Atmosphere models across the Substellar Boundary

Derek Homeier[1]

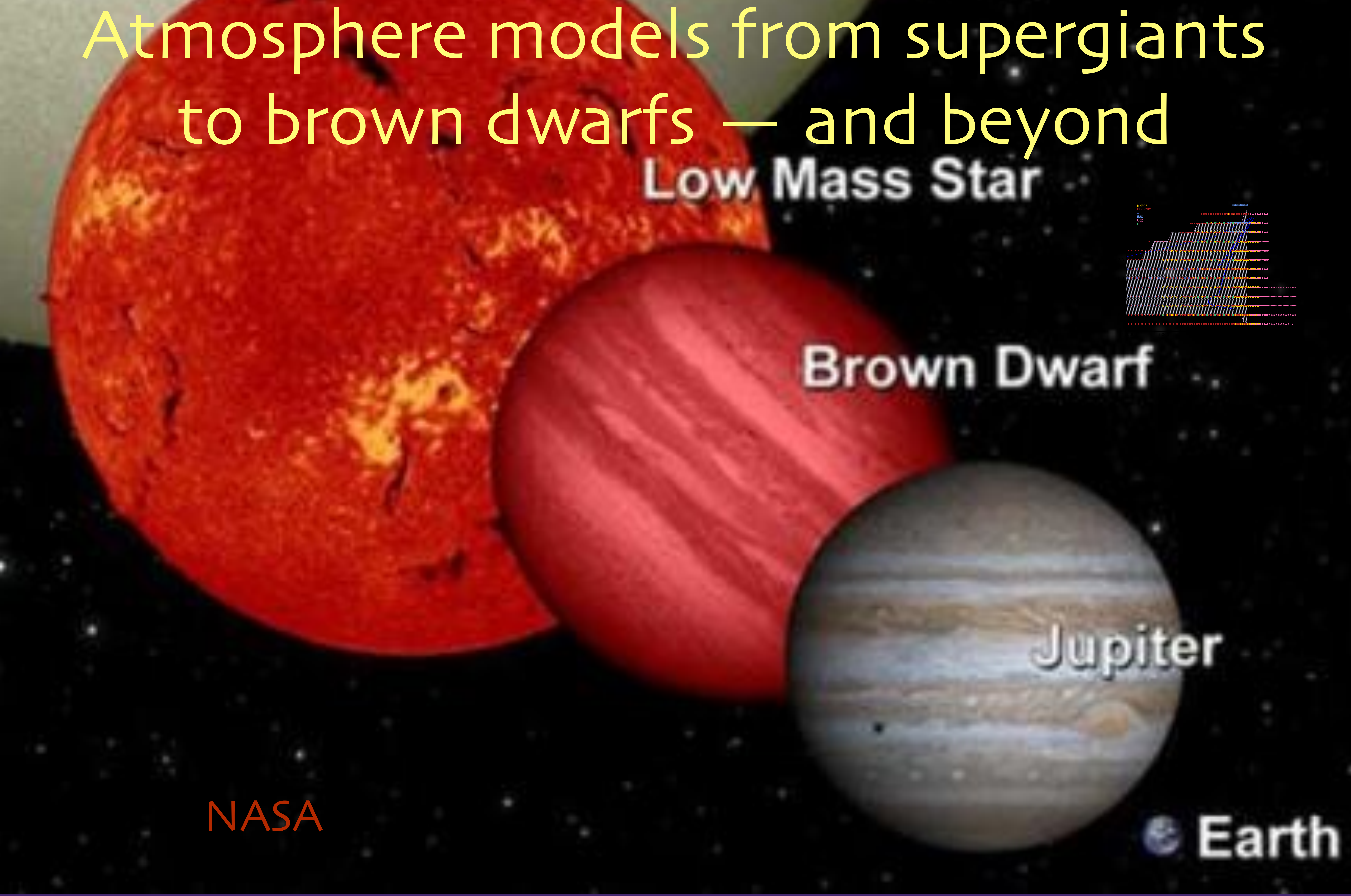
France Allard[1]
Isabelle Baraffe[2,1]
Bernd Freytag[3]
Gilles Chabrier[1,2]

[1]CRAL/École Normale Supérieure de Lyon

[2]University of Exeter

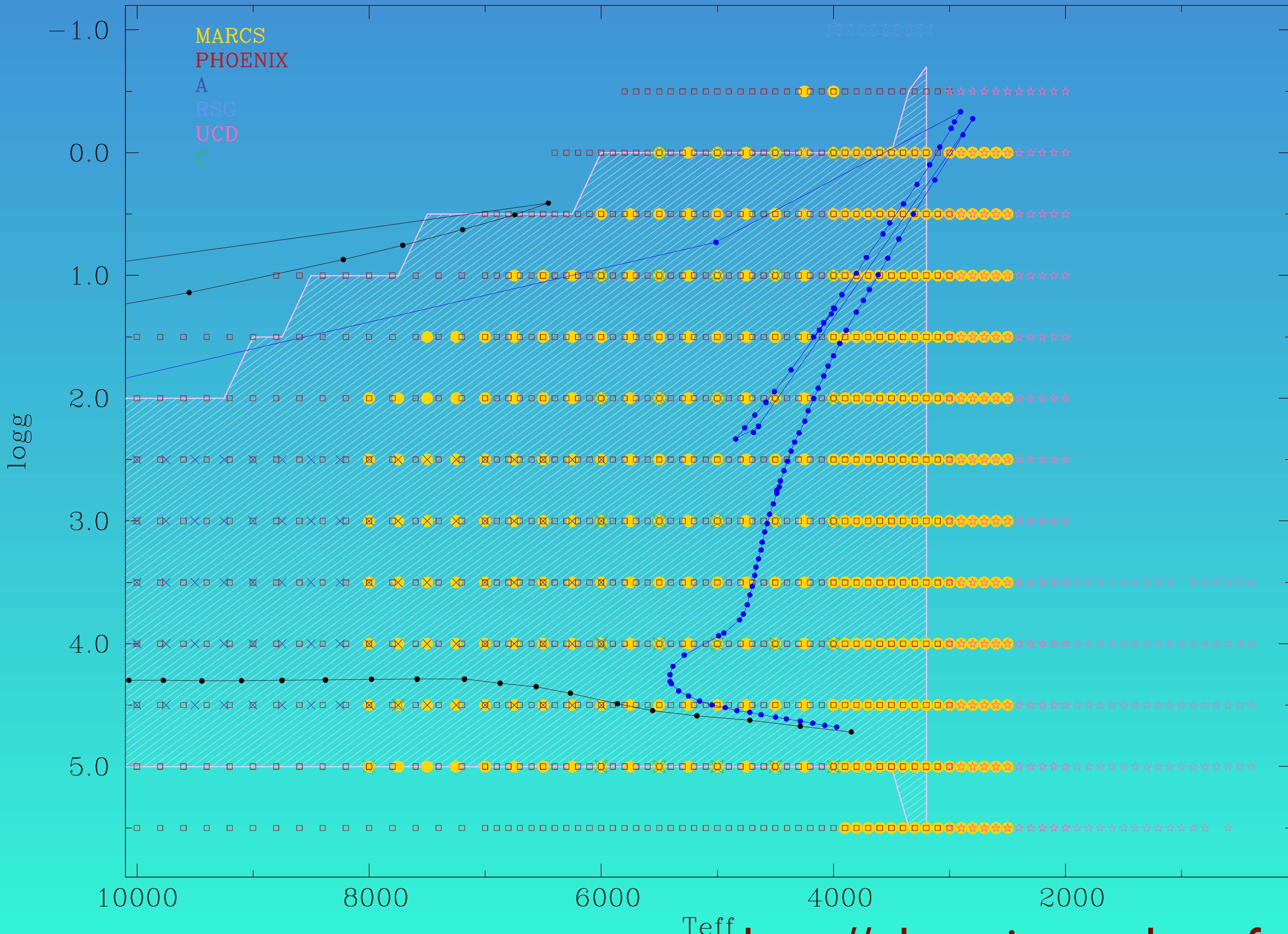
[3] Uppsala Universitet

Atmosphere models from supergiants to brown dwarfs — and beyond



NASA

Atmosphere models from supergiants to brown dwarfs — and beyond



Sordo et al. 2011

BP/RP and RVS spectra

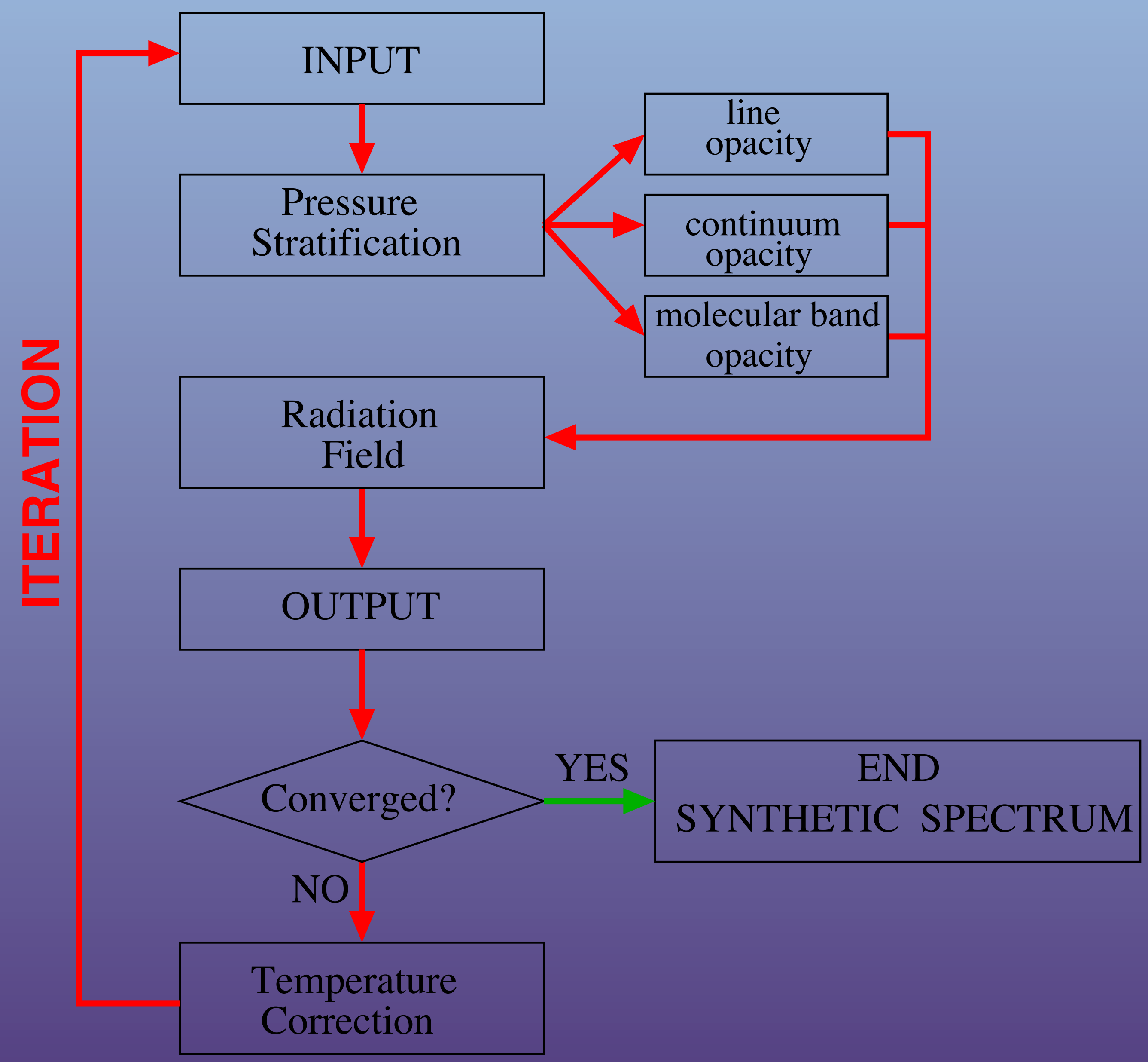
http://phoenix.ens-lyon.fr/fallard/GAIA/

