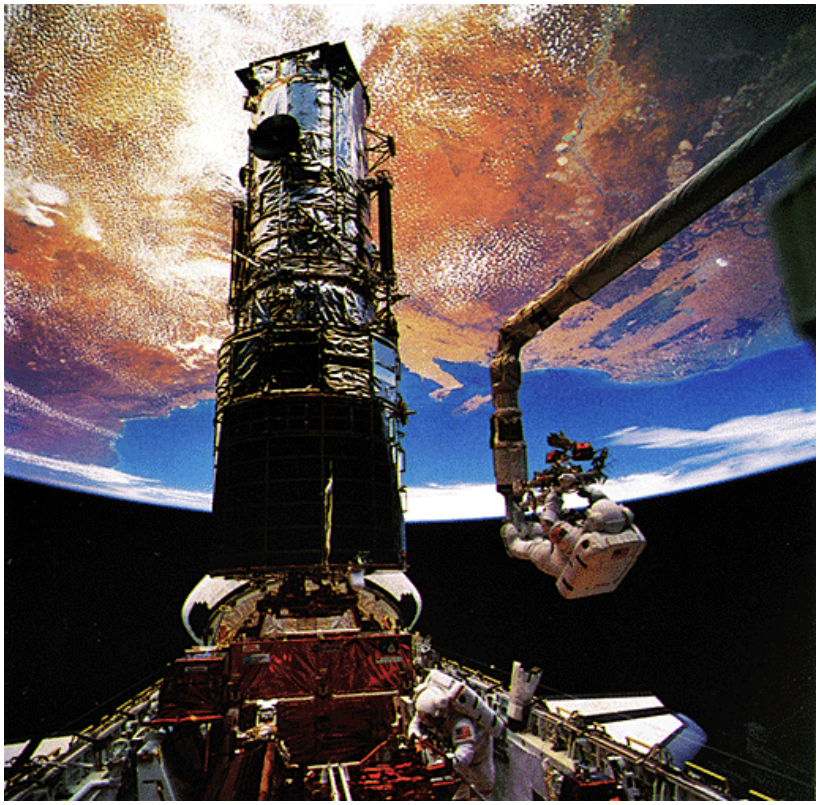

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HST Observations of Sodium in HD 189733b

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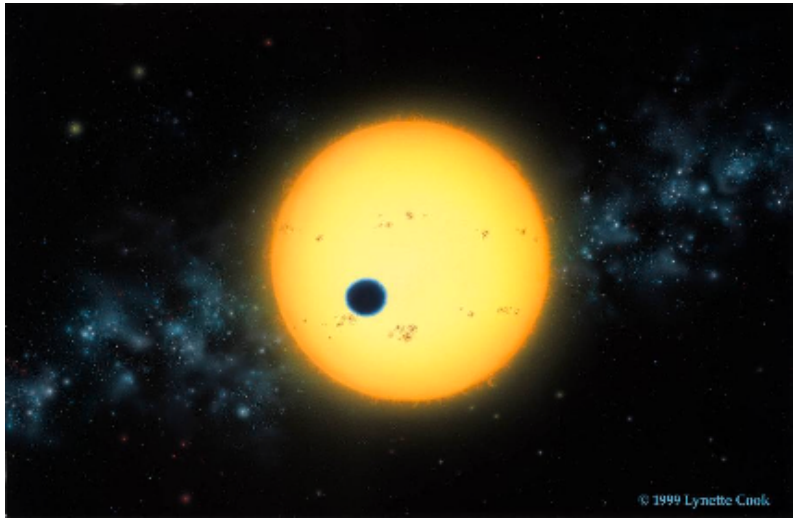
Collaborators: D.K. Sing, A. Vidal-Madjar, F. Pont, G.E. Ballester, A. Lecavelier des Etangs, J-.M. Désert

Comparing Two Hot Jupiters

HD 209458b:

