

Exoplanet transmission spectra and the importance of clouds/hazes in their interpretation

Matthias Mallonn



Outline

Introduction on transmission spectroscopy

Overview about recent results regarding clouds/hazes

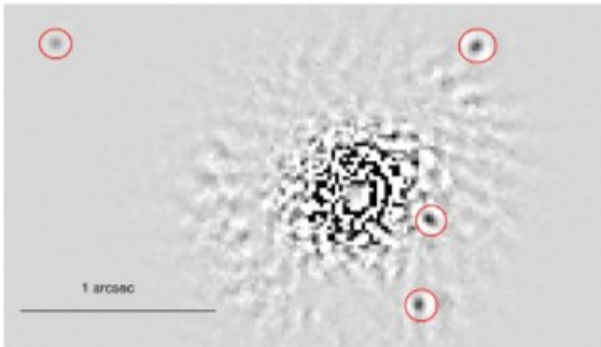
My own contribution

What can we learn from „flat“ spectra of Hot Jupiters

Observational aspects will be given by Elyar Sedaghati
and Ray Jayawardhana.

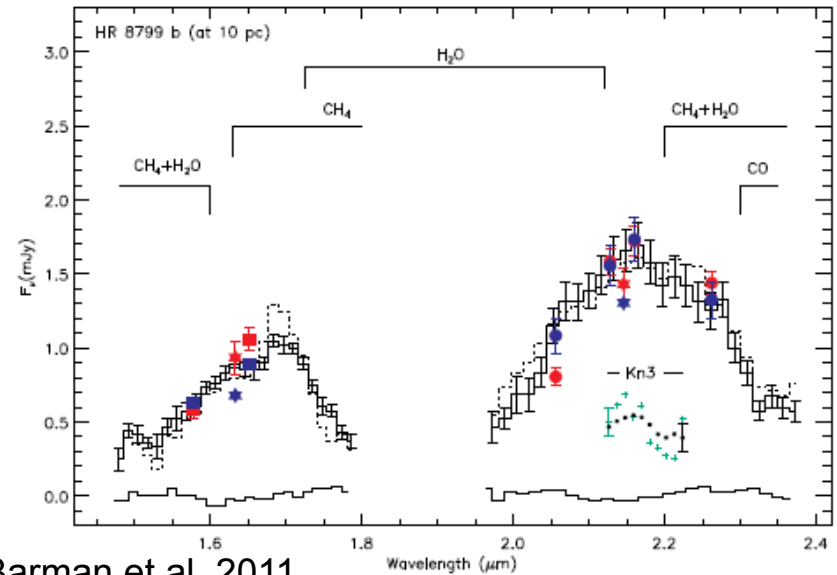
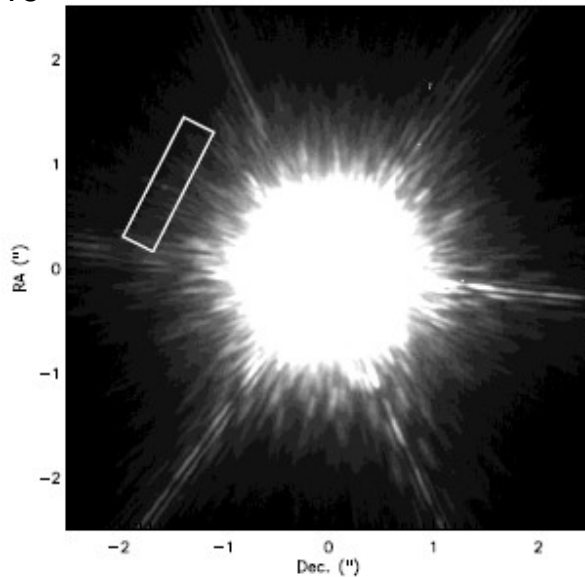
Spectroscopy of extrasolar planets

Planetary system HR8799



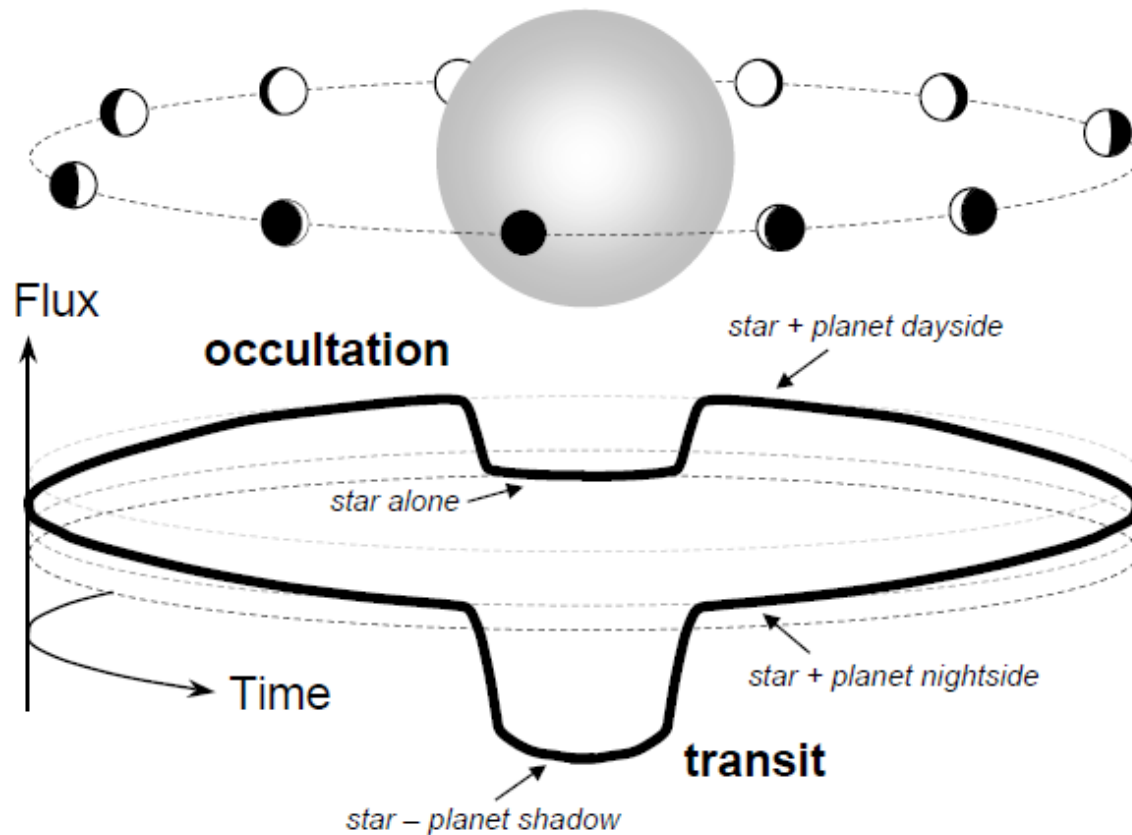
Direct spectroscopy hampered by contrast and angular separation.

