



Chemistry, Condensation & Clouds in Substellar Atmospheres

Derek Homeier^{1,2}

France Allard² Bernd Freytag³ Nicole Allard^{4,5}

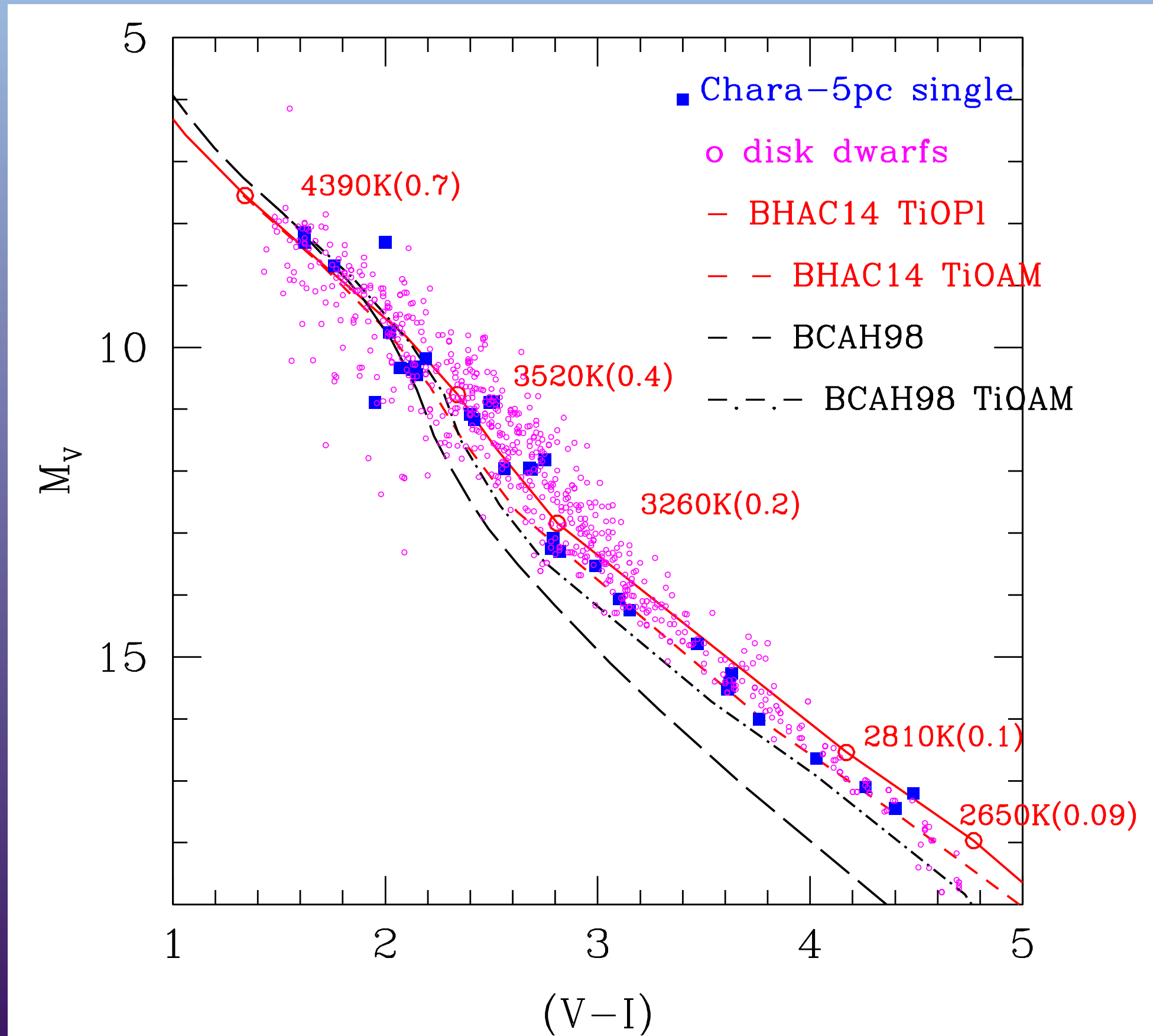
Isabelle Baraffe^{6,2} Gilles Chabrier^{2,6}

¹Zentrum für Astronomie Heidelberg, Landessternwarte

²CRAL/ENS de Lyon ³Uppsala Universitet ⁴Institut d'Astrophysique de Paris

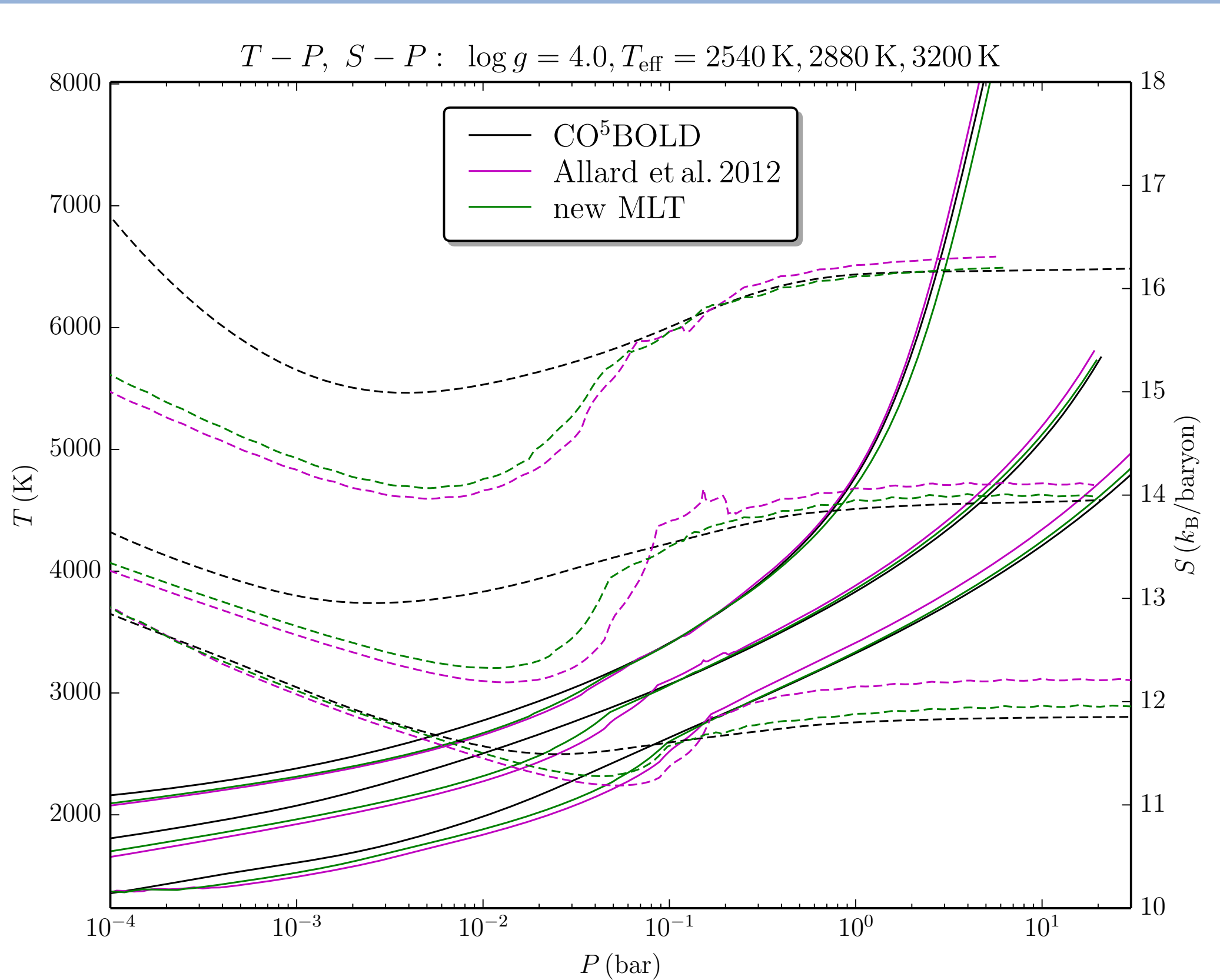
⁵Observatoire de Paris ⁶University of Exeter

