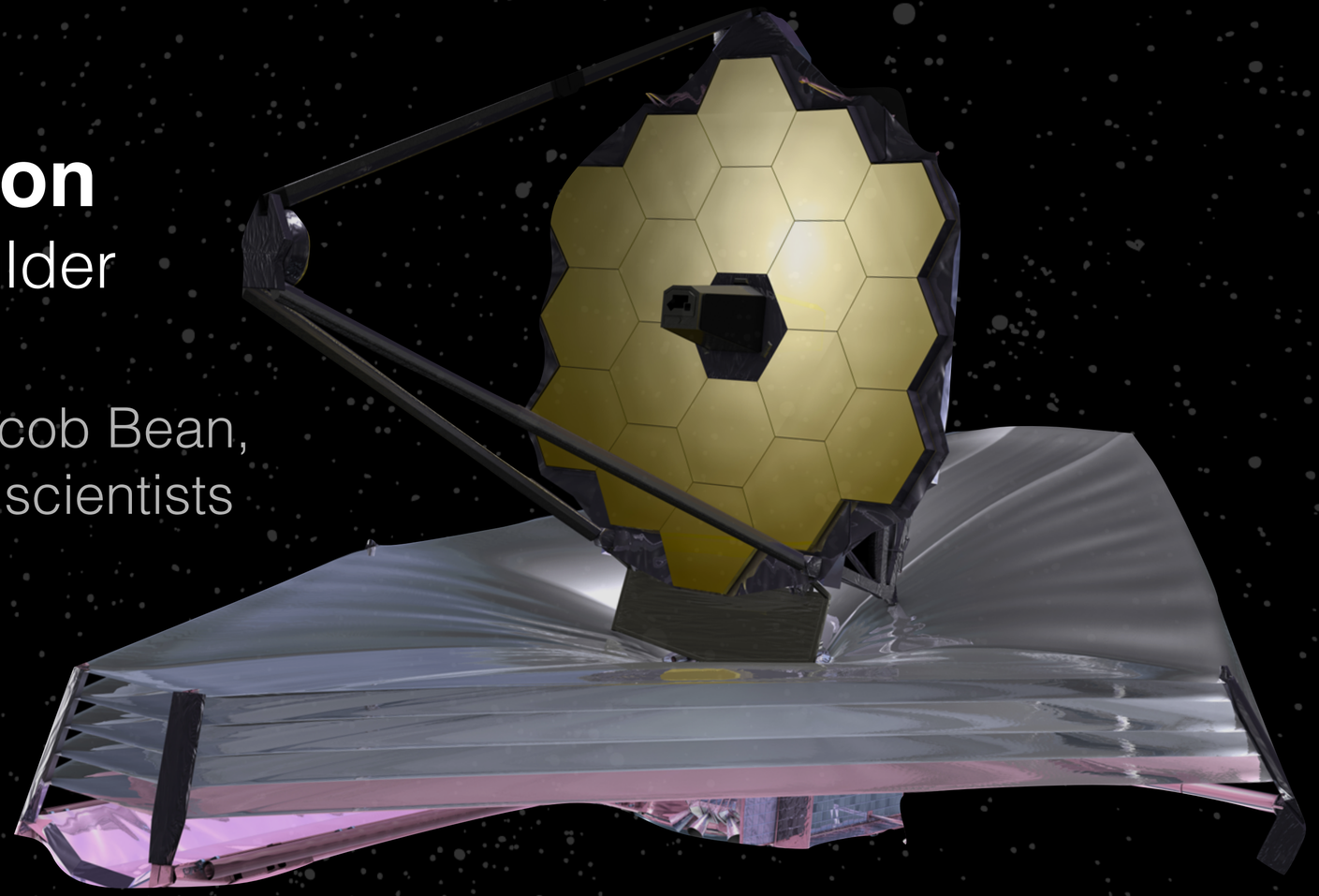
The Transiting Exoplanet Community Early Release Science Program for JWST

Zach Berta-Thompson
University of Colorado Boulder

presenting on behalf of
Natalie Batalha, Kevin Stevenson, Jacob Bean,
and 108+ other transiting exoplanet scientists



Co-Investigators:

Investigator	Institution	Country
M Alam	Harvard University	USA/MA
N Batalha	NASA Ames Research Center	USA/CA
N Batalha	Space Telescope Science Institute	USA/MD
J Bean	University of Chicago	USA/IL
B Benneke	Universite de Montreal	CAN
Z Berta-Thompson	University of Colorado at Boulder	USA/CO
J Blecic	New York University	USA/NY
G Bruno	Space Telescope Science Institute	USA/MD
A Carter	University of Exeter	GBR
J Chapman	Jet Propulsion Laboratory	USA/CA
I Crossfield	Massachusetts Institute of Technology	USA/MA
N Crouzet	Instituto de Astrofisica de Canarias	ESP
L Decin	Katholieke Universiteit Leuven	BEL
B Demory	University of Bern	CHE
J Desert	Universiteit van Amsterdam	NLD
D Dragomir	Massachusetts Institute of Technology	USA/MA
T Evans	University of Exeter	GBR
J Fortney	University of California - Santa Cruz	USA/CA
J Fraine	Space Telescope Science Institute	USA/MD
P Gao	NASA Ames Research Center	USA/CA
A Garcia Munoz	Technische Universitat Berlin	DEU
N Gibson	The Queen's University of Belfast	GBR
J Goyal	University of Exeter	GBR
J Harrington	University of Central Florida	USA/FL
K Heng	University of Bern	CHE
R Hu	Jet Propulsion Laboratory	USA/CA
E Kempton	University of Maryland	USA/MD
S Kendrew	ESA-European Space Astronomy Centre	ESP
B Kilpatrick	Brown University	USA/RI
H Knutson	California Institute of Technology	USA/CA
L Kreidberg	Harvard University	USA/MA
J Krick	Caltech/IPAC	USA/CA
P Lagage	Commissariat a l'Energie Atomique (CEA)	FRA
M Lendl	Space Research Institute, Austrian Academy of Sciences	AUT
M Line	Arizona State University	USA/AZ
M Lopez-Morales	Smithsonian Institution Astrophysical Observatory	USA/MA
T Louden	The University of Warwick	GBR
N Madhusudhan	University of Cambridge	GBR
A Mandell	NASA Goddard Space Flight Center	USA/MD
M Mansfield	University of Chicago	USA/IL
E May	University of Michigan	USA/MI
G Morello	University College London	GBR
C Morley	Harvard University	USA/MA
J Moses	Space Science Institute	USA/CO
N Nikolov	University of Exeter	GBR
V Parmentier	University of Arizona	USA/AZ
S Redfield	Wesleyan University	USA/CT
J Roberts	University of Colorado at Boulder	USA/CO
E Schlawin	University of Arizona	USA/AZ
A Showman	University of Arizona	USA/AZ
D Sing	University of Exeter	GBR
J Spake	University of Exeter	GBR
K Stevenson	Space Telescope Science Institute	USA/MD
M Swain	Jet Propulsion Laboratory	USA/CA
K Todorov	Universiteit van Amsterdam	NLD
A Tsiaras	University College London	GBR
O Venot	Laboratoire Interuniversitaire des Systèmes Atmosphériques	FRA
W Waalkes	University of Colorado at Boulder	USA/CO
H Wakeford	Space Telescope Science Institute	USA/MD
P Wheatley	The University of Warwick	
R Zellem	Jet Propulsion Laboratory	

nber of investigators: 61
SA investigators: 23
SA investigators: 1

+ about 50 more Collaborators

1366

James Webb Space Telescope

Cycle 1 ERS Proposal

The Transiting Exoplanet Community Early Release Science Program

Scientific Category: Planets and Planet Formation

Scientific Keywords: Extrasolar Planets, Planetary Atmospheres, Transits

Instruments: NIRSPEC, NIRISS, MIRI, NIRCAM

Proprietary Period: 0 months

Allocation Information (in hours):

Science Time: 52.1

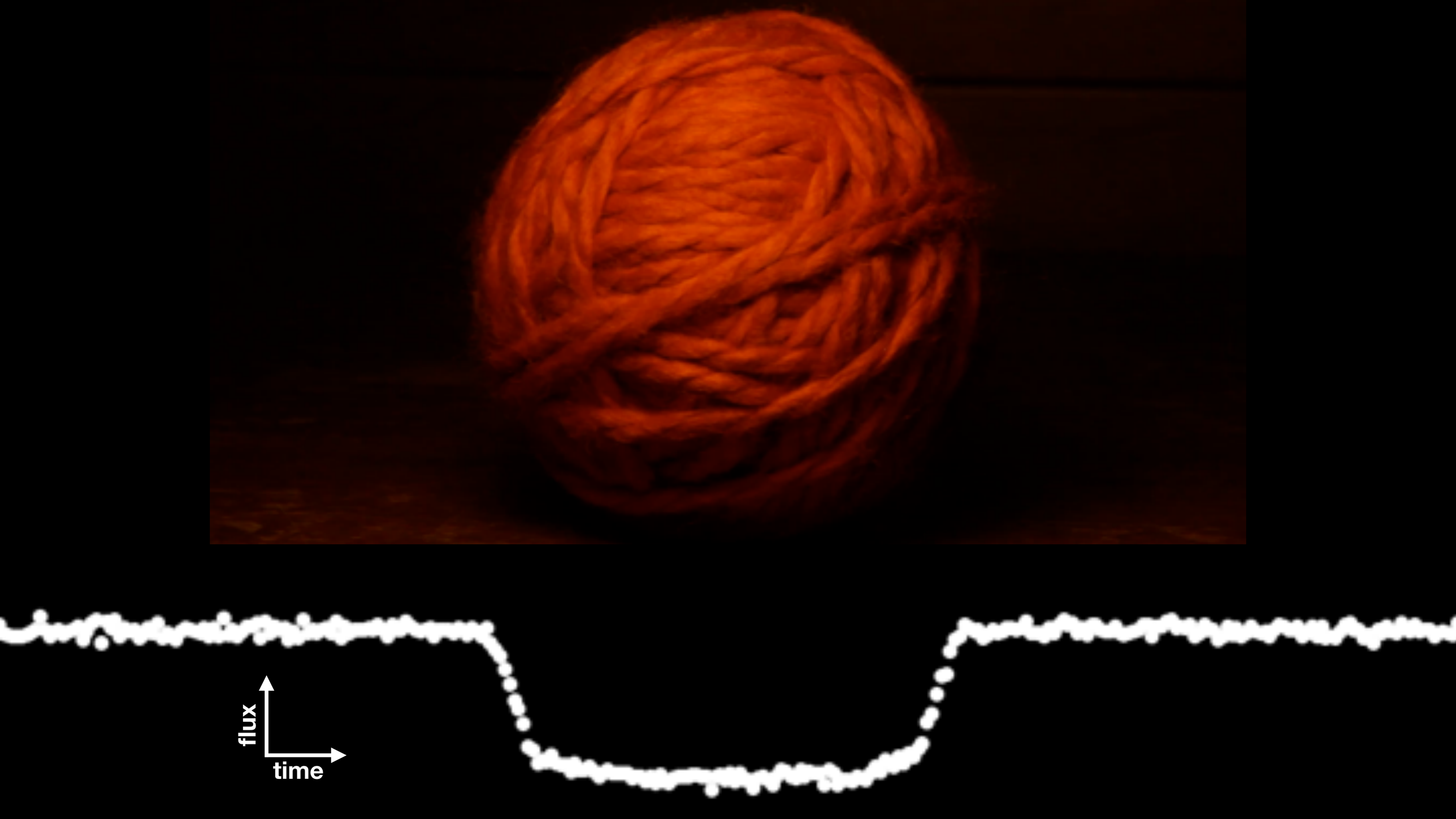
Charged Time: 78.1

- Transiting exoplanets are laboratories for studying planetary processes across diverse environments.
- JWST will make pioneering observations of three transiting hot Jupiters for Early Release Science.
- The community will use these observations to prepare for awesome exoplanet science with JWST.