(Sub-) stellar atmosphere modelling

★ independent Variables (minimal):

- effective temperature T_{eff}
- surface gravity $g(r) = GM/r^2$
- mass M or radius R or luminosity $L = 4 \pi R^2 \sigma T_{eff}^4$
- composition ("metallicity")
- convection → (micro-) turbulence & mixing
- rotation
- chemical peculiarities
- magnetic fields etc….

→ adding more dimensions to the modelling problem



PHOENIX workflow (P. Hauschildt)

(Ultra)cool Atmospheres — Molecular Bands

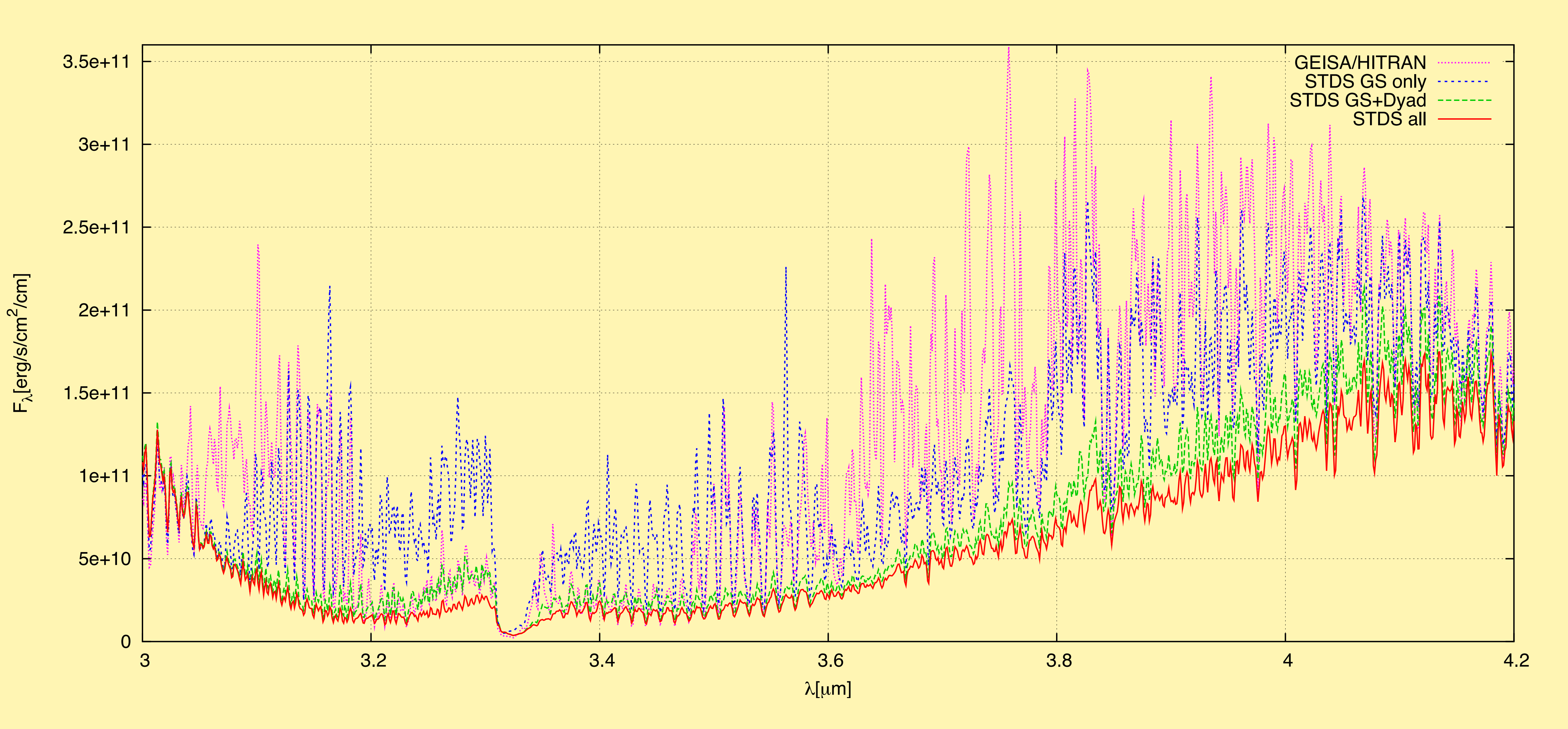
Importance of molecular bands dependent on

- Line strengths → *gf*, Abundances
- Line shapes
- Line numbers
- Line distribution

Bands with complex spectra
(polyatomic molecules)
produce strongest blanketing effects.

Molecular line blanketing: Methane

- 30 Mio. lines computed with the STDS program (Université de Bourgogne) — 2013 update: 80 Mio.
- Vibrational and rotational states up to ~ 8000 cm^{-1}
- Completeness: ~50% (mid-IR) - 10% (H-band) - 0% (Y/J)