Esposito et al. 2013



Barman et al. 2011

Indirect methods using transiting planets



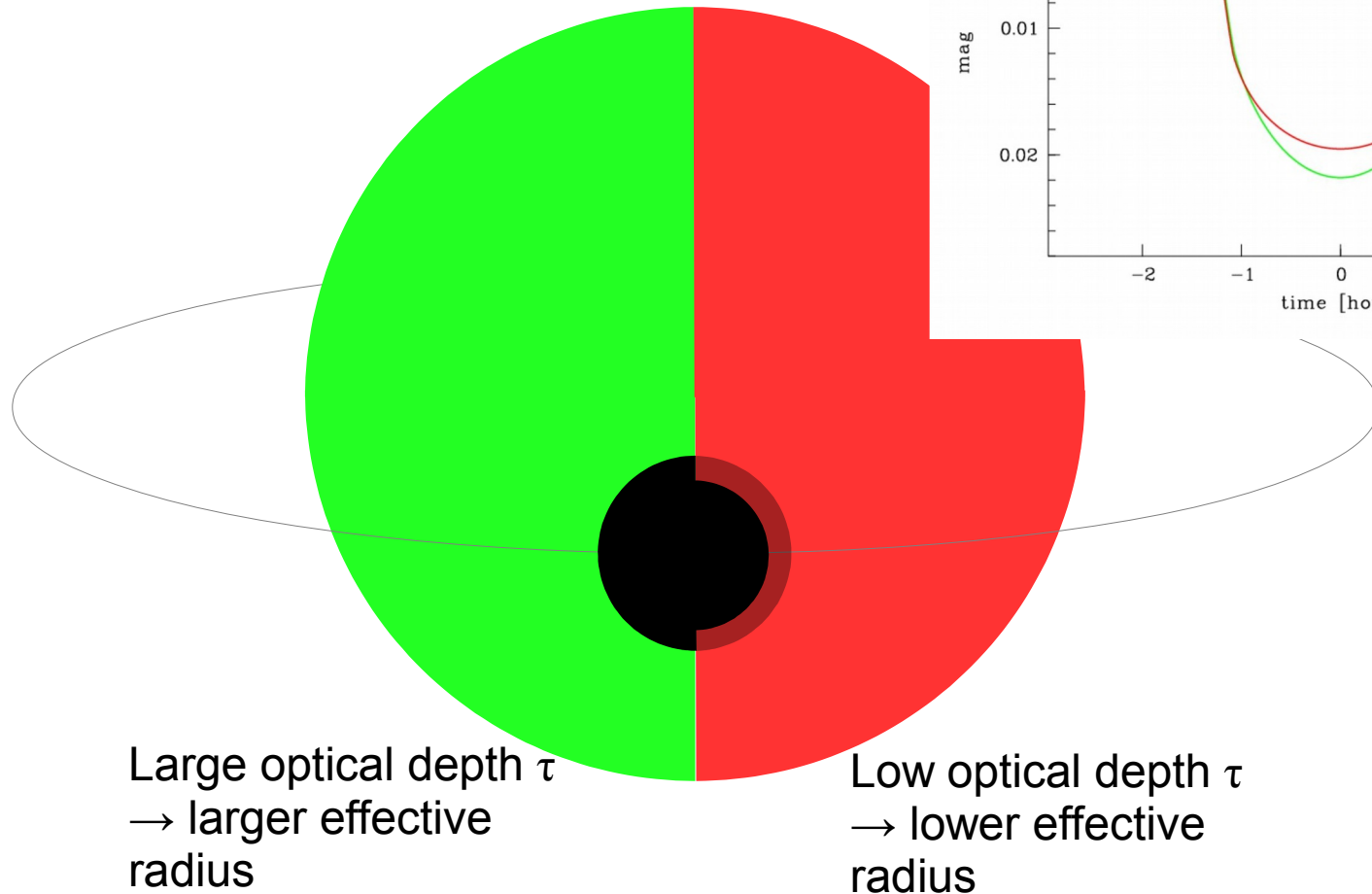
Information from

1. Transit
2. Secondary eclipse
3. Phase curve

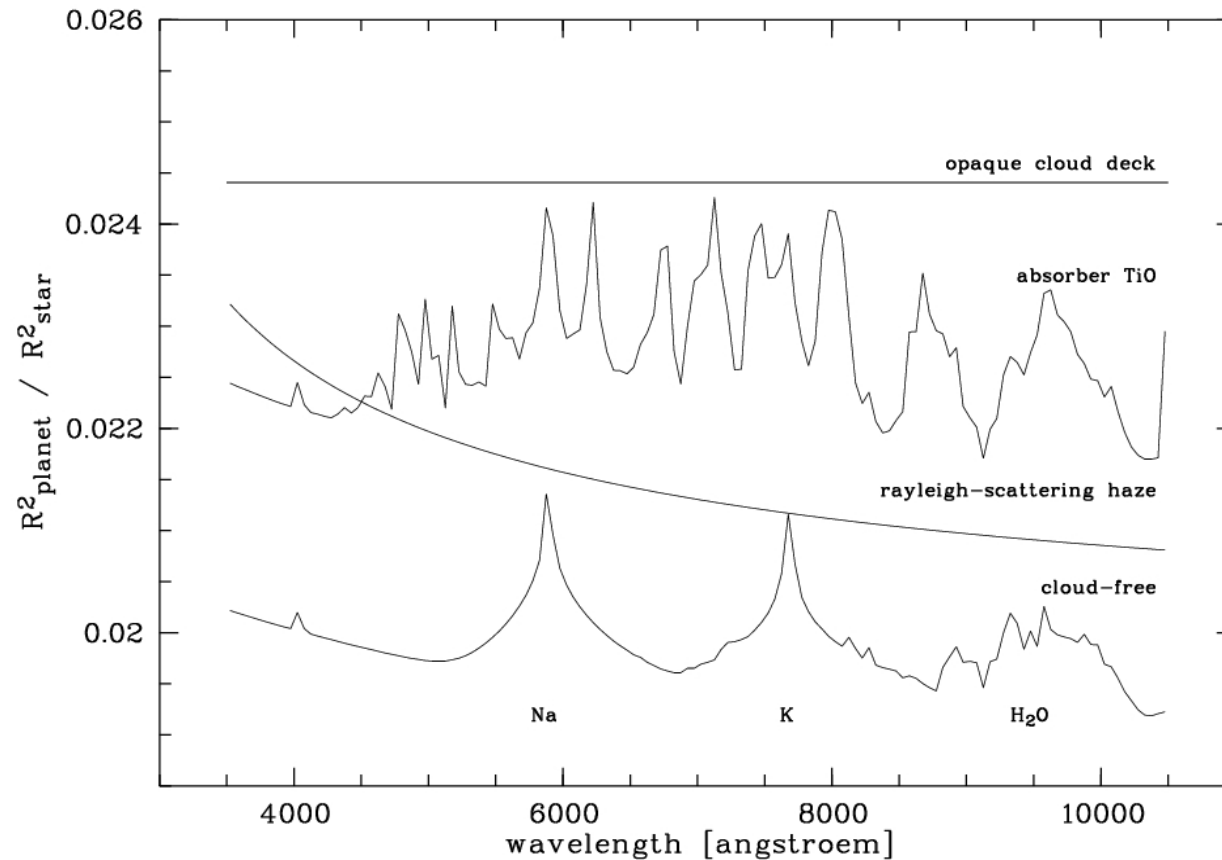
Winn 2011

Transmission spectroscopy

