STUDYING EXOPLANETS WITH JWST:

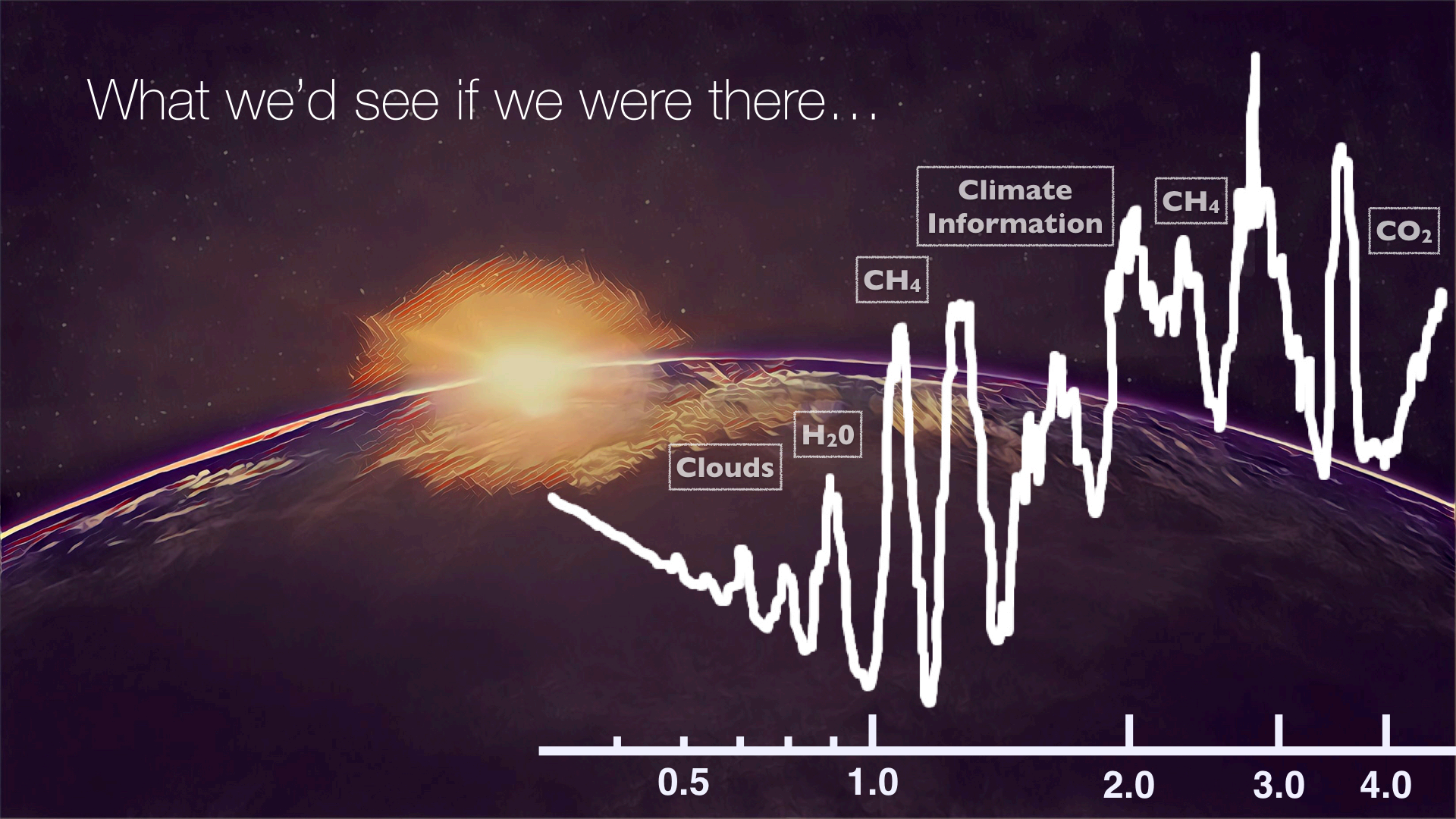
Community Efforts for Early Release Science & Beyond

