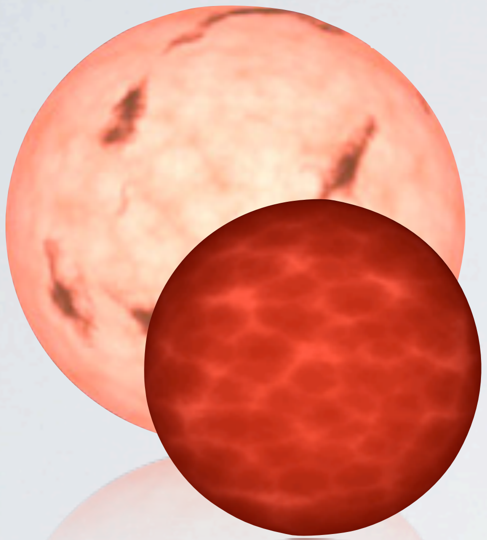
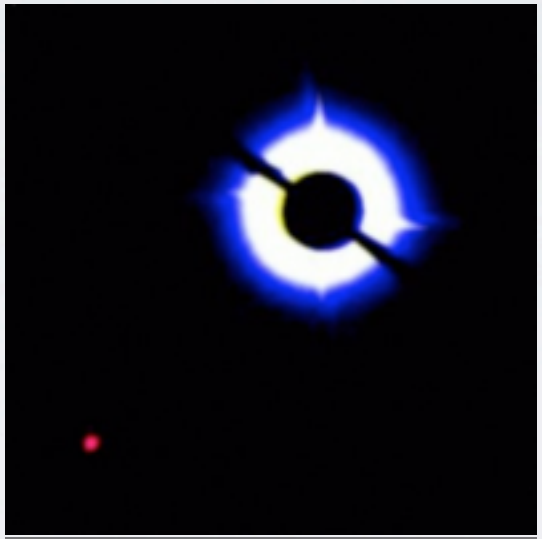
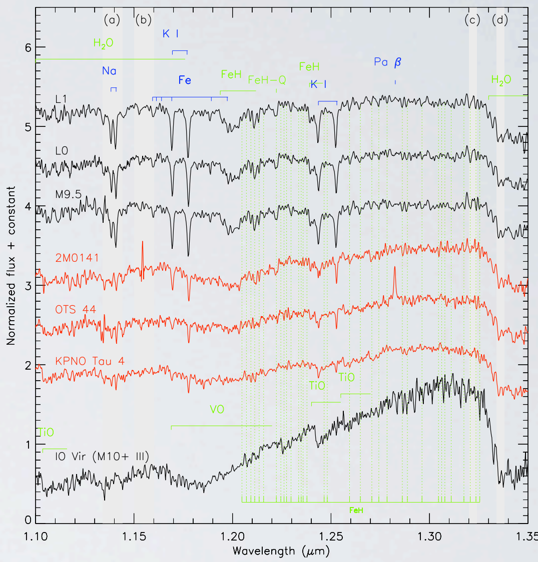
NIR INTEGRAL FIELD SPECTRA OF YOUNG M AND L DWARFS AT THE PLANET/BD BOUNDARY







Mickaël Bonnefoy[1]

also G. Chauvin (IPAG, Fr), A.-M. Lagrange (IPAG, Fr), P. Rojo (U. Chile), F. Allard (ENS-Lyon, Fr), C. Pinte (IPAG, Fr), C. Dumas (ESO), D. Homeier (ENS-Lyon, Fr)

[1] Max Planck Institute for Astronomy

Observing Planetary Systems II - Santiago de Chile - March 7, 2012

OUTLINE

I - Motivations

II - Target sample & Data reduction

III - Empirical analysis

IV - Physical properties

V - Conclusions

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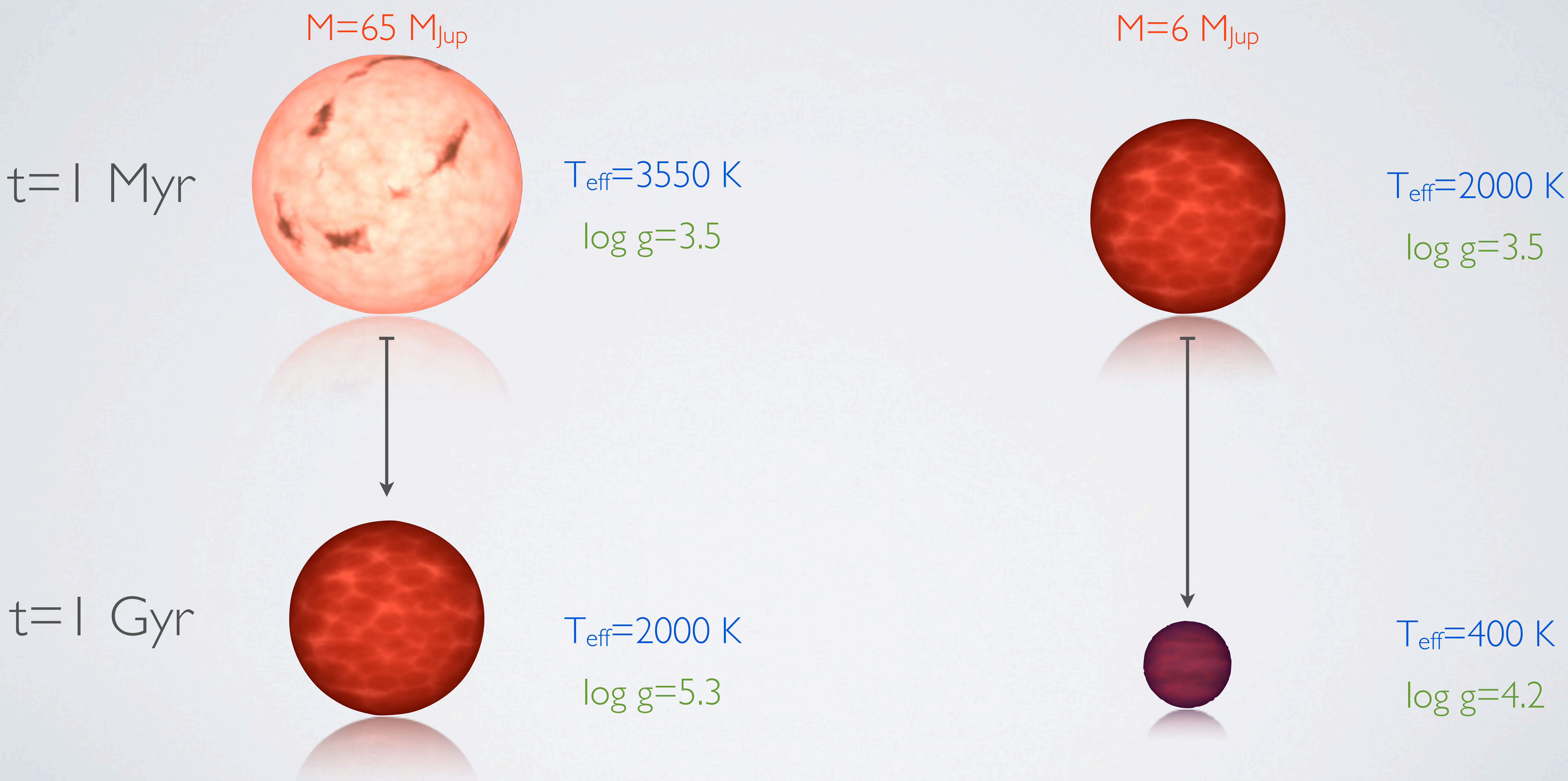
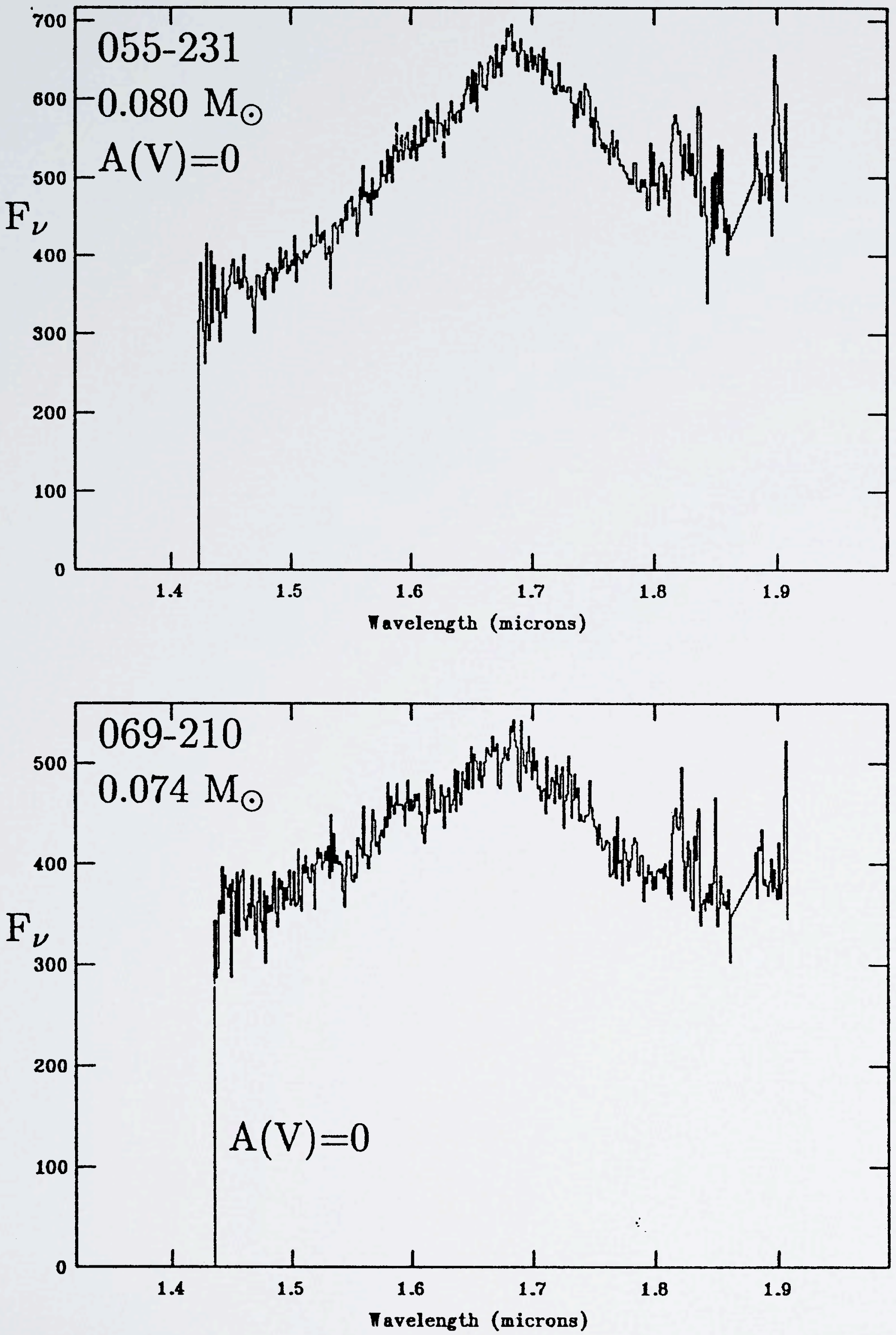
MOTIVATIONS