Search for a chromatic transit depth



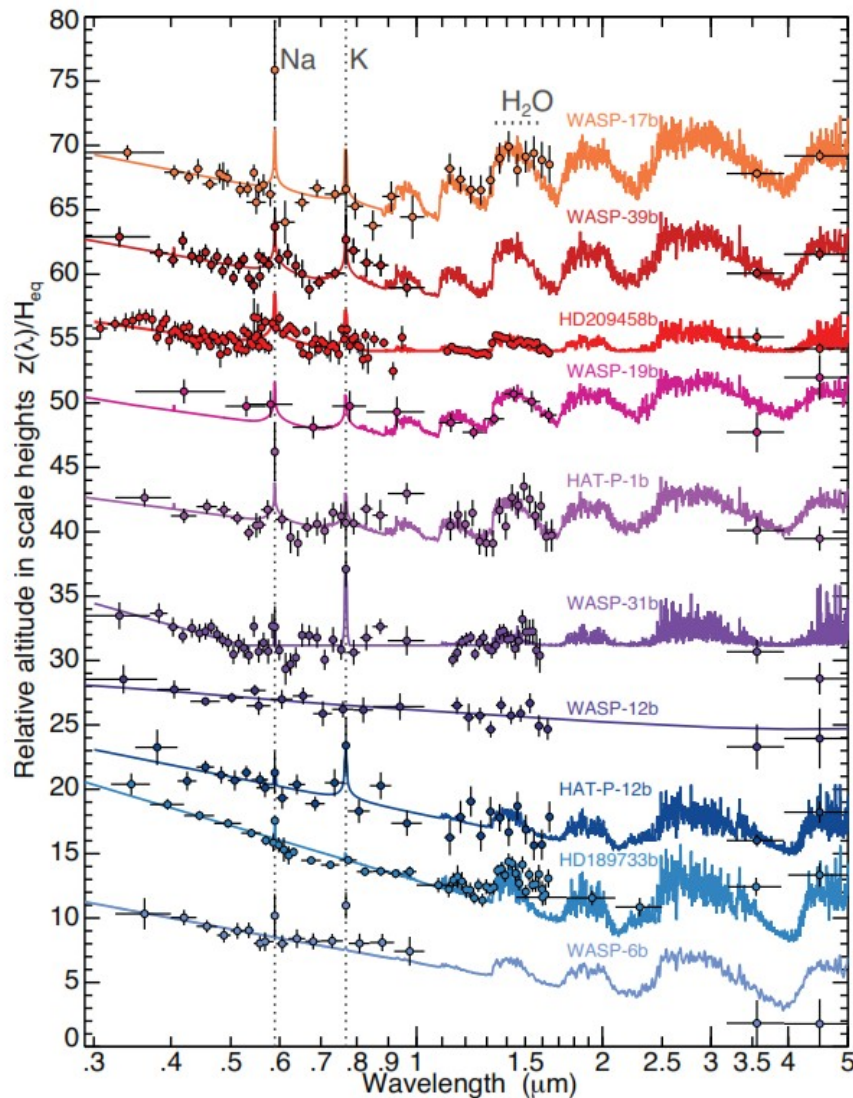
Possible spectral scenarios



TiO and cloud-free model by Fortney et al. 2010

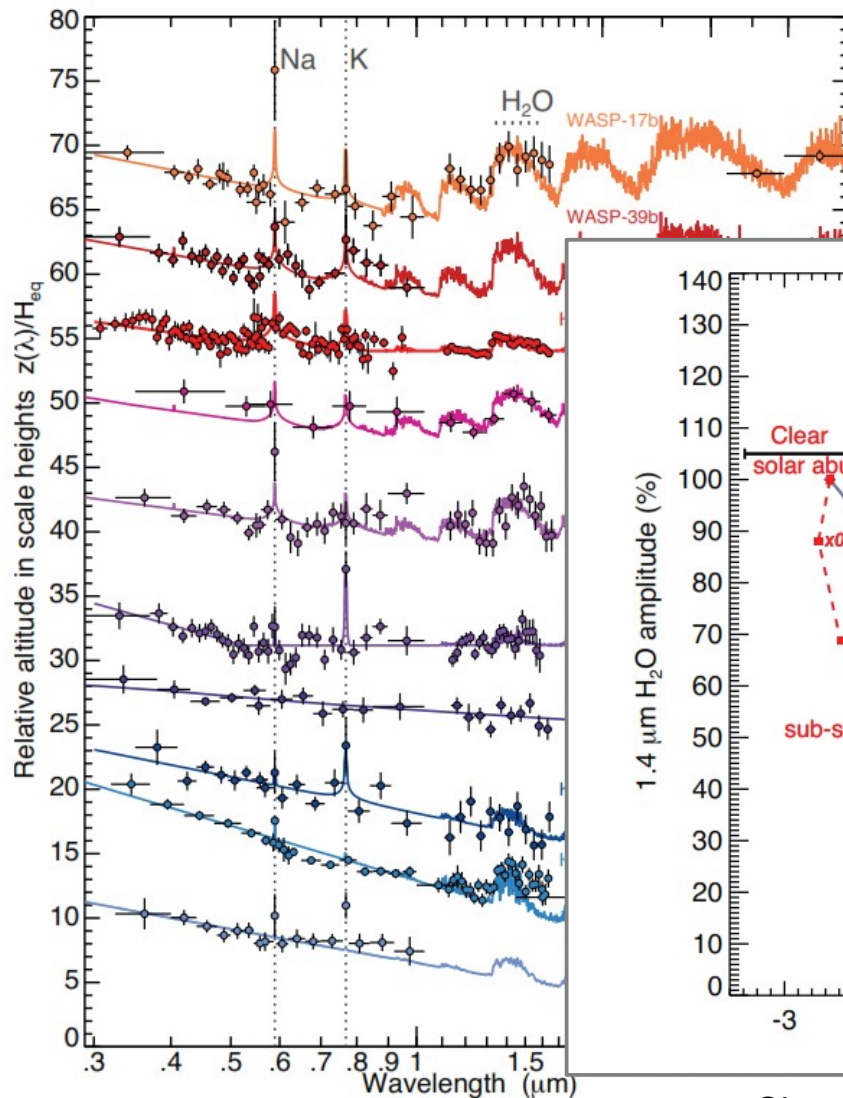
The current results for Hot Jupiters