Molecular Bands — Methane

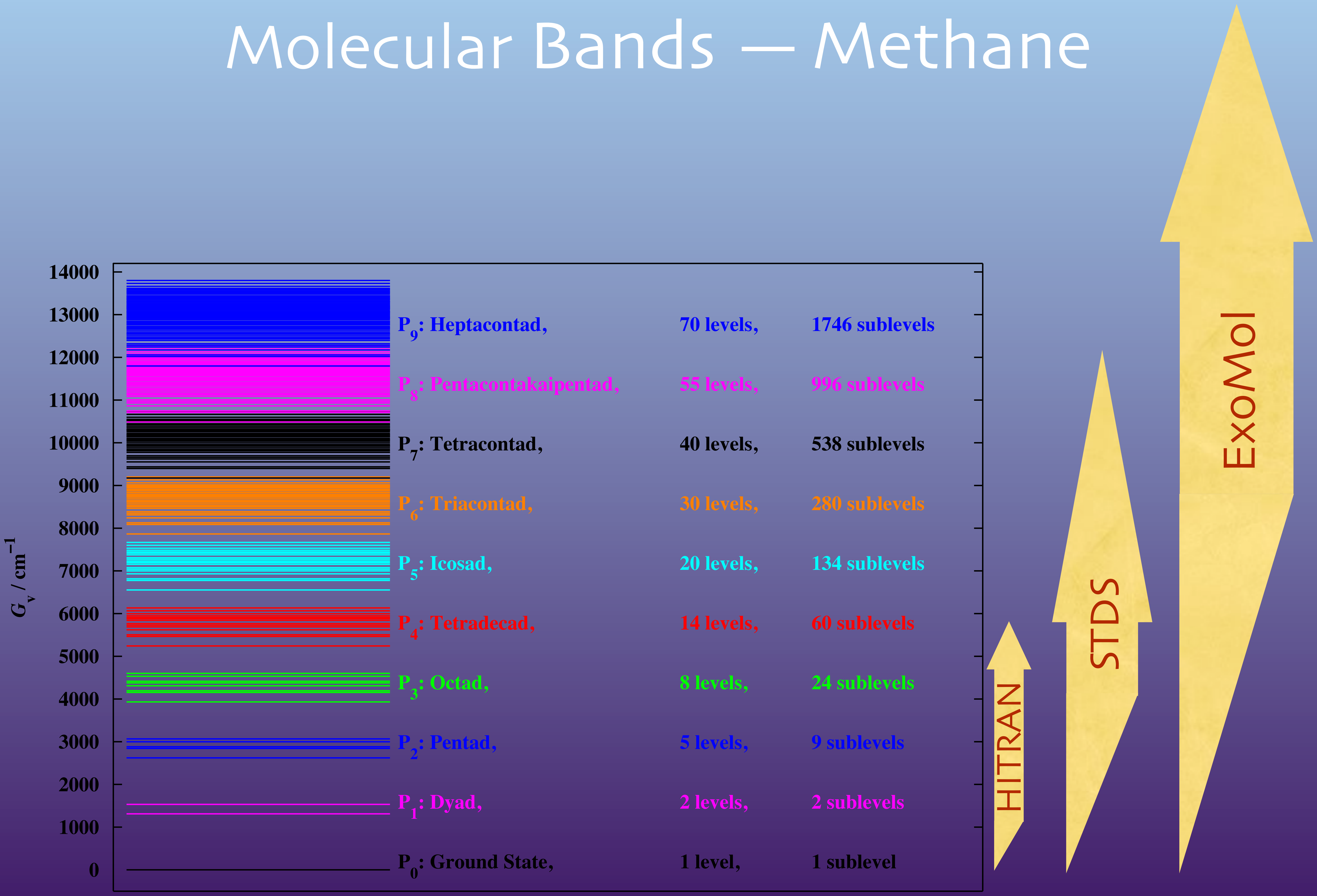


Fig. 2. Polyad energy-level structure for $^{12}CH_4$. Boudon et al. 2006

Molecular Bands — Methane

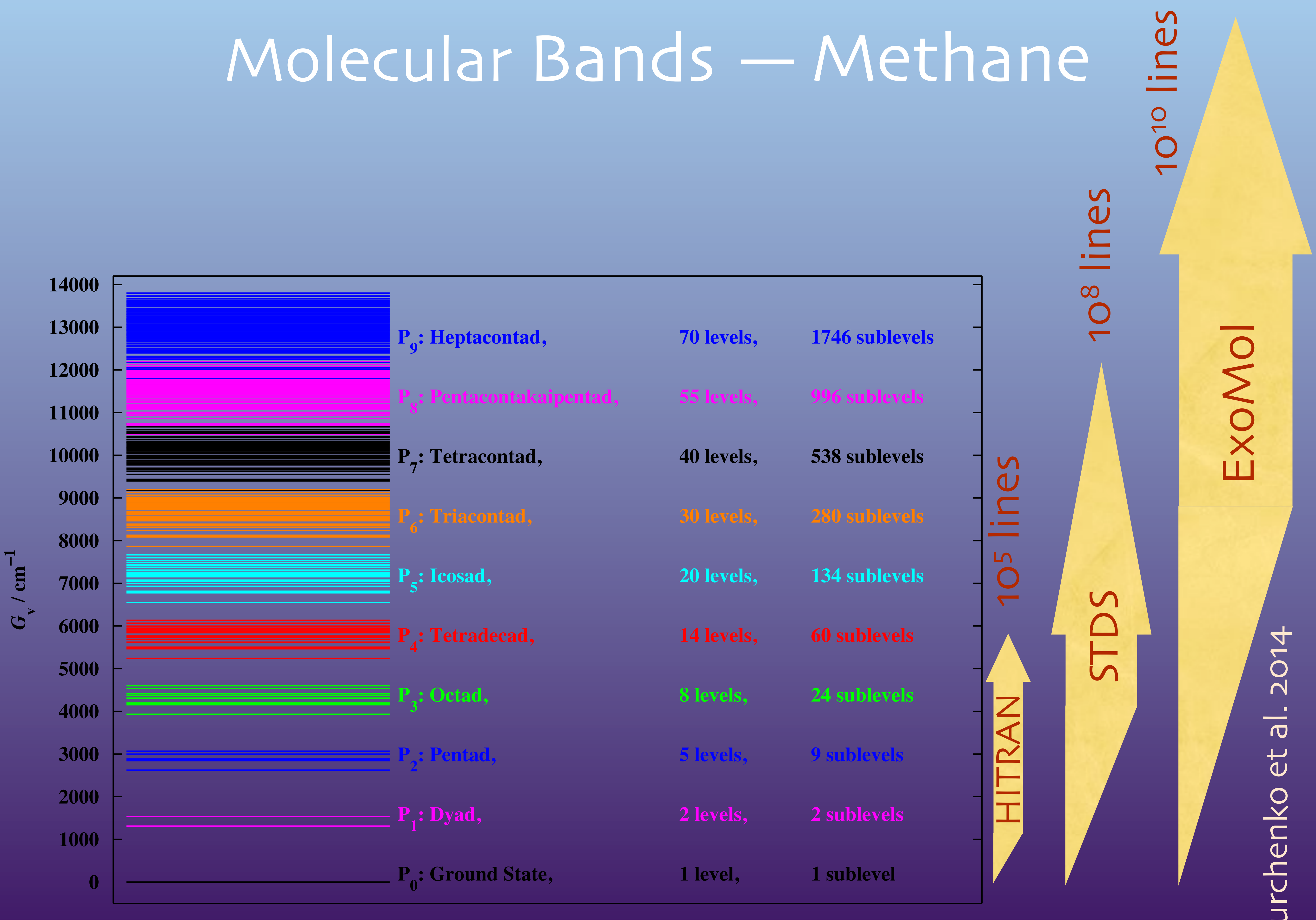


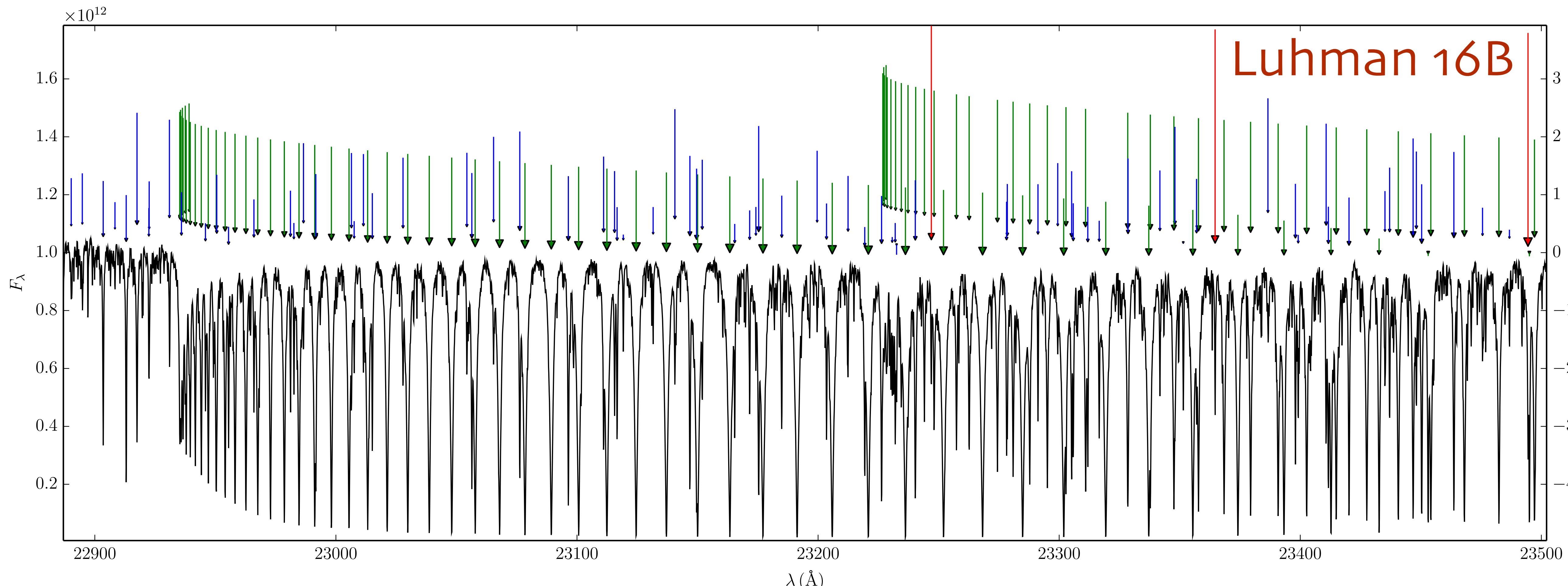
Fig. 2. Polyad energy-level structure for $^{12}CH_4$. Boudon et al. 2006

Molecular Line Profiles - Data

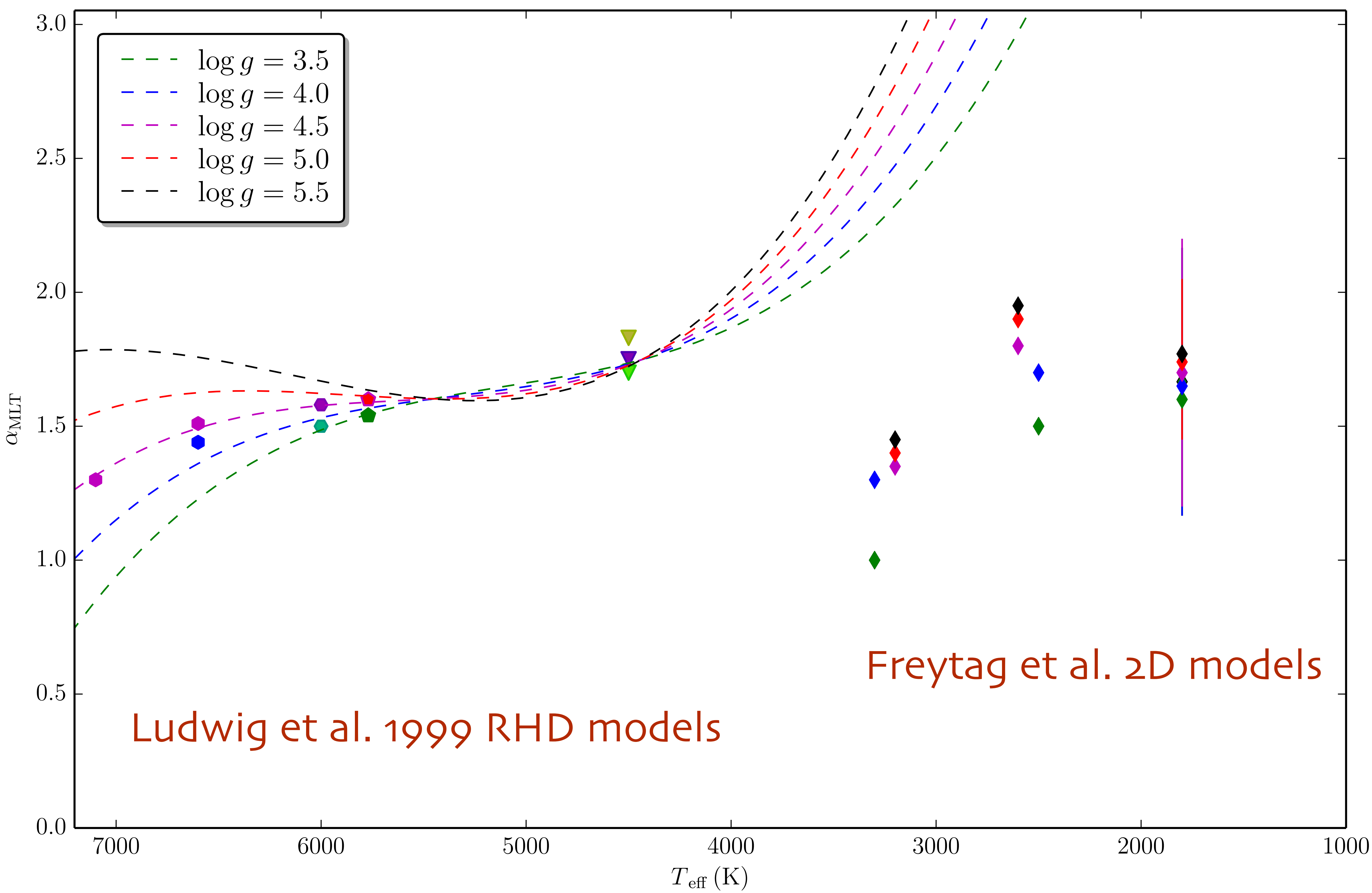
- Molecular line data for stellar atmosphere calculations:
  - Extensive data available from spectroscopy line lists (HITRAN and others)
  - Often damping widths and shifts included, sometimes temperature dependence
- Challenges:
  - Most data for Earth and outer planets' atmosphere studies
    → line lists complete only at 296 K
    → damping constants at low temperatures
  - Most experimental measurements for N_2 and O_2 as perturbers
  - Generalisation for large theoretical line lists required