Model atmospheres — connecting physics to observables



Baraffe et al.
2015

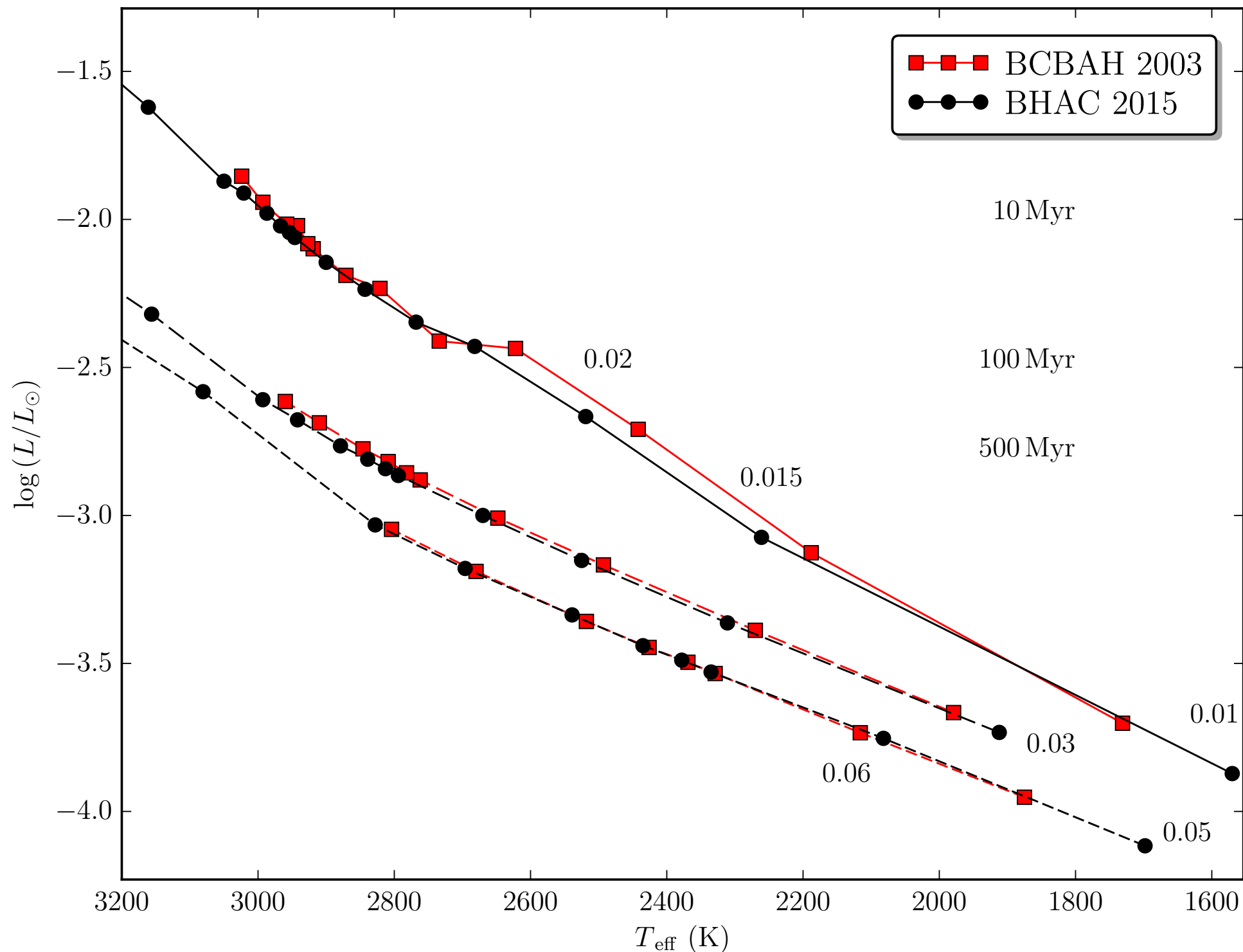
Modelling convection — calibration of MLT



radiative
hydrodynamic
models calibrate
temperature
gradient and
convective flux

convective
structure defines
deep thermal
profile →
boundary
condition for
evolution!