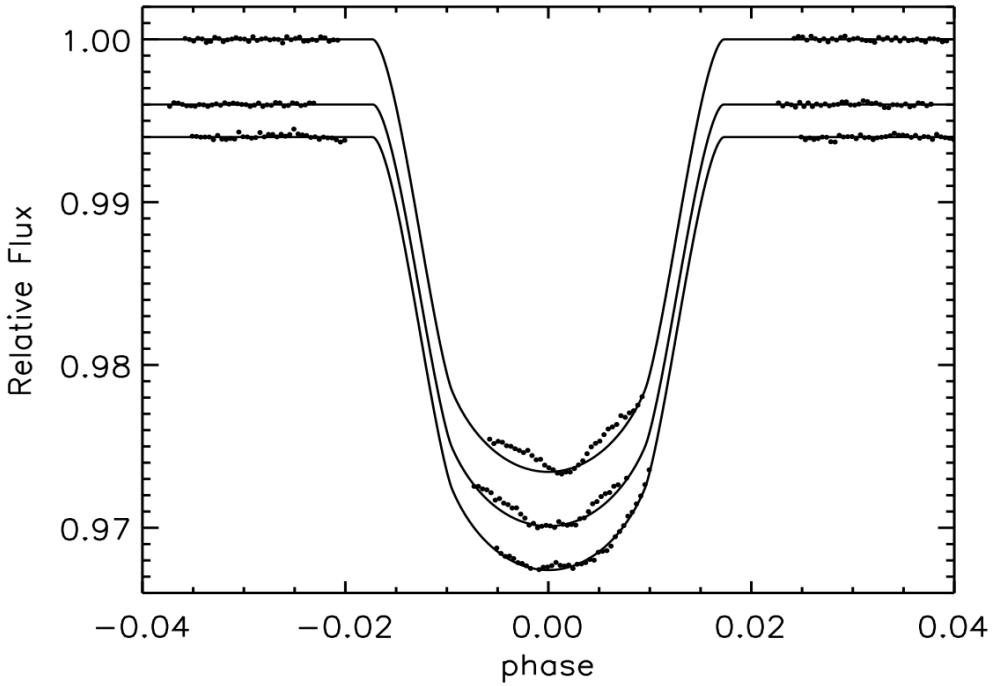


- G0V star
- Inflated radius
- Stratospheric inversion
- Na line wings reveal haze-free atmosphere

HD 189733b:

- Active K2Vstar
- Non-inflated radius
- No stratospheric inversion
- Flat spectrum, dominated by haze