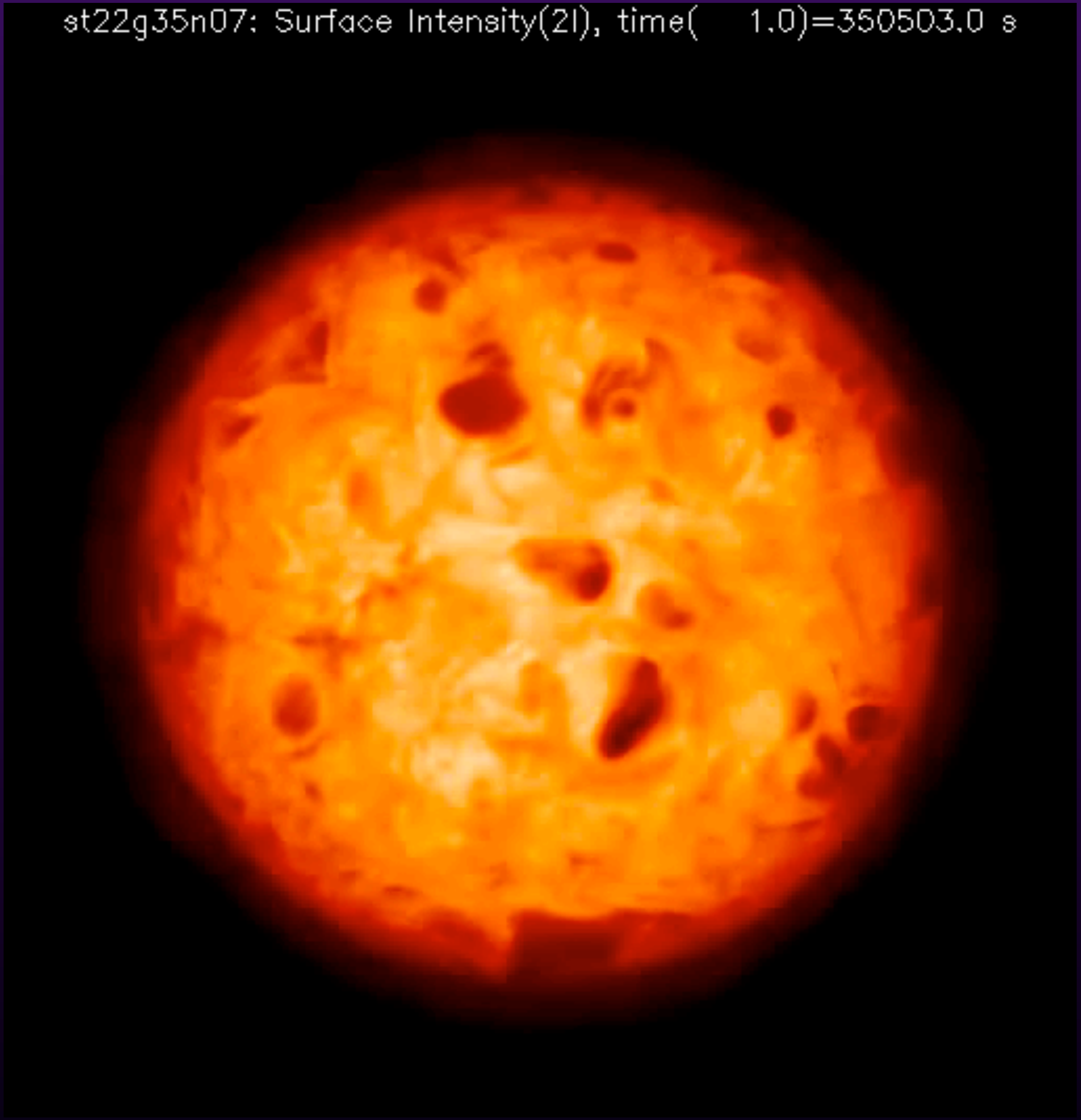
Molecular Line Profiles - Data

- Molecular line data for stellar atmosphere calculations:
  - Extensive data available from spectroscopy line lists (HITRAN and others)
  - Often damping widths and shifts included, sometimes temperature dependence



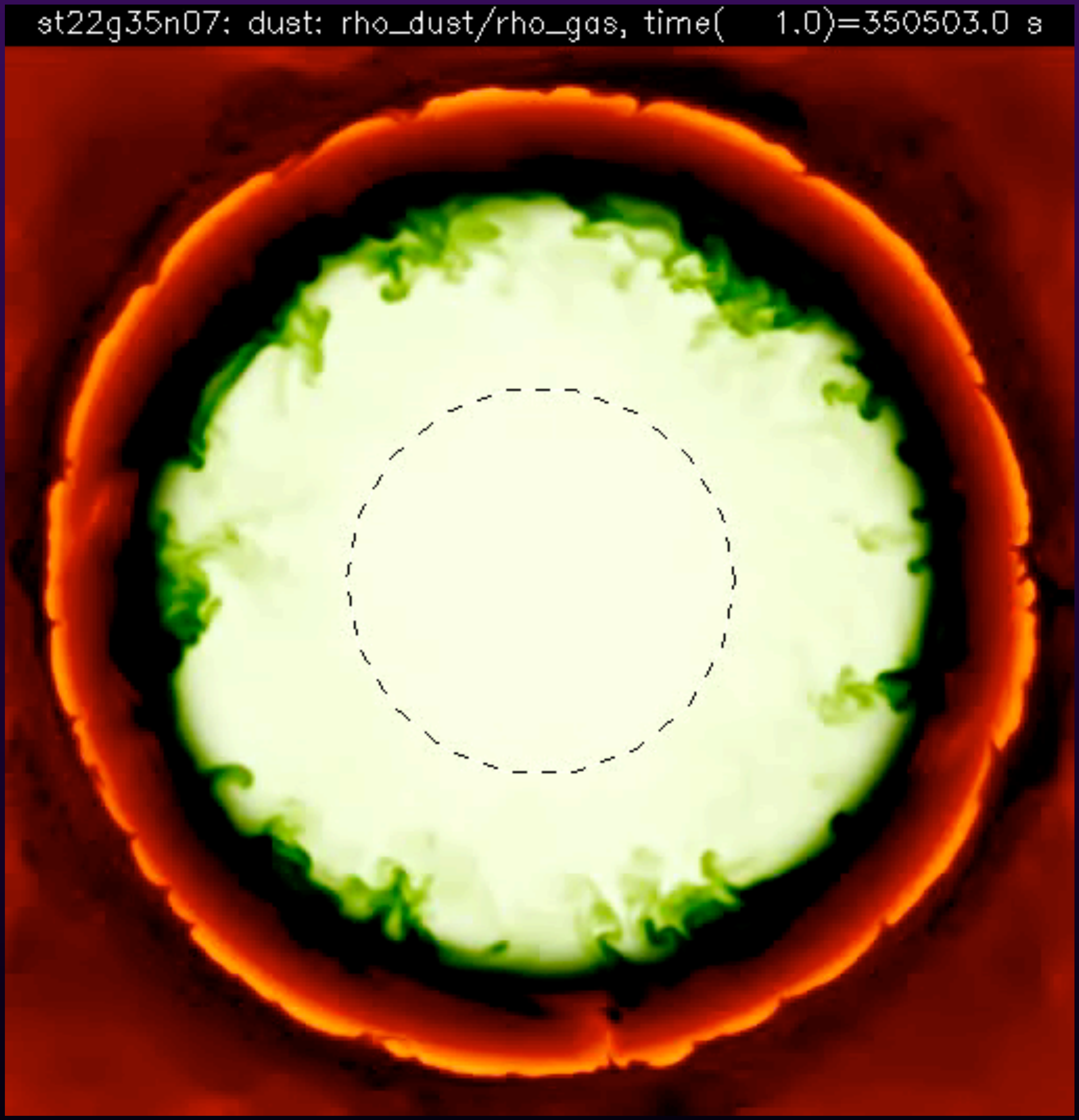
Modelling convection — calibration of MLT





CO5BOLD 3D global RHD Simulation of scaled-down 2200 K L dwarf atmosphere with Forsterite (Mg_2SiO_4) cloud model