T_{EFF}, MASS, AGE, AND SURFACE GRAVITY

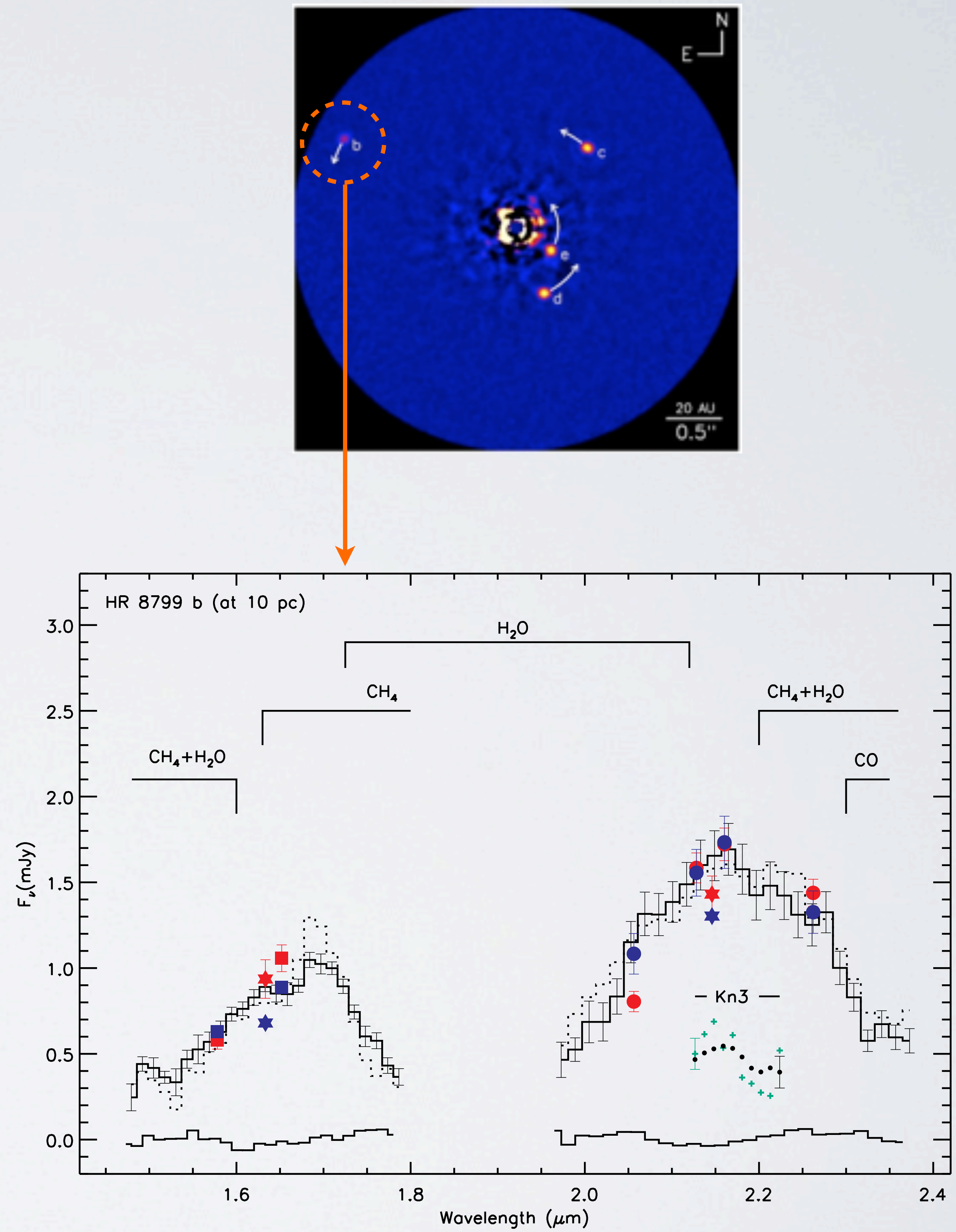


MOTIVATIONS

NIR SPETRA OF YOUNG OBJECTS



Lucas et al. 2001



Barman et al. 2011b

Lack of **high quality NIR spectra** of **young** objects

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TARGET SAMPLE & DATA REDUCTION

SAMPLE & INSTRUMENTAL SETUP

Sample:
- ♣ 11 objects with low log g features or members of clusters/young nearby associations
- ♣ 1 L0 field dwarf (for comparison)
- ♣ 1 giant star spectrum (IO Virginis; for comparison)
- ♣ 5 companions | 1 binary | 5 isolated objets

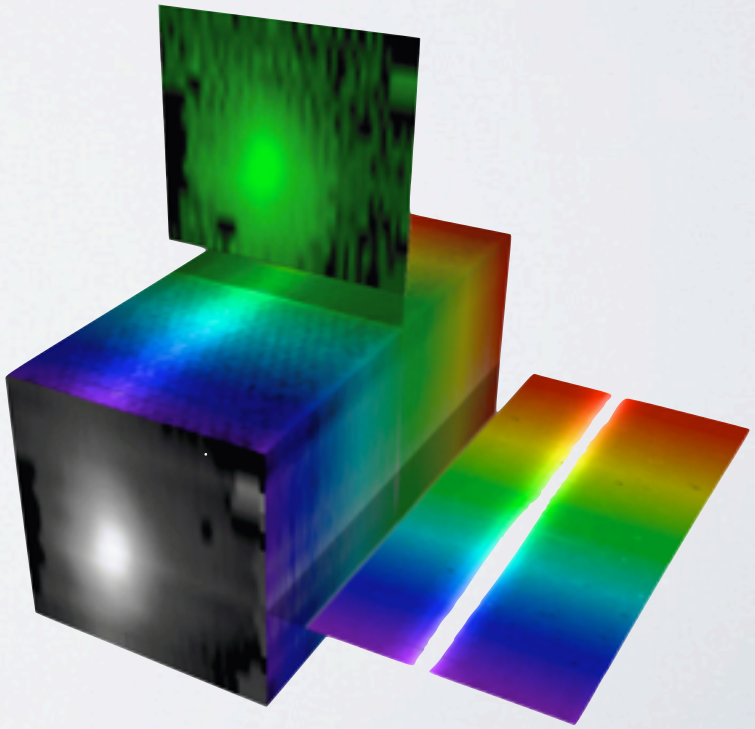
Instrument: SINFONI at VLT

See also the talk of Christophe Dumas

- ♣ Integral field spectrograph functioning in the near-infrared with an adaptive-optics module (MACAO)
- ♣ Medium resolution: 2000 (J band), 1500 (H+K band) spectra