HST Hot-Jupiter transmission spectral survey by D. Sing et al.

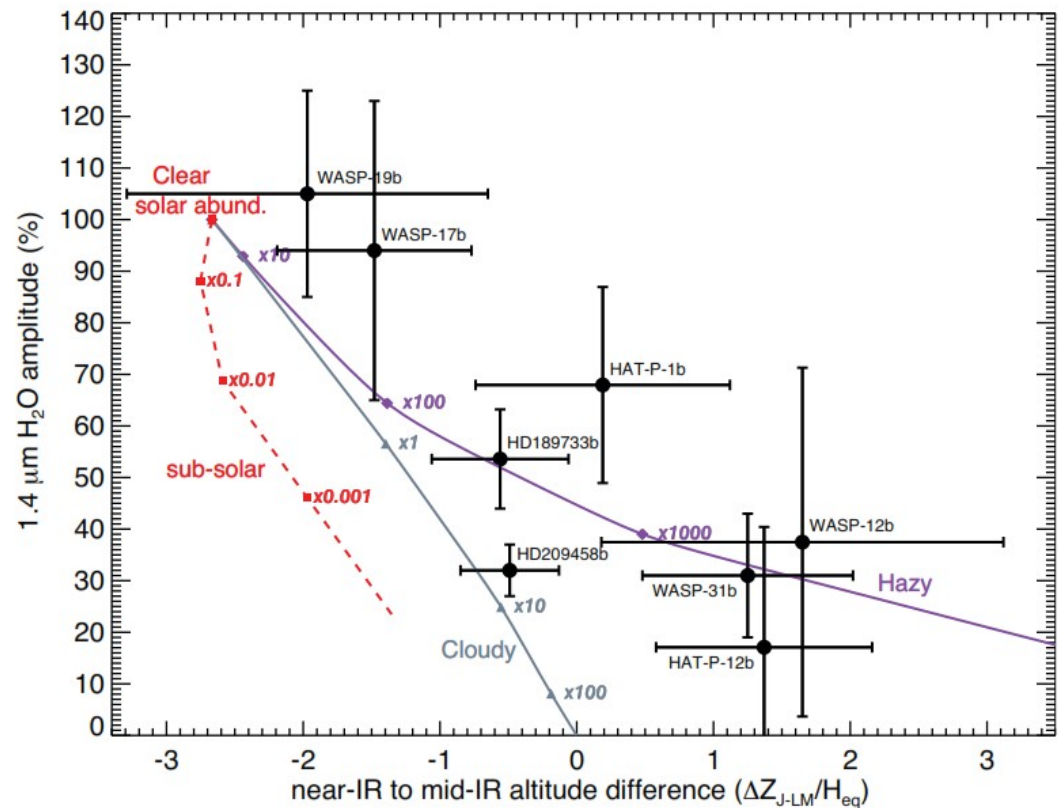


Sing et al. 2016

The current results for Hot Jupiters



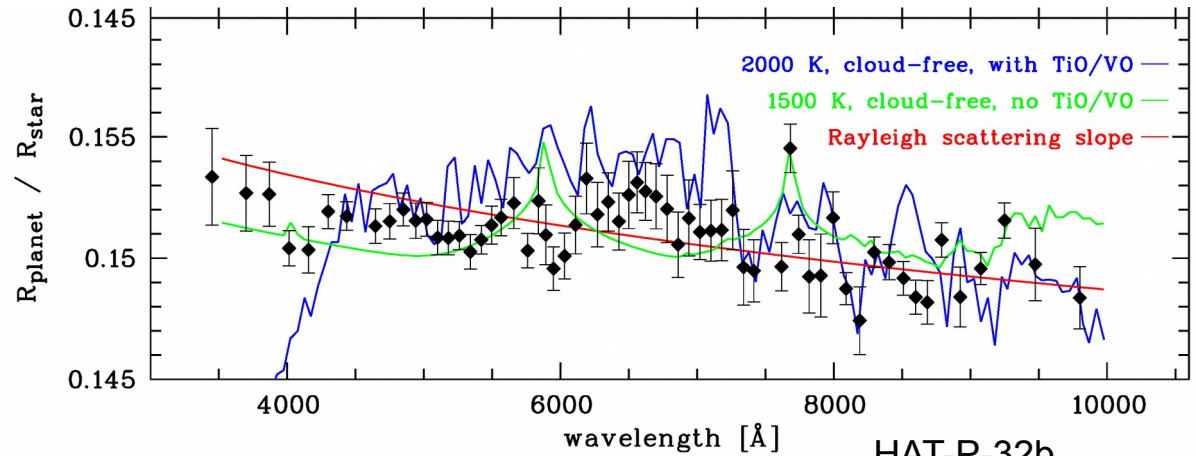
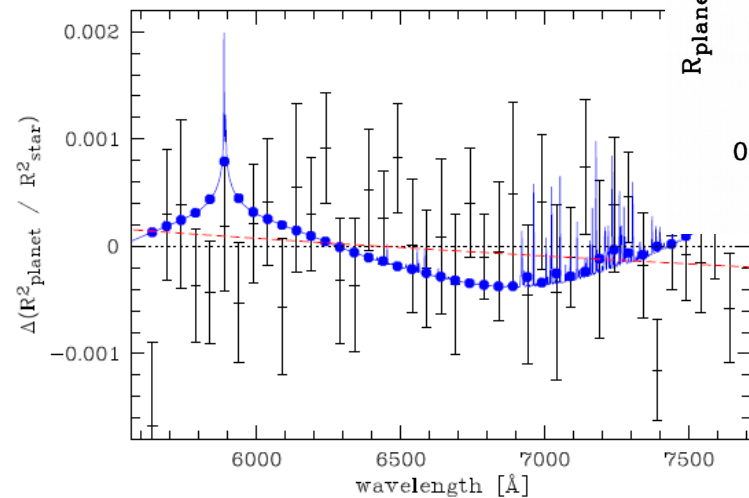
Majority of Hot Jupiters is not cloud-free