Model atmospheres — boundary condition for evolution

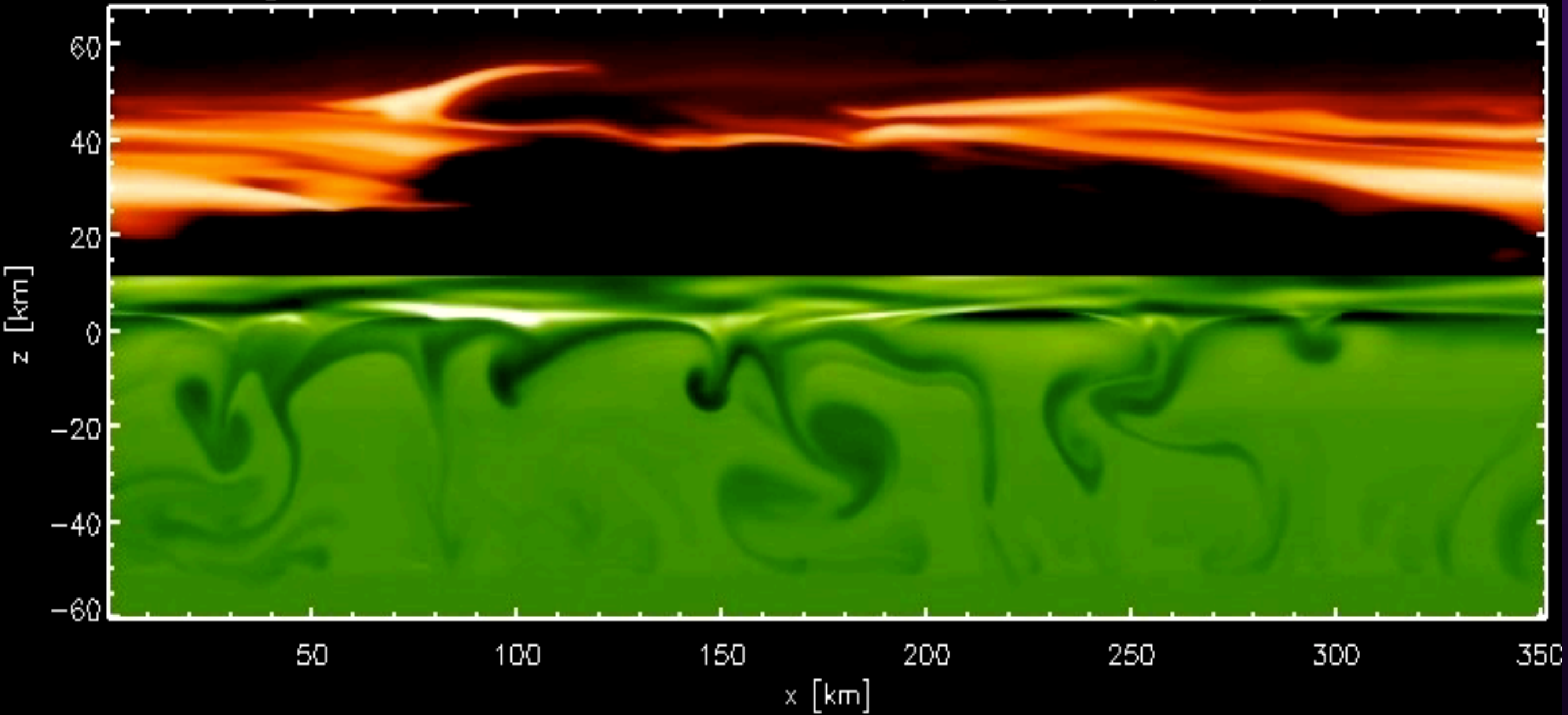


cooling rates are significantly affected by photospheric opacity

consistent treatment of interior and atmospheric modelling essential

Baraffe et al. 2015

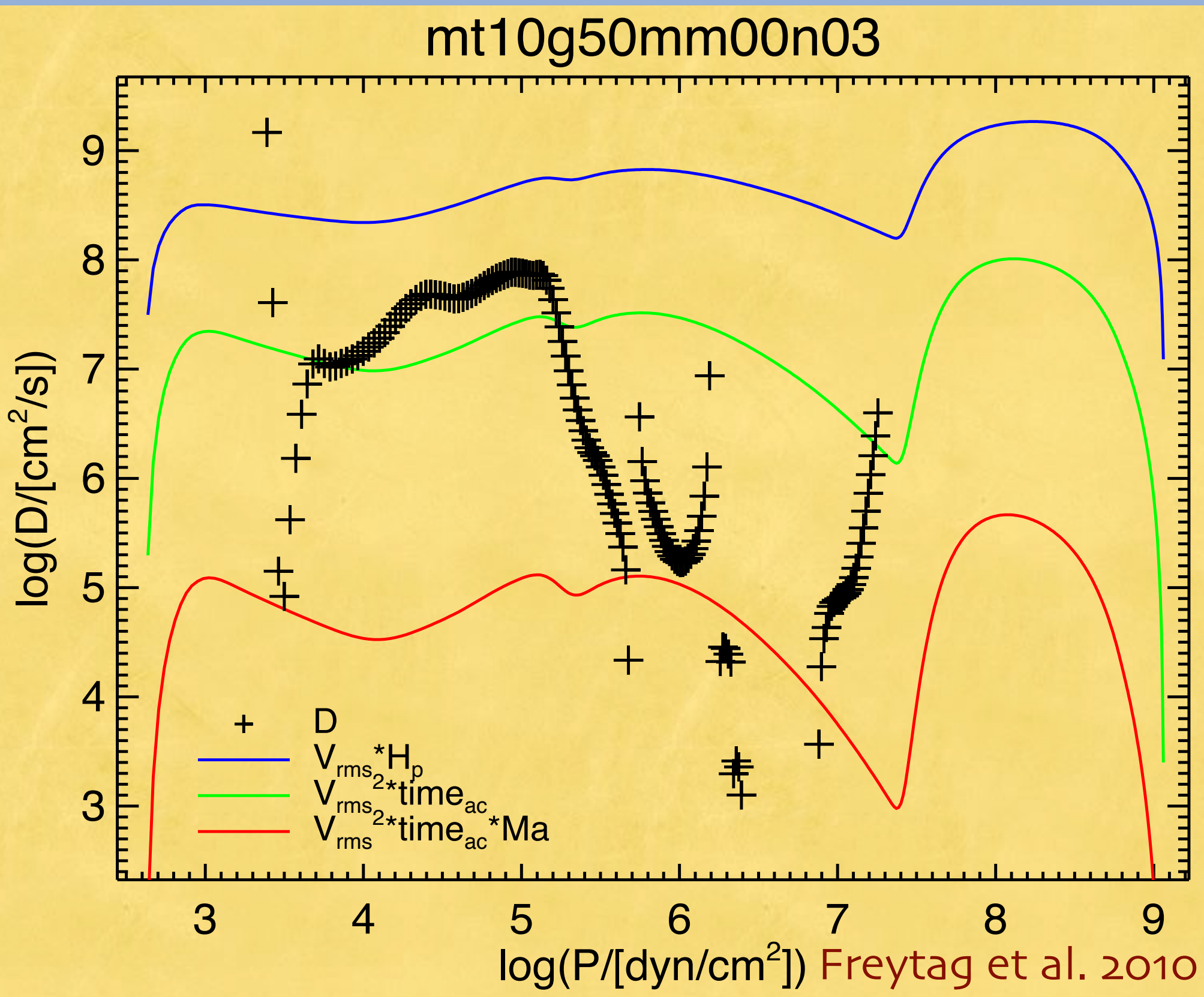
mt16g50mm00n06: dust concentration: dust/rho_gas, time(1.0)= 90040.1 s



CO⁵BOLD 2D-Hydrodynamic Simulation of 1600 K L dwarf atmosphere
with Forsterite (Mg_2SiO_4) cloud model

