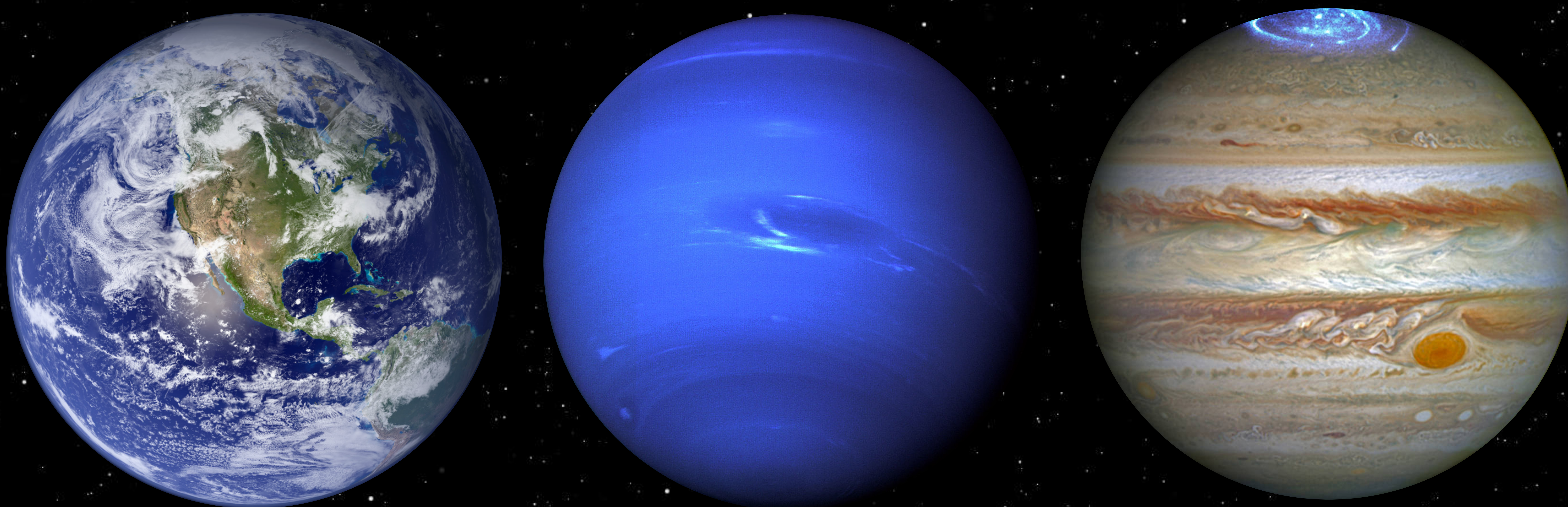
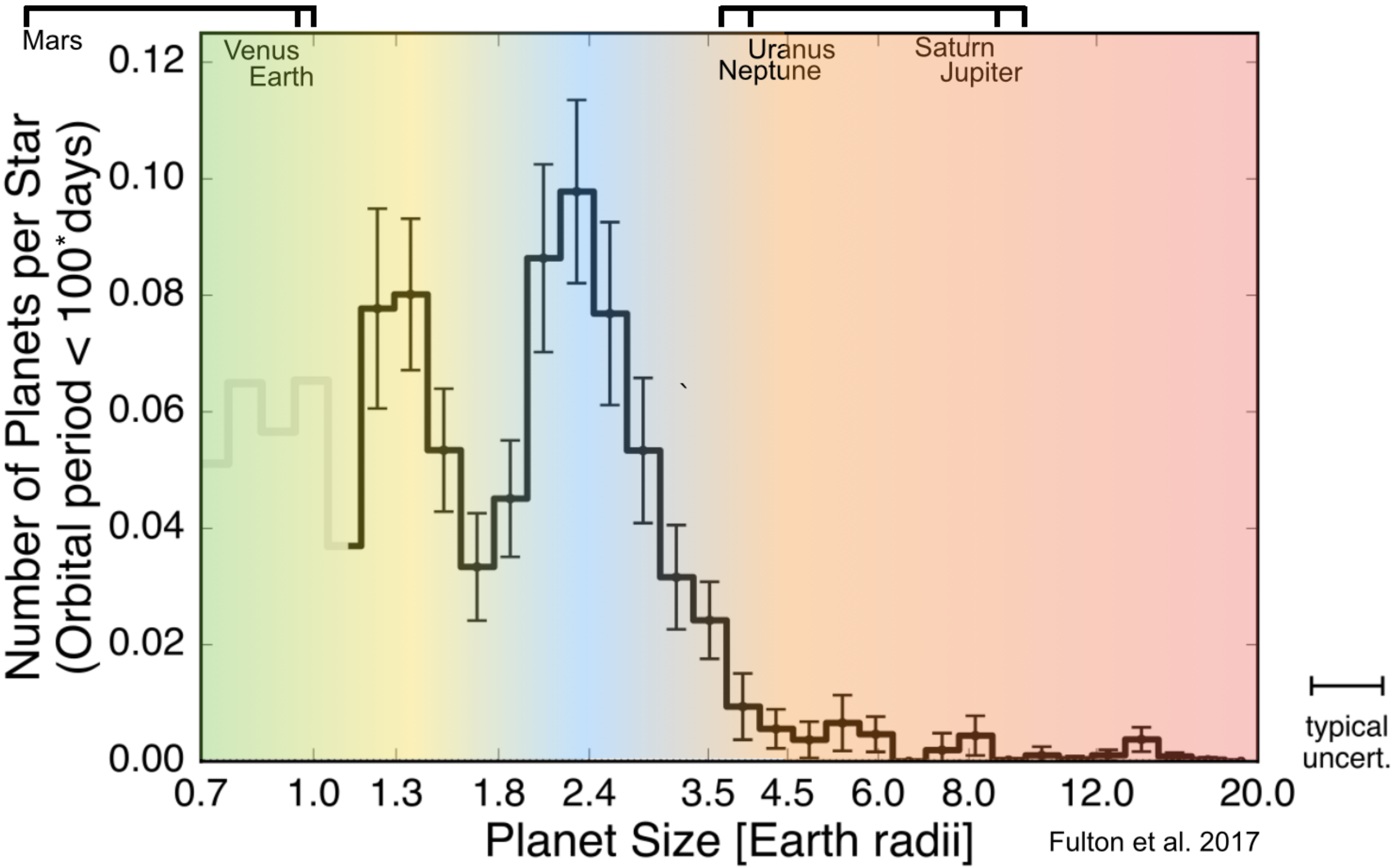
MEASURE: the MMT Exoplanet Atmosphere SURvEy



Jayne Birkby

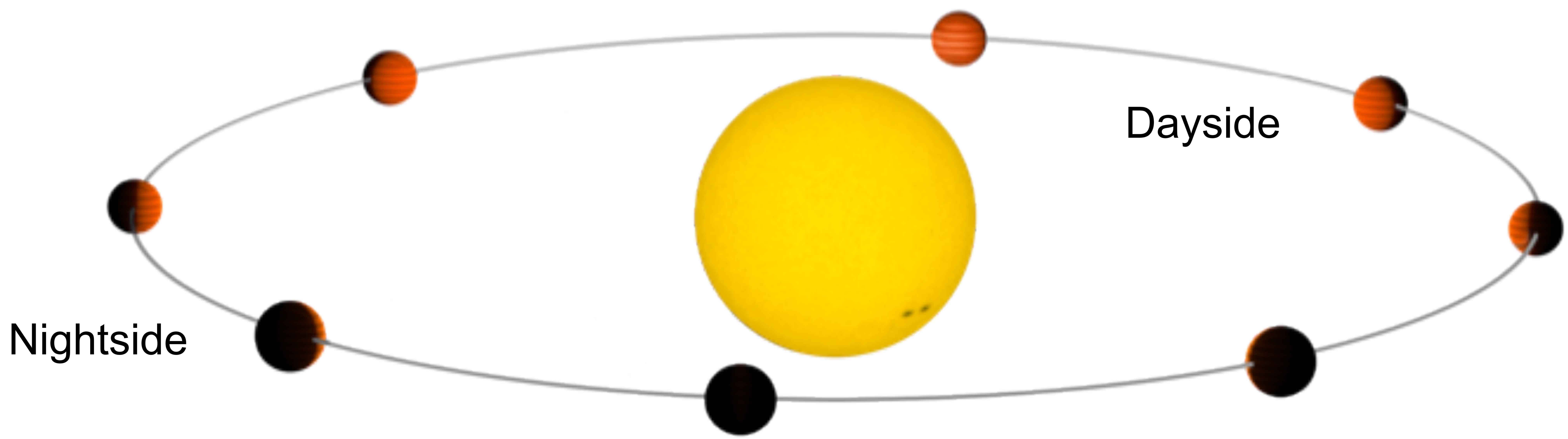
Assistant Professor, University of Amsterdam

