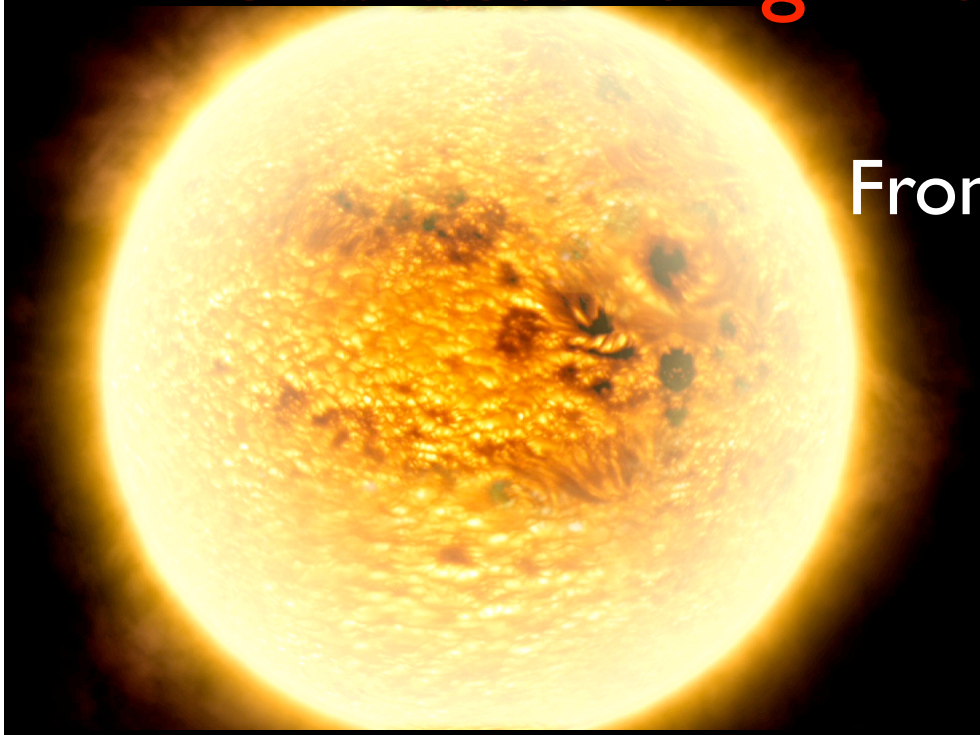
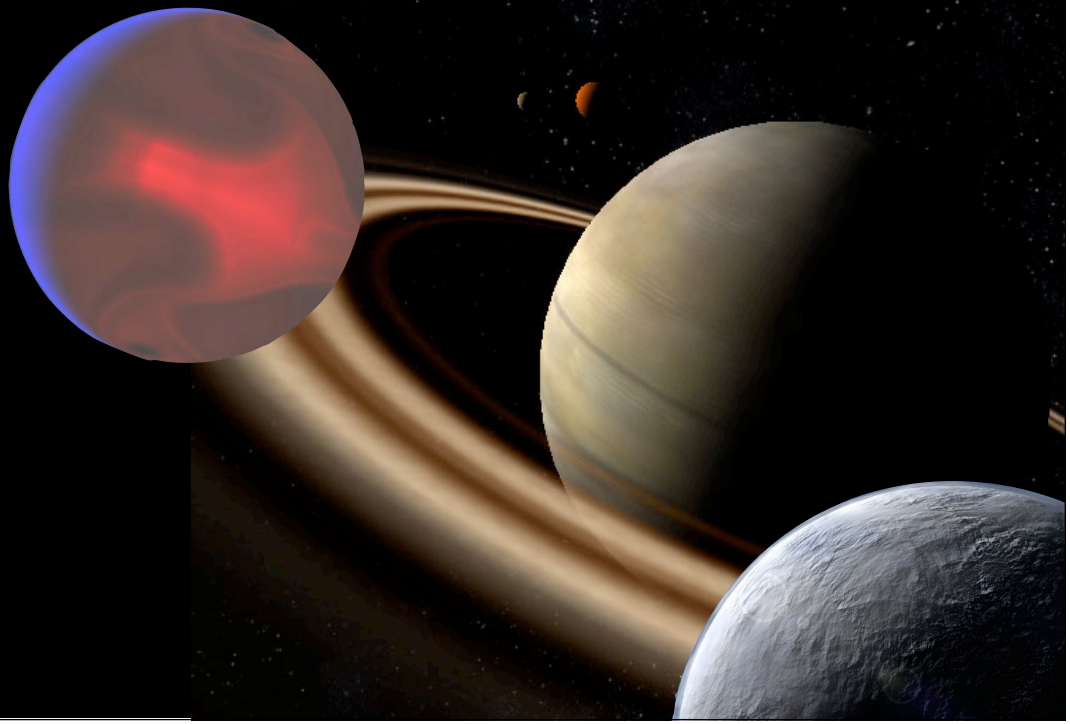
Characterising Exoplanet Atmospheres Through Transmission Spectroscopy

From the start of new millennium toward the next decade





David K. Sing

UNIVERSITY OF EXETER

Exoclimes 2010

Colleagues and Collaborators

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Jean-Michel Désert	IAP, France
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Jonathan Fortney	UCSC, USA
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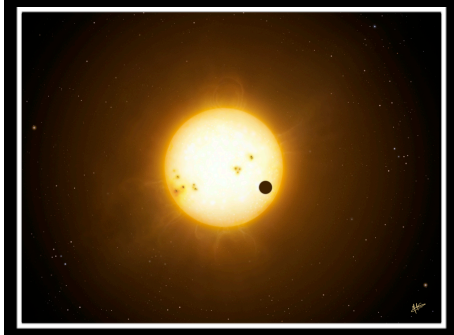
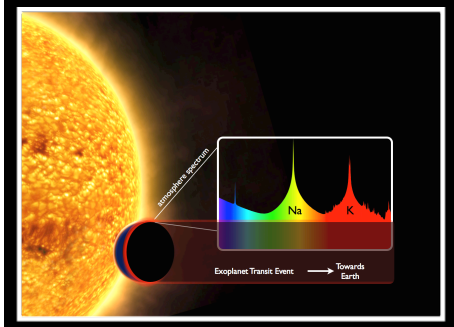
Mercedes López-Morales	ICE, Spain
Frédéric Pont	Exeter, UK
Justin Rogers	JHU, USA
Alfred Vidal-Madjar	IAP, France

Outline

- Introduction to Transit spectroscopy
  - why, how
- Overview of Past Results
  - including HD189733b
- Difficulties
- New Results
  - potassium
  - sodium
- Comparative Exoplanetology

Exoplanet Atmosphere Characterisation by Spectra





Transits

Close-In Planets

M_{pl}, $R_{pl}(\lambda)$, i, P, a, $Flux_{pl}(\lambda,\Phi)$

Atmo. Composition

Clouds/Hazes

Dynamics, Winds

Thermal profile

- Stratospheres
- Thermospheres
- Exospheres

Escape

Photochemistry

Direct Imaging

Wide-Separations

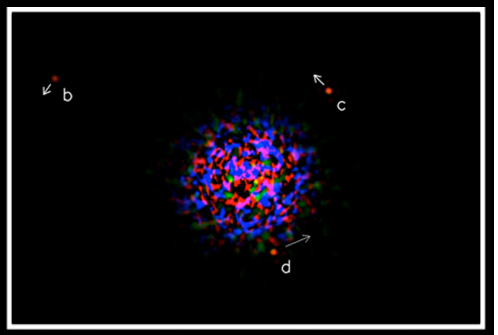
$a\sin(i)$, $Flux_{pl}(\lambda)$

Atmo. Composition

Clouds/Hazes

Dynamics, Winds

Thermal Profile



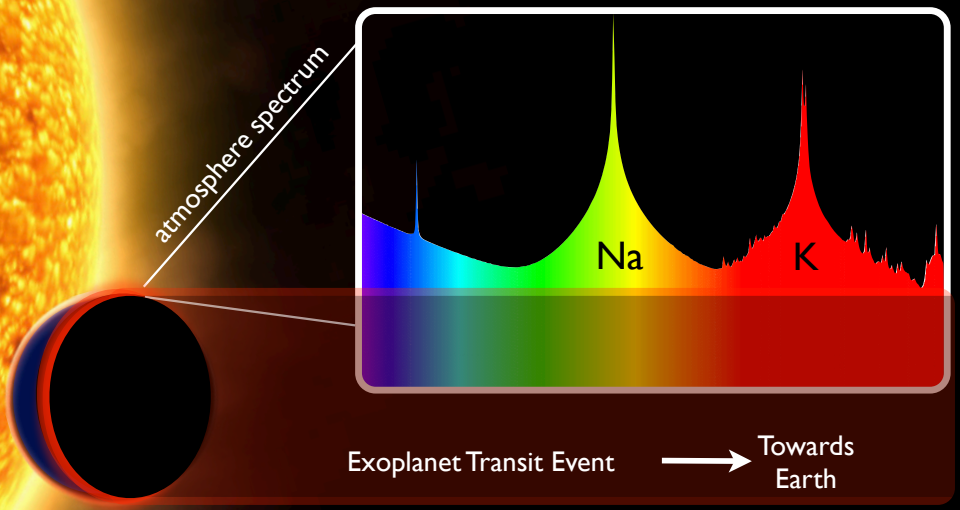
terrestrial planets, biomarker signatures

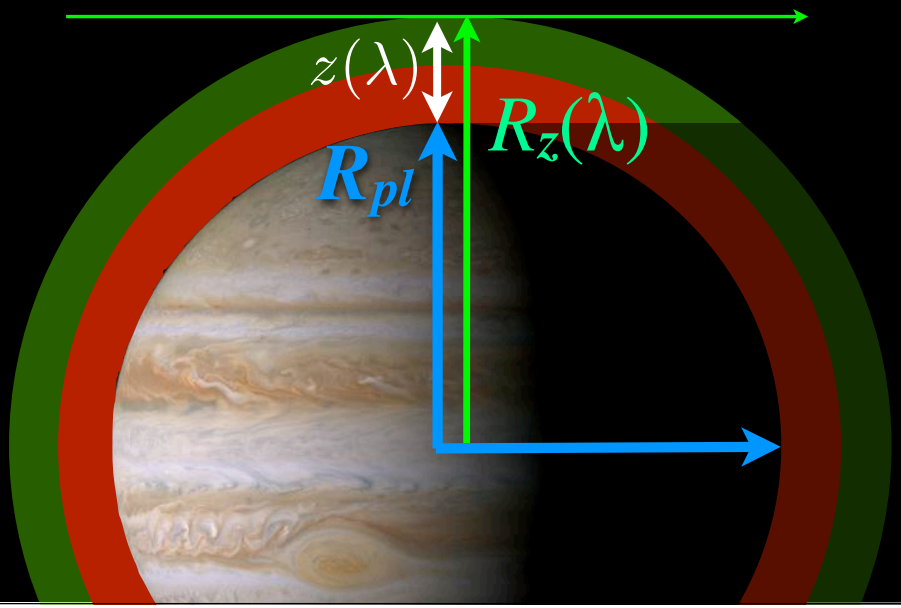
Transmission Spectra 101

Analytic equation Lecavelier et al. (2008)

Relation between: Altitude - Composition - Temp - Press×Abund

$$z(\lambda) = H\ ln\left(\frac{\xi_{abs} P_{z=0} \sigma(\lambda)}{\tau \mu g}\sqrt{\frac{2\pi R_{pl}}{H}}\right)$$





Transmission Spectra 101

technique: measure

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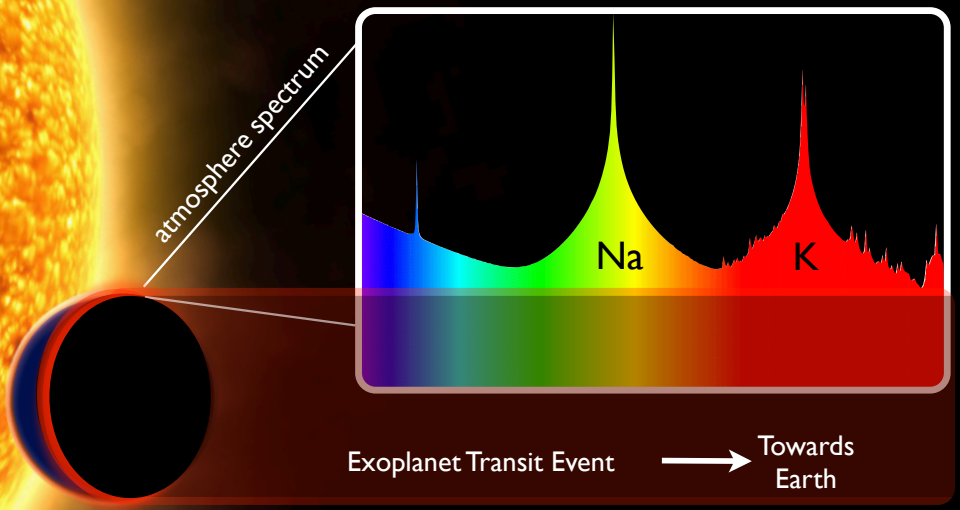

