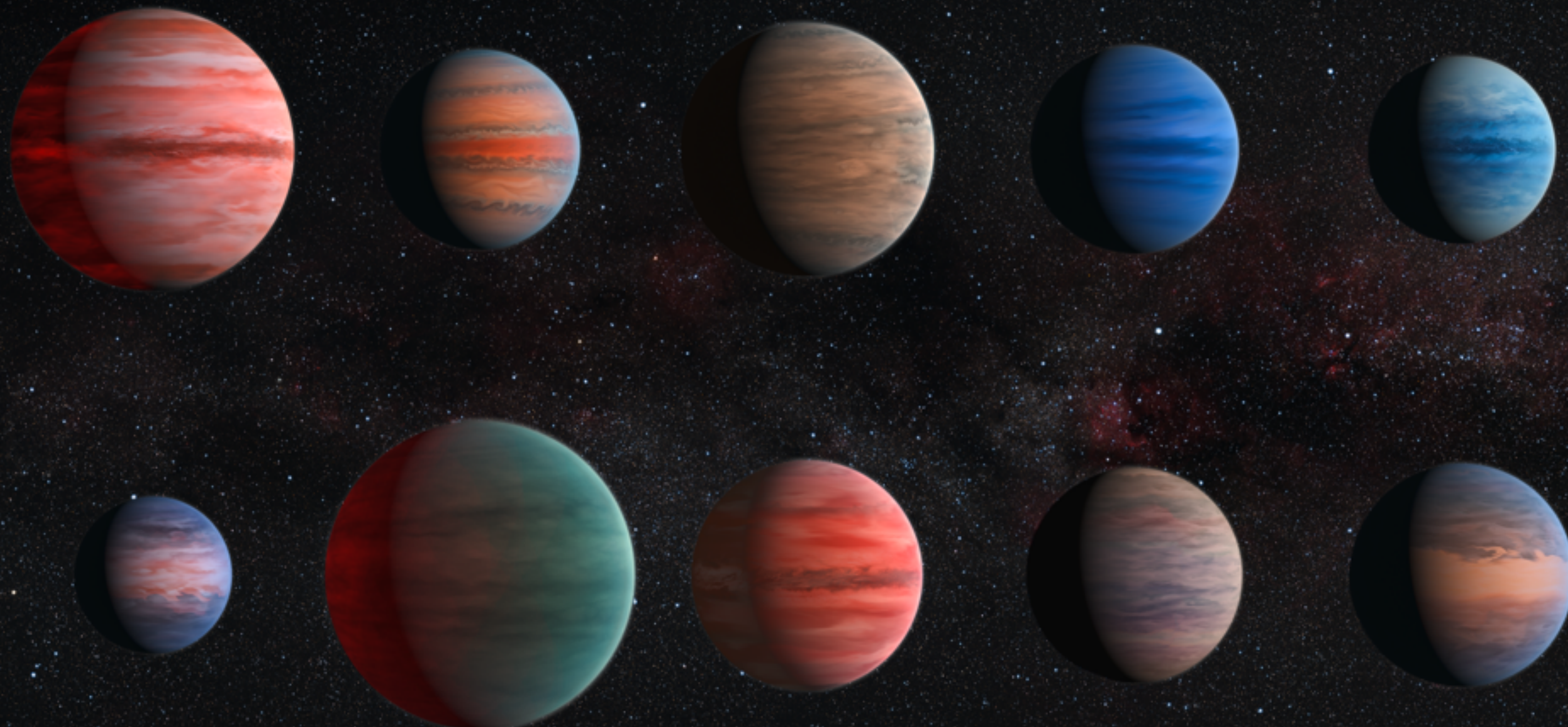
HST hot-Jupiter Transmission Spectral Survey

A continuum from clear to cloudy exoplanets

& JWST

David K. Sing



@ExoSing

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erc European Research Council

Exeter
EXOM2016
31 March 2016

HST Hot Jupiter Transmission Survey

HST Large Program (GO12473)

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Paul Wilson	IAP, France
Alfred Vidal-Madjar	IAP, France
Jonathan Fortney	UCSC, USA
Gilda Ballester	UofA, USA
Adam Showman	UofA, USA
Drake Deming	Maryland, USA
Heather Knutson	Berkley, USA
Adam Burrows	Princeton, USA
Suzanne Aigrain	Oxford, UK
Gibson Neale	Belfast, UK

Goal: Comparative Planetology

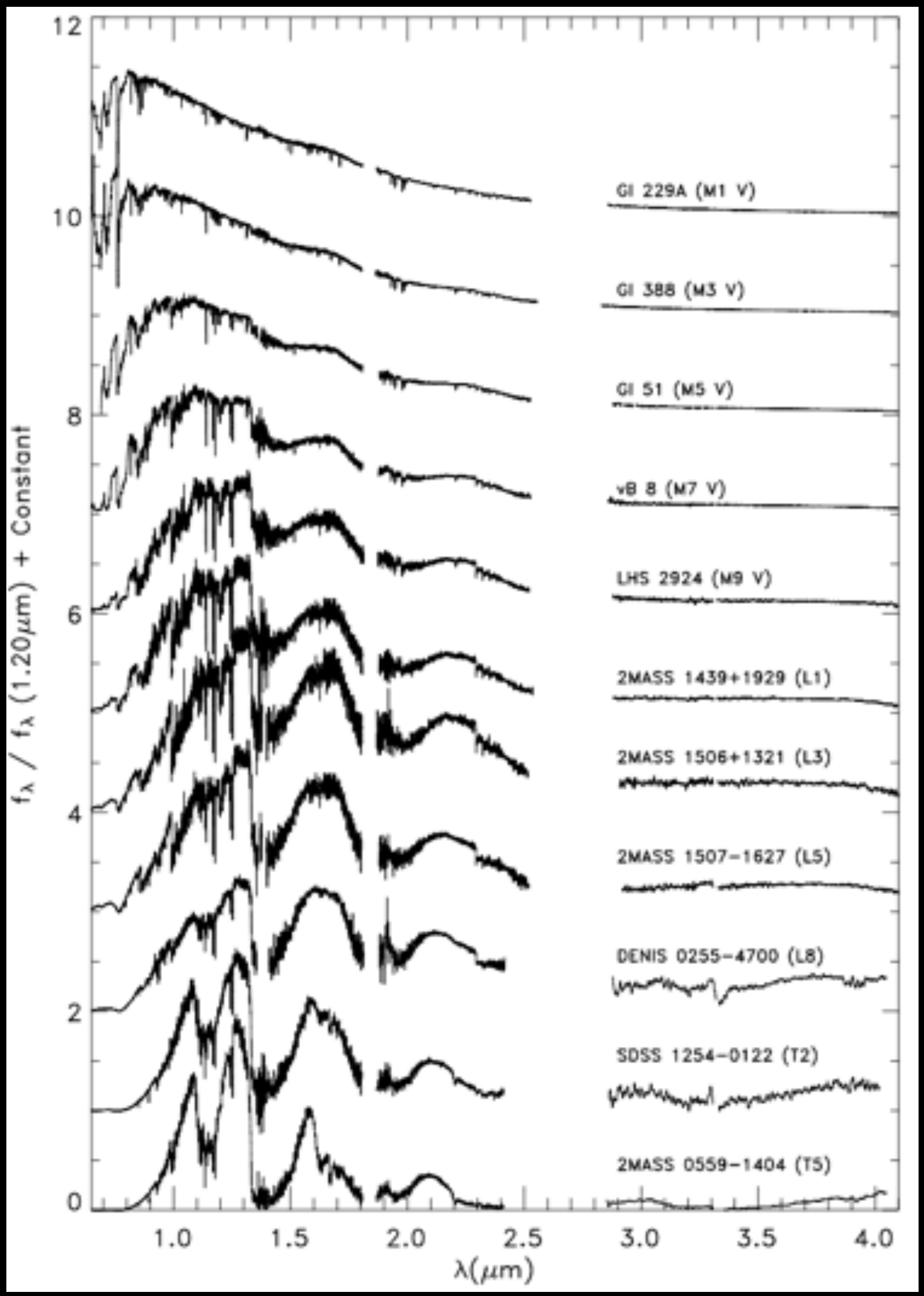
Sing et al. (2016, Nature)
arXiv:1512.04341