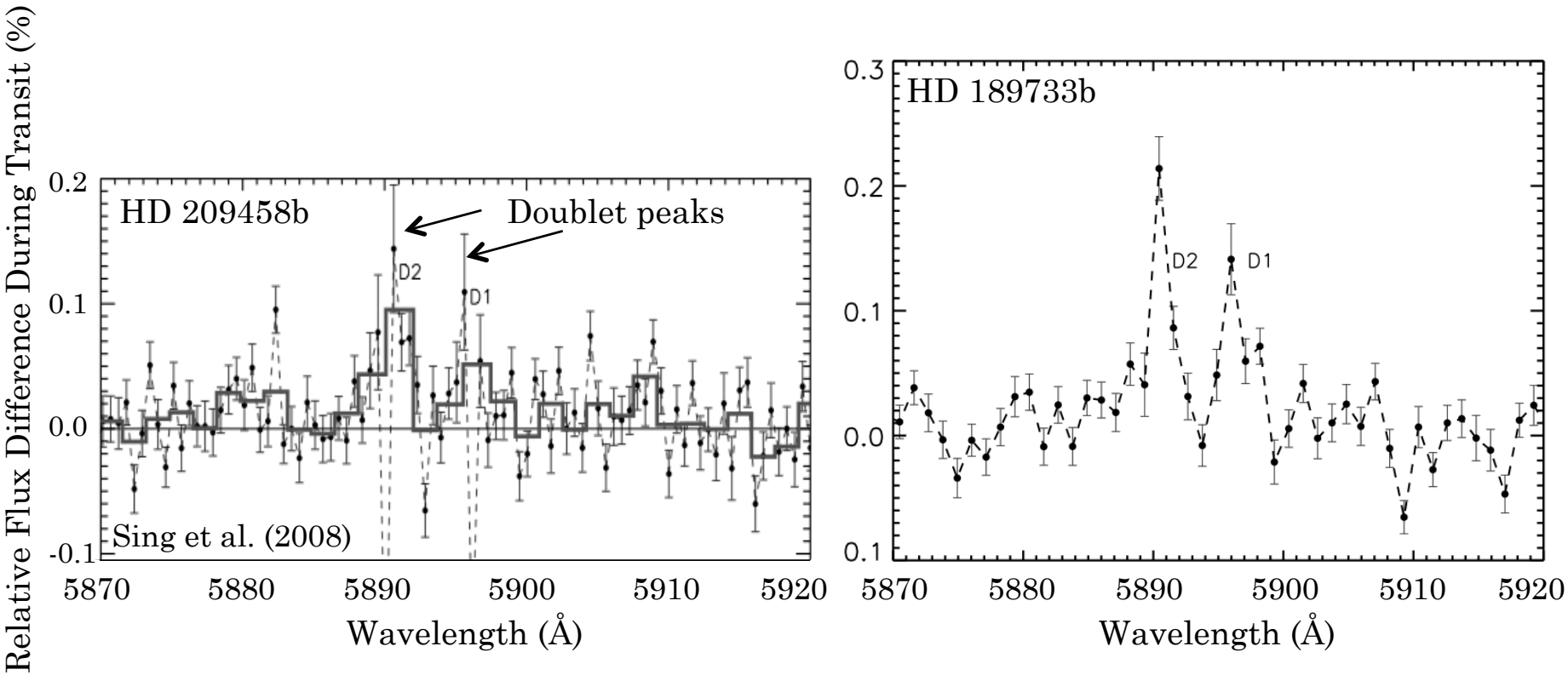
HST STIS Transits of HD 189733b



- STIS G750 M (5808-6300 Å)
- Detrended white light curves. S/N = 10,000
- 1.1 Å resolution
- Can see evidence of occulted starspots
- Rp/Rstar = 0.15628

Analytic transit models from Mandel & Agol (2002)