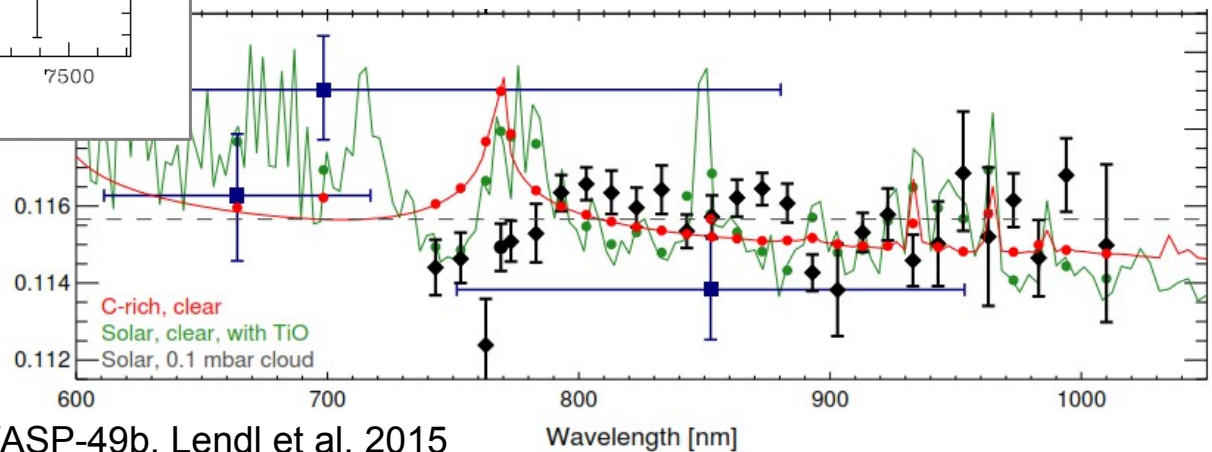
Sing et al. 2016

The current results for Hot Jupiters

HAT-P-19b,
Mallonn et al. 2015



HAT-P-32b,
Mallonn & Strassmeier,
submitted



WASP-49b, Lendl et al. 2015

Absorption features in hot-Jupiter atmospheres

features
as predicted by
cloud-free models

features weakened
or absent

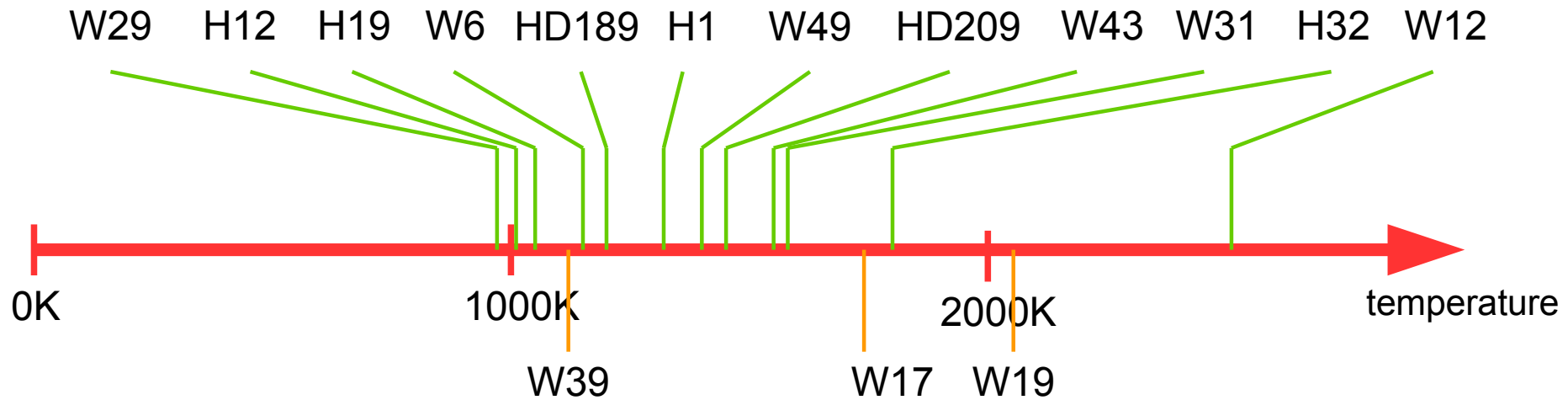
