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The Effective Temperature Scale of M Dwarfs from Spectral Synthesis

Céline Reylé,[1] Arvind S. Rajpurohit,[1] Mathias Schultheis,[1] and France Allard[2]
[1]*Observatoire de Besançon, Institut Utinam, UMR 6213 CNRS, BP 1615, F-25010 Besançon Cedex, France*

[2]*Centre de Recherche Astrophysique de Lyon, UMR 5574 CNRS, Université de Lyon, École Normale Supérieure de Lyon , 46 Allée d'Italie , F-69364 Lyon Cedex 07, France*

Abstract. We present a comparison of low-resolution spectra of 60 stars covering the whole M-dwarf sequence. Using the most recent PHOENIX BT-Settl stellar model atmospheres (see paper by F. Allard, in this book) we do a first quantitative comparison to our observed spectra in the wavelength range 550-950 nm. We perform a first confrontation between models and observations and we assign an effective temperatures to the observed M-dwarfs. Teff-spectral type relations are then compared with the published ones. This comparison also aims at improving the models' opacities.

1. Introduction

Low-mass dwarfs are the dominant stellar component of the Galaxy. Our understanding of the Galaxy therefore relies upon the description of this faint component. Indeed M-dwarfs have been employed in several Galactic studies. Moreover, M dwarfs are now known to host exoplanets, including super-Earth exoplanets (Bonfils et al. 2007; Udry 2007). The determination of accurate fundamental parameters for M dwarfs has therefore relevant implications for both stellar and Galactic astronomy.

Over the last decade, stellar models of very low mass stars have made great progresses. One of the most important recent improvements is the availability of new atomic line profile data that give a much improved representation of the details of the line shapes in the optical spectra of cool dwarfs, and become especially important in situations where line blanketing and broadening are crucial for the model. Still models have to use some incomplete or approximate input physics such as uncertain oscillator strengths for some line and molecular bands missing opacities sources (VO, FeH, CaOH, and some TiO bands). Descriptions of these stars therefore need a strong empirical basis, or validation.

In section 2, we present a comparison of low-resolution spectra covering the whole M-dwarf sequence with recent stellar atmosphere models. In section 3, we derive a spectral type - effective temperature relation and compare it with the published ones.