THE SPECTRUM

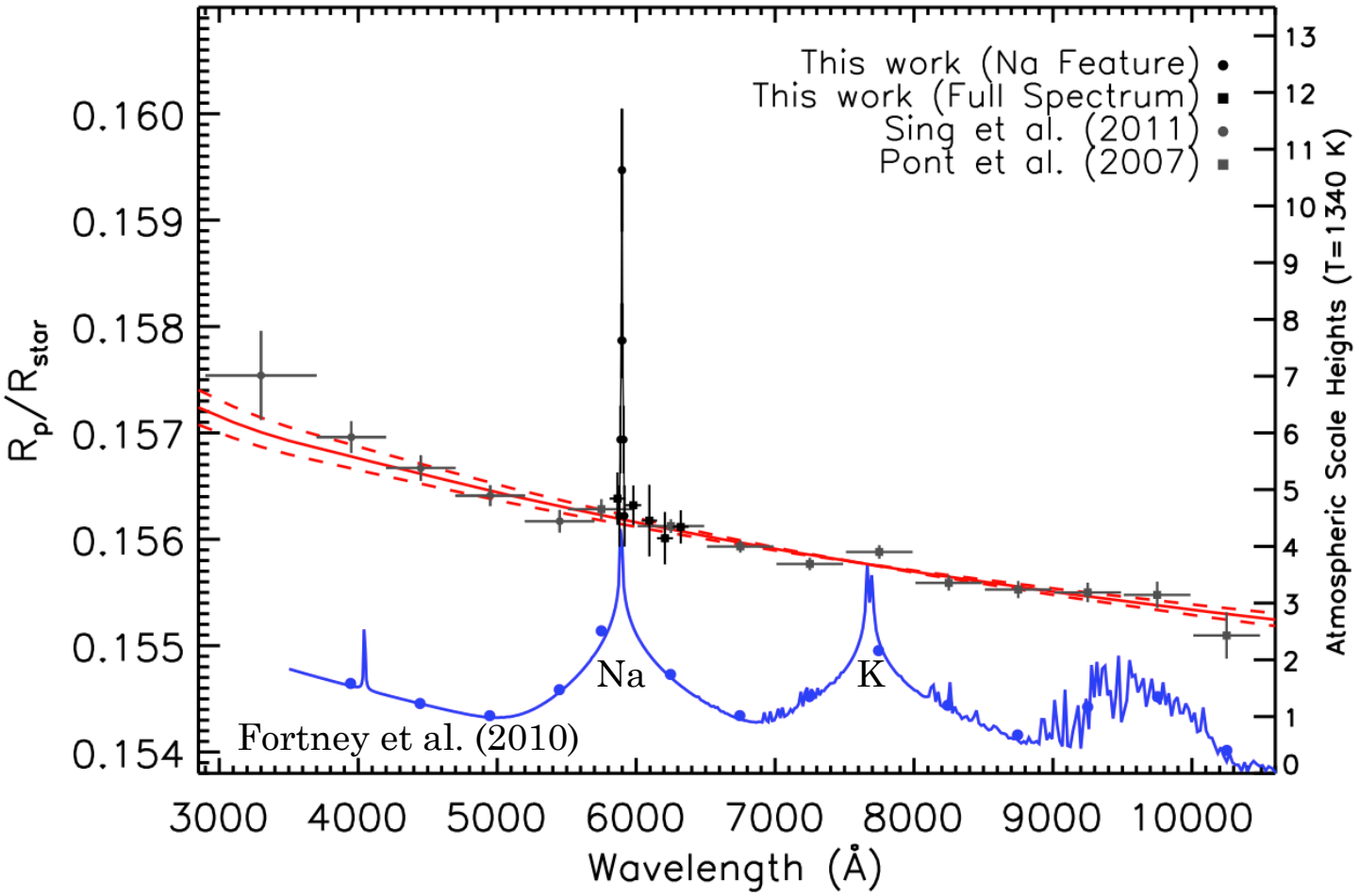


Huitson et al. submitted

Relative integrated absorption depth in a 12 Å band:
$(51.1 \pm 5.9) \times 10^{-5}$ (this work: 8.5 sigma)
$(52.6 \pm 16.9) \times 10^{-5}$ (Jensen et al. 2011)