The exoplanet zoo is rich in diversity

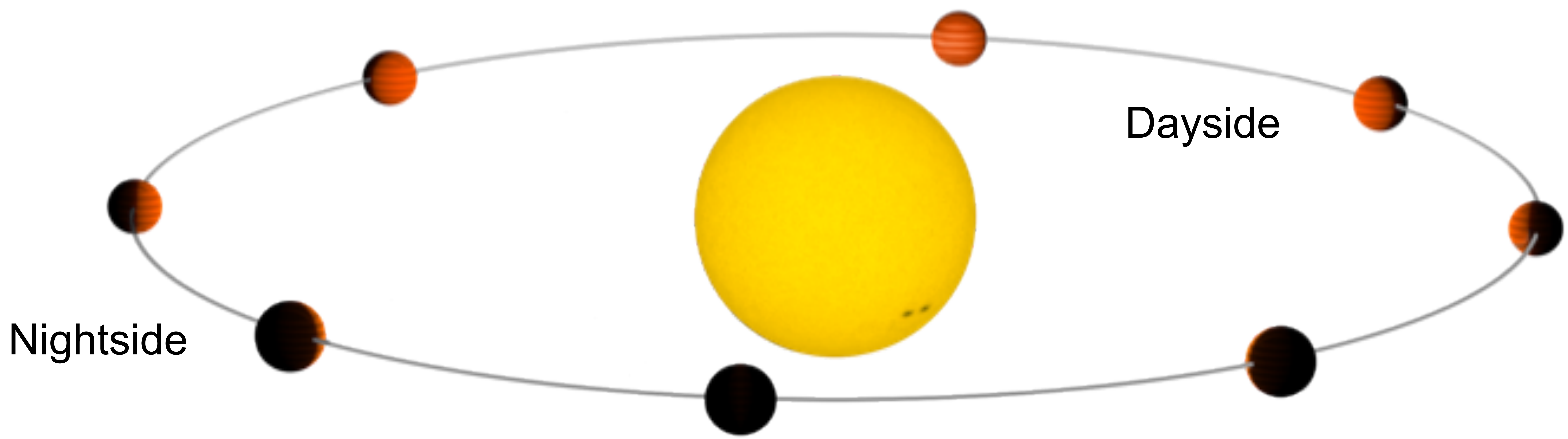


Fulton et al. 2017

Observe planet's dayside at high spectral resolution

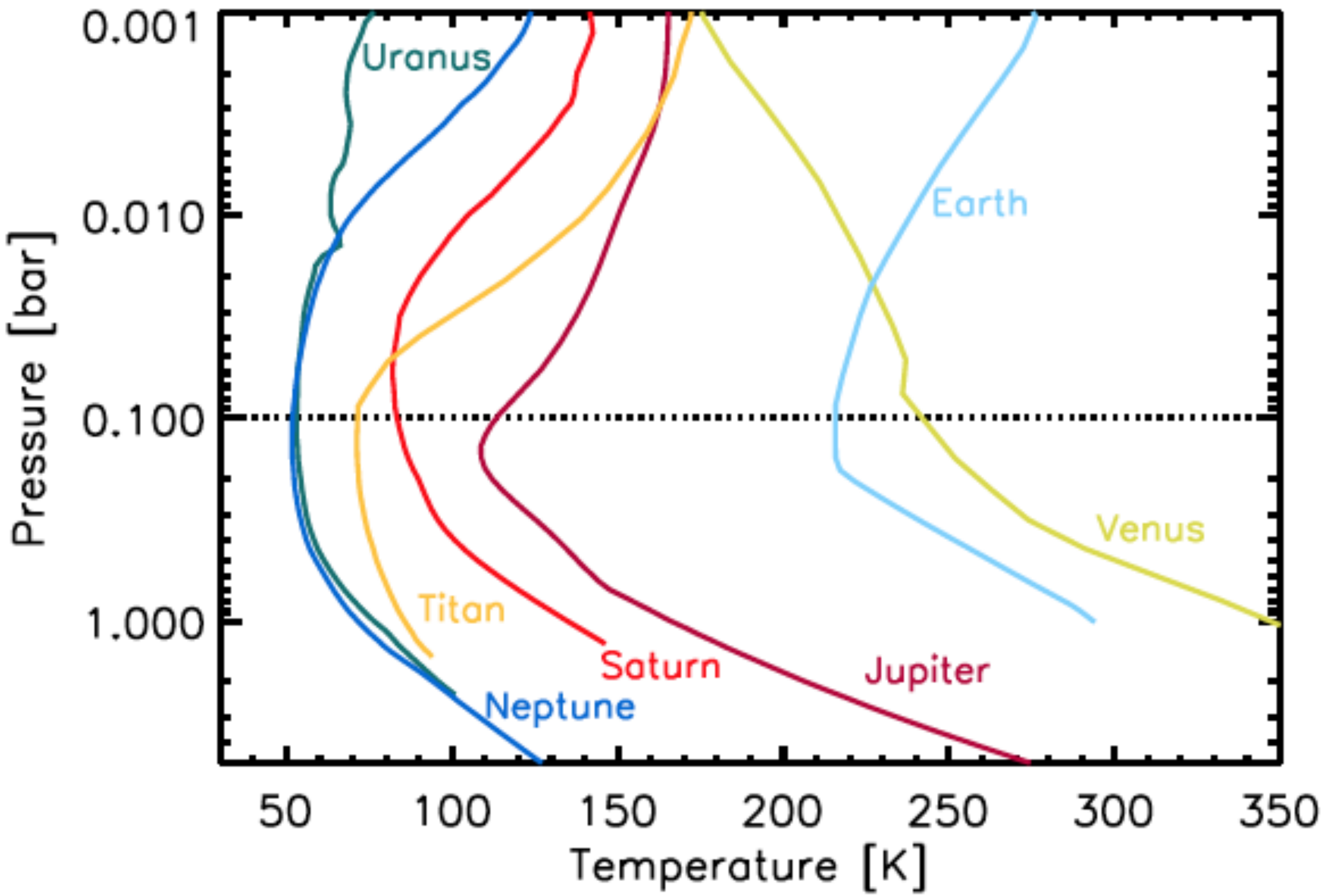


Observe planet's dayside at high spectral resolution



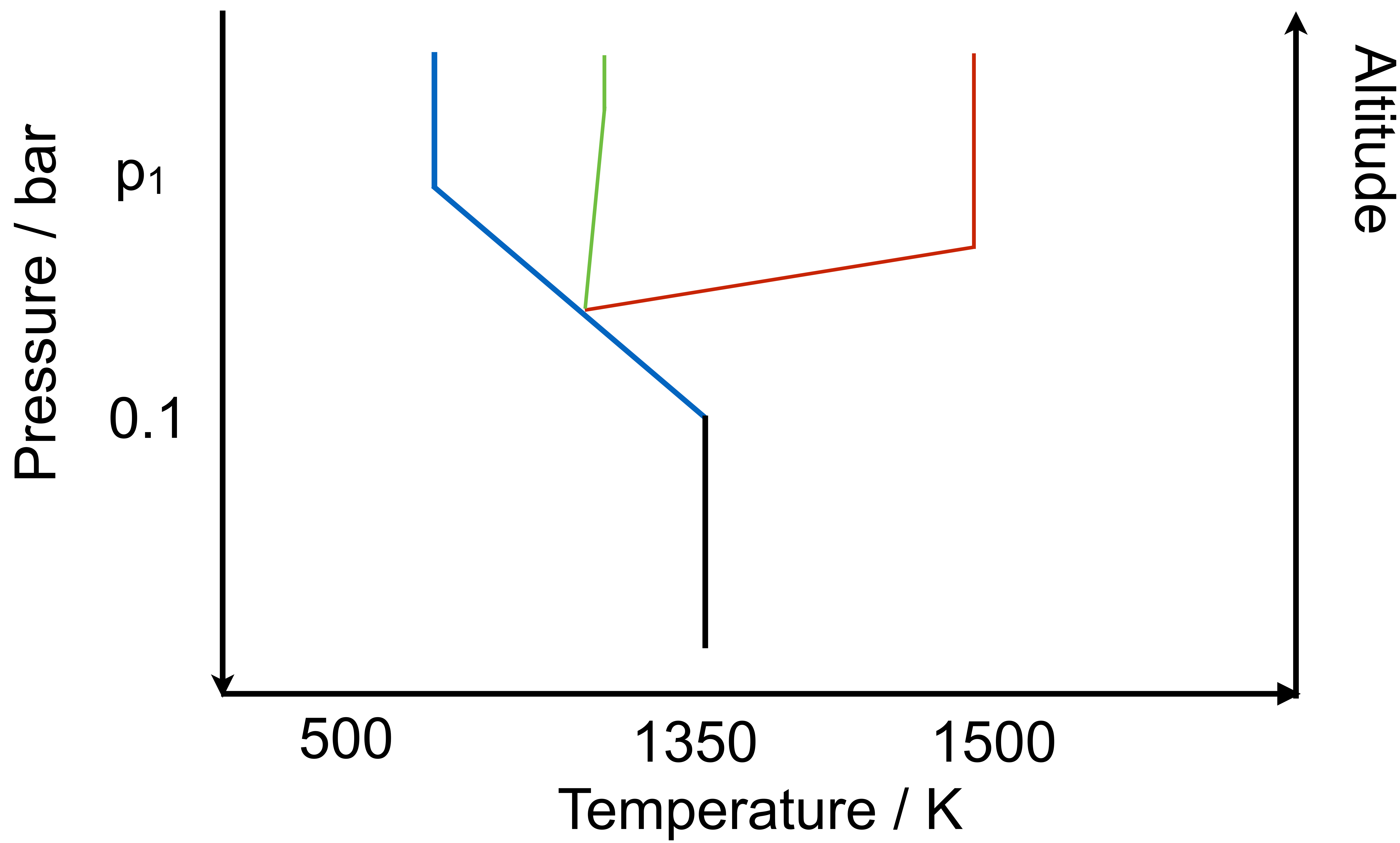
Use template matching (cross-correlation) to find molecules in spectrum (e.g. water, carbon monoxide)

Inversion layers are common in the Solar system

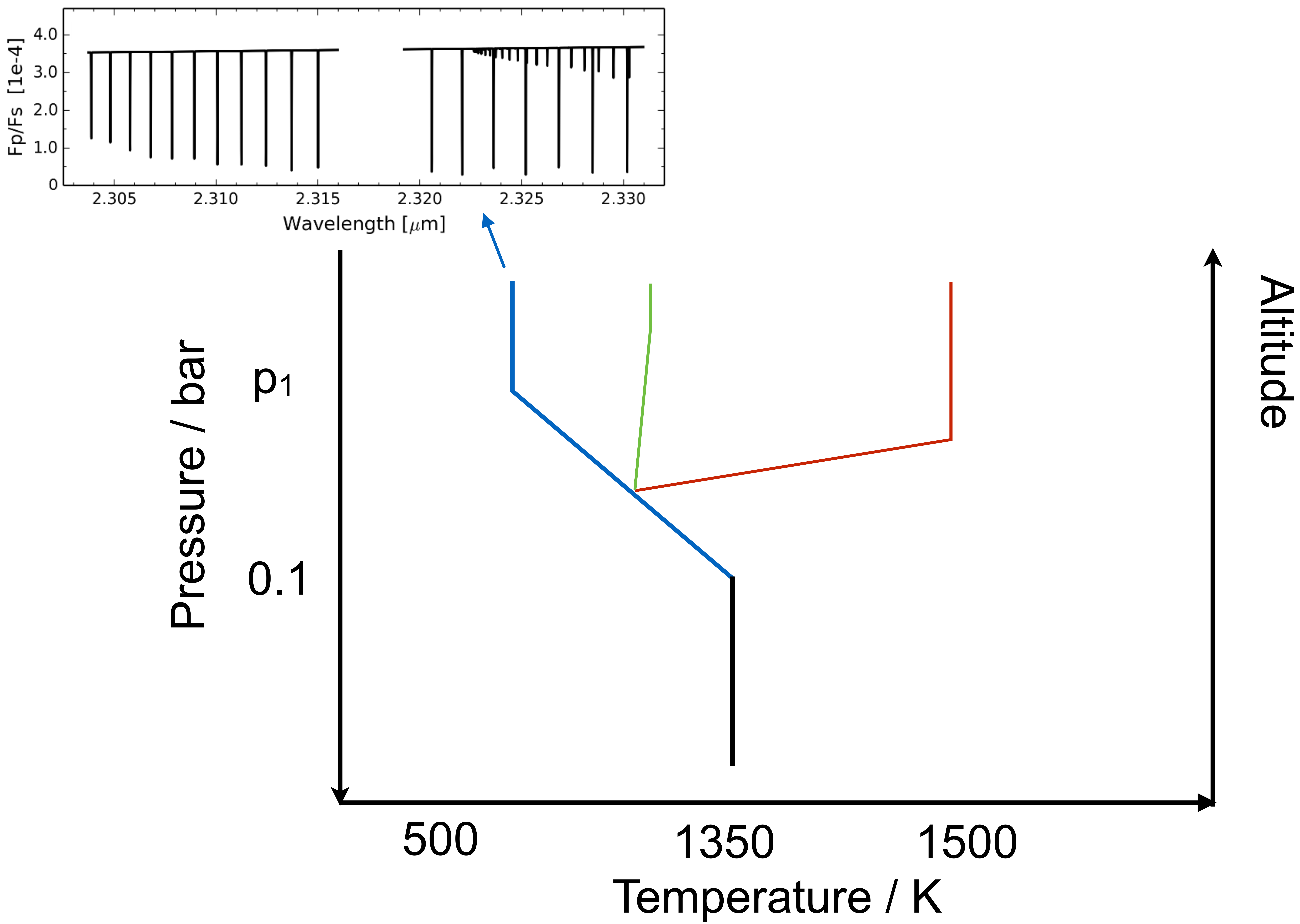


Robinson & Catling 2013

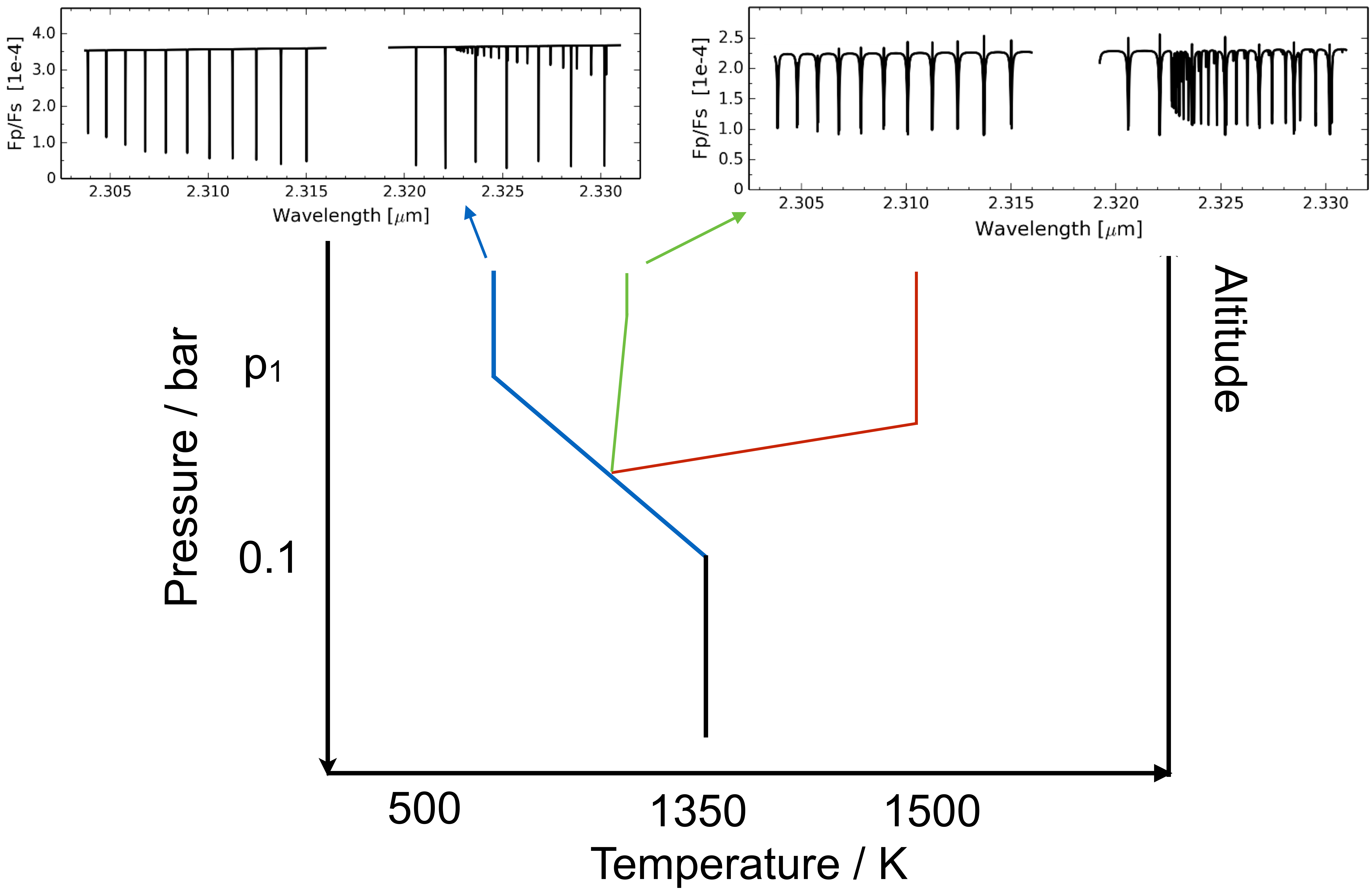
Inversion layers are revealed by many emission lines at high spectral resolution