Produces datacubes (2 spatial + 1 spectral dimension) from 2D raw data

Reduces differential flux losses



TARGET SAMPLE & DATA REDUCTION

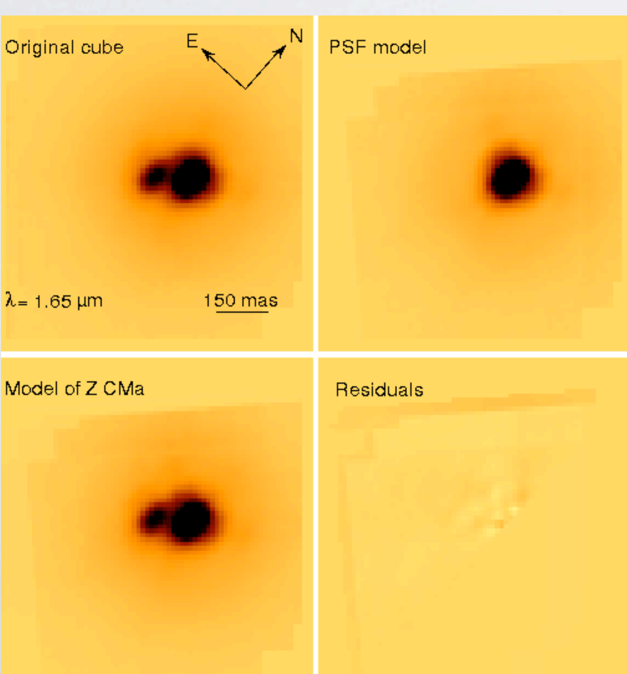
DATA PROCESSING & EXTRACTION

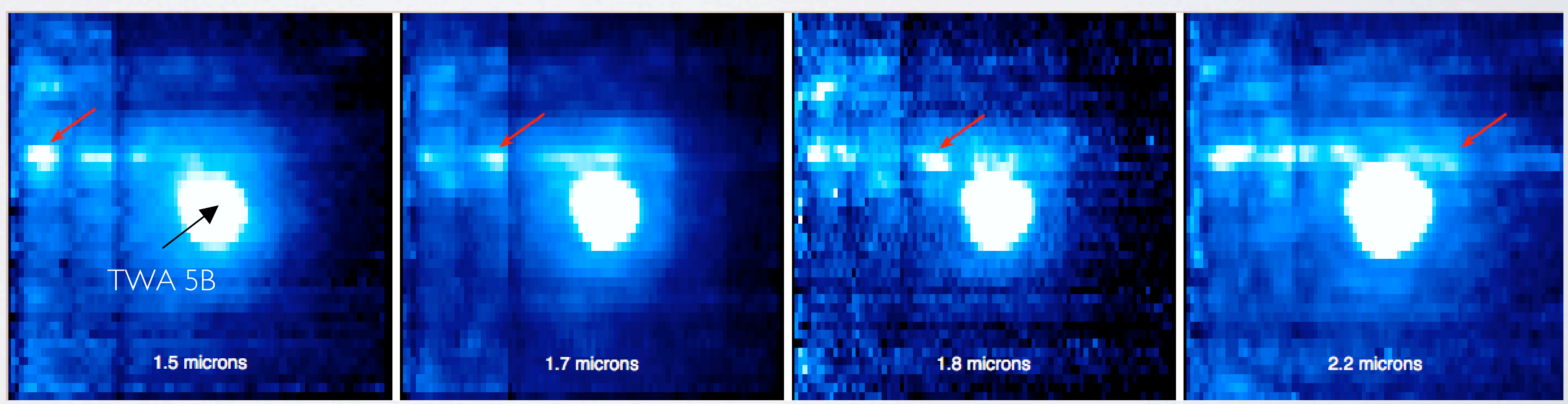
Carefull reduction using the ESO instrument pipeline + custom routines

Custom routines for:

- ♣ Correction of bad lines (due to hot pixels in the 4 first/last columns of the detector)
- ♣ Correction & flagging of electronic cross-talk on slitlet 25 + other slitlets
- ♣ Correction of detector mean level variations
- ♣ Correction of refraction (not handle correctly by the pipeline)
- ♣ Correction of residual bad pixels
- ♣ Filtering of skyline residuals

Developments of 2 spectral extraction algorithms for TWA 22, DH Tau b, TWA 5b, and GSC8047 B





Method similar to that presented by Tobias Schmidt

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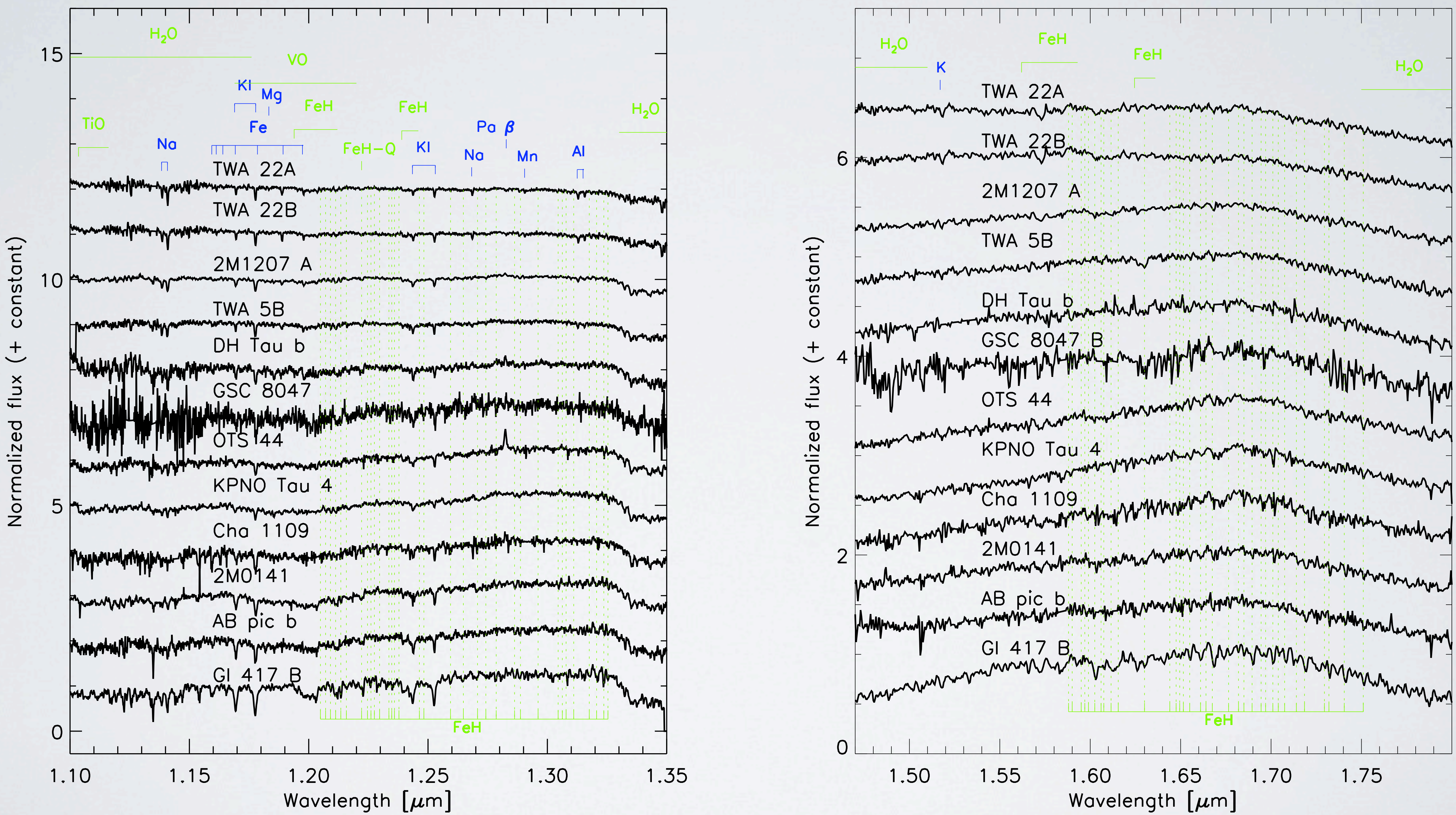
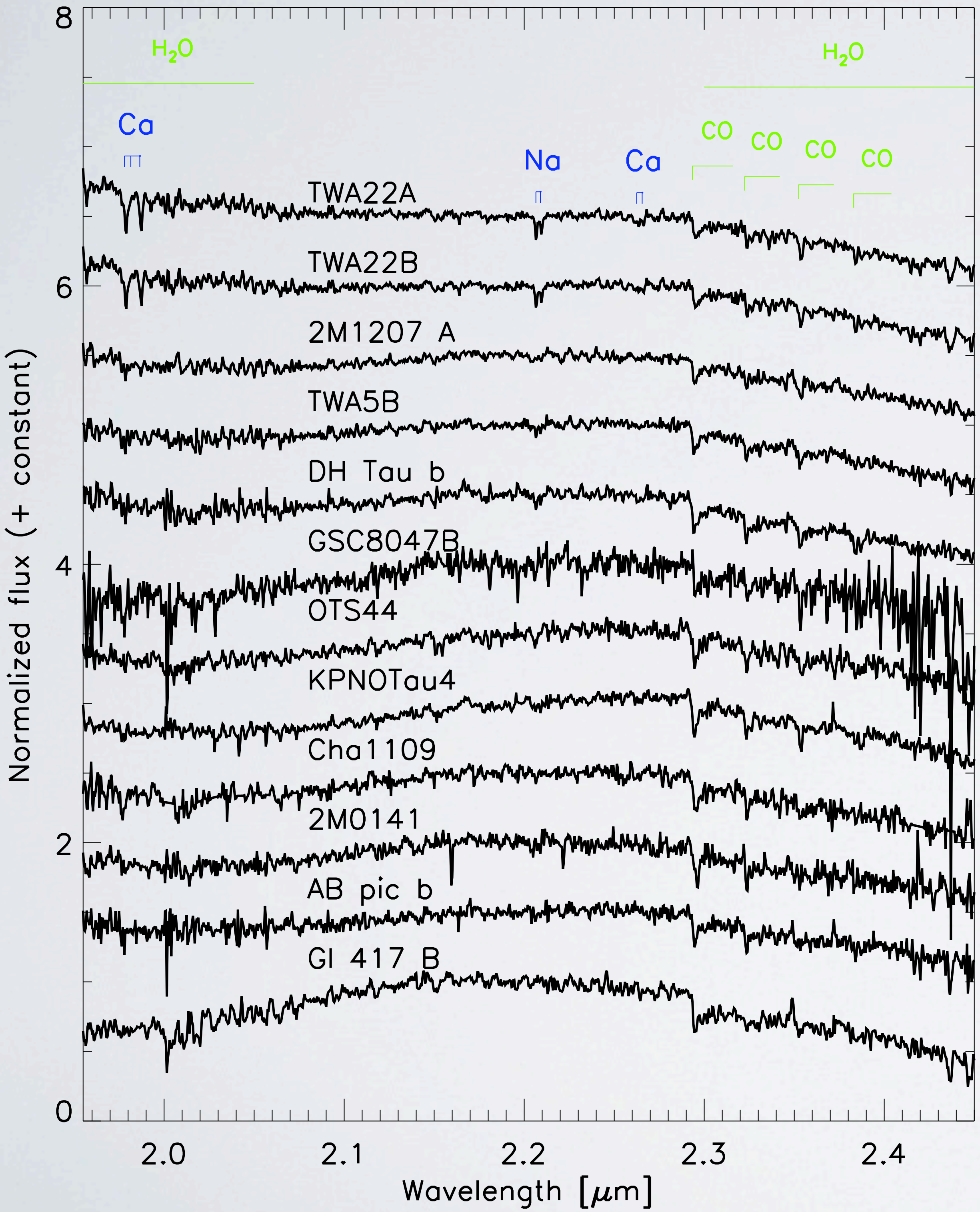
EMPIRICAL ANALYSIS