9 sigma detection in the line cores:
$(90 \pm 10) \times 10^{-5}$

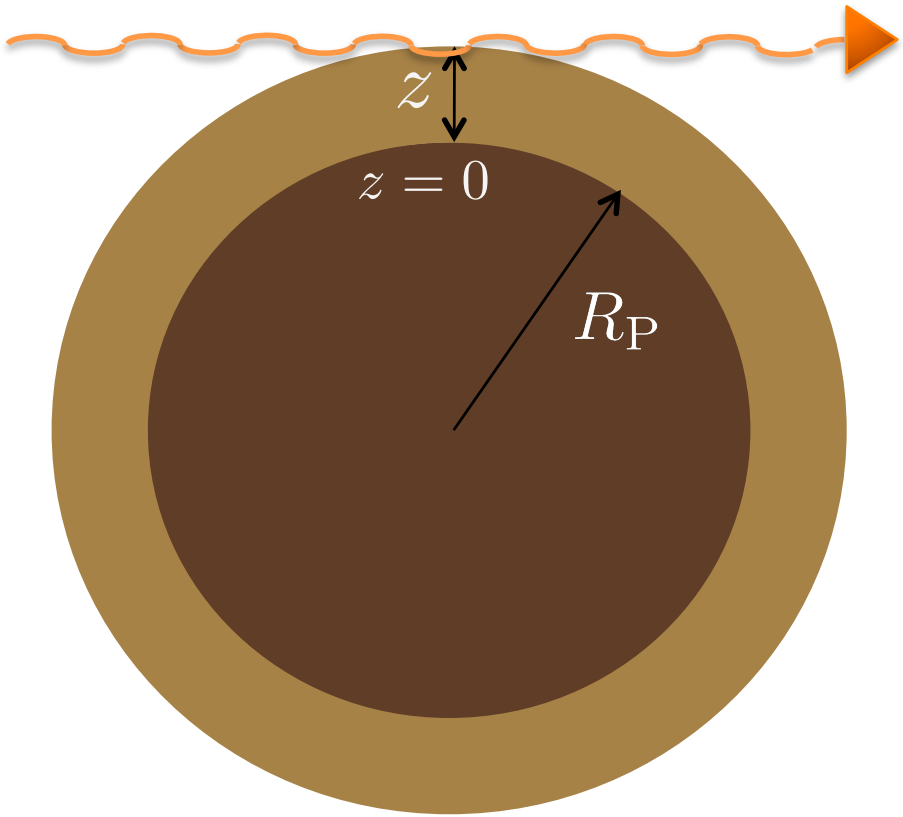
Full Optical Spectrum of HD 189733b



See poster by Husnoo et al.

T=1340 ± 150 K Rayleigh slope from Lecavelier et al. (2008)

The Model



- Grazing geometry:

$$\tau = \sigma(\lambda) n(z) \sqrt{2\pi R_P H}$$

$$\tau = \tau_{\rm eq} = 0.56$$

- Assume ideal gas

$$P_o = \frac{n_{z=0}}{\xi_{\rm Na}} kT$$

- Assume Hydrostatic Equilibrium (Barometric formula)

$$\frac{n(z)}{n_{z=0}} = e^{-z/H}$$

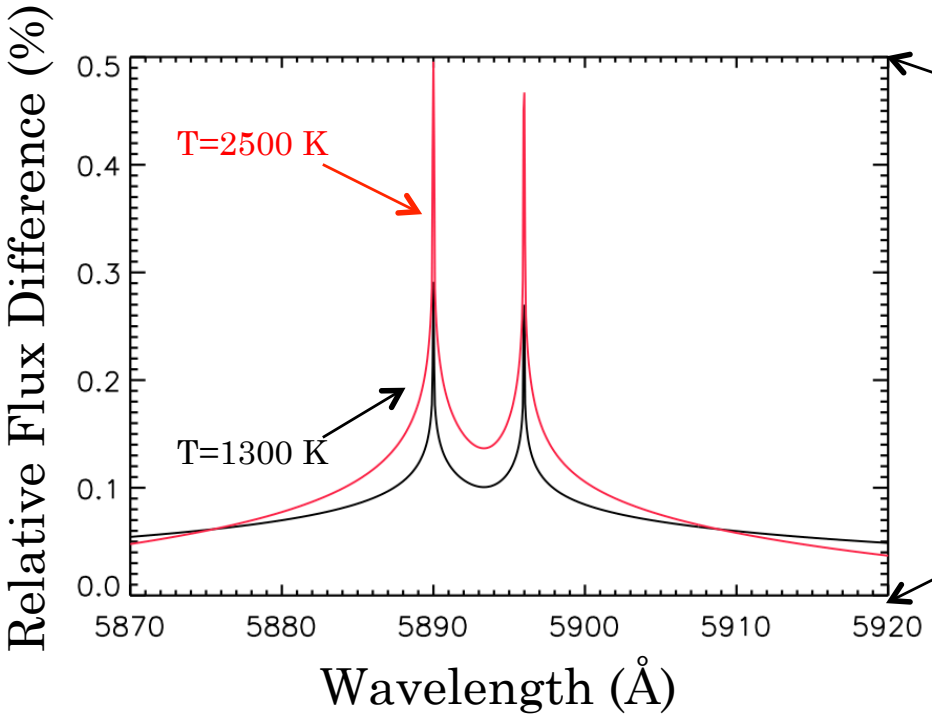
$$z = H \ln \left(\frac{\sigma(\lambda) P_o \xi_{\rm Na}}{\tau} \sqrt{\frac{2\pi R_P}{kT\mu g}} \right)$$