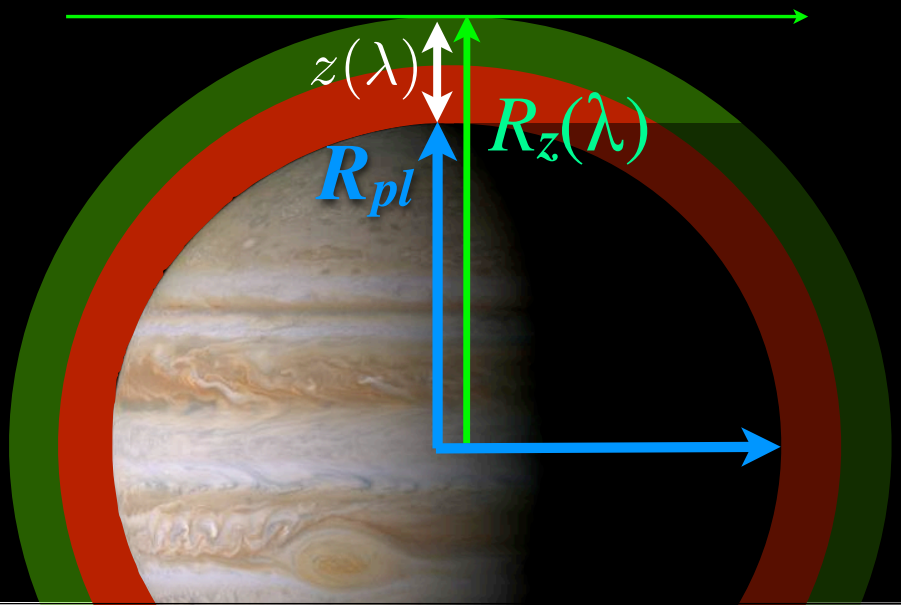

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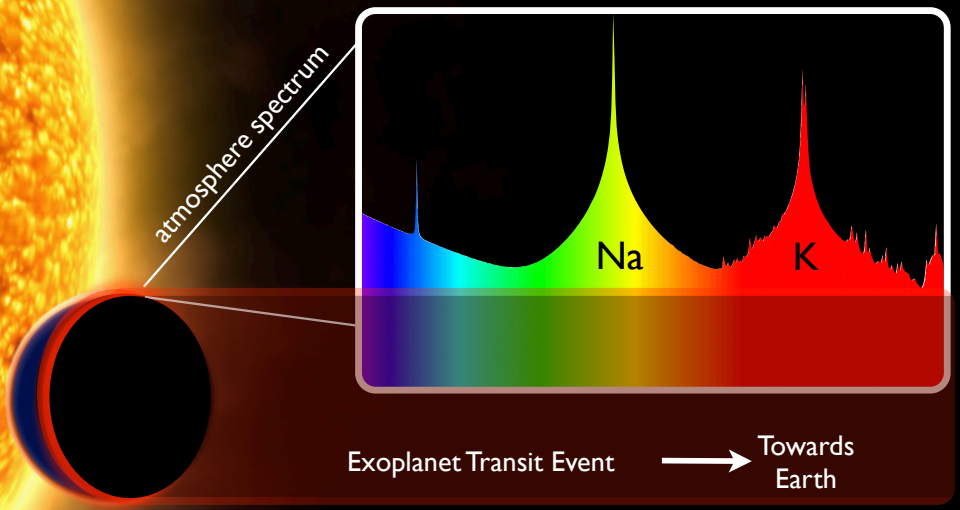

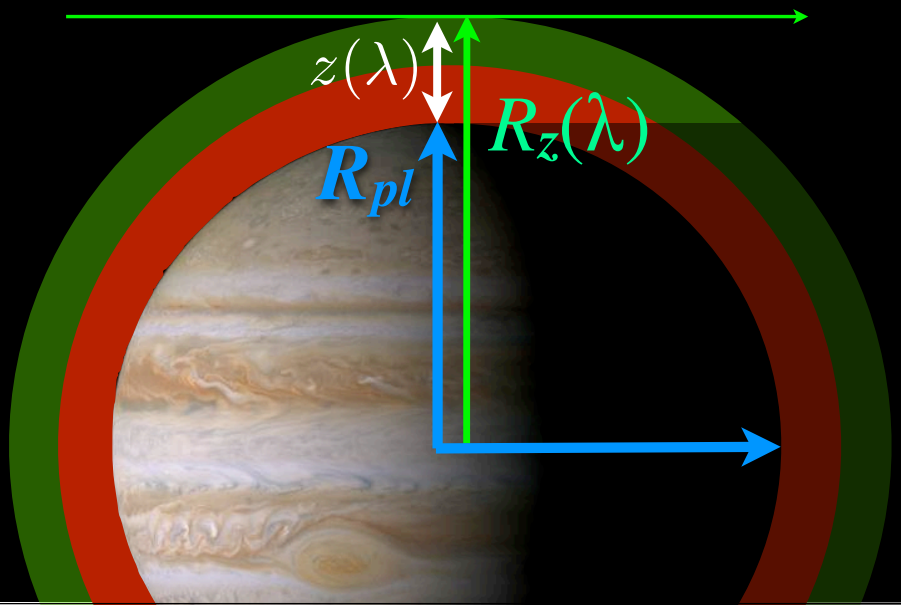

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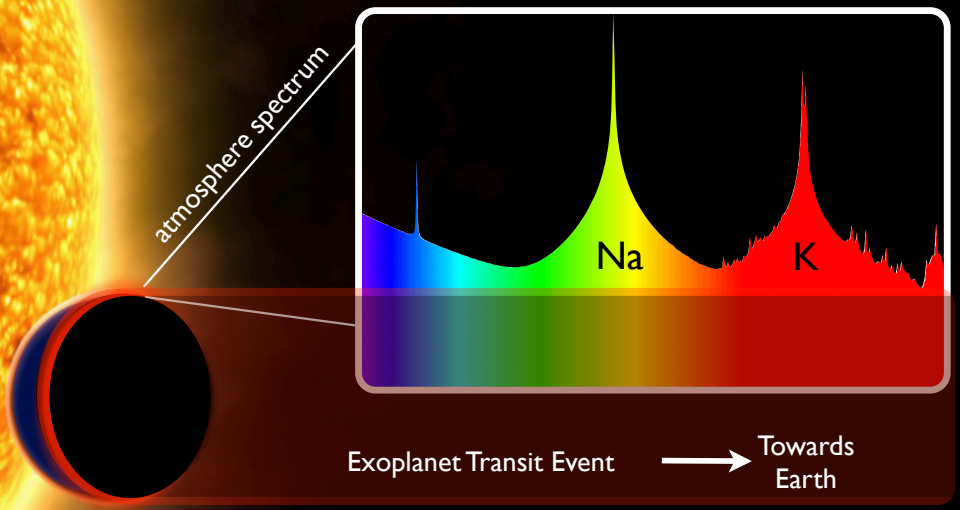

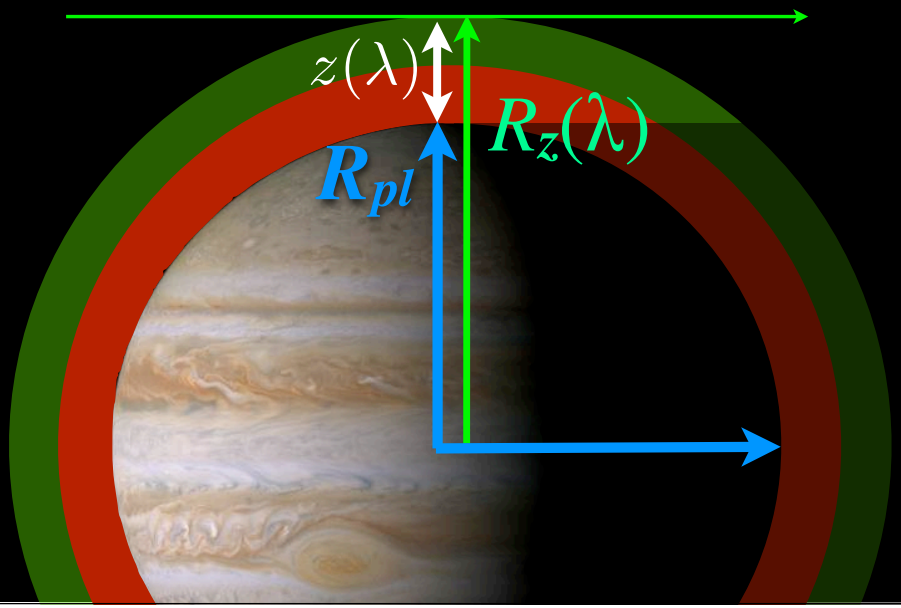

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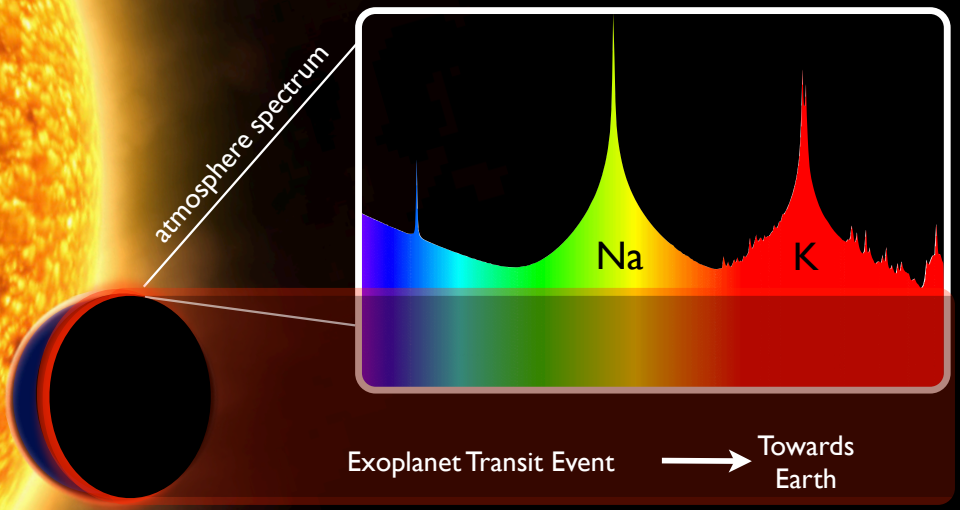

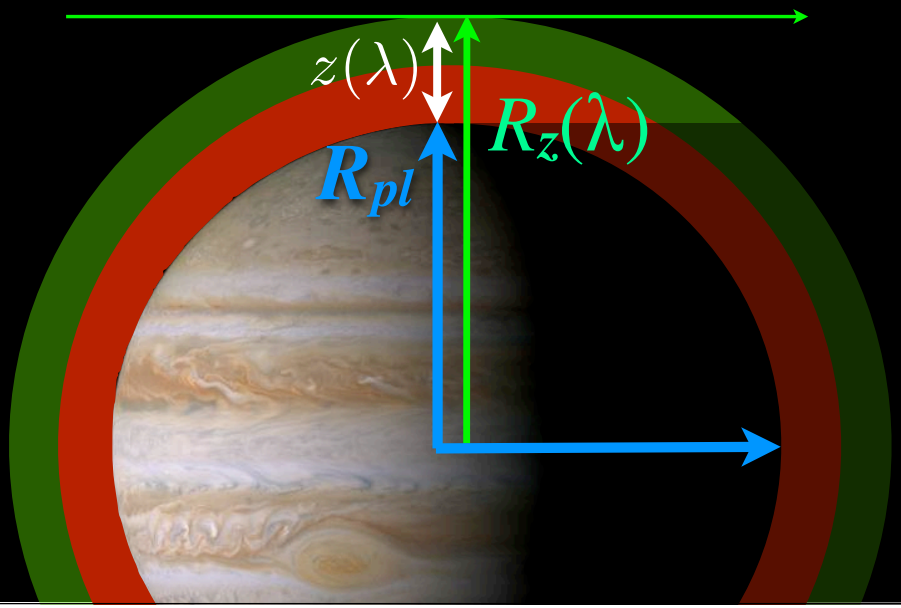

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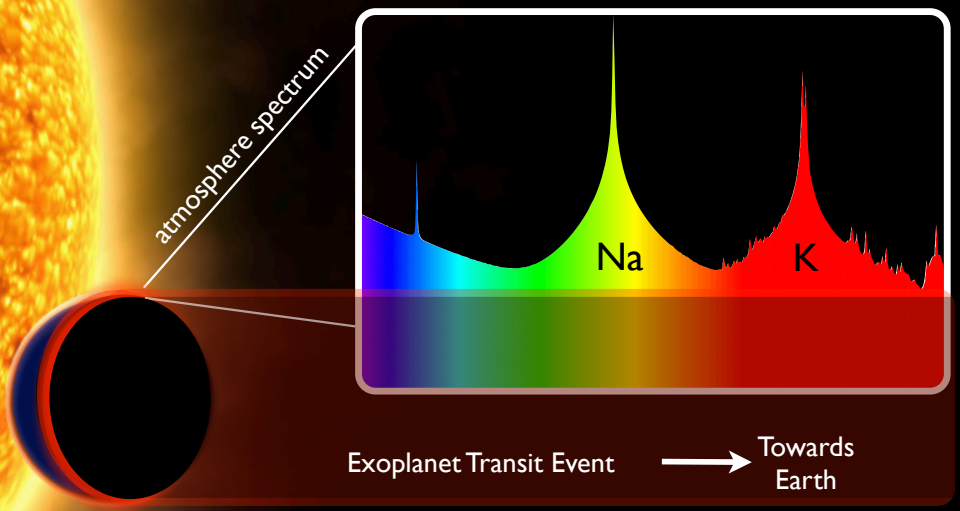
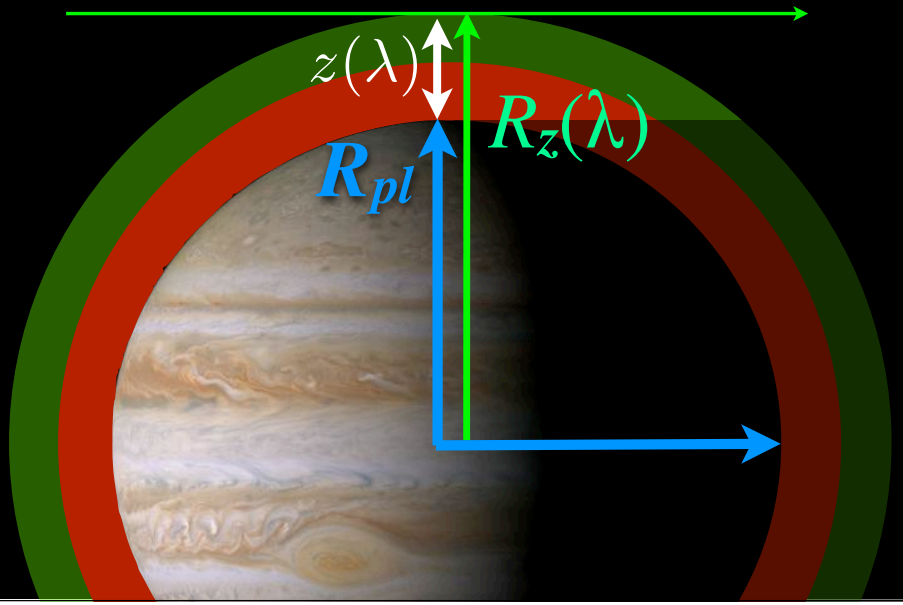