Comparative Studies: Stars & Brown Dwarfs

Spectral Sequence

T_{eff} — L to T / CO to CH_4

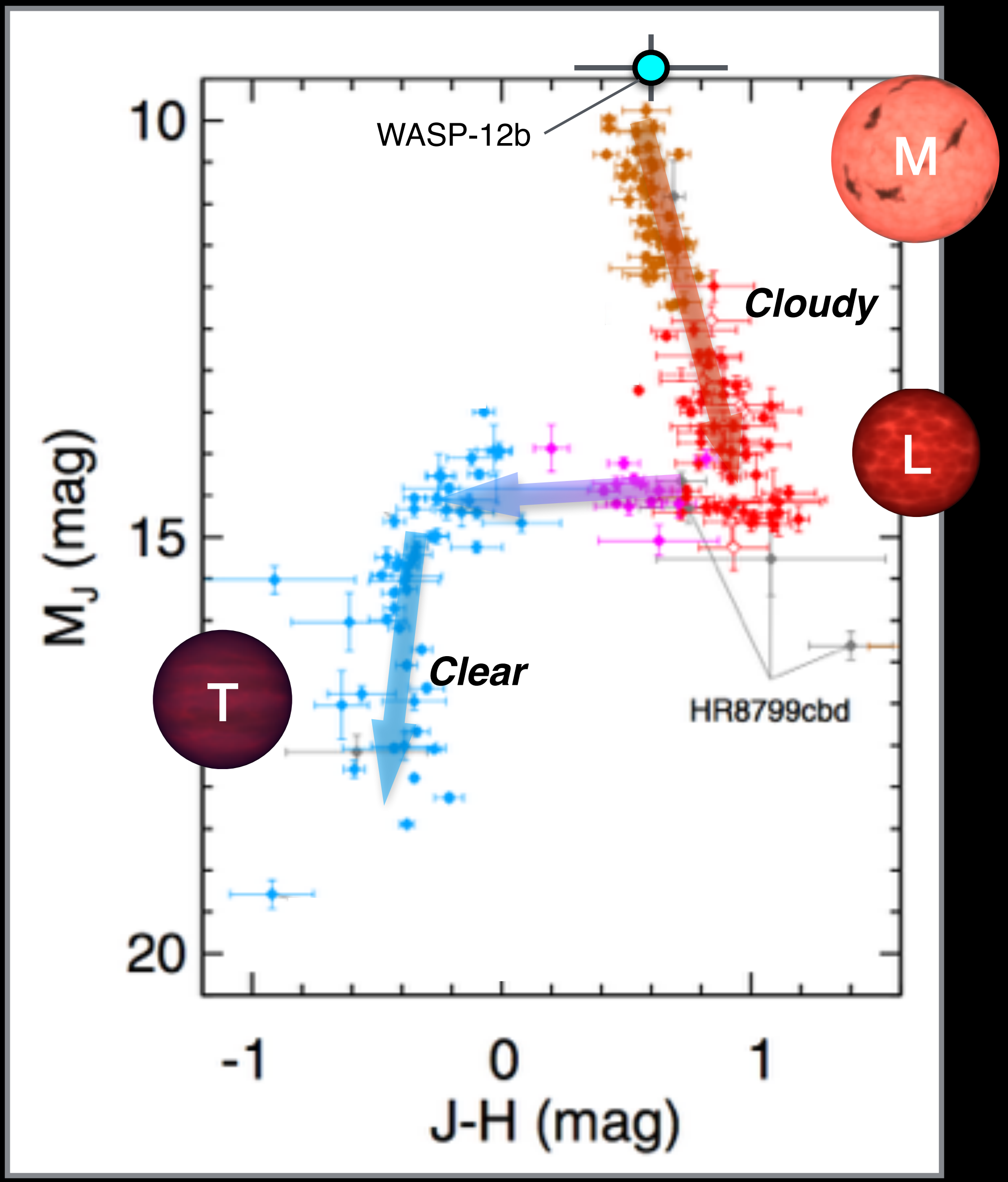
3500
2400
2000
1500
1200



Cushing et al. (2005)

Color-Magnitude Diagrams

Clouds



Dupuy et al. (2012)
Triaud et al. (2014)

See Chemistry In Action

Comparison: insight of Complex Physics

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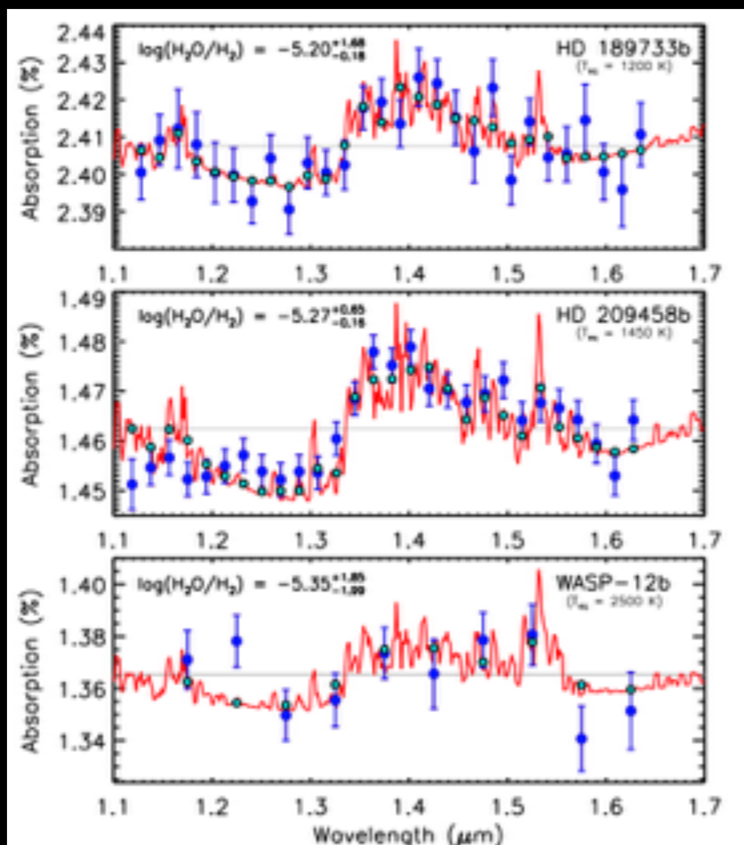
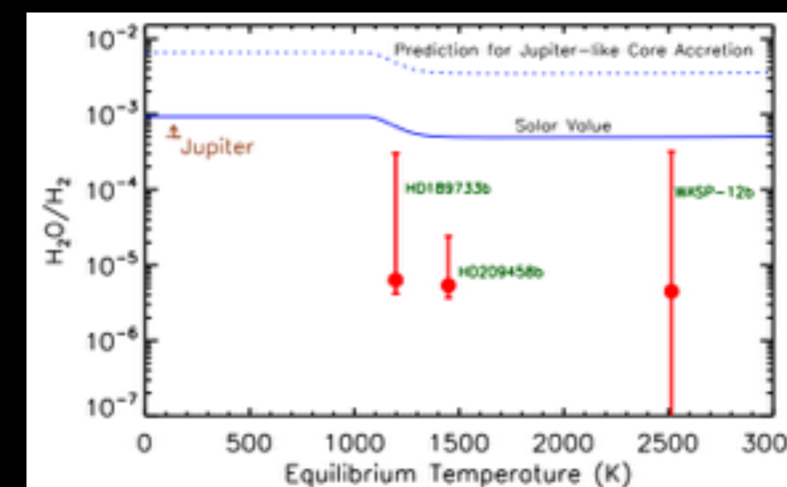
Comparative Studies: Hot Jupiters

H_2O



Lots of NIR data
Large, Muted & Absent H_2O
Puzzling variety

Low O Abundances?
From Formation?
Clouds & Hazes?