UNIVERSITY OF CALIFORNIA SANTA CRUZ

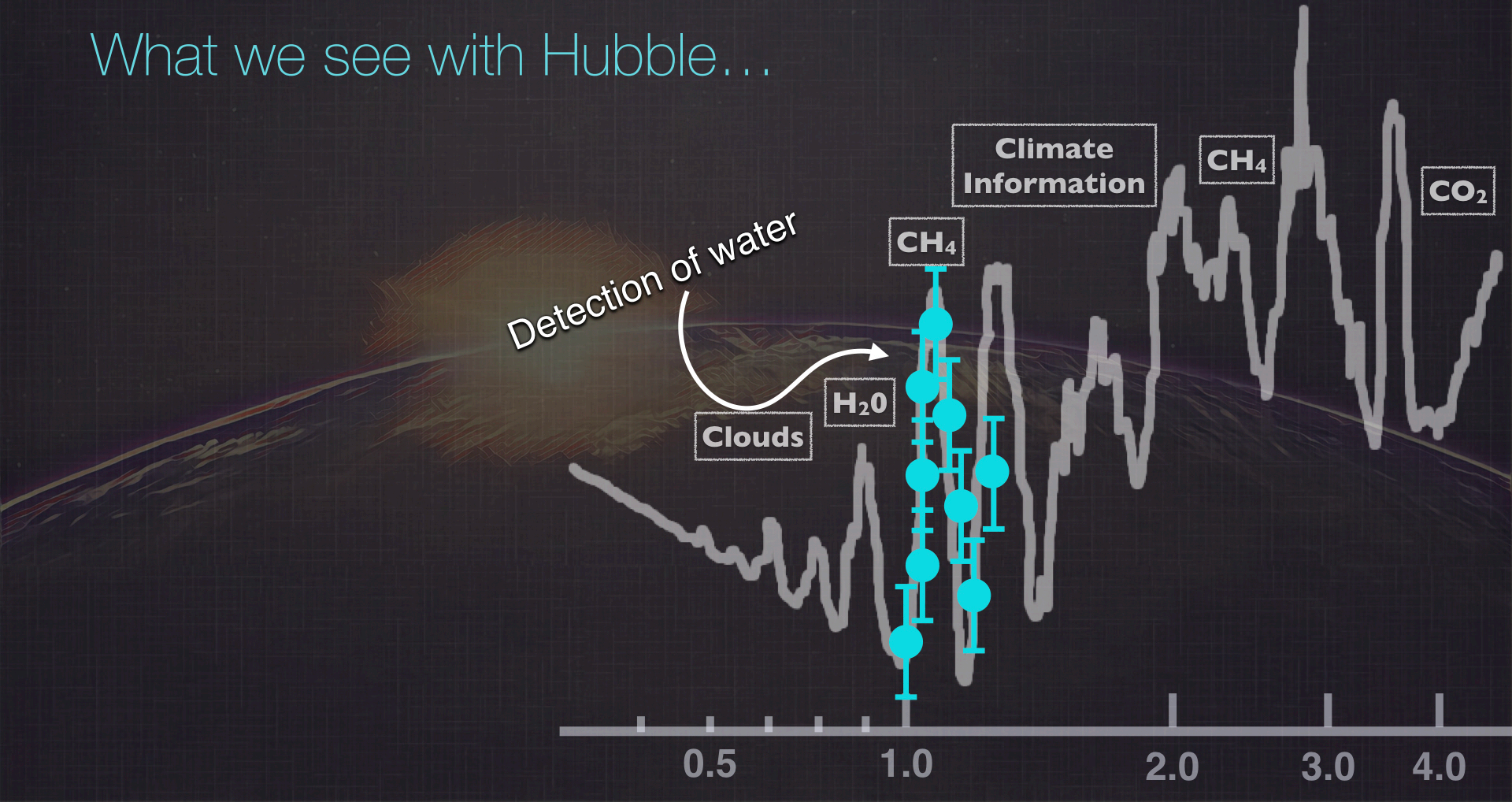
Natalie Batalha

2019 Sagan Workshop

What we'd see if we were there…

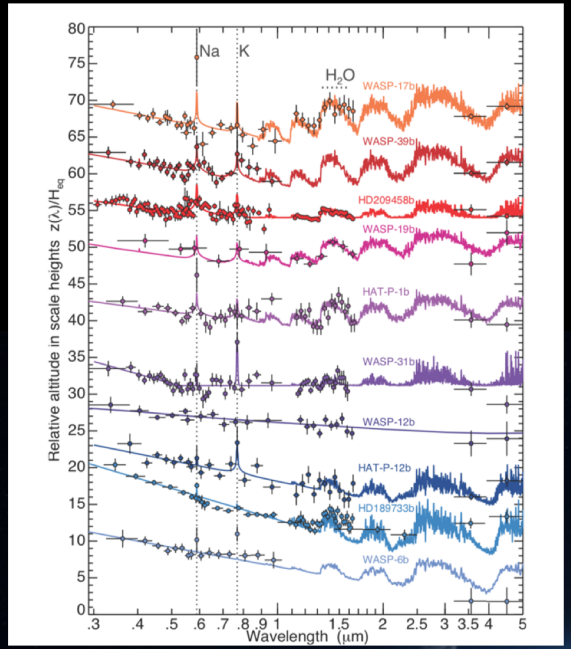


What we see with Hubble…



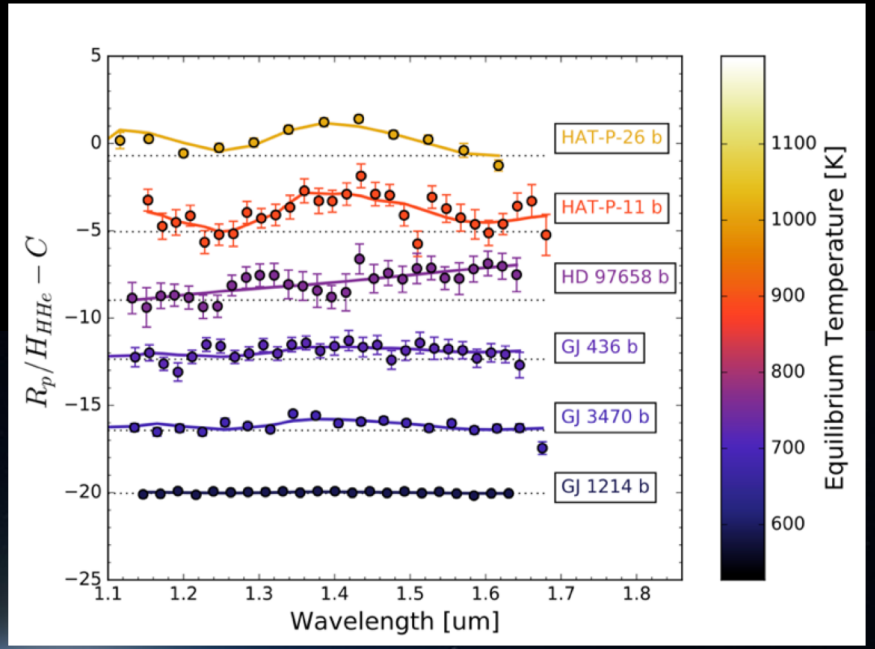
HST Results to Date

Sing+2016



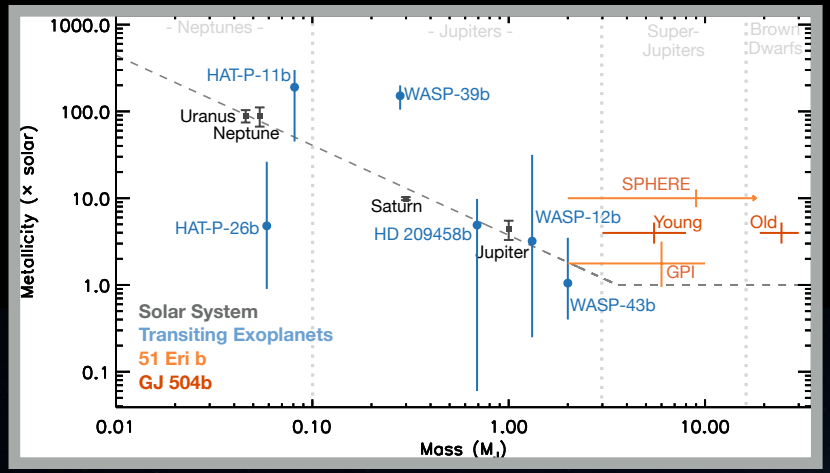
Hot Jupiters

Crossfield+2017

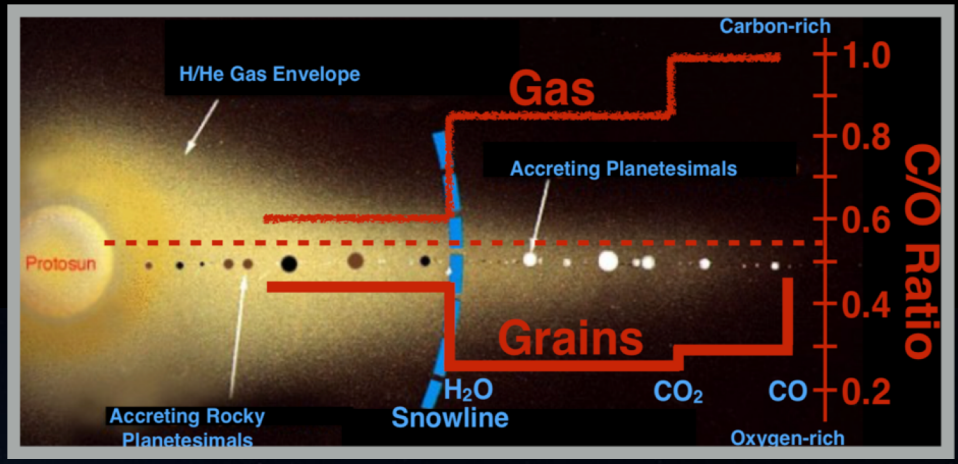


Warm Neptunes

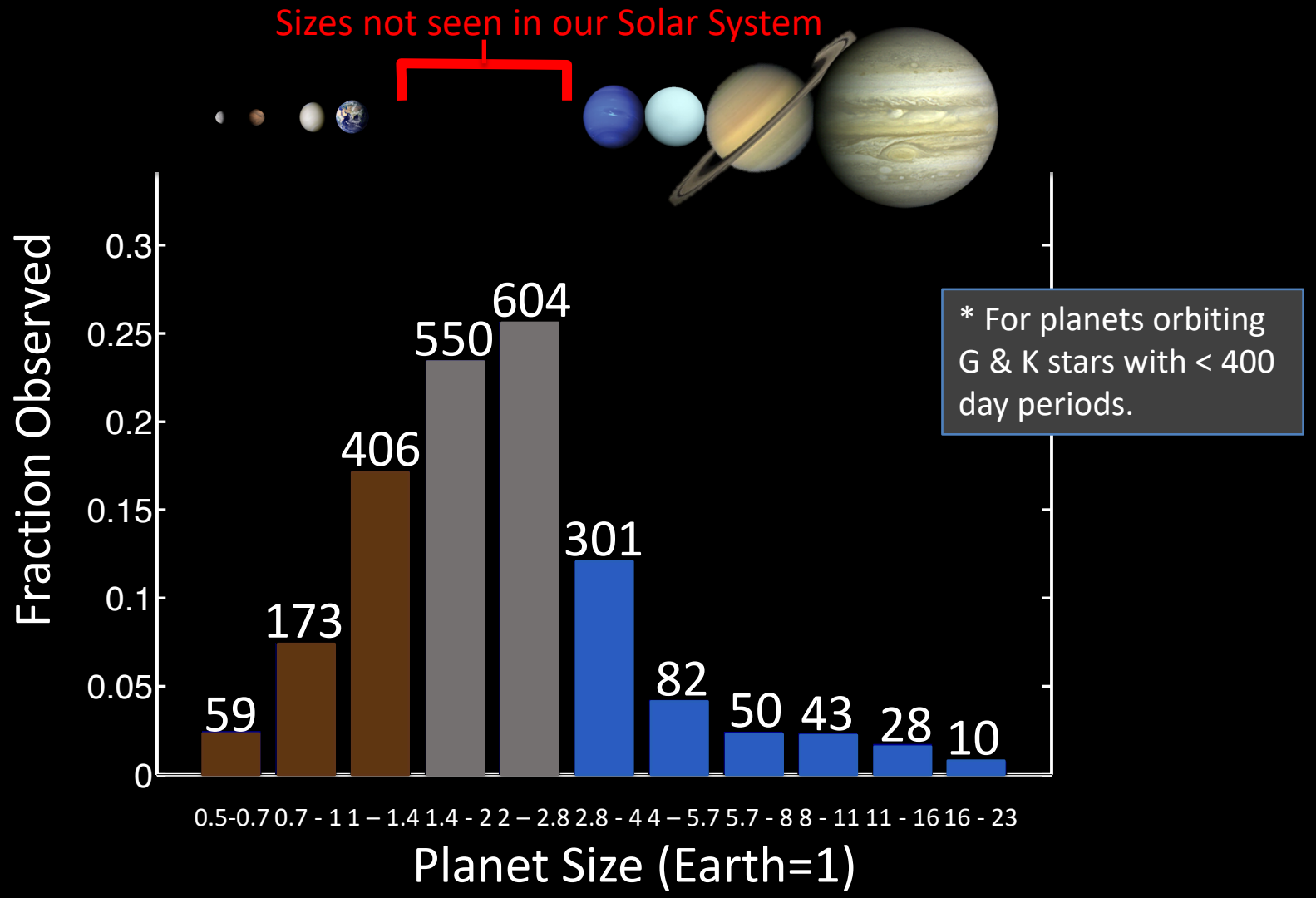
Formation/Evolution Diagnostics



Mass-Metallicity Correlation



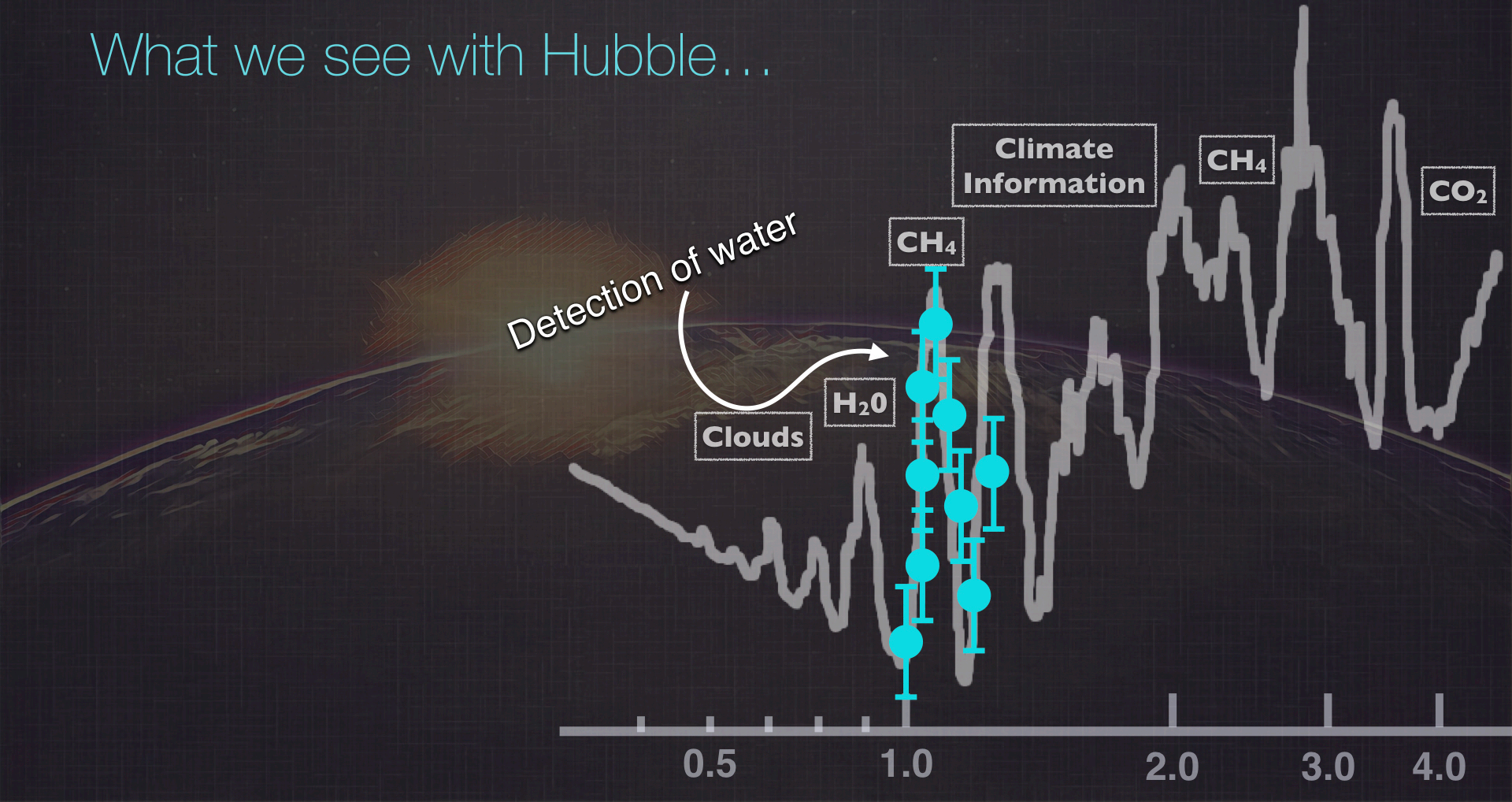
C/O Ratio & Disk Condensation


Sizes not seen in our Solar System
Fraction Observed
0.3
0.25
0.2
0.15
0.1
0.05
0
59
173
406
550
604
301
82
50
43
28
10
0.5-0.7
0.7 - 1
1 – 1.4
1.4 - 2
2 – 2.8
2.8 - 4
4 – 5.7
5.7 - 8
8 - 11
11 - 16
16 - 23
Planet Size (Earth=1)
* For planets orbiting G & K stars with < 400 day periods.