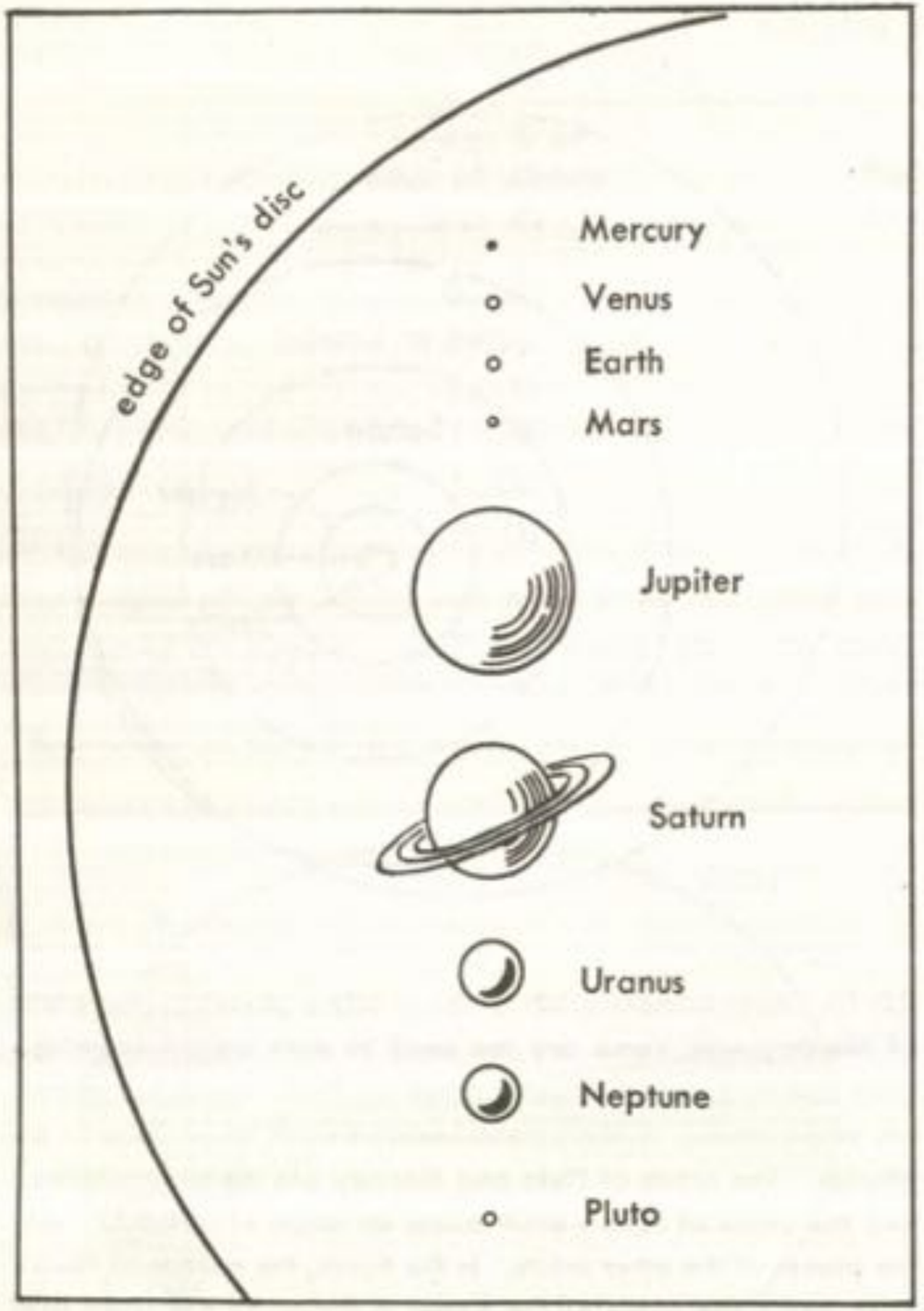
Transiting exoplanets are laboratories for studying planetary processes across diverse environments.

JWST will make pioneering observations of three transiting hot Jupiters for Early Release Science.

The community will use these observations to prepare for awesome exoplanet science with JWST.

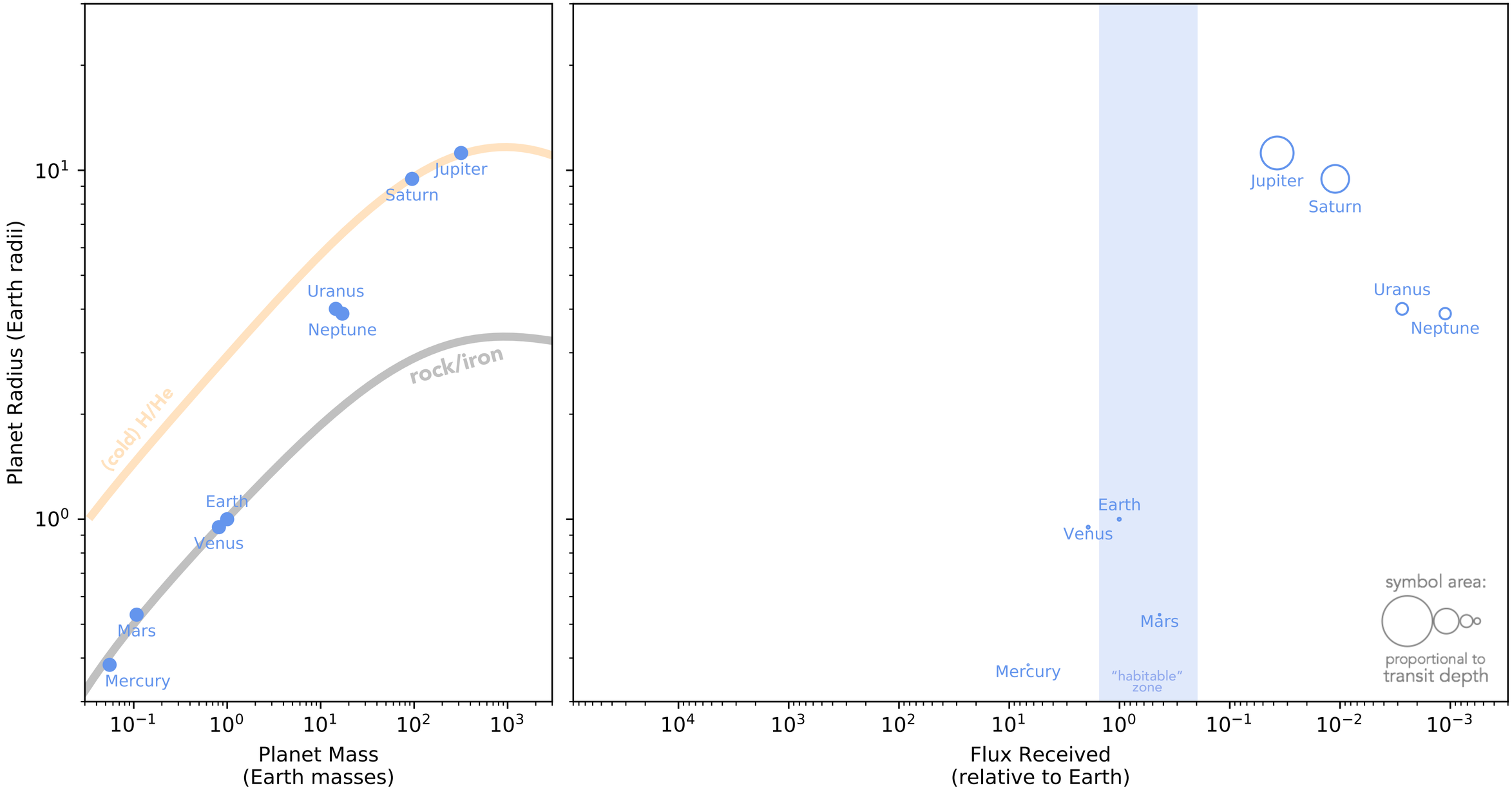

flux
time

Let's meet the planets.



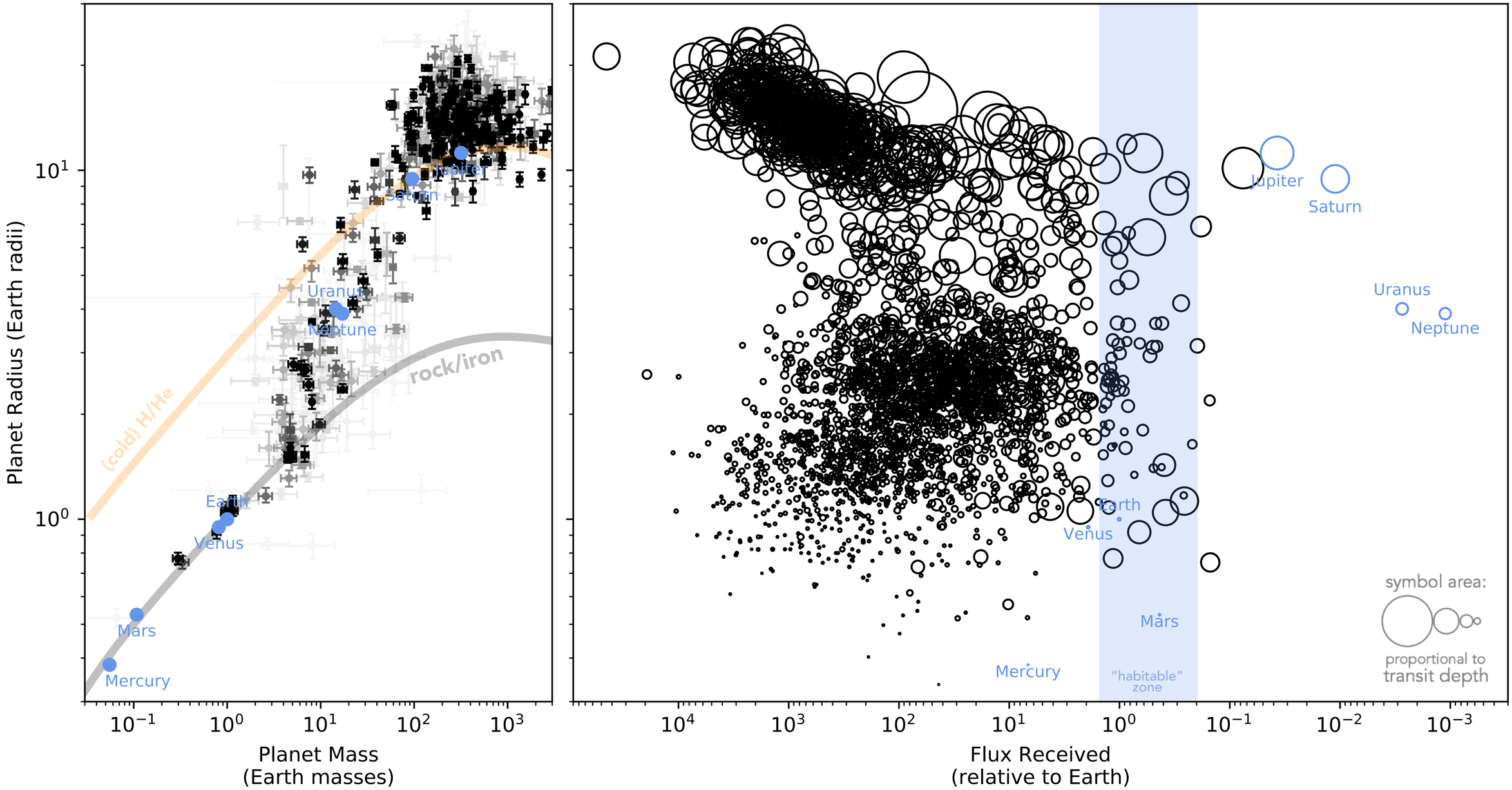
Images: PHYSICS by Physical Science Study Committee; NASA

Planetary scientists have beautiful data on eight Solar System planets.



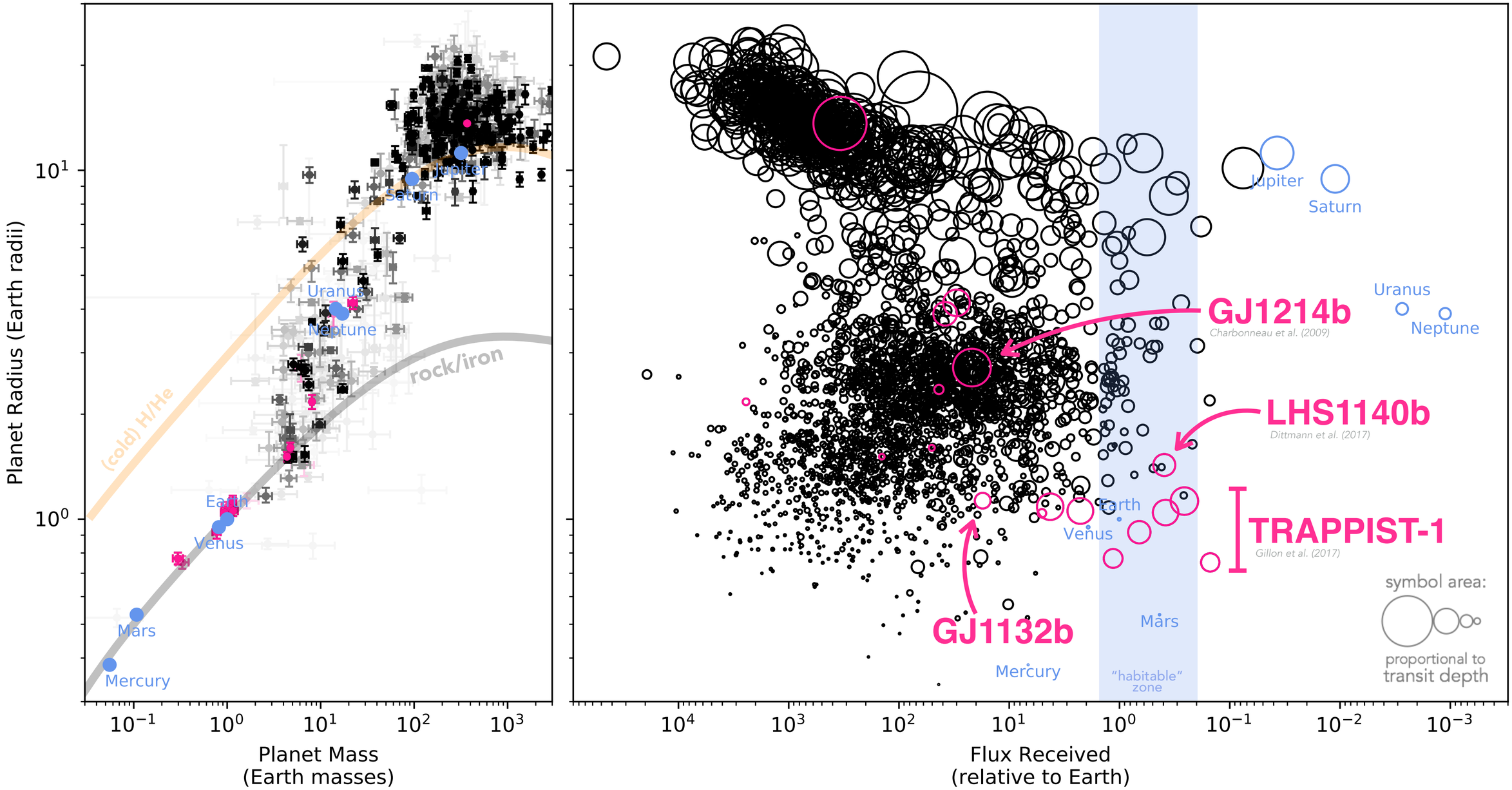
exoplanet properties from NASA Exoplanet Archive, with some curation; mass-radius models from Seager et al. (2007); HZ from Kopparapu et al. (2013)

We know thousands of transiting exoplanets, spanning diverse environments.