B. Freytag et al., in prep.

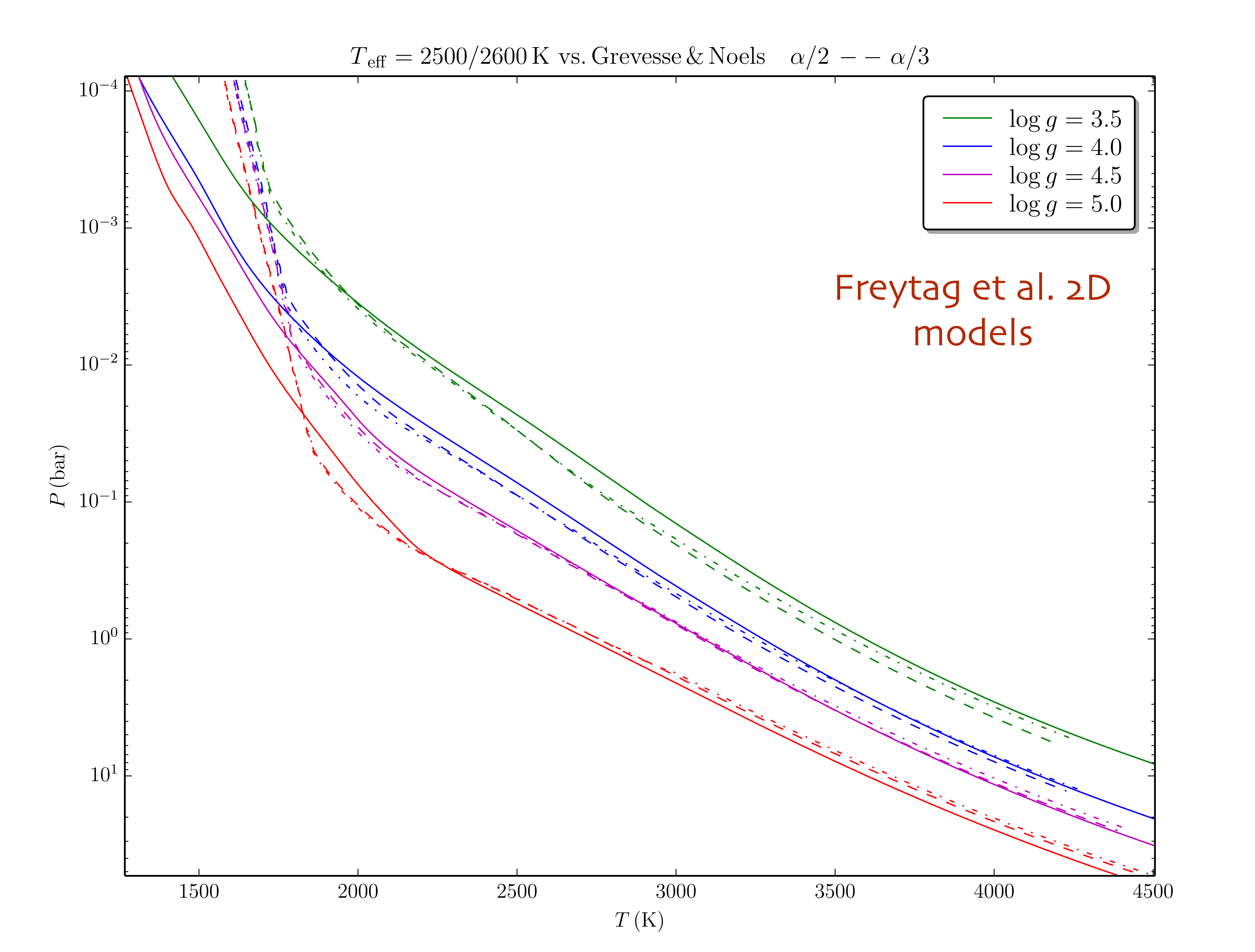


CO5BOLD 3D global RHD Simulation of scaled-down 2200 K L dwarf atmosphere with Forsterite (Mg_2SiO_4) cloud model

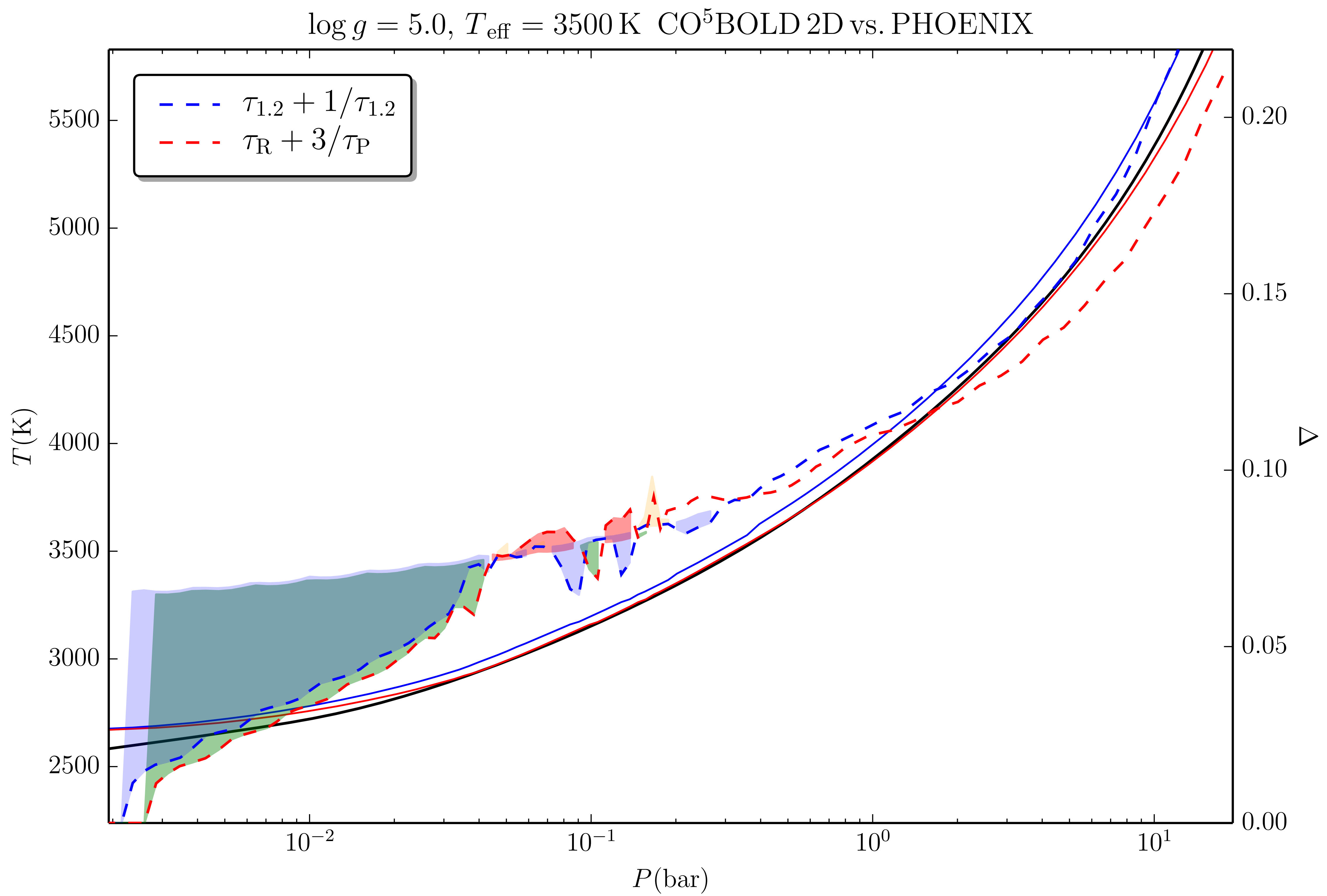
B. Freytag et al., in prep.

Entropy traces sub-photospheric circulation

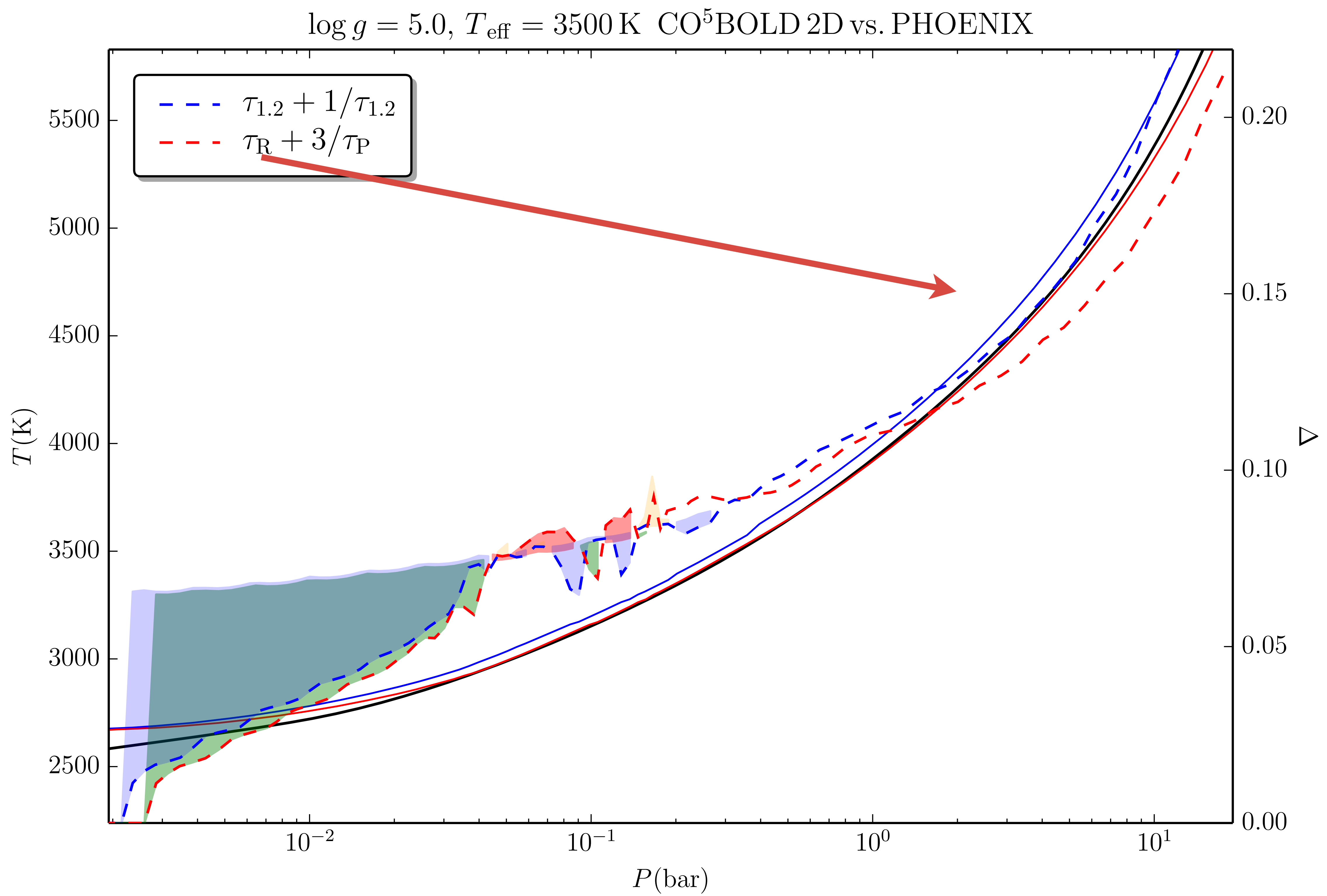
Modelling convection — calibration of MLT



