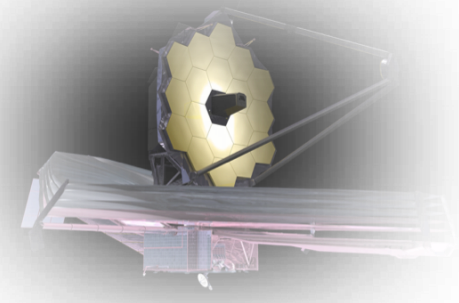
Transiting exoplanet observations with JWST:

Preparing the Early Release Science program

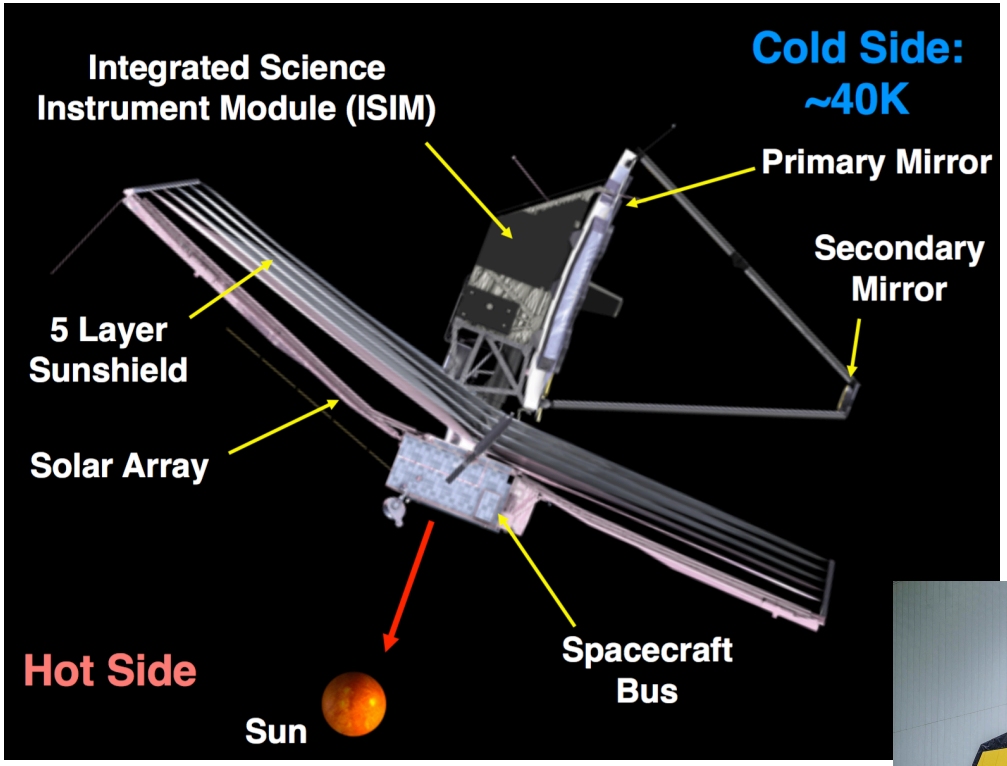


Nicolas Crouzet

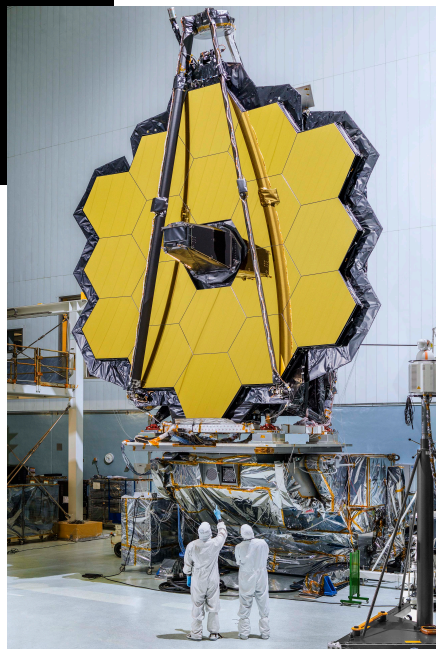
In collaboration with Laura Kreidberg, Vivien Parmentier, Natalie Batalha, David Sing, Pierre-Olivier Lagage, Jacob Bean, Kevin Stevenson, Hannah Wakeford, Zach Berta-Thomson, Bjorn Benneke, Julianne Moses, Pascal Tremblin, Olivia Venot, Peter Gao, Sarah Kendrew, Tom Greene, Kamen Todorov, Jonathan Fraine, Ludmila Carone, Sarah Casewell, Fred Lahuis, Mike Line, Jean-Michel Désert, Heather Knutson, Daniel Angerhausen, Jasmina Blecic, Eliza Kempton, Natasha Batalha, *et al.*

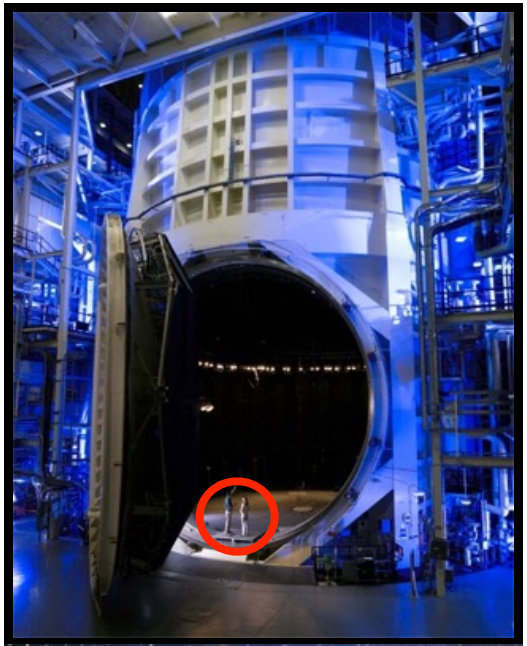
European Week of Astronomy and Space Science – June 27, 2017 – Prague