Important Degeneracy: $\xi_{abs} P_{z=0}$

Unknown Abundances & Unknown Total Pressure can be compensated by each other - *altitude shift*



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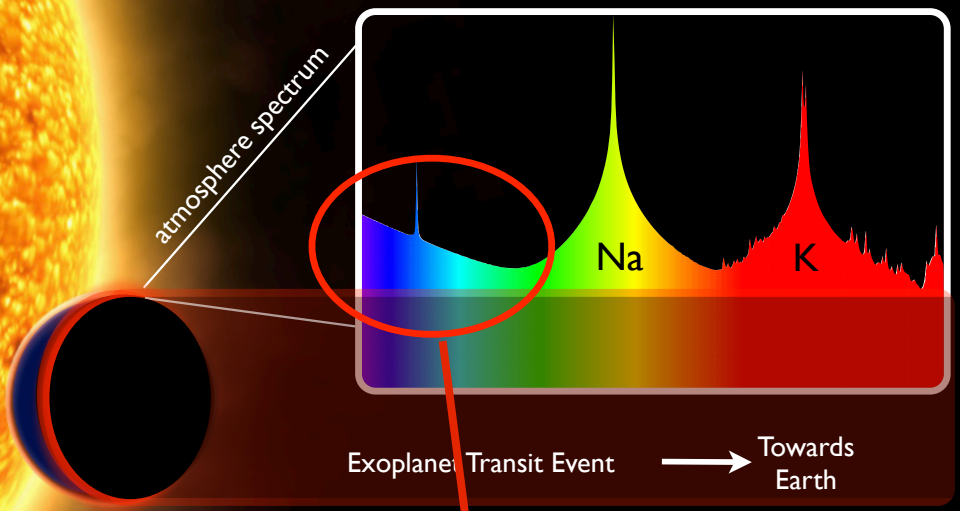


Identify H_2 Rayleigh Scattering

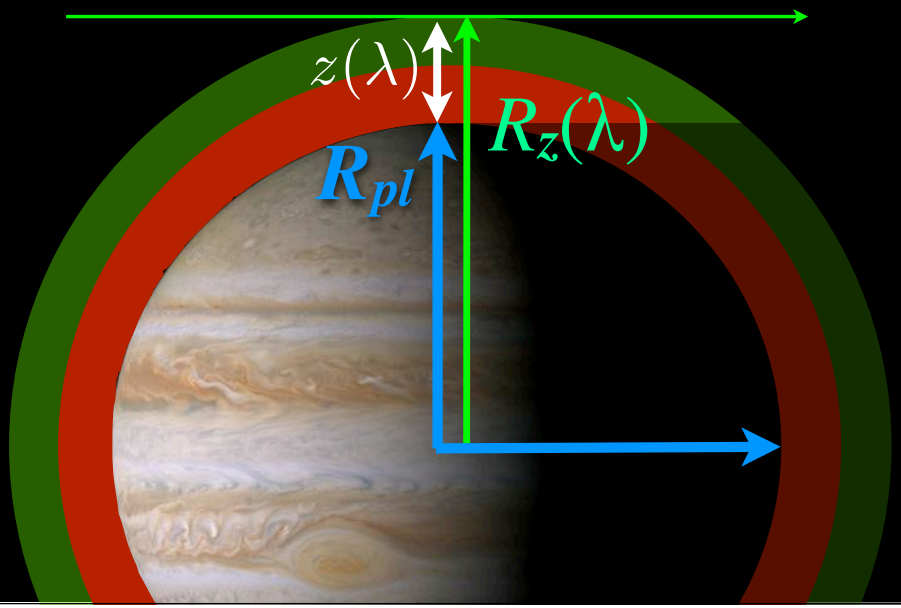
H_2 Abundance known ~ 1

Breaks Degeneracy

Absolute Pressure scale *Absolute Abundances*

Important Degeneracy: $\xi_{abs} P_{z=0}$

Unknown Abundances & Unknown Total Pressure can be compensated by each other - *altitude shift*

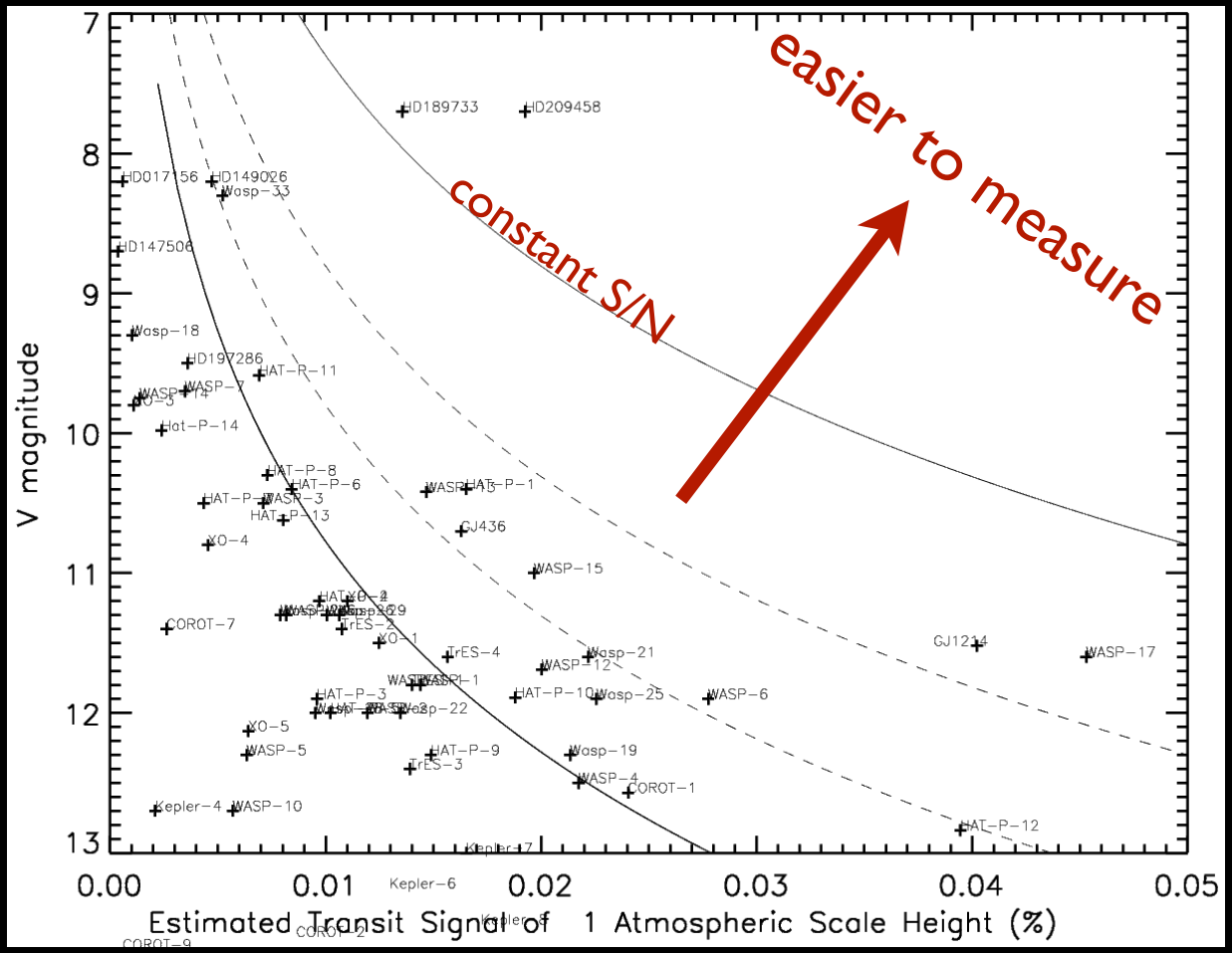


Which Transiting Planets Do We Look At?

Signal is easier to detect if:

- Brighter star
- Large contrast (deeper transit)
- Large atmosphere H (lower surface g, higher T_{eff})

higher photometric signal



larger atmosphere signal

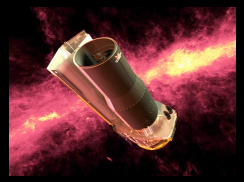
Transmission signals are typically 1-10 scale heights H

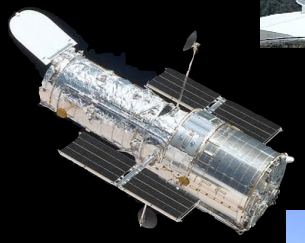
Very high S/N needed... *quickly*

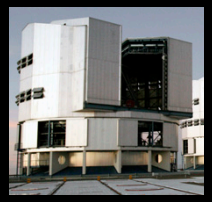
0.02% => S/N of 5,000

25,000,000 photons with hour time scales

Transit Spectroscopy: Methods & Science





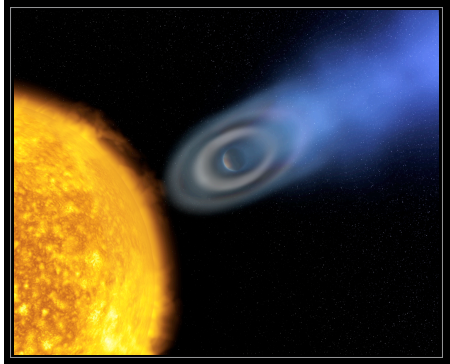


Different methods for different *Science Aims*

- Spectrophotometry
  - broadband (UBVRIZJHK, Spitzer) - *molecules, broadband opacity, chemistry*
  - narrowband (HST, GTC) - *atmo. composition elements/molecules*
- Spectroscopy
  - Low & Medium Res. space-based (HST) - *broadband opacity, hazes, chemistry*
  - High-Res. ground-based - *specific elements/molecules, winds*
  - UV Space-based (HST) - *atmospheric escape*
- Multiple - Atmosphere *T-P-z* profile, inversion mechanism, photo-chemistry, abundances, ionization, mass-loss, clouds, winds,

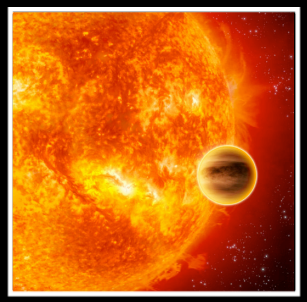
  comparative-exoplanetology...

Overview of Transmission Results



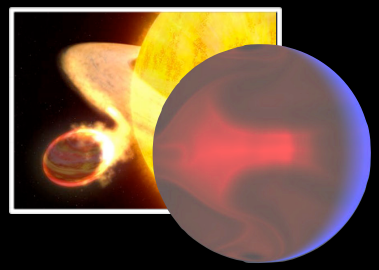
HD209458b

Na	CONFIRMED:	HST STIS & Subaru high-res.	02, 08
C II	CONFIRMED:	UV HST STIS & COS	04, 10
H_2O, H I, H_2, TiO/VO	initial:	HST STIS	07,07,08,08
CO	initial:	VLT CRIRES	10
H I, O I, Si III	initial:	UV HST STIS & COS	03,04,10
H_2O	initial:	Spitzer IRAC	09



HD189733b

Na	confirmed:	Hobby-Eberly & HST STIS	08,10
haze	initial:	HST ACS grism & NICMOS photo	08,09
CO, H I	initial:	HST ACS; Spitzer	09,10
H_2O, CH_4	*disputed*:	HST NICMOS grism vs. photo.	08,09
H_2O	*disputed*:	Spitzer systematics	07,10