Inversion layers are revealed by many emission lines at high spectral resolution



Inversion layers are revealed by many emission lines at high spectral resolution

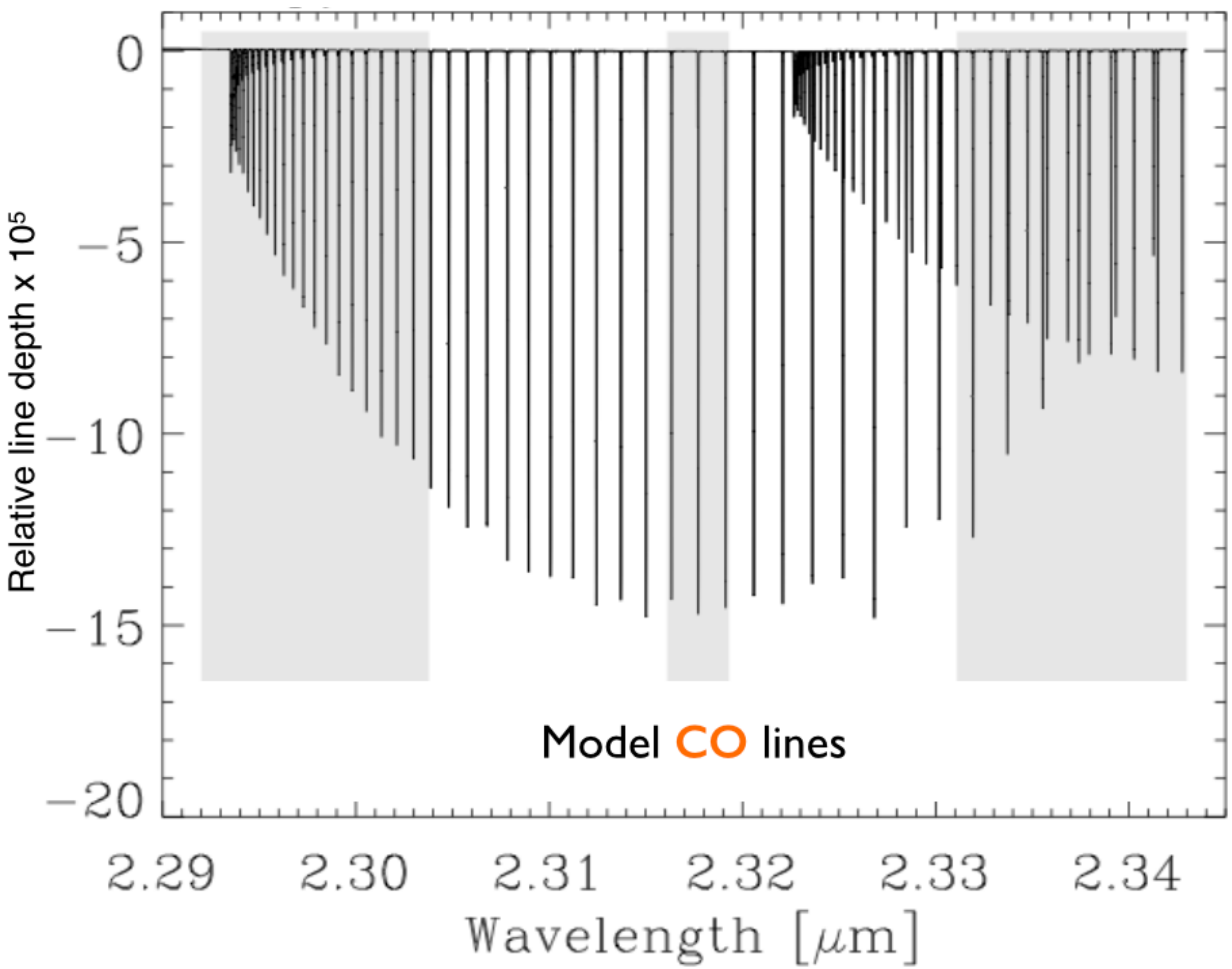


Inversion layers are revealed by many emission lines at high spectral resolution

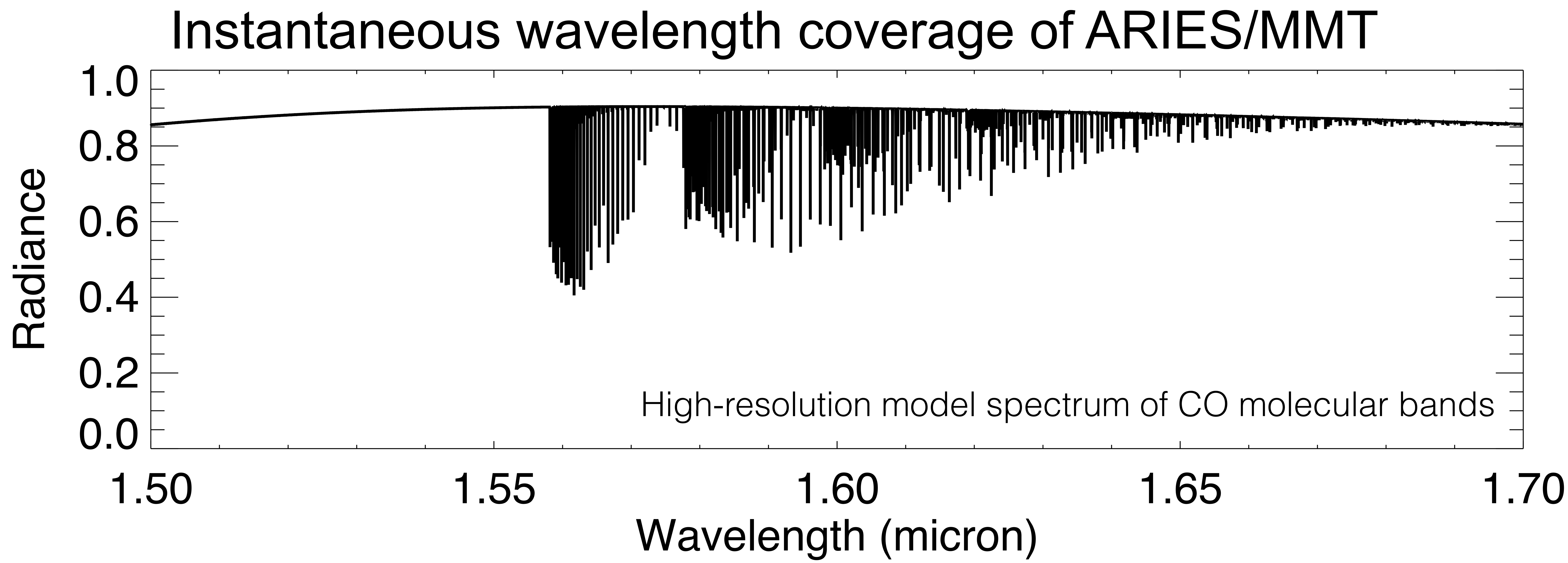
MEASURE: the MMT **E**xoplanet **A**tmosphere **SUR**v**E**y

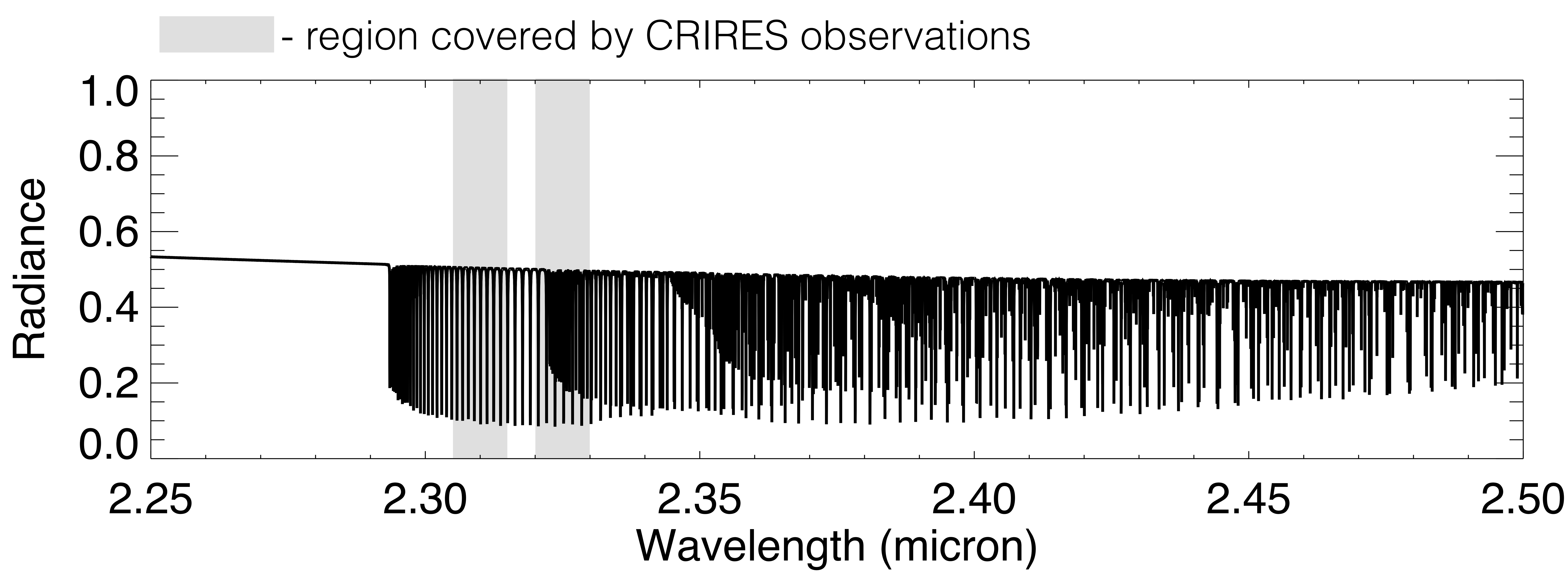
A **40 night** program on an **AO**-assisted **6.5 m** telescope
at **R=30,000** with **1.5-2.5 micron** simultaneous wavelength coverage

HRS strength $\propto$ number of lines detected



HRS strength ∝ number of lines detected





MEASURE: the MMT Exoplanet Atmosphere SURvEy

A **40 night** program on an **AO**-assisted **6.5 m** telescope
at **R=30,000** with **1.5-2.5 micron** simultaneous wavelength coverage

MEASURE: the MMT Exoplanet Atmosphere SURvEy

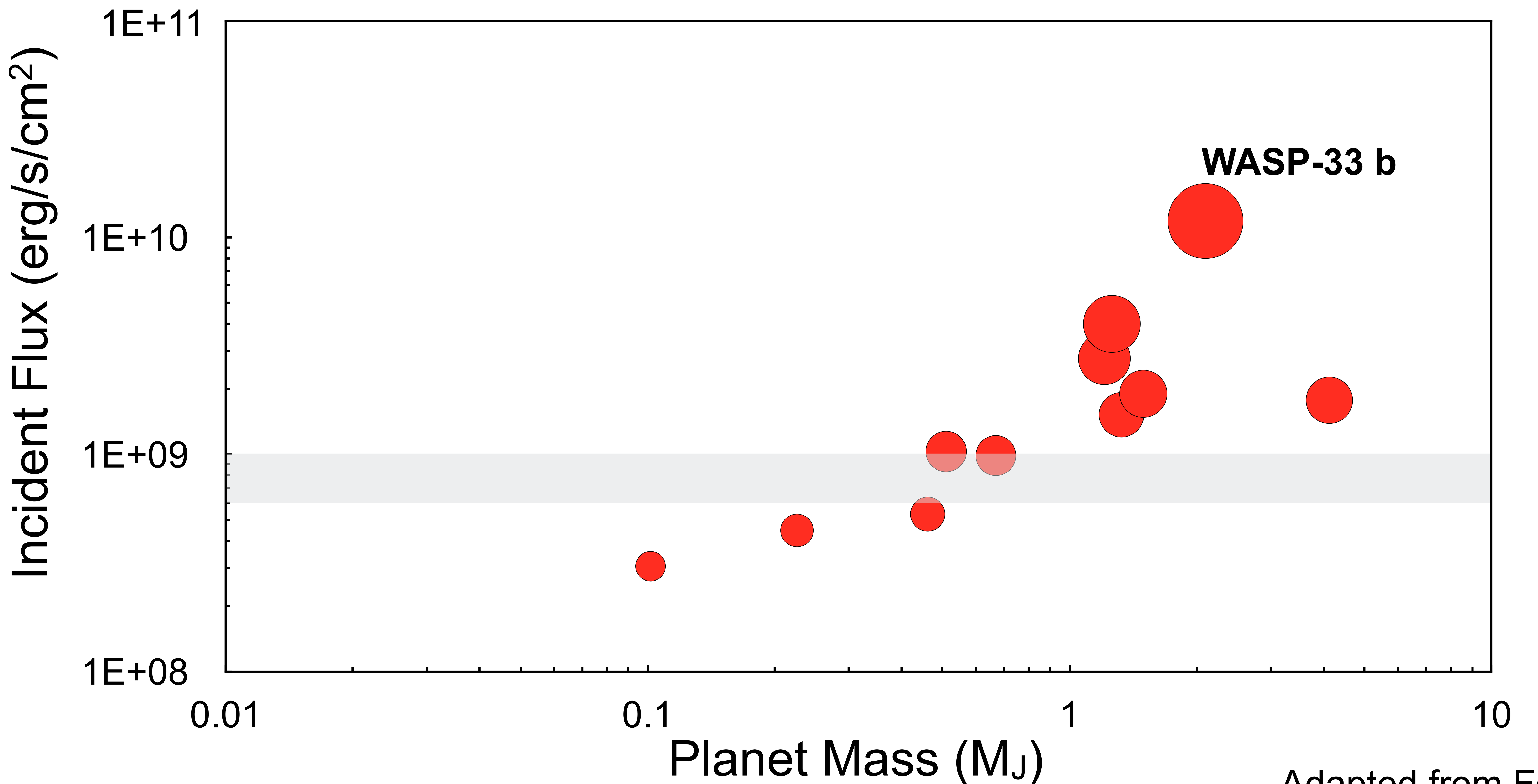
A **40 night** program on an **AO**-assisted **6.5 m** telescope at **R=30,000** with **1.5-2.5 micron** simultaneous wavelength coverage

Nine hot Jupiters (two transiting), **two** sub-Saturns, five observed **dayside *and* nightside,** four non-transiting *Spitzer* phase curves

MEASURE: the MMT Exoplanet Atmosphere SURvEy

A **40 night** program on an **AO**-assisted **6.5 m** telescope
at **R=30,000** with **1.5-2.5 micron** simultaneous wavelength coverage

Nine hot Jupiters (two transiting), **two** sub-Saturns, five observed **dayside *and* nightside,** four non-transiting *Spitzer* phase curves