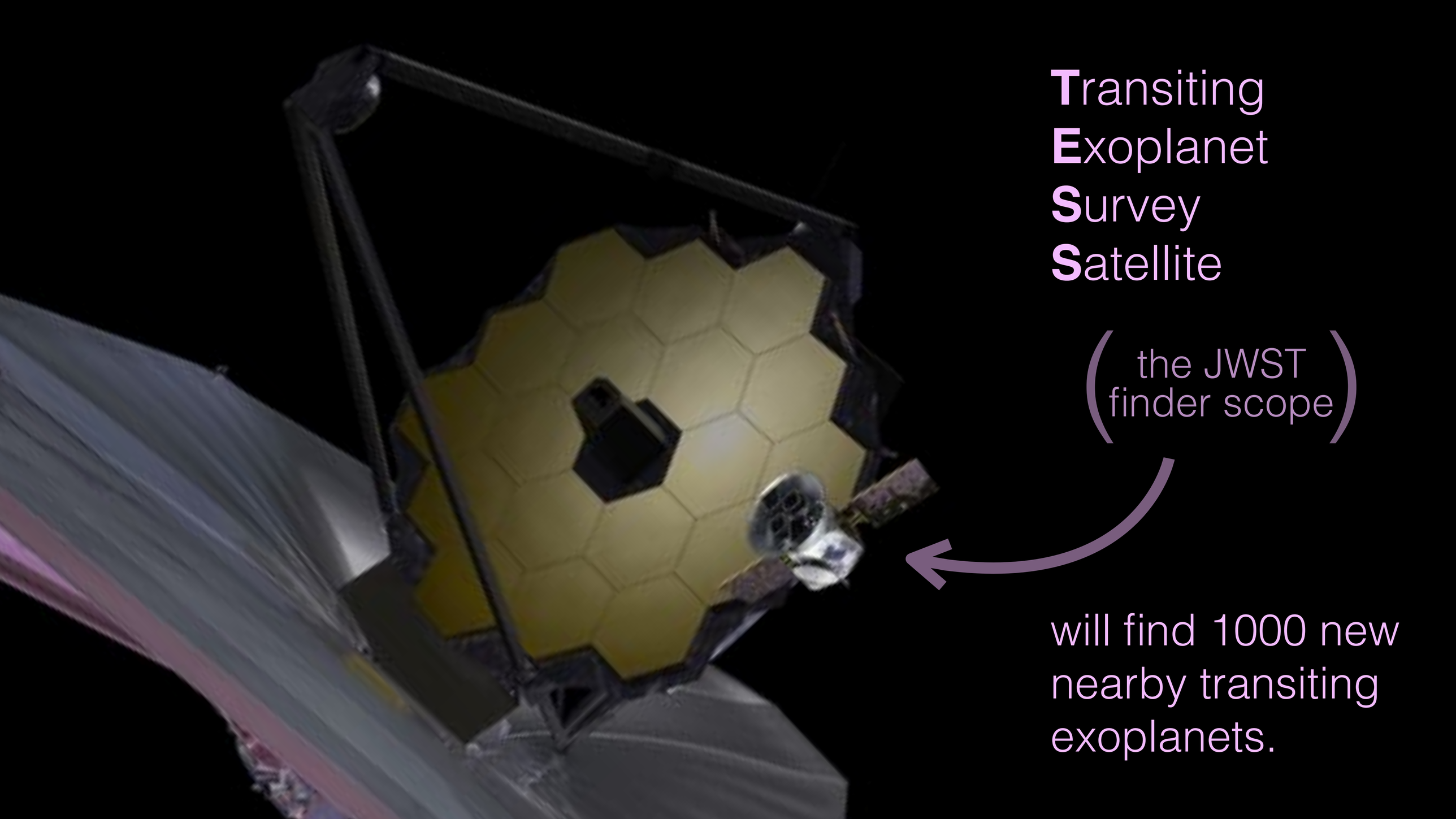


exoplanet properties from NASA Exoplanet Archive, with some curation; mass-radius models from Seager et al. (2007); HZ from Kopparapu et al. (2013)

The transiting exoplanets within 30pc include easy-to-study small planets.



exoplanet properties from NASA Exoplanet Archive, with some curation; mass-radius models from Seager et al. (2007); HZ from Kopparapu et al. (2013)



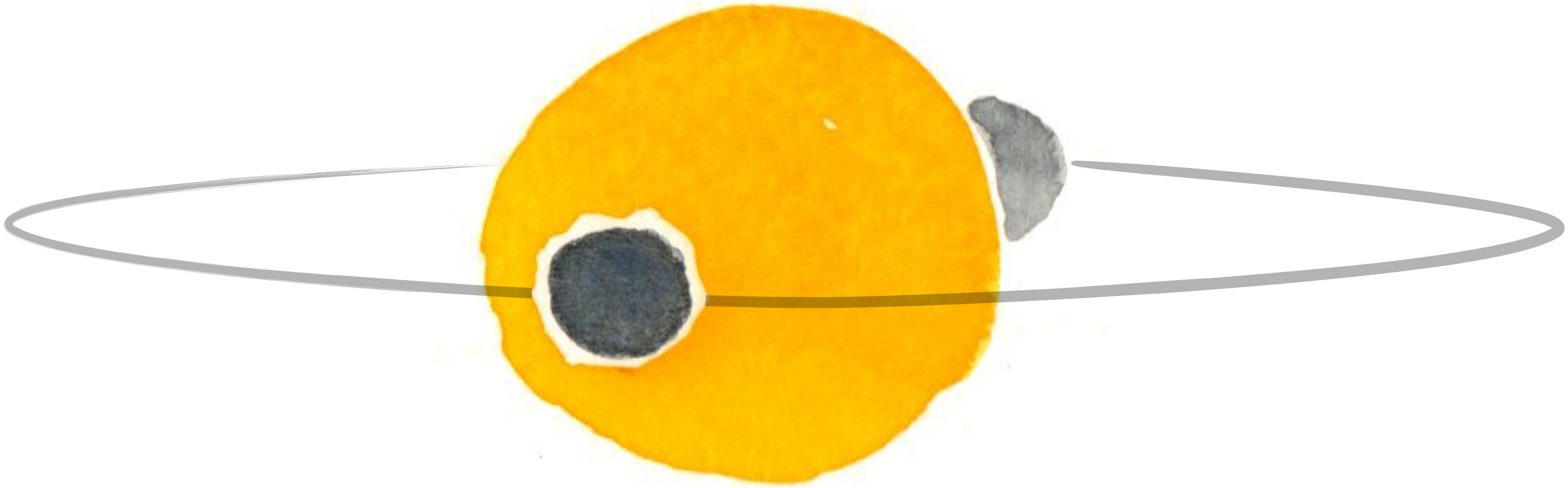
Transiting
Exoplanet
Survey
Satellite

(the JWST finder scope)

will find 1000 new nearby transiting exoplanets.

Transiting
Exoplanet
Survey
Satellite
launched in April!

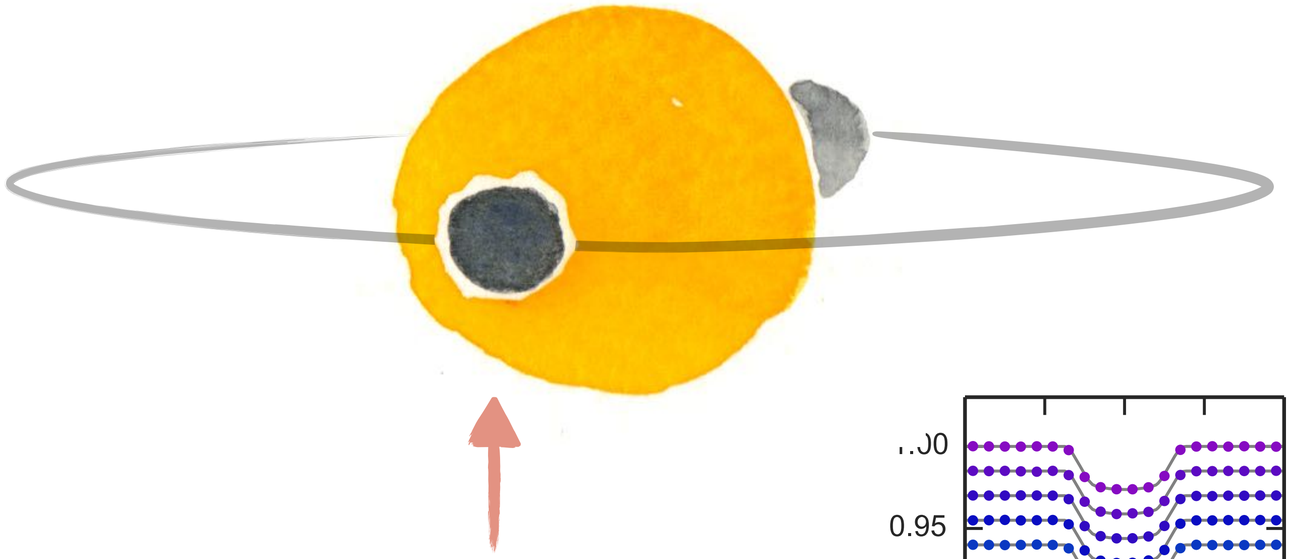
Transiting exoplanets are useful laboratories.



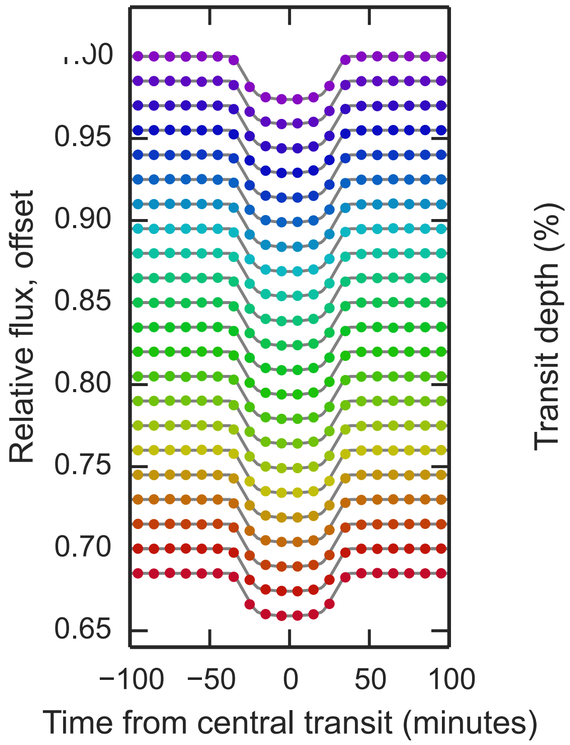
For a transiting exoplanet, we can directly observe
planet size + orbit + mass + atmosphere.

painted by Zach Berta-Thompson, adapted from original by Tim Brown, circa 2000

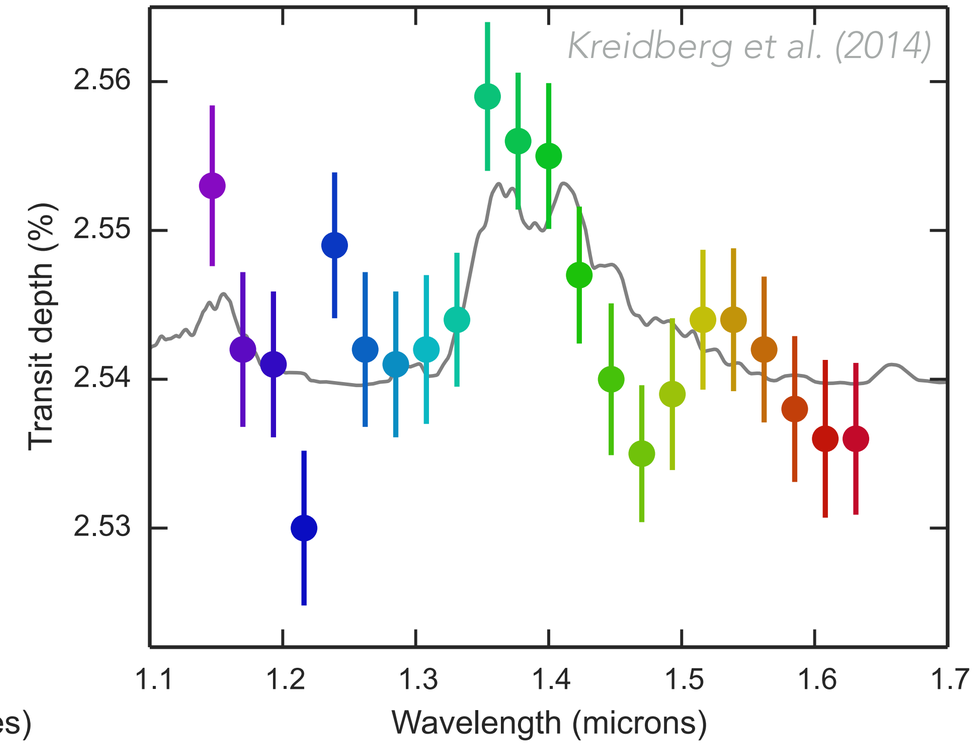
How do we observe transiting exoplanet atmospheres?



