# New constraints on the formation and settling of dust in the atmosphere of young M and L dwarfs


E. Manjavacas[1], M. Bonnefoy[1], G. Chauvin[2], P.Rojo[3], B.Goldman[1], F. Allard[4], J. Schlieder[1], D. Homeier[4], T. Henning[1]

[1]Max-Planck-Institut für Astronomie, Heidelberg (Germany)

email: manjavacas@mpia.de

[2]UJF-Grenoble, CNRS-INSU,Institut de Planétologie et d'Astrophysique de Grenoble (IPAG) UMR527, 38041 Grenoble, France.

[3]Departamento de Astronomía, Universidad de Chile, Casilla 36-D, Santiago, Chile.

[4]CRAL-ENS, 46, Allée d'Italie , 69364 Lyon Cedex 07, France.


Results in Manjavacas et al. 2013, submitted


**Abstract** At young ages, low surface gravity affects the atmospheric properties of ultracool dwarfs. The impact on medium-resolution near-infrared (NIR) spectra has only been slightly investigated at the M-L transition so far. We obtain 6 near-infrared, medium resolution (R~1500), spectra of young M9.5-L3 dwarfs. We build an age-sequence of spectra of optically classified M9.5 dwarfs and identified age-sensitive features. We also use the spectra and complementary photometry to test the 2010 and 2012 releases of the BT-SETTL models (Allard et al. 2012). We find that the models can reproduce the spectral energy distributions (SED) and the JHK band spectra of young L2-L3 dwarfs for close temperatures. But we find/confirm that 1/ *these* models give a spread of $T_{eff}$ at the M-L transition 2/ that they do not fit the SEDs and the individual J, H, and K band spectra simultaneously. This inconsistency likely arises from a deficit of dust at high altitude in the cloud models (in particular in the BT-Settl 2012). A modification of the nucleation rate might solve the issue.


## Introduction

Young BDs (≤ 200 Myr) have lower masses and a higher radius than mature field dwarfs with similar temperatures discovered in the field. Their lower surface gravity affect the chemical and physical properties of their atmospheric layers, and in particular the formation and settling of dust grains. This results in peculiar spectral properties that can be investigated in the near-infrared, and that in return enable to study the mechanisms at play in these peculiar atmospheres.

## Data

We obtained spectroscopy of 6 young M9.5-L3 dwarfs using ISAAC at VLT/UT3. We used the low-resolution mode of the instrument with the 0.3'' slit to obtain spectra with R~1500-1700 over 1.1-2.5 μm.

## Empirical analysis

We use different empirical template spectra: young companions, young and mature field dwarfs, to confirm that all our objects are young. Our spectrum of DENIS J1245 (TWA, 8 Myr) is used to complete an age sequence of M9.5 dwarfs classified in the optical (Fig. 1).

