JWST NIRISS GTO program on transiting exoplanets atmosphere characterization

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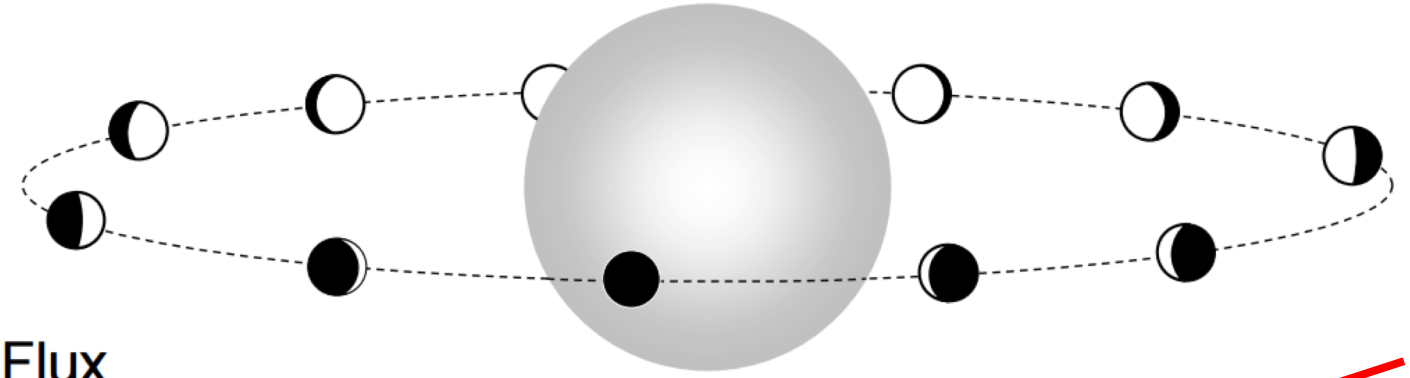
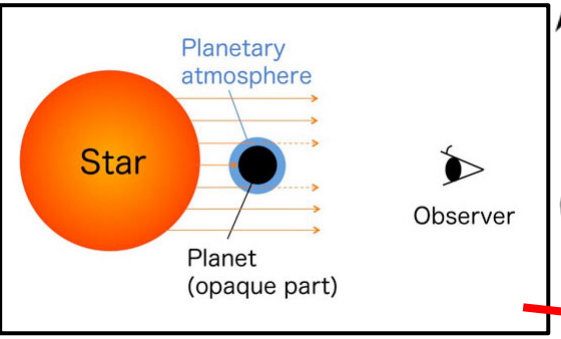
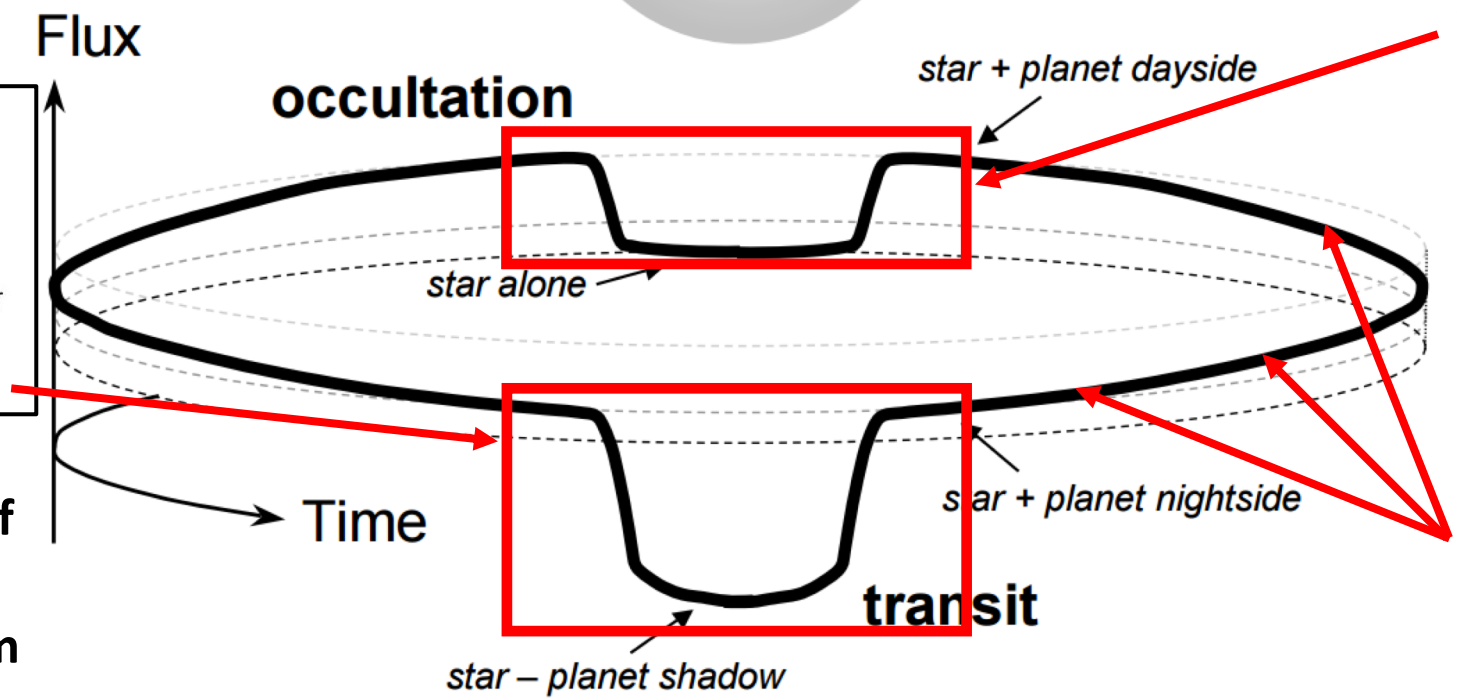
Future of Space Astronomy in Canada workshop

Montreal, 2018 November 6-7

The approach: spectroscopy at transit, eclipse, & full orbit







The **depth of the transit as a function of wavelength** provides **transmission spectrum** of planet **terminator**