The James Webb Space Telescope (JWST)

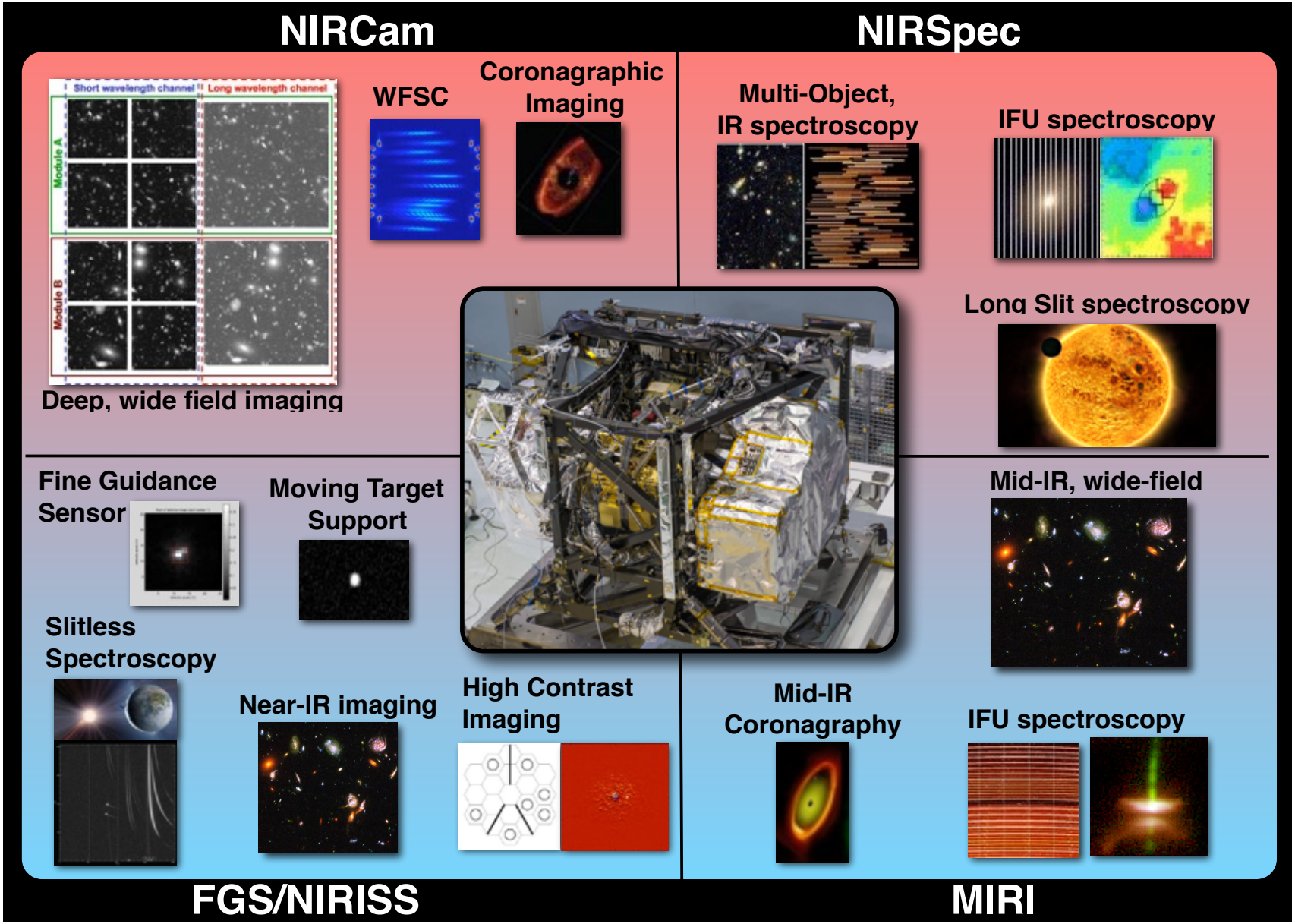


- NASA/ESA/CSA mission
- D = 6.5 meters
- λ = 0.6 – 28 μm
- Orbit at Lagrange point L2
- Launch: October 2018
- Lifetime: 5 – 10 years
- ESA: at least 15% of the time