XO-1b:	H_2O, CH_4, CO_2	*disputed*:	HST NICMOS grism systematics	10
Wasp-12b:	Mg II, Metals	initial:	HST COS	10
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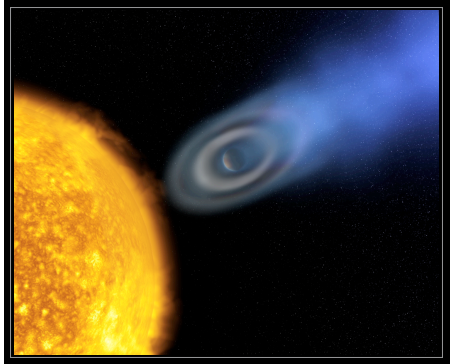
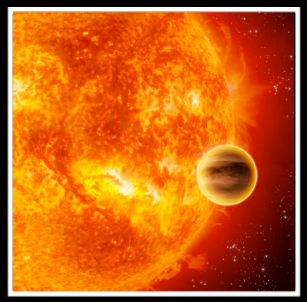
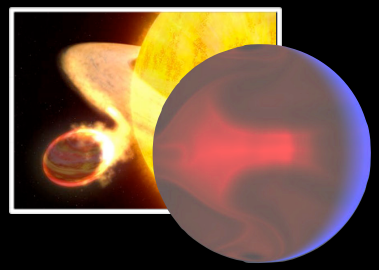
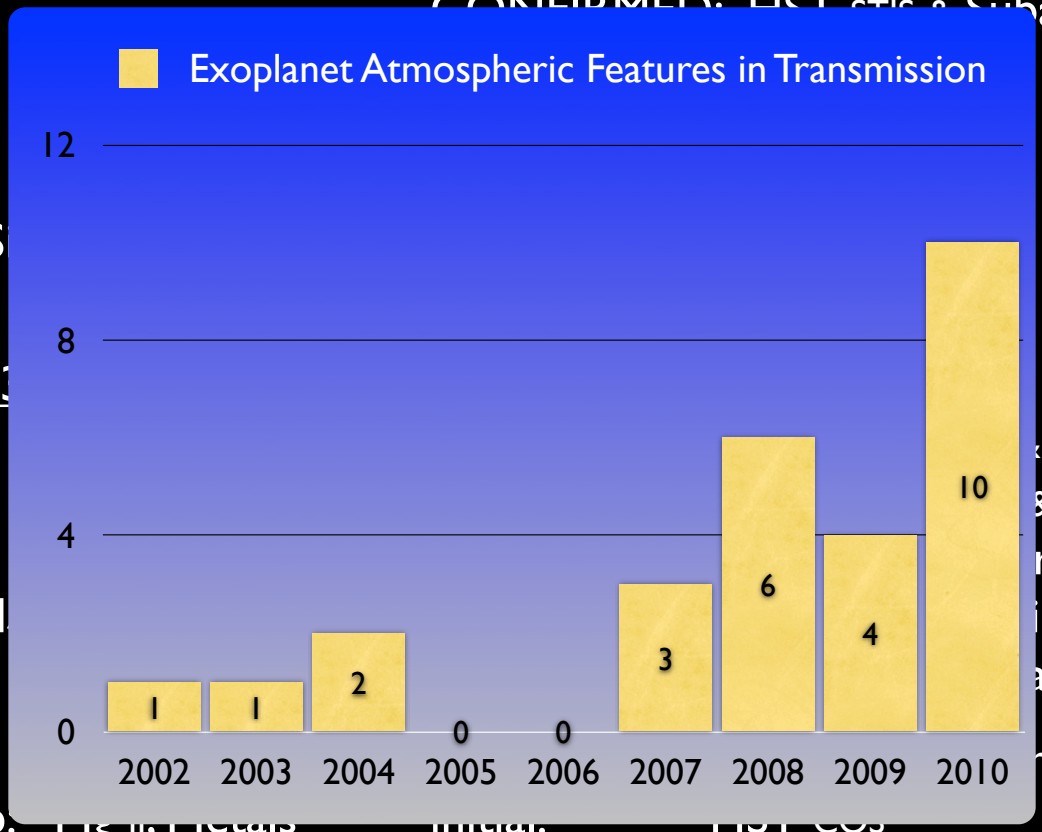
HD80606b:	K	initial:	GTC OSIRIS	10

Overview of Transmission Results









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C II			COS	04, 10
H_2O, H I,				07,07,08,08
CO				10
H I, O I, S			COS	03,04,10
H_2O				09

HD189733

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CO, H I			r	09,10
H_2O, CH			ism vs. photo.	08,09
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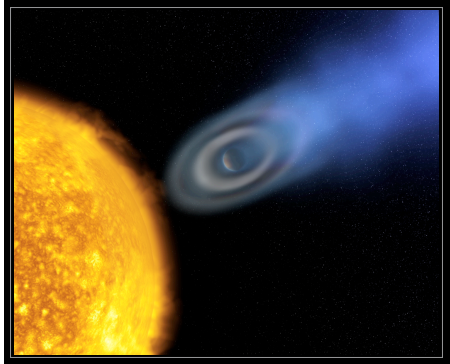

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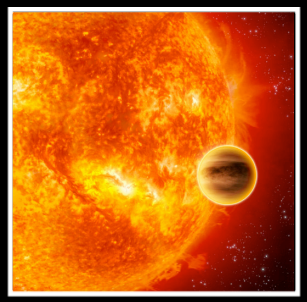

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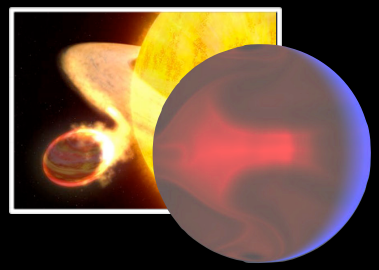

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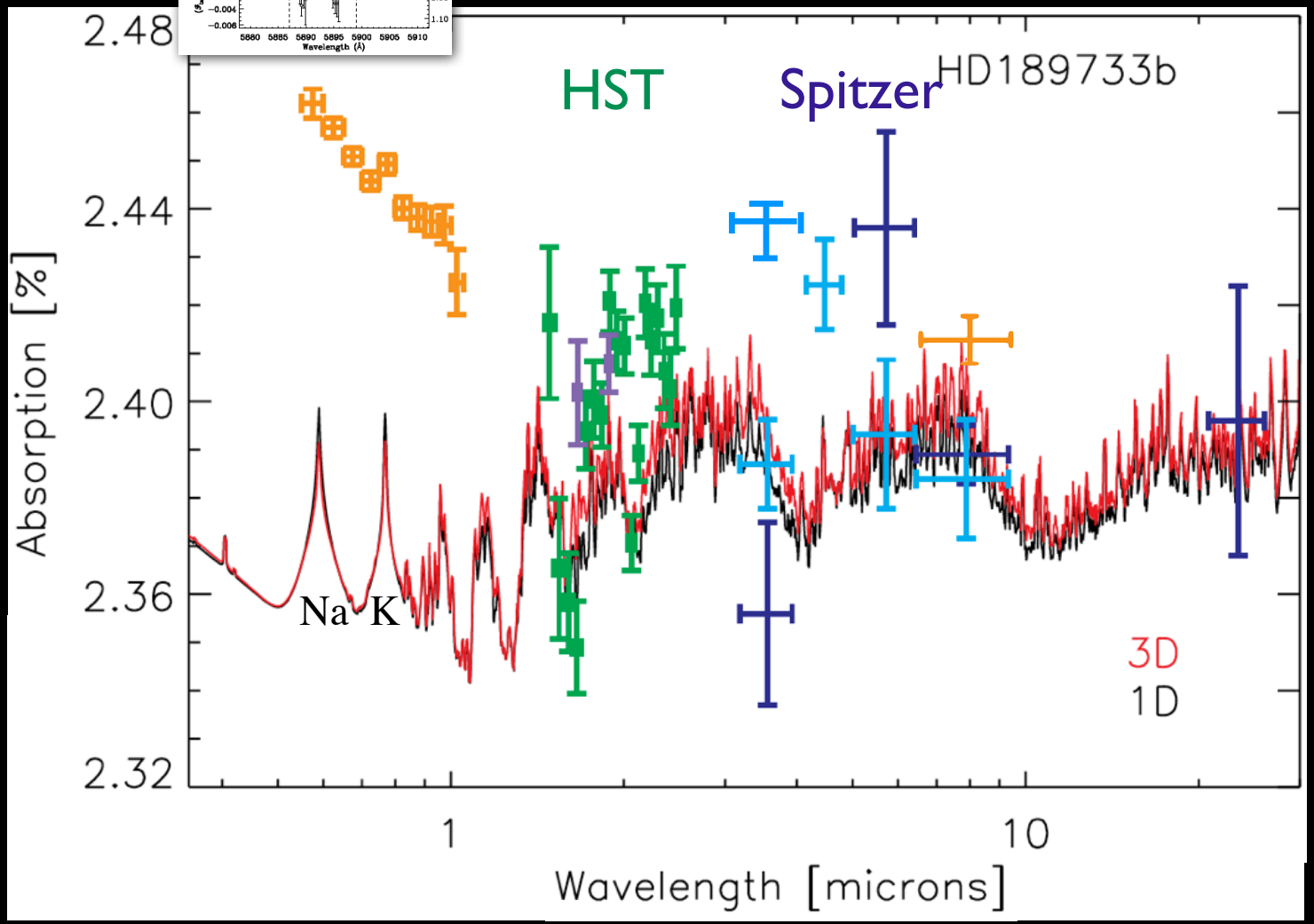
HD189733b Overview exploring the diversity...



Confusing

- HST, Spitzer, & ground Spec.
- Many datasets
- Little agreement on basic atmospheric picture
  - Optical haze
  - near-IR haze or molecules
  - IR molecules?

Knutson et al. (2007,2009)
Tinetti et al. (2007)
Redfield et al. (2008)
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Swain et al. (2008)
Desert et al. (2009,2010)
Sing et al. (2009)
Agol et al. (2010)

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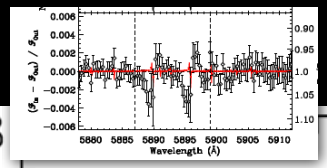

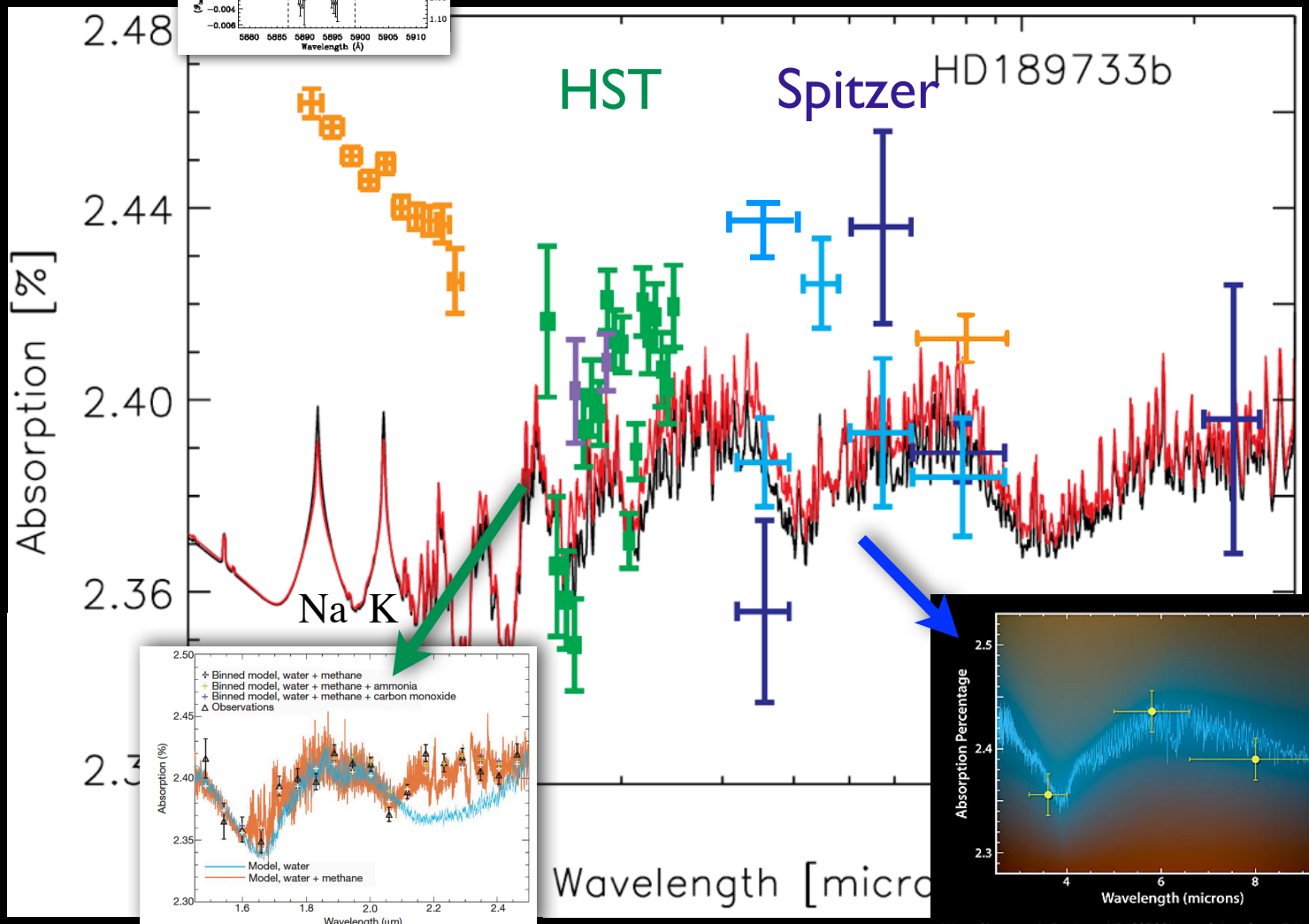

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Agol et al. (2010)

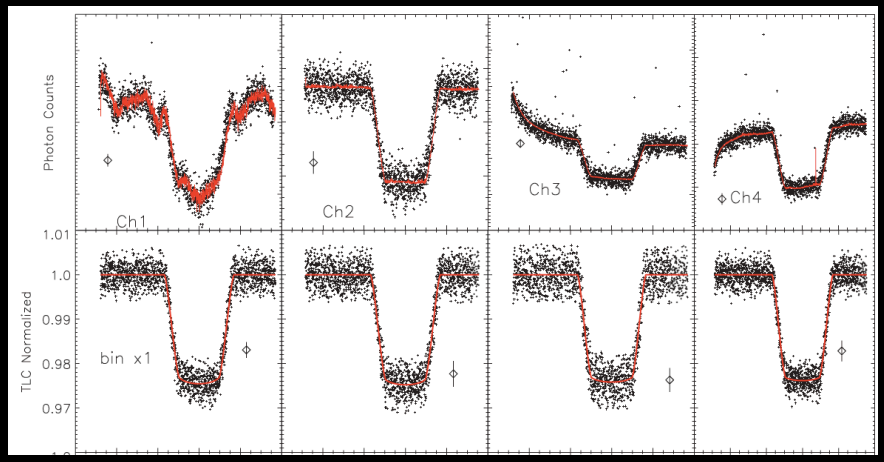
Heart of the '189 Debate small signals and troublesome instruments