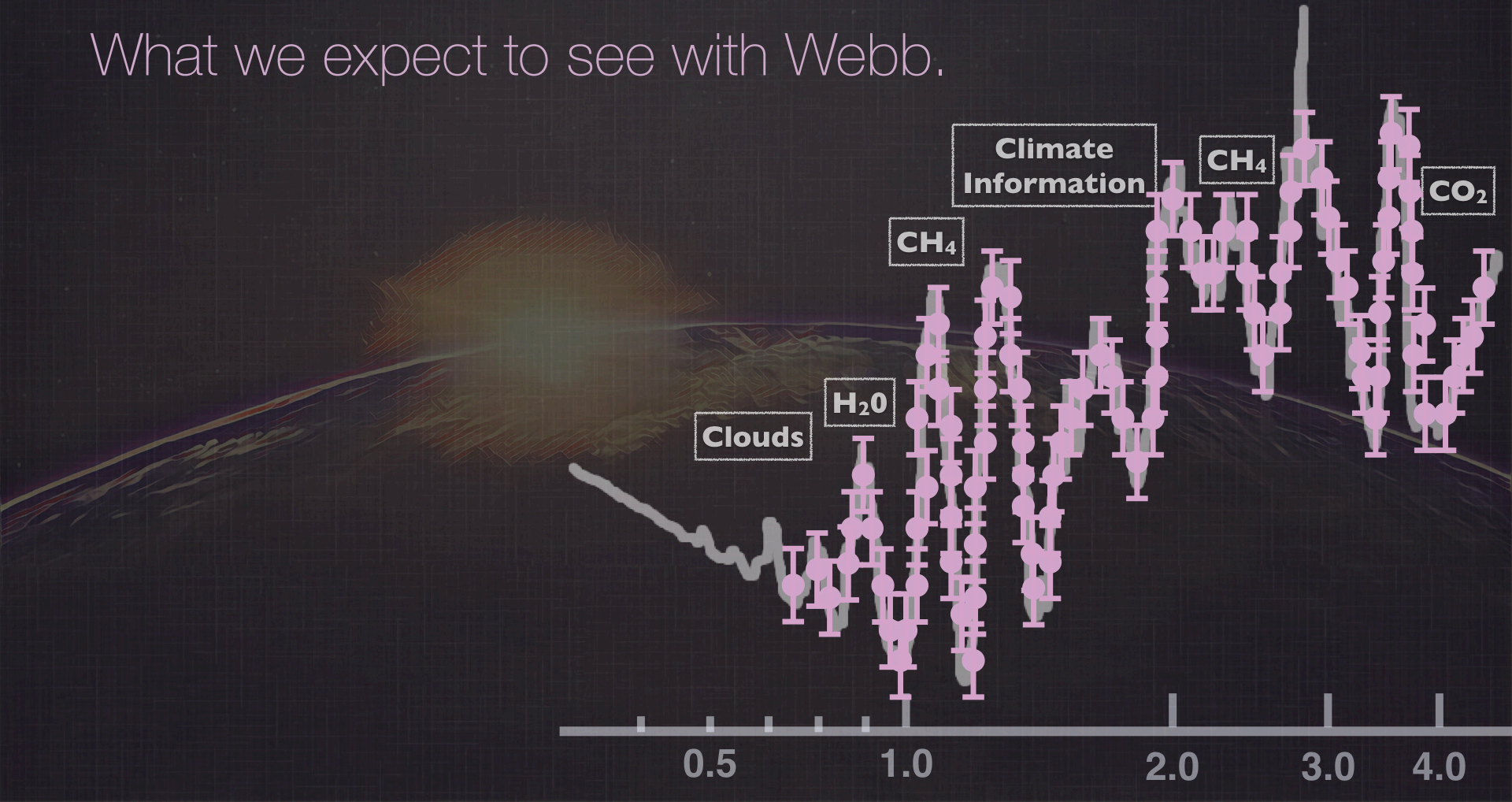
Science Drivers

- Abundances (beyond water, He, alkali metals)
- Mass-Metallicity Relation (beyond the hot/warm planets)
- C/O Ratios (using carbon-bearing species)
- Temperature/Pressure versus Altitude and Longitude
- Disequilibrium Chemistry

What we see with Hubble…



What we expect to see with Webb.



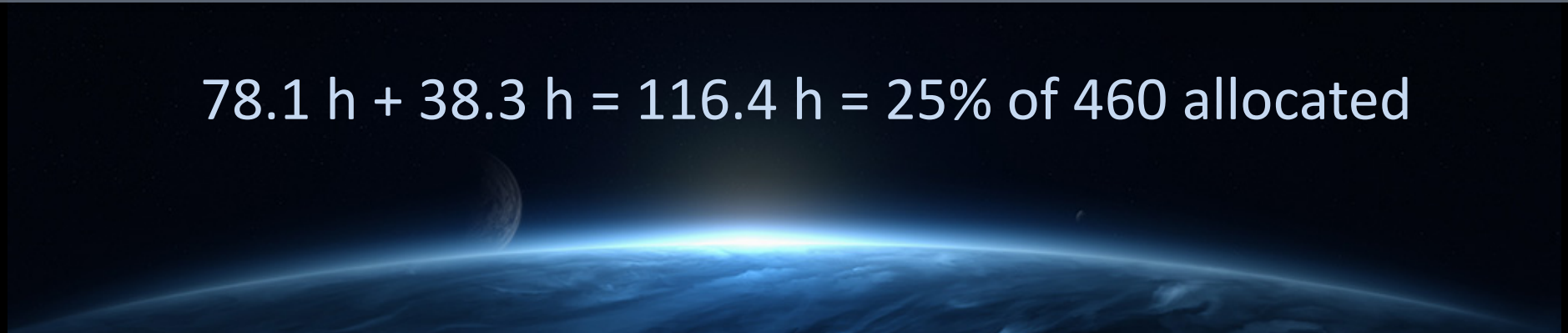
JWST Early Release Science Awards

1309	IceAge: Chemical Evolution of Ices during Star Formation	McClure (Amsterdam)	Stellar Physics
1324	Through the Looking GLASS: A JWST Exploration of Galaxy Formation and Evolution from Cosmic Dawn to Present Day	Treu (UCLA)	Galaxies and the IGM
1328	A JWST Study of the Starburst-AGN Connection in Merging LIRGs	Armus (CalTech)	Galaxies and the IGM
1334	The Resolved Stellar Populations Early Release Science Program	Weisz (UC Berkeley)	Stellar Populations
1335	Q-3D: Imaging Spectroscopy of Quasar Hosts Analyzed with a Powerful New PSF Decomposition & Spectral Analysis	Wylezalek (ESO)	Massive Black Holes and their Galaxies
1345	The Cosmic Evolution Early Release Science (CEERS) Survey	Finkelstein (Austin)	Galaxies and the IGM
1349	Establishing Extreme Dynamic Range with JWST: Decoding Smoke Signals in the Glare of a Wolf-Rayet Binary	Lau (CalTech)	Stellar Physics
1355	TEMPLATES: Targeting Extremely Magnified Panchromatic Lensed Arcs and Their Extended Star Formation	Rigby (GSFC)	Galaxies and the IGM
1364	Nuclear Dynamics of a Nearby Seyfert with NIRSpec Integral Field Spectroscopy	Bentz (Georgia State)	Massive Black Holes and their Galaxies

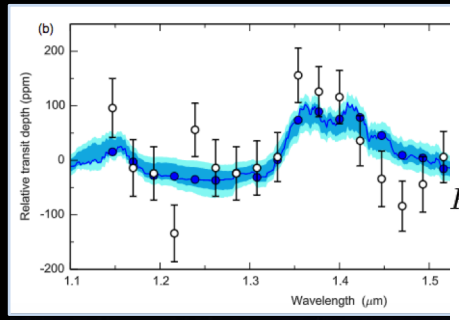
JWST Early Release Science Awards

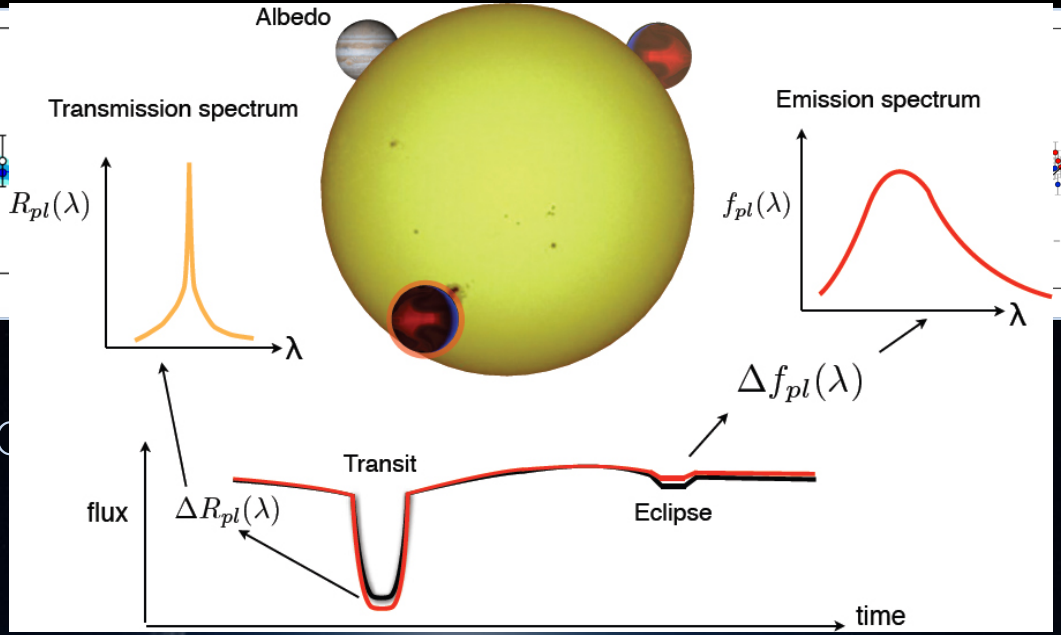
1366	The Transiting Exoplanet Community Early Release Science Program	Batalha (NASA ARC), Bean (Chicago), Stevenson (STScI)	Planets and Planet Formation
1373	ERS observations of the Jovian System as Demonstration of JWST's Capabilities for Solar System Science	de Pater (Berkeley)	Solar System
1386	High Contrast Imaging of Exoplanets and Exoplanetary Systems with JWST	Hinkley (Exeter), Skemer (UCSC), Biller (Edinburgh)	Planets and Planet Formation

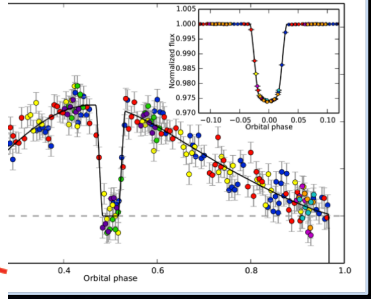
78.1 h + 38.3 h = 116.4 h = 25% of 460 allocated