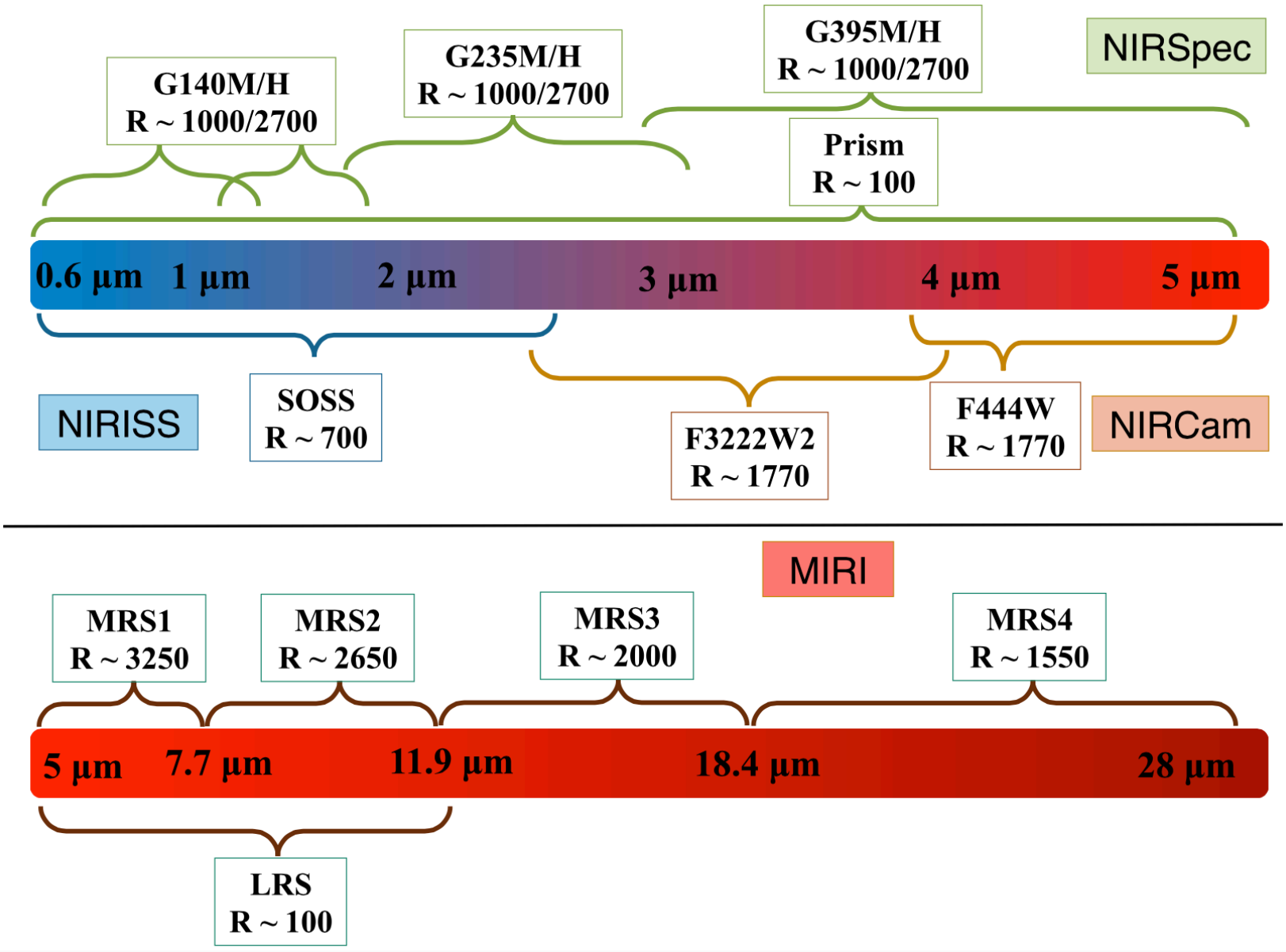


The JWST Instruments



Slide from Mark Clampin (GSFC, JWST Observatory Project Scientist)

Spectroscopic modes for transiting exoplanets



The JWST Early Release Science Program

"Realizing JWST's full science potential requires that the scientific community rapidly learn to use its sophisticated capabilities"

- ~**500 hours** of STScI Director's discretionary time (DD-**ERS**)
- Span the **four science themes**
- Ensure open access to **representative datasets**
- Engage a broad cross-section of the **astronomical community**
- Substantive **science demonstration programs** that utilize key instrument modes
- Design, create, and deliver **science-enabling products** to help the community understand JWST's capabilities
- All observations must be schedulable **within the first 5 months** of Cycle 1
- Data will have **no proprietary time**
- **Diverse** and **inclusive** scientific teams