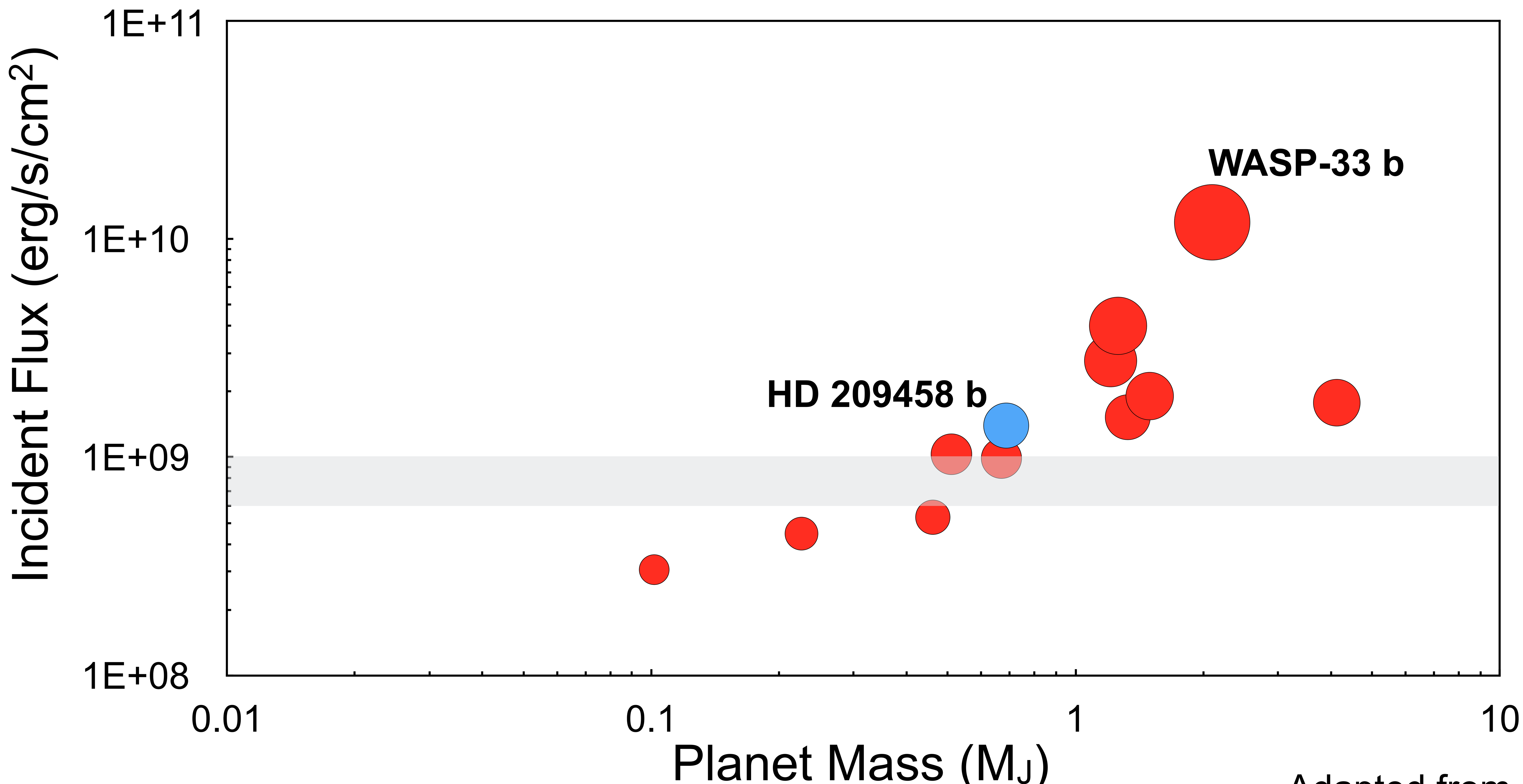


Adapted from Fortney et al. 2008

MEASURE: the MMT Exoplanet Atmosphere SURvEy

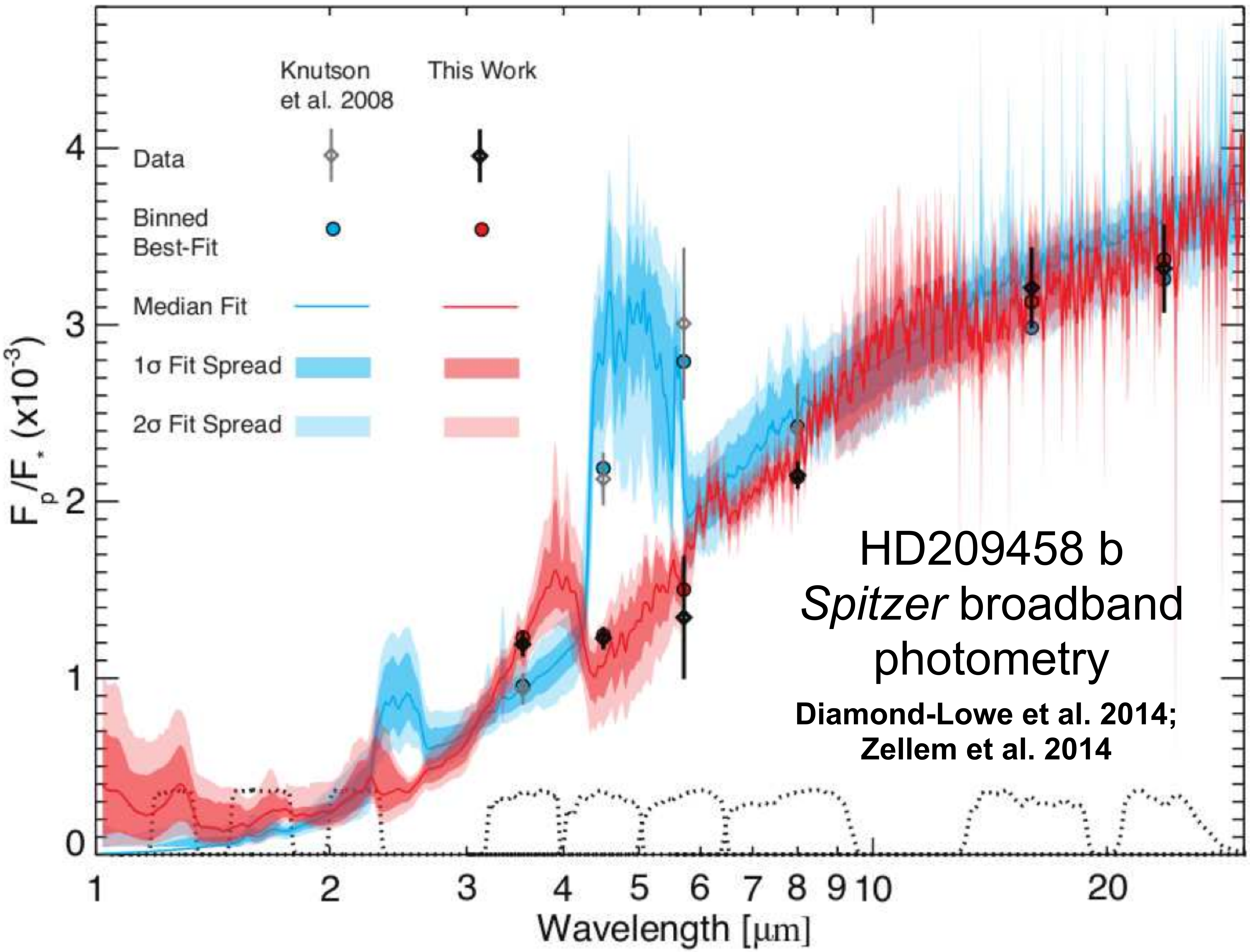
A **40 night** program on an **AO**-assisted **6.5 m** telescope at **R=30,000** with **1.5-2.5 micron** simultaneous wavelength coverage

Nine hot Jupiters (two transiting), **two** sub-Saturns, five observed **dayside *and* nightside,** four non-transiting *Spitzer* phase curves