THE LIBRARY



EMPIRICAL ANALYSIS

THE LIBRARY



SNR (apart for GSC8047 B):

- 30-150 in the J-band
- 30-80 in the H+K band

1.1-2-5 μm flux calibrated spectra reconstructed using the JHK band photometry **when avaliable and reliable**.

EMPIRICAL ANALYSIS

SPECTRAL CLASSIFICATION

Method 1: comparison to template spectra of young objects classified in the optical (Luhman et al. 2004)

Method 2: Selection and use of 3 spectral indexes slightly + 1 extremely sensitive to the age

Object	Continuum	Indexes	Adopted
2M1207 A	M8.5±0.5	M8.5±2	M8.5±0.5
OTS 44	M9.5±0.5	L0±2	M9.5±0.5
KPNO Tau 4	M9.5±0.5	L1±2	M9.5±0.5
2M0141	L0±1	L0.5±2	L0±1
TWA 5B	M8.5±0.5	M8.25±2	M8.5±0.5
Cha 1109	L0±1	L0.5±2	L0±1
Gl 417 B	L3.5±0.5	L4.5±2	L4.5±2
AB Pic b	L0±1	L0±2	L0±1
DH Tau b	M9.25±0.25	M9.25±2	M9.25±0.25
GSC8047 B	M9.5±0.5	M9±2	M9.5±0.5
TWA 22A	M5±1	M5±2	M5±1
TWA 22B	M5.5±1	M5.5±2	M5.5±1
2M0345	L0±1	M9.5±2	L0±1

No outlier!

De-reddened spectrum of DH Tau b intermediate between spectrum of young M9 and M9.5

GSC0847 B has features caracteristics of low log g

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PHYSICAL PROPERTIES

CHOICE OF ATMOSPHERIC MODELS GRIDS

Choice of the **2 most advanced** atmospheric models with associated dust cloud models:

DRIFT-PHOENIX:

- ♣ Use a cloud model with dust grains **formed in phase non equilibrium from seeds that grow, and evaporate while settling**
- ♣ Grains fraction and size distribution computed **from top to bottom**
- ♣ **Equilibrium chemistry only**
- ♣ Takes into account the supersaturation

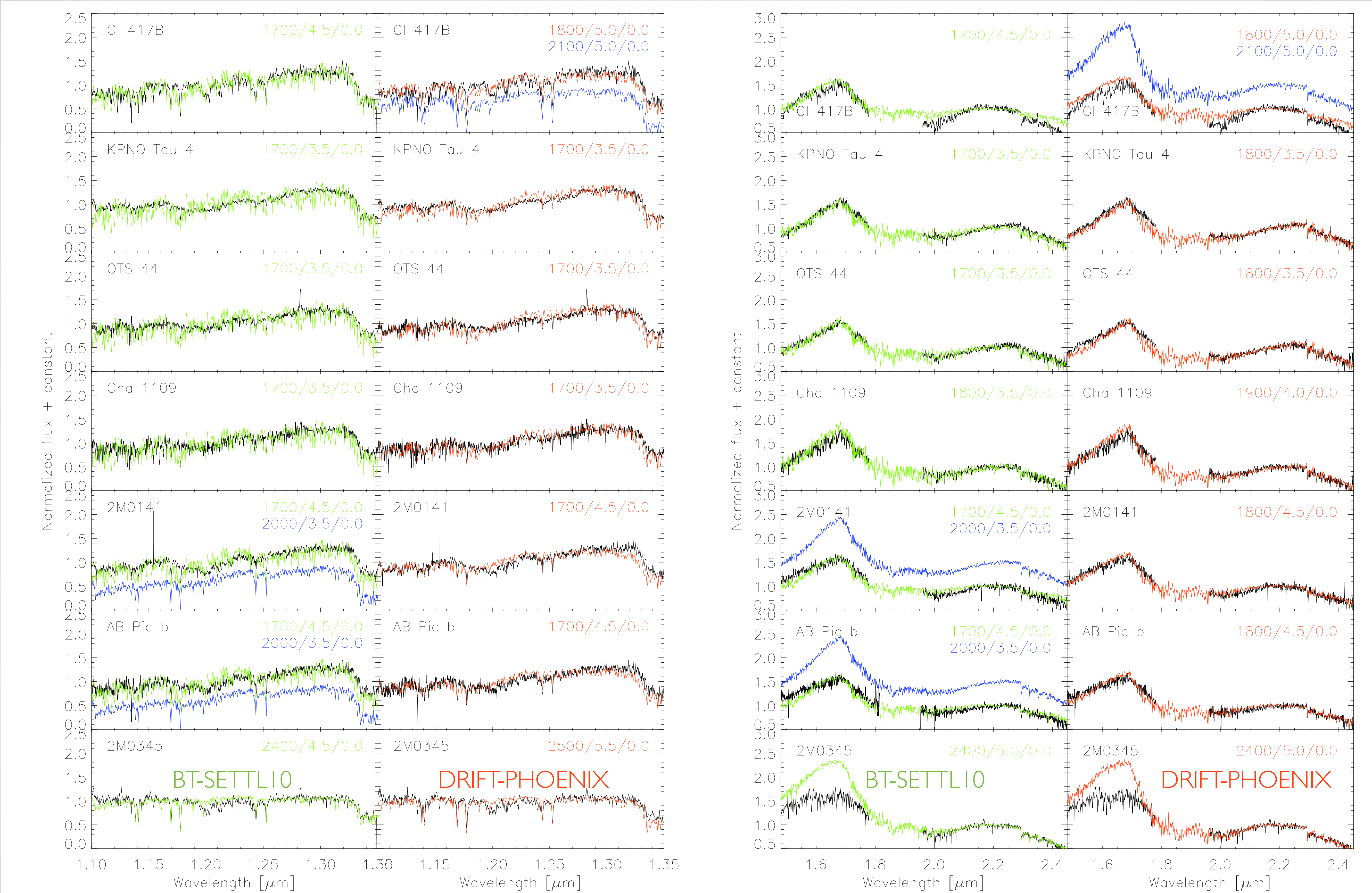
BT-SETTL10:

- ♣ Computes fraction + mean size of grains + effects of depletions, **from bottom to the top** of the photosphere, comparing timescales for condensation and **growth**, gravitational **settling**, and turbulent mixing
- ♣ More grains species than DRIFT-PHOENIX (55 vs 7)
- ♣ Use detailed calculation of the supersaturation
- ♣ Takes into account **non-equilibrium chemistry** (N_2, NH_3, CO, CO_2 & CH_4)
- ♣ Based on **updated solar abundances** (Asplund et al. 2009, Caffau et al. 2010)
- ♣ No hypothesis on the chemical equilibrium between grains and the gaz phase

+ Grainless (pure gaz phase-equilibrium chemistry) models GAIA-COND for early-type objects (T_{eff} > 2000 K)