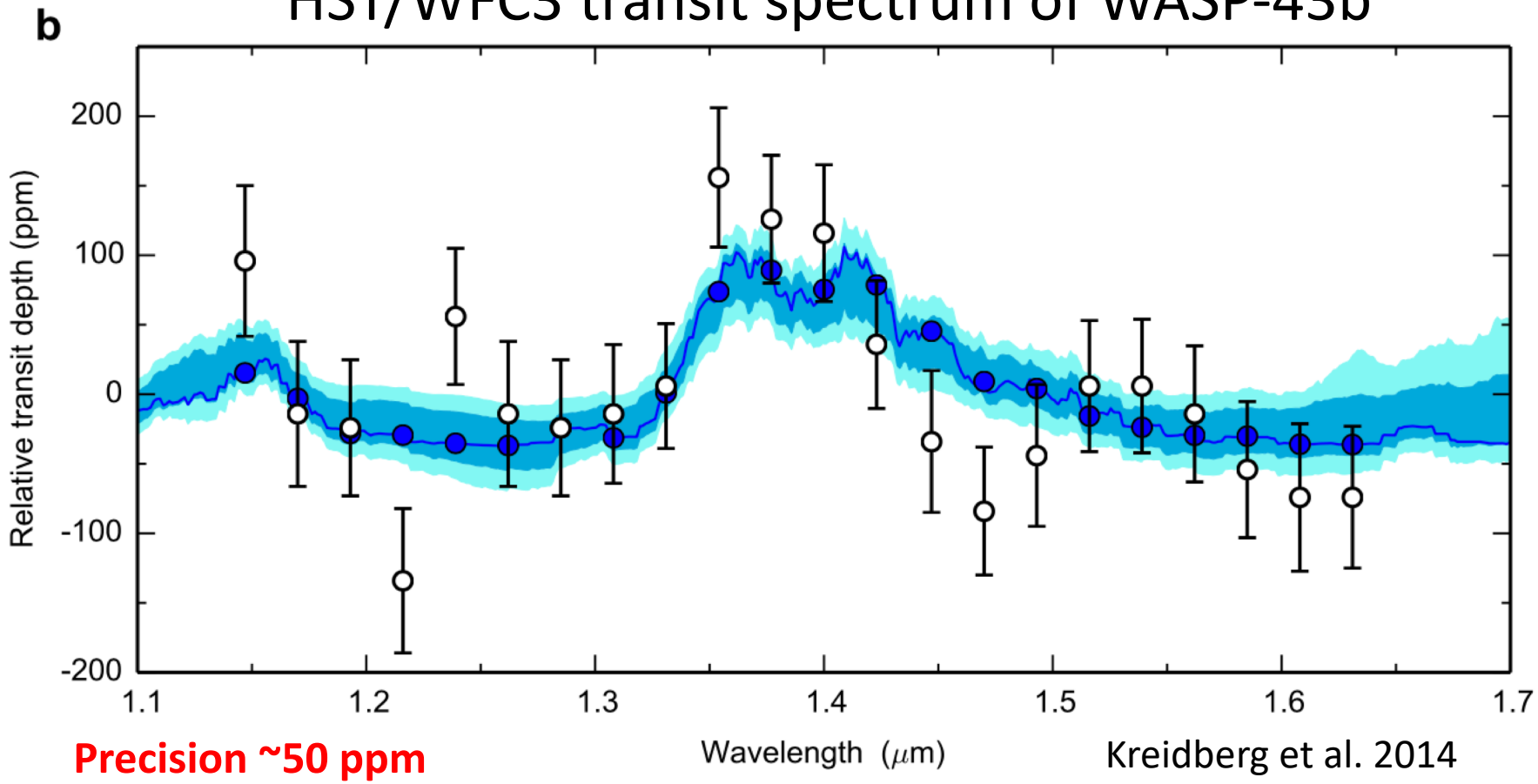
The **depth of the eclipse as a function of wavelength** provides **emission + scattered spectrum** of planet **dayside**