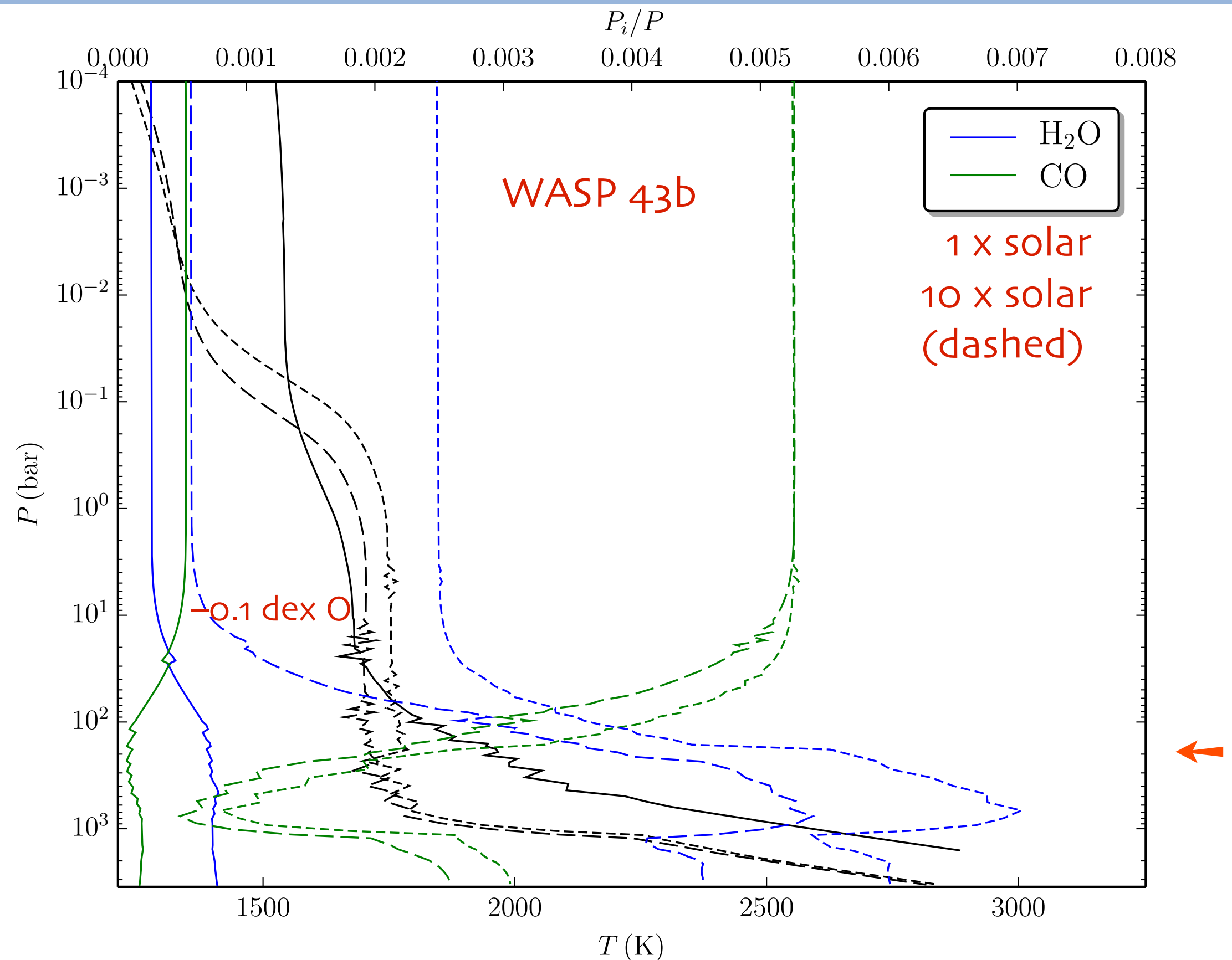
Freytag et al. 2010

Mixing and Diffusion - a closer Look



convective overshoot and gravity wave excitation dominant in brown dwarfs

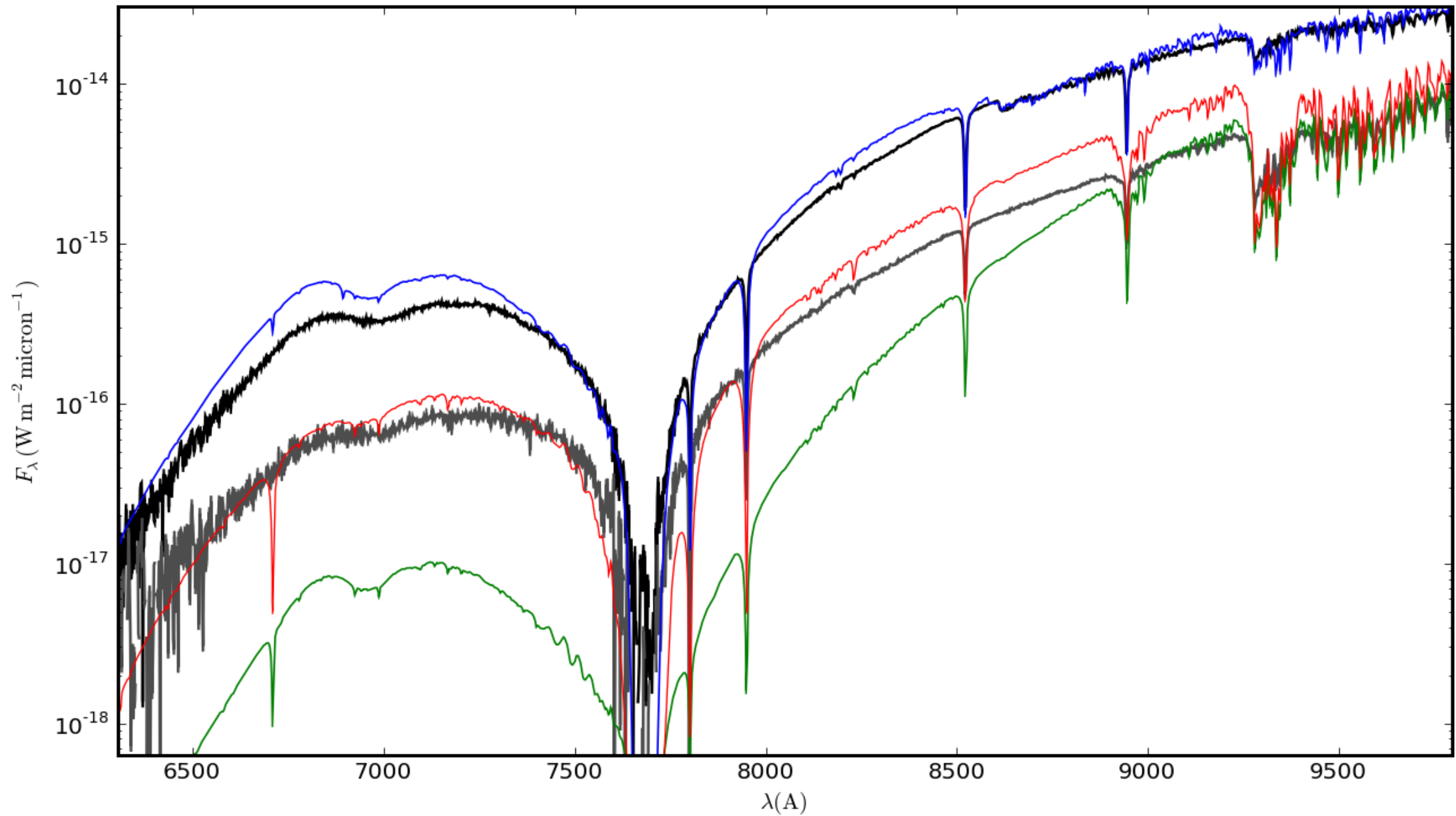
Clouds affect carbon/oxygen chemistry



sequestration
of oxygen in
deep silicate
clouds!