PHYSICAL PROPERTIES

COMPARISON TO SYNTHETIC SPECTRA



PHYSICAL PROPERTIES

T_{EFF}, MASS, AND RADII

Method I:

Evolutionary models: T_{eff} —*Age*→ Mass, **Theoretical Radius**

Method II: use of bolometric corrections of Todorov et al. 2010 for young M9.5-L0 objets

Photometry —*Distance* / *Bolometric corrections*→ Luminosity

T_{eff}, Luminosity —$L=4\pi\sigma R^2 T_{eff}^4$→ **Semi-empirical radii**

T_{eff}, Luminosity —*Evolutionary tracks*→ New mass estimates

Conclusions: AB Pic b, DH Tau b right at the planet/BD boundary

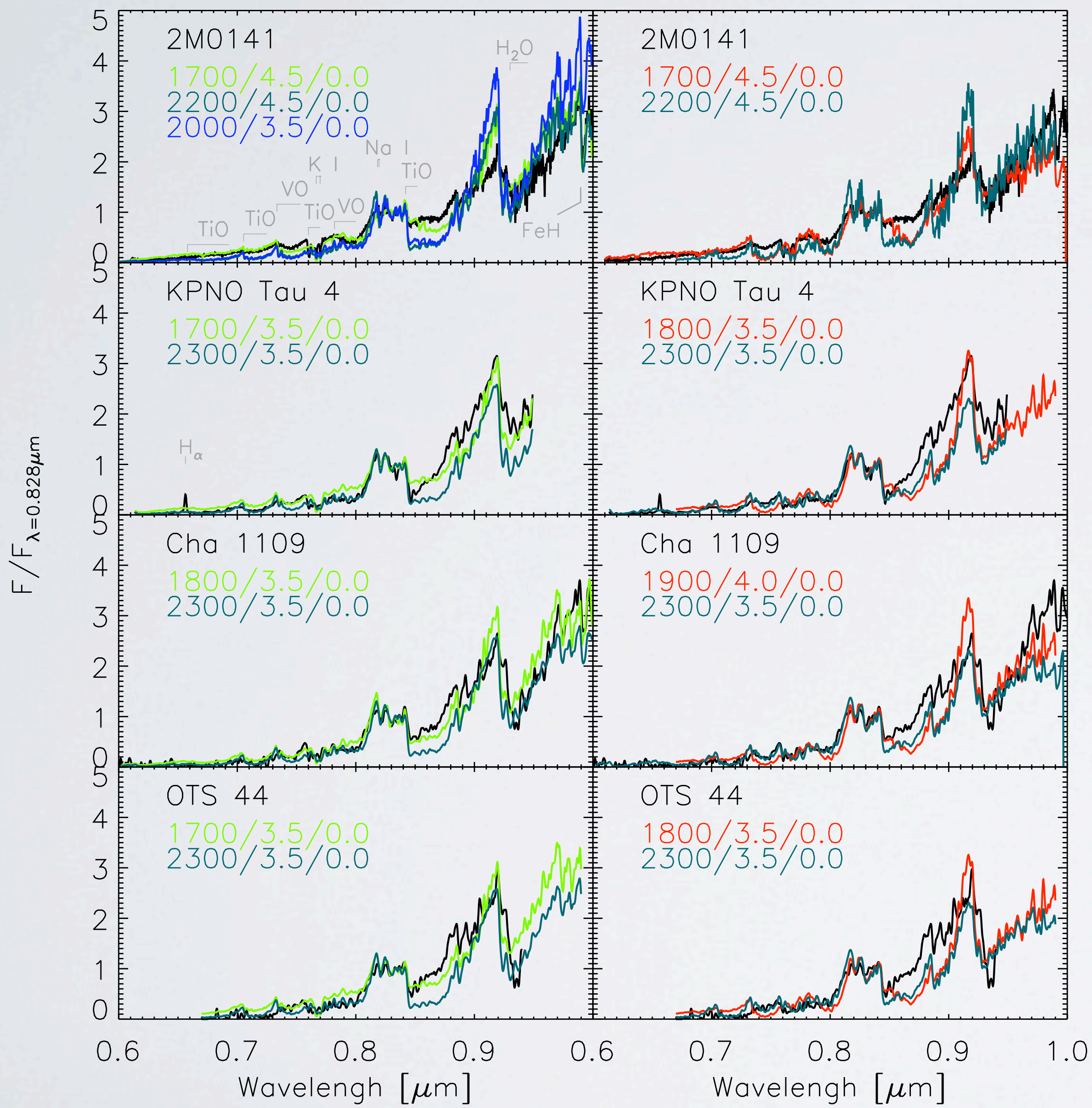
... but semi-empirical radii are **1.4 to 3 times larger** than models predictions for 1-3 Myr old objects

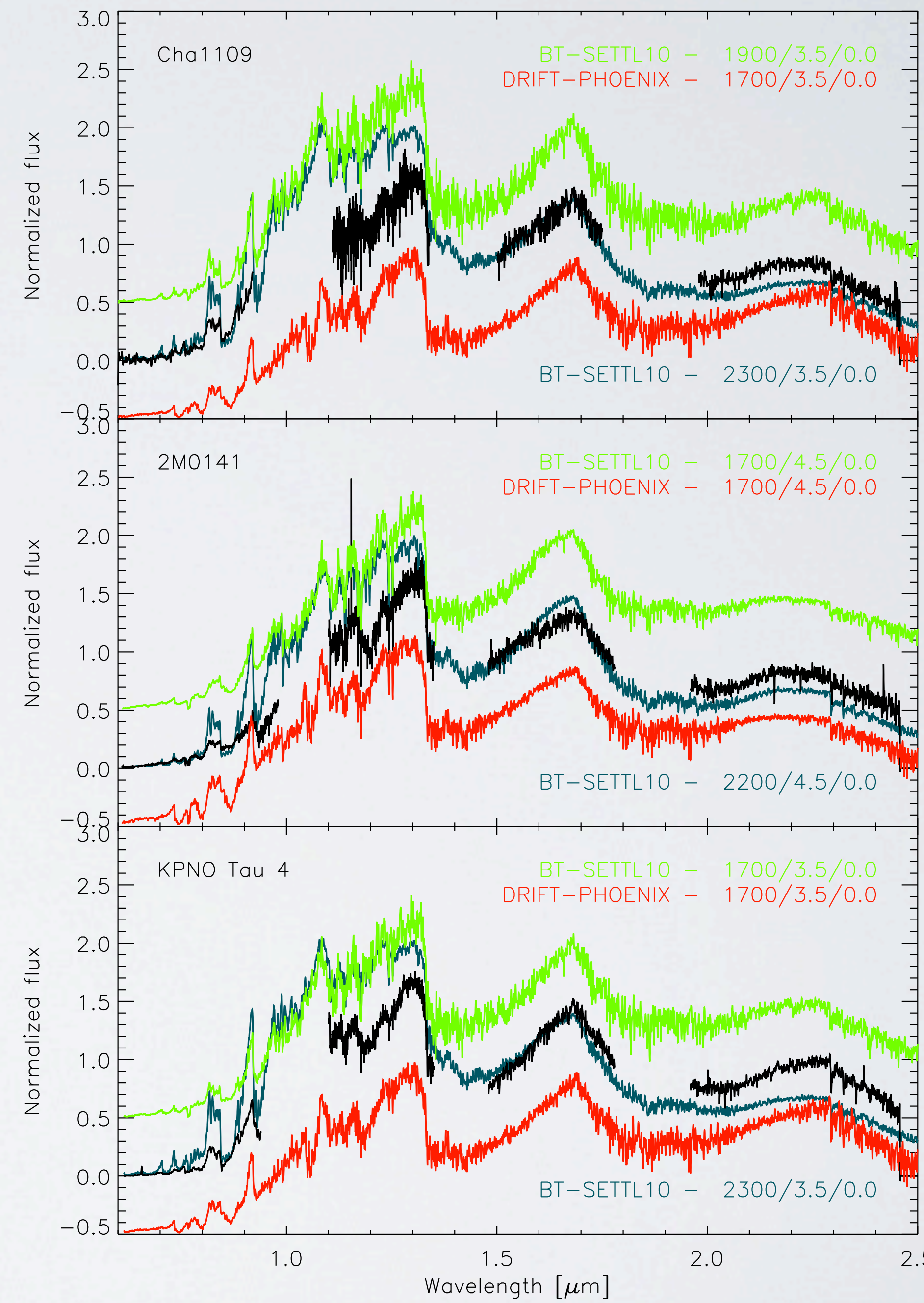
However, **spectroscopic T_{eff} 300-500 K lower than expected from tracks** and T_{eff}/spectral types conversion scales (Luhman's paper).

PHYSICAL PROPERTIES

BIAS - IDENTIFICATION

Atmospheric models: **problems for TiO, VO** absorptions in the optical. But the **optical+NIR continuum is well reproduced** simultaneously for T_{eff}=1700-1800 K





But **troubles at high log g** (field dwarfs), in the H band. Probably a **deficit of dust** (Witte et al. 2011 ; this work). But also **missing FeH absorptions** in this region.