Diversity of Phenomena





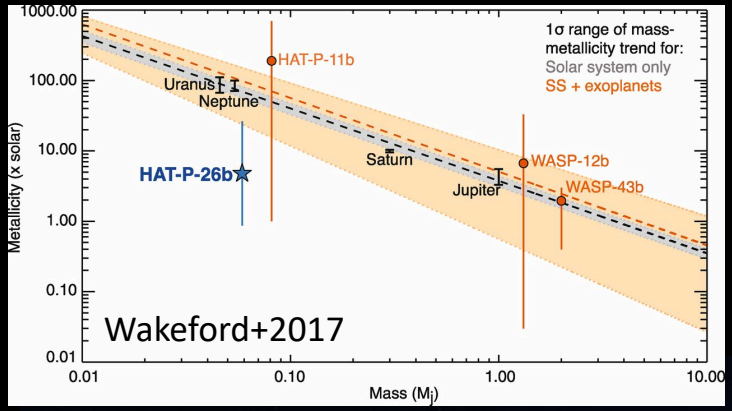


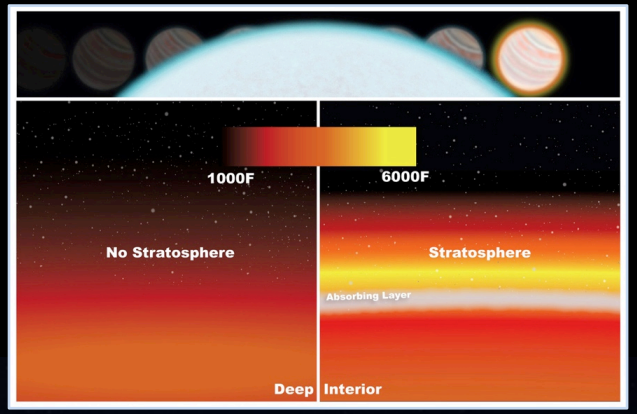
Transmissio

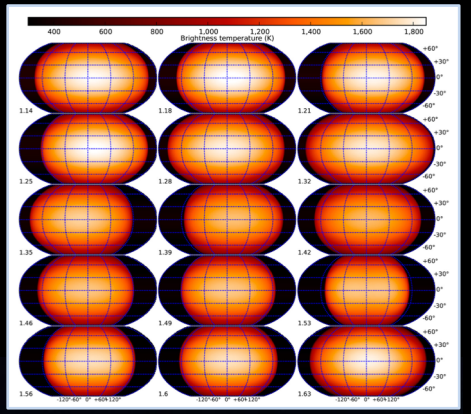
Phase

Sing+2017

Diversity of Science





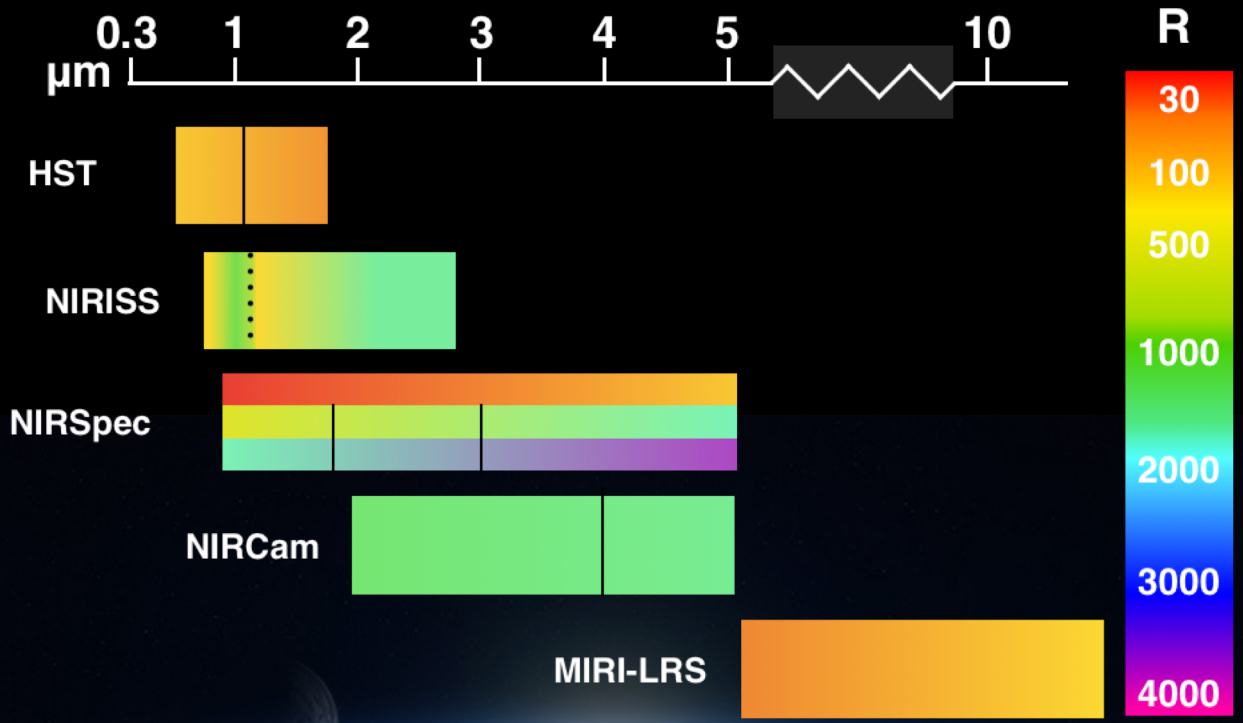


C/O Metallicity

T/P Profiles

Longitudinal Maps

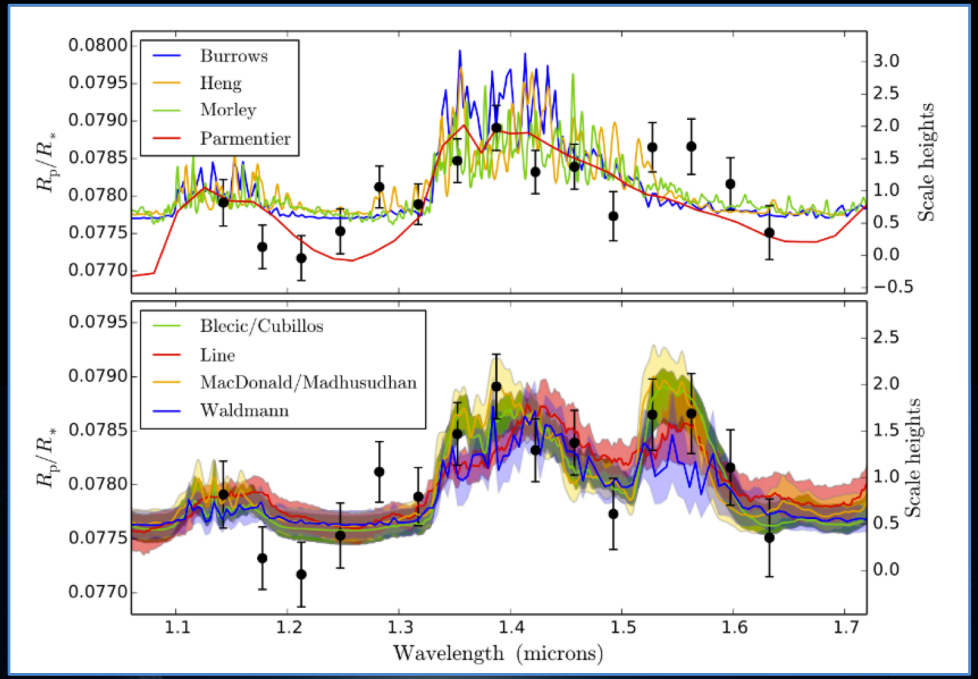
Diversity of Observing Modes



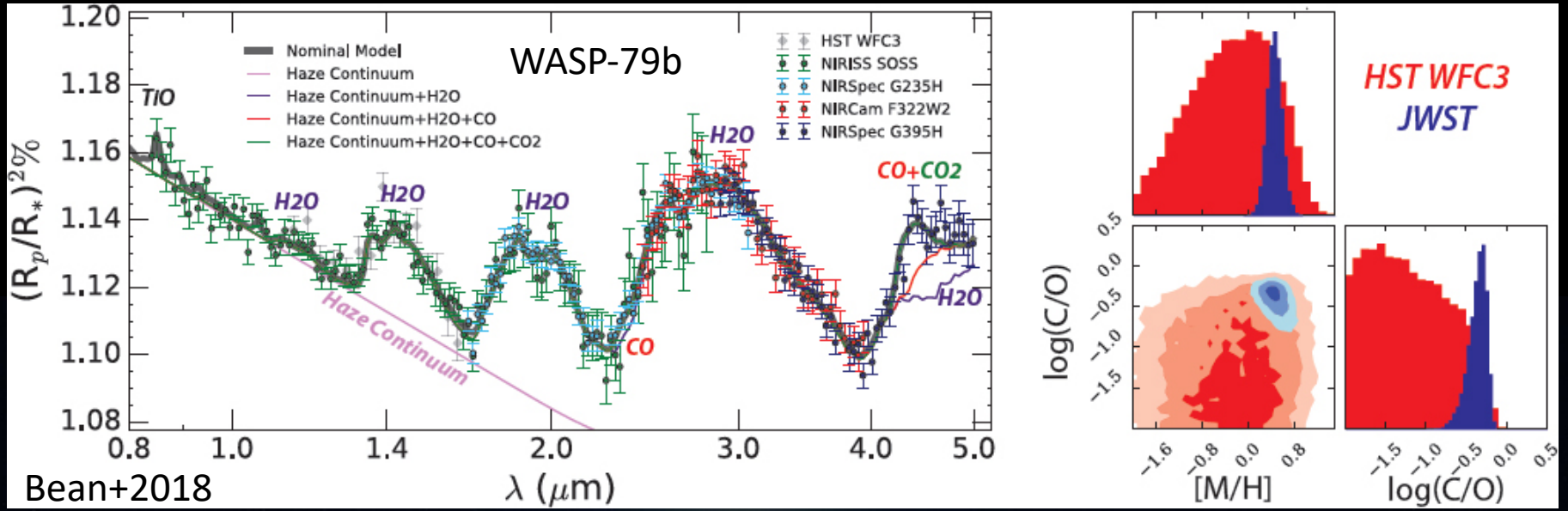
Targets with Previously Measured Features

WASP-63 b
WFC3 Transmission
Kilpatrick et al. 2017

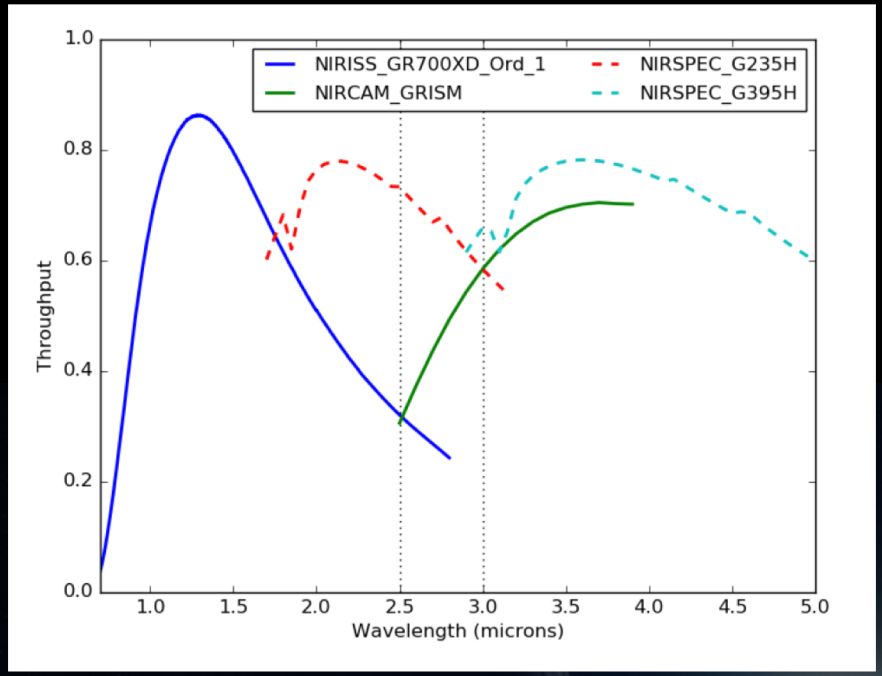
Forward models (top)
Retrieval models (bottom)



1) Transmission Program (42 h)