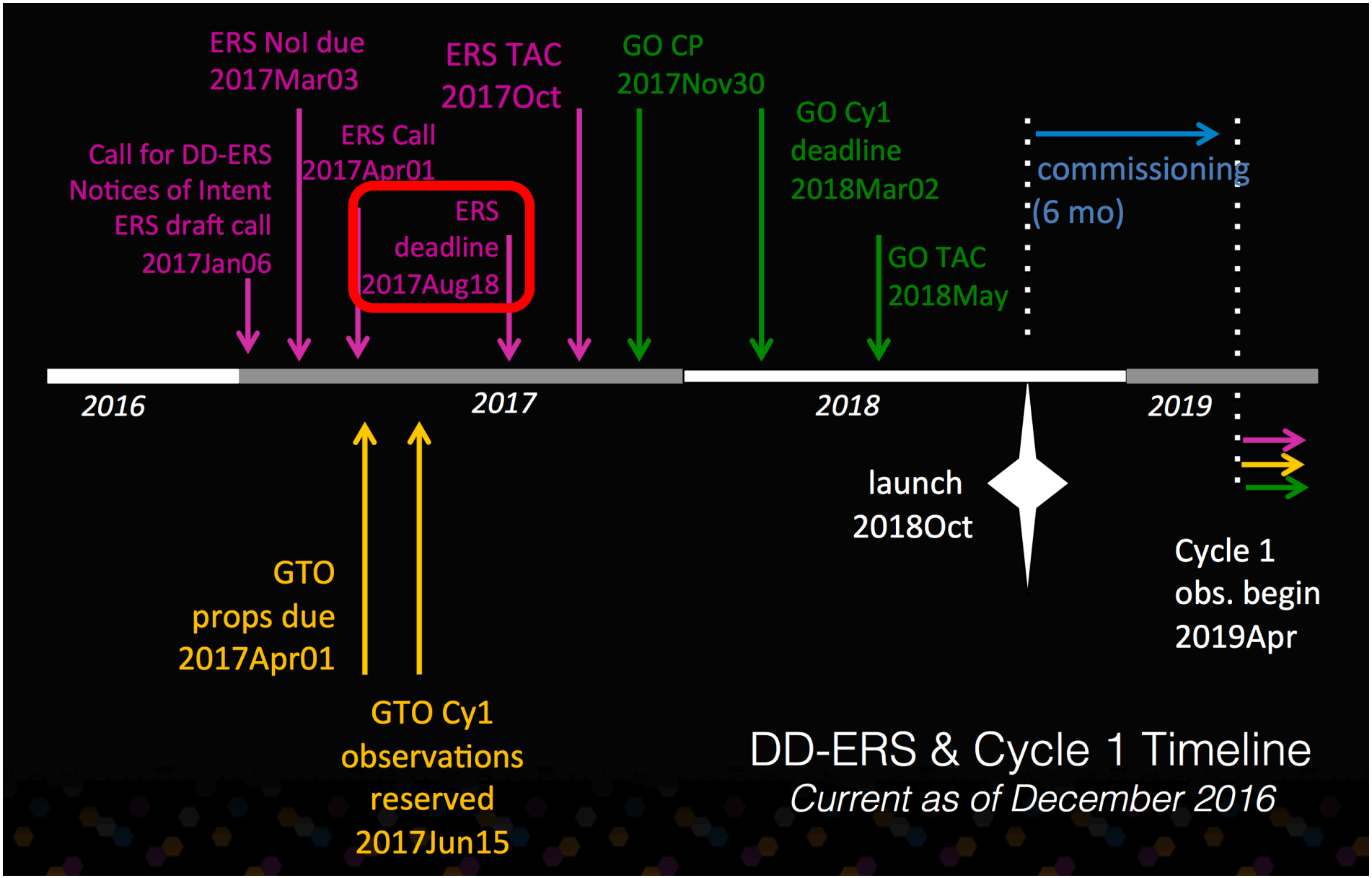
First Light & Reionization

Assembly of Galaxies

Birth of Stars & Protoplanetary Systems

Planets & Origins of Life

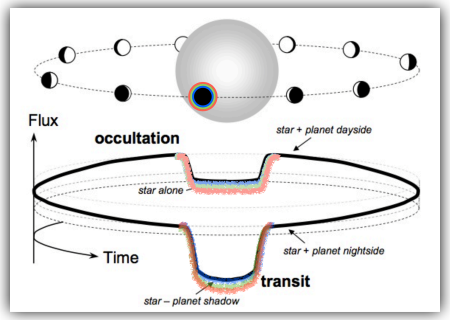
JWST Timeline



Slide from Nikole Lewis, STScI

The Transiting Exoplanet ERS program

<u>Overview</u>:



- **Transiting exoplanet atmosphere spectroscopy**
- A **community program**: ~80 people involved
- PI: Natalie Batalha, co-PIs: Jacob Bean & Kevin Stevenson, Science council led by David Sing
- Ideas summarized in *Stevenson et al. 2016, PASP 128, 4401*
- Divided in **four sub-programs**, all in one proposal
- ~**80 hours** of observing time in total

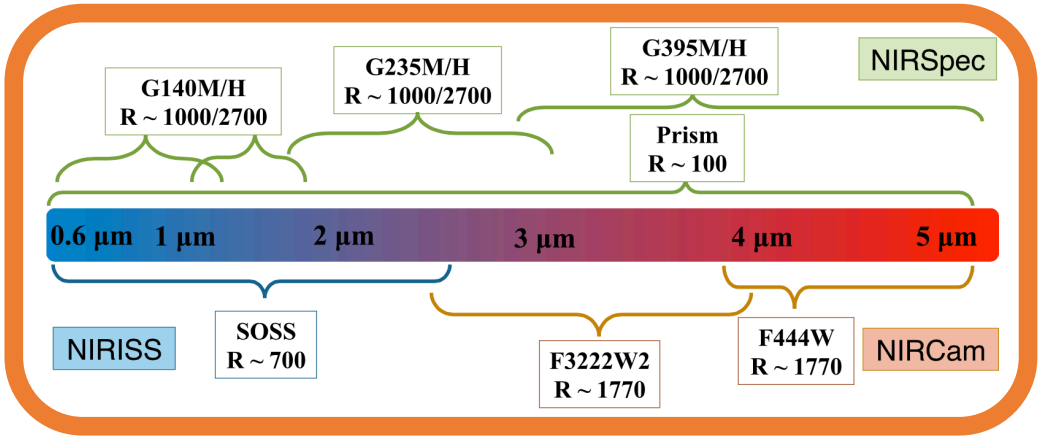
The Community ERS Team (as of NOI)

Alam, Munazza
Angerhausen, Daniel
Barrado, David
Batalha, Natalie
Batalha, Natasha
Bean, Jacob
Benneke, Björn
Berta-Thompson, Zach
Betremieux, Yan
Blecic, Jasmina
Bouwman, Jeroen
Carone, Ludmila
Carter, Aarynn
Casewell, Sarah
Chapman, John
Crossfield, Ian
Crouzet, Nicolas
Cubillos, Patricio
Dalba, Paul
Decin, Leen
Demory, Brice-Olivier
Desert, Jean-Michel
Dragomir, Diana
Espinoza, Nestor
Fortney, Jonathan
Fraine, Jonathan
France, Kevin
Gao, Peter
García Muñoz, Antonio
Gibson, Neale
Gizis, John
Greene, Thomas
Harrington, Joseph
Heng, Kevin
Henning, Thomas
Hu, Renyu
Iro, Nicolas
Iyer, Aishwarya
Jordan, Andres
Kataria, Tiffany
Kempton, Eliza
Kendrew, Sarah
Kilpatrick, Brian
Knutson, Heather
Kreidberg, Laura
Krick, Jessica
Lagage, Pierre-Olivier
Lahuis, Fred
Lendl, Monika
Lillo-Box, Jorge
Line, Mike
Lopez-Morales, Mercedes
Madhusudhan, Nikku
Mancini, Luigi
Mandell, Avi
Marchis, Franck
Marley, Mark
Mollière, Paul
Morley, Caroline
Moses, Julianne
Nikolov, Nikolay
Palle, Enric
Parmentier, Vivien
Redfield, Seth
Rogers, Leslie
Roudier, Gael
Schlawin, Everett
Sing, David
Spake, Jessica
Stevenson, Kevin
Swain, Mark
Teske, Johanna
Todorov, Kamen
Tremblin, Pascal
Tucker, Gregory
Venot, Olivia
Wakeford, Hannah
Weaver, Ian
Wheatley, Peter
Zellem, Rob

Add your name here

Program 1: “Transmission Spectroscopy”

- Chair: **Kevin Stevenson**, Co-Chair: **Hannah Wakeford**
- <u>Goals</u>: - Compare the various observing modes available for transmission spectroscopy
  - Extract exoplanet transmission spectra from 1 to 5 μm
- <u>Observations</u>: transits of one or several planets using different modes



Which modes *will be the best?*
Which ones should we evaluate?