← cf. also talk
by T.
Kopytova

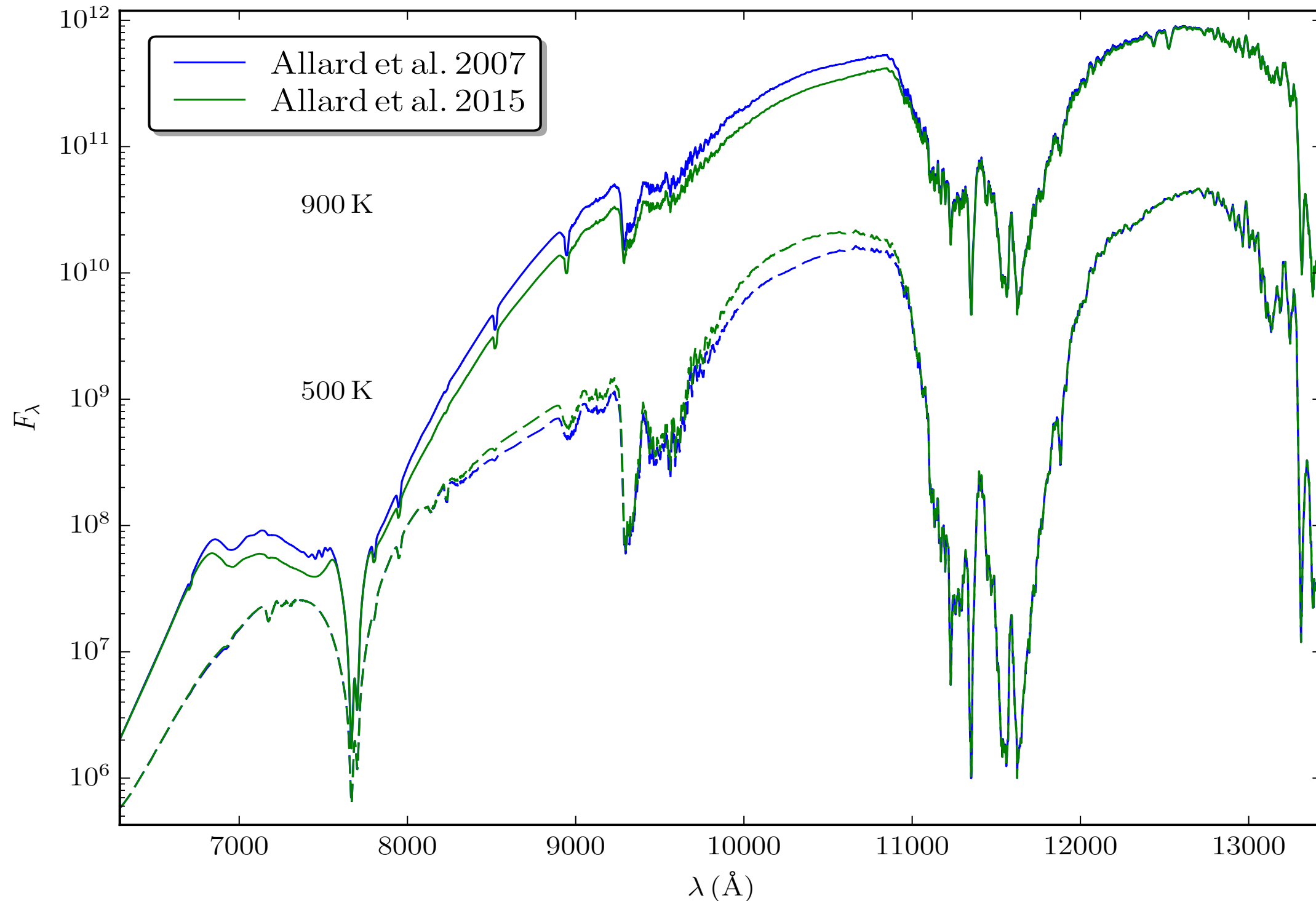
Condensation



- cloud opacity changes spectral energy distribution
- depletion changes gas phase composition \rightarrow changes spectra as well

King et al. 2010

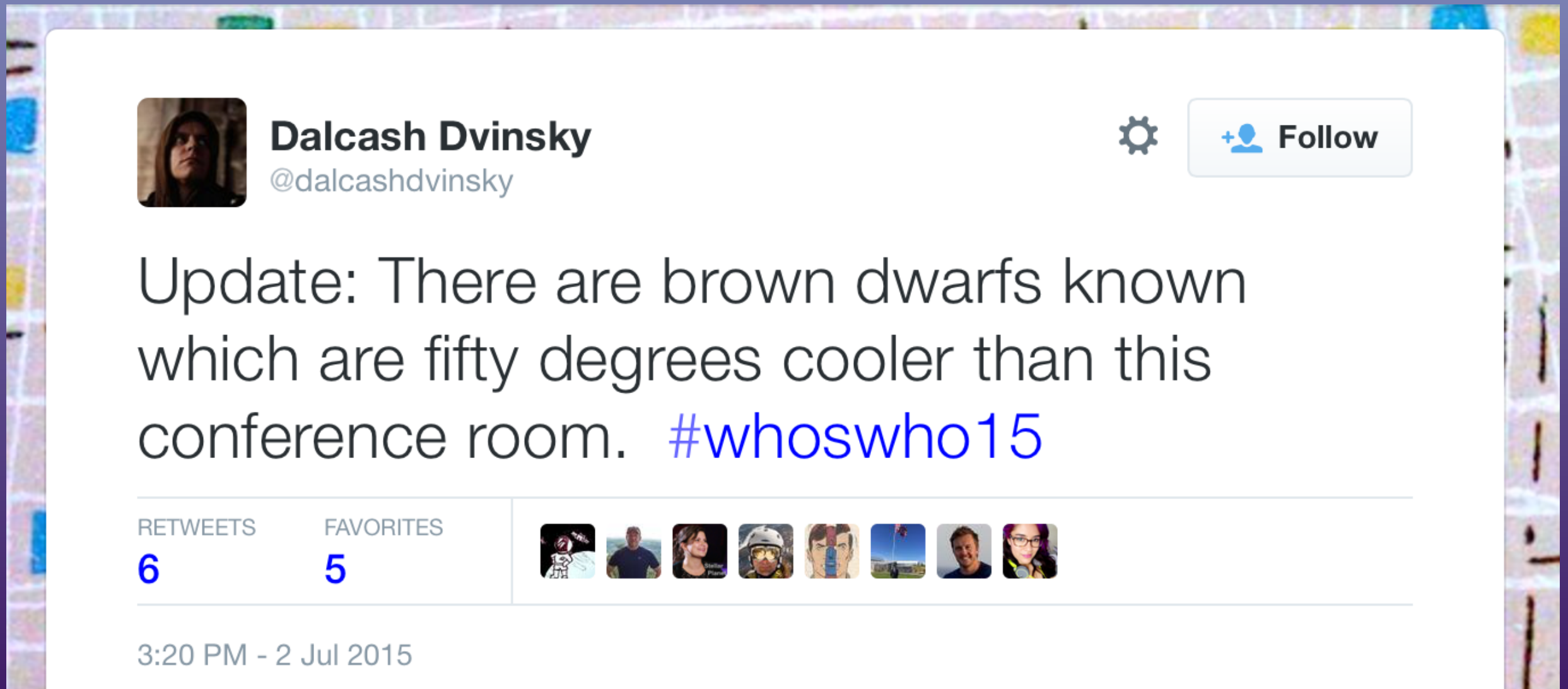
Condensation




- depletion and accurate broadening theory important
 - Allard et al. in prep. & poster

Clouds in Brown Dwarfs and Planets

- with T and Y dwarfs, getting into the domain of sulphide, halide, and ultimately water ice clouds (Morley et al. 2012, 2014...)



A screenshot of a tweet from Dalcash Dvinsky (@dalcashdvinsky) posted on July 2, 2015, at 3:20 PM. The tweet text reads: "Update: There are brown dwarfs known which are fifty degrees cooler than this conference room. #whoswho15". The tweet has 6 retweets and 5 favorites. The user's profile picture shows a woman with long dark hair. To the right of the name is a gear icon and a "Follow" button with a plus sign and a person icon. Below the text, there are two columns: "RETWEETS" with the number "6" and "FAVORITES" with the number "5". To the right of these columns is a horizontal row of eight small profile pictures of users who interacted with the tweet. The background of the tweet card is white with a light blue border.