Transmission Program: 4 Modes

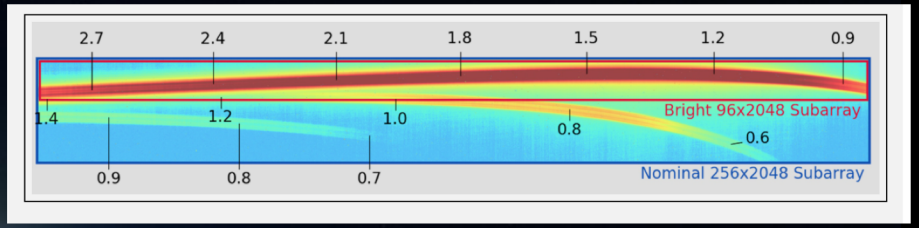


NIRISS SOSS

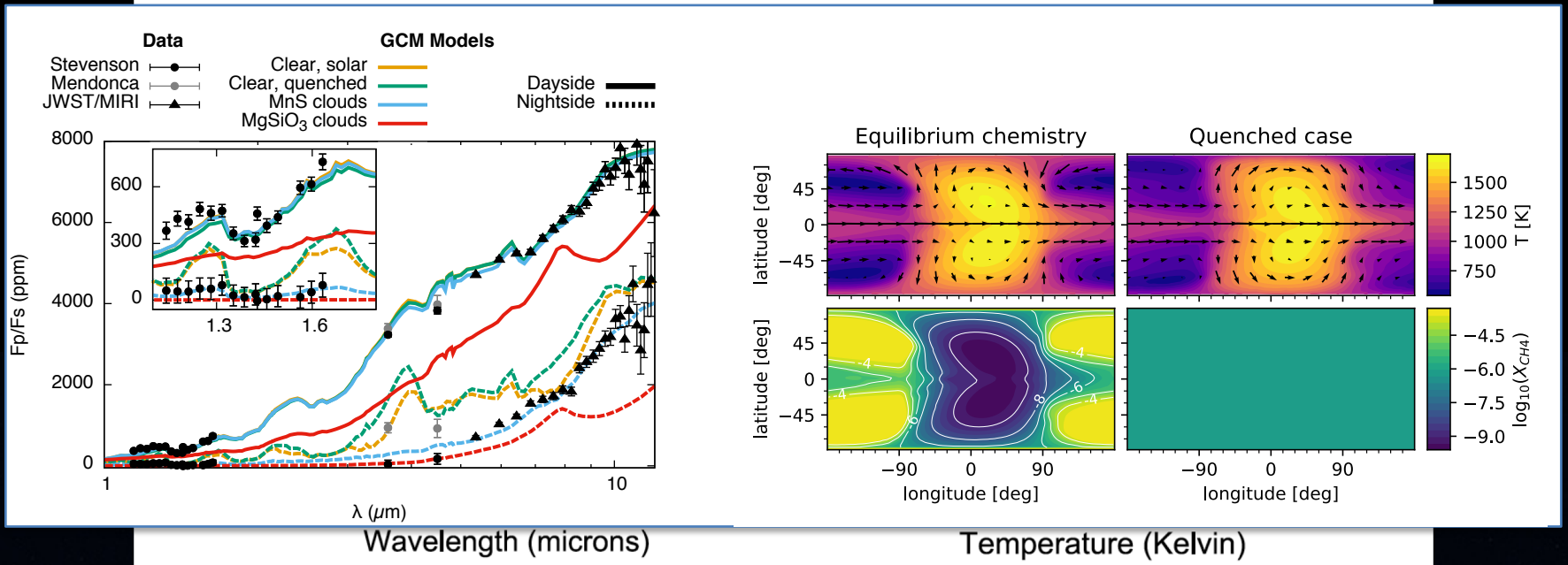
NIRCAM F322W2

NIRSpec G235H

NIRSPEC G395H

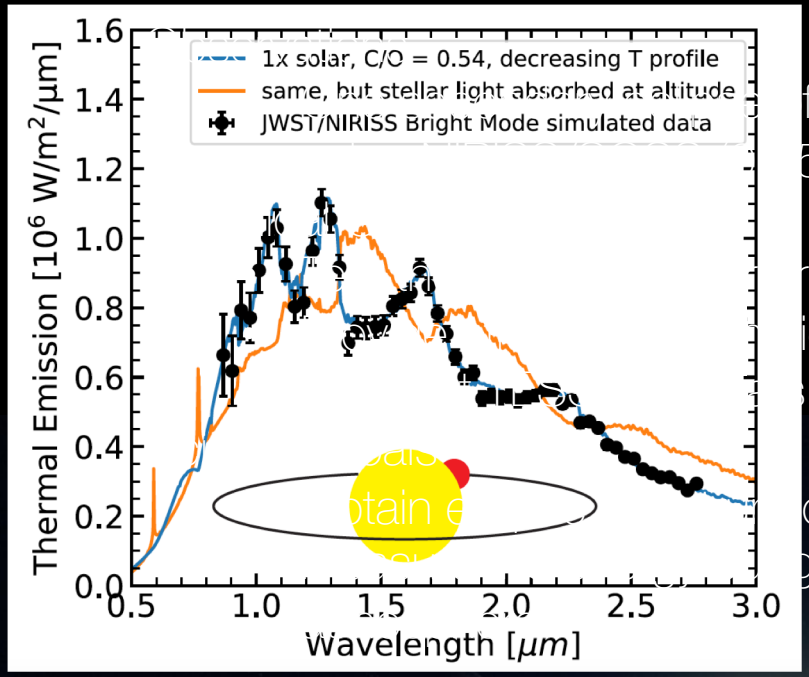


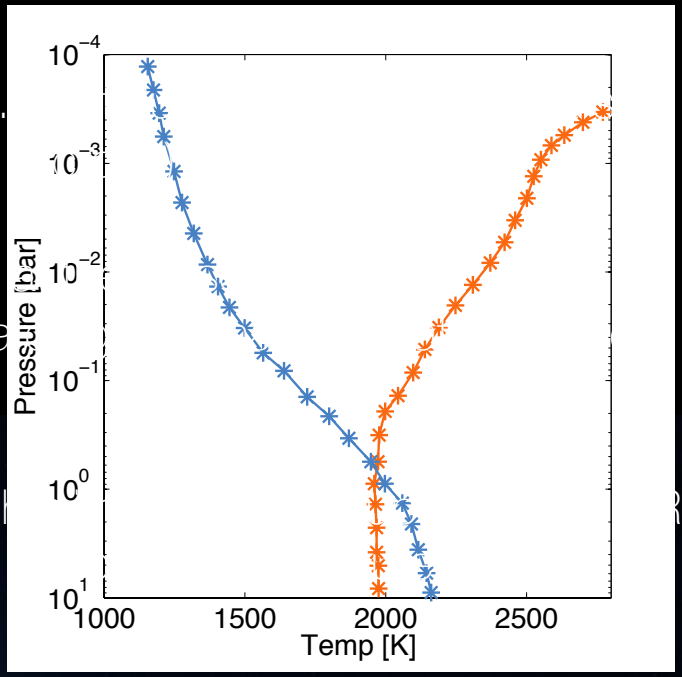
2) MIRI Phase Curve Program (29.5 h)



WASP-43b: Venot et al. 2019, submitted

3) Bright Star Test (8.6 h)





(WASP-18b: See Arcangeli et al. arXiv:1801.02489 & Sheppard et al. 2017 ApJL 850 32)

Data Challenge & Deliverables

The centerpiece of the ERS work plan is a two-phase Open Data Challenge designed to:

- Engage a broad cross-section of the astronomical community to familiarize them with JWST data and scientific capabilities.
- Design, create, and deliver science-enabling products to help the community understand JWST capabilities.
- Foster open-science and compare methodologies for the betterment of all.

Goals of Data Challenge #1 (Summer 2021)

- Exercise data analysis tools on simulated data for each instrument mode.
- Test performance by internal validation of science results against input properties of simulated data.
- Test consistency of methodologies through cross-comparison of results between different team members.
- Discuss robustness of analysis and vulnerabilities to systematics.
- Identify lessons learned.

Goals of Data Challenge #2 (Fall 2021/Winter 2022)

- Apply tools to real JWST data.
- Present & intercompare independent analyses.
- Compare achieved and predicted performance.
- Generate deliverables for Cycle 2 Call for Proposals.
  a) worked examples from pixels to planetary spectrum (required goal) to planetary properties (desired goal)
  b) documented lessons learned.
- Publish workbooks and documentation on ExoCTK website at STScI.

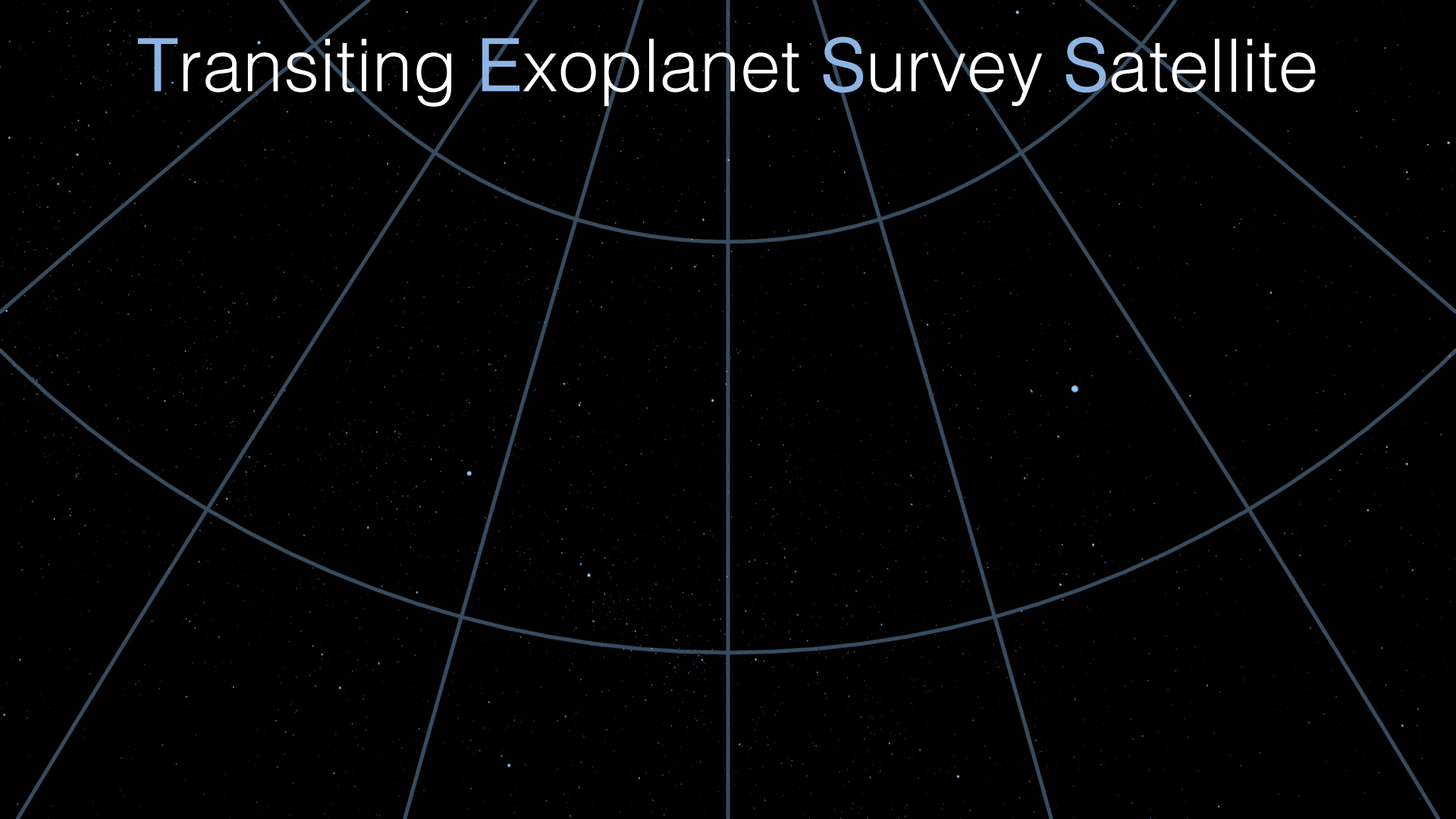
Pre-launch Boot Camp: Summer 2020

- Promote open-source tools for data analysis, modeling, and retrieval
- Train early-career scientists to use open-source tools
- Define requirements for Data Challenge