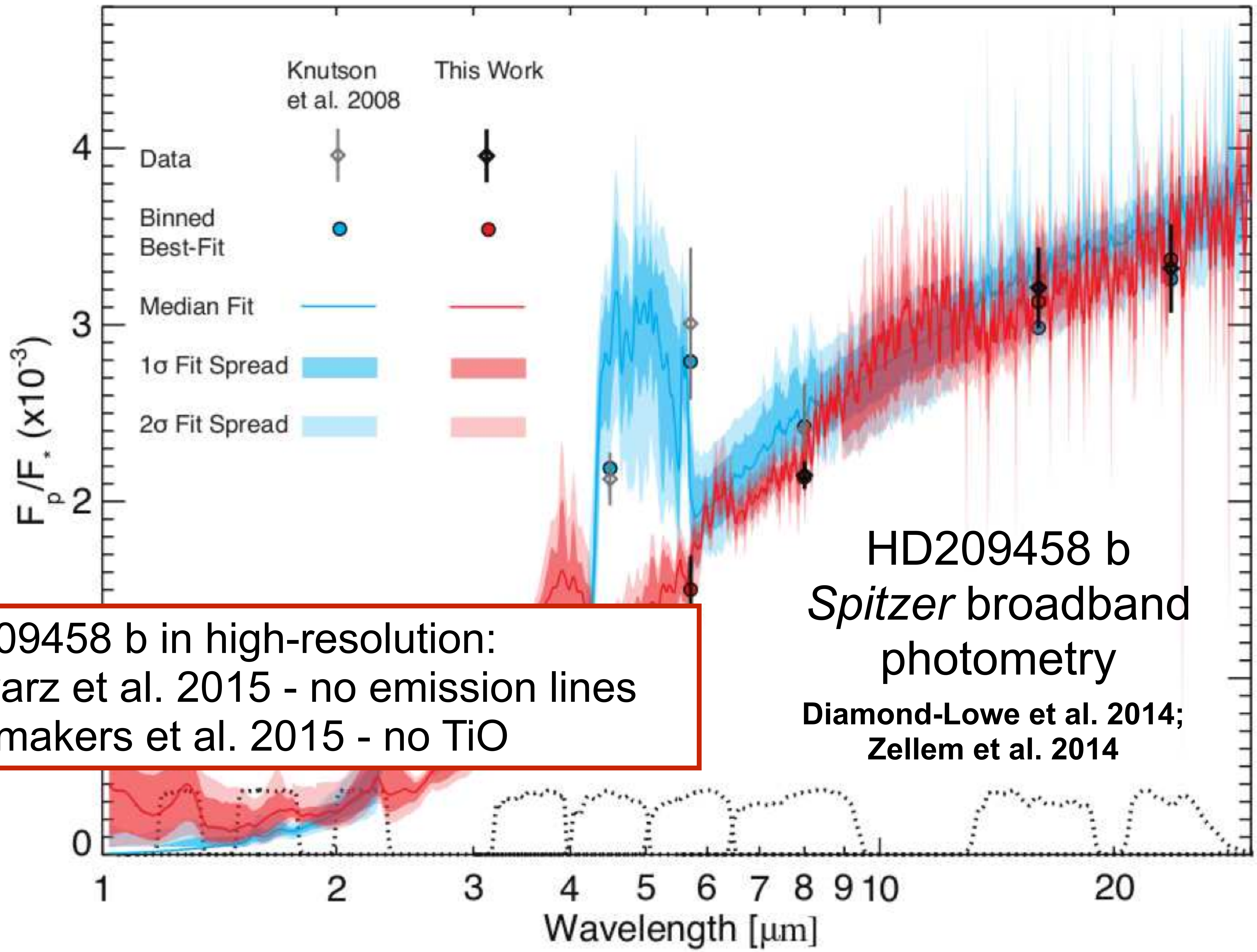


Adapted from Fortney et al. 2008

Until recently, thermal inversions in low resolution spectroscopy were unclear

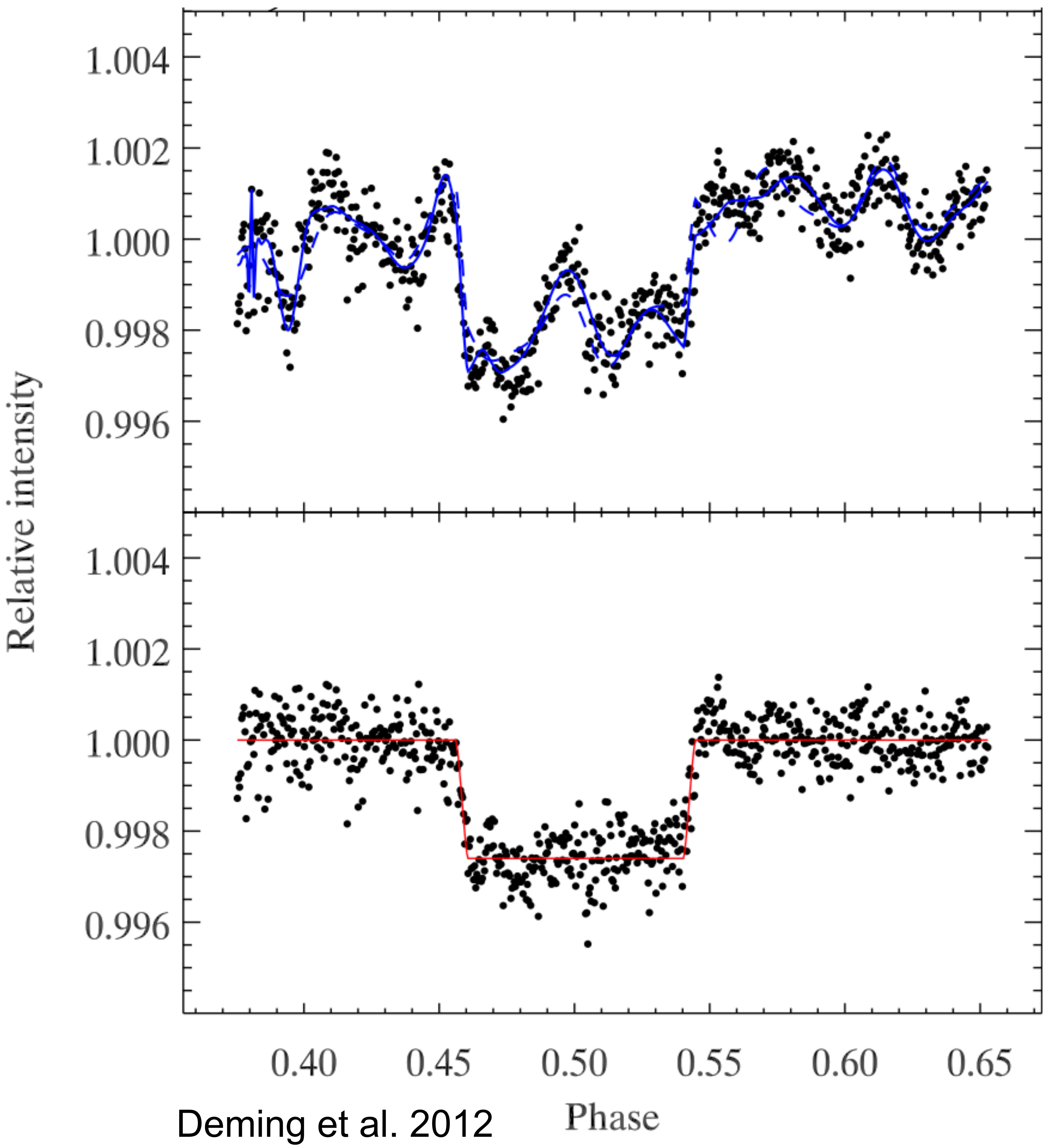


Until recently, thermal inversions in low resolution spectroscopy were unclear



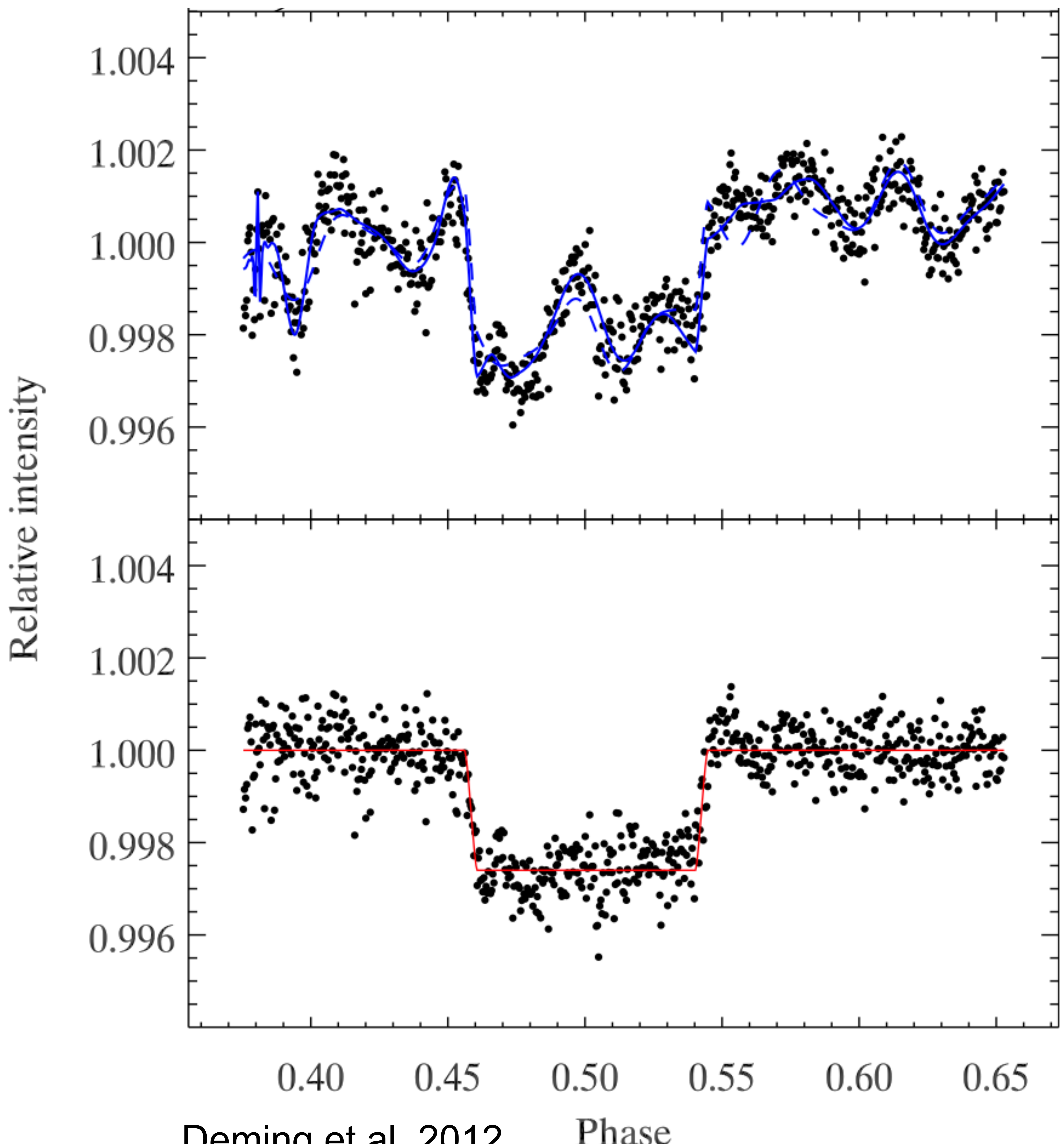
HD 209458 b in high-resolution:
Schwarz et al. 2015 - no emission lines
Hoeijmakers et al. 2015 - no TiO

WASP-33 b orbits a δ Scuti pulsating variable star adding ambiguity to its precise eclipse depth

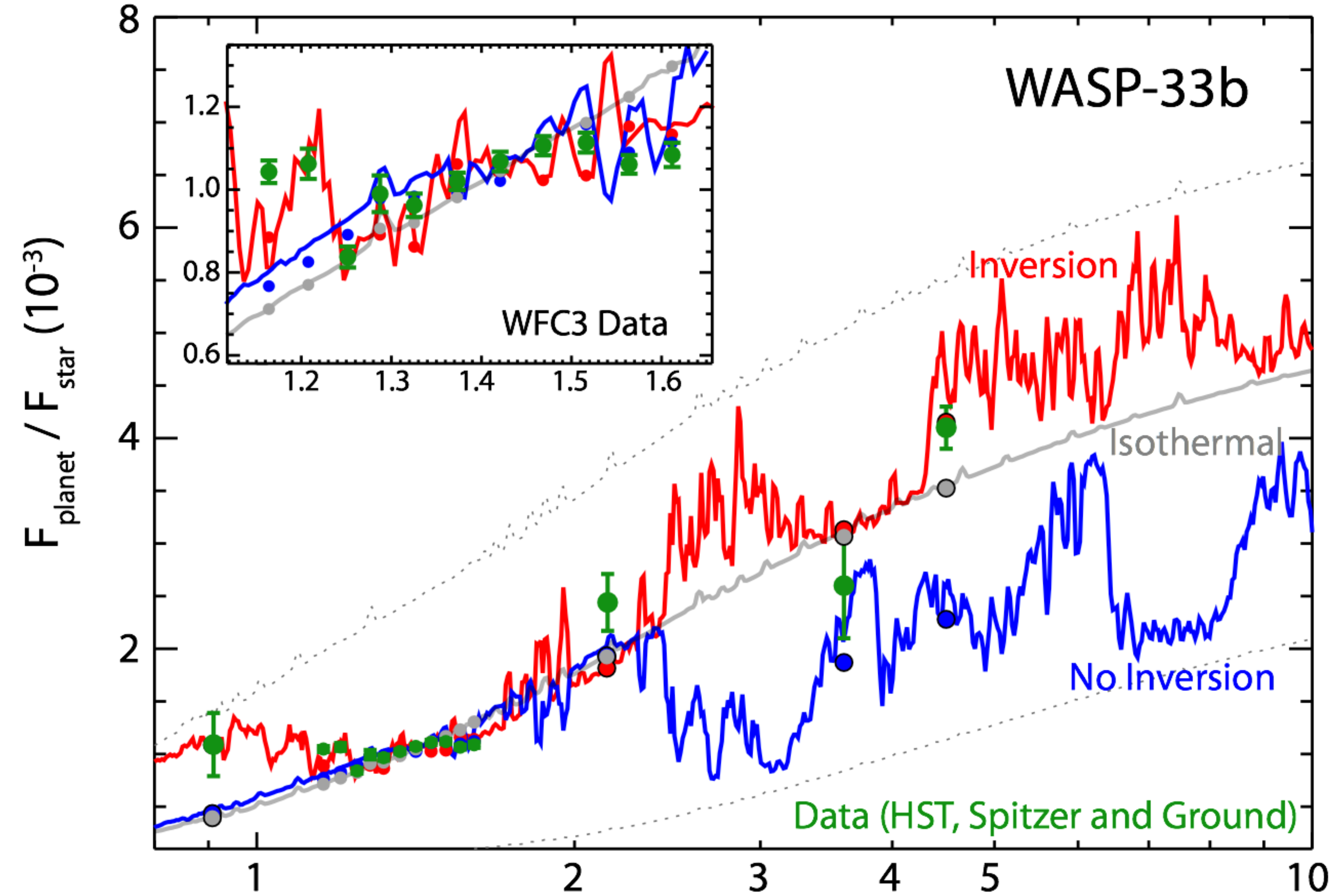


Deming et al. 2012

WASP-33 b orbits a δ Scuti pulsating variable star adding ambiguity to its precise eclipse depth

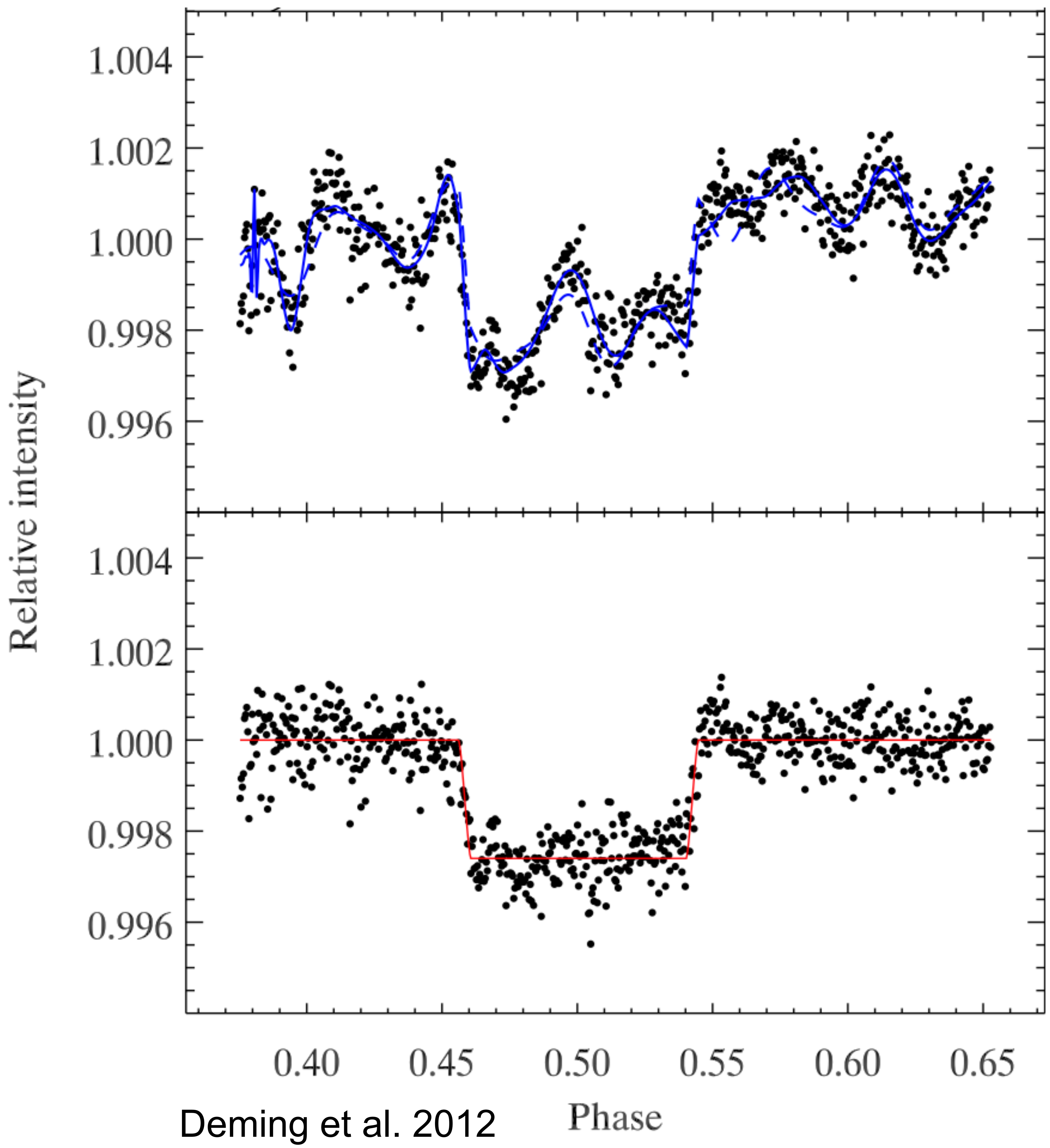


Deming et al. 2012

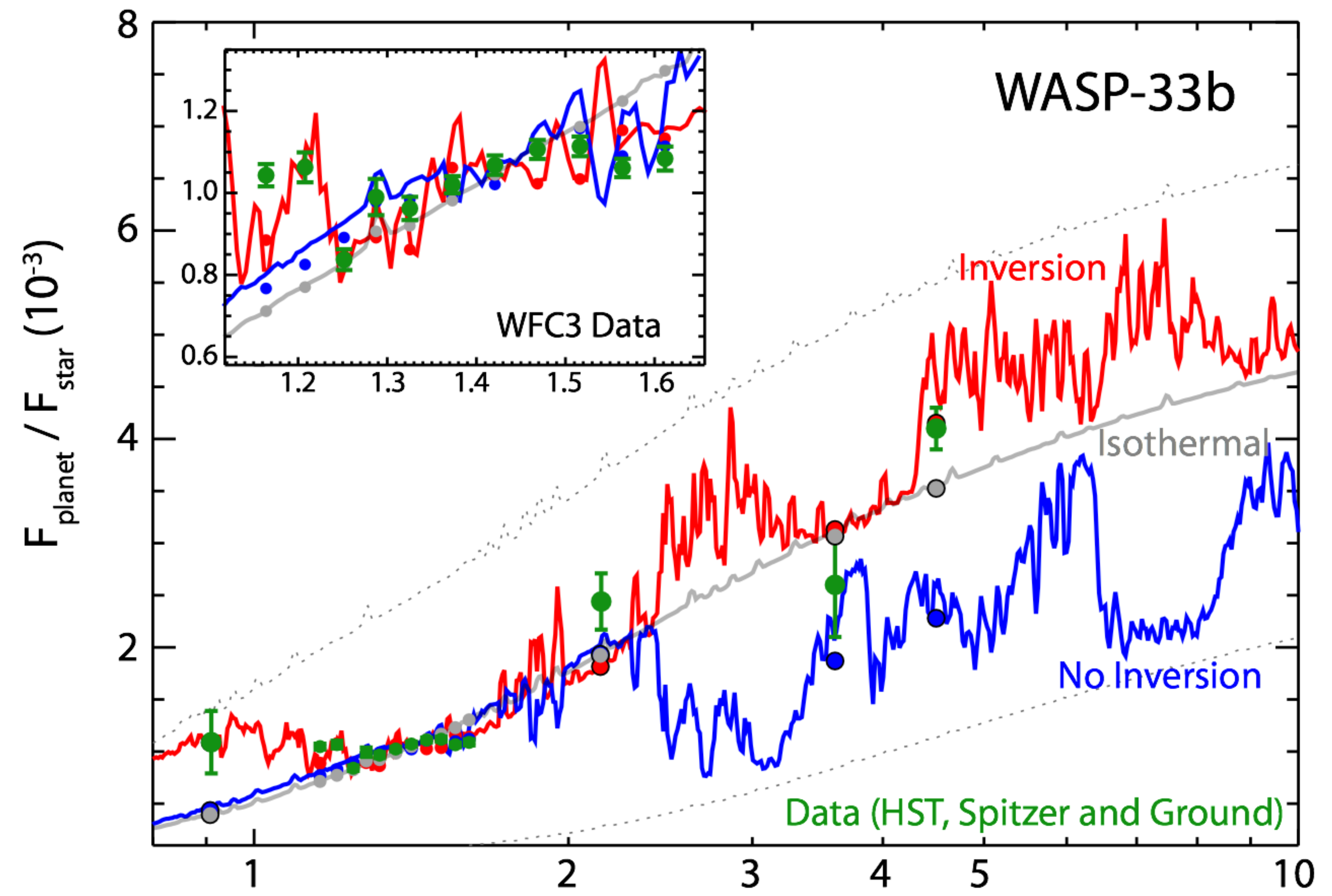


Haynes et al. 2015

WASP-33 b orbits a δ Scuti pulsating variable star adding ambiguity to its precise eclipse depth