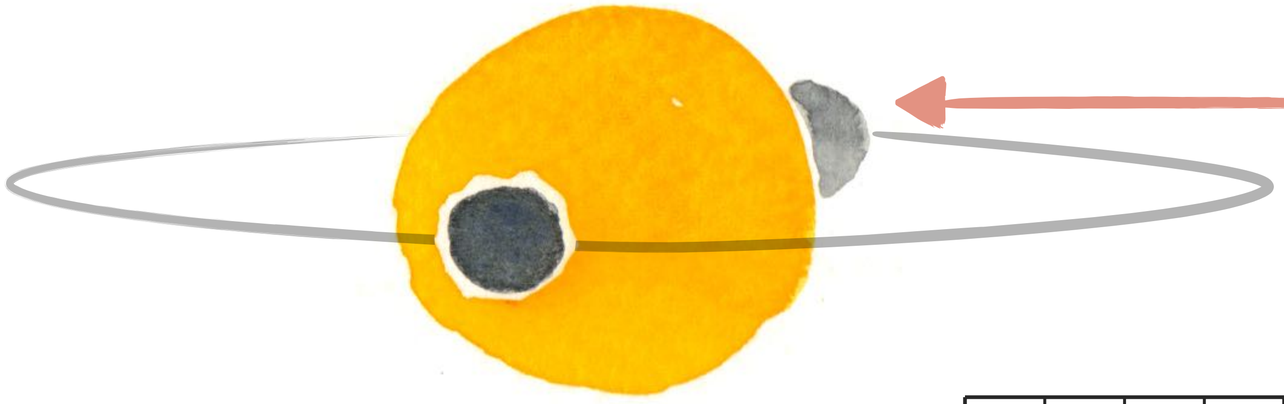
during TRANSIT, see light transmitted through planet's atmosphere



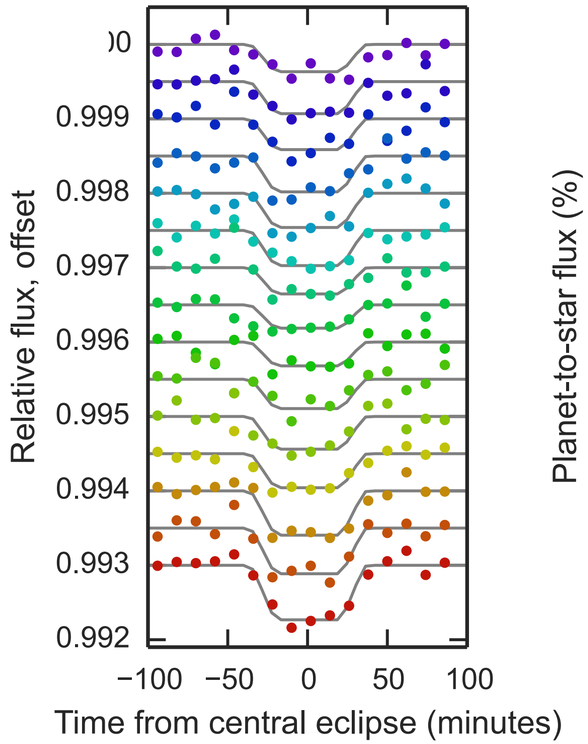
Hubble WFC3/G141
WASP-43b transmission spectrum



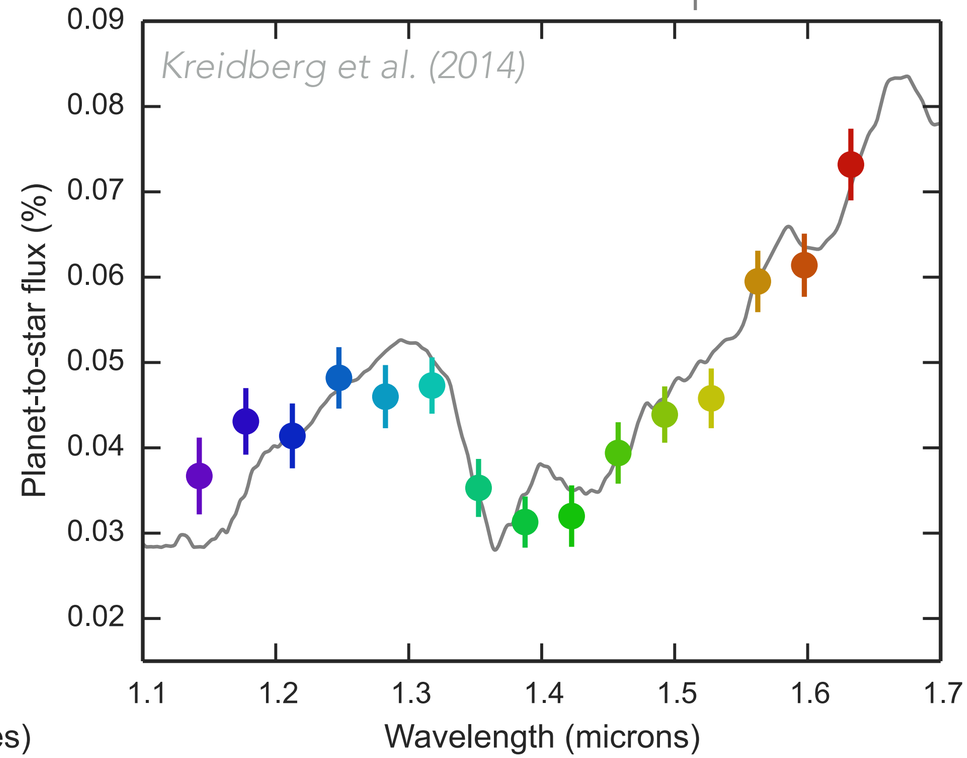
How do we observe transiting exoplanet atmospheres?



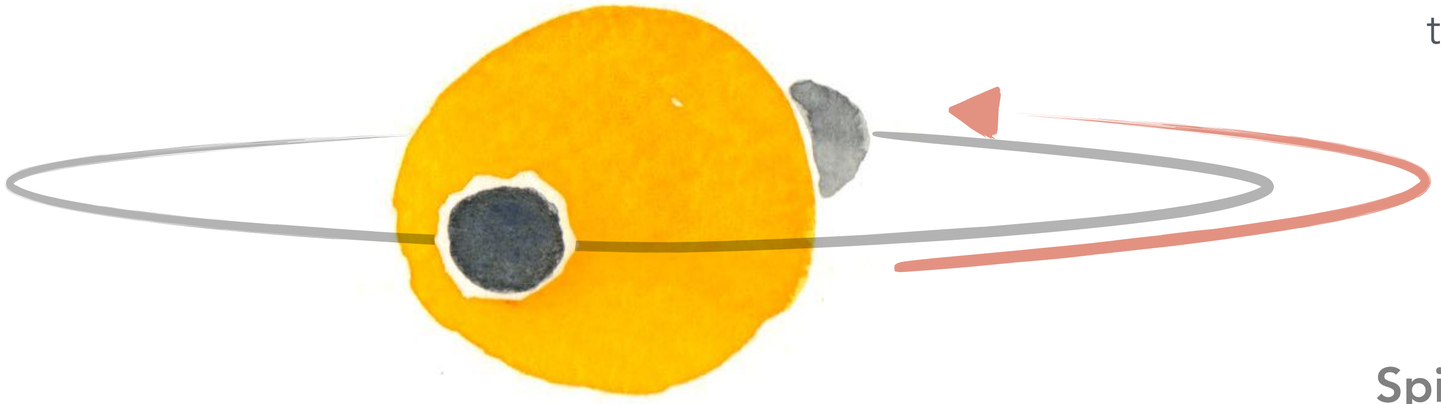
at secondary
ECLIPSE,
infer light emitted
by planet's day side



Hubble WFC3/G141
WASP-43b emission spectrum



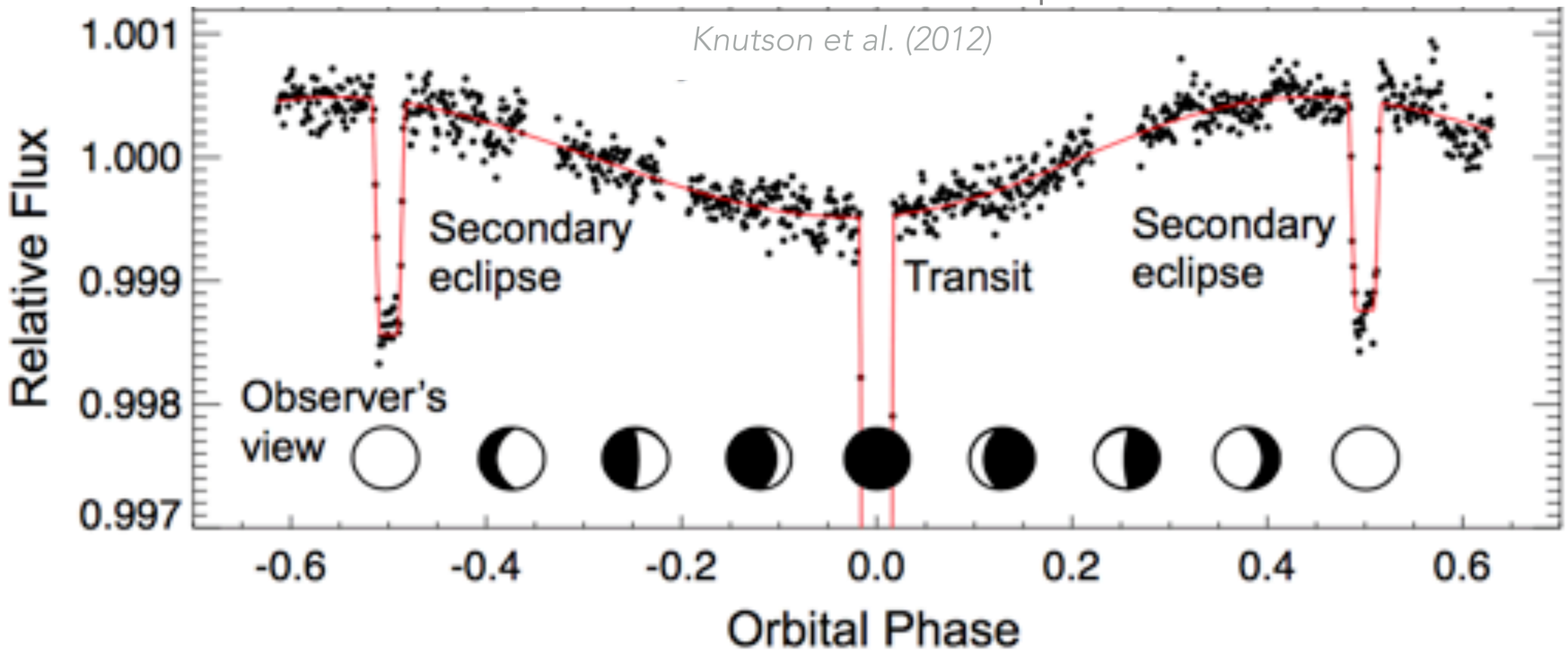
How do we observe transiting exoplanet atmospheres?