Program 1: "Transmission Spectroscopy"

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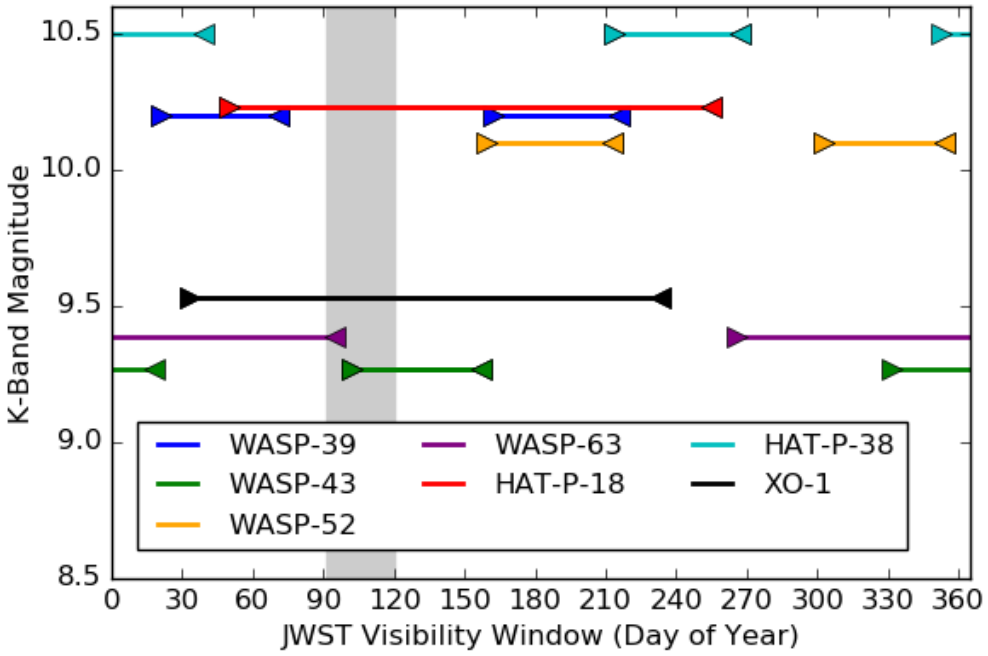
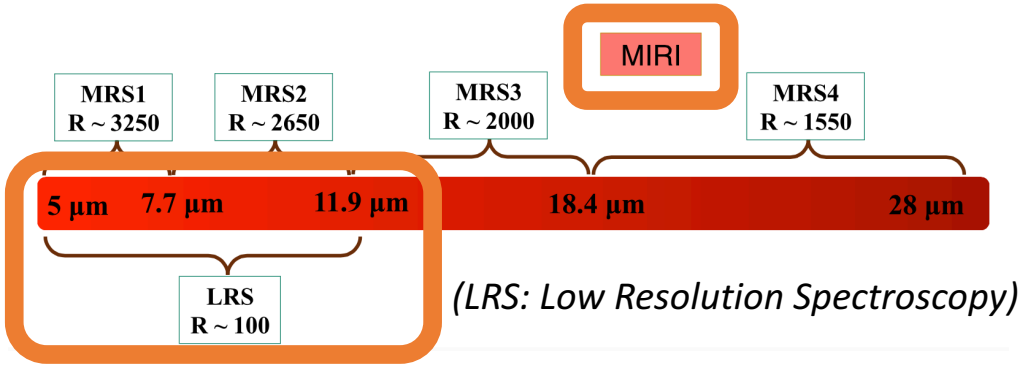
Which target?
(visibility, spectral features, S/N)

One or several targets?
(more consistent comparisons -vs- more exoplanet science)



Program 2: “MIRI Phase Curve”

- Chair: **Laura Kreidberg**, Co-Chair: **Nicolas Crouzet**
- Goal: A deep evaluation of MIRI/LRS for transiting exoplanets



(LRS: Low Resolution Spectroscopy)

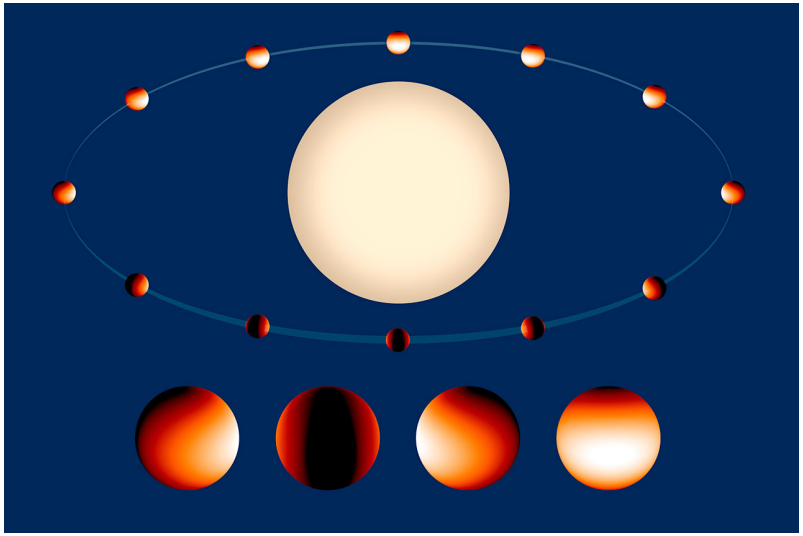
MIRI:
- *Only instrument at $\lambda > 5$ µm*
- *Different detectors and systematics*