Emission+reflexion from different hemispheres/phases

These observations are best done from space

An example of state-of-the-art observations

HST/WFC3 transit spectrum of WASP-43b



Precision ~50 ppm
R~60

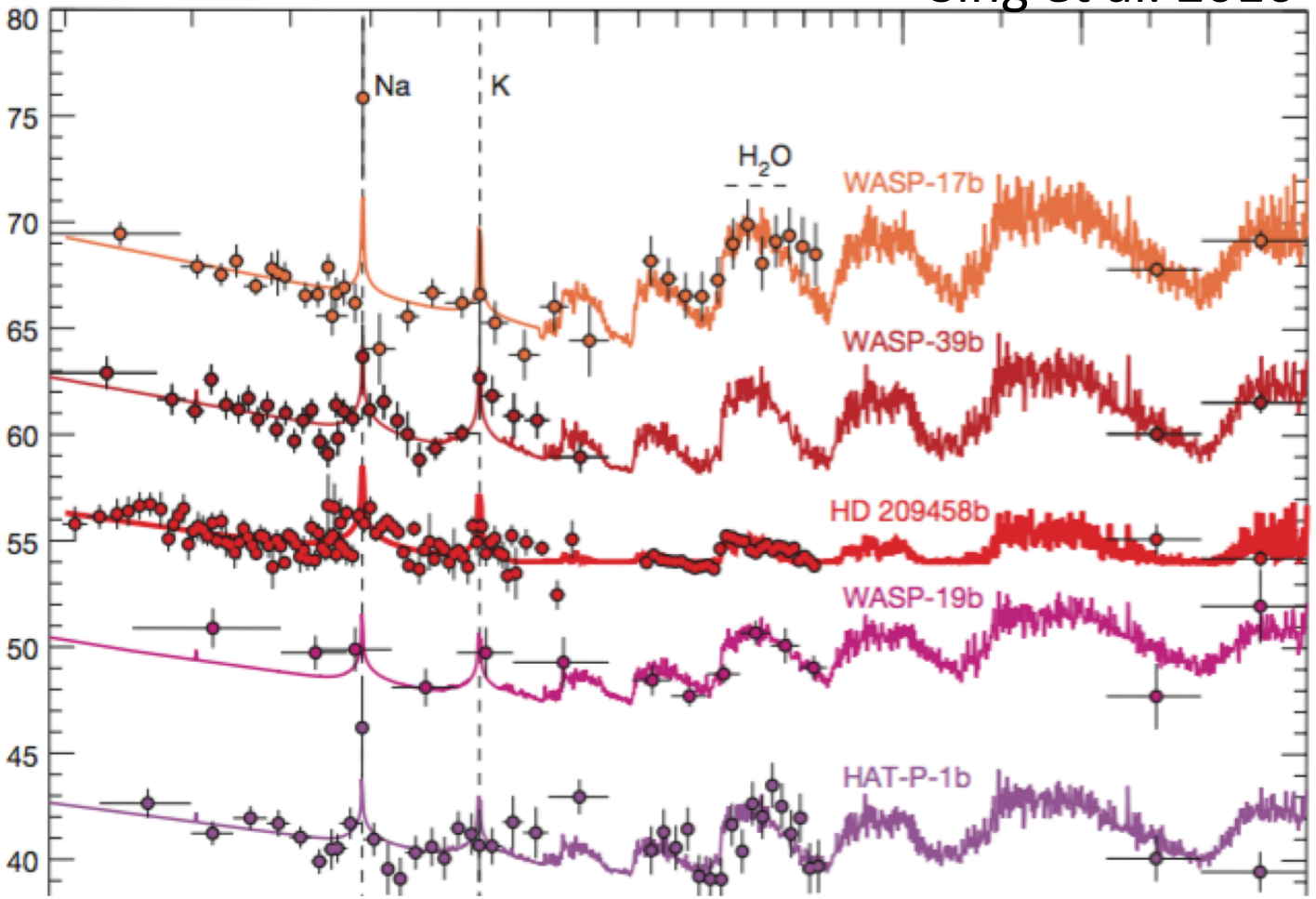
Kreidberg et al. 2014

Some achievements of space-based transit/eclipse spectro/photometry

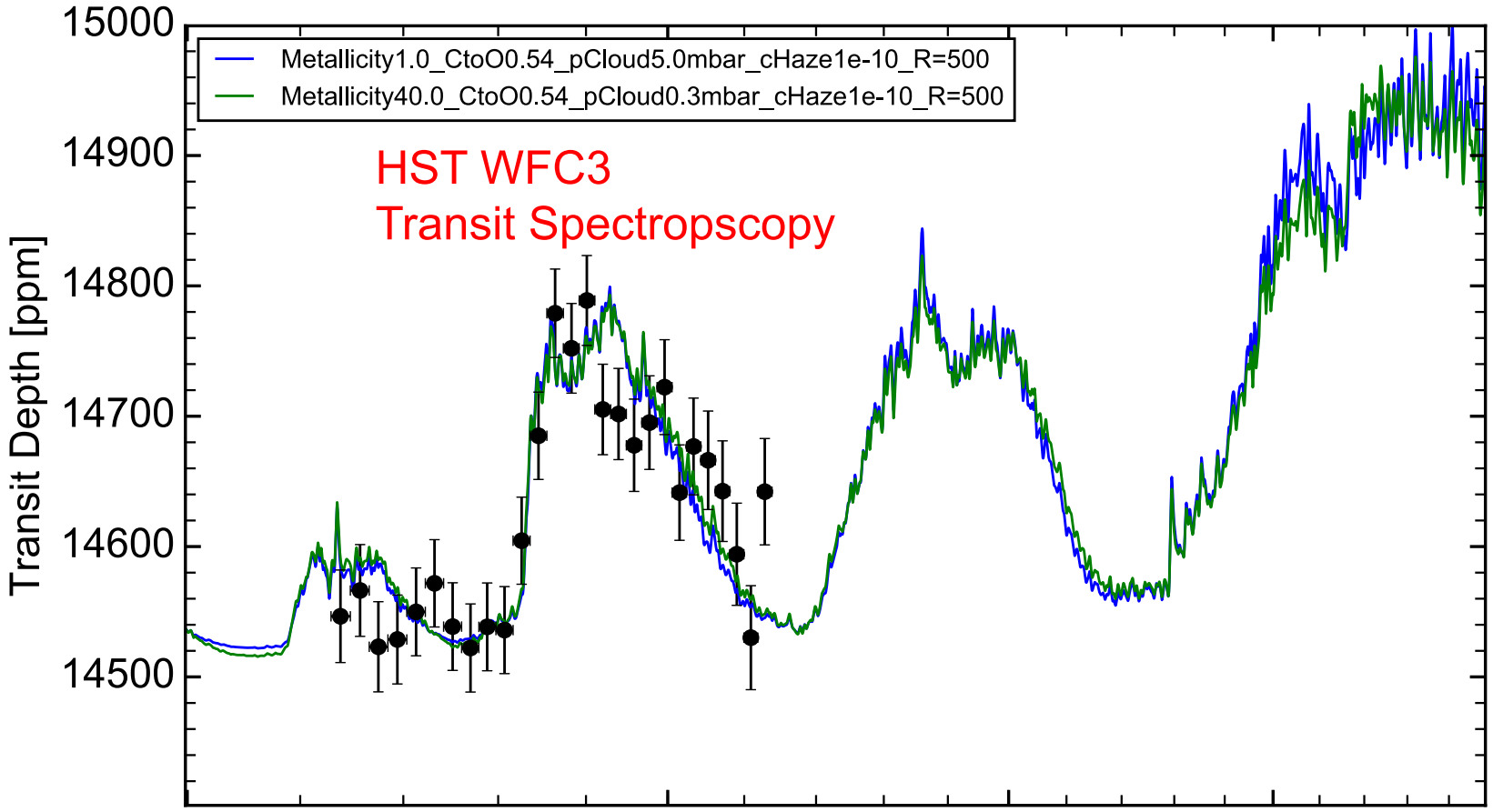
- Detection of H2O, Na, K, NH3
- Detection of Rayleigh scattering due to hazes/aerosols/H2
- Detection of particulate clouds
- Detection of thermal emission
- Thermal inversion

- But the properties related to all of the above are all (mostly) unconstrained

Sing et al. 2016



Overall metallicity/clouds degeneracy in transit spectro.