Instrument Systematics

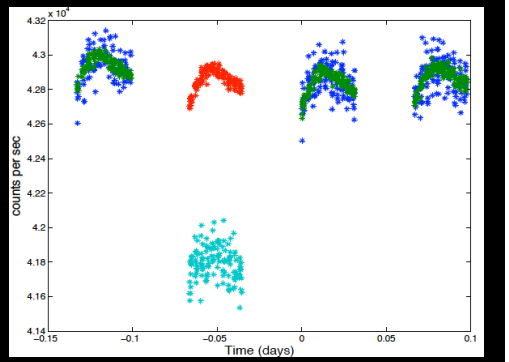
Different Observations = Different Results
Different Reductions = Different Results

- Spitzer IRAC
  - Tinetti et al. & Desert et al. DISAGREE
    3.6μm intra-pixel sensitivity
    5.8μm ramp
  - Resolved (?) New 3.6μm
    Quadratic+ intra-pixel function
    Simultaneous Parameter fits
- HST Nicmos grism
  - Grism has MULTIPLE Instrument Systematics
  - H_2O Not confirmed by photometry

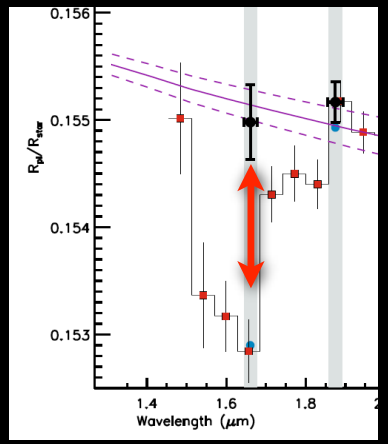
Need New Observations
Need fully Explore Instrument Systematics



Spitzer Instrument Systematics



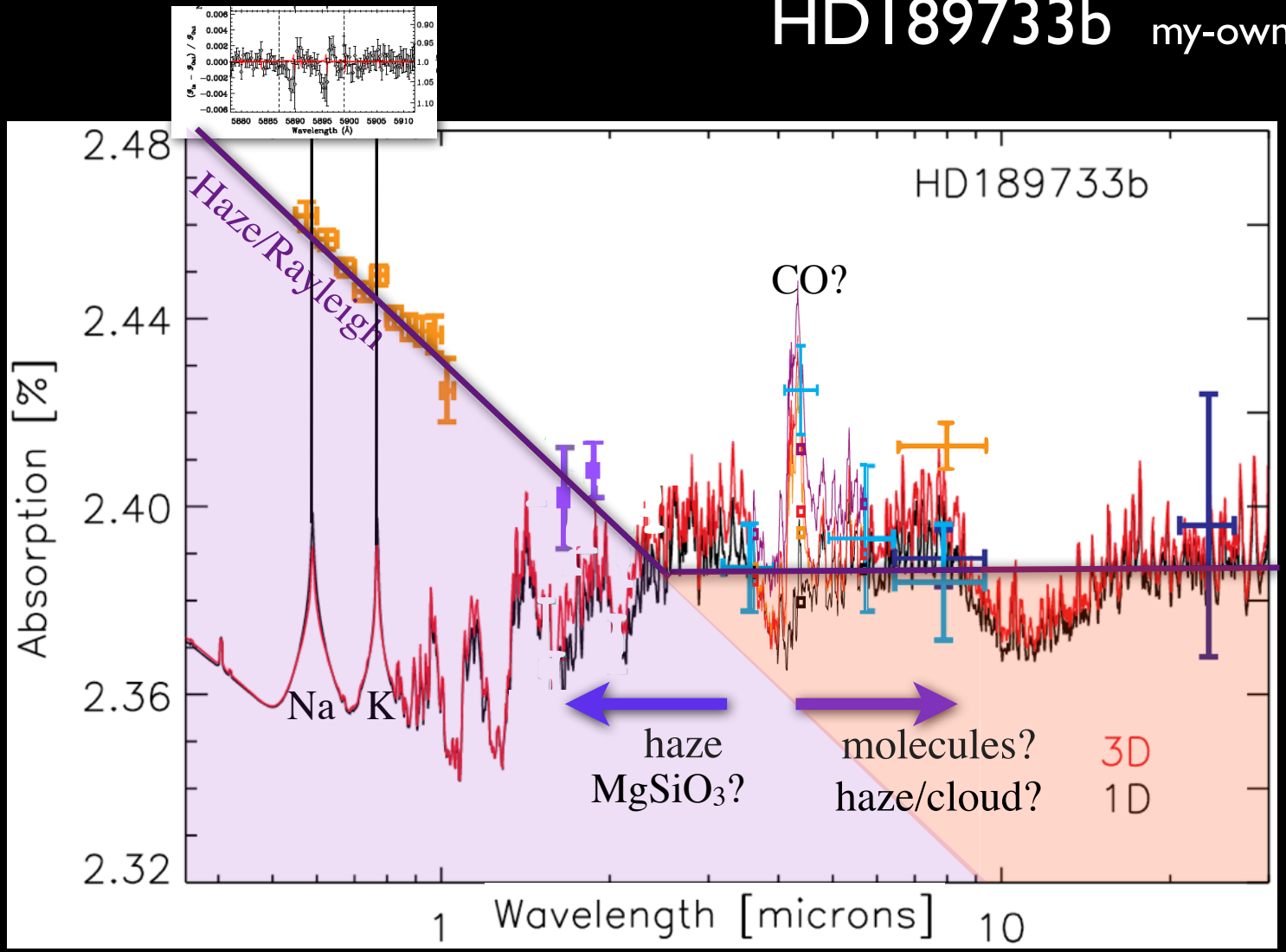
Nicmos Grism Systematics



Nicmos Photometry vs. Grism

See POSTER 2.10 by Neale Gibson
A new look at Nicmos transmission spectroscopy

HD189733b my-own-personally-biased-view



Transmission Data that are...

- Spot-Corrected
- "resistant" to systematics
- reduced in a consistent manner

Knutson et al. (2007,2009)
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Pont et al. (2008)
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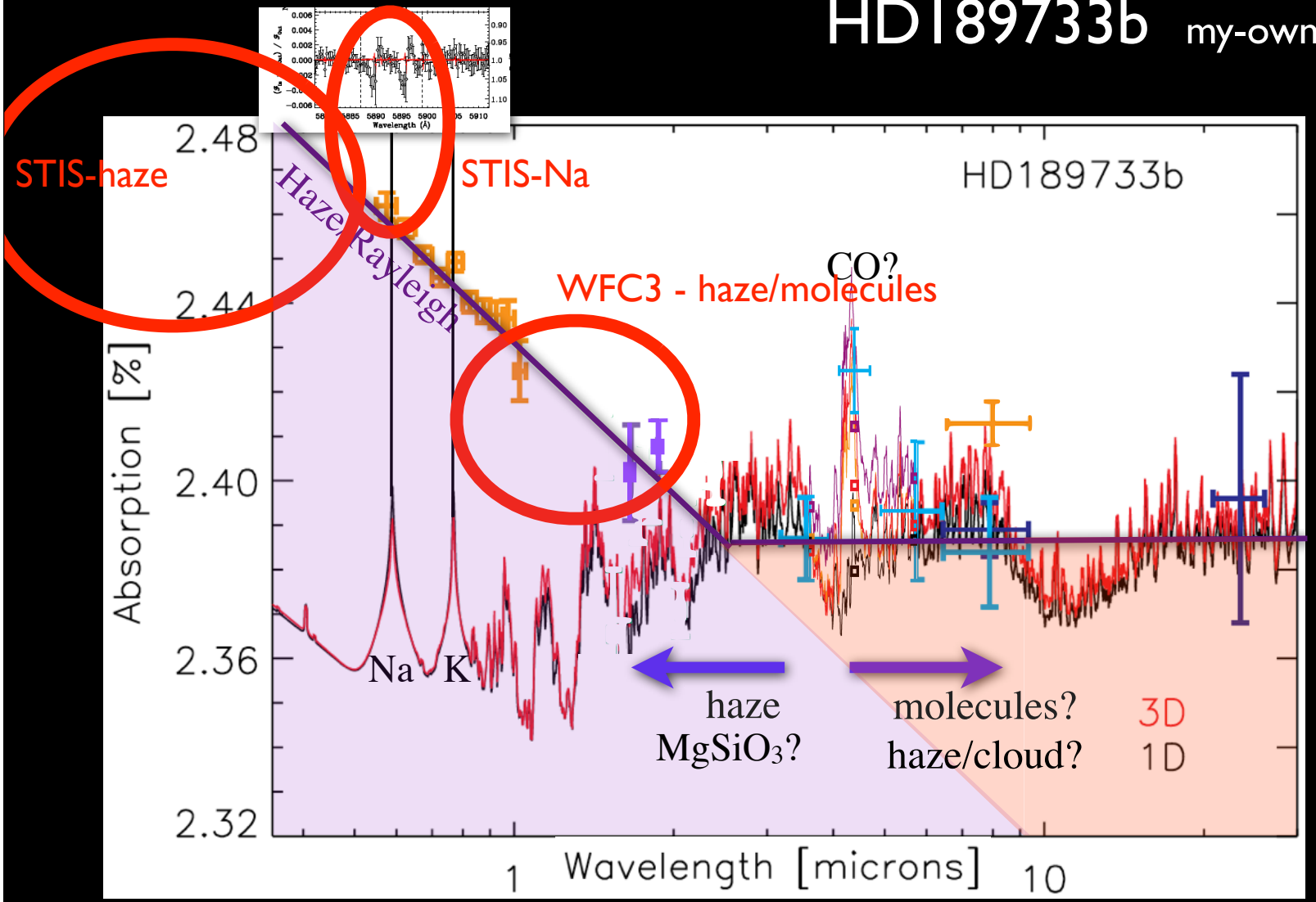

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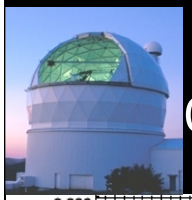
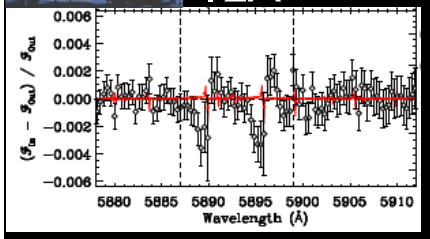
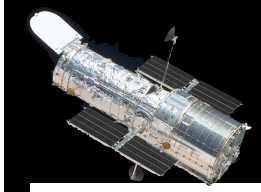
Na in HD189733b: replicate of '209 STIS measurement

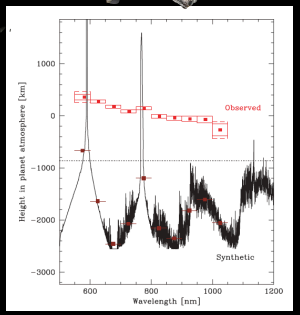


0.067%
12Å



Redfield et al. (2008)





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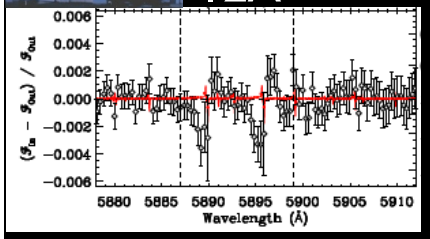
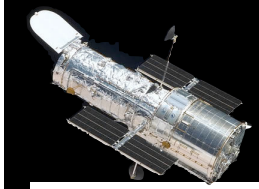
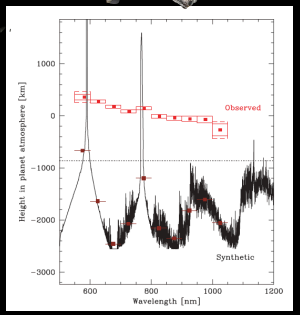


Redfield et al. (2008)

thanks Mike Massimino





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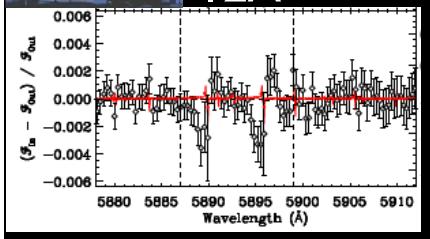

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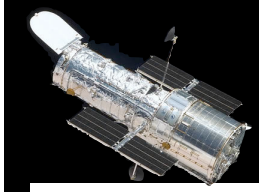
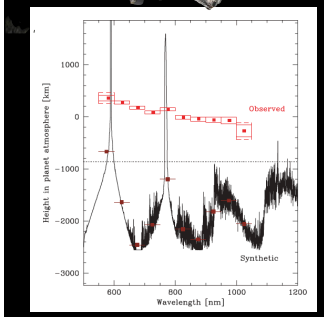
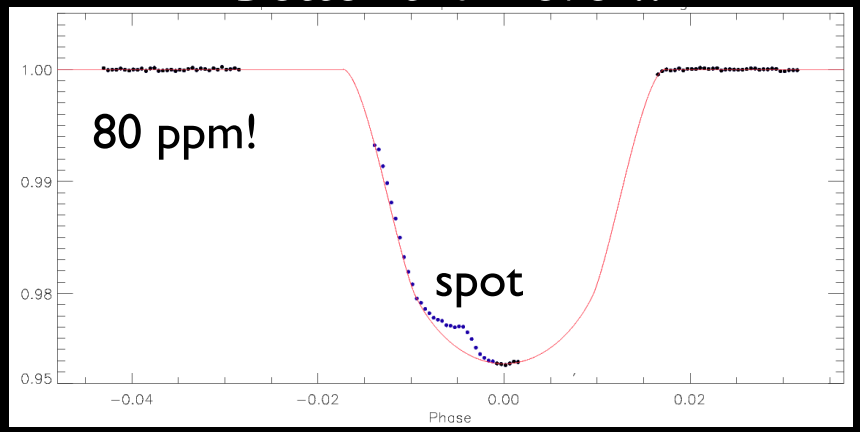




Pont et al. (2008)

better than ever!!