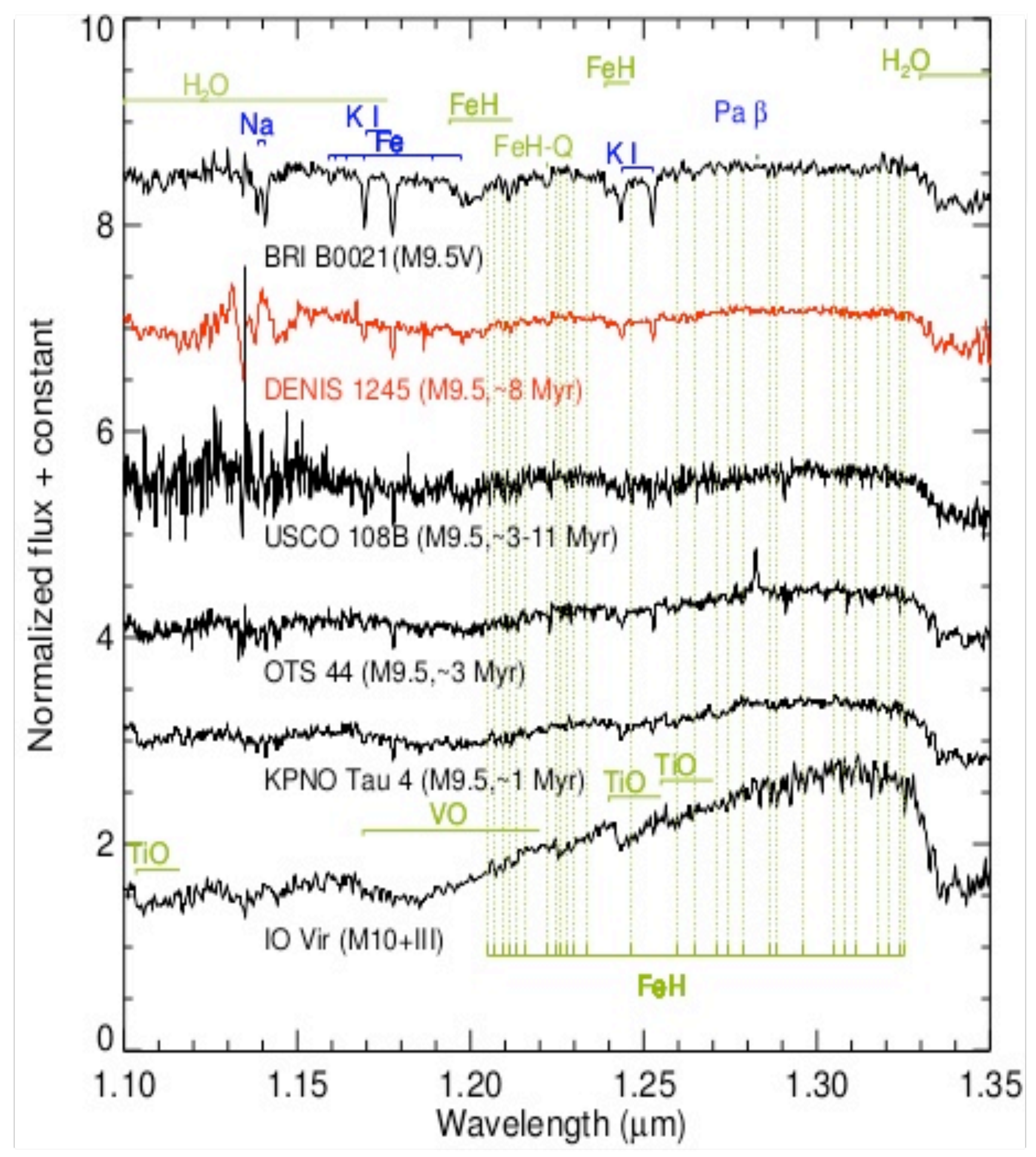


*Figure 1: Evolution of the spectral features with age for opticaly classified M9.5 dwarfs with well assigned memberships in the J-band. When the age increases, the alkali and FeH lines get deeper.*