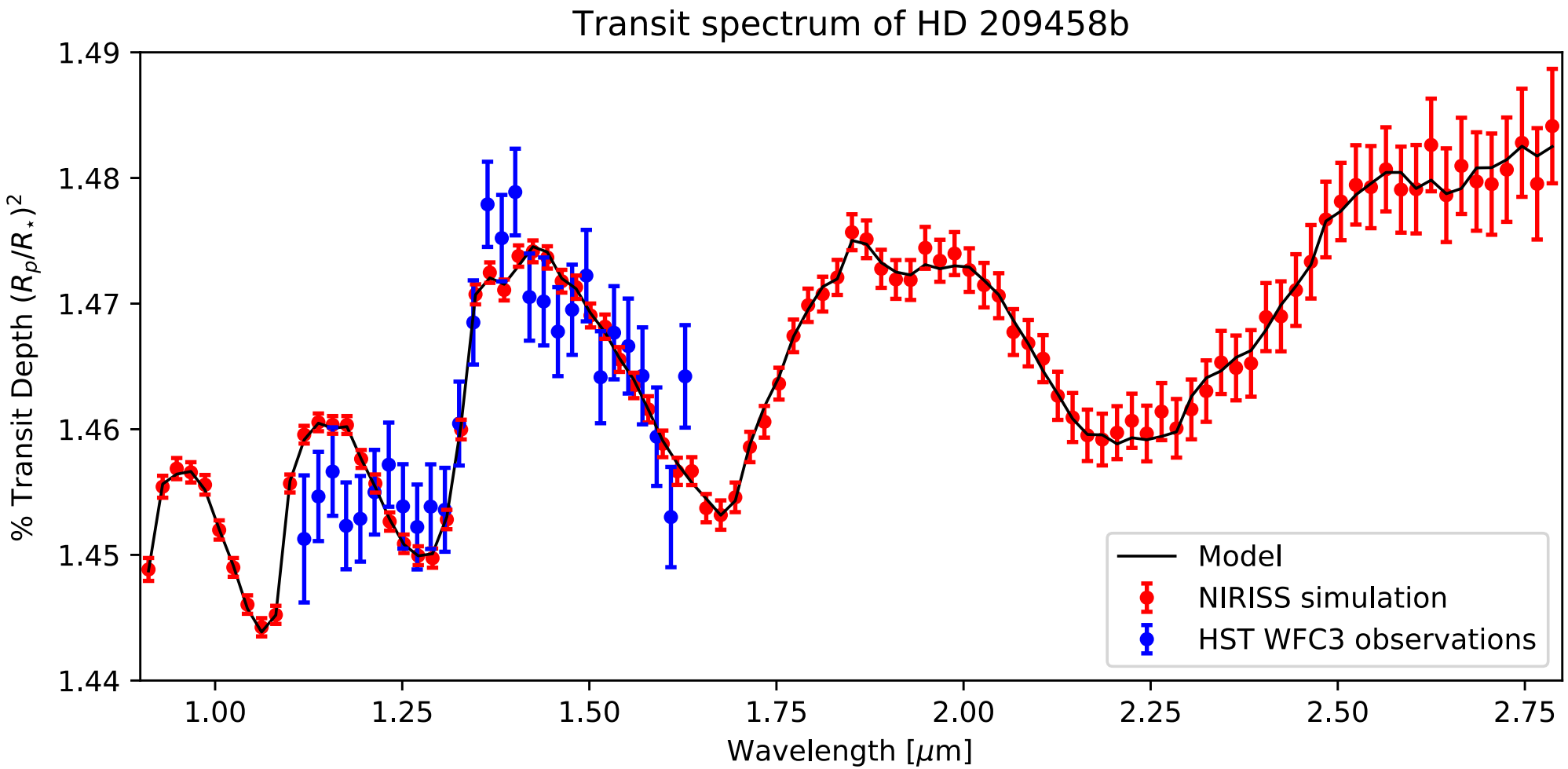
HD 209458b

Figure/models: B. Benneke
Data points: Deming et al. 2013

Blue: solar metallicity, low clouds (5 mbar)

Green: 40X solar metallicity, high clouds (0.3 mbar)

Transit spectrum of HD 209458b
HST/WFC3 vs JWST/NIRISS

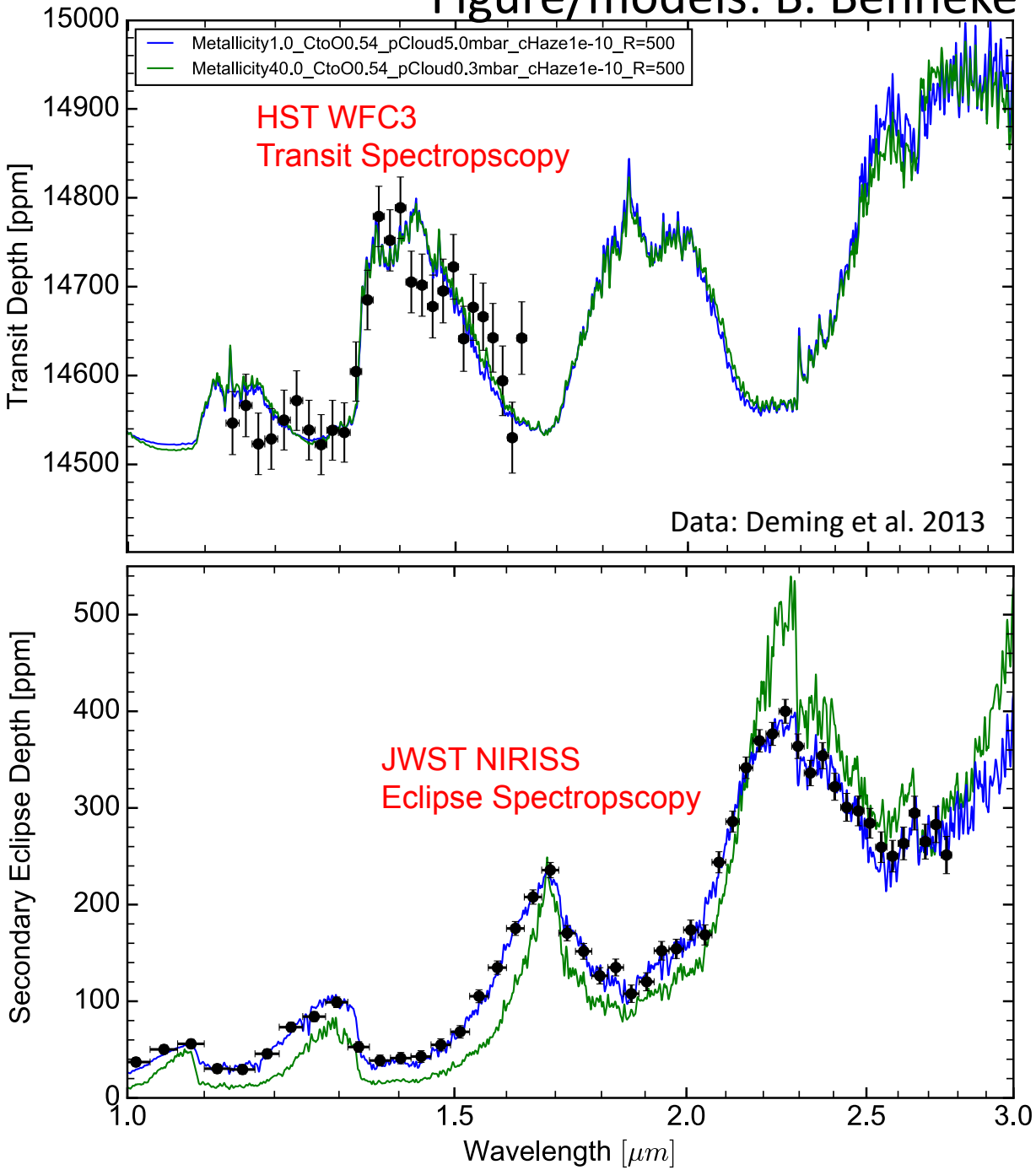


Metallicity/cloud degeneracy

HD 209458b transit+eclipse
Blue: solar metallicity, low clouds (5 mbar)
Green: 40X solar metallicity, high clouds (0.3 mbar)