Madhusudhan et al. (2014)

Deming et al. (2013)
McCullough et al. (2014)
Oberg (2011)
Stevenson et al. (2014)
Sing et al. (2015)
Wakeford et al. (2013)

Degenerate with only WFC3

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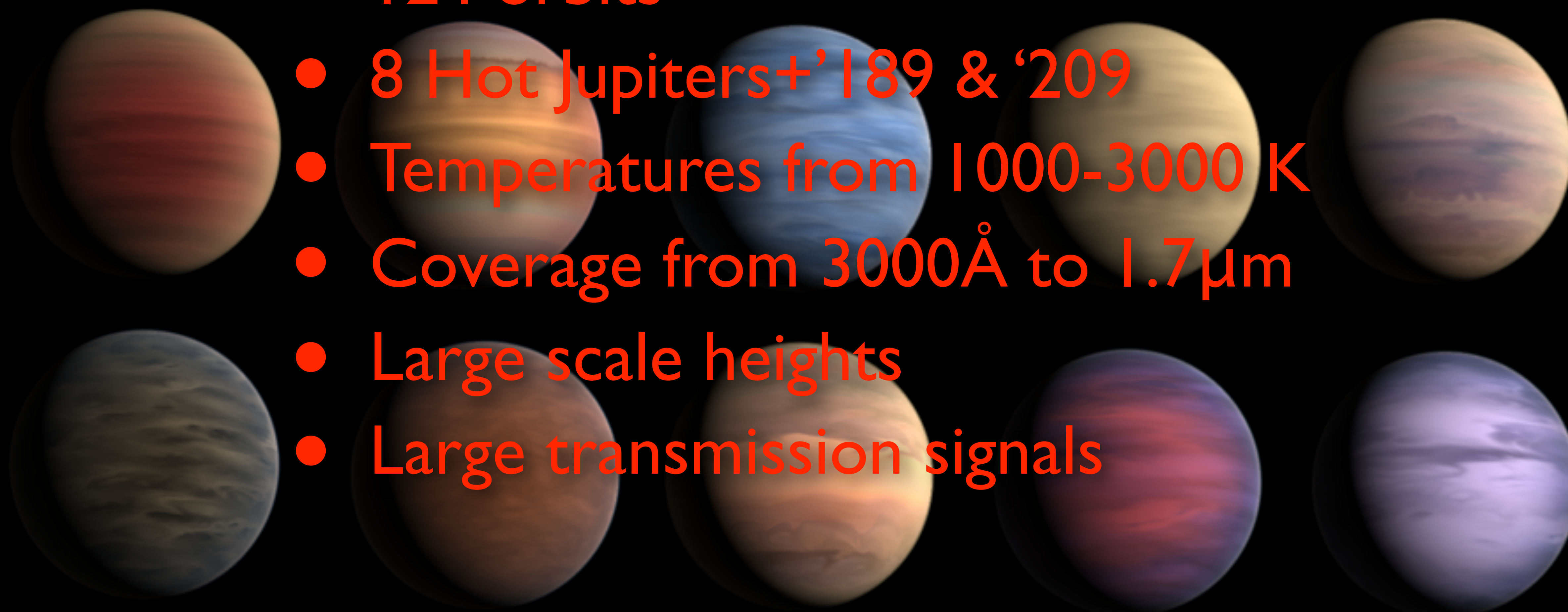
Hot Jupiter Atmospheric Survey



- 124 orbits
- 8 Hot Jupiters+'189 & '209
- Temperatures from 1000-3000 K
- Coverage from 3000Å to 1.7μm
- Large scale heights
- Large transmission signals

See individual planet papers for details

5 years and several PhDs later

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Comparative Studies: exoplanet spectral sequence

HST+Spitzer

10 exoplanets

0.3 - 5 µm

T_{eq} 950 - 2500 K

Detect

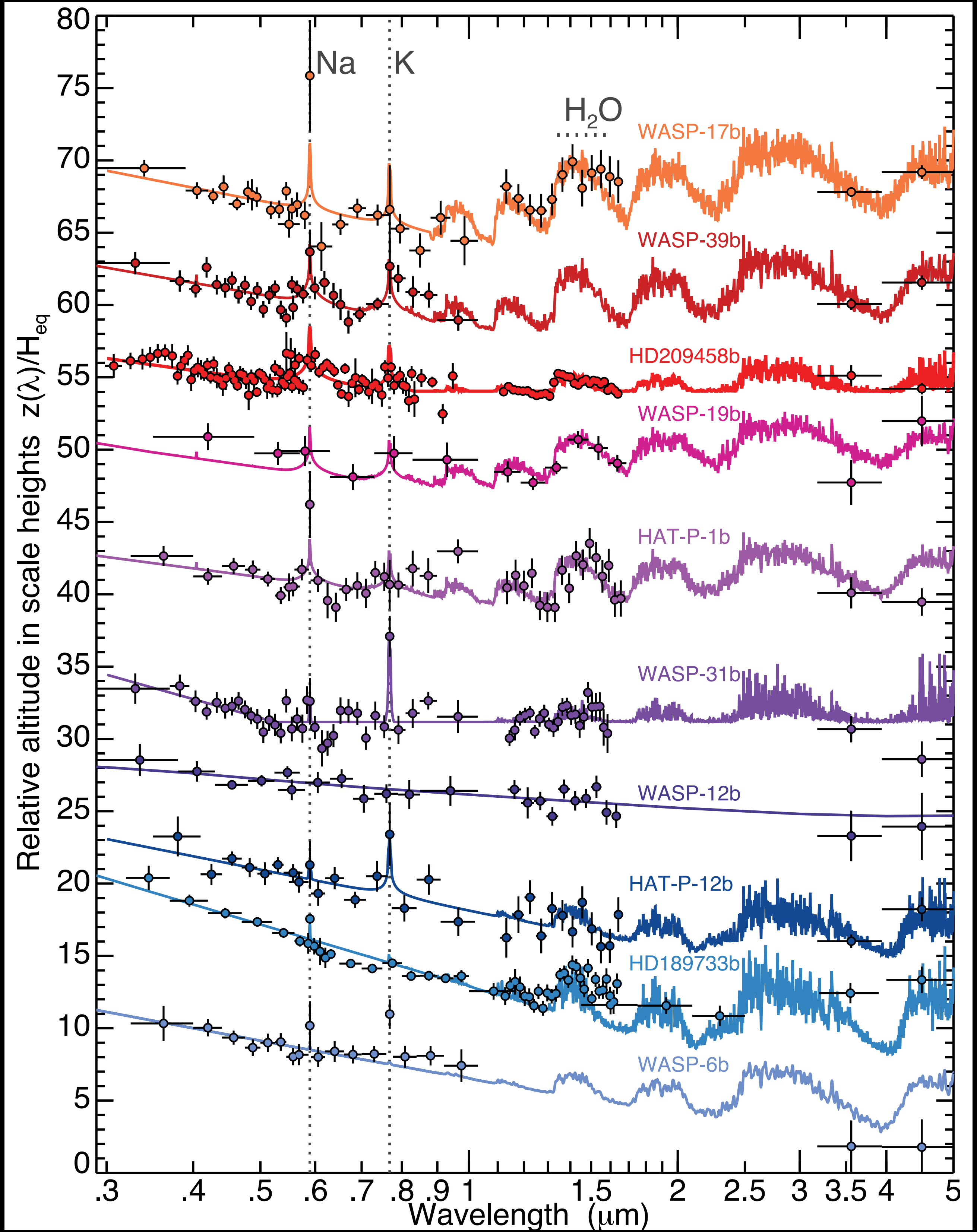
Na

K

H_2O

Haze

Clouds



Clear Skies

Strong Haze

Sing et al. (2016, Nature)