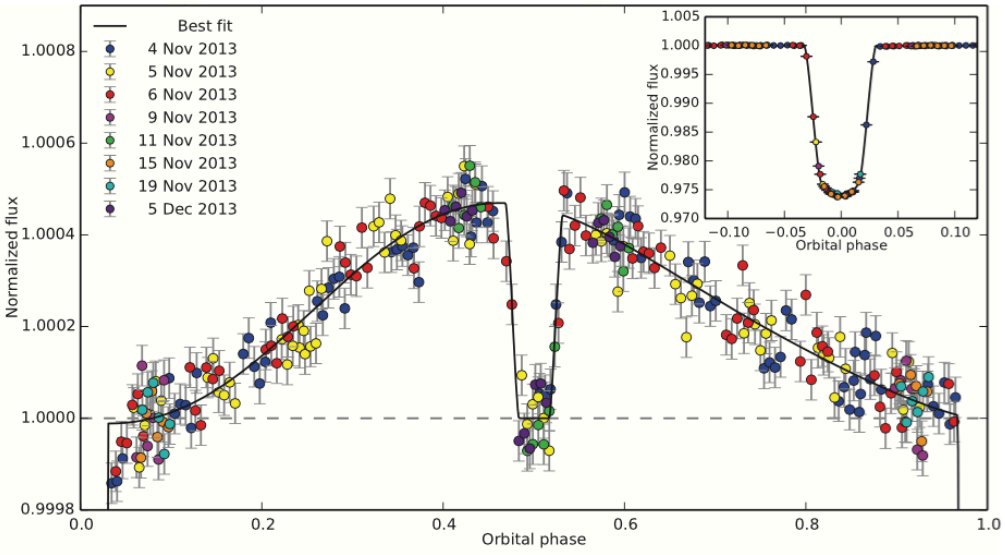
LRS:
- *Only MIRI mode available for time-series observations*
- *5 - 12 µm, R ~ 100*

Program 2: “MIRI Phase Curve”

Observations:

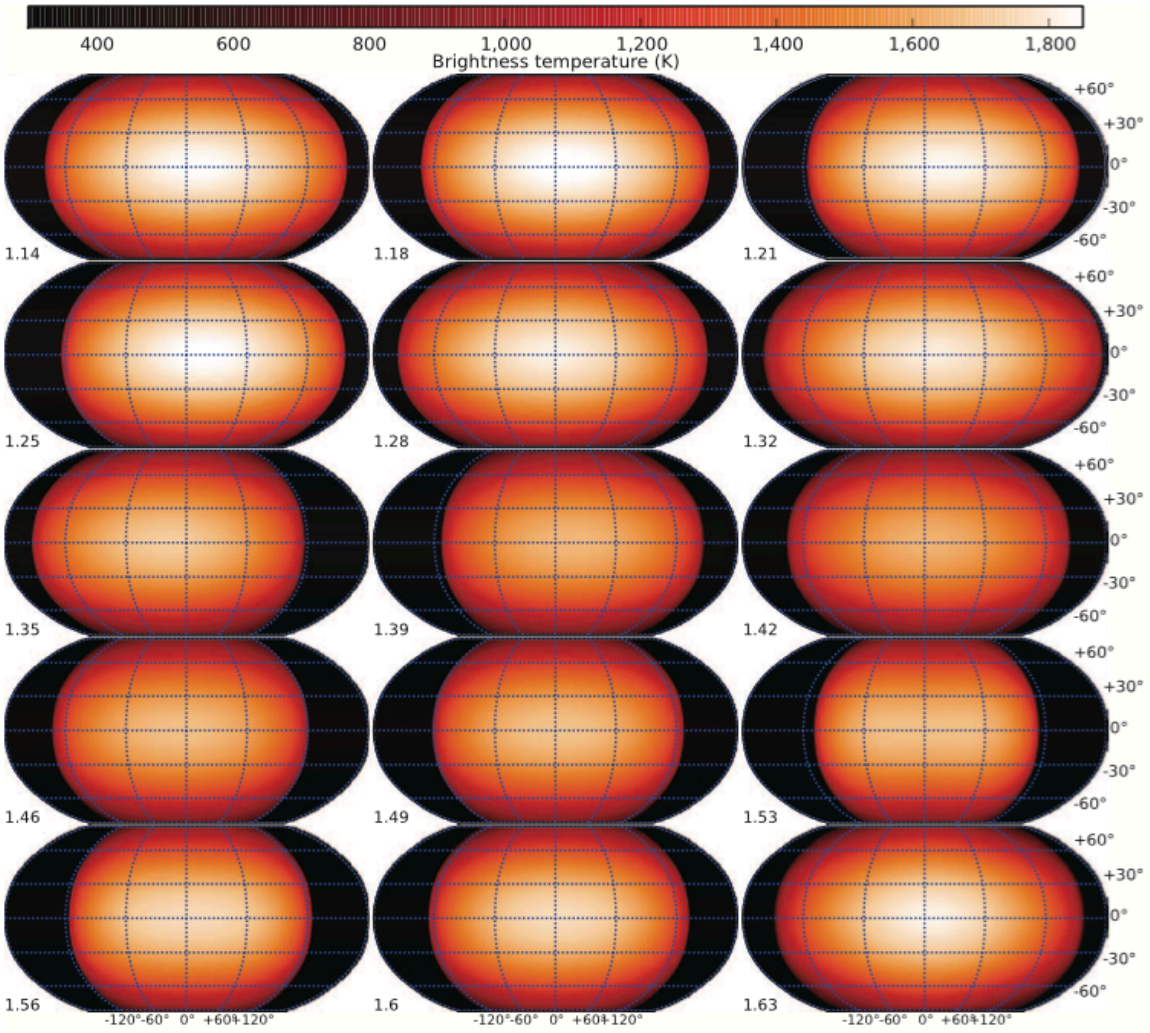
- Spectroscopic phase curve of a short period transiting hot Jupiter
  (P < 24 hours , full orbit including 1 transit and 2 eclipses)
- Target: WASP-43b