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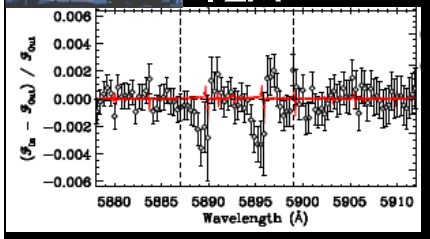

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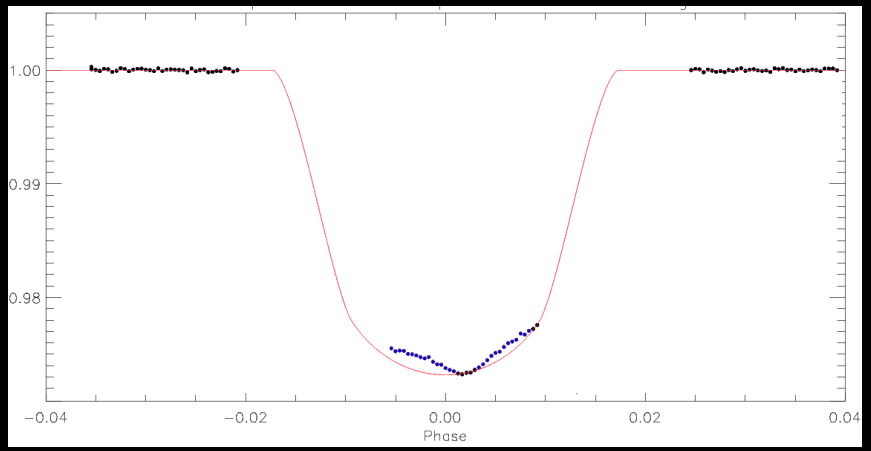

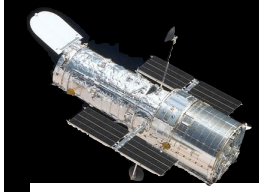

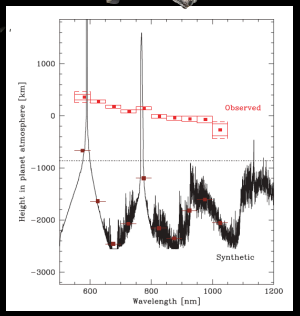

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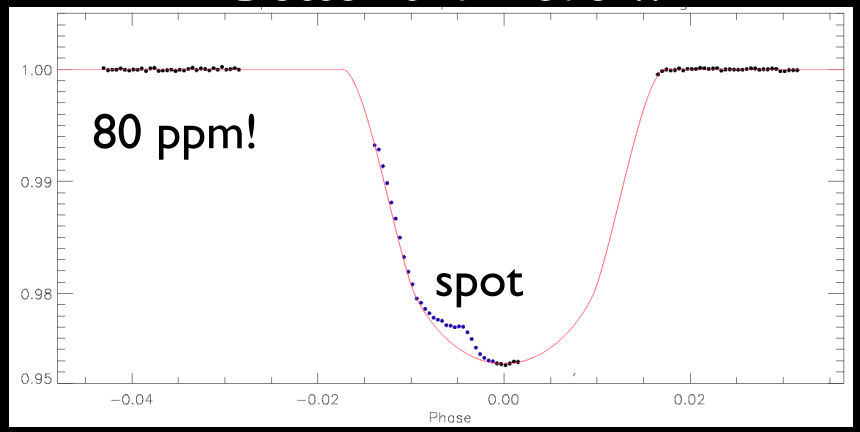
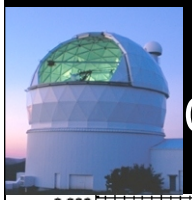


Na in HD189733b: replicate of '209 STIS measurement *Na confirmed!*



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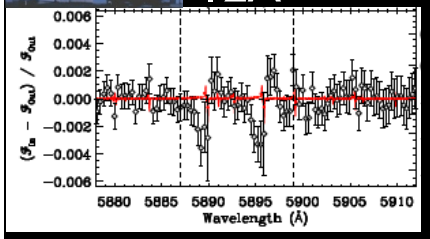

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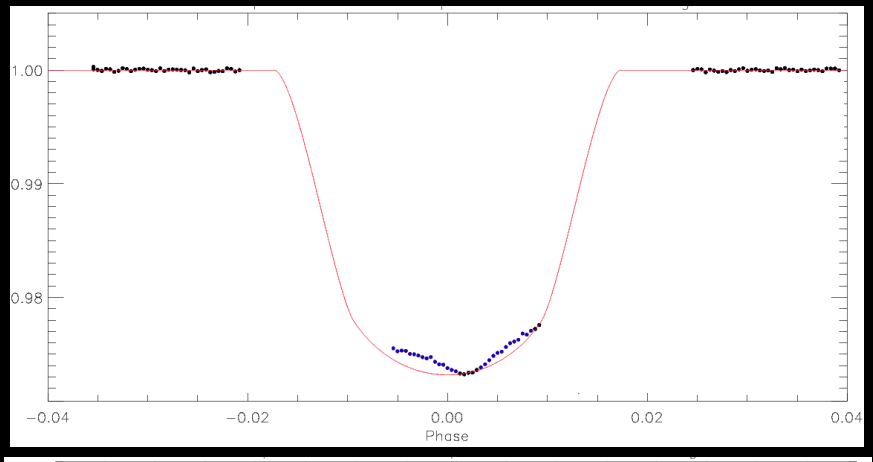

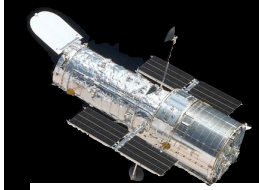

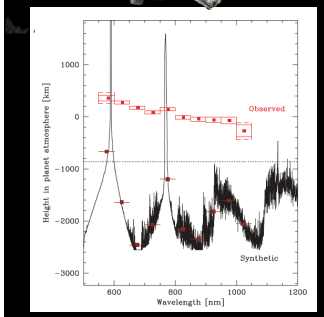

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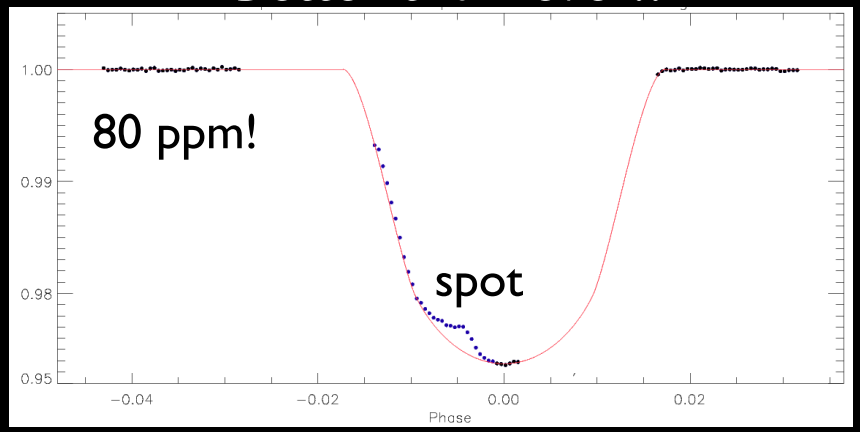
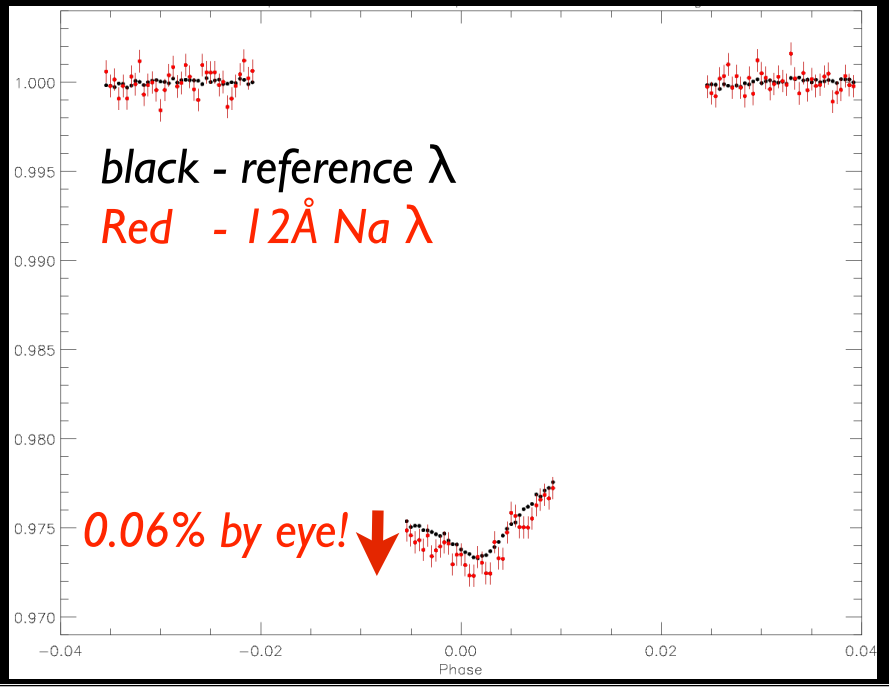
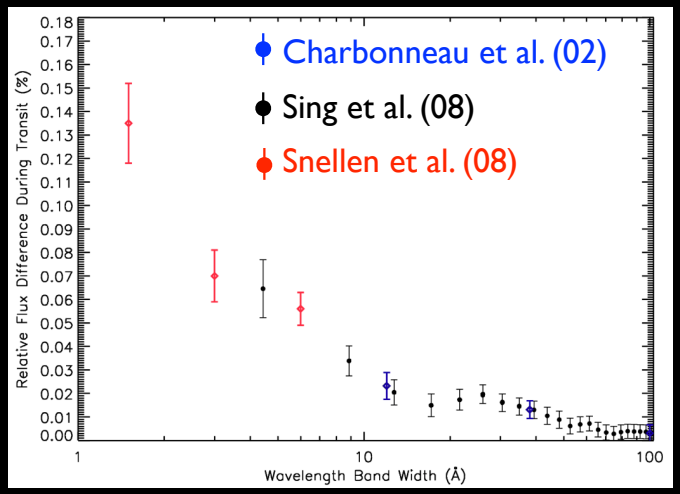




HD209458b Na: Strength of multiple detections

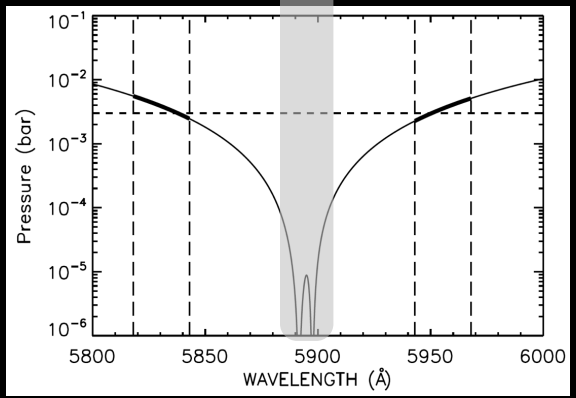
Med-res HST + High-res ground

smaller width ← higher altitude

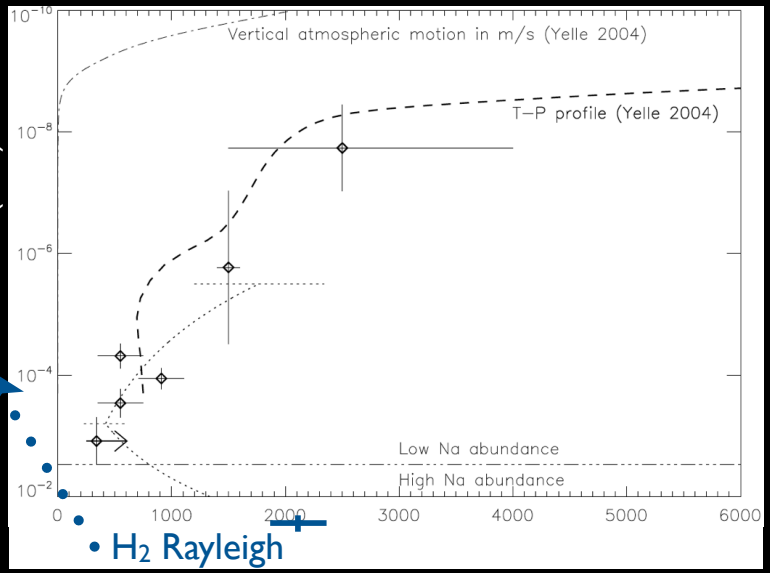


12Å

Different Bandwidths probe different altitudes



higher altitude → atmo escape



Combining Space + Ground spectra provides more complete picture of the *T-P-z* profile

- Large 1500 K Isothermal Region revealed between 10^{-5} to 10^{-7} bar
- Signs of escape process at very high altitudes?