link to data arXiv:1512.04341

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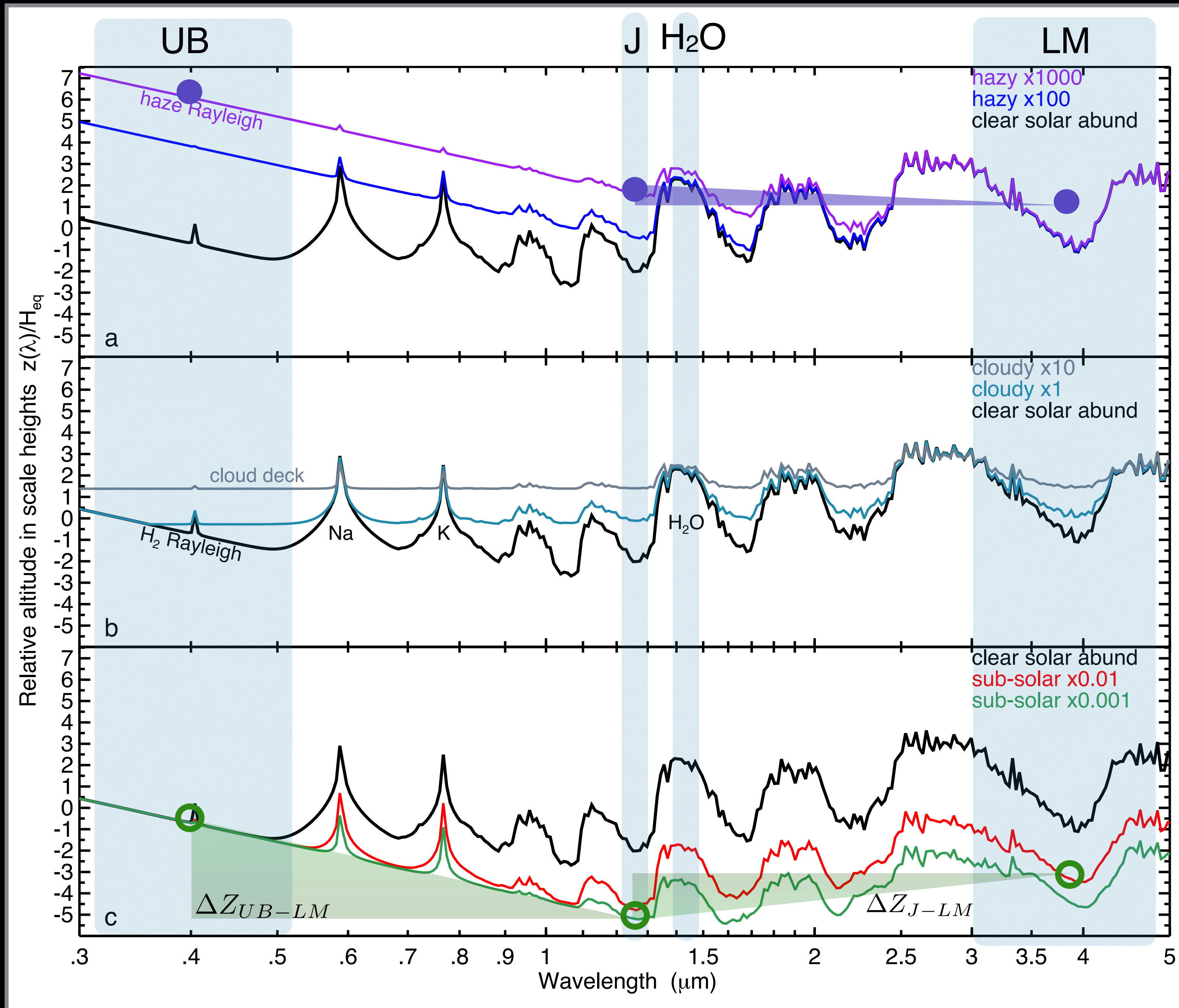
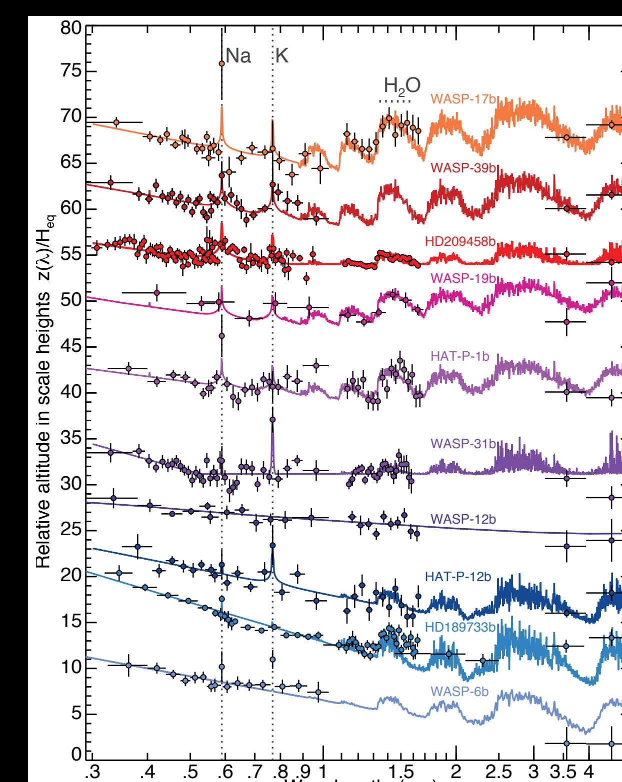
Comparative Exoplanetology: transmission metrics

Scattering   Scattering & H_2O Molecules: H_2O, CO, CH_4



Sing et al. (2016, Nature) arXiv:1512.04341

Spectral Indices	HST & Spitzer
ΔZ_{J-LM}	WFC3 - IRAC
ΔZ_{UB-LM}	STIS - IRAC
$1.4\mu m\ H_2O$ Amplitude	WFC3



Degeneracies: Metallicity, Clouds, & Haze

Break with wide λ   Only Haze $\Delta Z_{J-LM} > 0$

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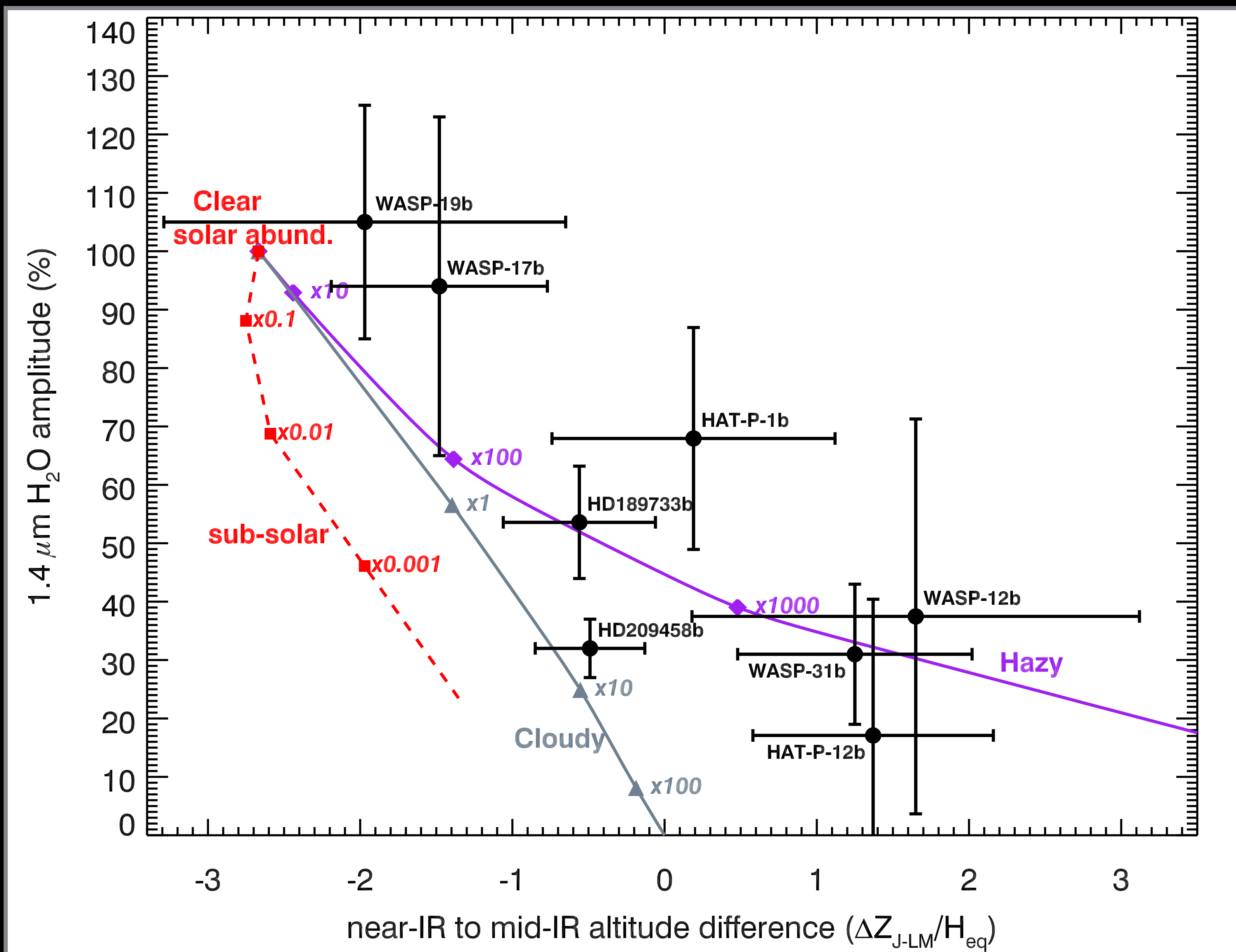
Comparative Exoplanetology: transmission metrics