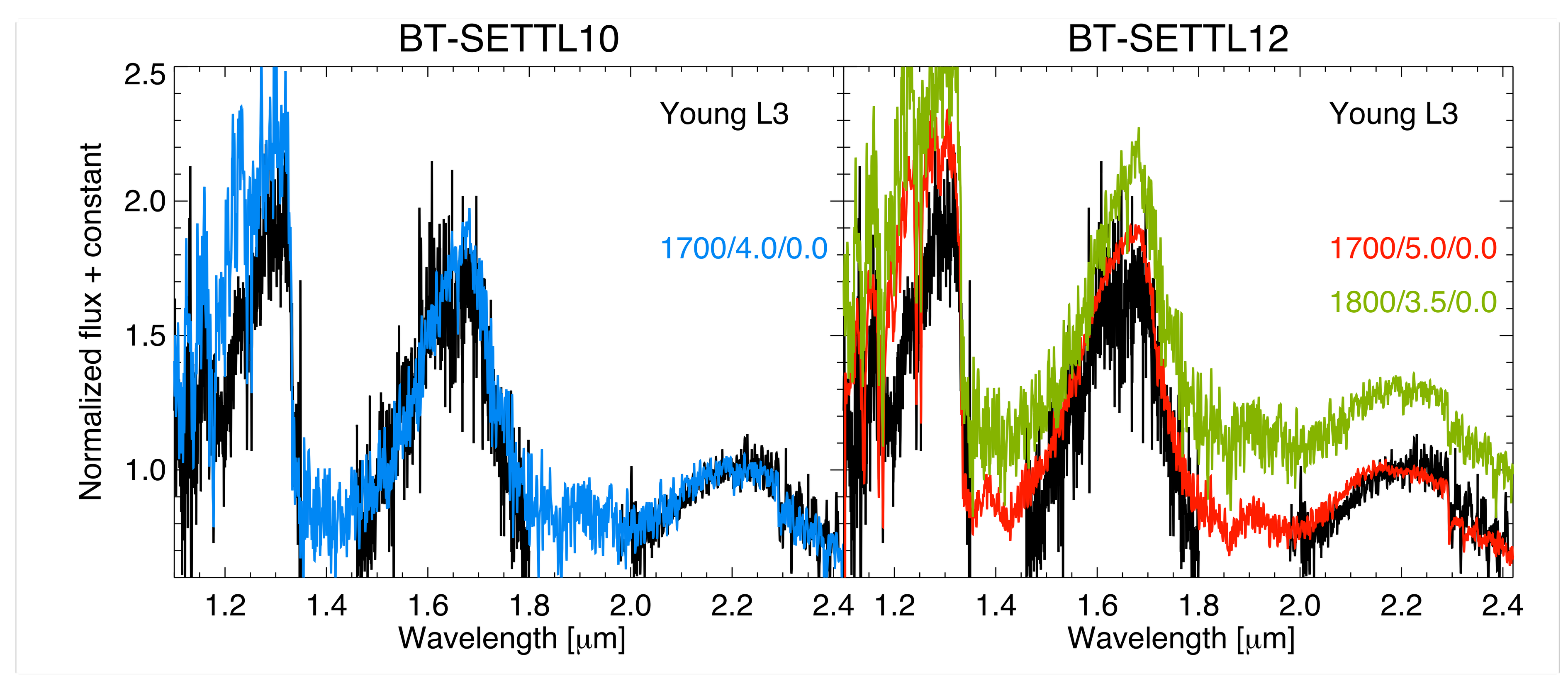


*Figure 2: Comparison of the spectrum of a young L3 dwarf (black) to best fitting model spectra of the BT-SETT10 (blue) and BT-SETTL12 (red) libraries. Alternative solutions are shown in green. The BT-SETTL2010 give a better fit of our data.*

## Synthetic spectra

We compared the spectra to grids of BT-Settl2010 and BT-Settl2012 (Allard et al. 2011, 2012) synthetic spectra. The models couple the PHOENIX code to a cloud model. The cloud model accounts for the formation, transport, and sedimentation, of dust grains. We used spectra with 1500 K ≤ $T_{eff}$ ≤ 3500 K, 3.5 ≤ log g ≤ 5.5, and M/H=0. We computed least-square fits to identify the best matches. Our results were checked visually. We also fitted the 0.5-4.6 μm SED of the sources with these models using the procedure described in Bonnefoy et al. 2013.