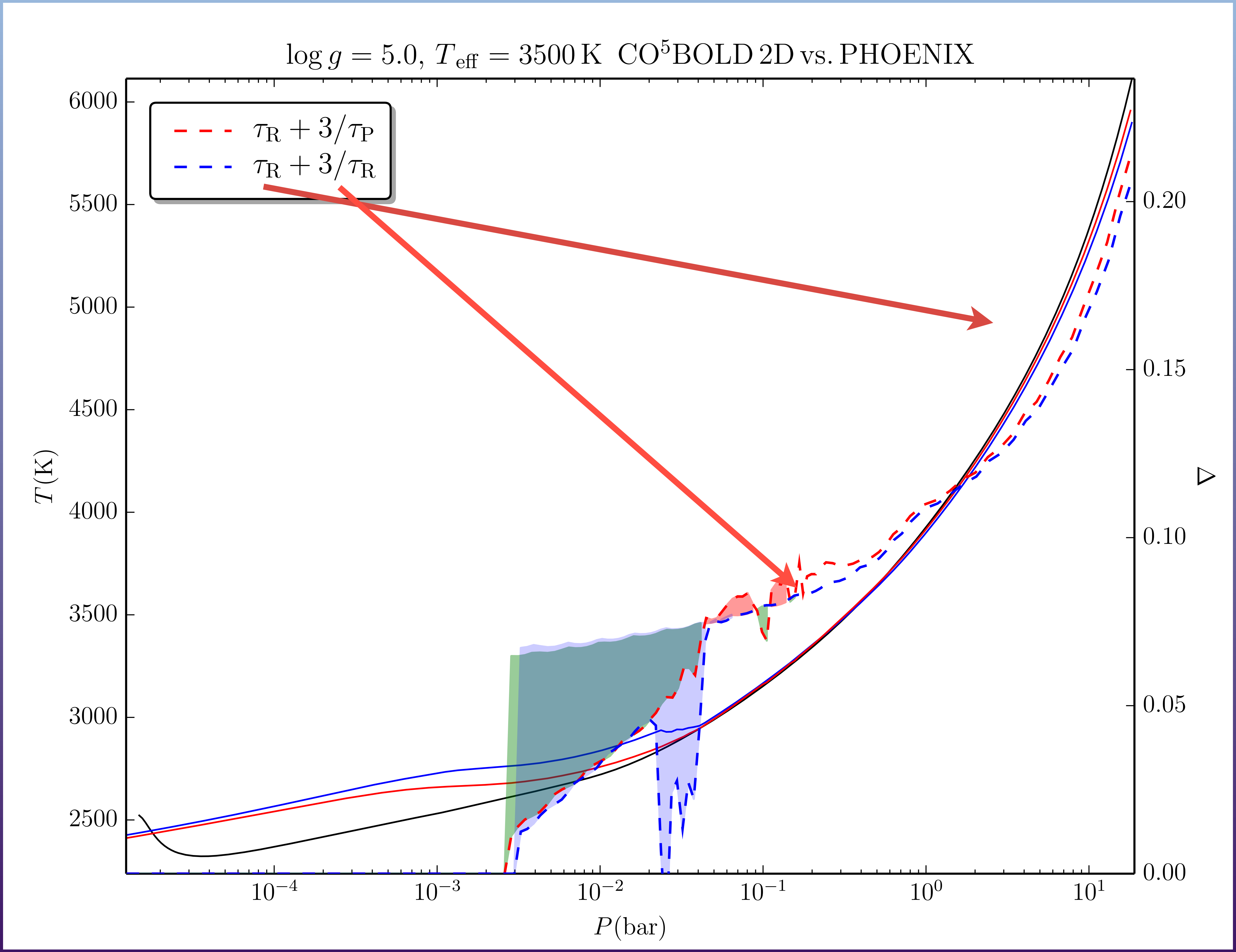
Modelling convection — calibration of MLT



Modelling convection — calibration of MLT

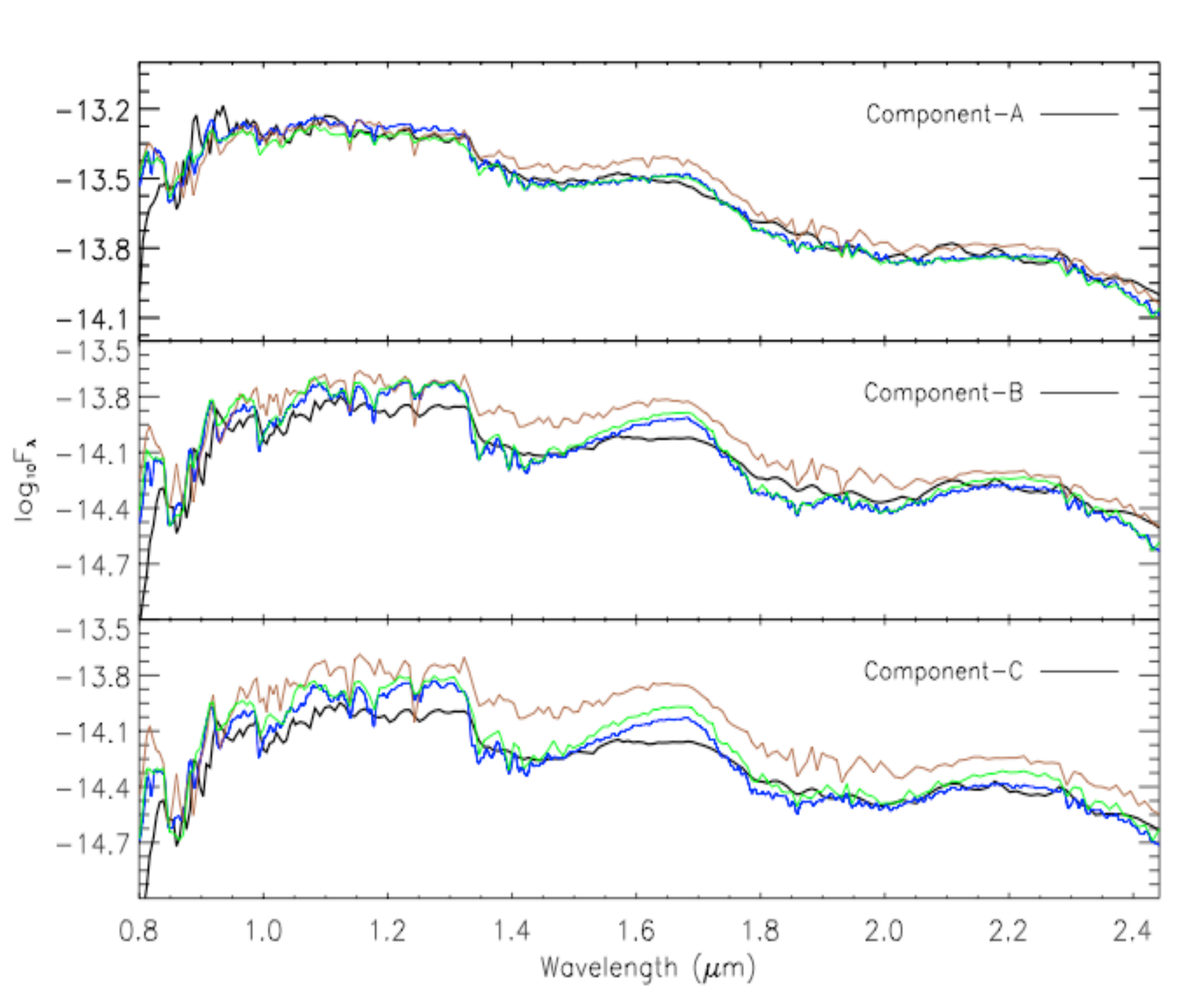


Modelling convection — calibration of MLT



Baraffe et al. in prep.