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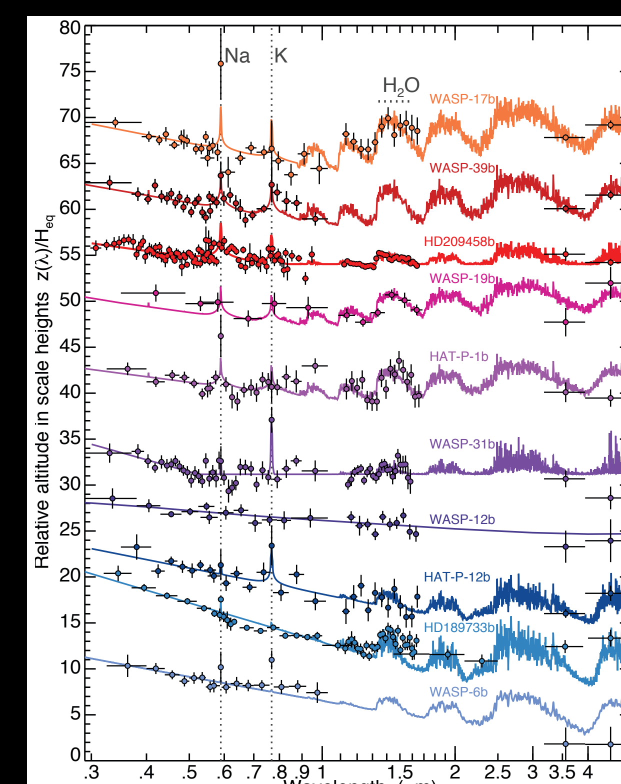

Small H_2O features due to **Haze**

Rule out low abundance scenario

5.9σ

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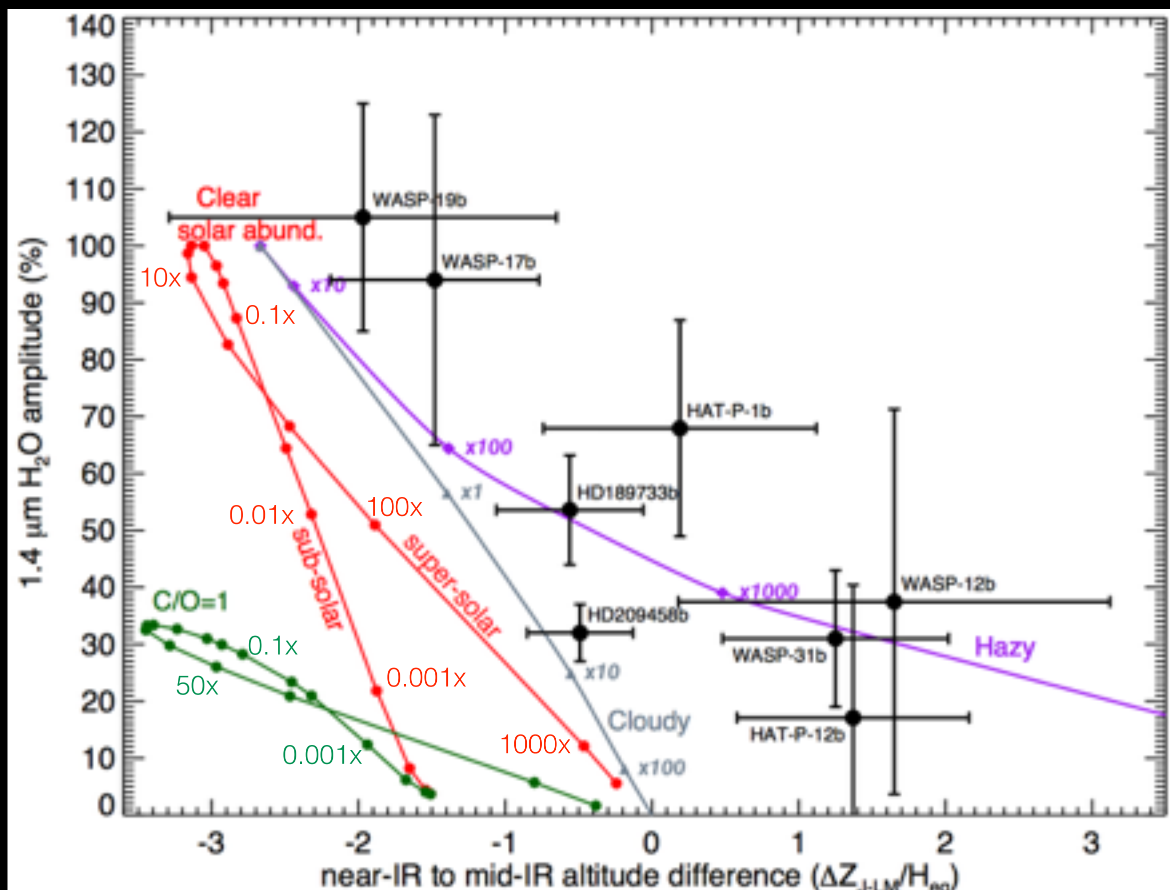
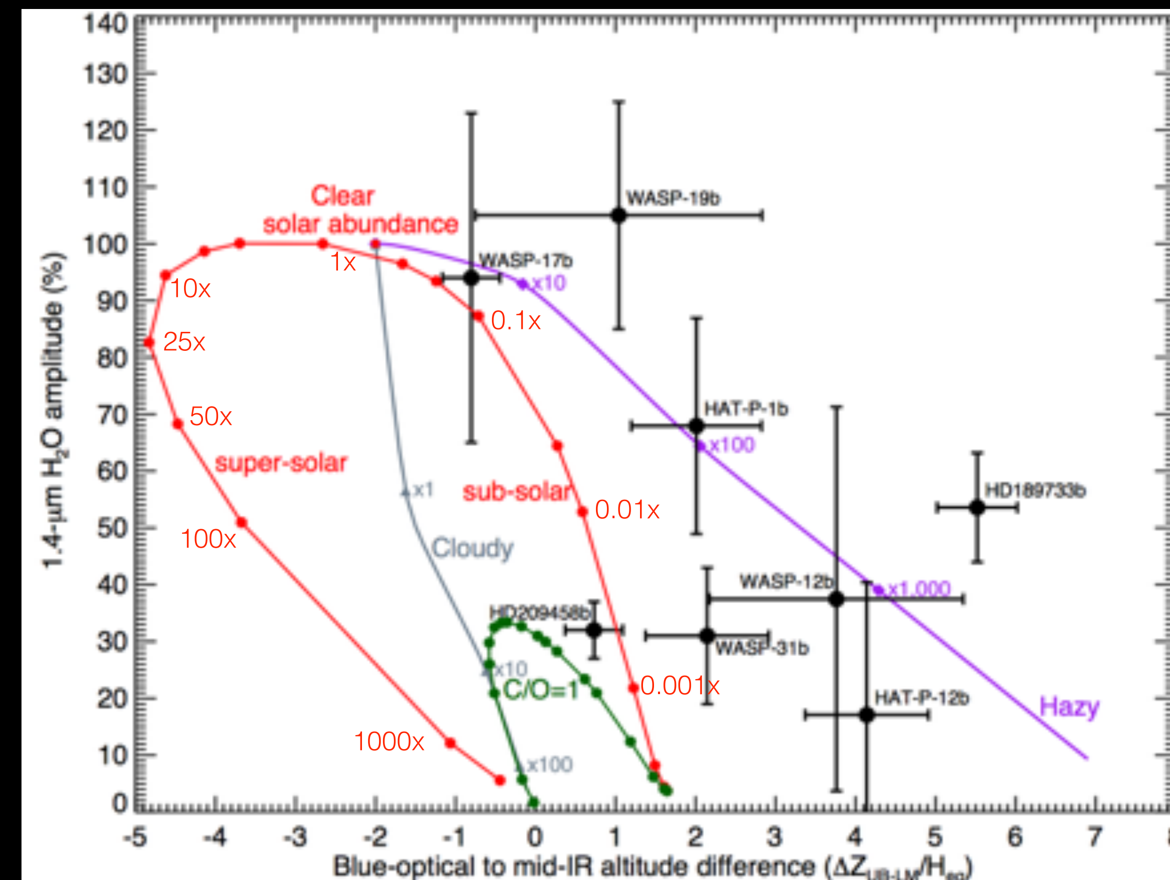
Comparative Exoplanetology: transmission metrics