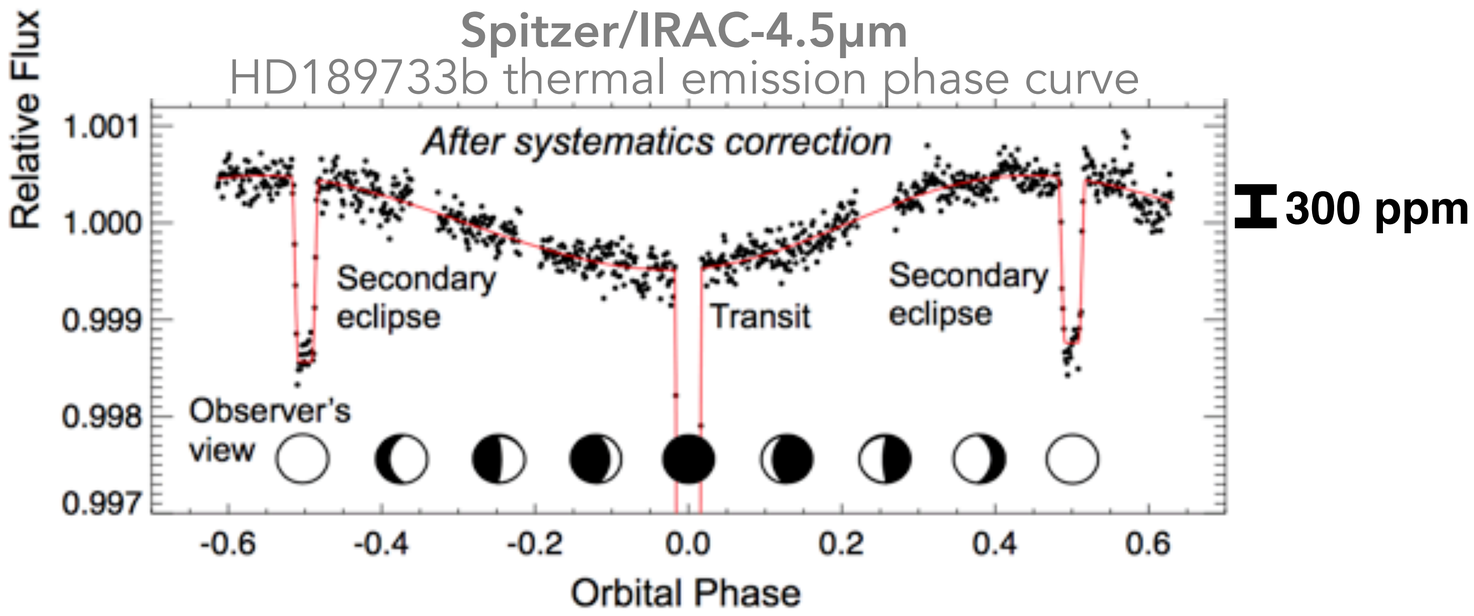
throughout the orbit, see emission from different longitudes as the
PHASE CURVE

Spitzer/IRAC-4.5μm
HD189733b thermal emission phase curve

Knutson et al. (2012)

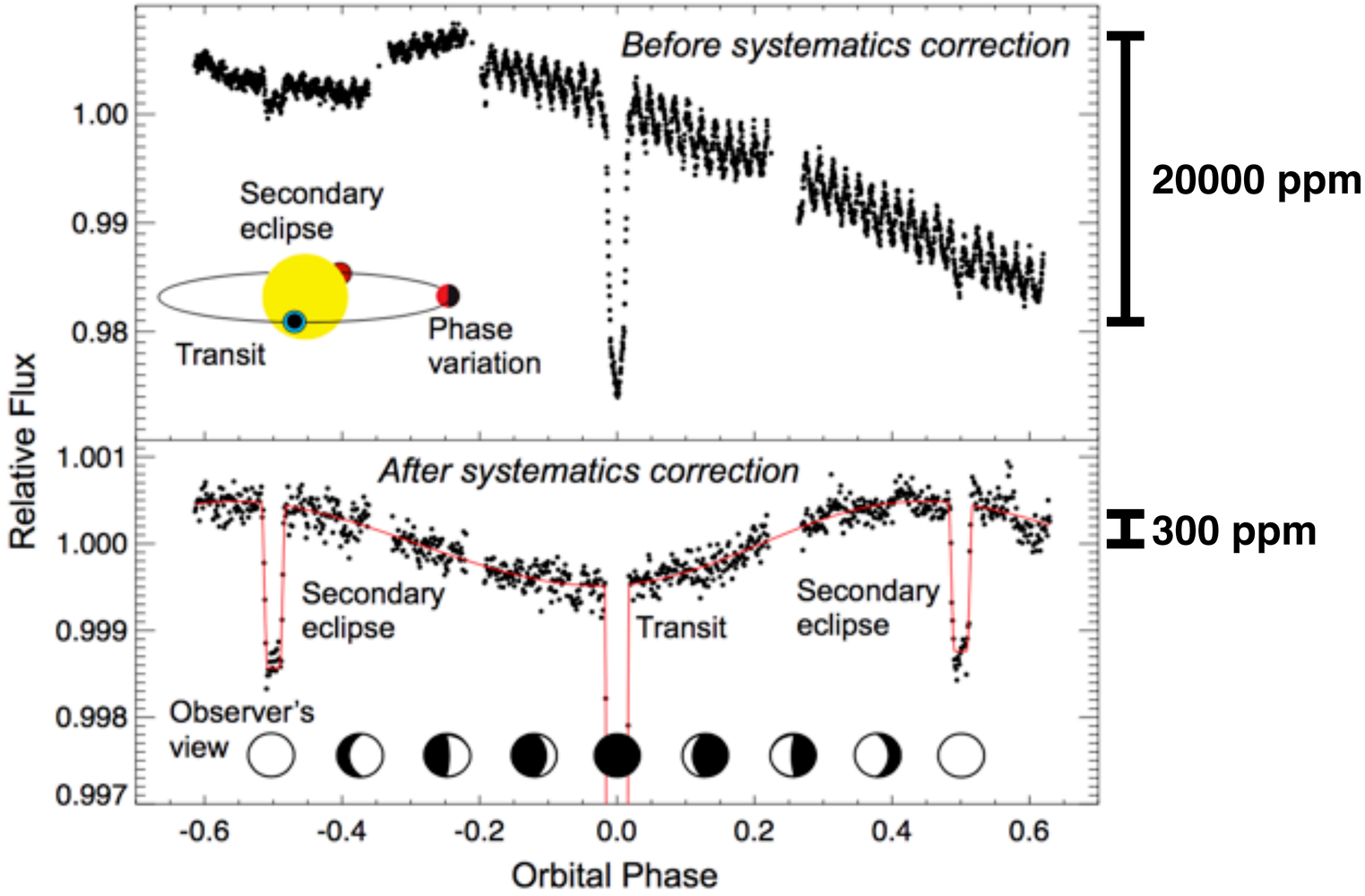


Exoplanet atmosphere observations require extreme precision.



observations and analysis of HD189733b from Knutson et al. (2012)

Exoplanet atmosphere observations require extreme precision, and careful understanding of instrumental noise sources.



observations and analysis of HD189733b from Knutson et al. (2012)

Transiting exoplanets are laboratories for studying planetary processes across diverse environments.

JWST will make pioneering observations of three transiting hot Jupiters for Early Release Science.

The community will use these observations to prepare for awesome exoplanet science with JWST.

The Transiting Exoplanet Community Early Release Science Program for JWST

- Let's understand what spectrophotometric precision we can achieve with JWST.
- Let's develop the best practices for transiting exoplanet studies with each JWST instrument.
- Let's provide the community with really cool observations of really neat planets!

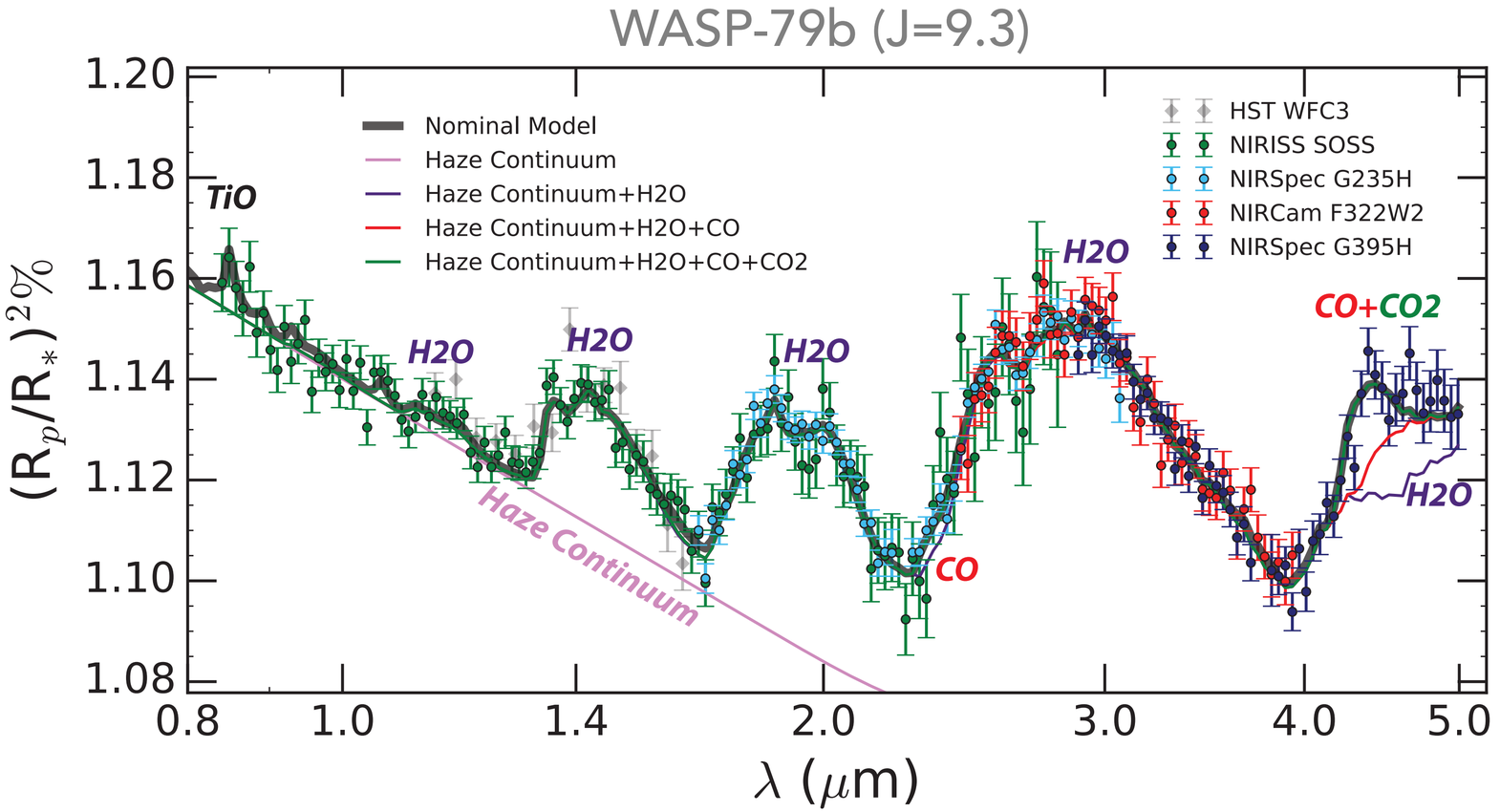
We began a transparent and inclusive process for designing this program at a STScI workshop in **November 2015.**

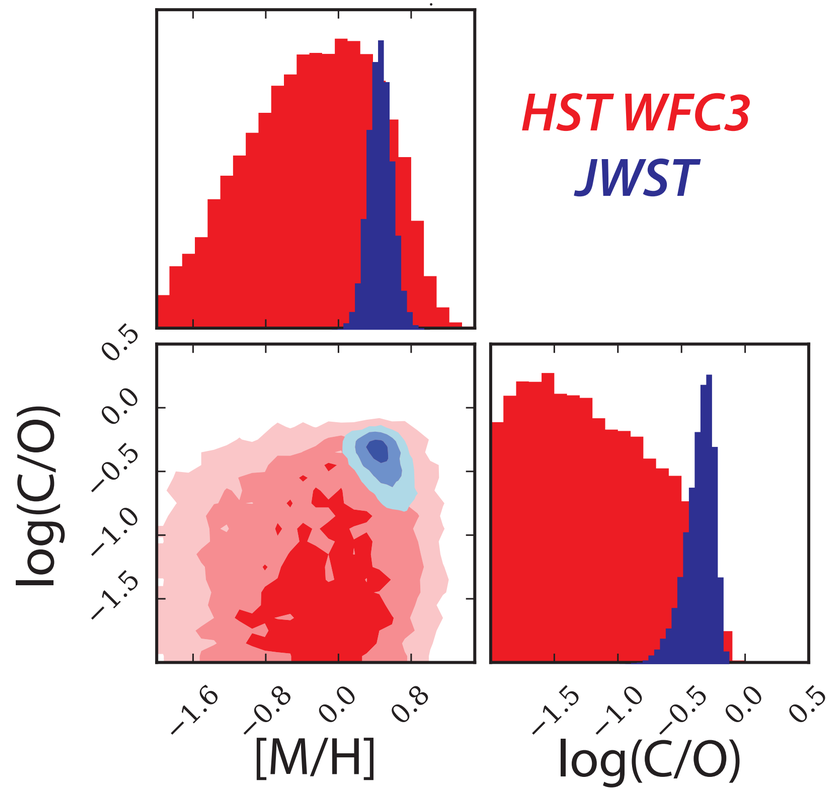
With 22 months of work by $\mathcal{O}(100)$ exoplanet and instrument experts, we identified a **consensus set of high-priority observations** that

- exercises all four JWST instruments
- includes three characterization geometries
- focuses only on previously vetted, easy-to-observe planets

(1) Pan-chromatic transmission spectrum of a hot Jupiter

(NIRISS + NIRSpec + NIRCam — 0.6-5μm)