WASP-17b
WASP-19b
WASP-39b

3

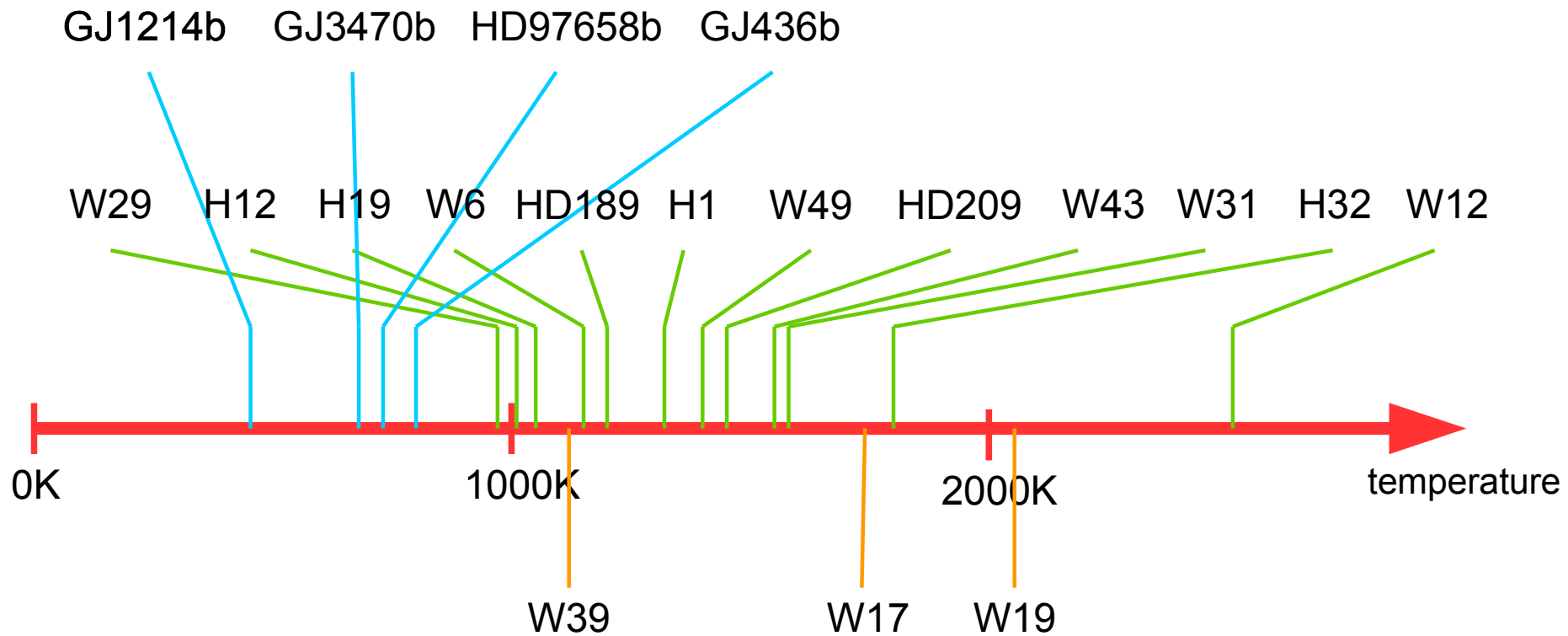
12

HD189733b
HD209458b
WASP-6b
WASP-12b
WASP-29b
WASP-31b
WASP-43b
WASP-49b
HAT-P-1b
HAT-P-12b
HAT-P-19b
HAT-P-32b

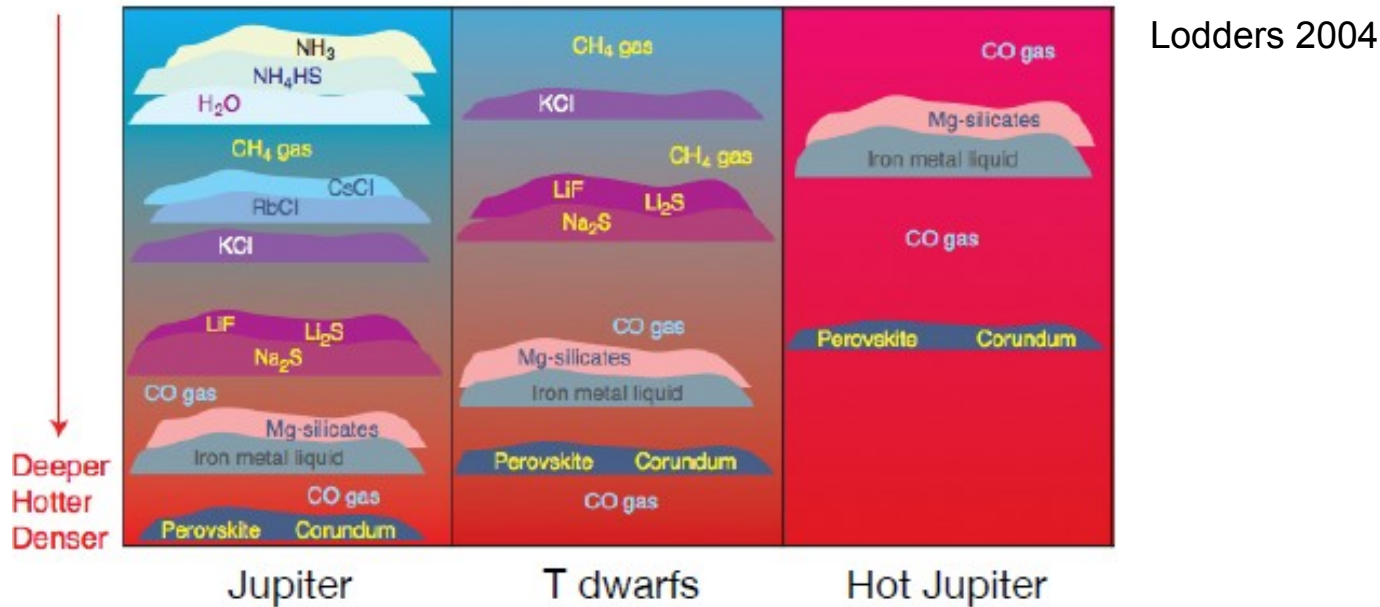
Dependence on planetary atmospheric temperature



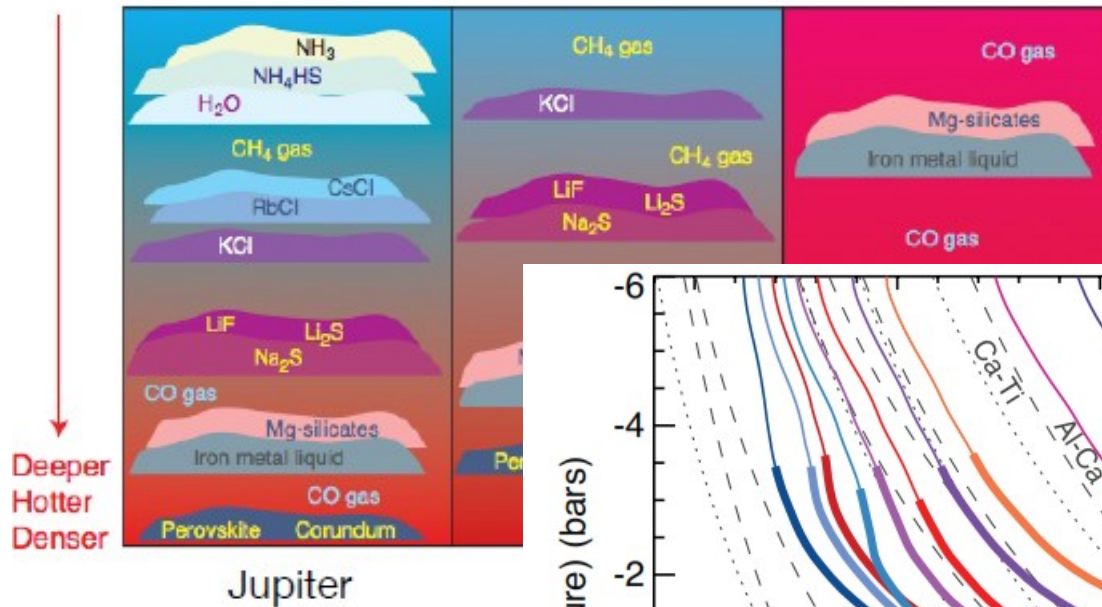
Dependence on planetary atmospheric temperature