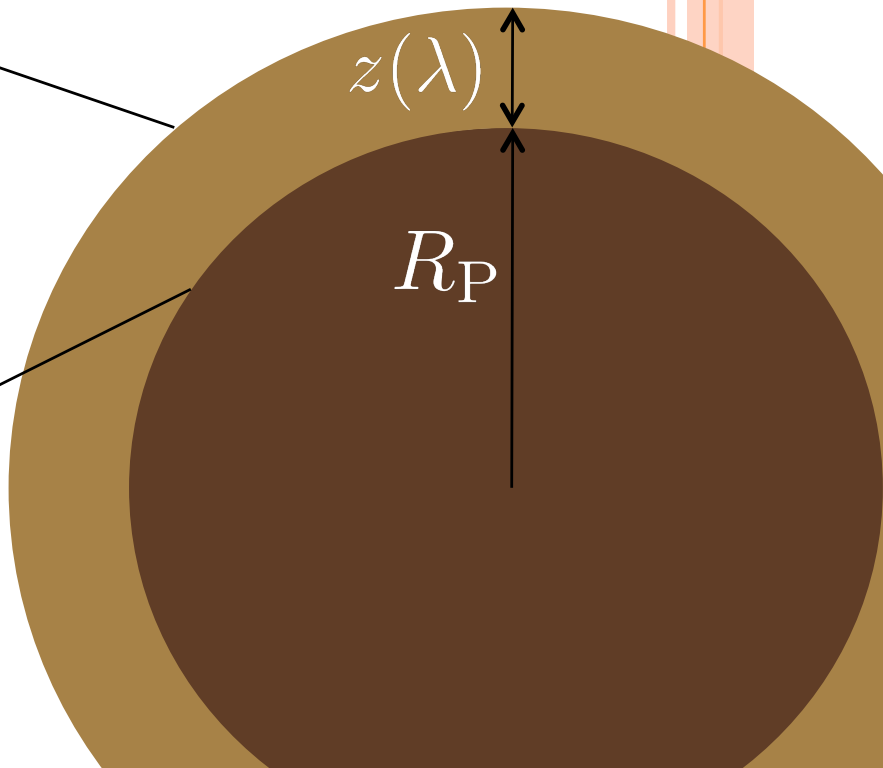
Burrows et al. (2004), Fortney et al. (2005)

Lecavelier et al. (2008)