high C/O ratios?



super-solar metallicities?



Sing et al. (2016) with Additional Models. log[M]=-6 to 4

Positive ΔZ_{J-LM}

H₂O amplitude > 40%

rules out high C/O

Positive ΔZ_{UB-LM}

rules out super-solar metallicities (≲10x)

also see: Benneke (2015, arXiv)

Line & Parmentier (2015, arXiv)

Kopparla et al. (2015, arXiv)

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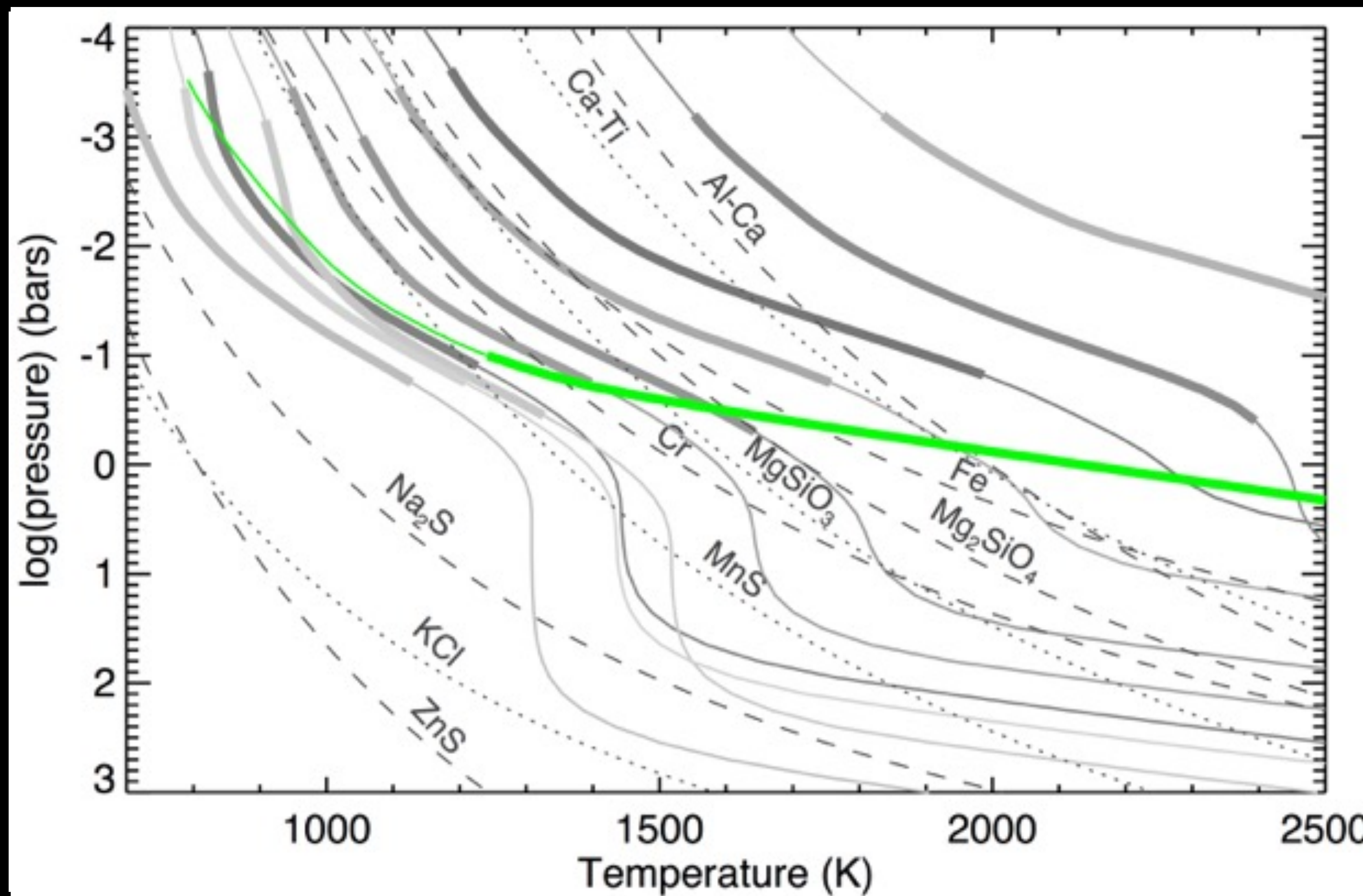
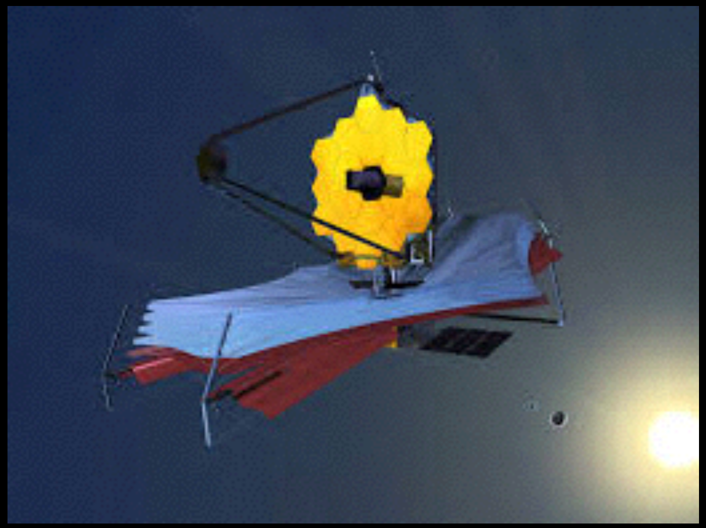
Pressure-Temperature



So why are exoplanet clouds stochastic?