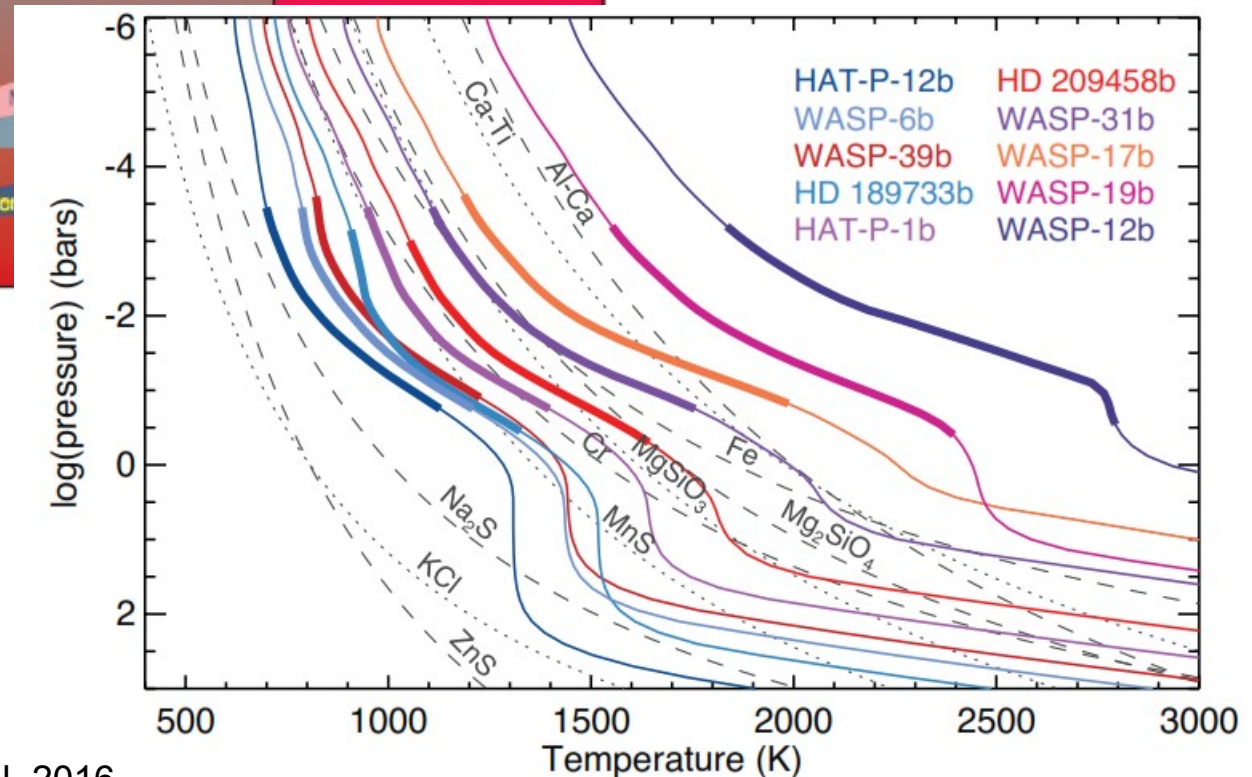
Cloud condensation in Hot Jupiter atmospheres



Cloud condensation in Hot Jupiter atmospheres



Lodders 2004



Sing et al. 2016

Cloud formation not fully understood

Clouds or hazes produced by condensation or photochemistry?

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Condensates formed at the night side and transported horizontally?

Condensates formed deeper and transported vertically?

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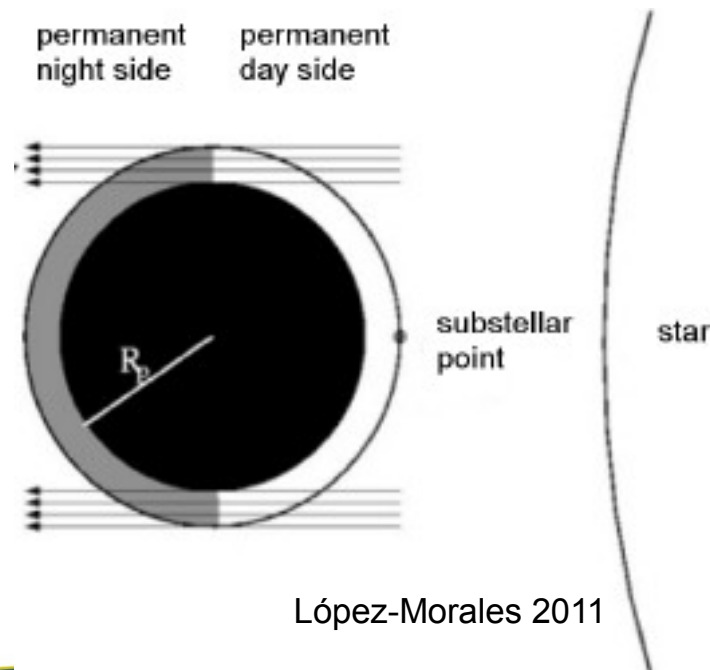
No correlation with incident UV flux or stellar activity of the host star

Condensates formed at the night side and transported horizontally?

Condensates formed deeper and transported vertically?