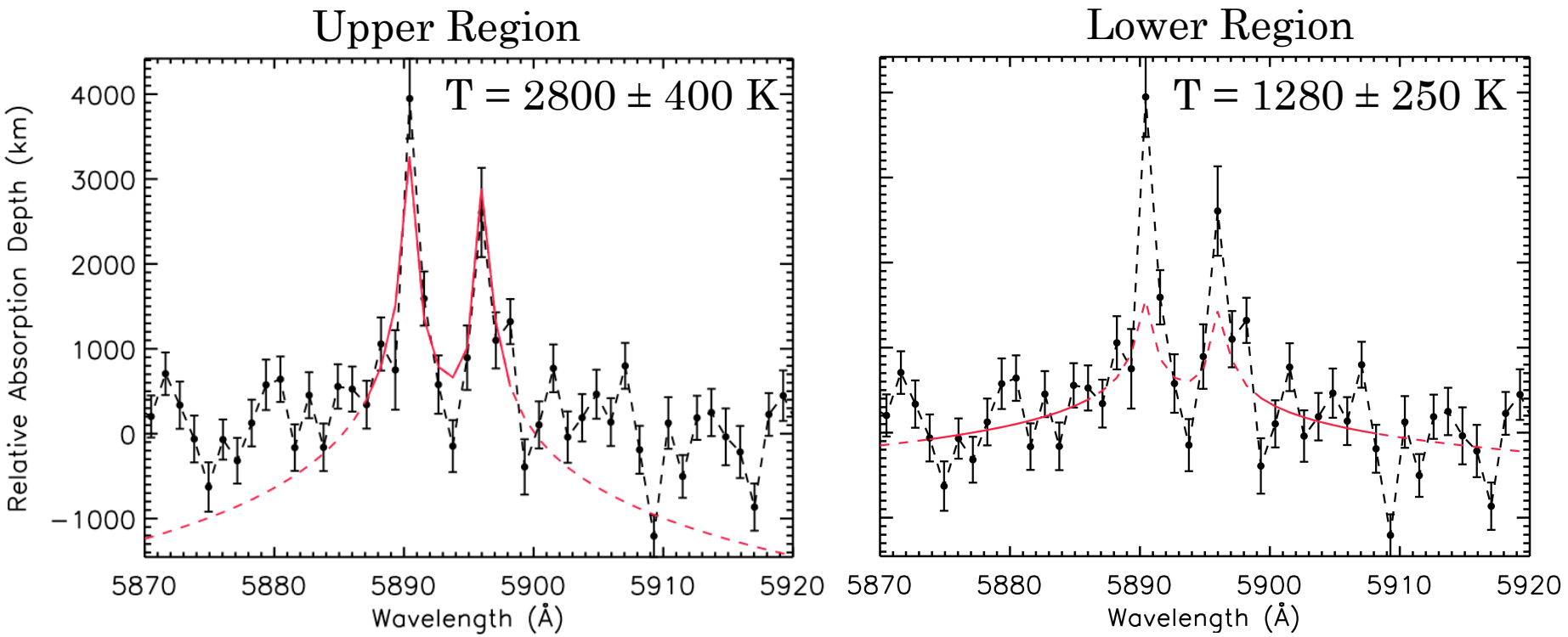
Determining Atmospheric Temperatures

- Measure the local slope of the feature
- For hydrostatic equilibrium, scale height $H = kT/\mu g$





Determining Atmospheric Temperatures



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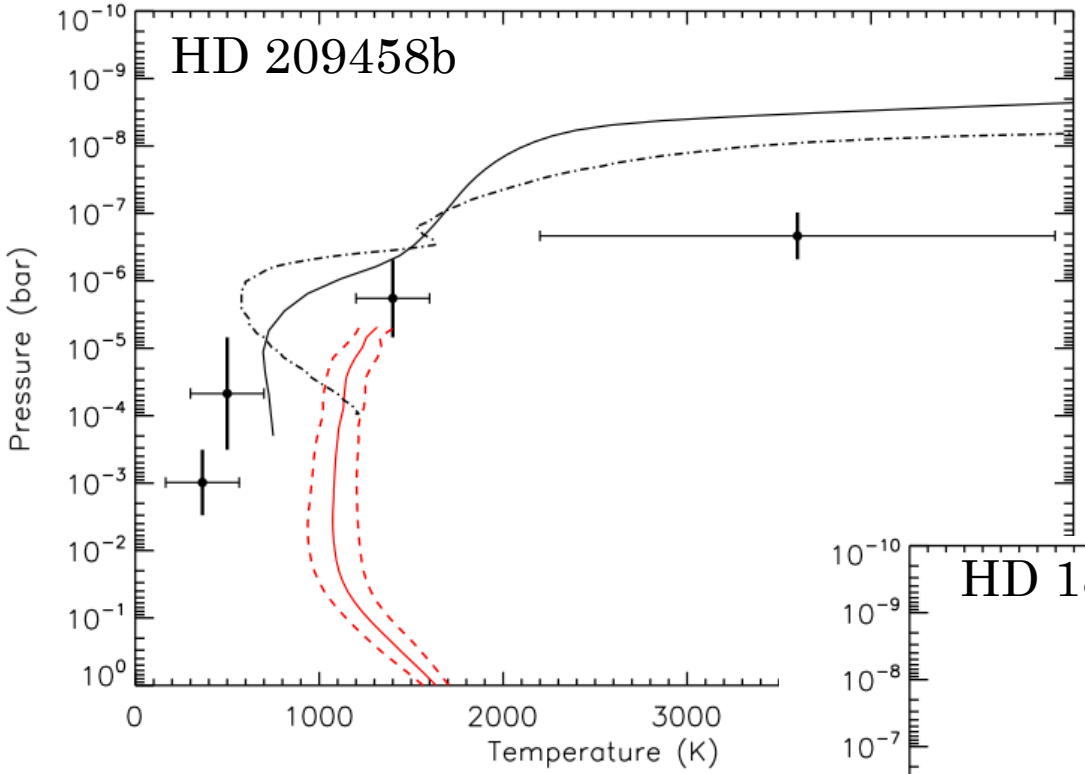
T-P Profiles of Two Hot Jupiters