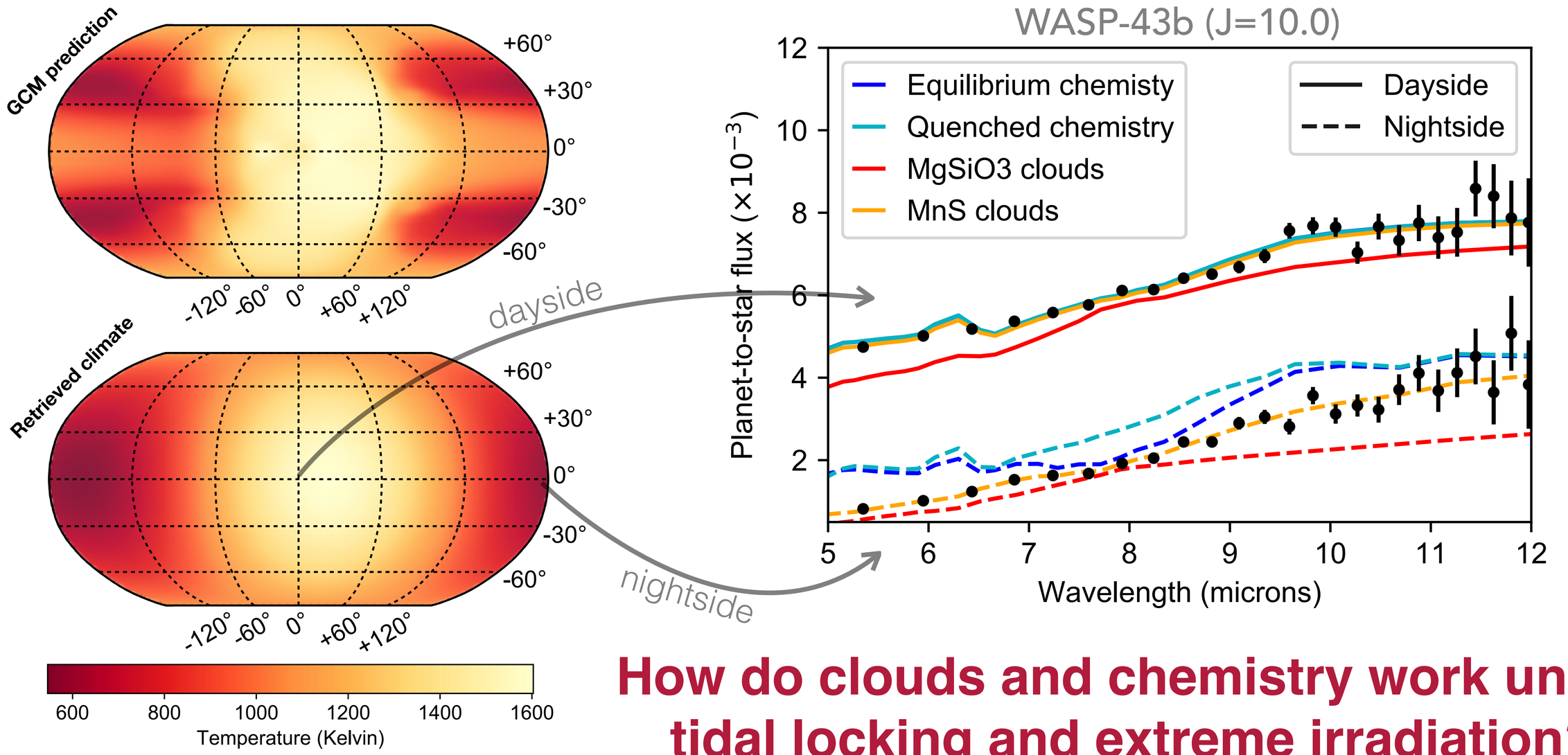


What is the chemical composition of a hot Jupiter atmosphere?

Transmission Working Group Leads: ***Hannah Wakeford, David Sing, Kevin Stevenson***

(2) Mid-infrared thermal emission phase curve of a hot Jupiter

(MIRI LRS — 5-12μm)

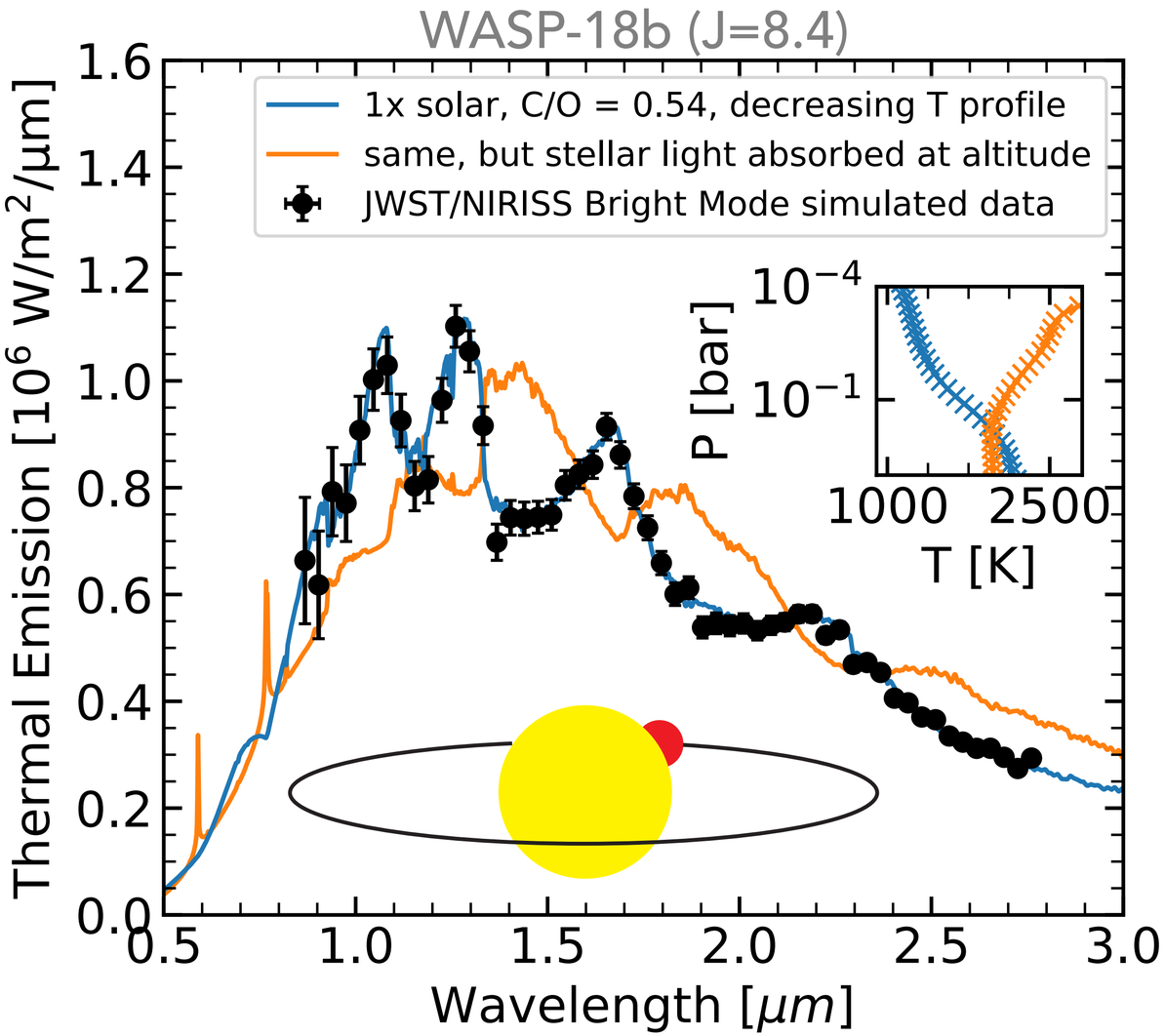


How do clouds and chemistry work under tidal locking and extreme irradiation?

MIRI Phase Curve Working Group Leads: ***Laura Kreidberg, Nicolas Crouzet, Julie Moses***

(3) Thermal emission eclipse for a hot Jupiter transiting a very bright star

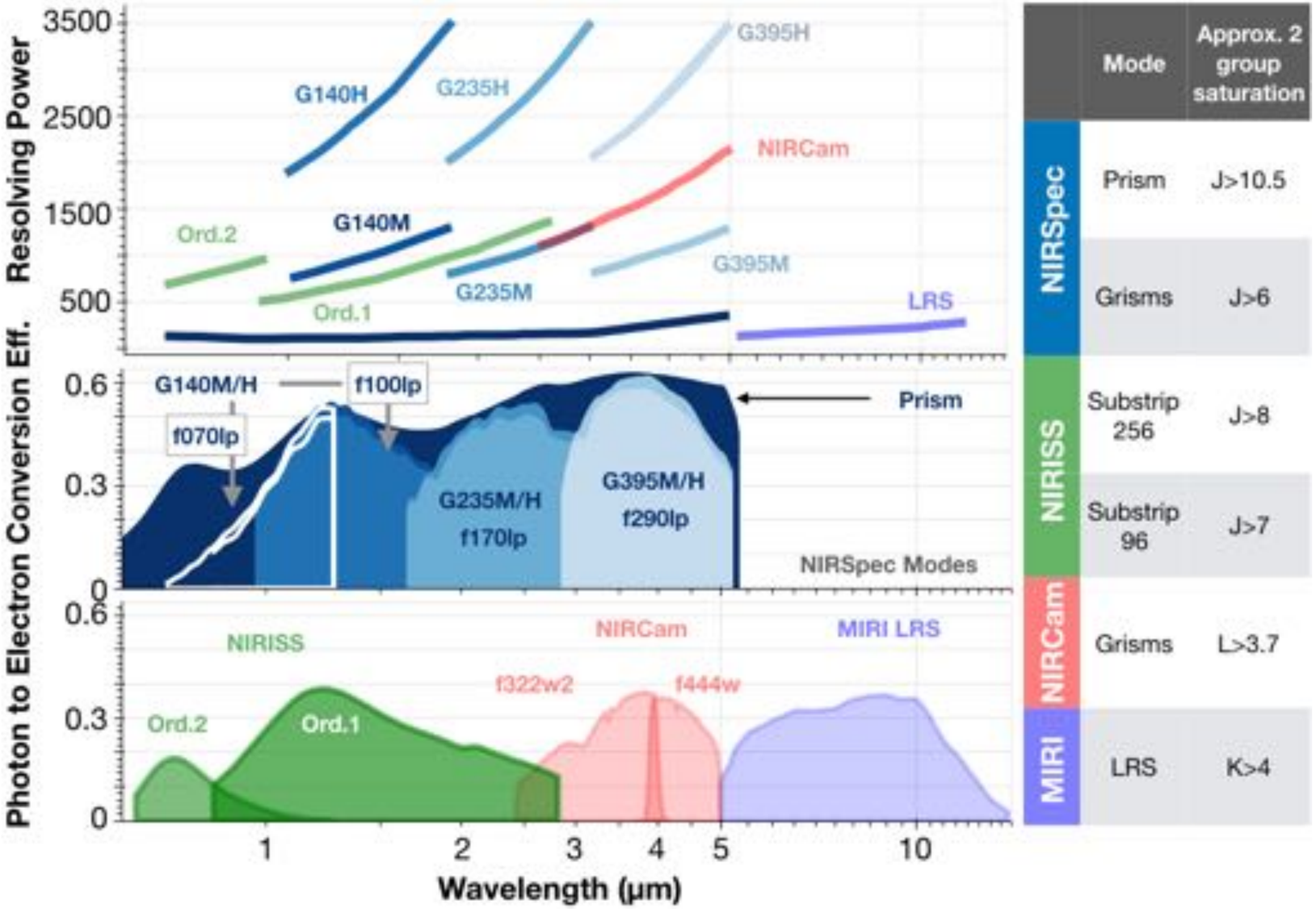
(NIRISS — 0.8-2.7μm)



What is the thermal structure and global energy budget for extremely hot Jupiter atmospheres?

Bright Star Eclipse Curve Working Group Leads: ***Björn Benneke, Jacob Bean, Eliza Kempton***

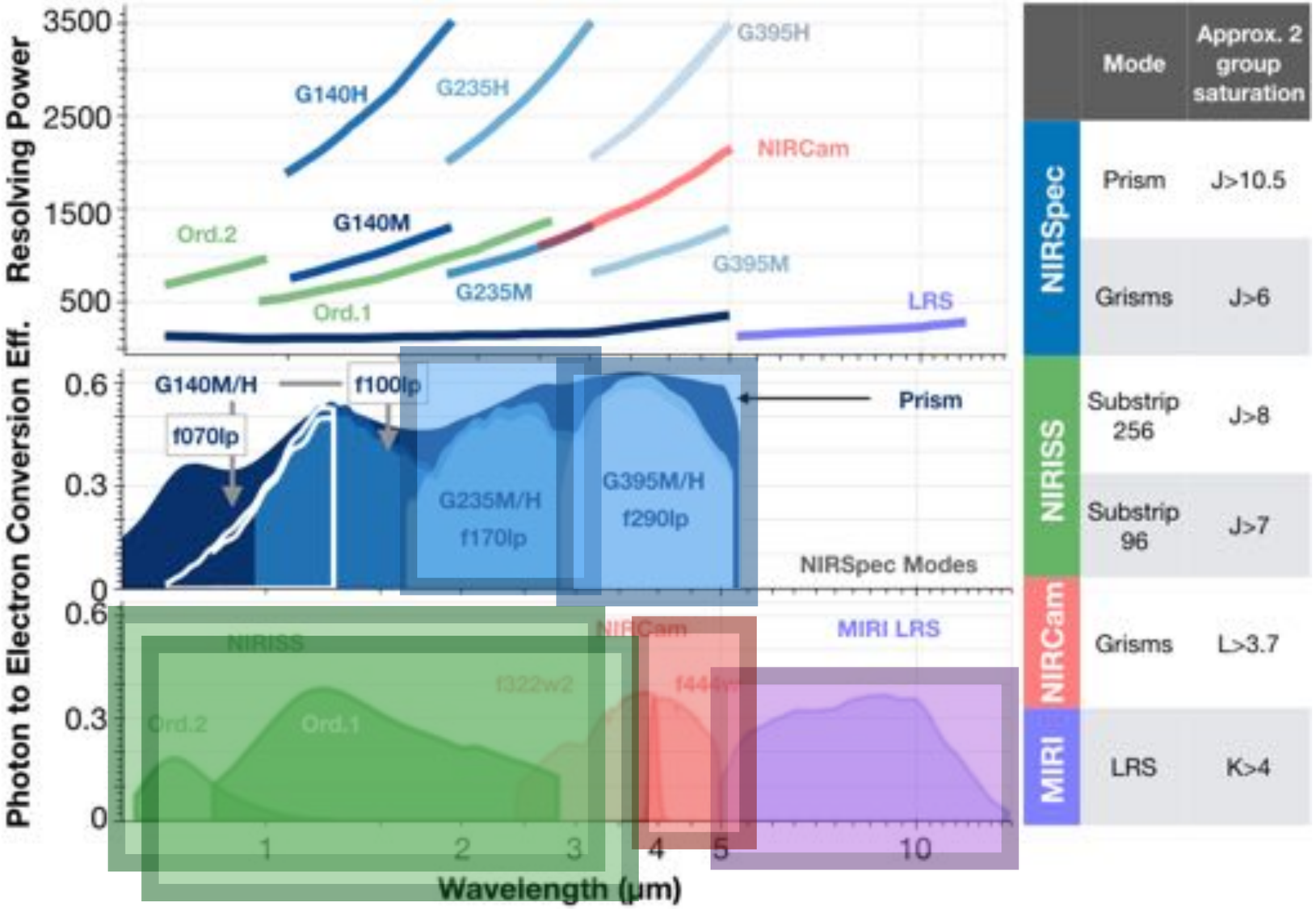
JWST has many spectroscopic modes for transiting exoplanets.