Deming et al. 2012

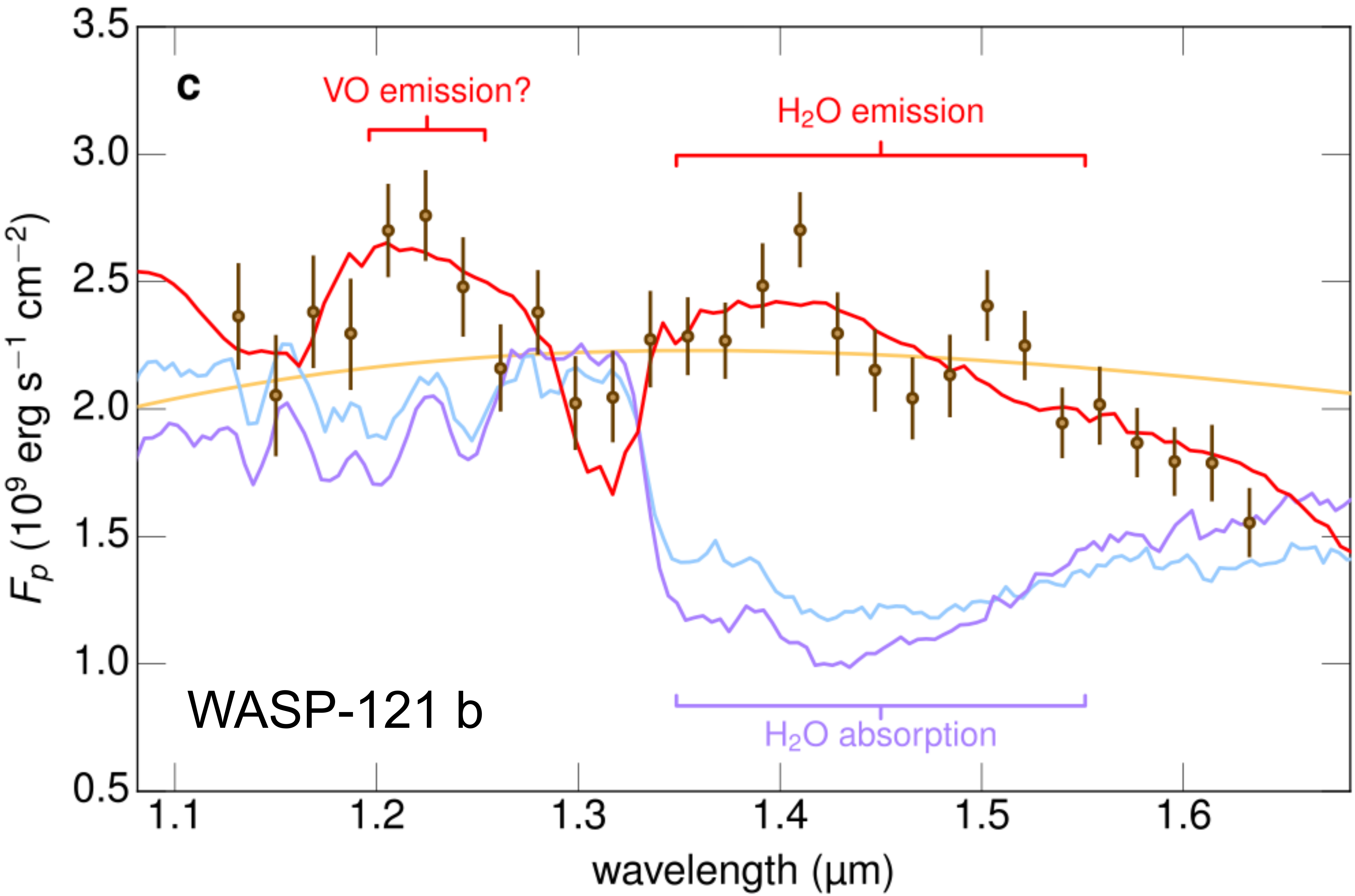


Haynes et al. 2015

C/O>1?

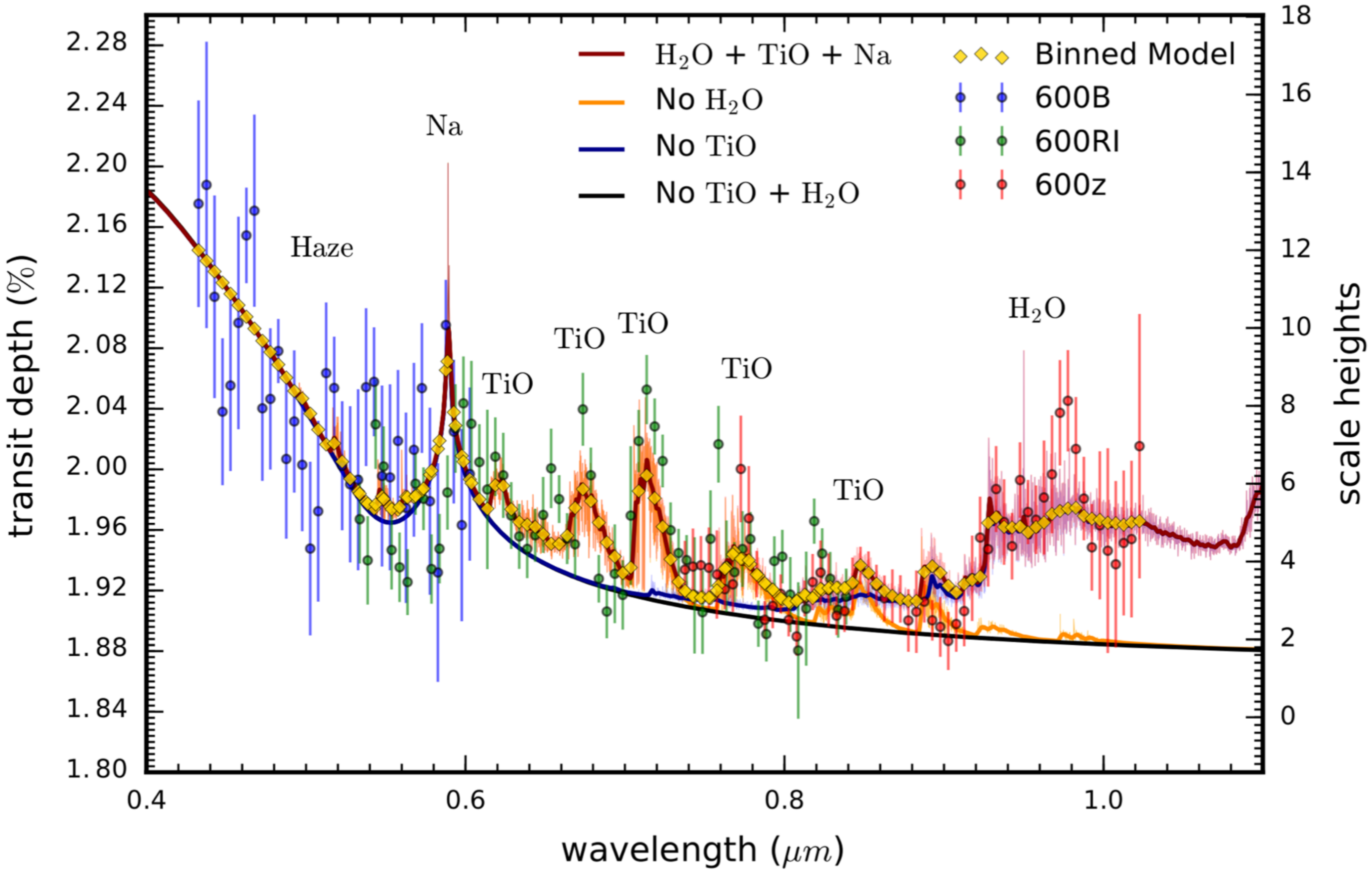
Madhusudhan 2012

Stratosphere finally seen at high significance in a hot Jupiter!



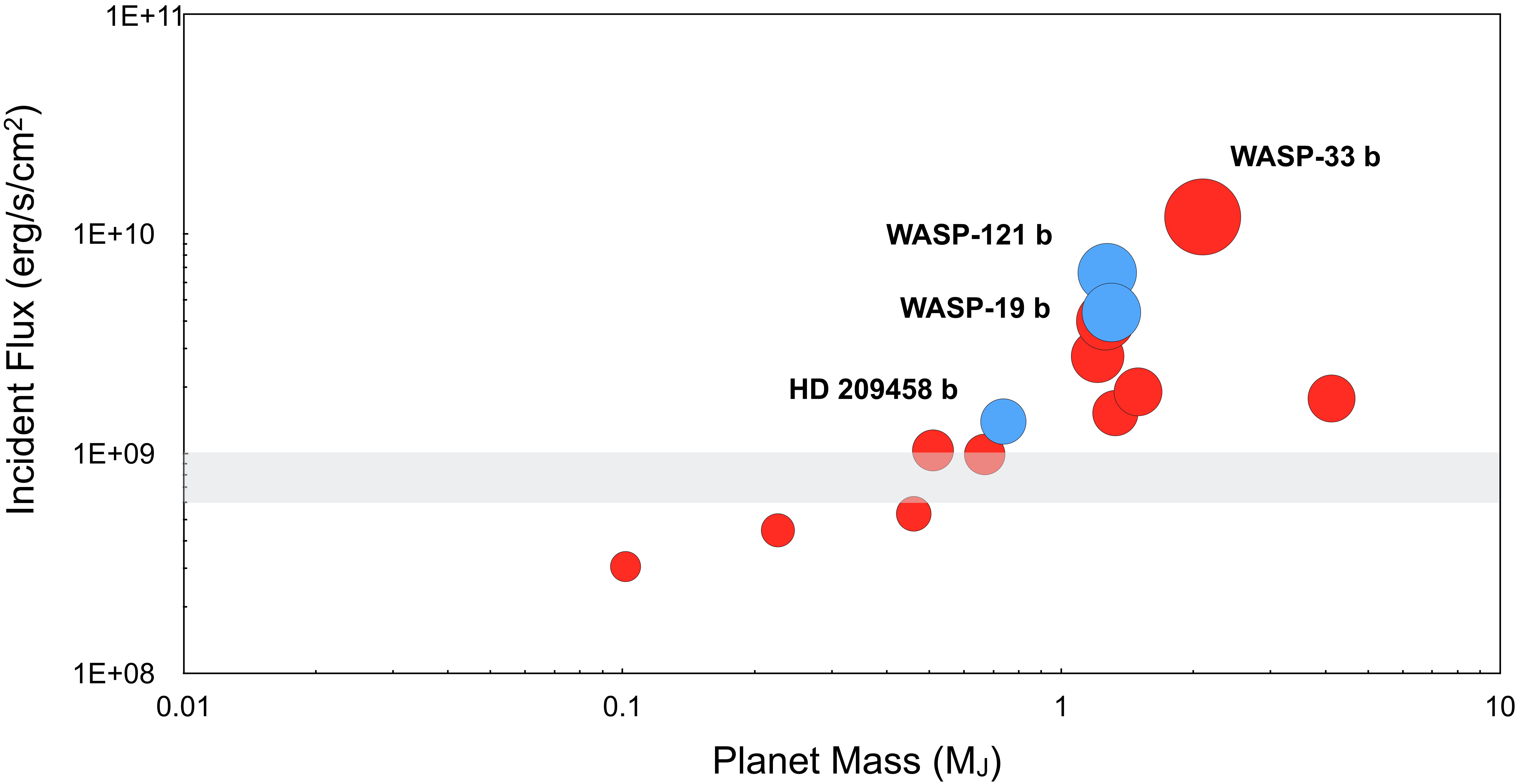
Evans et al. 2017

TiO detected in hot Jupiter WASP-19 b

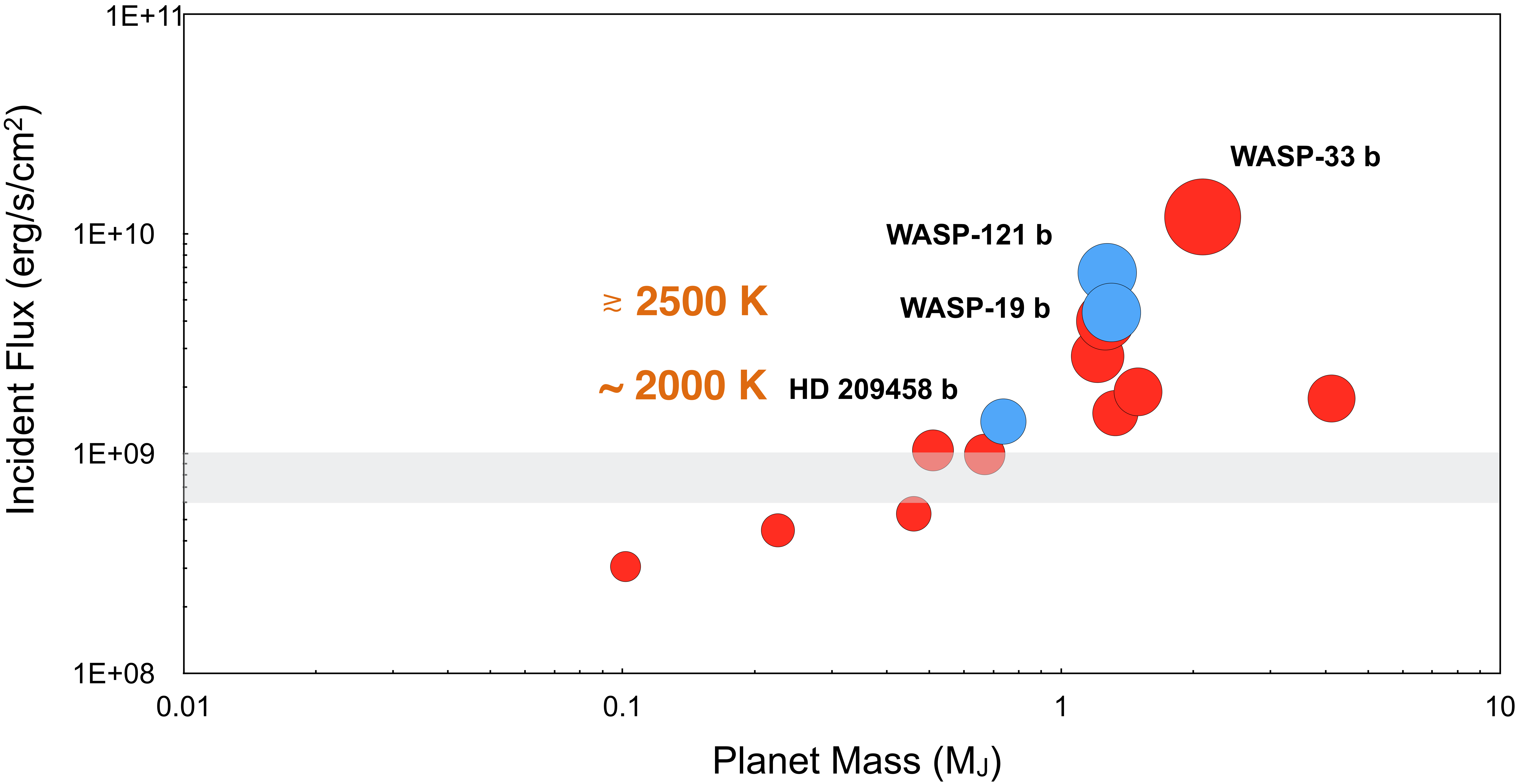


Sedaghati et al. 2017

Transition region for inversion layers in hot Jupiters likely hotter than initial predictions