Parallel T-P & Condensation Curves

JWST IS COMING… SOON



Is the "*perfect*" Exoplanet Observatory

50 Spitzers
14 HSTs

All 4 Cameras Can Observe Transits

Diverse Exoplanet science: Direct Imaging, Disks…

More Time available than you think

HST: 3400 Orbits/year => 2720 Hours/year observing

JWST: at L2 => 6000 Hours /year on-target integration

Conservative >0.5 years on JWST for Exoplanets in 5yrs

Demand: HST doubled in 5yrs. 15%

JWST should be 15 - 20%

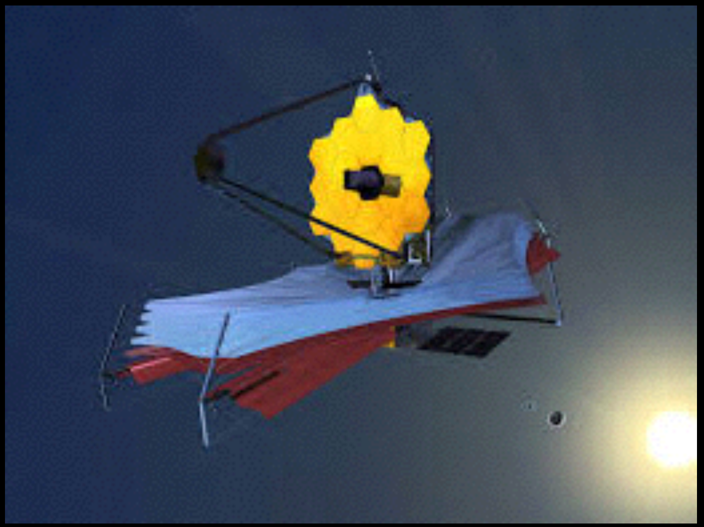
~200/1300 'good' targets

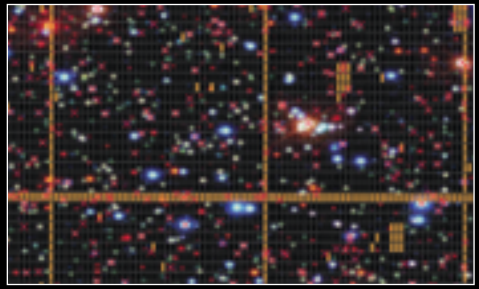
~100 transits/year

Exoplanet demand similar to Cosmology on HST

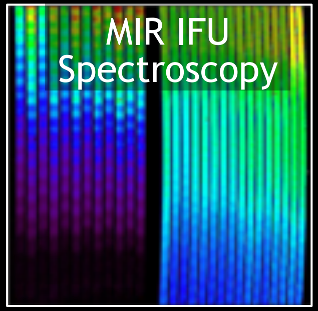
JWST Complex Instruments

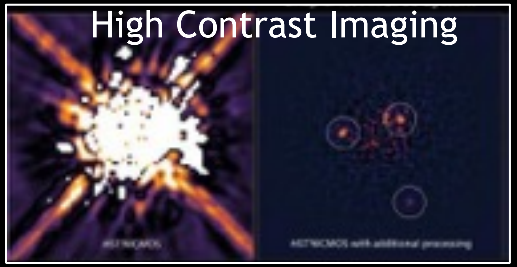
>40 imaging filters
8 spectroscopic modes
(multi-object, IFU, wide field grism, single object)
multiple coronagraphs