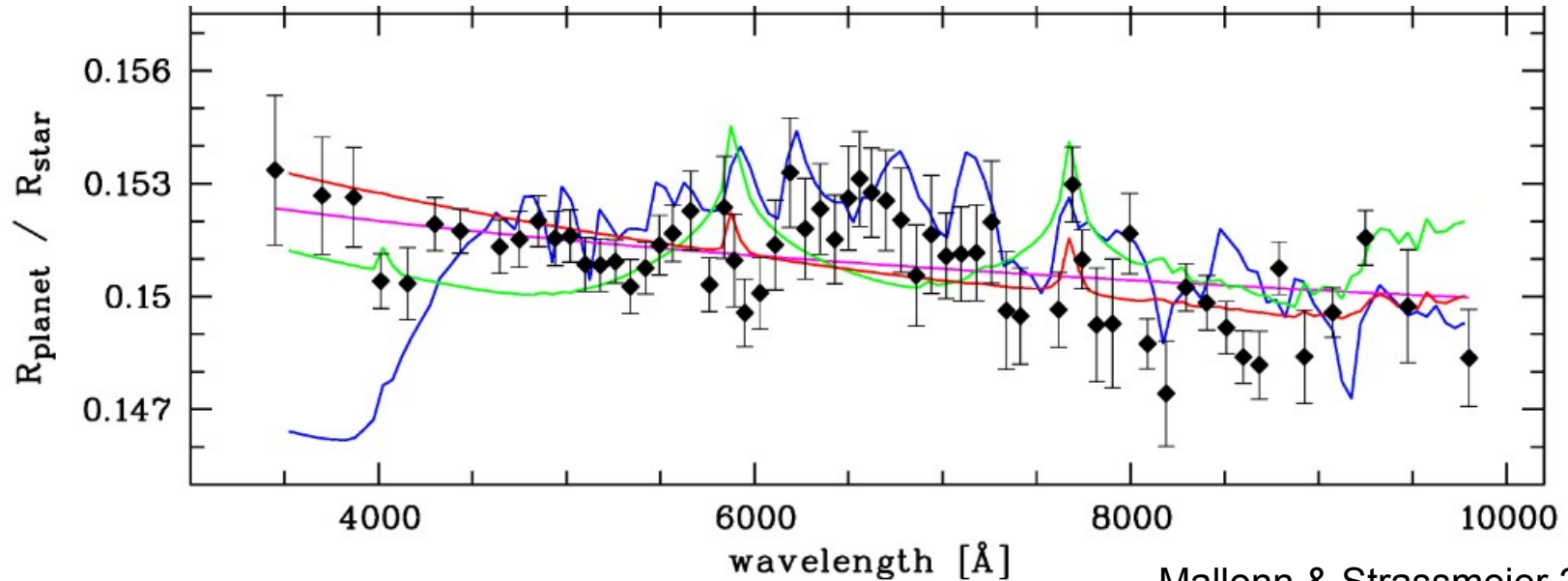
slant viewing geometry:
high opacity for trace species
of condensates

Fortney et al. 2005



López-Morales 2011

Transmission spectrum of HAT-P-32b observed with MODS@LBT

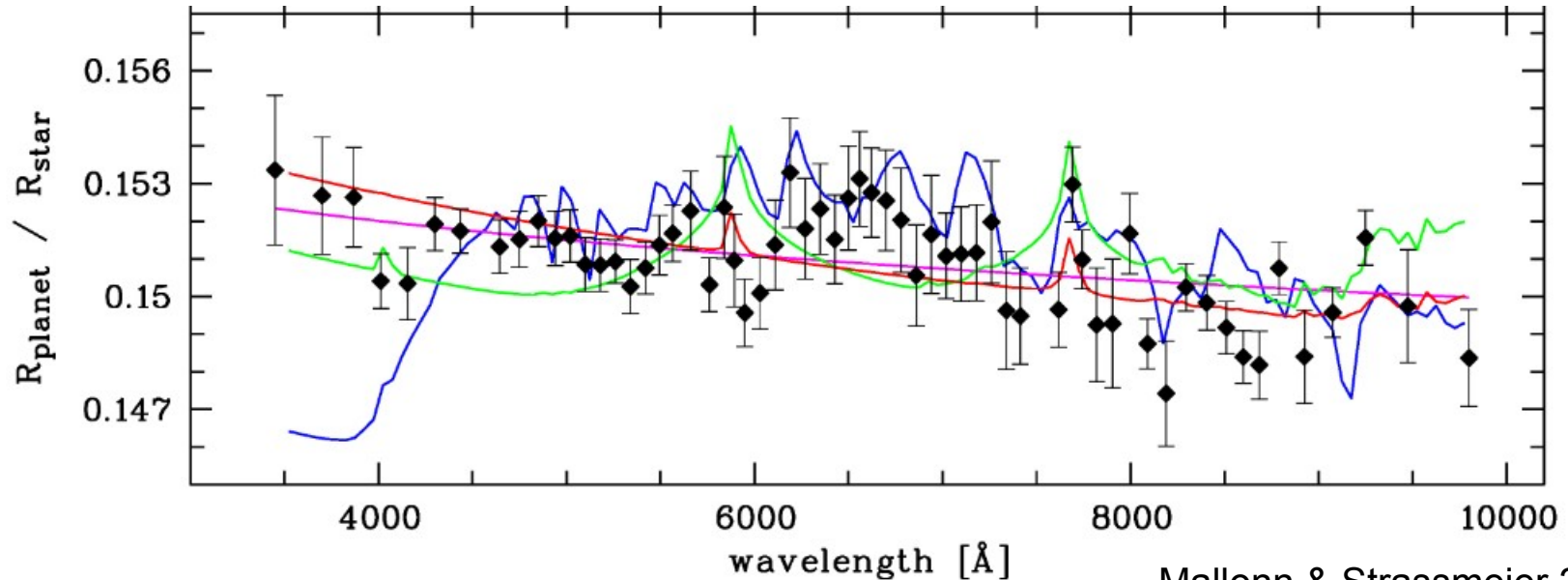


Mallonn & Strassmeier 2016,
submitted

Cloud-free models (green and blue) ruled out.

Significant gradient toward blue wavelengths.

Transmission spectrum of HAT-P-32b observed with MODS@LBT



Mallonn & Strassmeier 2016,
submitted

Significant gradient toward blue wavelengths!

A fit of a Rayleigh-slope yields $T = 890 \pm 230$ K **too cool**

→ **Mie-scattering instead of Rayleigh-scattering**

Future observations will yield grain size/ composition

Conclusion

Transmission spectra of most Hot Jupiters and super-Earths/Neptunes are influenced by clouds/hazes.

The spectral features are weakened or totally absent.

We do not understand cloud formation well enough yet to predict the cloud effects on the transmission spectra of habitable planets.