Fit of the SED at the same T_{eff}

PHYSICAL PROPERTIES

BIAS - IDENTIFICATION

Redenning/excesses: no for KPNO Tau 4, OTS 44, and AB Pic b. Little influence for Cha1109

Binarity: possible. But would have to be the case for all our 1-3 Myr old M9.5-L0 targets.

Spectral/photometric variability

Evolutionary models: Previous results of Konopacky et al. 2010 for field BD and of Mohanty et al. 2004 pointing toward the same problems

Could past accretion be responsible (Barrafe et al. 2009) ?

Degeneracy on initial entropy (or radii; i.e. Spiegel et al. 2012) ?

But could also comes from wrong equation of states, heat transport efficiency,...

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CONCLUSIONS

Library: 11 medium-resolution near-IR (1.1-2.5 µm) spectra of young objets

Empirical analysis: DH Tau b spectral type intermediate between young M9.5 and M9 young dwarfs

Atmospheric models:

- ♣ Strong improvement wrt past generations: optical+NIR spectra (J, HK, JHK) +SED fitted simultaneously for same T_{eff} & log g
- ♣ But problems for mature field dwarfs: lack of dust at high log g and at optical wavelengths

Evolutionary models predictions:

- ♣ AB Pic b and DH Tau b at the planet/brown dwarf boundary
- ♣ But... semi-empirical radii of 1-3 Myr objects seems under-predicted by models

Possible origins:

	KPNO Tau 4	OTS 44	Cha1109	AB Pic b
Redenning, extinction	NO	NO	POSSIBLE	NO
Atmospheric models	NOT LIKELY	NOT LIKELY	NOT LIKELY	NOT LIKELY
Binarity	POSSIBLE	POSSIBLE	POSSIBLE	POSSIBLE
Variability	POSSIBLE	NO	POSSIBLE	POSSIBLE
Evol. model/ t_0	POSSIBLE	YES	YES	POSSIBLE

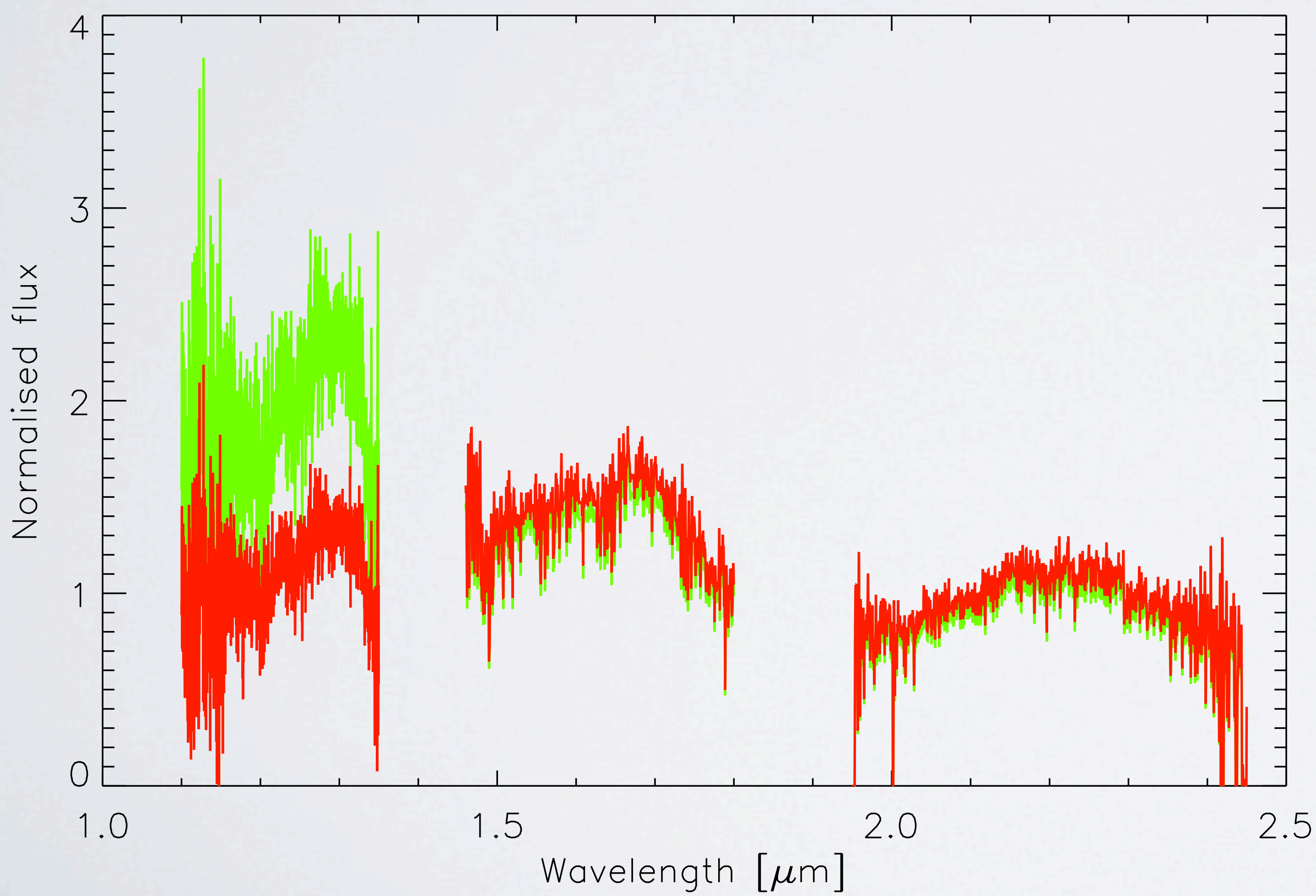
Results presented in Bonnefoy et al. 2012 (submitted)

THANK YOU!

COMMENTS ON *PATIENCE ET AL. 2012* RESULTS

Complementary study:

- ♣ Considered mostly companions spectra, but used 5 grids of synthetic spectra
- ♣ Short empirical analysis
- ♣ Some more companions (GQ Lup b, CT Cha b). No analysis of planetary mass objects spectra of OTS 44, Cha1109, KPNO Tau 4
- ♣ No SED fitting, and no JHK+optical fit. No semi-empirical radii using BC.



Different conclusions:

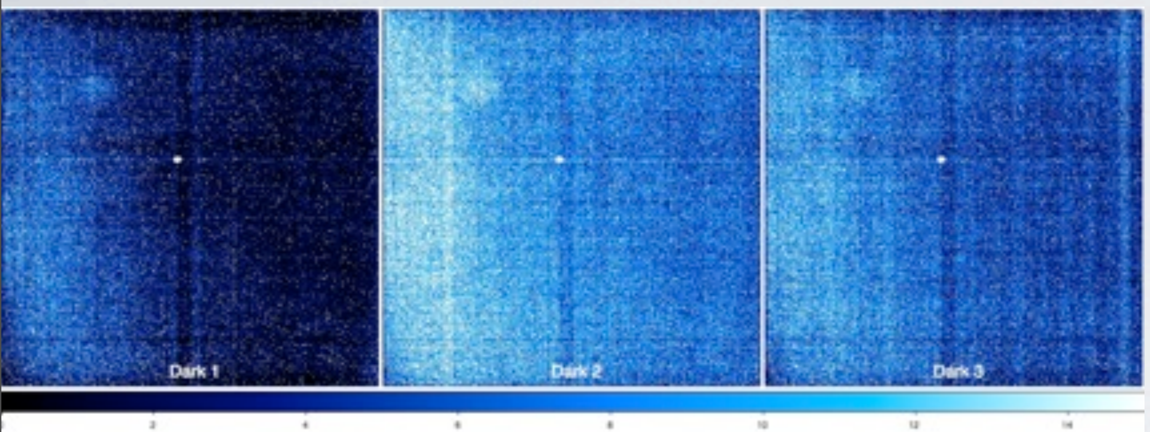
- ♣ Spread on T_{eff} up to 600 K using the different models
- ♣ Different T_{eff} for the fit of J, HK, JHK bands

...but resulting from a different analysis:

- ♣ Analysis of the JHK band of AB Pic b et GSC8047 B is risky!
- ♣ Comparison of auto-consistent, non autoconsistent (Marley), and extreme models (Dusty).

