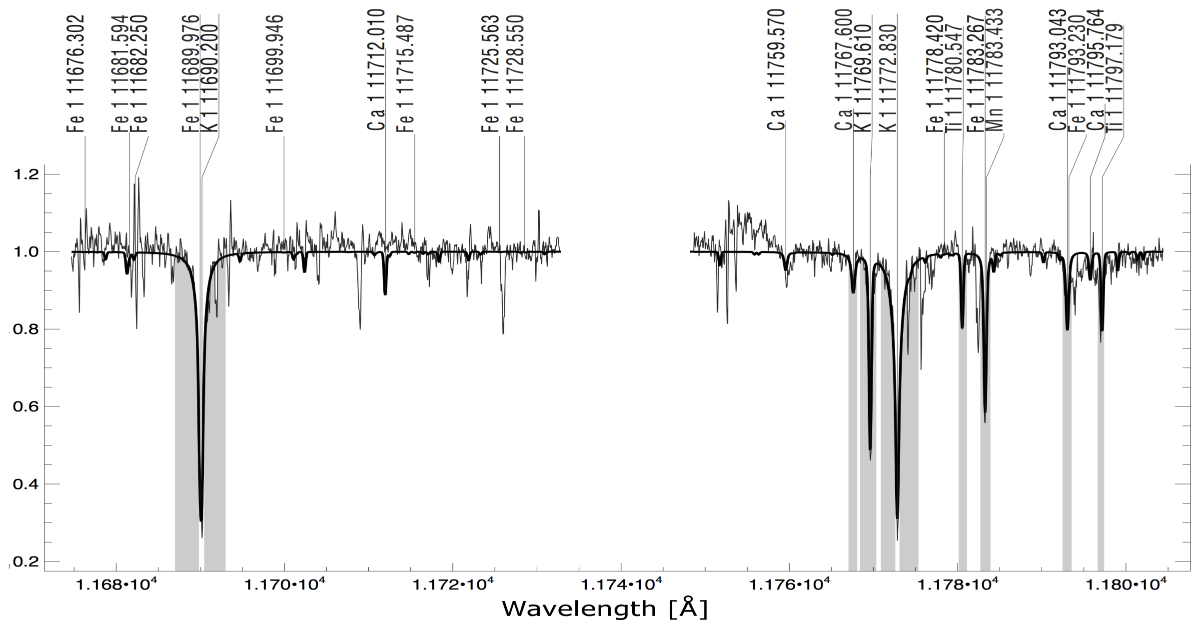

Figure .2: Two of the eight observed wavelength intervals of M dwarf GJ527 B. The thicker black line shows the best-fit synthetic spectrum with [Fe/H] = 0.32.

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Table .1: Adopted values of T_{eff} and *logg* used within SME to determine the metallicity of our four targets, as well as our derived metallicities with estimated errors. Including the average of metallicity values found in the literature.

Target	T_{eff} [K]	*logg* [cm s^{-2}]	[Fe/H] [dex]	Ave. lit. value [dex]	Refences
HIP12048 A	5750	4.1	0.14 ± 0.02	0.13 ($\sigma = 0.05$)	a
HIP12048 B	3300	4.8	0.16 ± 0.10		
GJ527 A	6350	4.2	0.29 ± 0.03	0.30 ($\sigma = 0.08$)	b
GJ527 B	3200	4.9	0.32 ± 0.12		

References. a) Adibekyan et al. 2012; Fuhrmann 1998; Gonzalez et al. 2001; Heiter & Luck 2003; Huang et al. 2005; Kang et al. 2011; Laws et al. 2003; Luck & Heiter 2006; Santos et al. 2001, 2004; Sousa et al. 2008; Takeda et al. 2005; Valenti & Fischer 2005. b) Erspamer & North 2003; Fuhrmann et al. 1998; Ghezzi et al. 2010; Gonzalez 1997; Gonzalez & Laws 2000; Heiter & Luck 2003; Luck & Heiter 2006; Santos et al. 2004; Takeda et al. 2005; Valenti & Fischer 2005; Zhao et al. 2002.

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