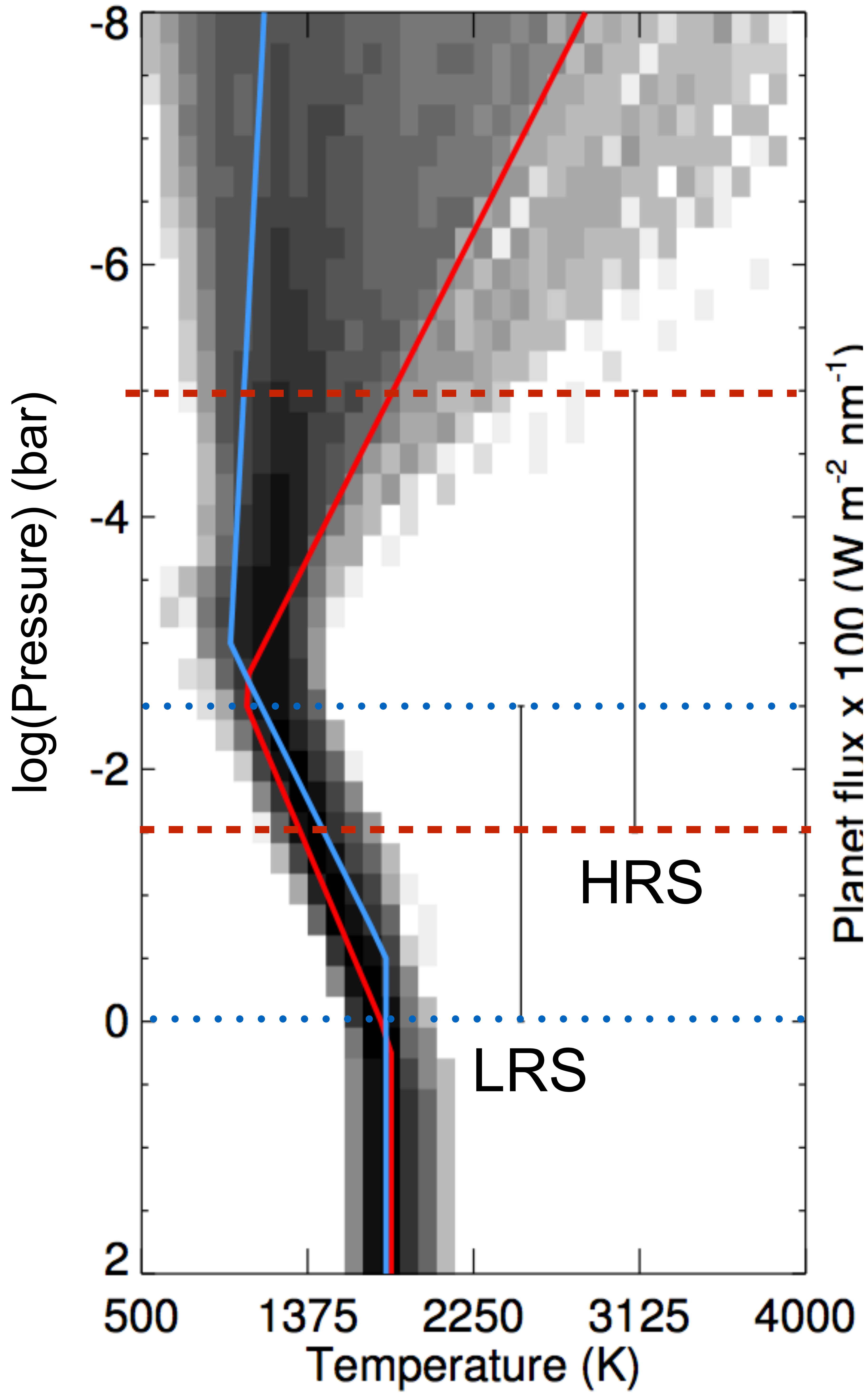
Transition region for inversion layers in hot Jupiters likely hotter than initial predictions



Preliminary results from MEASURE

Combining high and low resolution spectroscopy breaks degeneracies in composition and structure of atmosphere

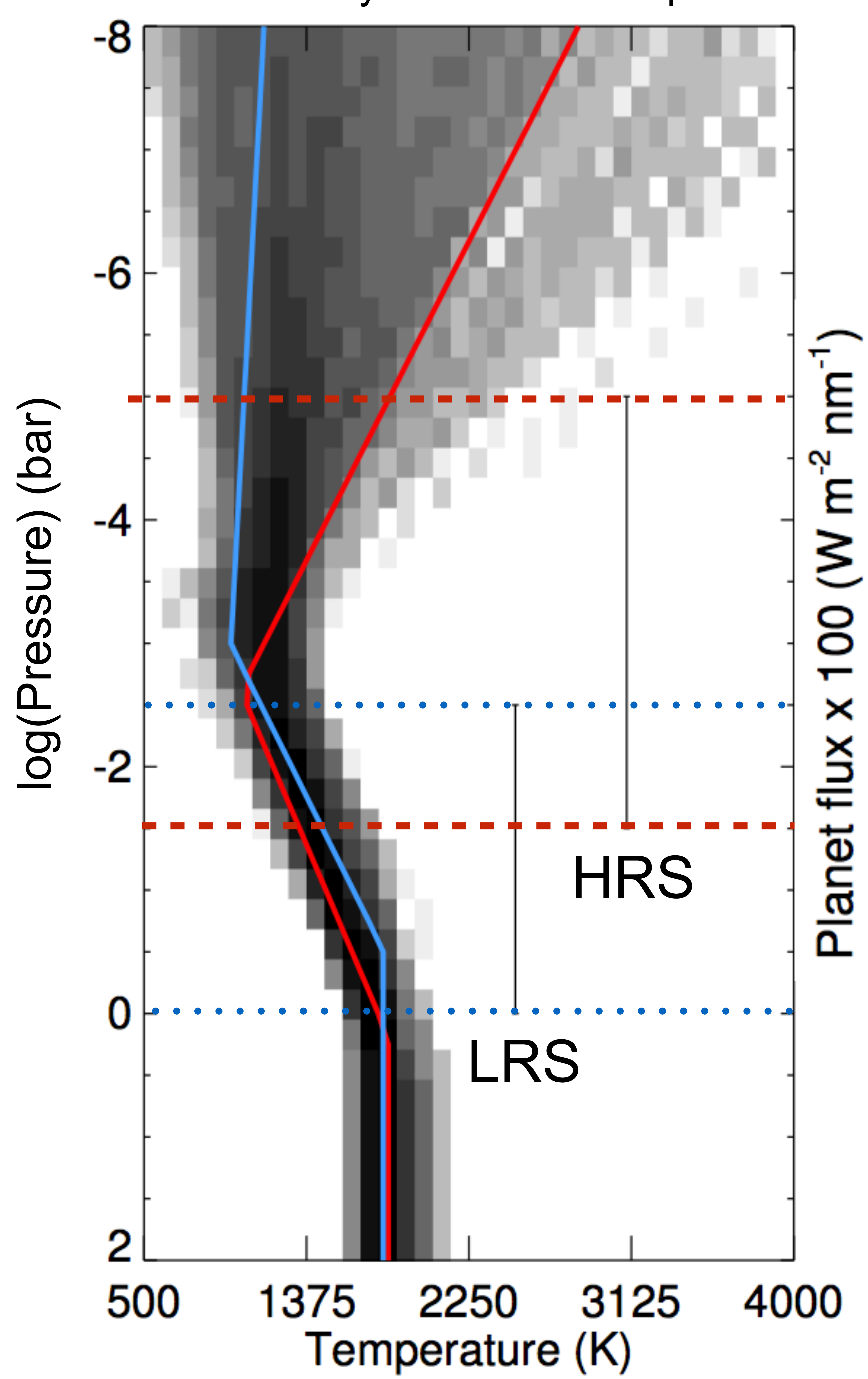
Models allowed by low-resolution spectra alone



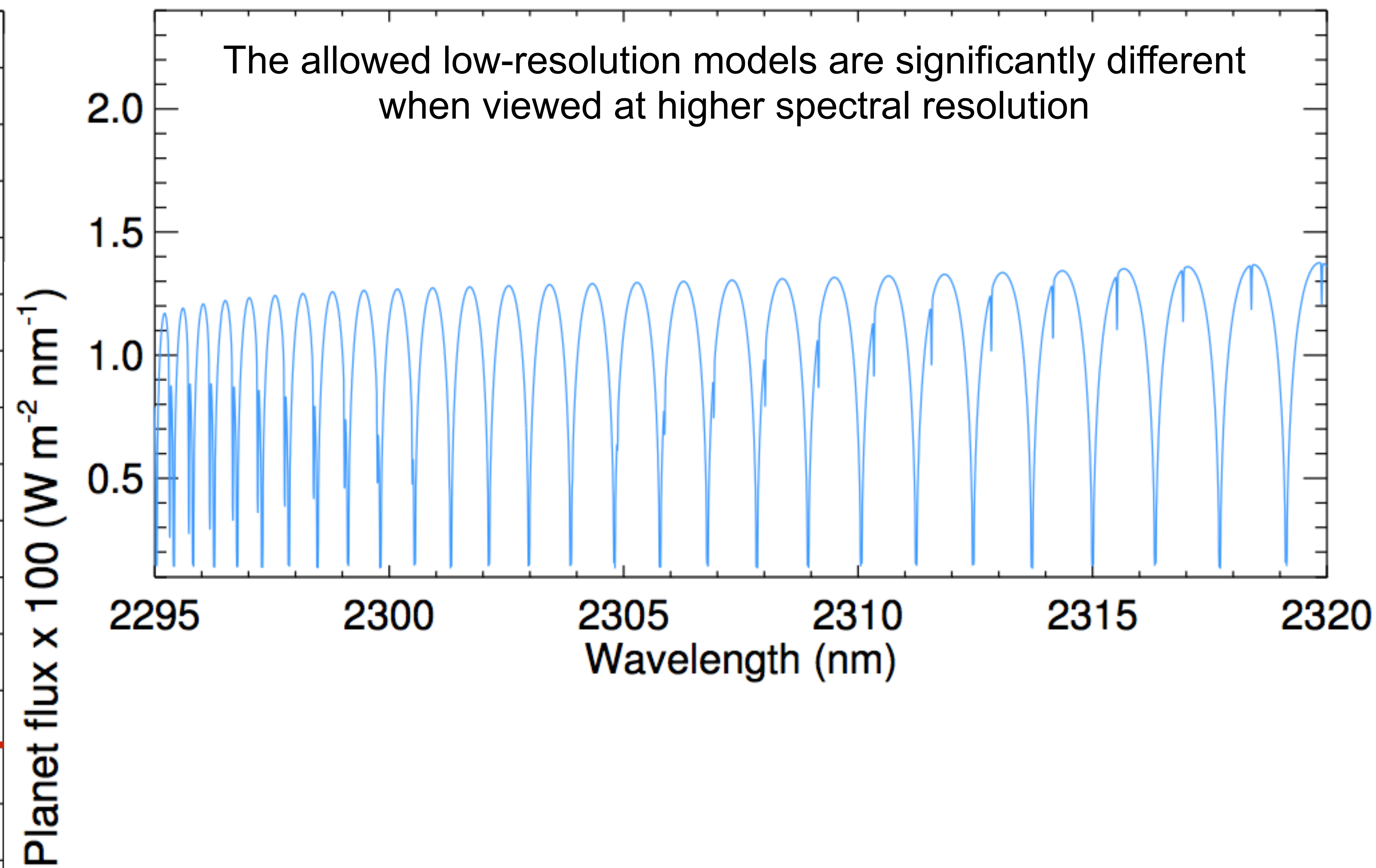
Adapted from Brogi, Line et al. 2017

Combining high and low resolution spectroscopy breaks degeneracies in composition and structure of atmosphere