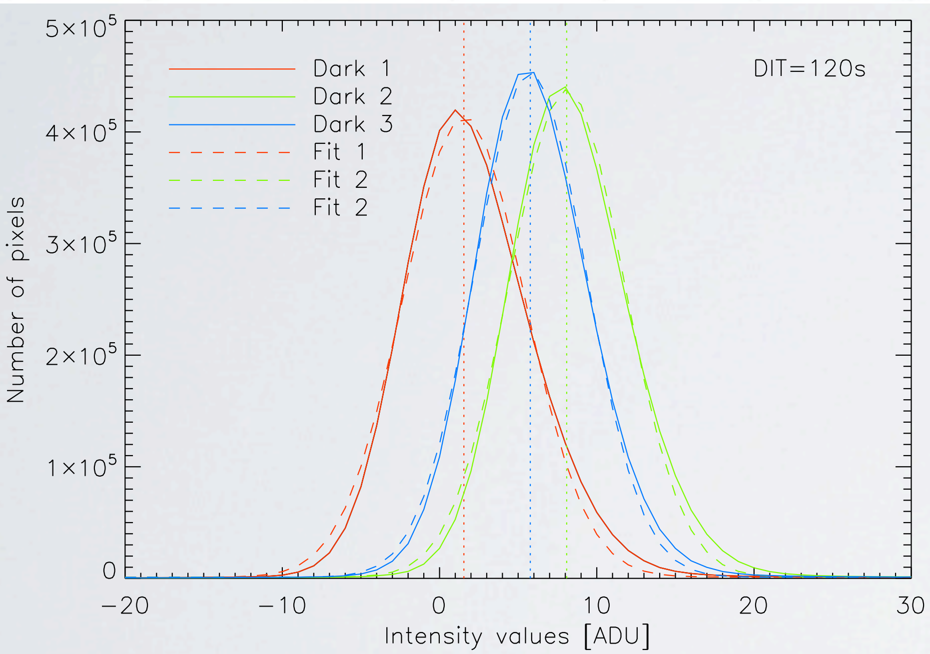
NOTES ON THE DATA PROCESSING

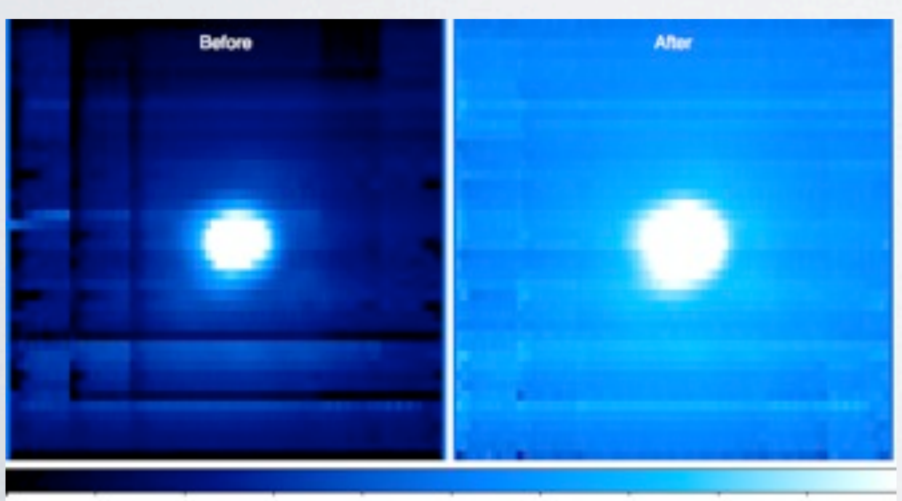
♣ Consecutive darks with same DIT, but variation of the mean detector level

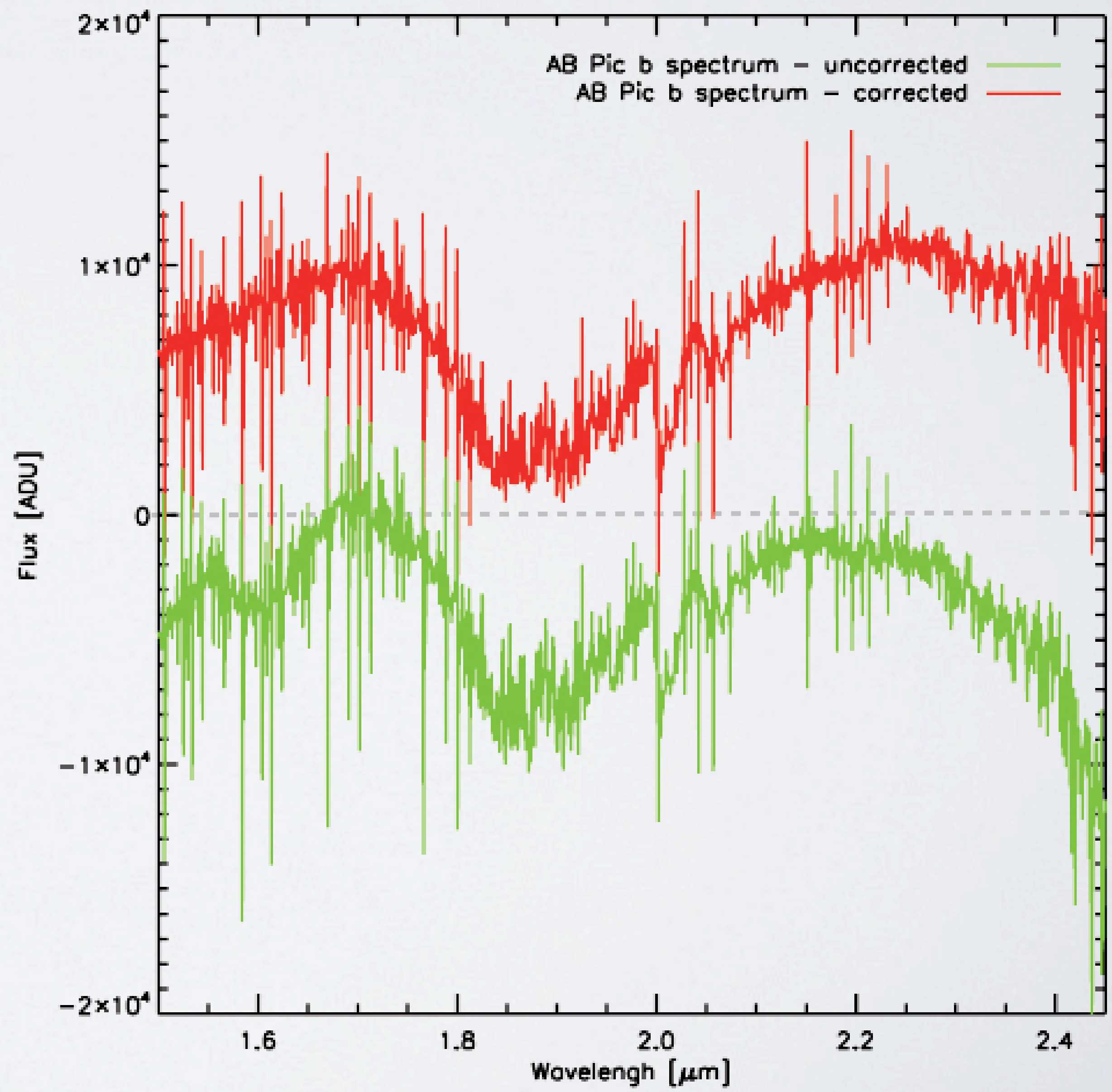


♣ Appears on 50% of frames series with DIT ≥ 300s

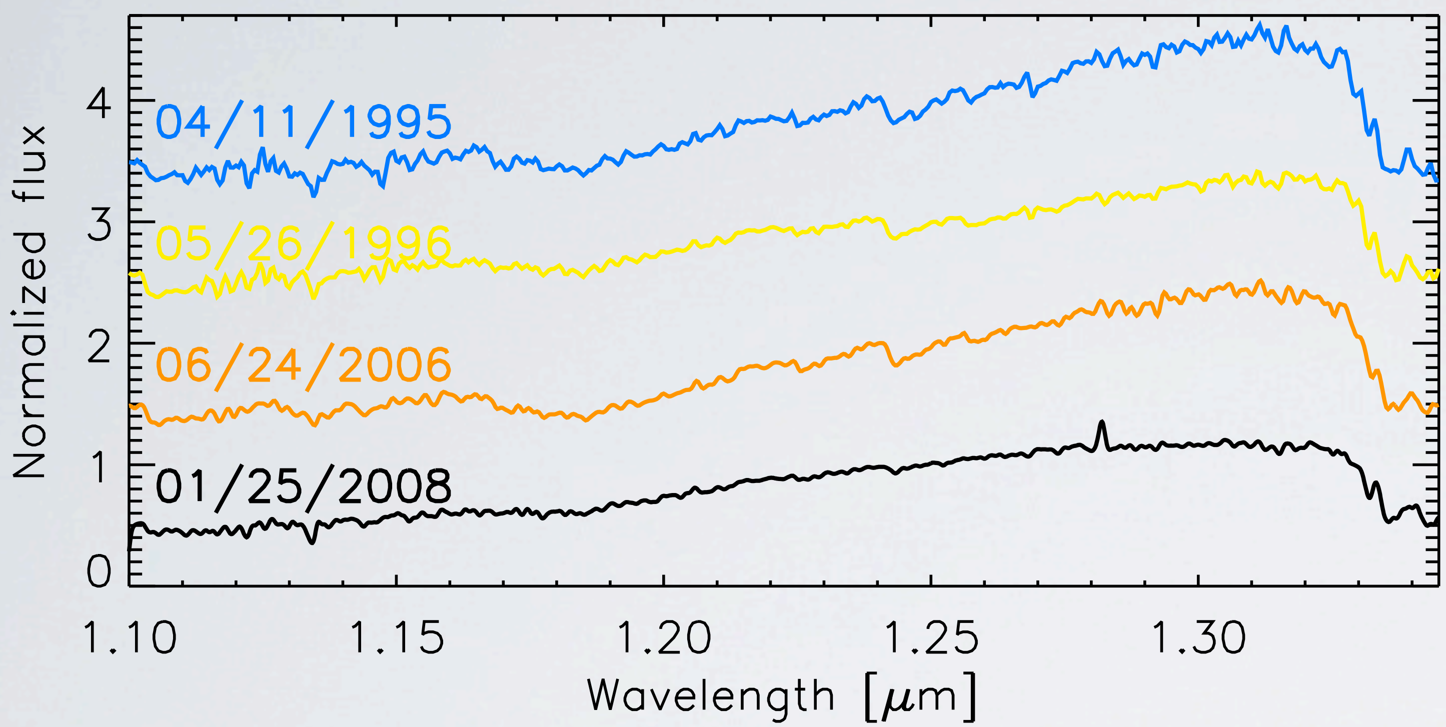
♣ No clear correlation with the temperature of the cold and warm parts of the instrument