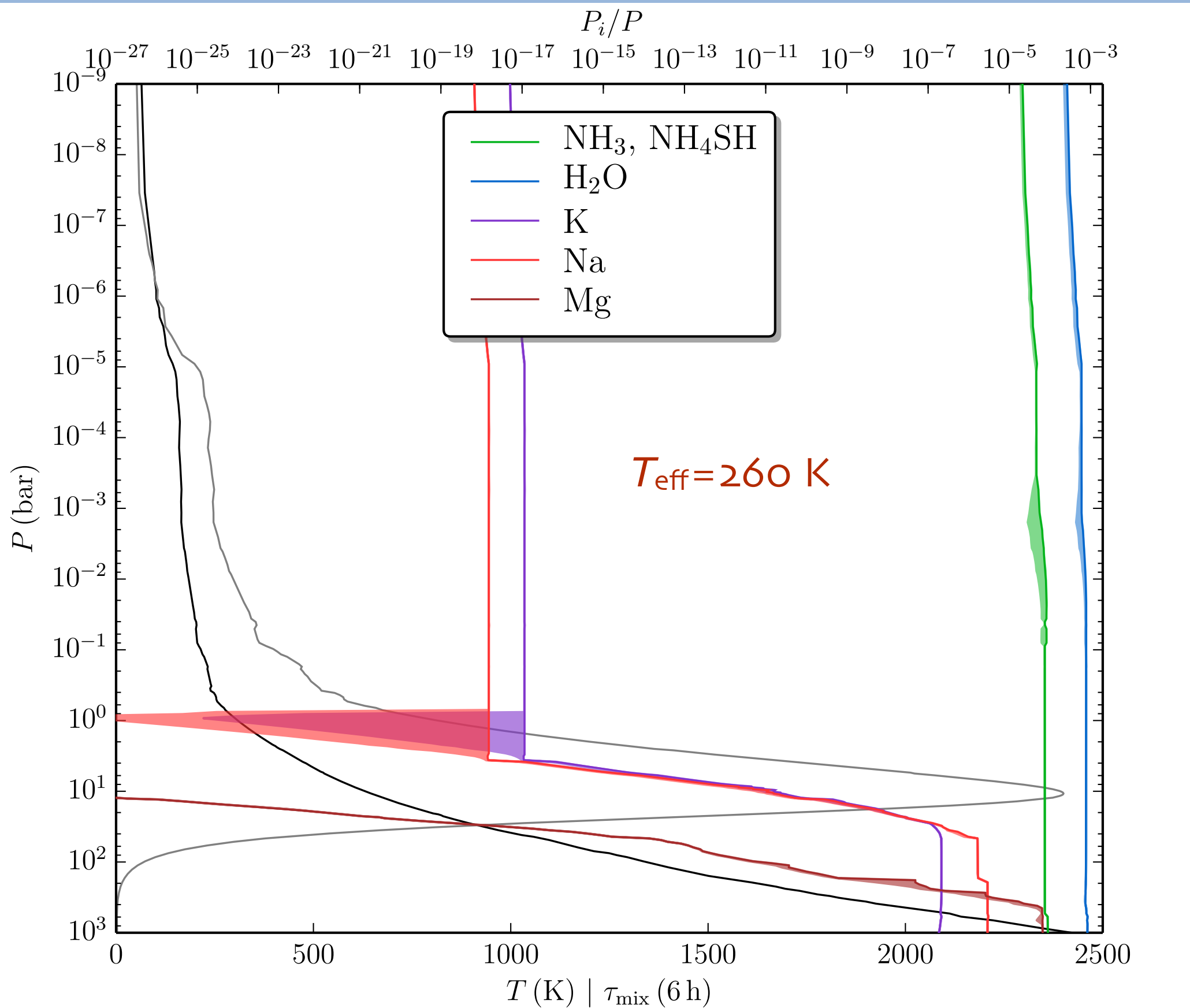
 **Dalcash Dvinsky**
@dalcashdvinsky

Update: There are brown dwarfs known which are fifty degrees cooler than this conference room. [#whoswho15](#)

RETWEETS 6 FAVORITES 5

3:20 PM - 2 Jul 2015

Clouds in Brown Dwarfs and Planets



WISE 0855-0714

Beamín et al. 2014,
poster by H. Boffin

water ice,
ammonium
hydrosulphide
clouds



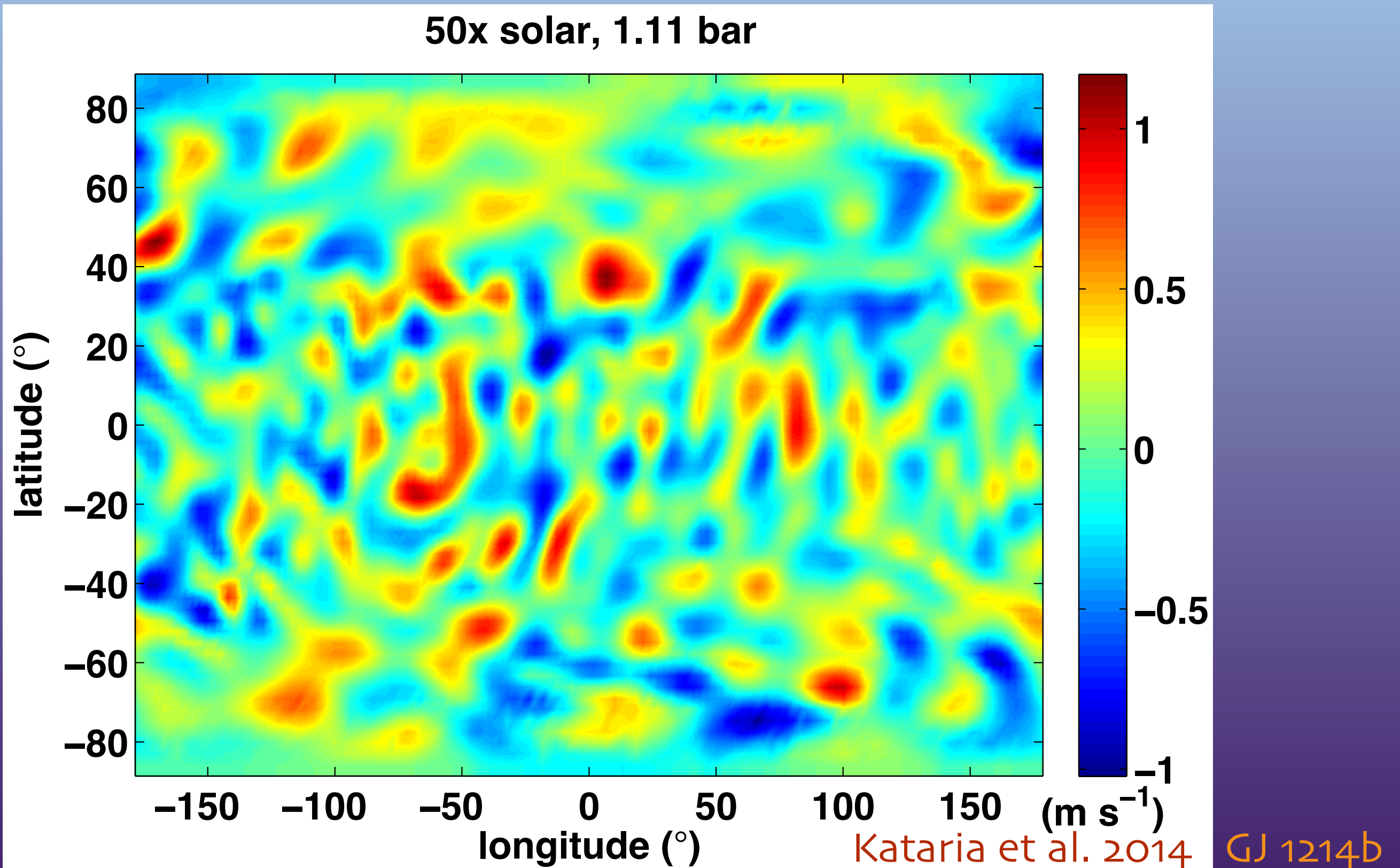
quenching of CO,
NH₃ in non-CE
(cf. Visscher
et al. 2010)