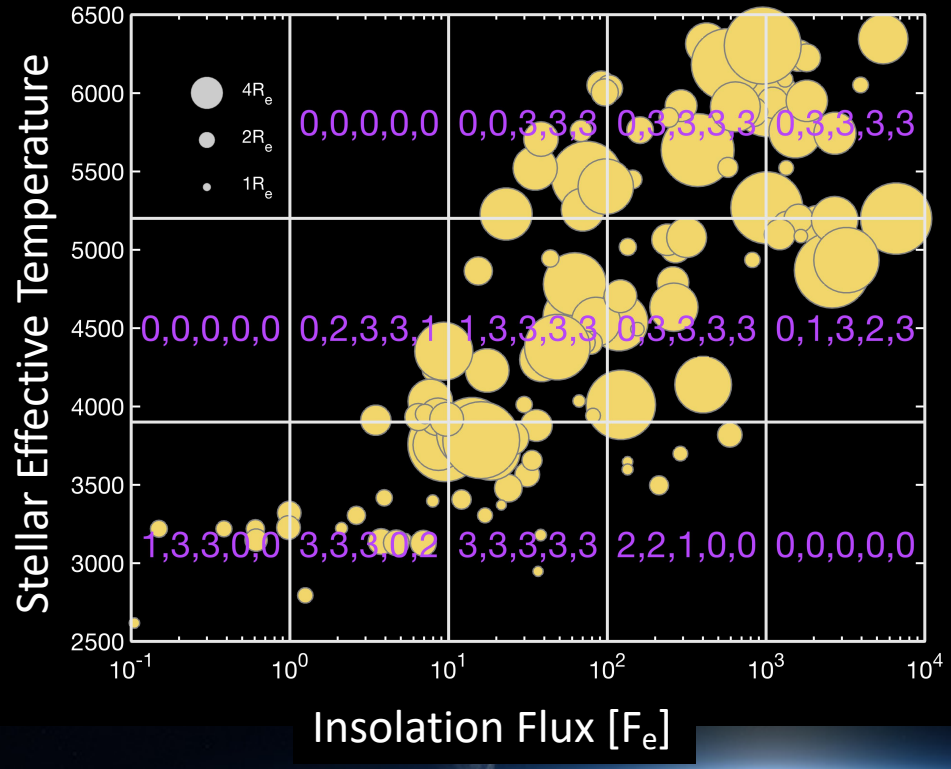
Looking Forward: Webb Legacy Survey

Recommendation: NASA should create a mechanism for community-driven legacy surveys of exoplanet atmospheres early in the JWST mission.

"With hundreds of high-quality atmospheric characterization targets to choose from, multiple choices of observing modes and wavelength coverage, and many competing research groups that have spent years eagerly awaiting the launch of JWST, one might expect an onslaught of observing proposals in the early cycles of the JWST mission with no clear overarching science vision. This leads to a third challenge, which is one of community organization. It would have a powerful impact if the transiting exoplanet community could come together behind a shared strategic vision of atmospheric characterization science with JWST." National Academies of Sciences Exoplanet Science Strategy 9/2018


Transiting Exoplanet Survey Satellite

Looking Forward: Webb Legacy Survey



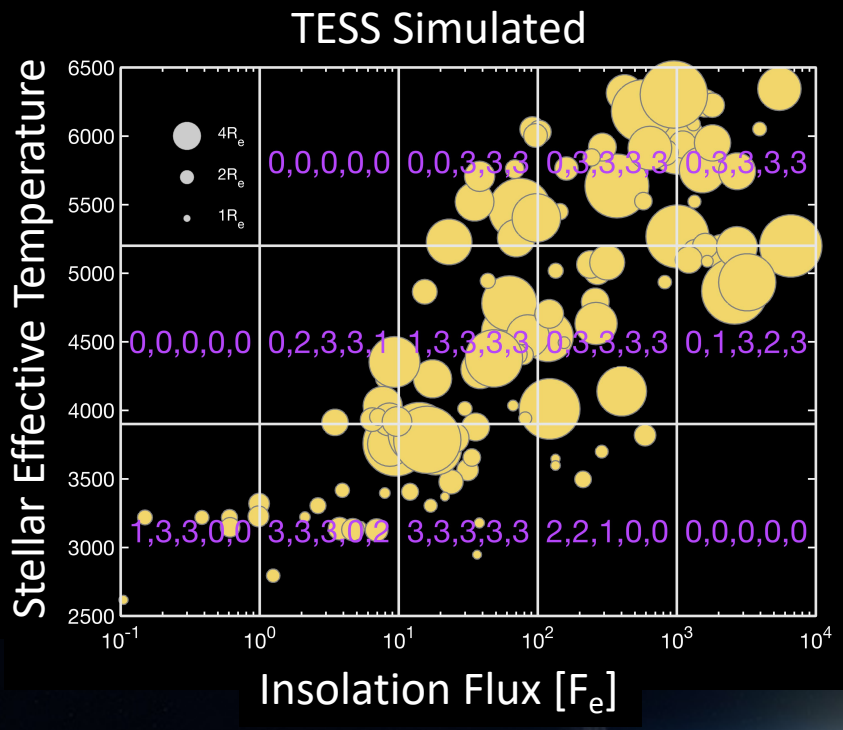
Atmospheric Characterization Targets

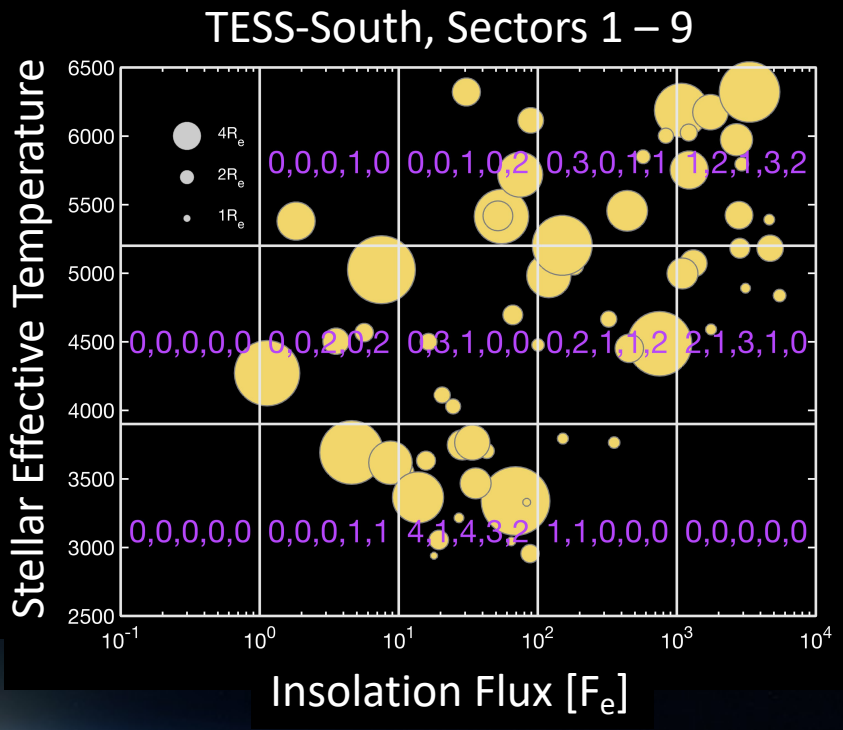
- Simulated TESS Yield from Barclay+2018
- NIRISS SNR Proxies from Kempton+2018
- Declination > -20 degrees
- Jmag < 12
- Velocity semi-amp > 2 m/s

Radius Bins:

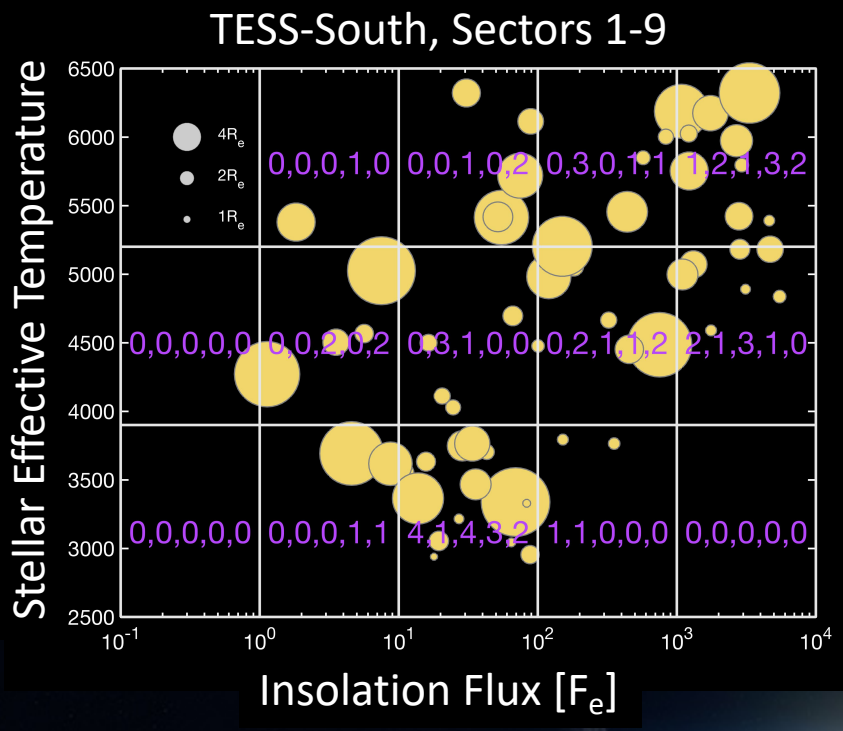
1.0 – 1.6
1.6 – 2.5
2.5 – 4.0
4.0 – 6.3
6.3 - 10