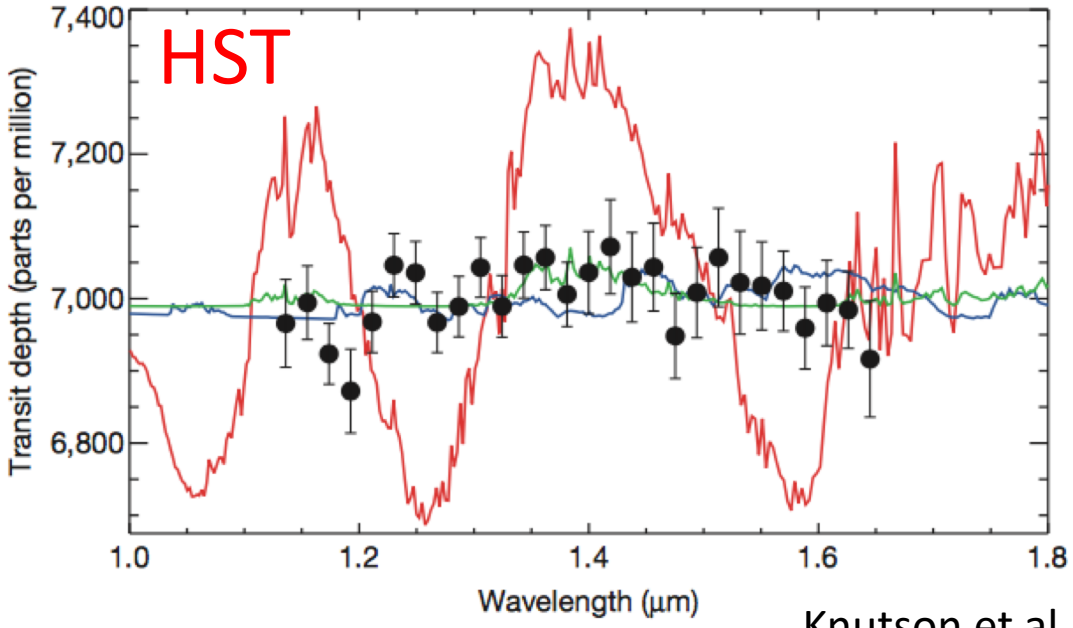
- JWST precision allows measuring the eclipse
- Degeneracy can be lifted by precise eclipse spectroscopy
  - In turn, with Z constrained, clouds can be constrained from transit
  - Eclipse gives better constraint of T-P profile

Figure/models: B. Benneke

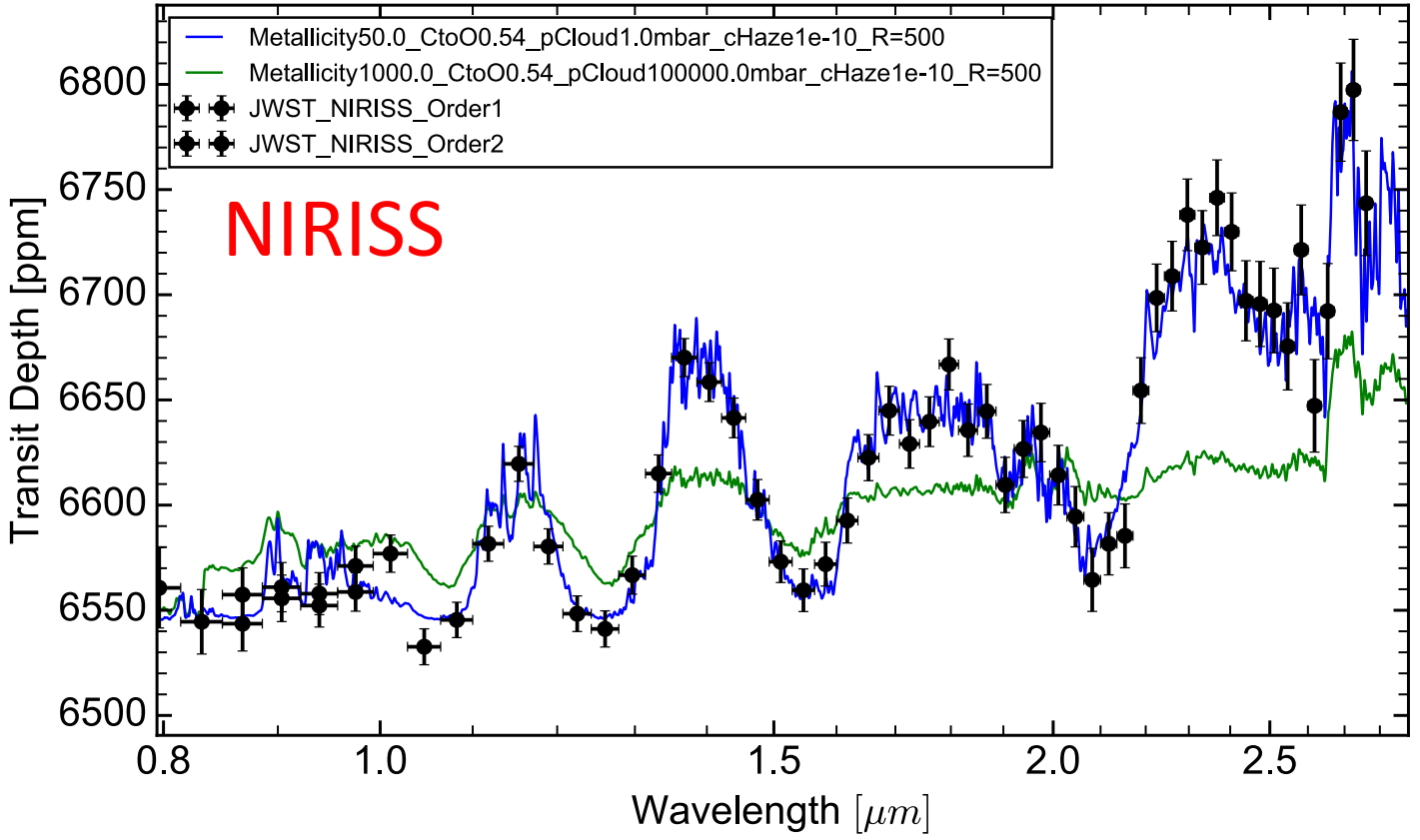


NIRISS transit of GJ 436b

- Metallicity of smaller planets can get much higher, transit useful by itself



Knutson et al. 2014



Blue: 50X solar metallicity, high clouds (1 mbar)