East and West Mean Temperature

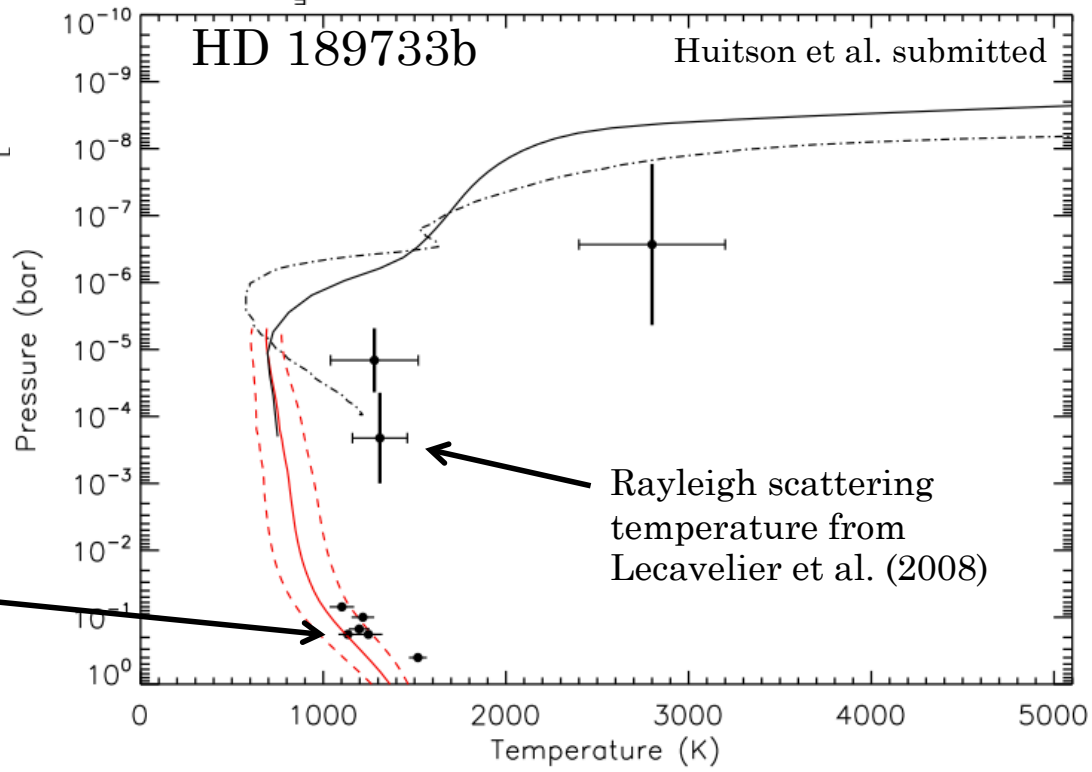
Mean East-West Terminator Temperature

HD 189: Showman et al. (2009)
HD 209: Fortney et al. (2010)

Yelle (2004)

García Muñoz (2007)

Vidal-Madjar et al. (2011; 2011b)
High resolution data from Snellen et al. (2008)



Rayleigh scattering temperature from Lecavelier et al. (2008)

Infrared points from literature (Deming et al. 2005; Knutson et al. 2007; Knutson et al. 2009; Charbonneau et al. 2008).

Unknown Reference Pressure

Unknowns

$$z = H \ln \left(\frac{\sigma(\lambda) P_o \xi}{\tau_{\rm eq}} \sqrt{\frac{2\pi R_p}{kT\mu g}} \right)$$

- Convert T-z profile to *T-P* profile
- Degeneracy between abundance and pressure
- Broken for HD 209458b by observing H_2 Rayleigh scattering

Summary and Conclusions

- Confirmed sodium detection at 9 sigma
- Resolved the Na I D feature
  - Narrow Na I feature and featureless low resolution spectrum
  - Consistent with high altitude haze
- High altitude temperature increase with increasing altitude, likely detection of the base of the thermosphere

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