	Mode	Approx. 2 group saturation
NIRSpec	Prism	J>10.5
NIRSpec	Grisms	J>6
NIRISS	Substrip 256	J>8
NIRISS	Substrip 96	J>7
NIRCam	Grisms	L>3.7
MIRI	LRS	K>4

instrument response schematics from ExoCTK and PandExo (Batalha et al. 2017)

JWST has many spectroscopic modes for transiting exoplanets.



	Mode	Approx. 2 group saturation
NIRSpec	Prism	J>10.5
NIRSpec	Grisms	J>6
NIRISS	Substrip 256	J>8
NIRISS	Substrip 96	J>7
NIRCam	Grisms	L>3.7
MIRI	LRS	K>4

The ERS program uses **eighty hours** to test and cross-validate **six observing modes.**

instrument response schematics from ExoCTK and PandExo (Batalha et al. 2017)

Transiting exoplanets are laboratories for studying planetary processes across diverse environments.

JWST will make pioneering observations of three transiting hot Jupiters for Early Release Science.

The community will use these observations to prepare for awesome exoplanet science with JWST.

The scientific utility of JWST for transiting exoplanets will be determined by:

- the *hardware* that will be collecting and recording photons
- the *software* with which we will analyze those data
- the *community* of people making and using these tools

We want to engage a large swath of the transiting exoplanet community.

We currently have 112 team members:
58% observers, 33% theorists
54% US, 46% EU + Canada
23% women, 44% women at leadership levels

PI: ***Natalie Batalha***
Co-PIs: ***Kevin Stevenson, Jacob Bean***

Transmission Working Group Leads: ***Hannah Wakeford, David Sing, Kevin Stevenson***
MIRI Phase Curve Working Group Leads: ***Laura Kreidberg, Nicolas Crouzet, Julie Moses***
Bright Star Eclipse Curve Working Group Leads: ***Björn Benneke, Jacob Bean, Eliza Kempton***
Data Challenge Working Group Leads: ***Zach Berta-Thompson, Mike Line, Mercedes Lopez-Morales***

Science Council: ***David Sing, Mike Line, Heather Knutson, Ian Crossfield, Laura Kreidberg, Jean-Michel Désert, Zach Berta-Thompson***

We welcome new members!

We will host a JWST Exoplanet Data Challenge, including two workshops.

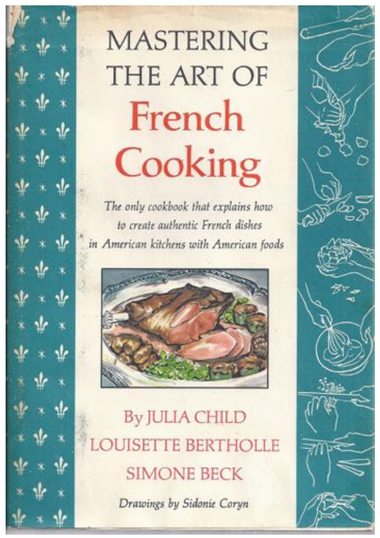
- **Before observations** — we will focus on simulated data, where we know the exact answers. We will meet to learn and develop analysis tools, and test the assumptions of different theoretical models and retrieval methods.

- **After observations** — we will focus on the real data, where we need cross-validation for robust results. We will meet to compare analyses and theoretical modeling frameworks, write papers, and produce science-enabling products.

These workshops will be open to the entire community, regardless of whether folks are Co-I/Collaborator on the proposal.

Science-Enabling Products

(1) Data Analysis Tutorials:



We will publish a worked example analysis of each JWST dataset (`jupyter` notebook), going from pixels to light curves and planetary spectra. These are **recipes** for future analyses.

Table 3. Core Ingredients for Data Analysis Toolkits

1	Visualize the time-series cube of 2D images, with static pixel-by-pixel mean and variance images and movies.
2	Extract 1D spectra and their predicted uncertainties, using both fixed apertures and optimal extractions. Measure time-series diagnostics that may inform instrumental models below.
3	Separate the instrumental and astrophysical signals, using physically-motivated causal models, as well as independent, statistical approaches such as Gaussian Process models and Principal/Independent Component Analysis techniques. Establish priors from our physical knowledge of the instrument.
4	Create a parameterized model of the planet feature that was observed (transit, eclipse, phase curve), including free parameters for stellar limb-darkening and stellar variability. Establish priors from our knowledge of the exoplanet system.
5	Fit this joint model to data, using MCMC or nested sampling to estimate the parameters' posterior probability distribution.
6	Extract the planetary spectra that are embedded within those fits, after marginalizing over all other parameters and possible instrumental models. These spectra constitute the core scientific measurements of the program, to be archived on MAST.

Data Challenge Working Group Leads: ***Zach Berta-Thompson, Mike Line, Mercedes Lopez-Morales***

Science-Enabling Products

(2) Instrument Performance Reports:

We will publish a report (`jupyter` notebook) documenting the systematics seen in each JWST instrument. These are **field guides** for what future observers should know.

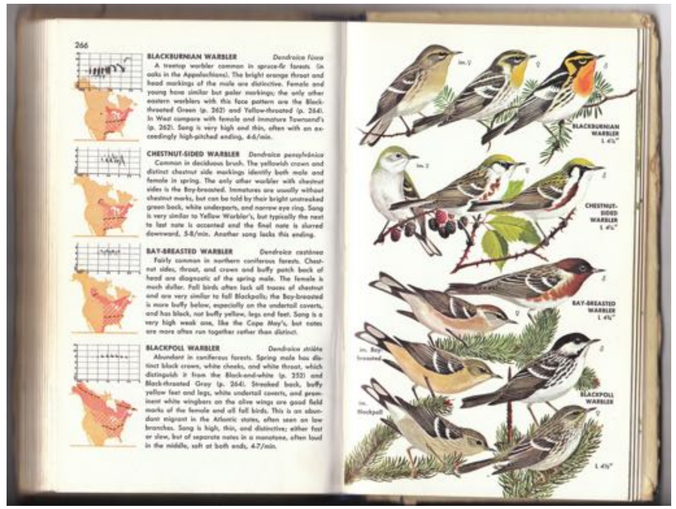
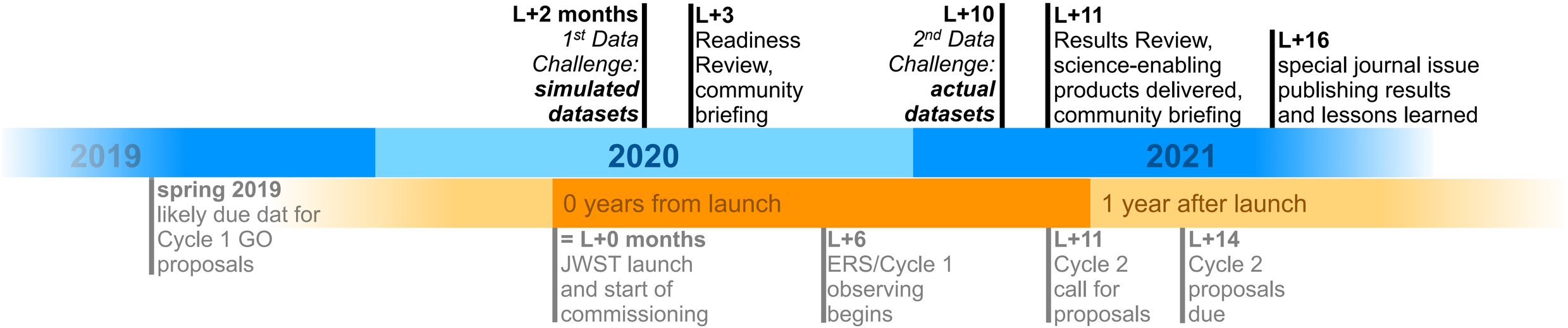


Table 4. Basic Outline of Instrument Performance Reports

The field guides will measure diagnostics...	**...to help answer basic questions about the instrument.**
• the number of photons detected per wavelength	Are `PandExo`/`Pandeia`'s core throughput estimates and instrument models accurate?
• the measured variance of the flux residuals compared to photon noise predictions • tests for non-Gaussianity of the flux residuals	Is the spectrophotometry photon-limited, or are there other significant time-series noise sources?
• the measured variance of time-binned flux residuals vs. temporal bin size • the power spectrum and autocorrelation function of the flux residuals	Is the noise correlated in time? How will this limit JWST's precision for exoplanet observables?
• the position/width/shape of the spectral trace vs. time • the background level and reference pixel values vs. time	How stable are the telescope/instrument optics and detectors over hours-to-days timescales?
• the strength and form of correlations between the residuals and other available time series (the above image diagnostics, temperature sensors, telescope pointing, antenna movements)	What physically-motivated models might explain systematic noise in time-series measurements?
• the measured variance of wavelength-binned residuals vs. wavelength bin size • a matrix of correlation strength between all possible wavelength bins	What instrumental systematics are "common-mode"? How well can we separate overlapping wavelengths?
• the descriptive morphology of any other time-dependent trends in the measured spectrophotometry	What is the timescale of detector persistence/charge-trapping? How long does *JWST* need to settle at the start of an observation?

Data Challenge Working Group Leads: ***Zach Berta-Thompson, Mike Line, Mercedes Lopez-Morales***

We need an effective and inclusive collaboration, to meet a tight schedule.



Draft version June 5, 2018
Typeset using LaTeX **twocolumn** style in AASTeX62

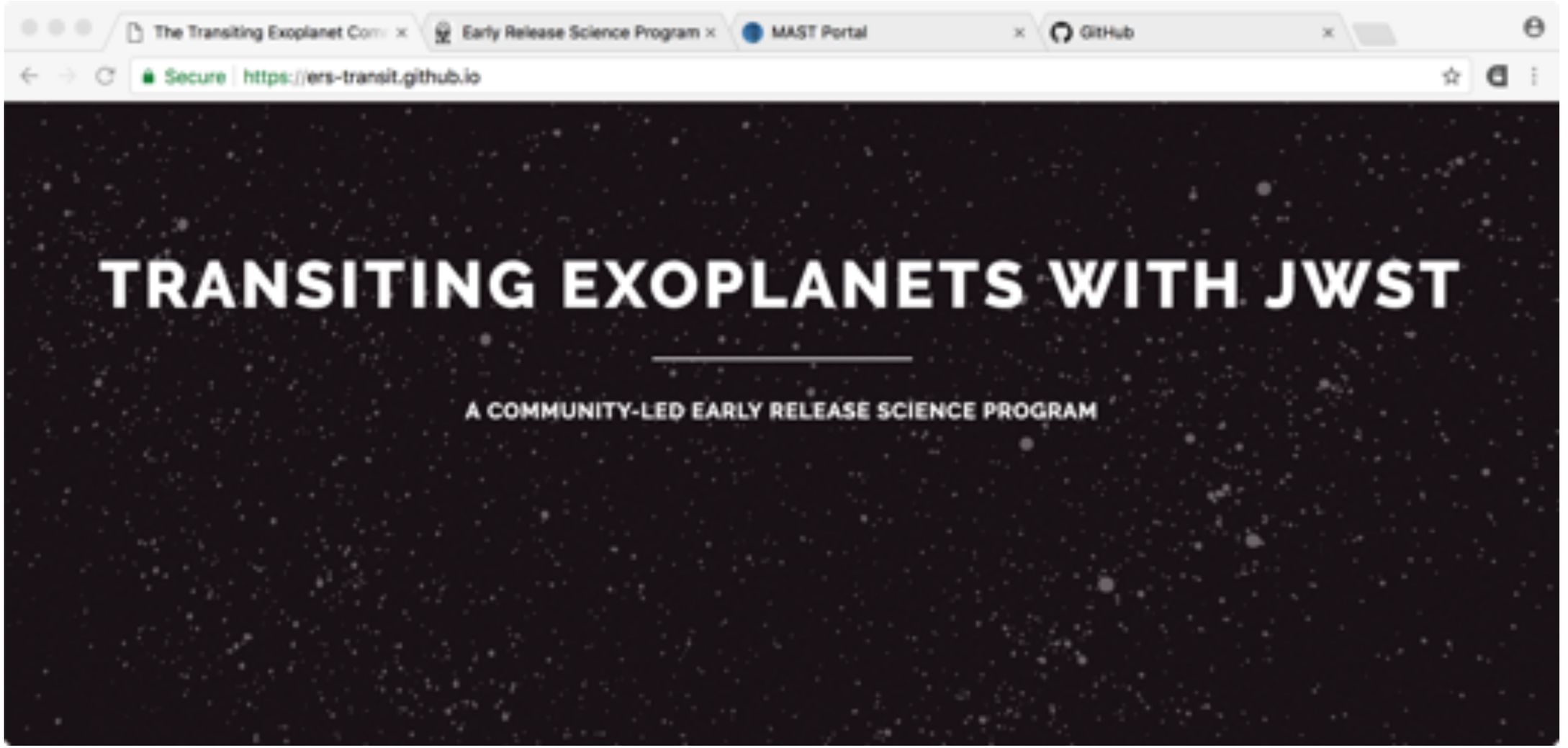
Want to learn more?

