3rd International Workshop on Spectral Stellar Libraries
ASI Conference Series, 2017, Vol. 14, pp 53–56
Editors: P. Coelho, L. Martins & E. Griffin

The VLT/X-shooter spectral library of M subdwarfs

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Received July 1st, 2017 ; accepted Oct 15th, 2017

Abstract. We present a library of intermediate-resolution (R=4000-6700) optical to NIR (400-2500 nm) spectra of metal-poor M dwarfs with metallicities (Fe/H) below −0.5 dex collected with the X-shooter spectrograph on the ESO Very Large Telescope. We present spectroscopic sequences and derive preliminary physical parameters comparing our observed spectra with the state-of-the-art BT-Settl models.

Keywords : subdwarfs – spectral classification – models

1. Introduction

Subdwarfs represent the first generation of stars in our Galaxy. Hence, they are important tracers of the enrichment of our Galaxy. Subdwarfs lie below the main sequence of solar-type M dwarfs. They are population II stars with a dearth of metals in their atmospheres. They exhibit large proper motions, large heliocentric velocities, and have kinematics typical of the thick disk and halo objects. M-type subdwarfs are usually bluer than their solar-metallicity counterparts at both optical (e.g. $r - z$) and NIR (e.g. $J - K$) wavelengths as shown in Fig. 1 (Lodieu et al. 2017). Subdwarfs differ from their solar-type counterparts because of the dearth of metals in their atmospheres, yielding to stronger calcium hydride and weaker titanium oxyde bands. Gizis (1997) proposed the first spectral classification for metal-poor M dwarfs and defined four spectral indices linked the CaH features and the TiO band around 630–720 nm. Ten years later, Lépine et al. (2007) revised the original classification of Gizis (1997) adding a new metal class to the subdwarfs (sdM) and extreme subdwarfs (esdM): the

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ultra-subdwarfs (usdM). This new classification is based on 400 M subdwarfs including new binaries and relies on a new index that measure the strength of the TiO/CaH ratio to infer the metallicity class and spectral types.

In these proceedings, we give a brief overview of subdwarfs. Then, we present the sample and describe the observations. In the second part of this review, we present spectroscopic sequences for metal-poor M dwarfs and infer the main physical parameters (Teff, gravity, and metallicity) by direct comparison with the latest BT-Settl models.

The goal of the project is to define a NIR spectral classification for metal-poor M dwarfs following the current optical scheme. Up to now, subdwarfs are classified in the optical but this classification has not been extended to the NIR. It is important to do so because: (1) cooler subdwarfs have more flux in the NIR, and (2) future or existing deep survey are more sensitive to cooler subdwarfs.

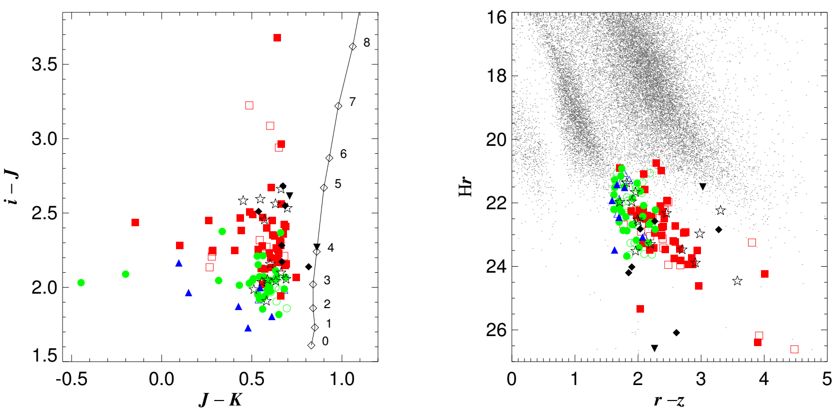

Figure 1. *Left:* $(i - J, J - K)$ colour-colour diagram. *Right:* $(r - z, H_r)$ reduced proper motion diagram, where $Hr = r + 5 \times \log(\mu) + 5$. Filled symbols represent subdwarfs confirmed spectroscopically: sdM (red squares), esdM (green circles), and usdM (blue triangles). Known subdwarfs are marked as open symbols while black diamonds show solar-metallicity M dwarf. Figures from Lodieu et al. (2017).

2. Sample and observations

We downloaded optical spectra from the public Sloan (SDSS) archive. These spectra covers the 320–920 nm range at a resolution of 1800. We requested all objects classified as subdwarfs in the archive based on the Lépine et al. (2007) scheme with spectral types between M0 and M9.5 (this limit depends on the metal class) and we kept only the brightest ones of each metal class and spectral sub-class i.e. M0, M0.5, etc.... We initiated a spectroscopic follow-up of these templates with the X-shooter spectrograph (d'Odorico et al. 2006; Vernet et al. 2011) on the ESO VLT.