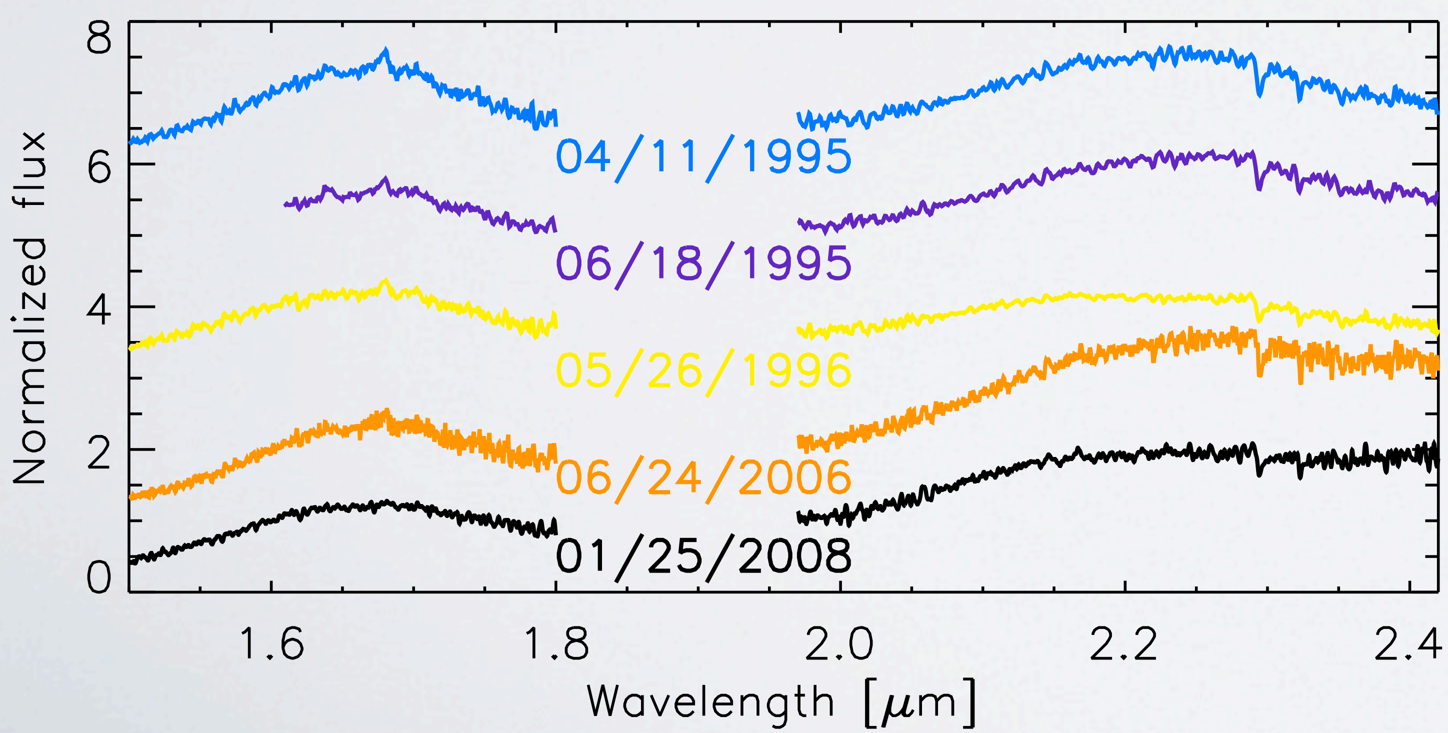






COMMENTS ON THE EMPIRICAL CLASSIFICATION





Classification scheme developped fopr M9.5-L0 by K. Luhman based on spectra of Mira that are spectroscopic variables...

MOTIVATIONS

ATMOSPHERIC MODELS

Goals: ♣ Reproducing the chemistry and physics of ultracool atmospheres.
♣ Getting rids of the T_{eff}/log g degeneracy

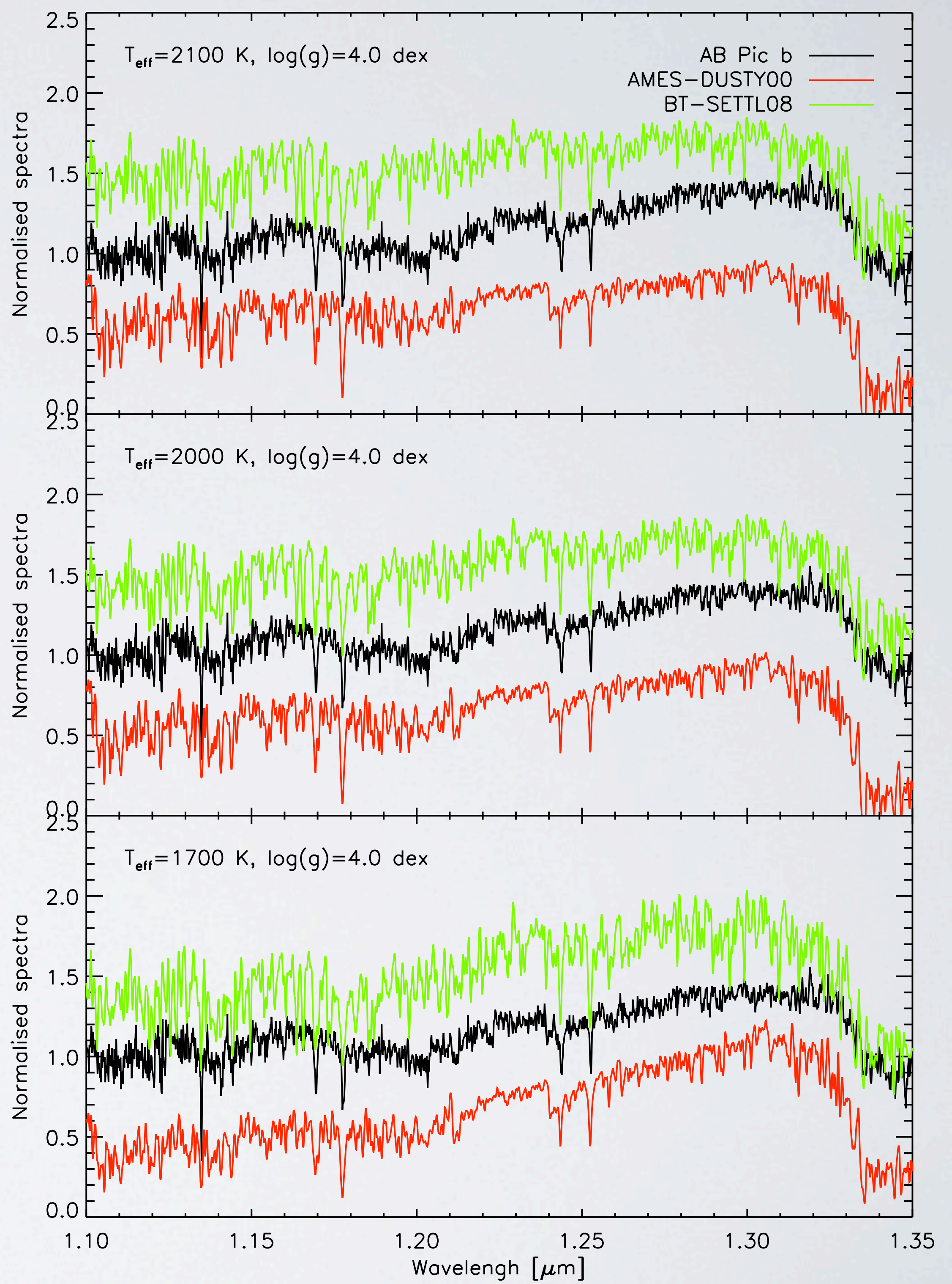
Outputs: Synthetic spectra for Teff, log g, M/H, etc

Below 2600 K: Need to model the **formation and settling of dust grains** (dust cloud model)

In the last 5 years, variety of models:

- ♣ Hubeny and Burrows et al. 2007 (NLCE)
- ♣ Fortney et al. 2008 (M/H≠0, NLCE)
- ♣ DRIFT-PHOENIX, (clouds, settling)
- ♣ BT-SETTL10 (clouds,settling)
- ♣ Madhusudhan et al. 2011 (Thick clouds)
- ♣ Spiegel et al. 2011 (Hybrid clouds)

Need to **test the models** using young & old objects spectra



Bonnefoy et al. 2010