Phase curve (tilted view) and white light curve of WASP-43b observed by HST WFC3, 1.1 – 1.7 μm (*Stevenson et al. 2014)*

Spectroscopic phase curves **before** the ERS: The case of the **hot Jupiter** WASP-43b



Stevenson et al. 2014

Brightness temperature maps measured with HST WFC3 between 1.1-1.7 μm

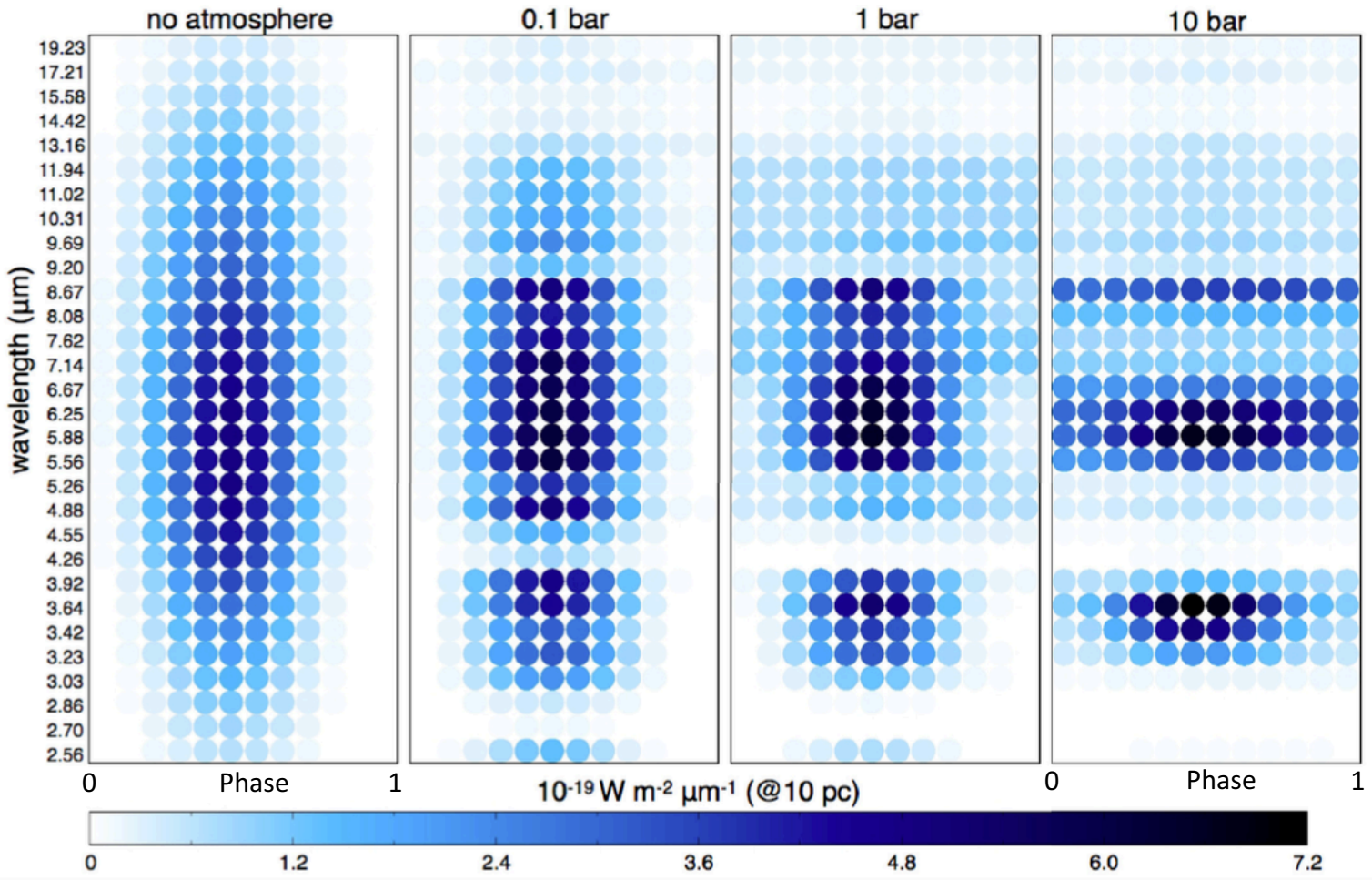
Reconstruct the **atmospheric structure** and **composition** in **altitude** and **longitude**

Measure presence and type of **clouds**

⇒ **Powerful technique**
We know it works!

Spectroscopic phase curves **beyond** the ERS: Crucial for **terrestrial planets** around M dwarfs

Fig. 3. Planetary emission maps as a function of wavelength and phase.