Vidal-Madjar et al. (2010) submitted

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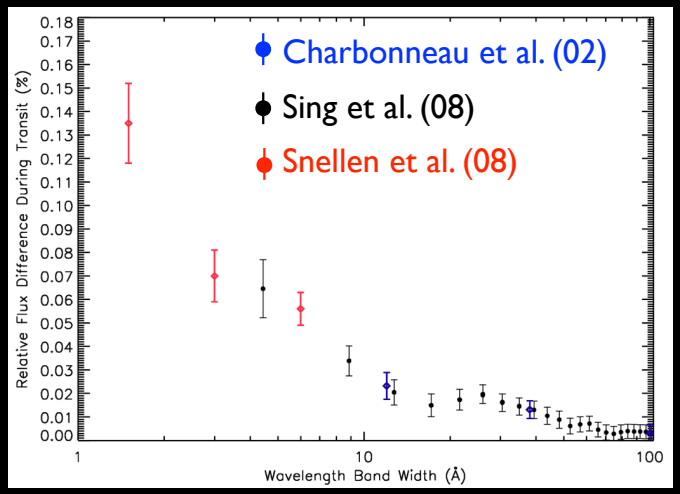

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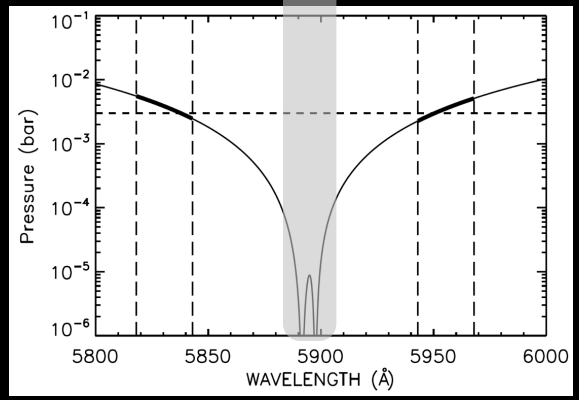

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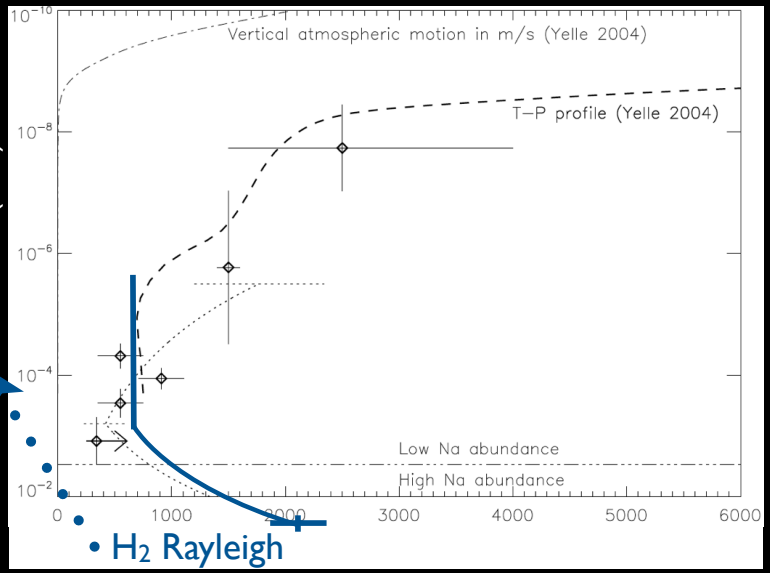
atmo escape



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Beyond ‘209 and ‘189

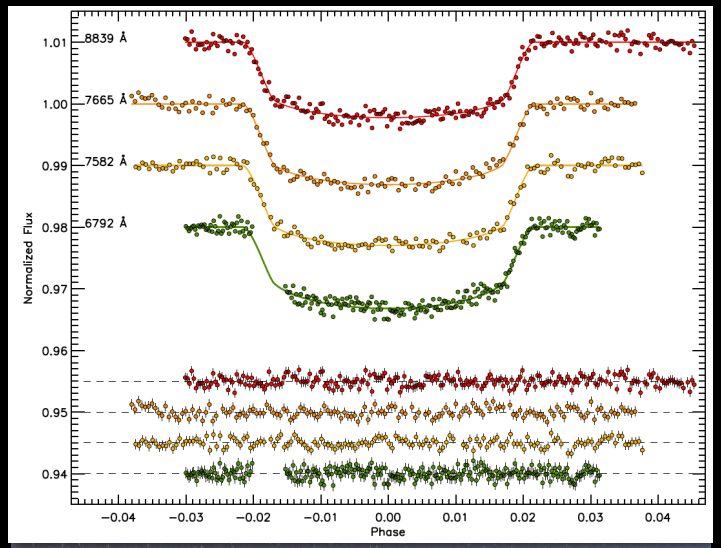
We now have...

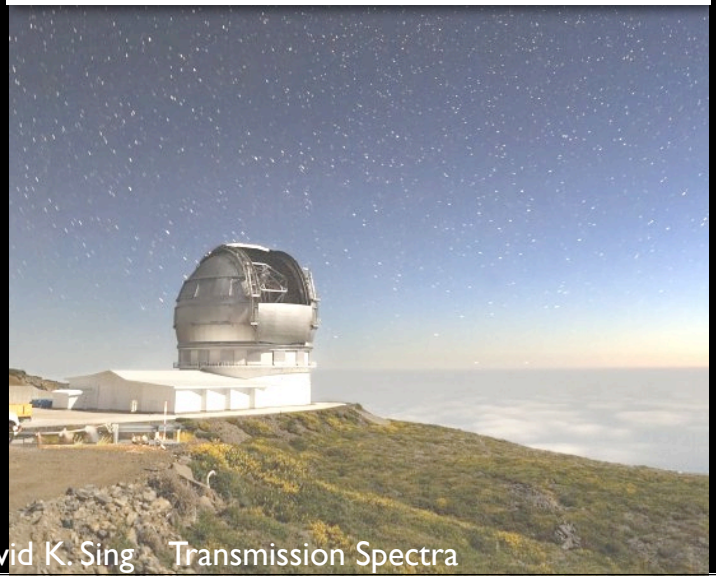
- Enough transiting planets to now do surveys
- Different Techniques for unique of surveys
- More experience and better tools

2010 marks the *start* of comparative exoplanetology with transmission spectra

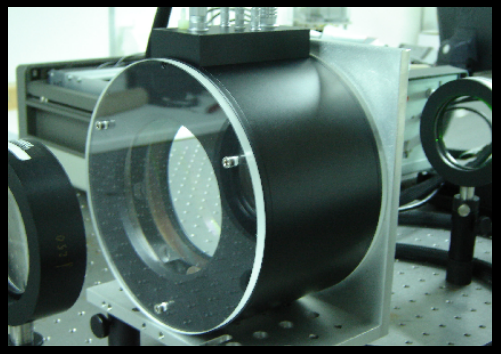
HST	Deming	near-IR	
Hobby-Eberly	Redfield	optical high-res	(POSTER 2.19)
GTC	Sing	optical med-res	
and others...			

Potassium in XO-2b



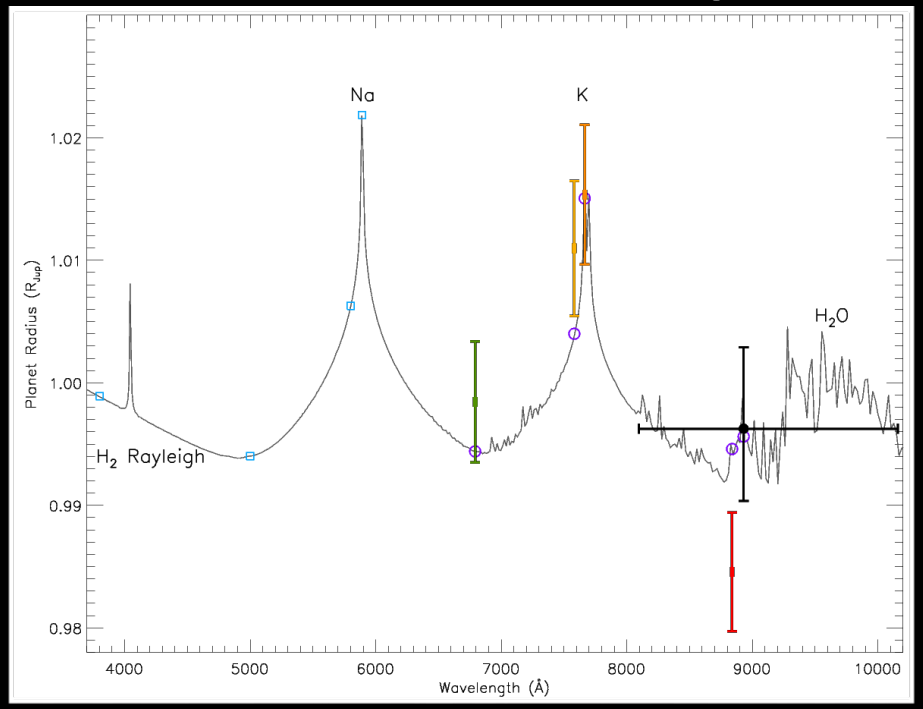


David K. Sing Transmission Spectra



Fabry-Perot etalon
narrow-band photometry
Tune to desired λ

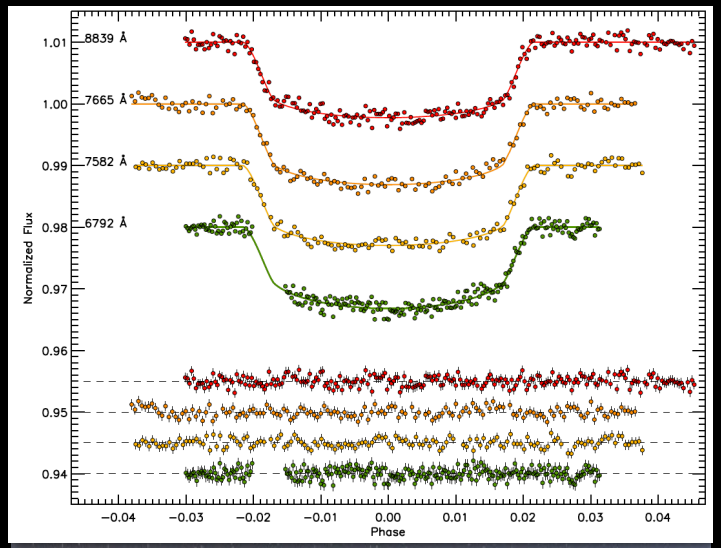
4 wavelengths; 3 transits

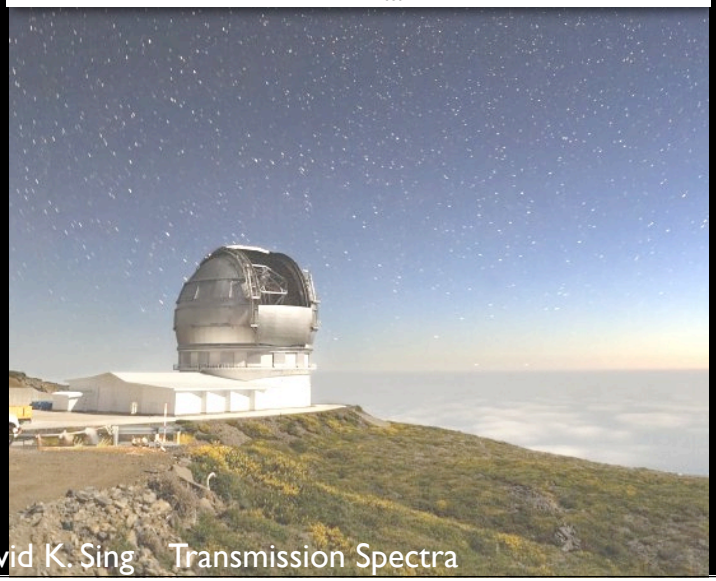


0.067%
12Å

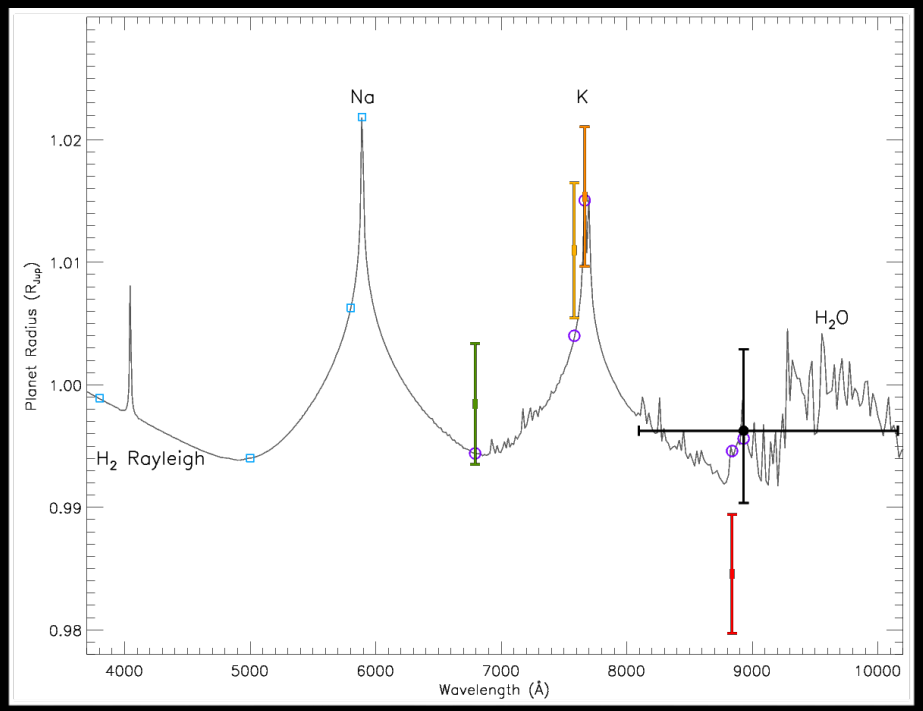
Sing et al. (2010) arXiv:1008.4795

Potassium in XO-2b





- Hot-Jupiters are Alkali-dominated optical (Na & K)
- Na/K producing low albedos