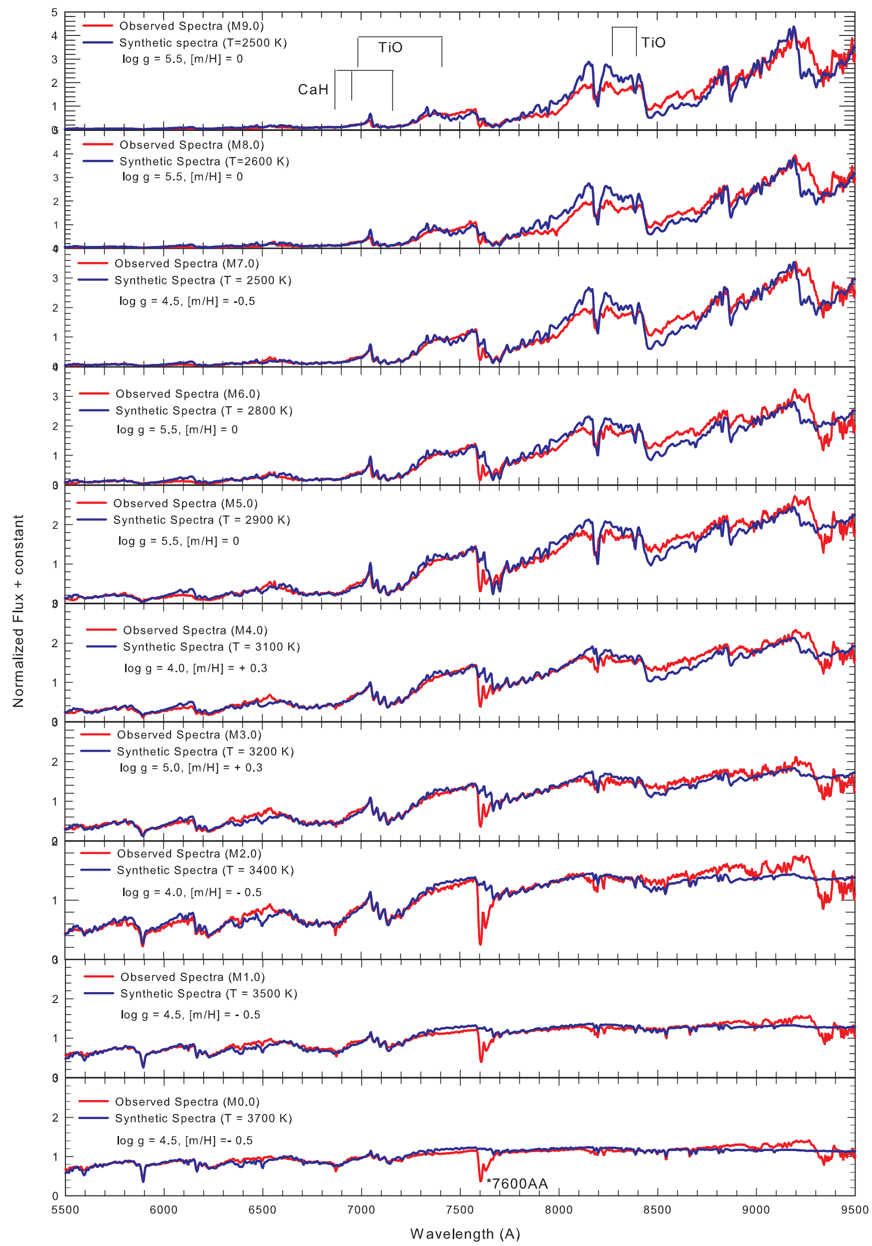

Figure 1. Comparison between model (blue line) and observations (red line) for M0 (bottom) to M9 (top) dwarfs. The strong telluric line around 7600Å is also indicated.

2. Comparison between atmosphere models and M-dwarf spectra

M-dwarfs remain elusive and enigmatic objects because of their small size and cool surface temperature. M-dwarf spectra are characterized by the presence of strong molecular absorptions such as TiO, VO, H_2O and CaH. The temperatures, abundances, sizes and luminosities are not yet well understood. We compared 60 M-dwarfs (from M0 to M9) with optical spectroscopic classification (Reylé et al. 2006), on a large wavelength range, with the most recent PHOENIX stellar atmosphere models, varying the effective temperature, gravity and metallicity. The models used are the most recent version BT-Settl 2010 (Allard, Homeier & Freytag, in this book), taking into account : i) the solar abundances revised by Asplund et al. (2009), ii) the most recent BT2 version of the water vapor line lists by Barber et al. (2008), iii) a cloud model based on condensation and sedimentation timescales by Rossow (1978), supersaturation computed from pre-tabulated chemical equilibrium, and mixing from 2D radiation hydrodynamic simulations by Freytag et al. (2010). The models are available on-line.[1].

Fig. 1 shows the comparison between model (blue line) and observations (red line) along the M-dwarf sequence, from M9 (top) to M0 (bottom). The slope of the optical to near IR spectra is well reproduced by the BT-Settl 2010 models, while some discrepancies remain in the strength of some absorption bands such as the TiO absorption around 6500Å. The discrepencies beyond 8500Åmay also be due to missing opacities or to flux calibration problems. The quality of the fit deteriorates as one goes from the early M to the late Ms and early L dwarfs. These results will allow to calibrate the missing oscillator strengths of molecular bands.

3. Effective temperature scale of M-dwarfs

Multicolour photometry is one way to determine the effective temperature of a star but it requires to know the distance of the star and relies on an assumption on the radius of the star. According to Bessell (1991), R-I and V-I colors are efficient to determine the effective temperature of M-dwarfs earlier than M5.5 but longer wavelength observations are required for later types. Johnson (1965) used eight-colour photometry in the infrared to derive effective temperature. Dahn et al. (2002) used z*JK photometry to derive absolute magnitue and to estimate bolometric corrections. Assuming models from Burrows et al. (1997) and Chabrier et al. (2000) they estimated stellar radii and computed effective temperature.