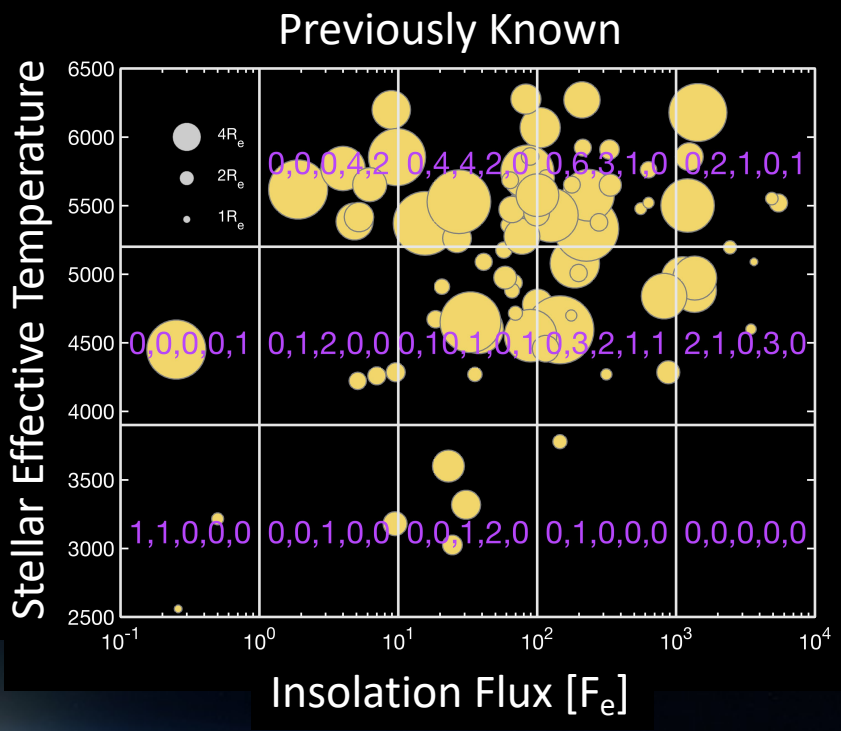
Looking Forward: Webb Legacy Survey



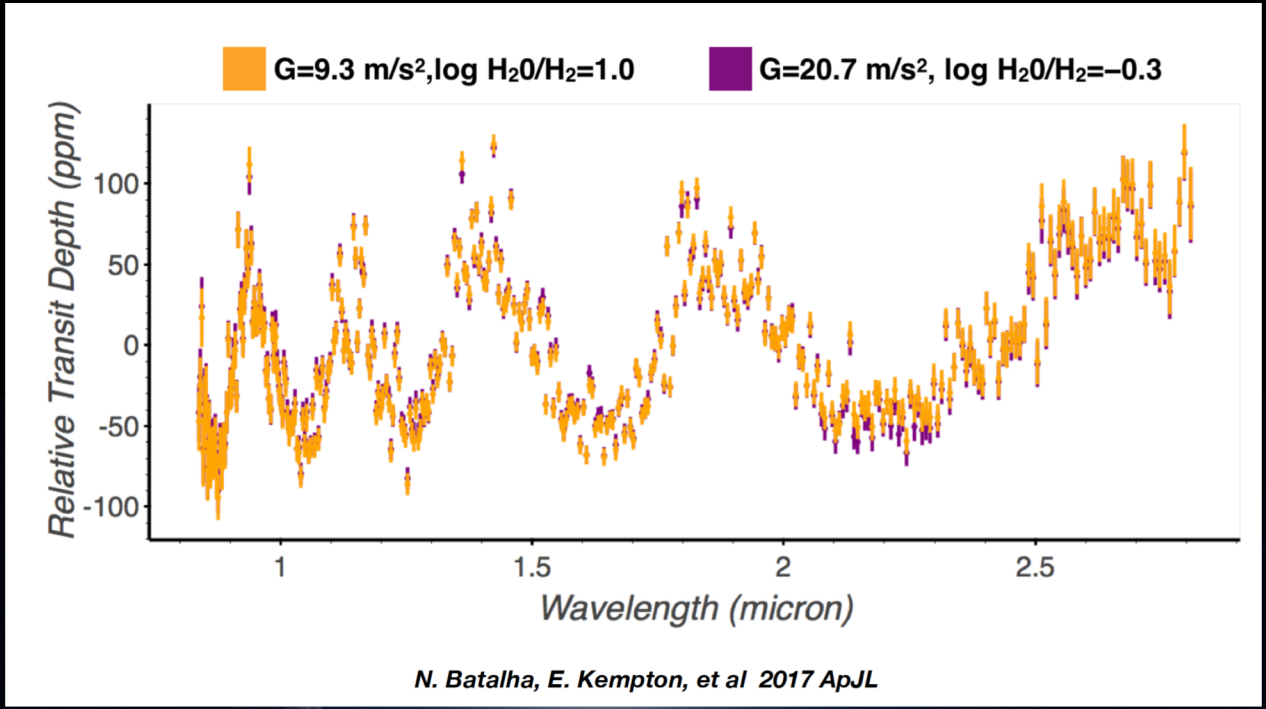


Looking Forward: Webb Legacy Survey



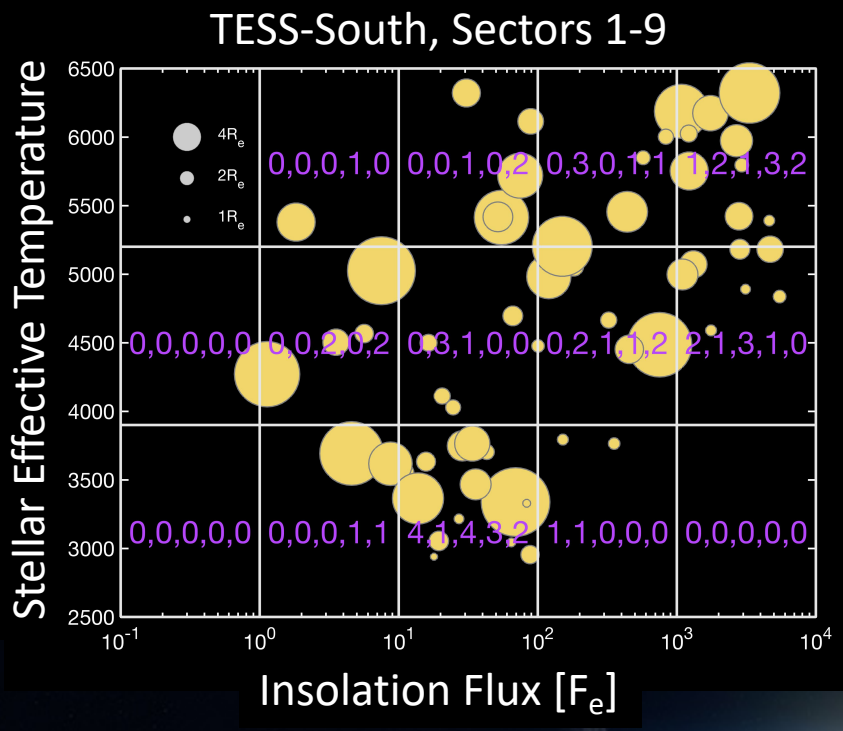


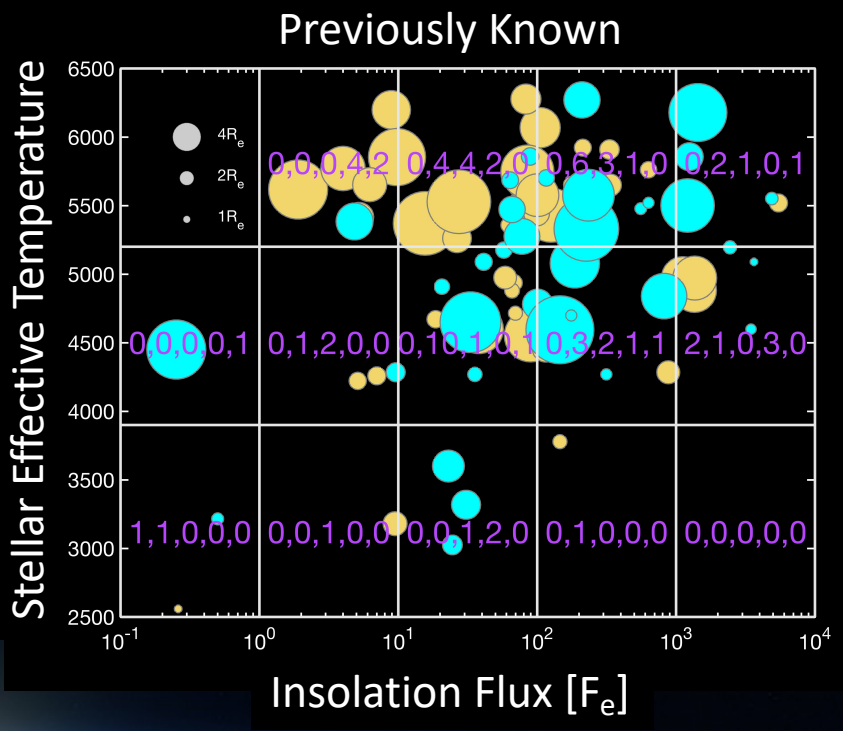
Degeneracies in Retrieval Analyses



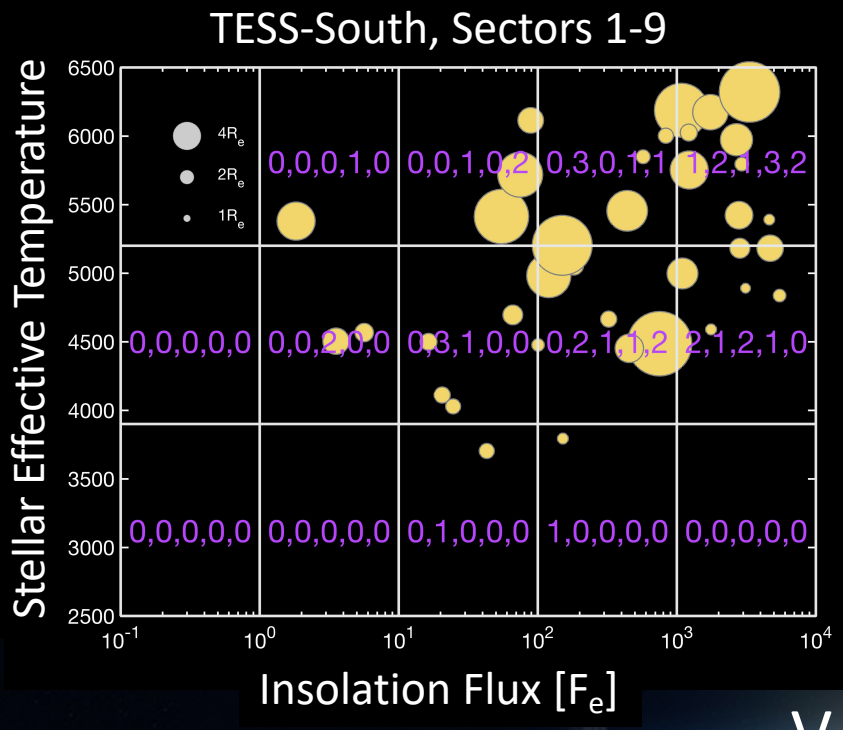
N. Batalha, E. Kempton, et al 2017 ApJL

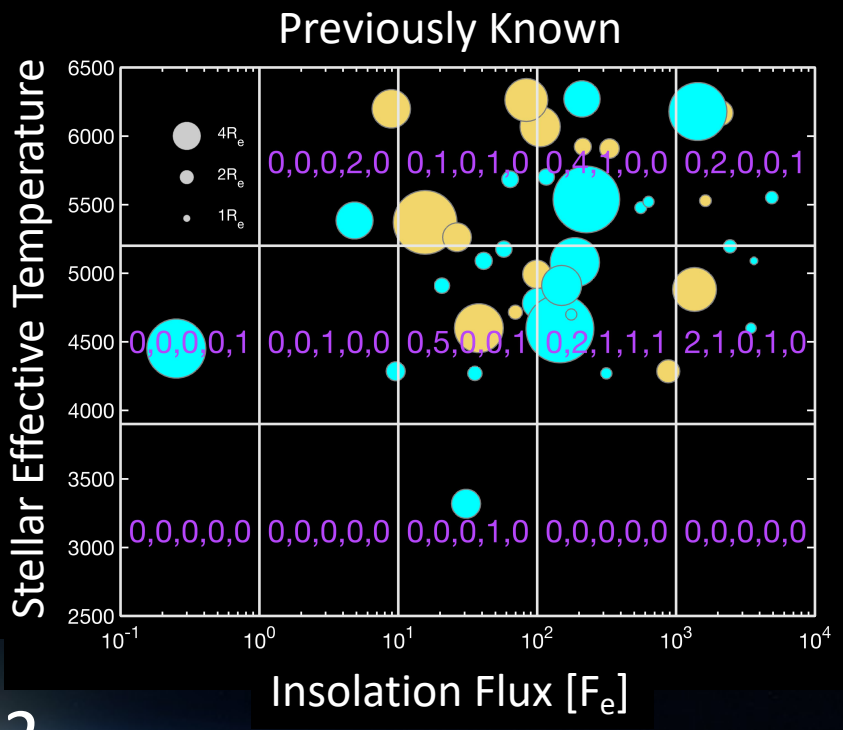
Looking Forward: Webb Legacy Survey





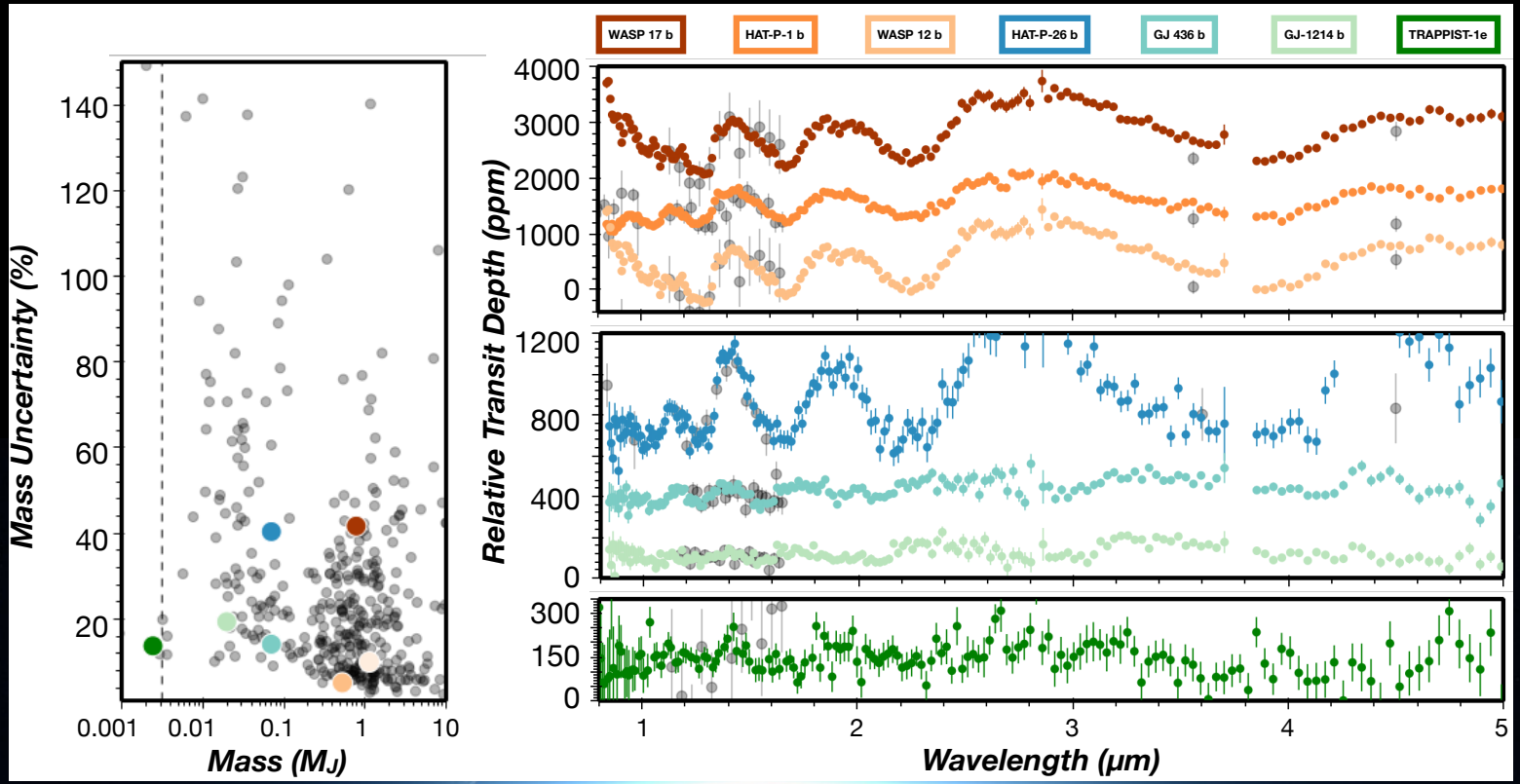
Looking Forward: Webb Legacy Survey





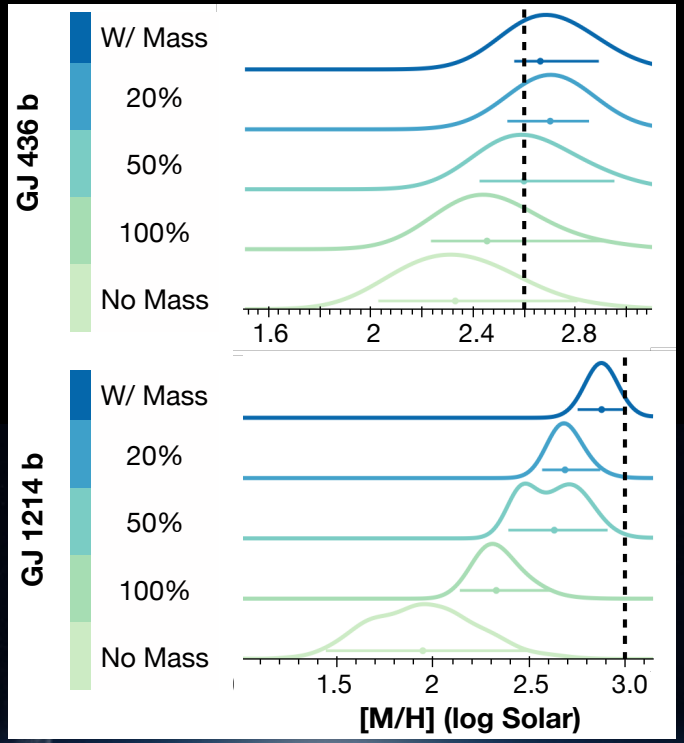
V < 12

How well do we need to know planet mass?



N.E. Batalha, in preparation

How well do we need to know planet mass?

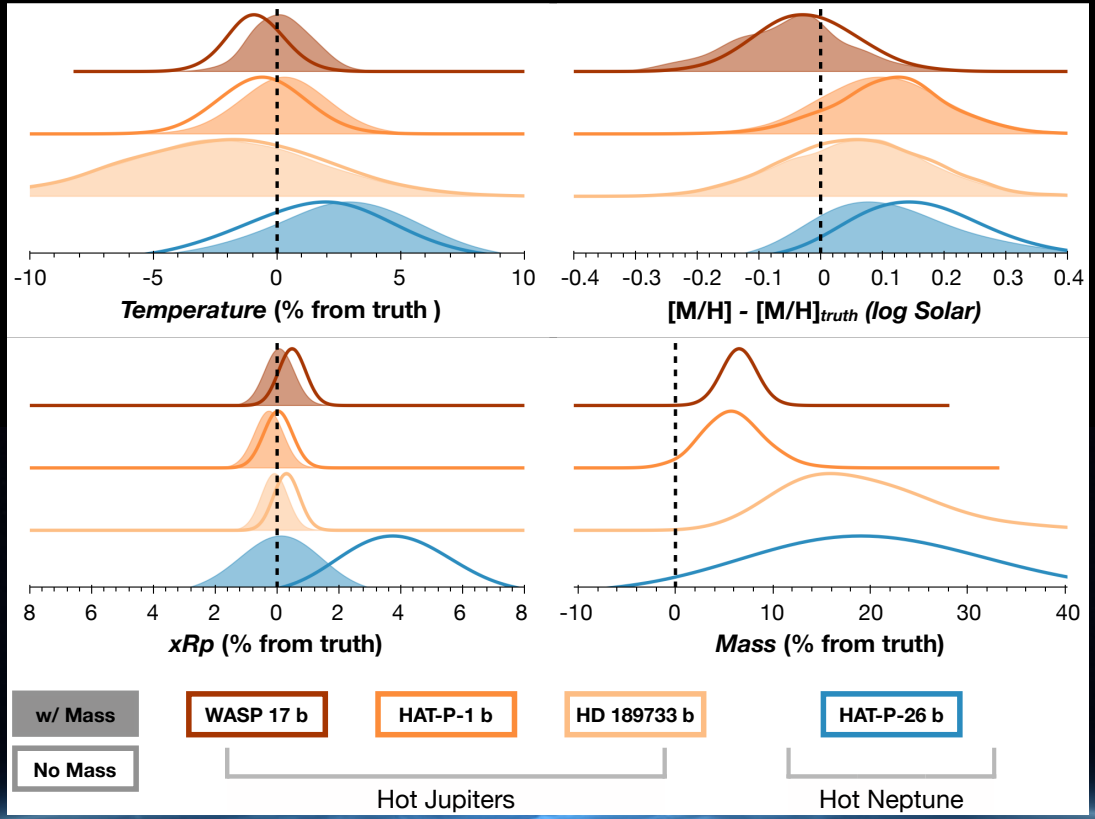


Warm Neptunes:

20% precision

N.E. Batalha, in preparation

How well do we need to know planet mass?



Hot Jupiters

Less important

N.E. Batalha, in preparation

Takeaway Messages

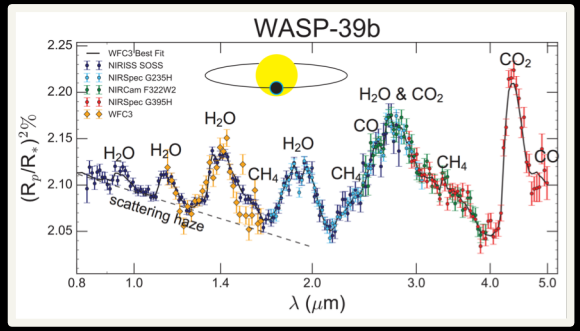
- Wavelength coverage of Webb is a boon to transiting exoplanet science.
- The Early Release Science program is designed to support the broader community; non-proprietary & open science.