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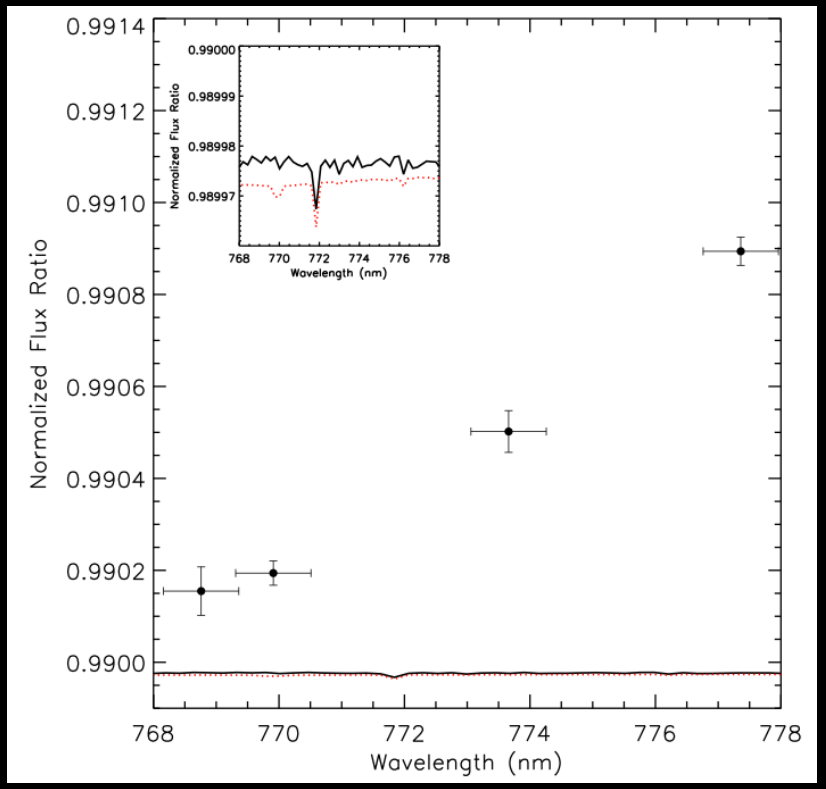
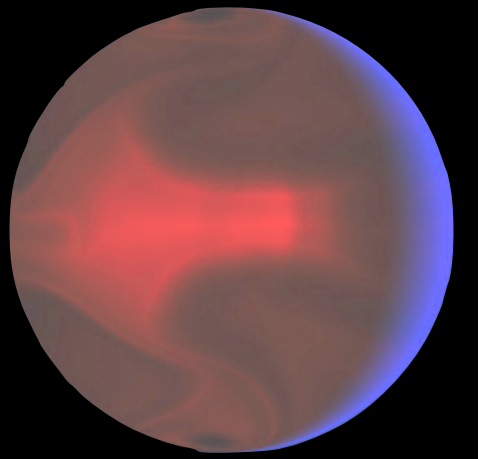
Potassium in HD80606b



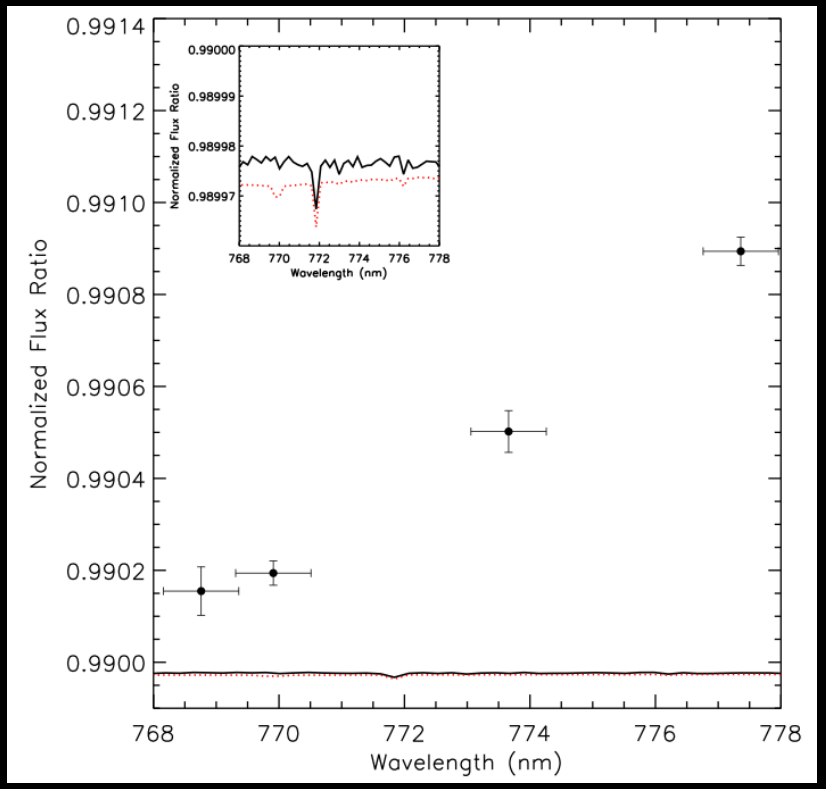
Colón et al. (2010) arXiv:1008.4800



See POSTER 2.5
by Knicole Colón
Characterising Planetary Atmospheres with Narrowband Transit Photometry

Potassium in HD80606b

- No absorption in K line-core
- absorption in K line-winds
- Winds?



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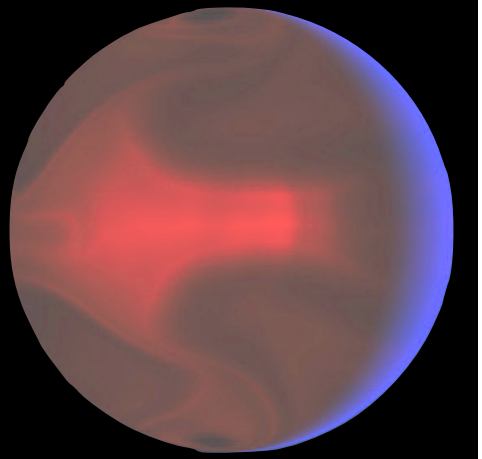

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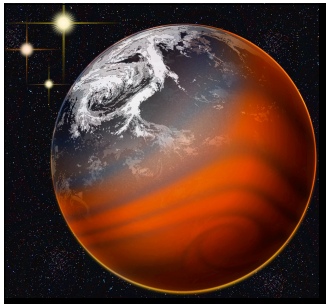
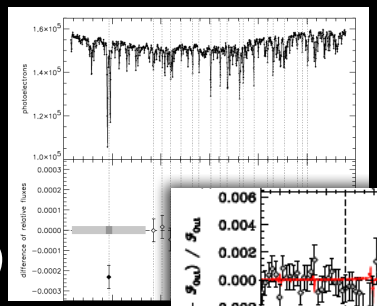


Na and K for 4 exoplanets

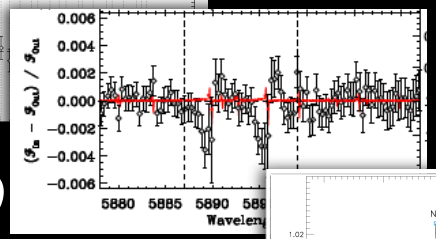
Exploring the diversity of Planetary Atmospheres

	Na	K
‘209	Yes	No?
‘189	Yes	No?
XO-2	-	Yes
‘606	-	Yes

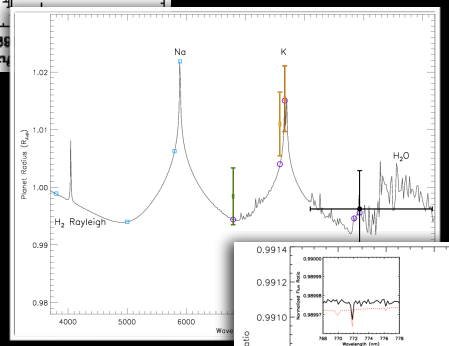
‘209



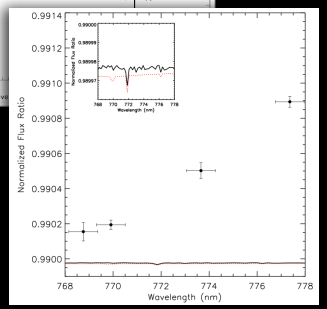
‘189

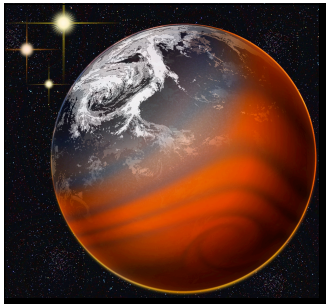


XO-2b



‘606





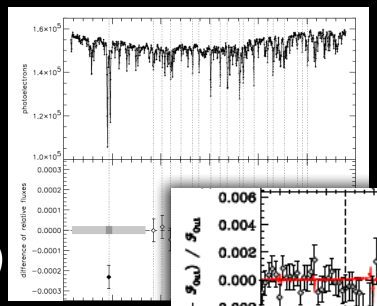
Na and K for 4 exoplanets

Exploring the diversity of Planetary Atmospheres

Conclusion

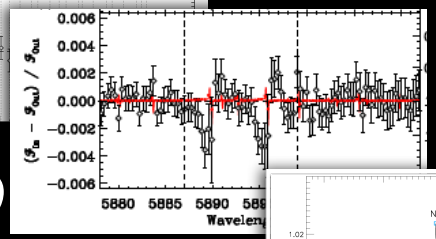
	Na	K
‘209	Yes	No?
‘189	Yes	No?
XO-2	-	Yes
‘606	-	Yes

‘209



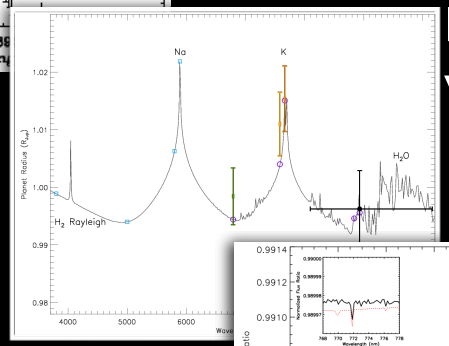
Na depleted at high-z, K?
Na Condensation/Ionization?

‘189



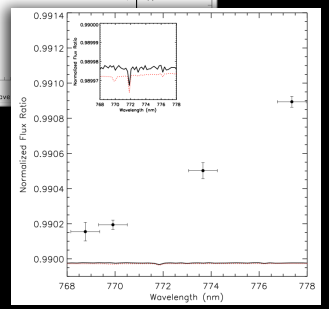
Where’s the K?
Haze obscuring

XO-2b

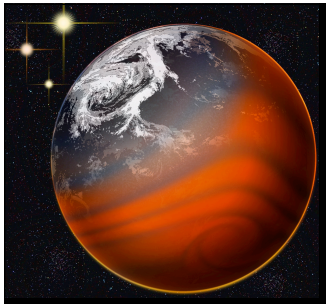


Normal?
weak inversion?

‘606



Wind?



Conclusion

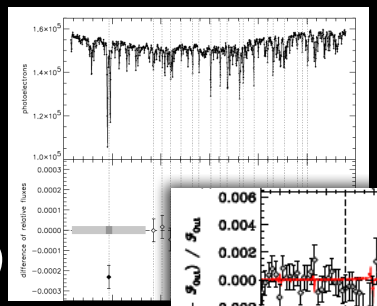
Na and K for 4 exoplanets

Exploring the diversity of Planetary Atmospheres

	Na	K
‘209	Yes	No?
‘189	Yes	No?
XO-2	-	Yes
‘606	-	Yes

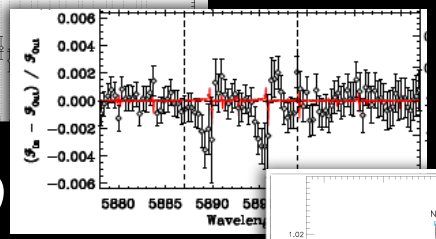
Wasp-17
Hat-P-12
Tres-4
GJ1214
CoRoT-1
GJ436

‘209



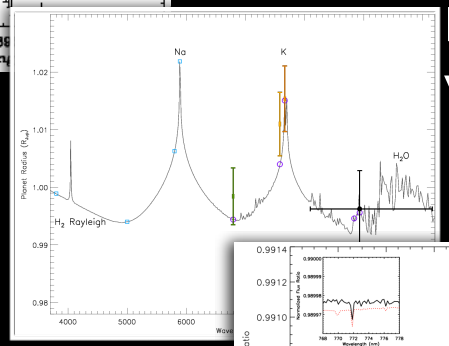
Na depleted at high-z, K?
Na Condensation/Ionization?

‘189



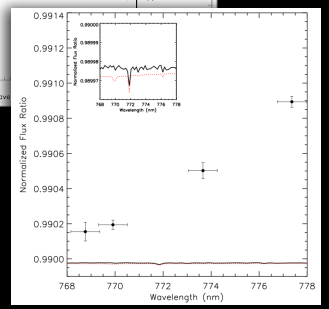
Where’s the K?
Haze obscuring

XO-2b



Normal?
weak inversion?

‘606



Wind?

stratosphere
optical-absorber
hazes & clouds
Abundances
Chemistry

TiO, VO, S_2, $MgSiO_3$, Rayleigh H_2, H_2O, CH_4, CO, CO_2...