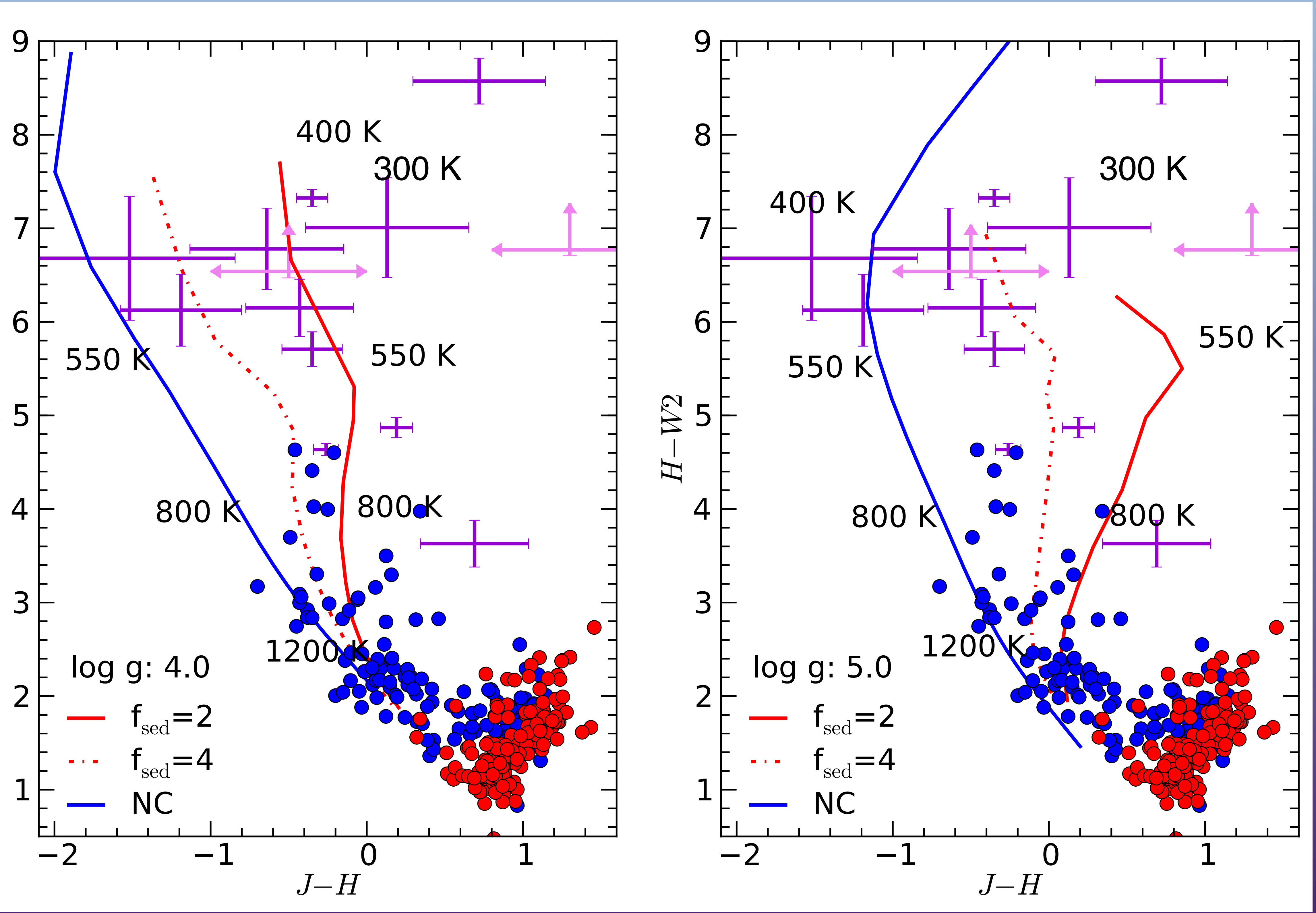
Atmosphere models — M dwarfs



Cloud opacity impacts spectra below T_{eff} ~2600K

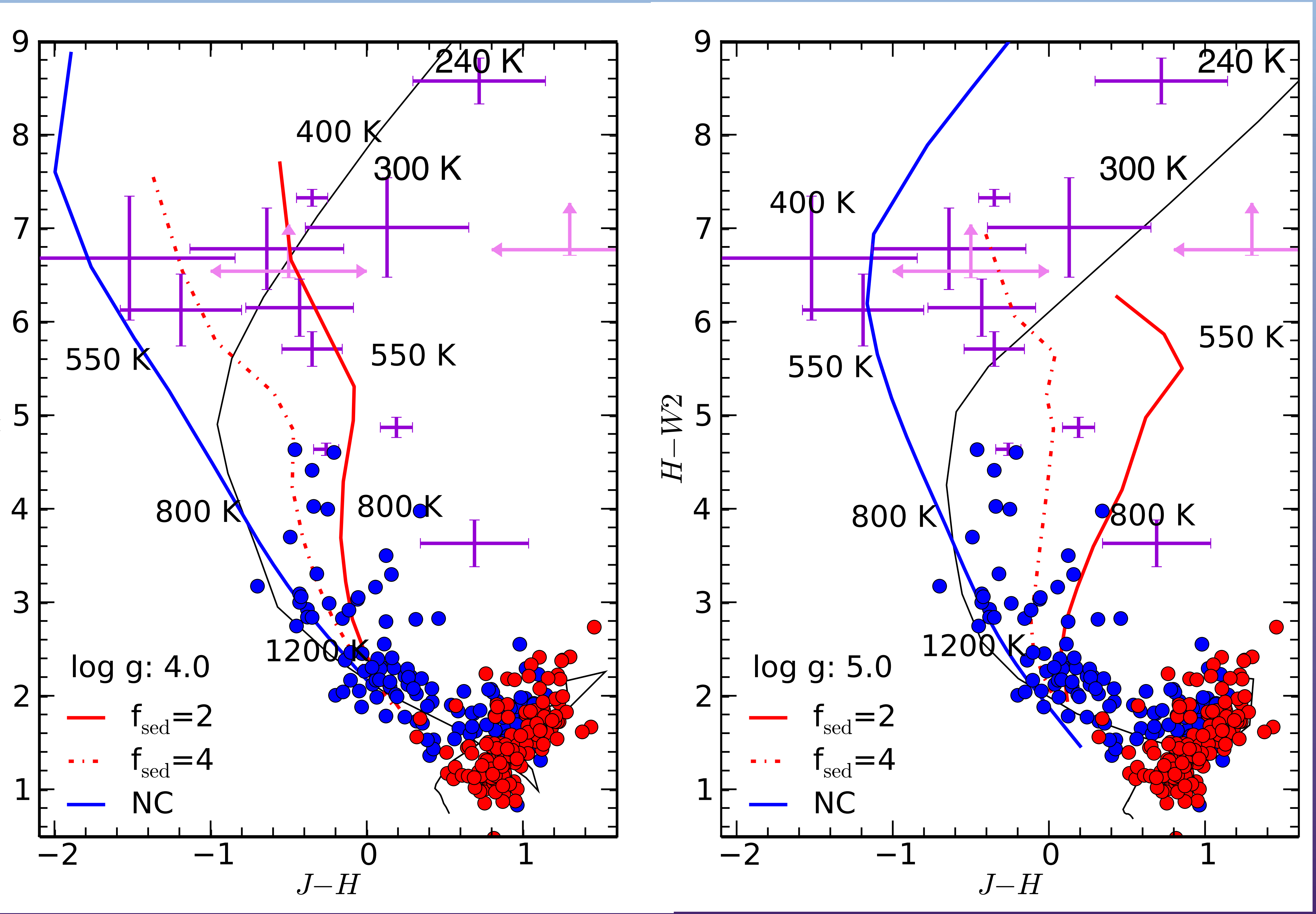
Rajpurohit et al. (2012)