deep silicate
clouds

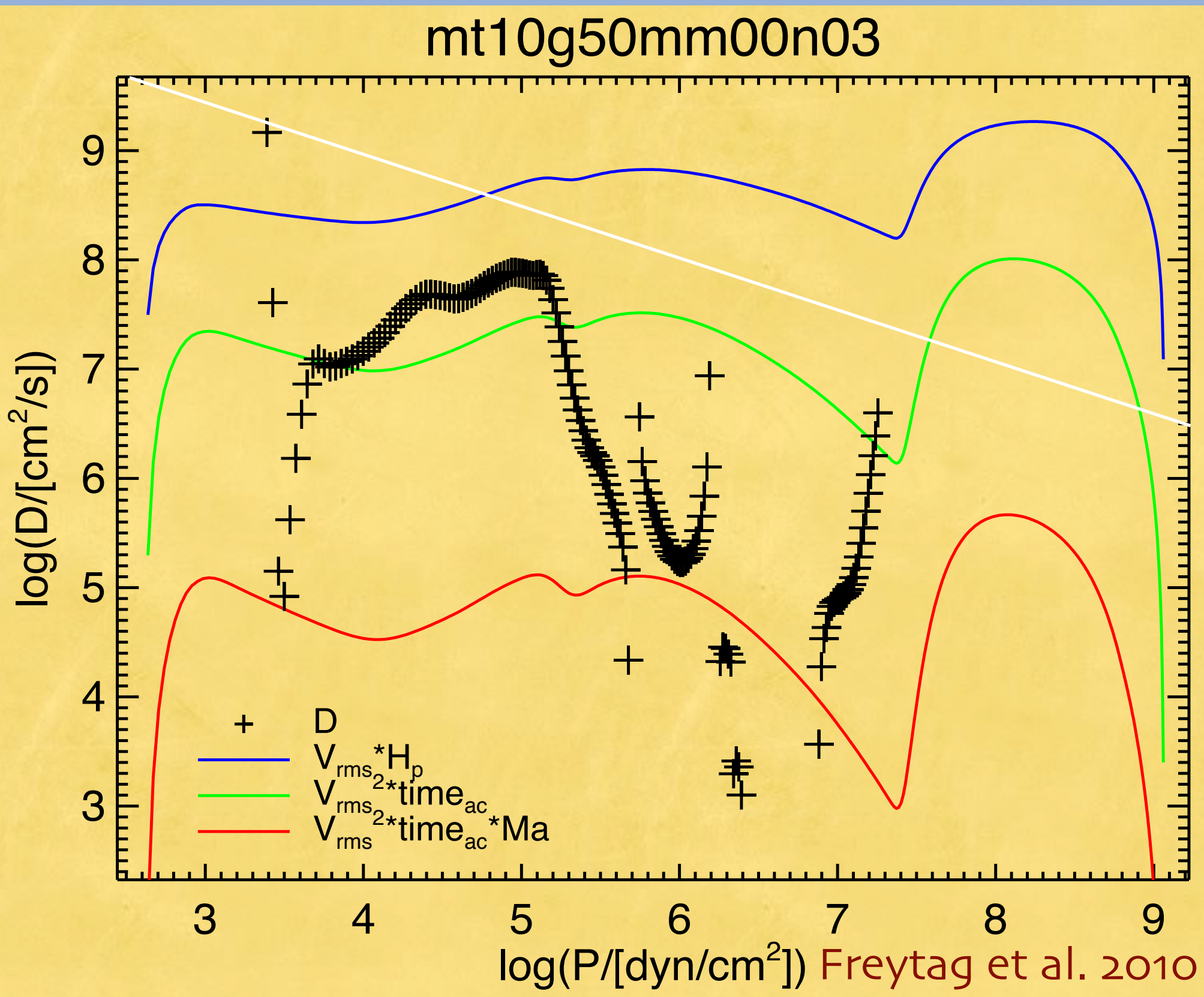


Exoplanets — Irradiation and Circulation



- General Circulation models predict vertical wind components

Mixing and Diffusion - a closer Look

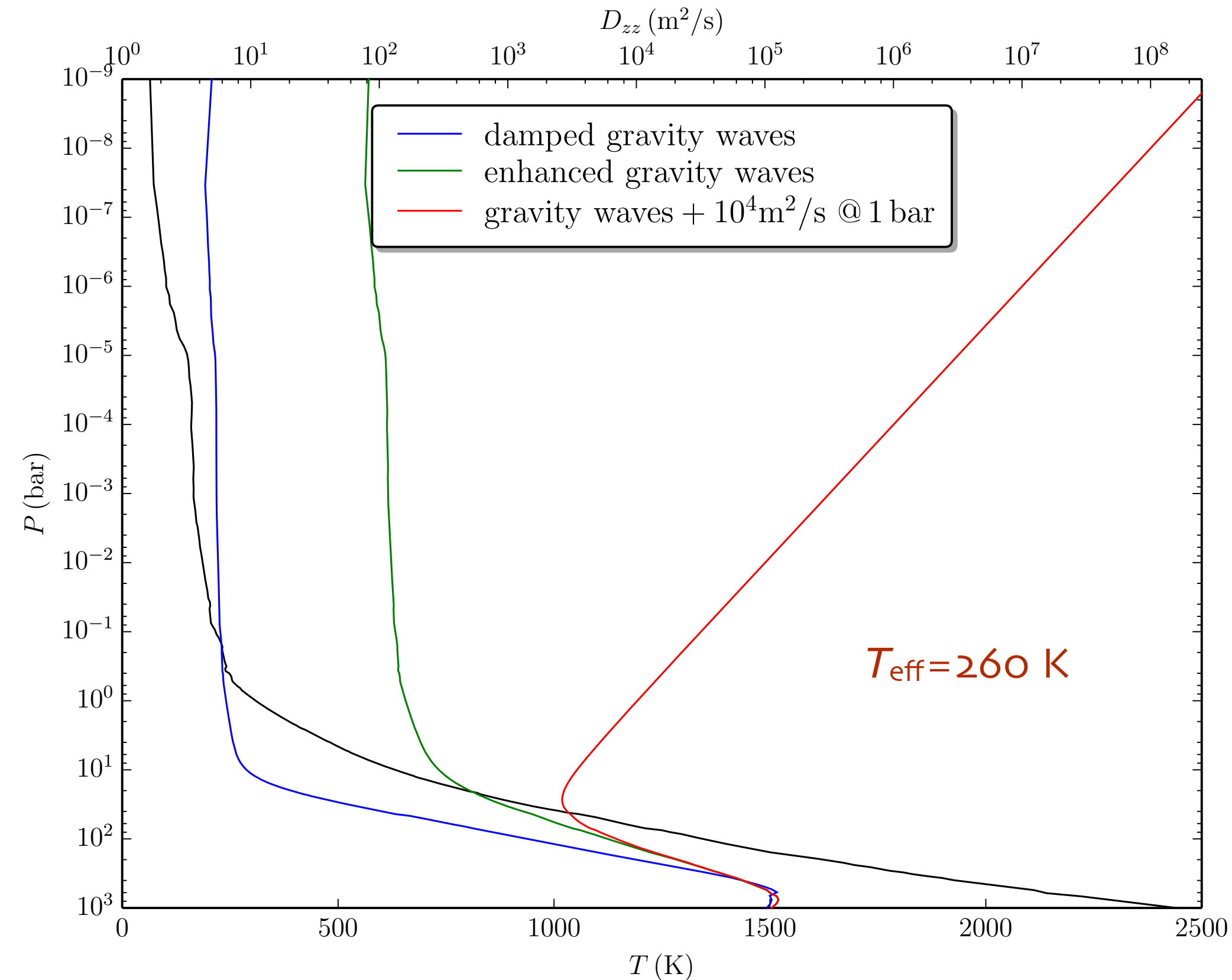


convective overshoot and gravity wave excitation dominant in brown dwarfs — but in planets too inefficient (Schwarzschild boundary @ $\tau \geq 100$)