Green: 1000X solar metallicity, ~no clouds

Model colors inverted in HST plot

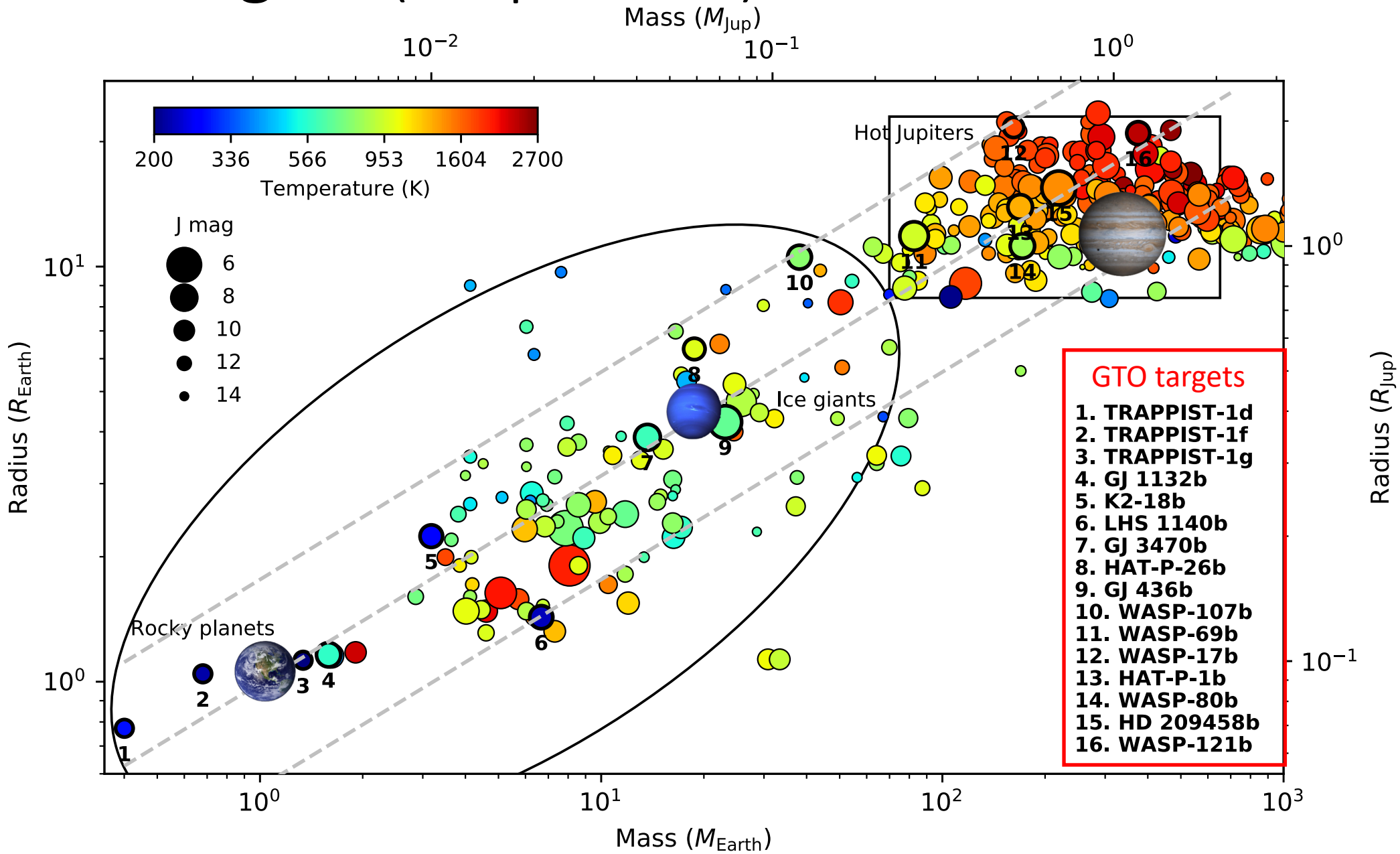
Our 200-hour GTO program: NEAT

(NIRISS Exploration of Atmospheric diversity of Transiting exoplanets)

Program goals

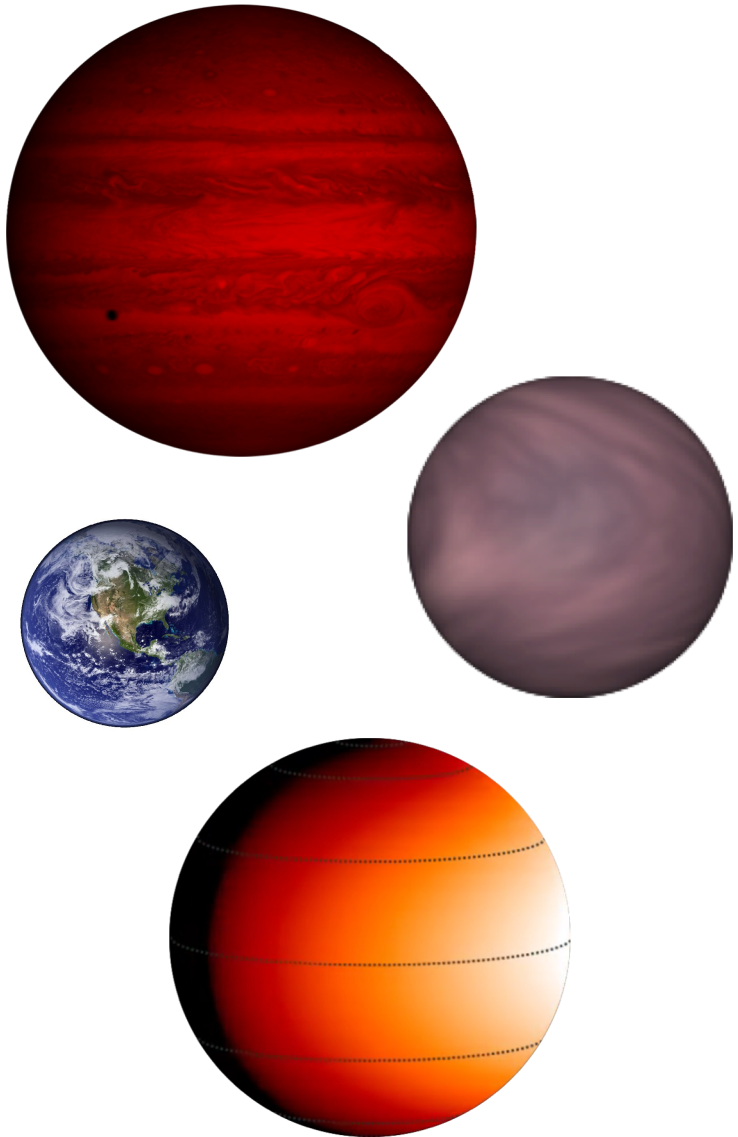
- Determine abundances of major atomic and molecular constituents, C/O ratio, overall metallicity, atmospheric scale height, mean molecular weight, and temperature-pressure profile
- Investigate presence & properties of haze, clouds, patchy clouds
- Explore wide range of planet masses & temperatures
- Determine longitudinal/vertical thermal & composition structure of atmosphere
- Detect atmosphere of rocky planets and infer their bulk composition

NEAT targets (16 planets)