The Transiting Exoplanet Community Early Release Science Program for *JWST*

Jacob L. Bean,[1] Kevin B. Stevenson,[2] Natalie M. Batalha,[3] Zachory Berta-Thompson,[4] Laura Kreidberg,[5,6] Nicolas Crouzet,[7,8] Björn Benneke,[9] Michael R. Line,[10] David K. Sing,[11] Hannah R. Wakeford,[2] Heather A. Knutson,[12] Eliza M.-R. Kempton,[13,14] Jean-Michel Désert,[15] Ian Crossfield,[16] Natasha E. Batalha,[2] Julien de Wit,[17] Vivien Parmentier,[18] Joseph Harrington,[19] Julianne I. Moses,[20] Mercedes Lopez-Morales,[5] Munazza K. Alam,[5] Jasmina Blecic,[21] Giovanni Bruno,[2] Aarynn L. Carter,[11] John W. Chapman,[22] Leen Decin,[23] Diana Dragomir,[16] Thomas M. Evans,[11] Jonathan J. Fortney,[24] Jonathan D. Fraine,[2] Peter Gao,[25] Antonio García Muñoz,[26] Neale P. Gibson,[27] Jayesh M. Goyal,[11] Kevin Heng,[28] Renyu Hu,[22] Sarah Kendrew,[29] Brian M. Kilpatrick,[30] Jessica Krick,[31] Pierre-Olivier Lagage,[32] Monika Lendl,[33] Tom Louden,[34] Nikku Madhusudhan,[35] Avi M. Mandell,[36] Megan Mansfield,[37] Erin M. May,[38] Giuseppe Morello,[32] Caroline V. Morley,[5] Nikolay Nikolov,[11] Seth Redfield,[39] Jessica E. Roberts,[4] Everett Schlawin,[40] Jessica J. Spake,[11] Kamen O. Todorov,[15] Angelos Tsiaras,[41] Olivia Venot,[42] William C. Waalkes,[4] Peter J. Wheatley,[34] Robert T. Zellem,[22] Daniel Angerhausen,[43,44] David Barrado,[45] Ludmila Carone,[46] Sarah L. Casewell,[47] Patricio E. Cubillos,[33] Mario Damiano,[41,48] Miguel de Val-Borro,[49,50] Benjamin Drummond,[11] Billy Edwards,[41] Michael Endl,[51] Nestor Espinoza,[46] Kevin France,[52] John E. Gizis,[53] Thomas P. Greene,[54] Thomas K. Henning,[46] Yucian Hong,[55] James G. Ingalls,[56] Nicolas Iro,[57] Patrick G. J. Irwin,[58] Tiffany Kataria,[22] Fred Lahuis,[59] Jérémy Leconte,[60] Jorge Lillo-Box,[61] Stefan Lines,[11] Luigi Mancini,[62,46,63] Franck Marchis,[64] Nathan Mayne,[11] Enric Palle,[7] Gaël Roudier,[22] Evgenya L. Shkolnik,[10] John Southworth,[65] Johanna Teske,[66] Giovanna Tinetti,[41] Pascal Tremblin,[67] Gregory S. Tucker,[30] Roy van Boekel,[46] Ingo P. Waldmann,[41] Ian C. Weaver,[5] and Tiziano Zingales[41,48]

(currently under revision for PASP)

Want to learn more?



ers-transit.github.io — future site for info, meetings, code, and more!

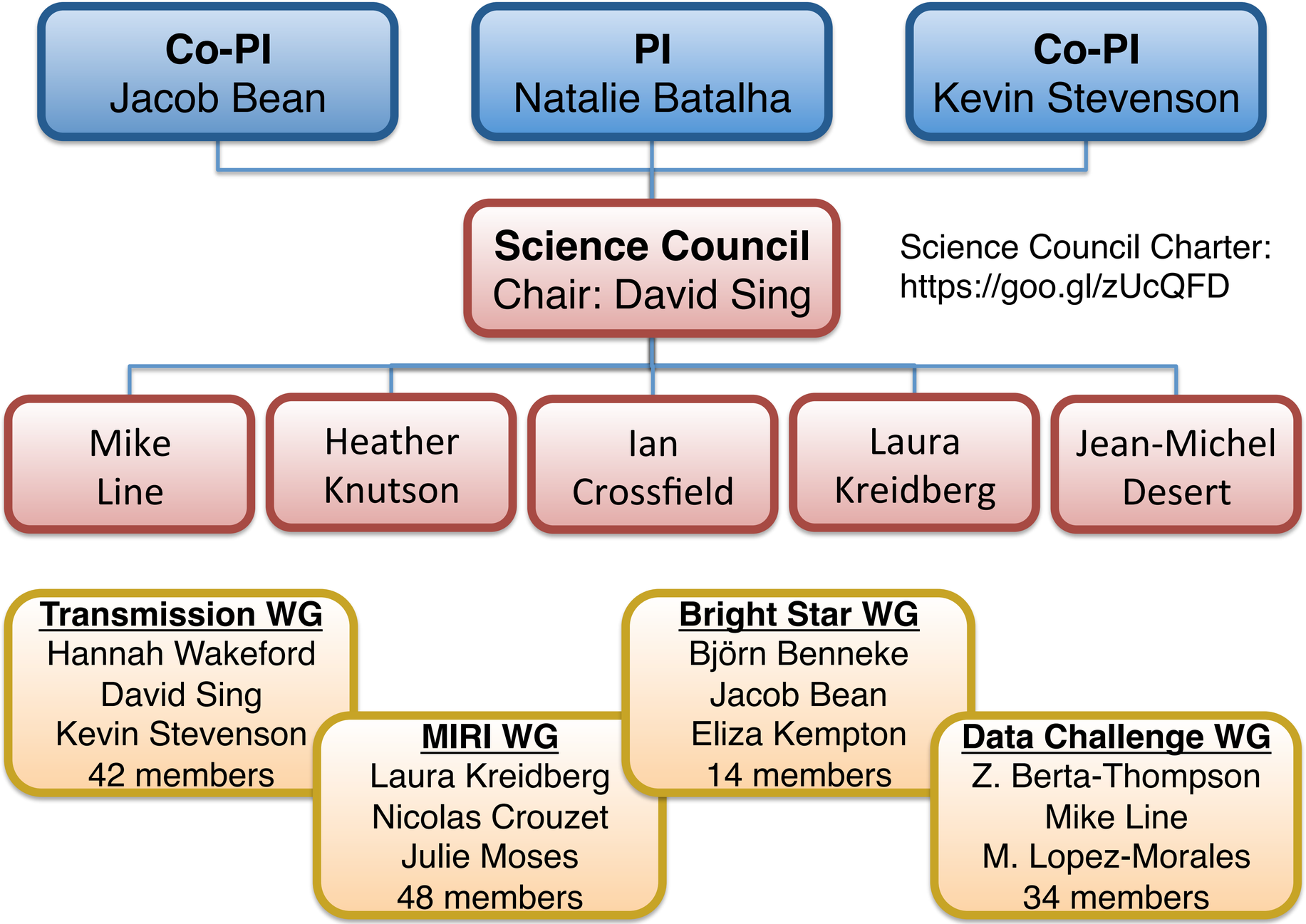
Transiting exoplanets are laboratories for studying planetary processes across diverse environments.

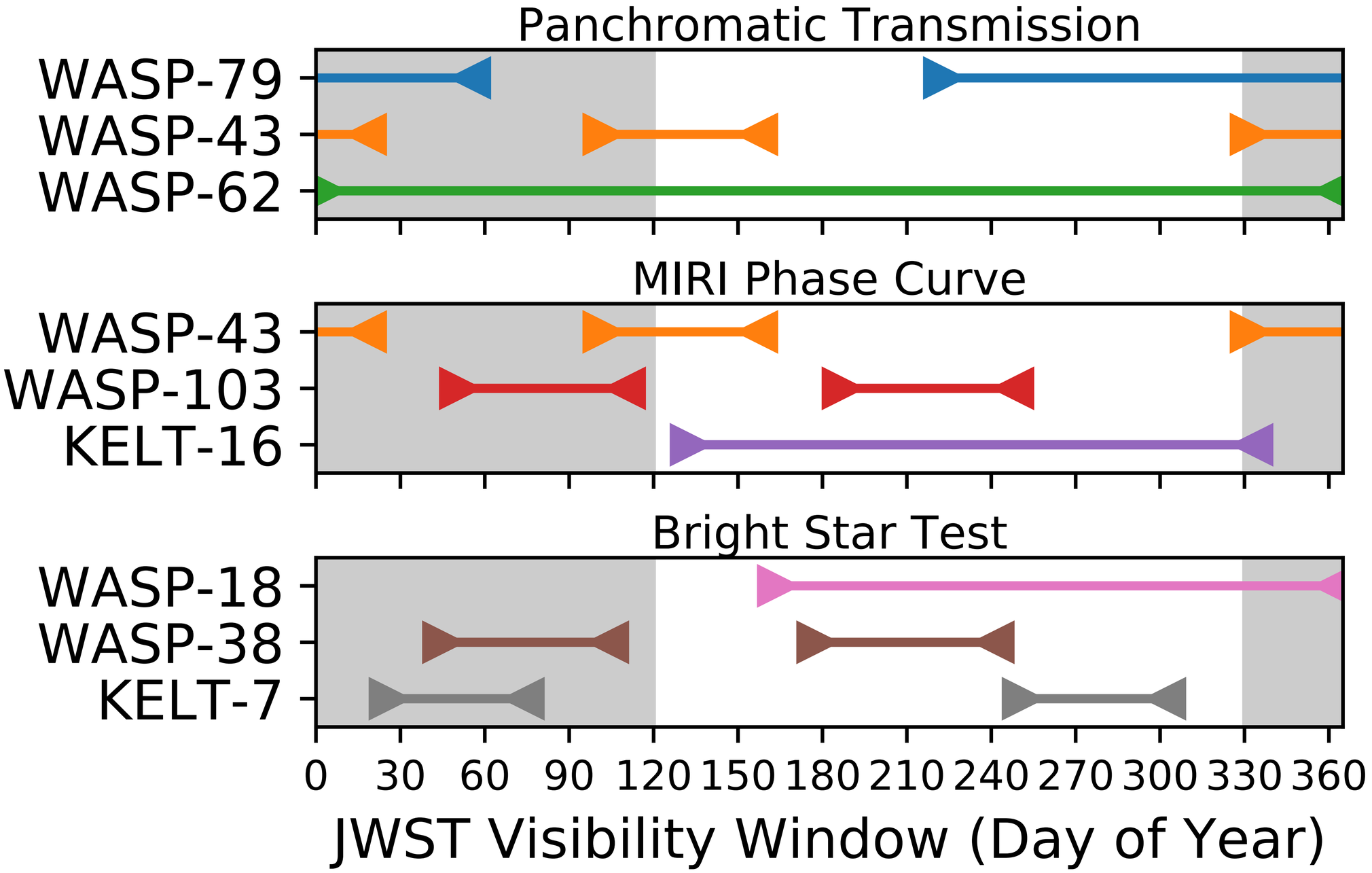
JWST will make pioneering observations of three transiting hot Jupiters for Early Release Science.

The community will use these observations to prepare for awesome exoplanet science with JWST.

If you want to play with early JWST transiting exoplanet data, please join the team!

(contact me, Natalie Batalha, Jacob Bean, or Kevin Stevenson)


Co-PI
Jacob Bean
PI
Natalie Batalha
Co-PI
Kevin Stevenson
Science Council
Chair: David Sing
Science Council Charter:
https://goo.gl/zUcQFD
Mike
Line
Heather
Knutson
Ian
Crossfield
Laura
Kreidberg
Jean-Michel
Desert
Transmission WG
Hannah Wakeford
David Sing
Kevin Stevenson
42 members
MIRI WG
Laura Kreidberg
Nicolas Crouzet
Julie Moses
48 members
Bright Star WG
Björn Benneke
Jacob Bean
Eliza Kempton
14 members
Data Challenge WG
Z. Berta-Thompson
Mike Line
M. Lopez-Morales
34 members


Panchromatic Transmission
WASP-79
WASP-43
WASP-62
MIRI Phase Curve
WASP-43
WASP-103
KELT-16
Bright Star Test
WASP-18
WASP-38
KELT-7
0
30
60
90
120
150
180
210
240
270
300
330
360
JWST Visibility Window (Day of Year)

Panchromatic **Transmission**

- nominal target: **WASP-79b**
- transits with NIRISS/SOSS, NIRSpec/G235H & G395H, and NIRCam/F322W2 (four total)

MIRI **Phase Curve**

- nominal target: **WASP-43b**
- one continuous, full-orbit observation covering two secondary eclipses and one transit with MIRI/LRS

Bright Star's Planet **Emission**

- nominal target: **WASP-18b**
- one secondary eclipse using NIRISS/SOSS