Y dwarfs — yet more clouds



Morley et al. 2012

Y dwarfs — yet more clouds



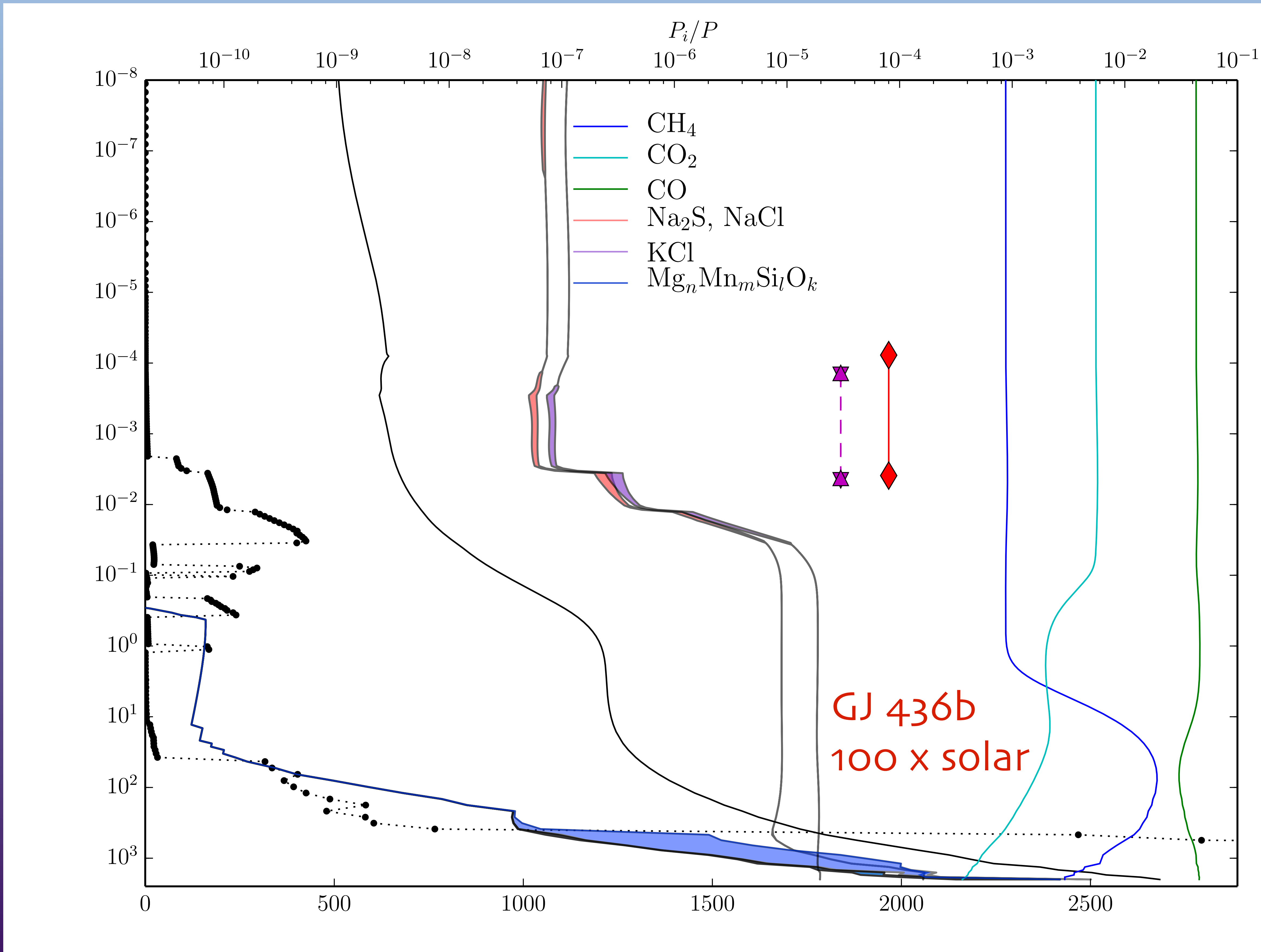
Morley et al. 2012

compared to

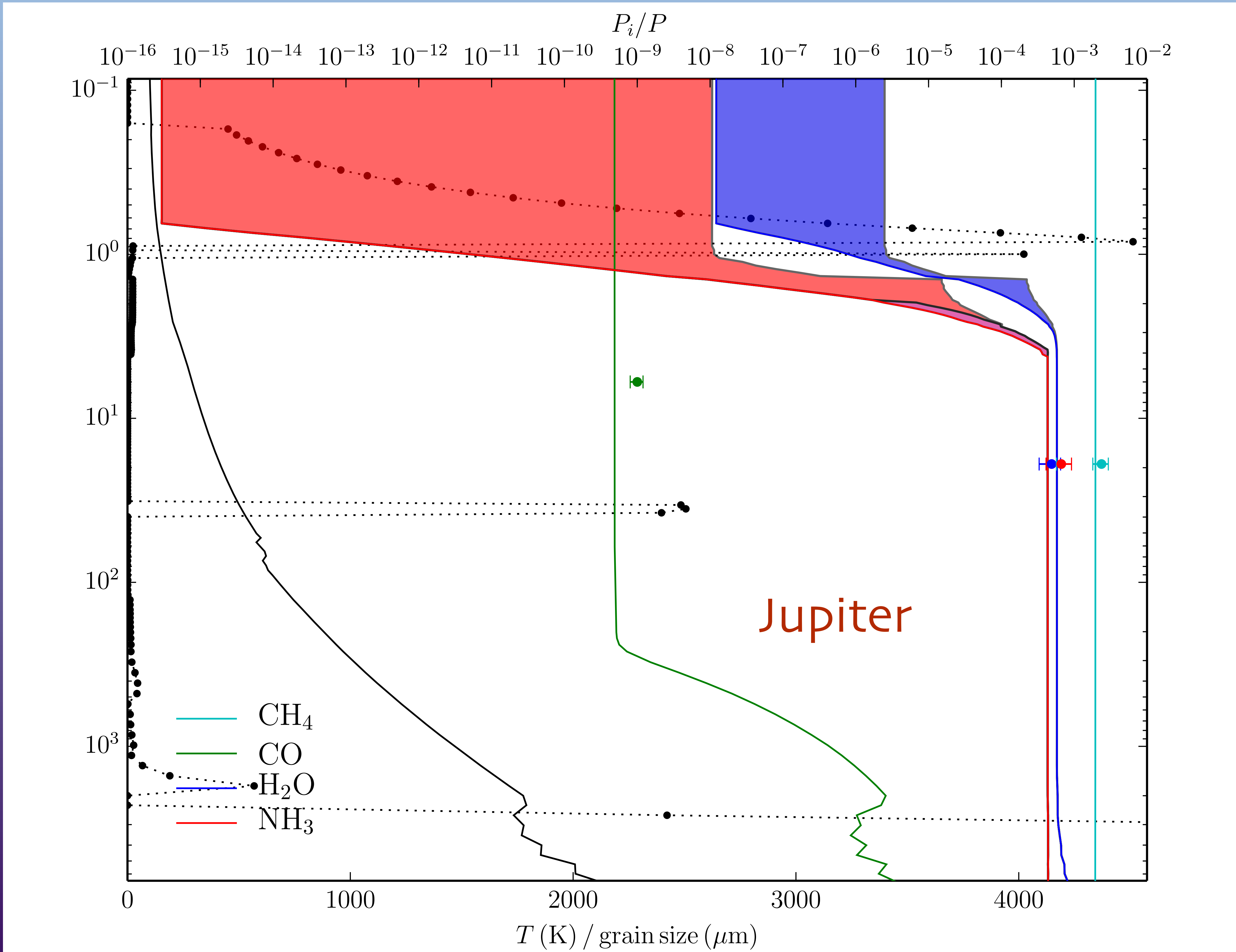
BT-Settl 2013

- Water ice clouds appearing between 300 and 400 K

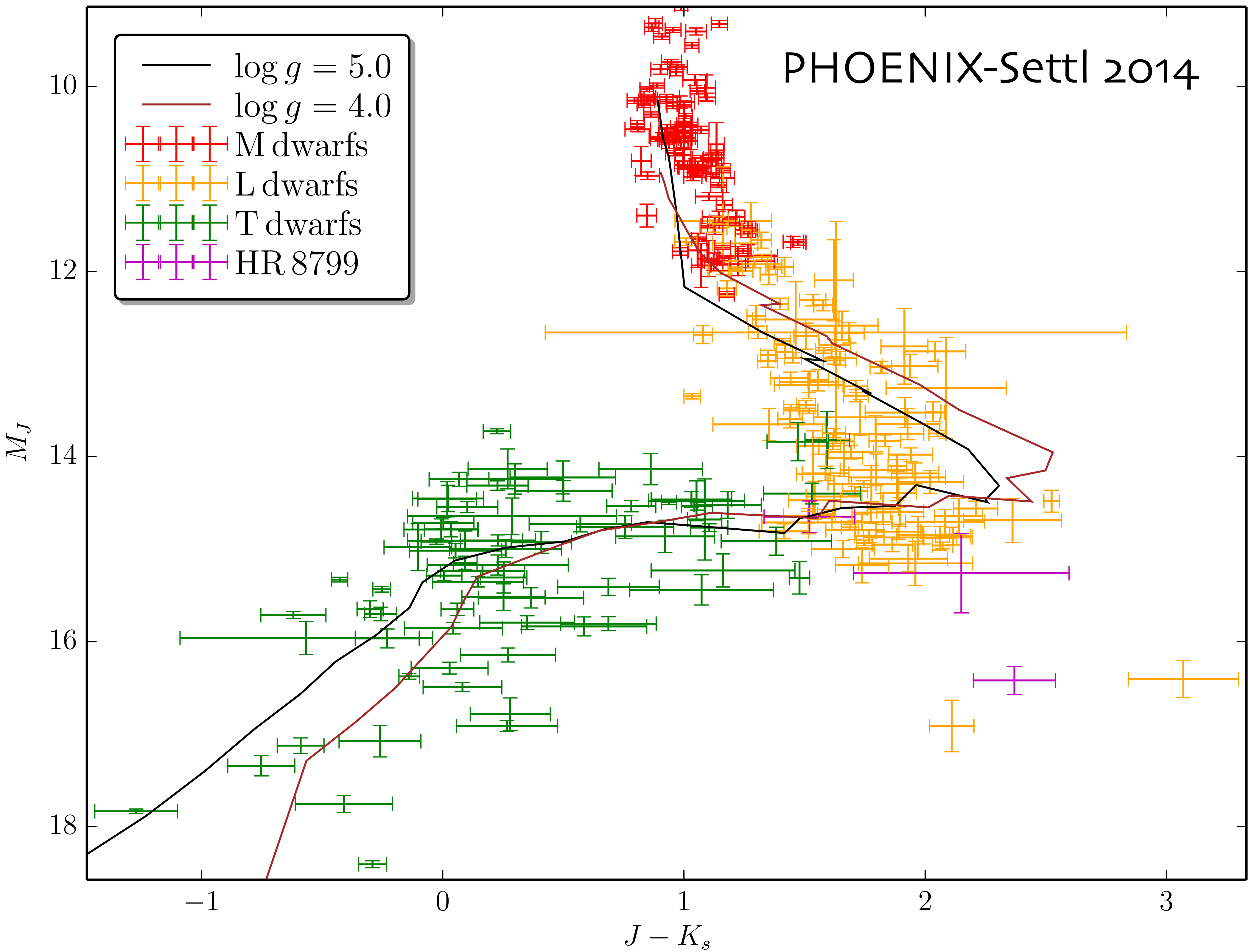
Clouds in Brown Dwarfs and Planets



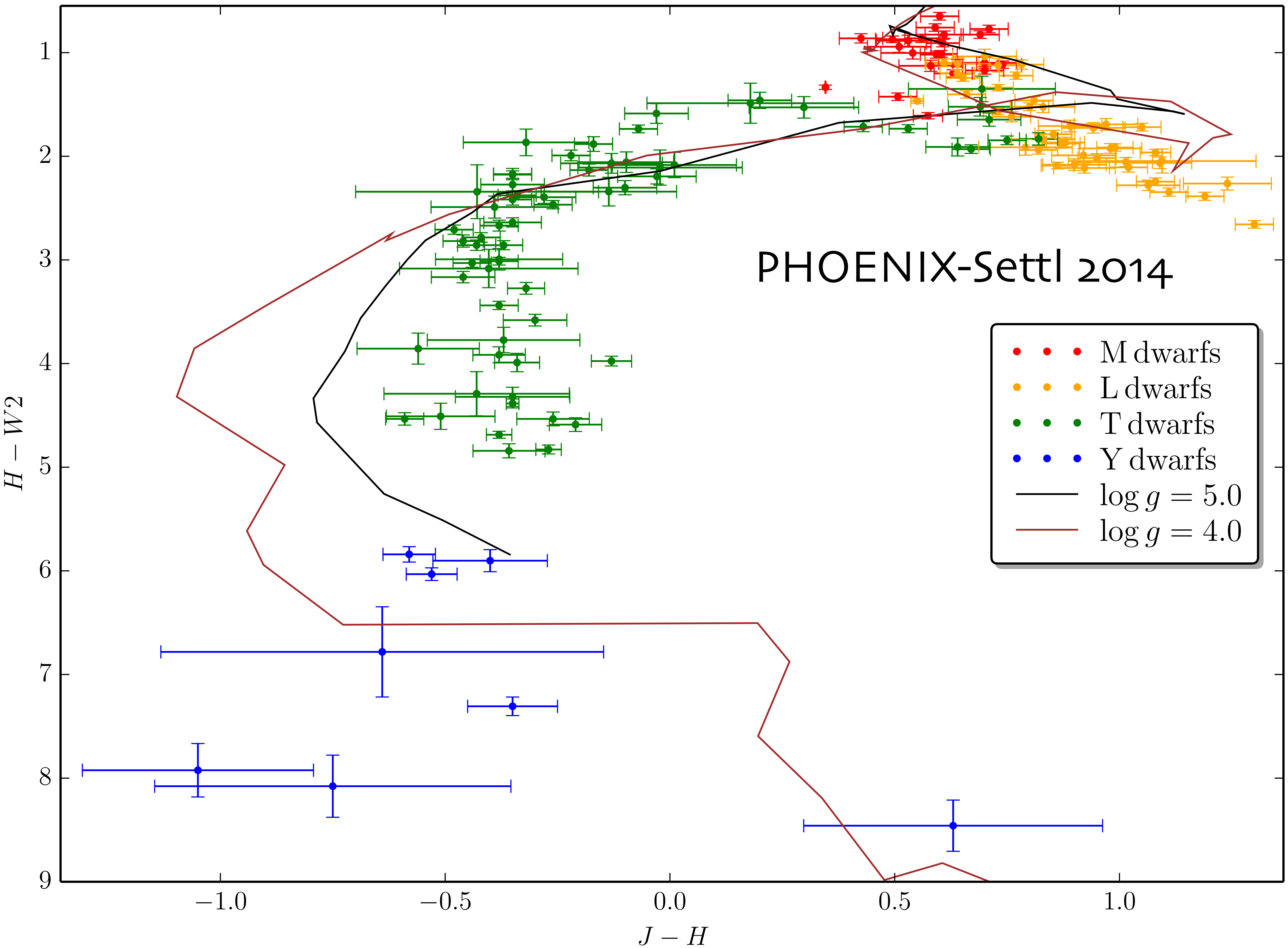
Clouds in Brown Dwarfs and Planets



Clouds from L to Y dwarfs



Clouds from L to Y dwarfs



- Water ice clouds appearing between 300 and 400 K

Conclusions

- Gaia will help to test our understanding of the M/L-transition
- Identification and study of different BD populations down to L dwarfs
- Hopefully many binary systems including T/Y dwarfs as benchmarks for metallicity, age...