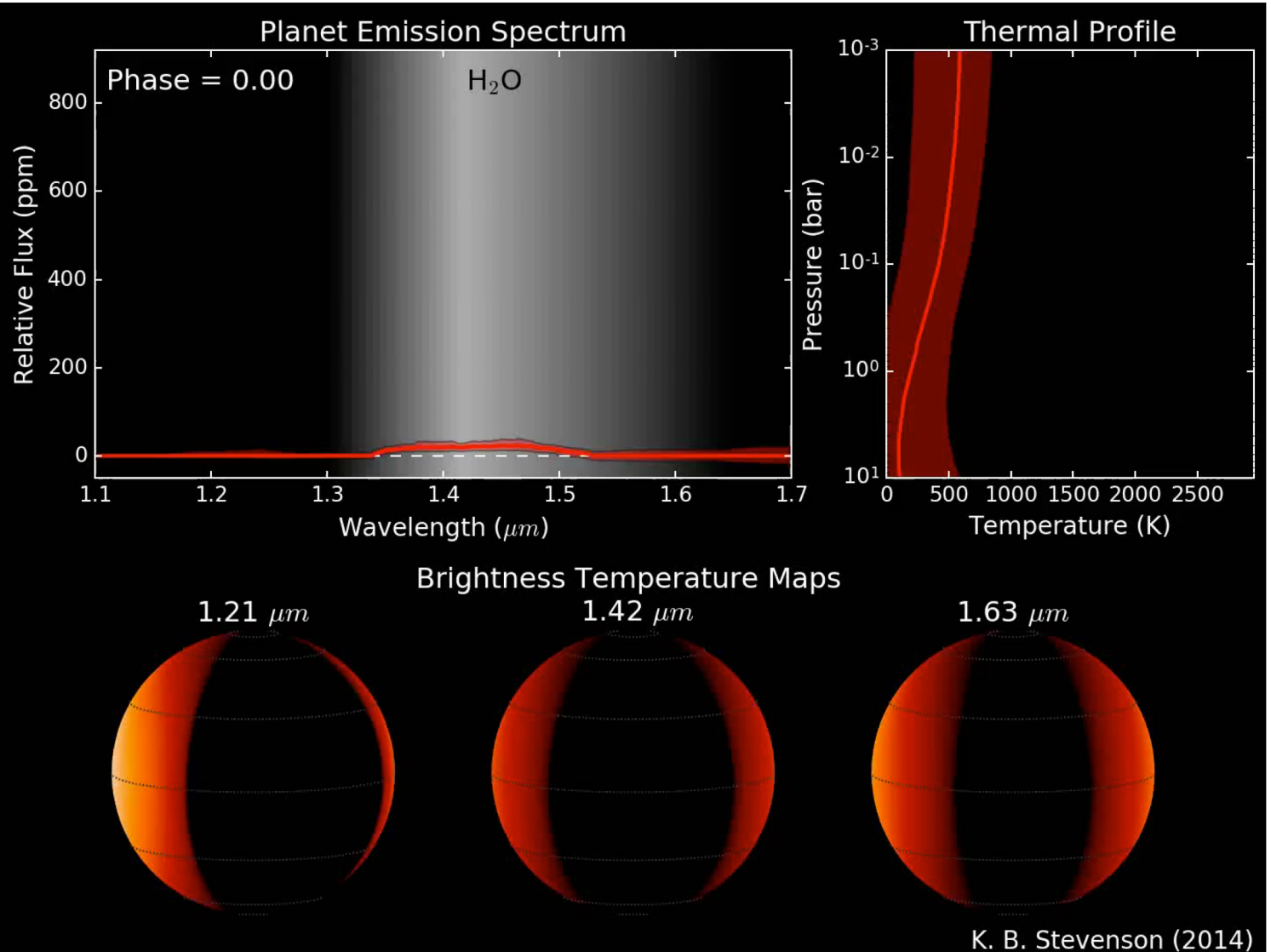


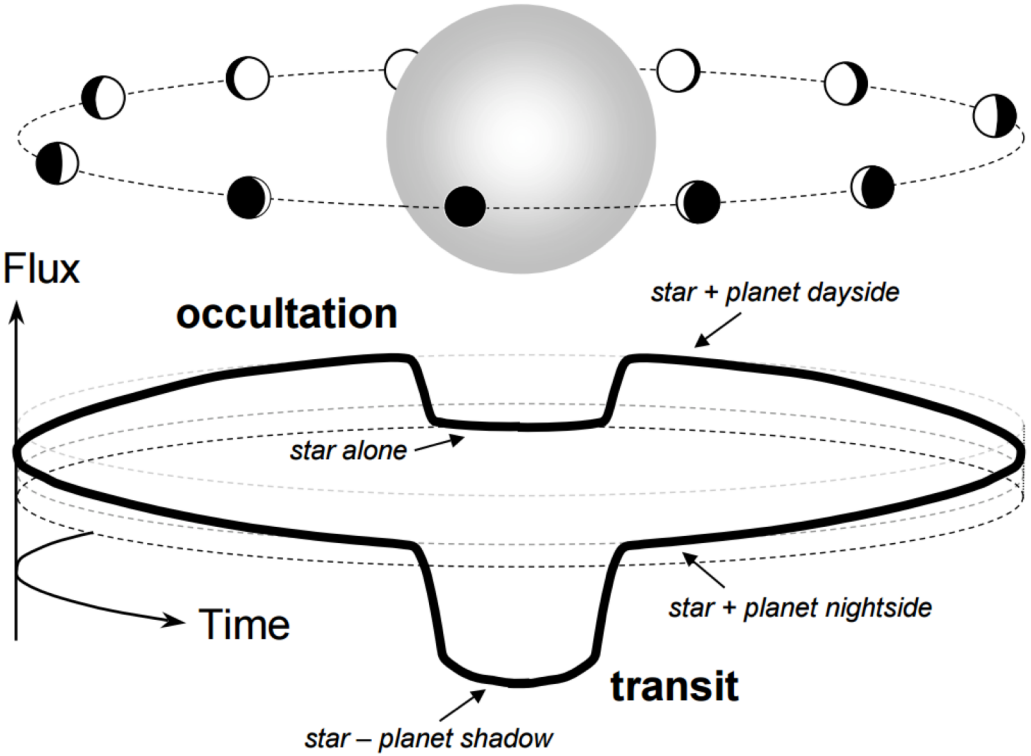
NEAT program components

- Ice & gas giants
  - 9 targets for which a single visit is sufficient to achieve a robust detection of atmospheric signature at the native resolving power of the SOSS mode
- Rocky planets
  - 6 planets for which a detection will require multiple visits and binning down the spectra to lower resolution
- Phase curve program
  - Full phase curve spectroscopy of one target



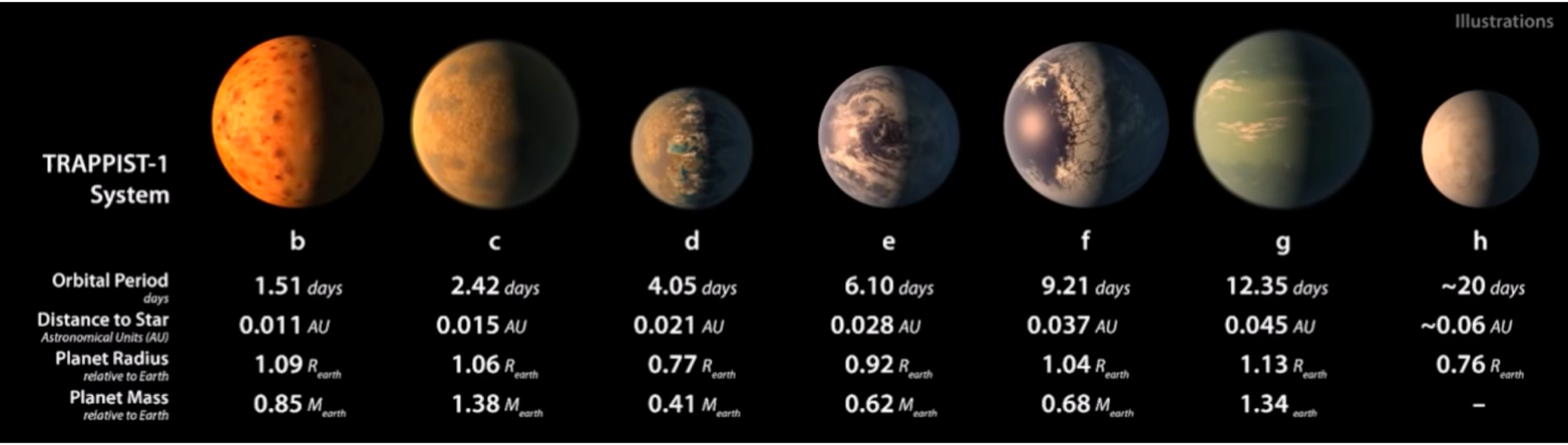
Phase curve spectroscopy of hot Jupiters