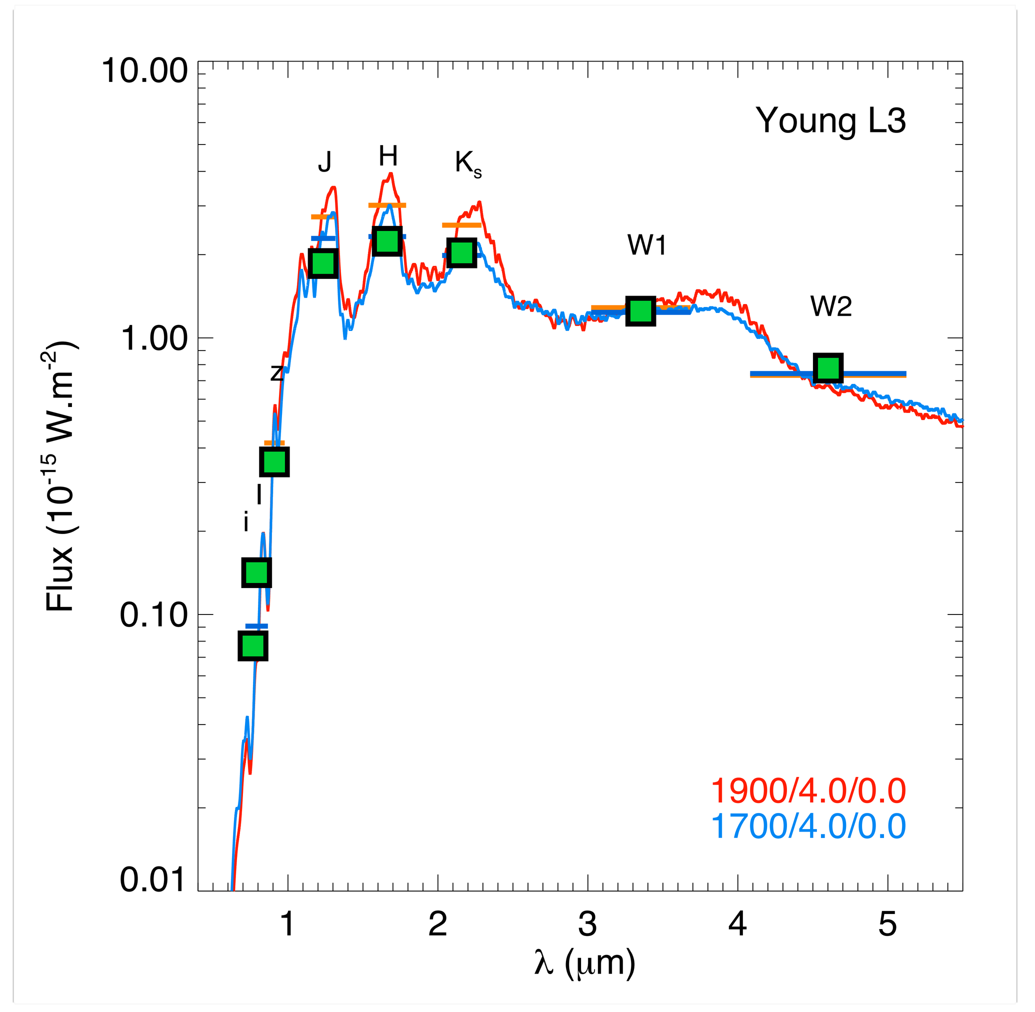


*Figure 3: Fit of the SED of a young L3 dwarf by synthetic spectra of the BT-SETTL 2010 and 2012 libraries. The SED is fitted for $T_{eff}$ close to the ones determined from the fit of the 1.1-2.5 μm spectra (Fig. 2).*

## Results

- JHK spectra: $T_{eff}$=2400-2500 K for M9.5 dwarf, 1600-2000 K for L0-L3 dwarfs (Fig. 2). But models do not reproduce the global slope of the spectra.
- Poor fit from 1.62-1.68 μm because of the lack of FeH opacities.
- SED of L0-L3: can be reproduced by models with $T_{eff}$ close to the ones determined from JHK spectra (±200 K, Fig. 3). $T_{eff}$ ~400 K higher for the M9.5 dwarf. This confirms the spread in $T_{eff}$ at the M-L transition (Bonnefoy et al. 2013), *which is likely caused by uncertainties in the models.*

## Conclusions

non-parametric models do not handle the M-L transition correctly at young ages. This likely arises from a lack of dust at high altitude in the cloud model, which translates to model spectra with too blue pseudo-continua for a given $T_{eff}$. A modification of the dust formation (nucleation rate) in the model could solve the issue.