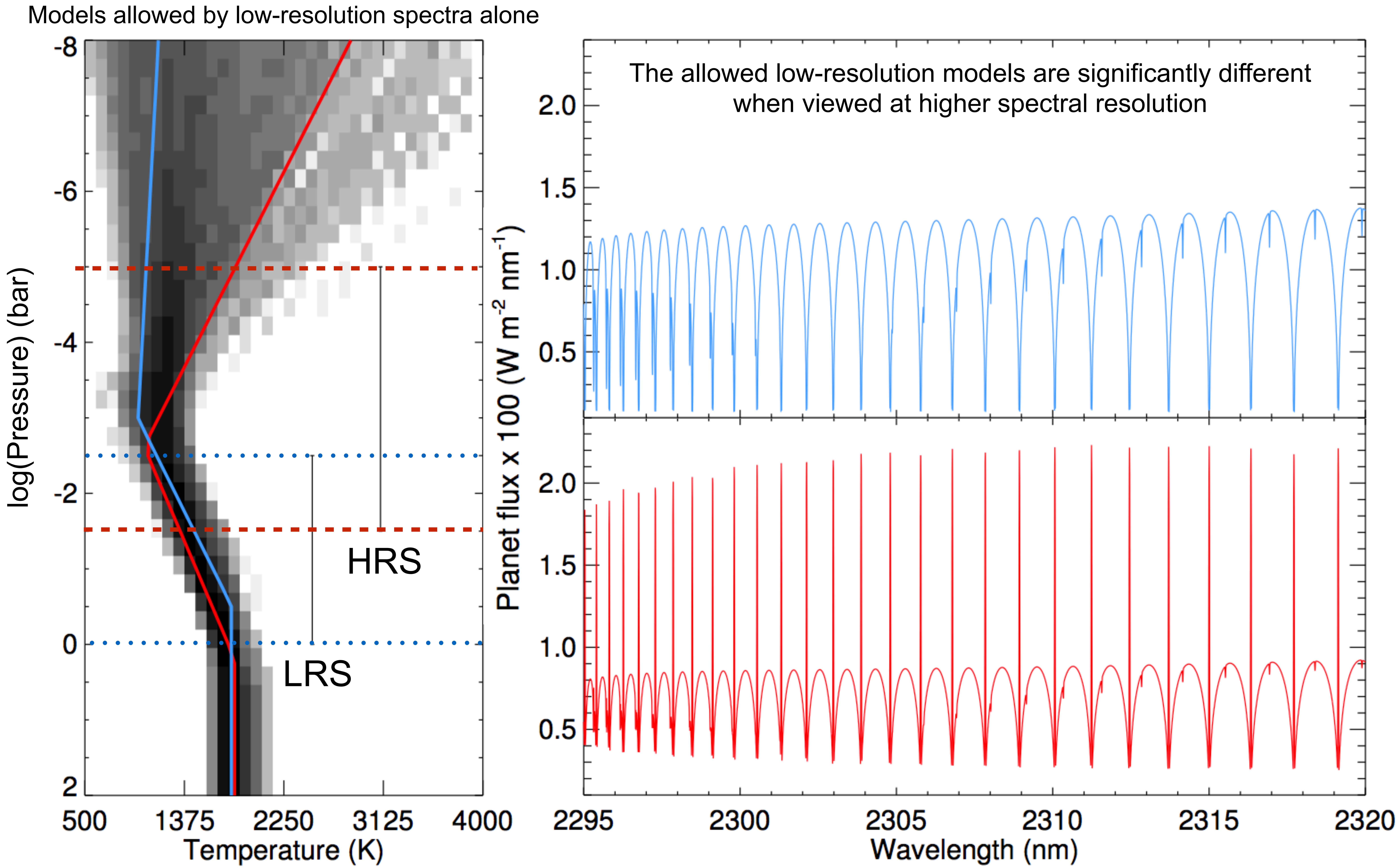
Models allowed by low-resolution spectra alone



Adapted from Brogi, Line et al. 2017

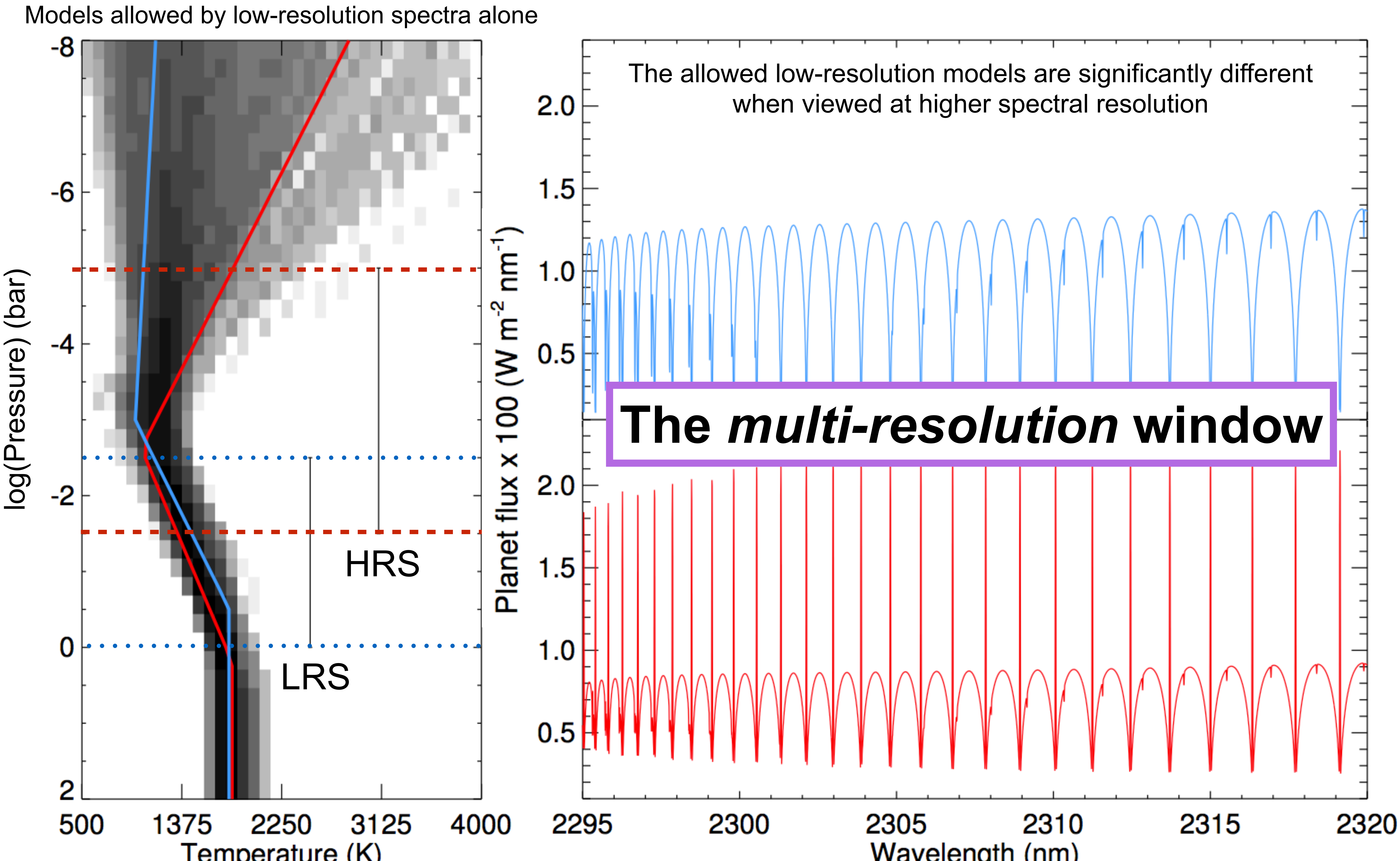


Combining high and low resolution spectroscopy breaks degeneracies in composition and structure of atmosphere



Adapted from Brogi, Line et al. 2017

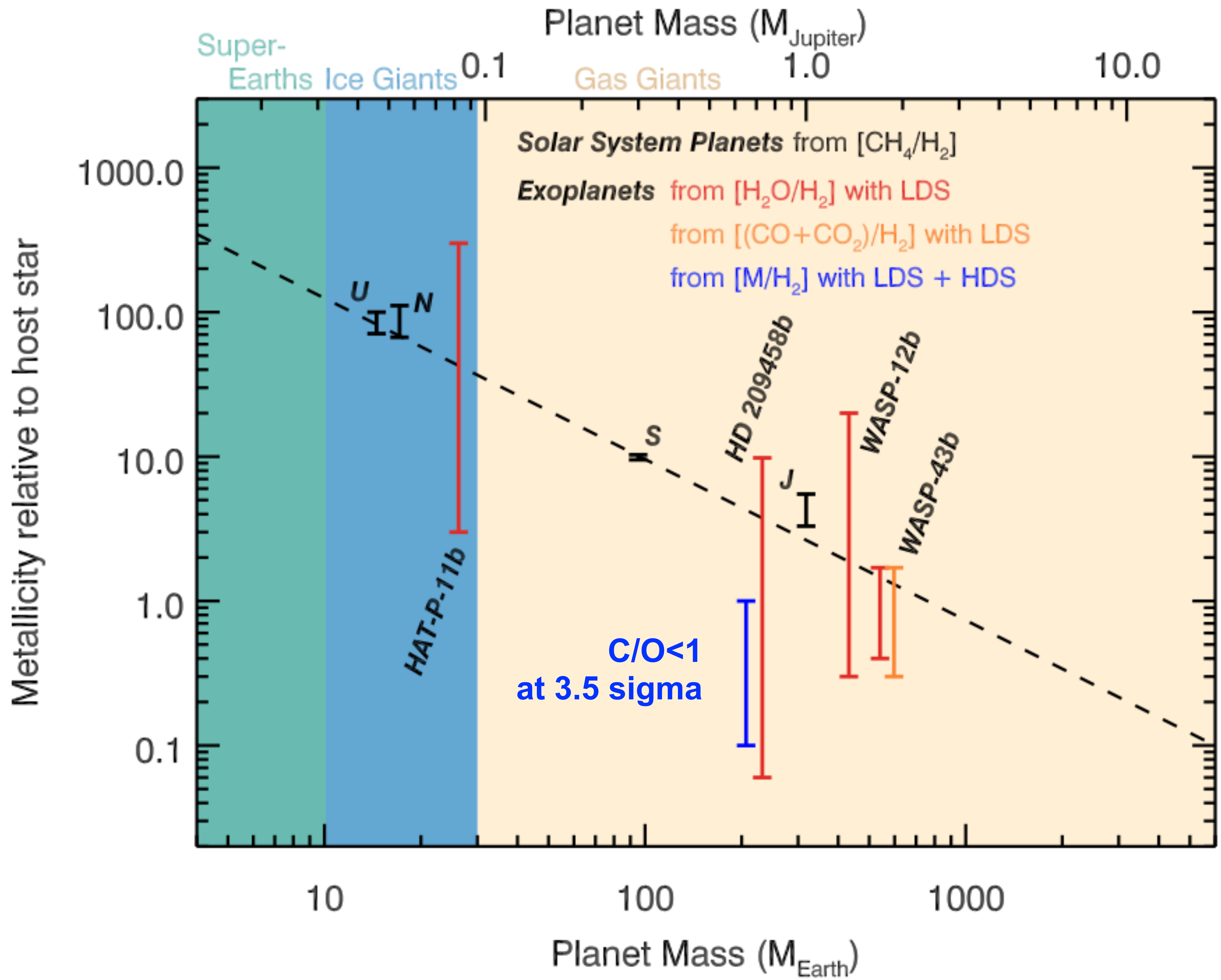
Combining high and low resolution spectroscopy breaks degeneracies in composition and structure of atmosphere



Adapted from Brogi, Line et al. 2017

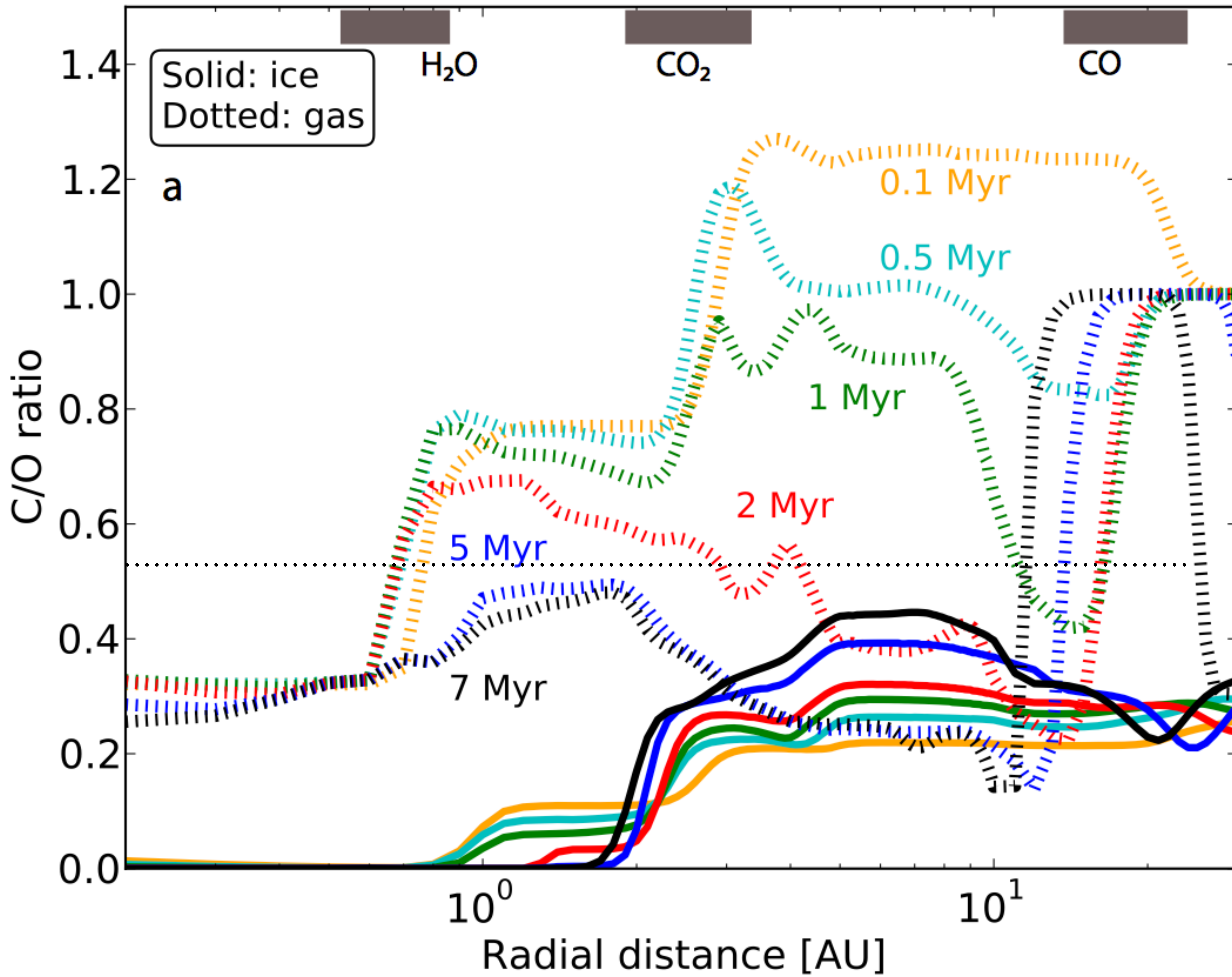
Requires comprehensive modelling of the parameter space in the most efficient way

Multi-resolution spectroscopy places tight constraints on metallicity and C/O ratios



Brogi et al. 2017

Include planet formation scenarios in our atmospheric models



Eistrup et al. 2017

Take home messages

1. We are stepping into the **era of detailed exoplanet characterization** and comparative exoplanetology.

2. Combining **multi-resolution datasets** is an important next step forward for exoplanet atmosphere characterization.

3. **High resolution spectroscopy** may be our **only avenue forward** in the coming decades to characterize the very **nearest non-transiting temperate worlds**.

4. **AO**-assisted **high-resolution spectrographs** are an **essential resource** for future exoplanet studies.

jbirkby@uva.nl http://staff.fnwi.uva.nl/j.l.birkby @jaynebirkby