WASP-43b
3 full planet orbits with HST/WFC3
Stevenson et al. 2014

Trappist-1 rocky planets



Gillon et al. 2017
Image: NASA/JPL

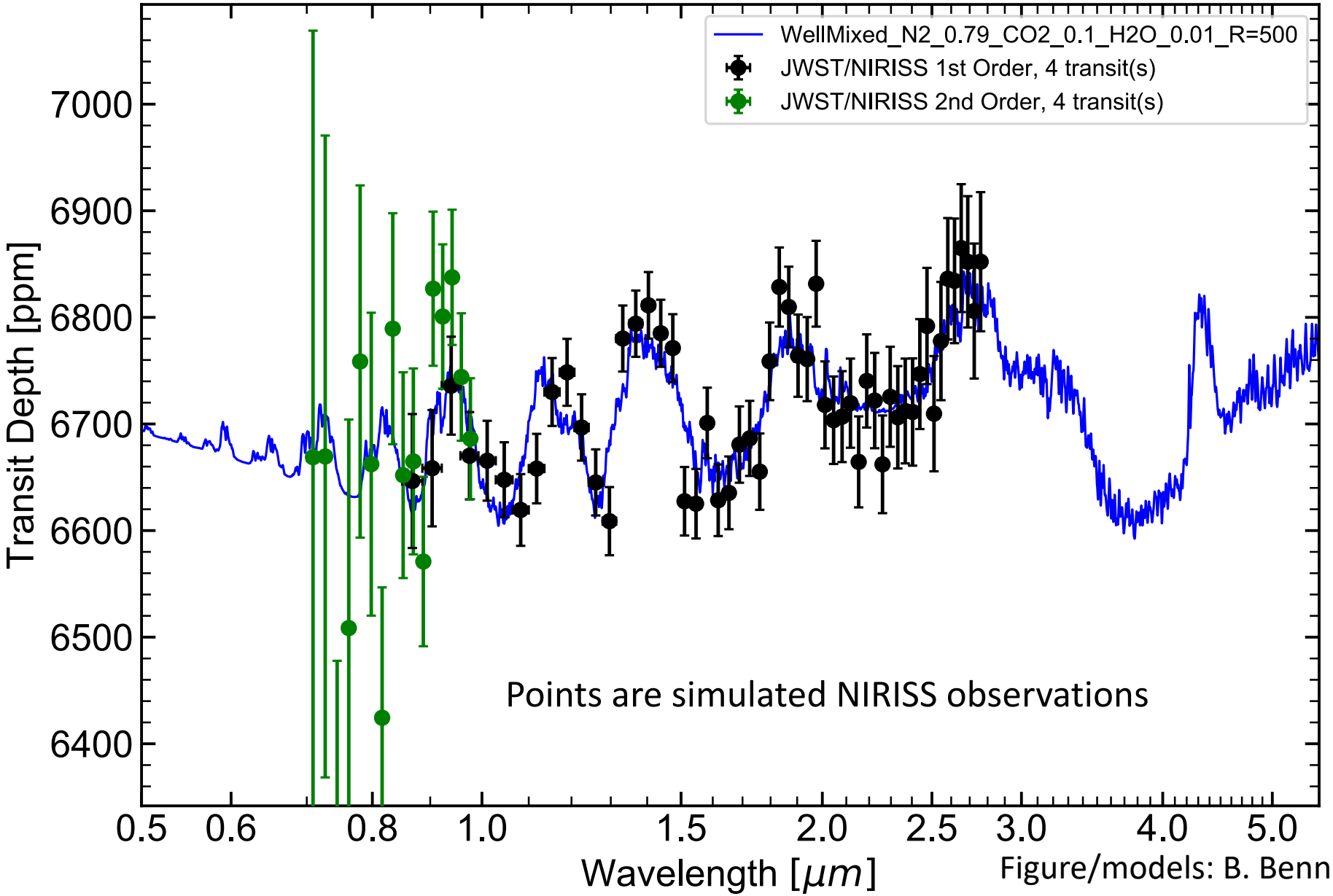
250 K

220 K

200 K

This one shown in next example

TRAPPIST-1f with Earth-like atmosphere composition



Figure/models: B. Benneke

All GTO & ERS programs

Total of 27 unique planets

Name	NIRISS-SOS	NIRSpec-G23	NIRSpec-G39	NIRSpec-Pris	NIRCam-F322	NIRCam-F444	MIRI-LRS	MIRIM-F150	MIRIM-F1280W
GJ 1132 b	transit								
GJ 436 b	transit				eclipse	eclipse	eclipse		
GJ 3470 b	transit								
HAT-P-1 b	transit,eclipse								
HAT-P-12 b		transit	transit				transit		
HAT-P-19 b					eclipse	eclipse	eclipse		
HAT-P-26 b	transit		transit,eclipse		transit	transit	transit,eclipse		
HD 149026 b					eclipse	eclipse			
HD 189733 b					eclipse	eclipse			
HD 209458 b	transit,eclipse				eclipse	eclipse			
K2-18 b	transit								
LHS1140 b	transit		transit						
TRAPPIST-1 b								eclipse	eclipse
TRAPPIST-1 d				transit					
TRAPPIST-1 e				transit					
TRAPPIST-1 f	transit								
TRAPPIST-1 g	transit								
WASP-17b	transit,eclipse		transit,eclipse				transit,eclipse		
WASP-18 b	eclipse								
WASP-43 b			phase-curve				phase-curve		
WASP-52 b				eclipse					
WASP-69 b	transit								
WASP-77 A b					eclipse	eclipse			
WASP-79 b	transit	transit	transit		transit				
WASP-80 b	eclipse				transit,eclipse	transit,eclipse	transit,eclipse		
WASP-107 b	transit		transit,eclipse		transit	transit	transit		
WASP-121 b	phase-curve								

In short, JWST GTO on transiting exoplanets atmosphere will

- Make the leap from qualitative detections & loose constraints to quantitative measurements of composition and physical conditions
- Enable comparative exoplanetology
- Initiate the study of rocky exoplanet atmospheres
- Have a strong and lasting legacy value

END