We collected UVB (400–550 nm), VIS (550–1000 nm), and NIR (1000–2480 nm) spectra with VLT/X-shooter for 16 sdM, 16 esdM, and 12 usdM. The sdM and esdM sequences are almost complete but we have gaps in the usdM sequence. We also downloaded X-shooter spectra from the ESO archive to cover the full range of solar-type M dwarfs. The spectral resolutions of our VIS and NIR spectra are 6700 and 3900, respectively. We have a unique sample of good-quality and medium-resolution spectra of metal-poor M dwarfs.

3. Results and analysis

3.1 Spectroscopic indices and sequences

We collected spectral indices defined in the literature to classify M and L dwarfs and measured them using the X-shooter NIR spectra. The aim is to find possible trends with spectral types and metallicity to provide guidance for NIR classification of M subdwarfs. For example, promising indices are the H/J and H_2Oc indices. The former measures the slope between the *J* and *H* bands and seems to decrease with decreasing metallicity. The latter measures the strength of the water band on the red side of the *H*-band whose value appears to increase with decreasing metallicity.

We plot the M0–M9.5 sequence of subdwarfs (sdM) in Fig. 2. We clearly see that M subdwarfs (sdM) become redder with later spectral types and appear relatively featureless over the 1000–2500 nm. We can also distinguish the sodium doublet at 820 nm and calcium triplet around 860–870 nm. The comparison of spectra for a dwarf of a given spectral type but at different metallicity shows strong changes from solar-type M dwarfs to subdwarfs over the full VIS+NIR wavelength range. Changes from subdwarfs to extreme subdwarfs are less obvious while extreme subdwarfs and ultra-subdwarfs look very similar.

3.2 Physical parameters of M subdwarfs

In Fig. 2 we compare our full 400–2500 nm VLT/X-shooter spectra to the latest BT-Settl models developed by the Lyon group (Allard et al. 2012). We can reproduce the full spectral energy distribution with one single gravity of log(g) = 5.5 dex with an uncertainty of 0.5 dex (corresponding to the steps of the models). We find that the effective temperature range of the M0–M7 sdM, esdM, and usdM is very similar, from 3800 K for the warmest down to 3000 K for the coolest. Our values are comparable within the error bars to the estimates from an independent sample of M subdwarfs targeted with X-shooter (Rajpurohit et al. 2016) and high-resolution optical spectra

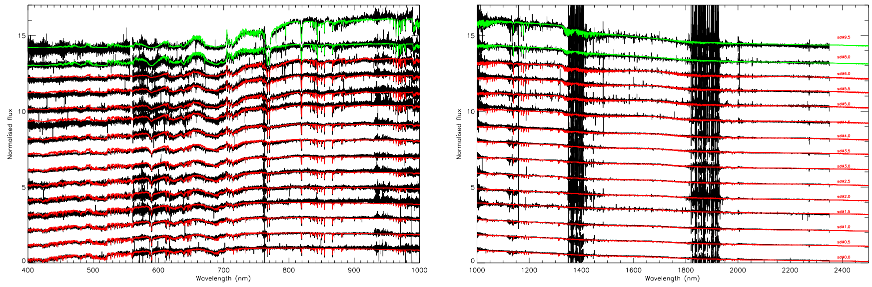

Figure 2. Ultraviolet (400–550 nm) plus visible (550–1000 nm; left) and near-infrared (1000–2500 nm; right) spectra of M subdwarfs (M0–M9.5) compared with smoothed BT-Settl synthetic models (red lines) at a fixed gravity (log(g) = 5.5 dex), metallicities of −1.0 dex), and T_{eff} between 3800 and 2700 K. Two models are plotted in green to fit the coolest M subdwarfs (top row) because the derived metallicity is different from the others (−2.0 dex instead of −1.0 dex for the other sdM). Spectral types are quoted above the associated spectrum on the right-hand side of the right plots.

(Rajpurohit et al. 2014). We find that early M dwarfs (M0–M2) have similar effective temperatures independently from metallicity whereas as later M dwarfs are warmer with decreasing T_{eff}. For example, a usdM5 is 400 K warmer than a solar-type M4 dwarf. We derive metallicities of −1.0, −1.5, and −2.0 dex with typical dispersions of 0.5 dex for sdM, esdM, and usdM, respectively. However, we find that the 2 coolest sources, sdM8 and sdM9.5 are best fit with a lower metallicity (−2.0 dex), which may suggest that the spectral classification proposed by Lépine et al. (2007) might need a revision for the latest spectral types. However, a larger sample of objects with systematic comparison to models is needed before such revision is possible.

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