- The transiting planet ERS program will focus on 3 Hot Jupiter exoplanets via Transmission. Emission, and Phase Modulation and will test all Webb instruments. https://ers-transit.github.io
- NASA's TESS Mission is yielding excellent candidates for atmospheric characterization. Many are very faint in the optical.
- Planet mass measurements are required for reliable retrieval of atmospheric properties for planets smaller than 10 R_earth
- A Webb legacy program will require strategic cooperation to optimize the science yield.

Transiting Exoplanet Community Early Release Science for Webb

I. Transmission Spectroscopy

0.6 μ < λ < 5 μ

WASP-79b, 42 h

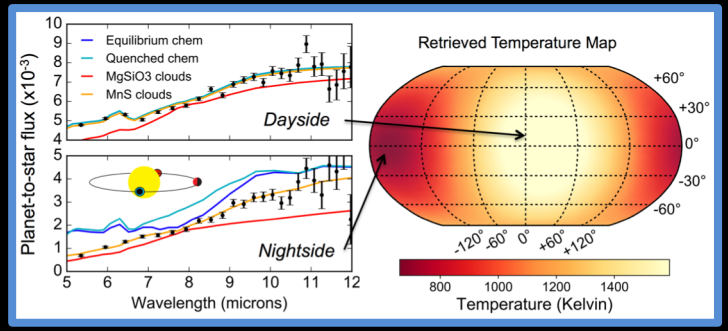


Observe one exoplanet feature (primary transit) with all available instruments (NIRISS, NIRCam, NIRSpec) and overlapping wavelengths to identify reliable modes.

2. MIRI Phase Curve

5 μ < λ < 10 μ

WASP-43b, 29.5

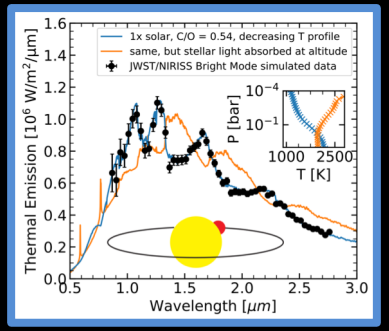


Observe all exoplanet features (primary transit, secondary eclipse, phase modulation) with the one instrument available at long wavelength & evaluate hour-to-hour stability.

3. Bright Star Test

0.85 μ < λ <2.8 μ

WASP-18b, 8.6



Test stability at the photon noise floor by observing the brightest star possible with NIRISS at secondary eclipse.