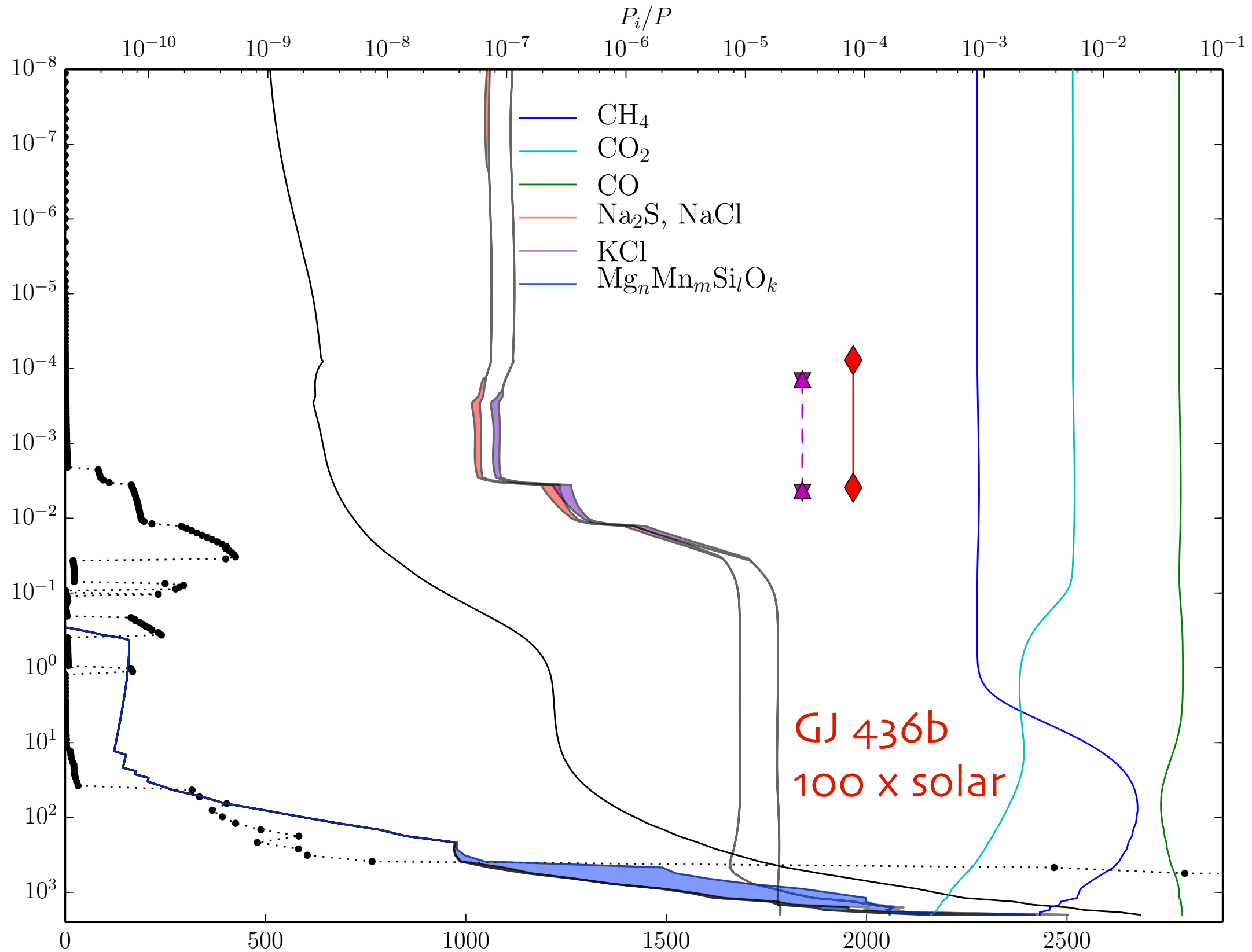
global circulation important!

Clouds in Brown Dwarfs and Planets



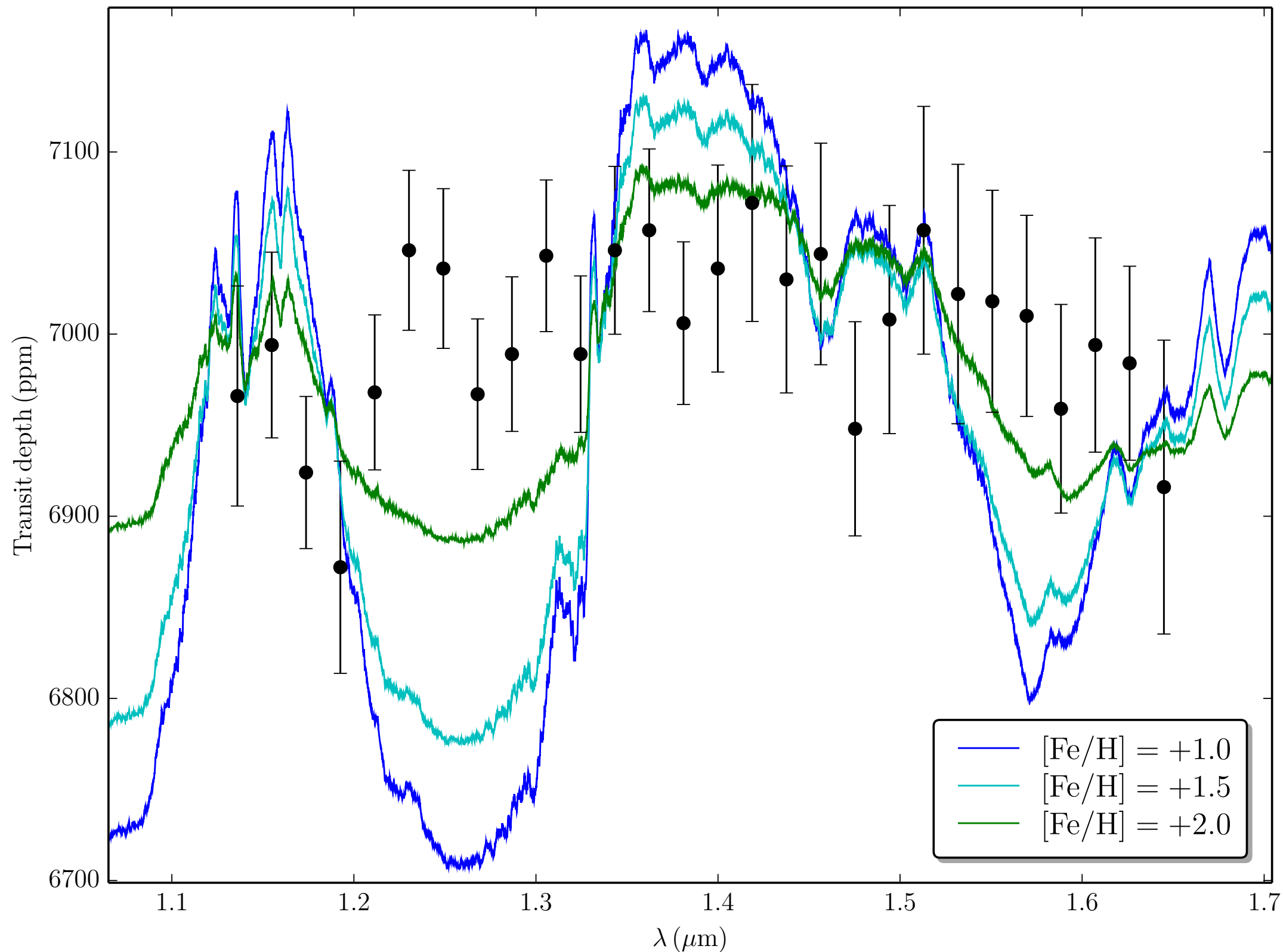
modelling mixing
based on
extrapolation of
RHD simulations
+ GCM models
(Parmentier et al.
Kataria et al.)

Clouds in hot Neptunes and super-Earths



Clouds in hot Neptunes and super-Earths

GJ 436b transit models and WFC3 observations (Knutson et al. 2014)



Conclusions

Low Mass Star

Brown Dwarf

- Cloud modelling successful in brown dwarfs
- Impact also on measured gas phase composition and thermal structure (evolution boundary!)
- Peculiarities of planetary atmospheres (mixing, nucleation processes) yet to be consistently implemented
- For mature, irradiated planets connection to circulation models essential

Jupiter

Earth

NASA