Spectral synthesis is another way to compute effective temperatures. Martín et al. (1999) determination of M and L-dwarfs temperature is based on spectrum synthesis of high-resolution profile, considering a model atmosphere that includes the formation and condensation of dust grains. Leggett et al. (2000) determined the effective temperature of disk dwarfs with spectral types from M1-M6.5. They compared the observed spectra with the synthetic spectra using NEXTGEN models (Hauschildt et al. 1999). Gizis (1997) used synthetic spectra computed by Allard & Hauschildt (1995) to determine temperature of a sample M-dwarfs and M-subdwarfs.

We used a grid of synthetic spectra computed using BT-Settl 2010 (see Section 2) and a χ^2 fitting method to derive the stellar parameters (effective temperature, metallicity, gravity) of our sample Effective temperature in the grid ranges from 2000 K to 4000 K with a 100 K step, log g ranges from 4.0-5.5 with a 0.5 step, and metallicity values are -0.5,0,+0.3,+0.5. Lower metallicity values are not considered as the sample contain disc stars as shown by Reylé et al. (2006). The spectral type are known were deter-

[1]http://phoenix.ens-lyon.fr/simulator

mined from optical spectroscopy classification (Reylé et al. 2006), using the spectral indices TiO_5, CaH_2, and CaH_3. We found that the effective temperature for the whole M-dwarf sequence (from M0 to M9) ranges from 2400 K to 4000 K. Fig. 2 shows the relation between spectral type and effective temperature, compared to others found in the literature. The plot shows a large dispersion, probably due to the different models and methods used by different authors.

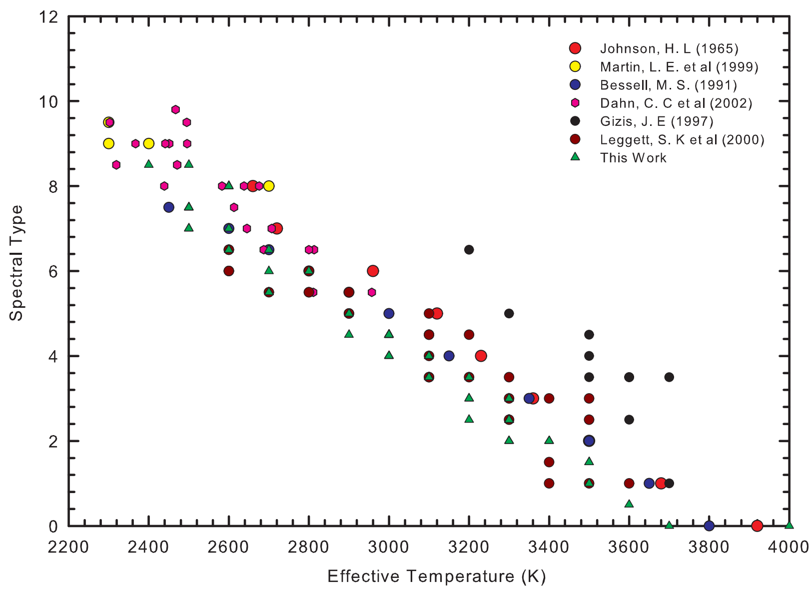

Figure 2. Our spectral type versus effective temperature (green triangles) compared to relations from Johnson (1965); Bessell (1991); Gizis (1997); Martín et al. (1999); Leggett et al. (2000); Dahn et al. (2002)

4. Conclusion

We compared 60 spectra in the wavelength range 550-950 nm of M dwarfs with synthetic spectra obtained with the most recent PHOENIX BT-Settl stellar model atmospheres (see Allard et al., in this book). Our sample covers the M-dwarf spectral sequence. We found that the slope of the optical to near IR spectra is well reproduced by the models, while some discrepancies remain in the strength of some absorption bands. The quality of the fit deteriorates as one goes from the early M to the late Ms and early L dwarfs. This comparison will allow to calibrate the missing oscillator strengths of molecular bands. We derived the effective temperature of the 60 M-dwarfs and drew a relation between effective temperature and spectral type. We found that the effective temperature of M0 to M9 dwarfs with typical metallicities of the disc ranges from 2400 K to 4000 K.

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