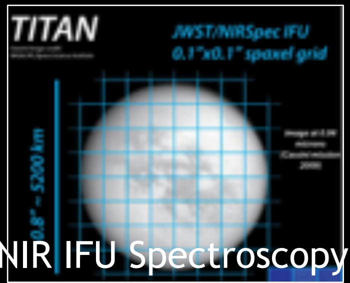




MOS in Space



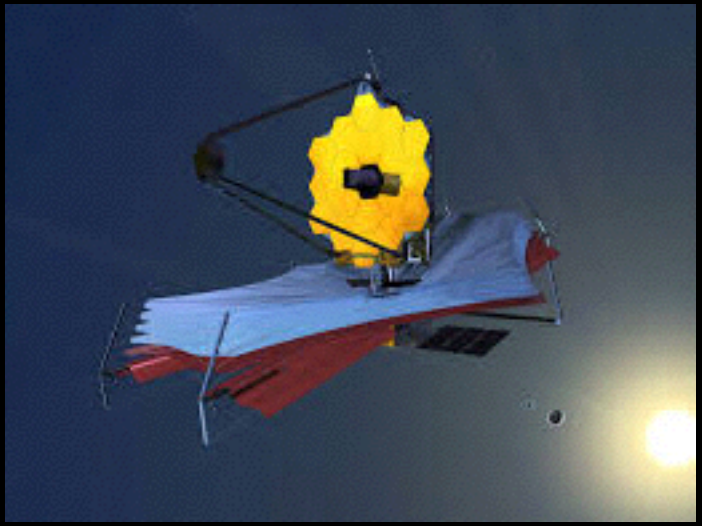


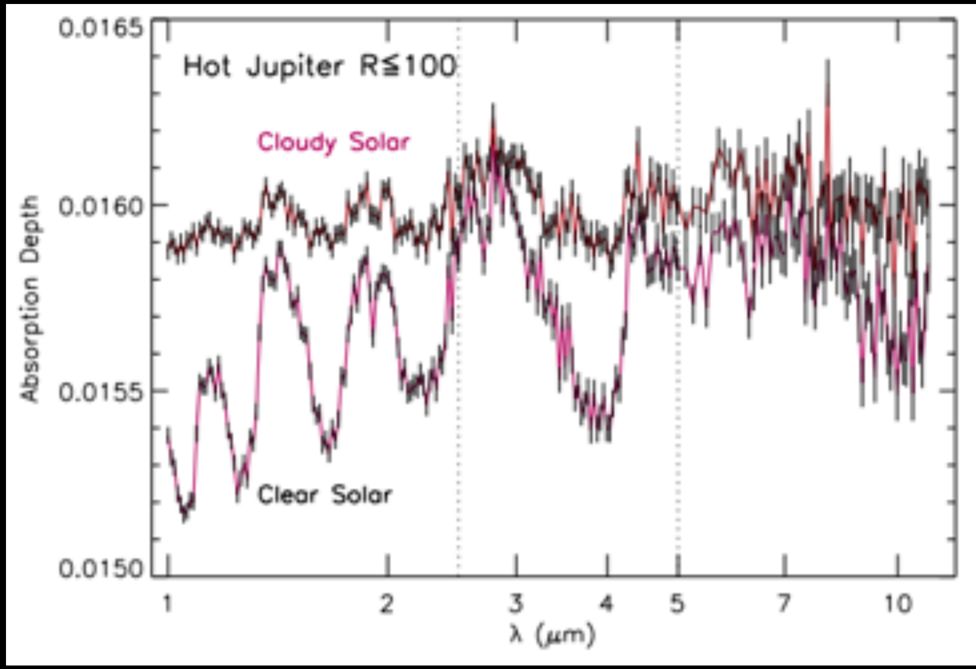


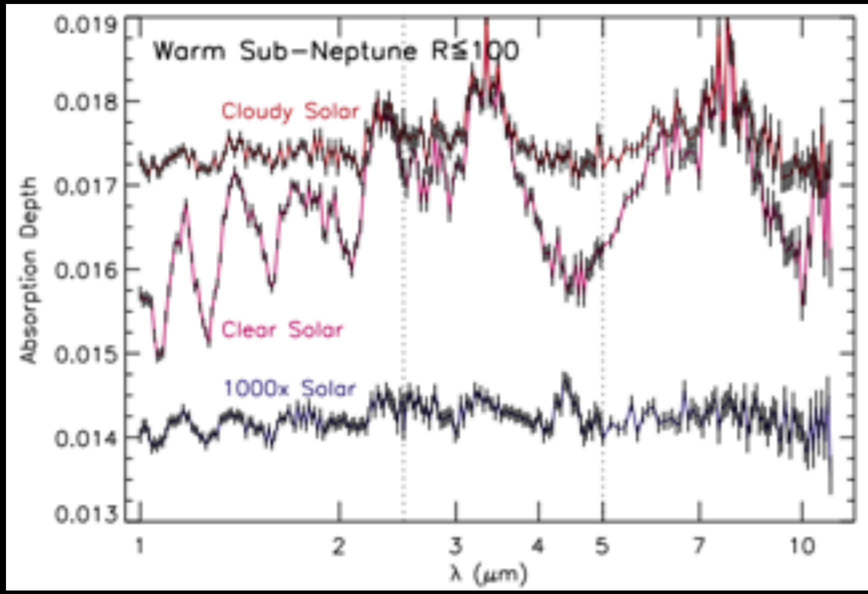
Slide adapted from Neill Reid STScI

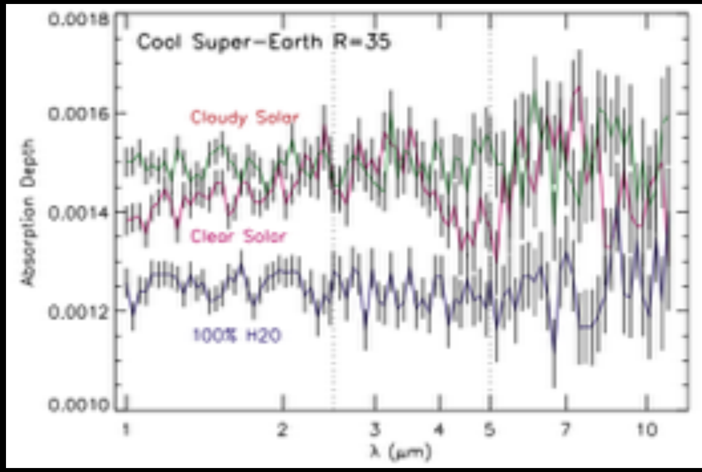
JWST Transiting Exoplanets

0.6- 2.5 um NIRISS
0.6- 5.0 um NIRISS+NIRCam
0.6 - 11 um NIRISS+NIRCAM+MIRI







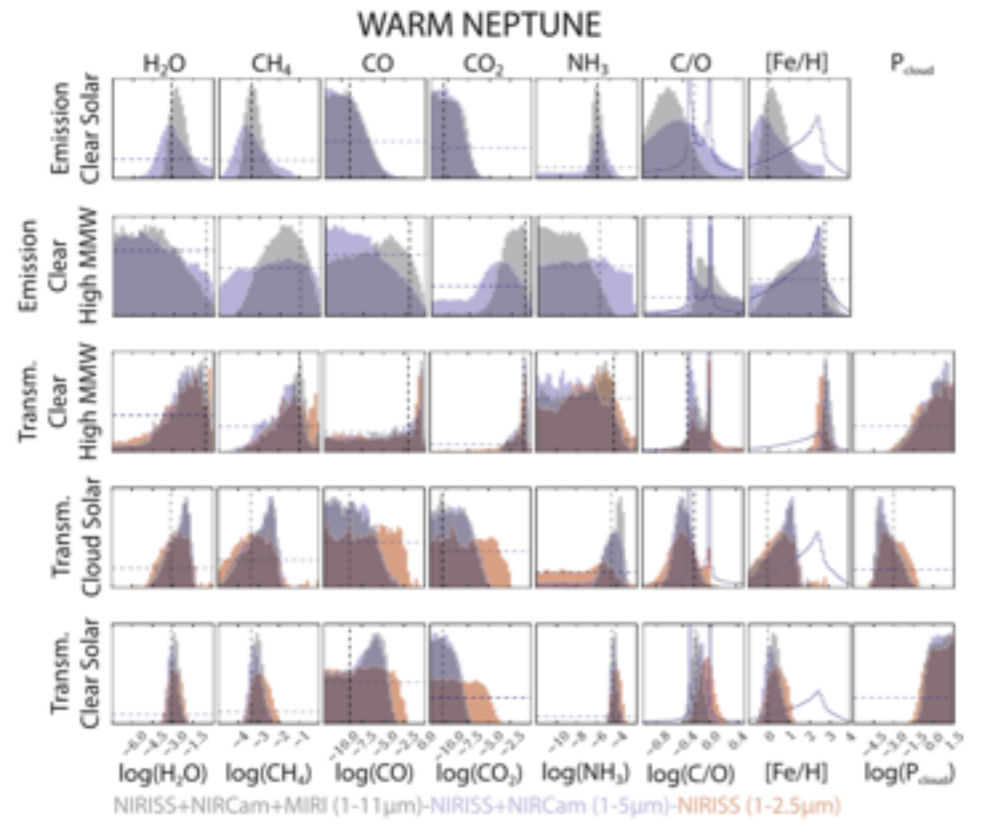


Extraordinary Hot Jupiters

Excellent Neptunes

Not too bad Super-Earths

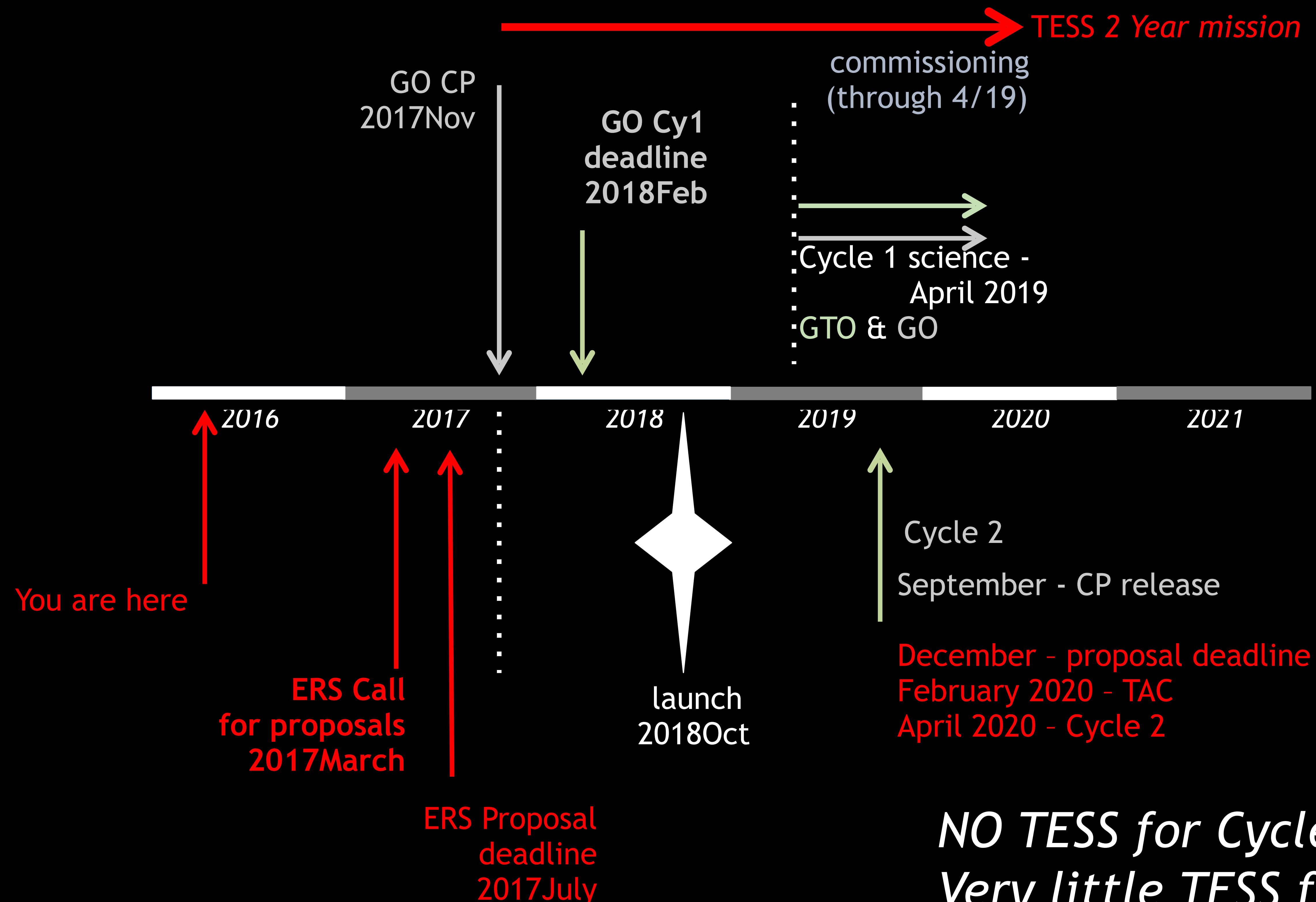
>50+ Targets at
0.6 to 11 um



Greene et al. (2016)

JWST Science Planning Timeline

(schedule as of January 2015)



NO TESS for Cycle 1

Very little TESS for Cy2

NEED WASP+NGTS+K2!!!

Slide adapted from Neill Reid STScI

Conclusions

Comparative Planetology   Exoplanets are very DIVERSE

Clouds & Haze Common NOT Universal

No Primordial Water Depletion

PREPARE FOR JWST

Metrics to Classify Cloudiness

~40/200 clear, know ~3