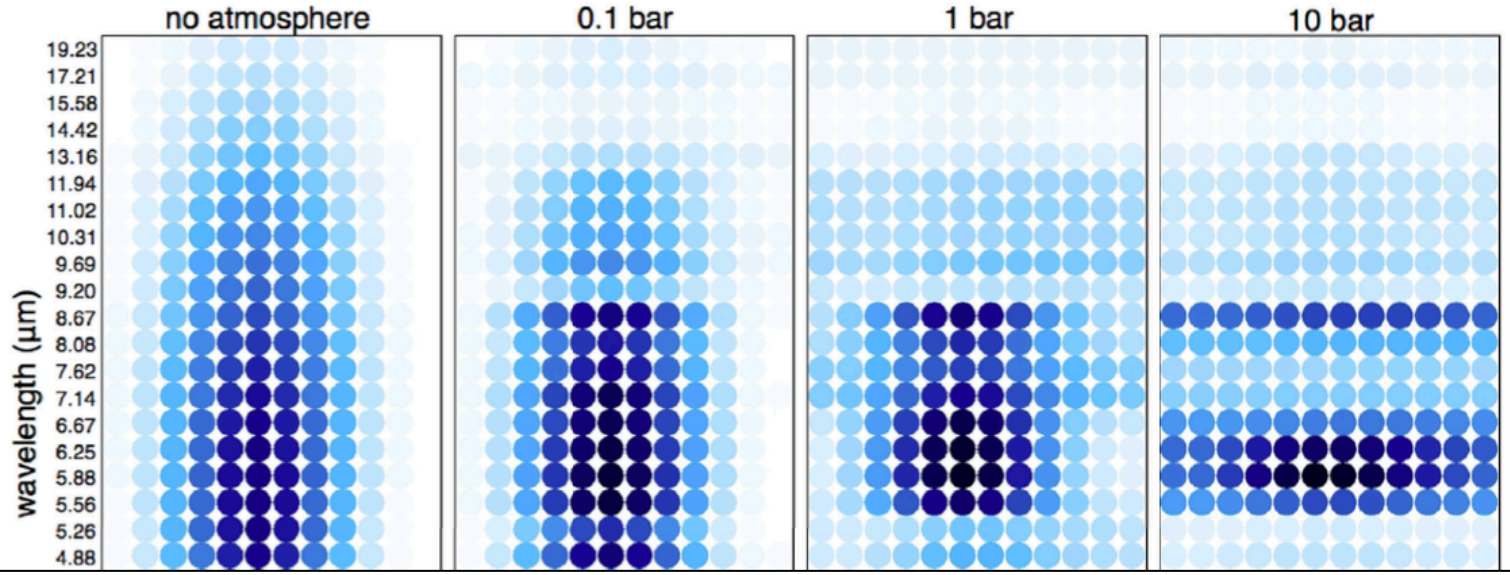


Model of a Super Earth emission *(Selsis et al. 2011)*

9.5 $M_{\oplus}$, 1.8 $R_{\oplus}$, 0.05 au, P = 8 day, $M_{\star}$ = 0.31 $M_{\odot}$, 10 pc

Spectroscopic phase curves **beyond** the ERS: Crucial for **terrestrial planets** around M dwarfs

Fig. 3. Planetary emission maps as a function of wavelength and phase.



Can **differentiate between no atmosphere and a thick atmosphere** (transit spectroscopy cannot: spectral features are absent or too weak)

We need MIRI wavelengths for these systems

Should be evaluated first on a hot Jupiter

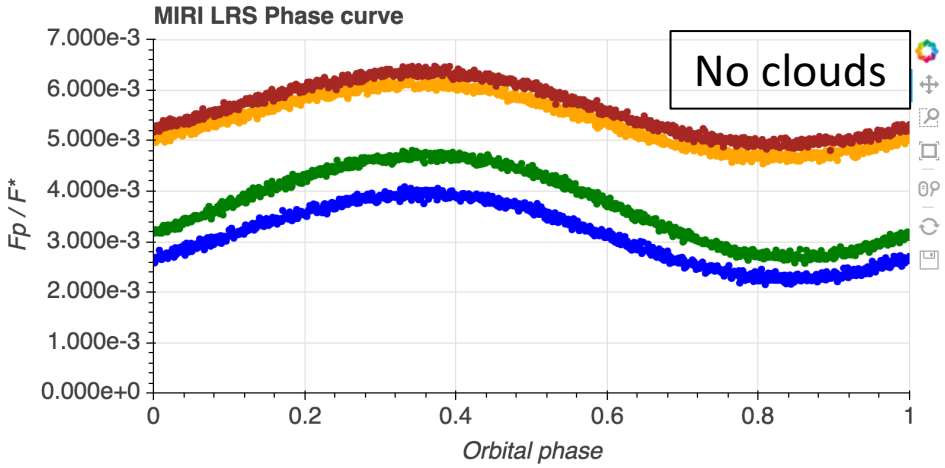
Program 2: “MIRI Phase Curve”

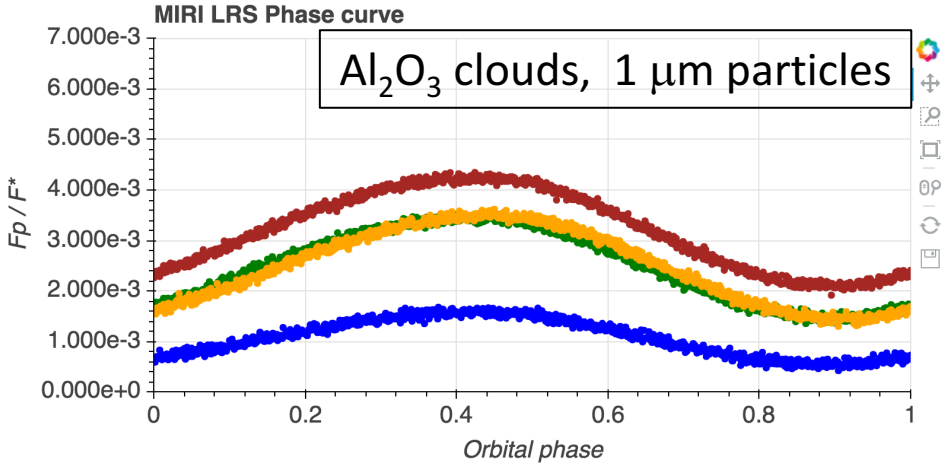
Feasibility study

- Target: **WASP-43** system
- Atmospheric model*:* **GCM** with or without clouds *(Vivien Parmentier)*

  Al_2O_3, $CaTiO_3$, Cr, Fe, $MgSiO_3$, MnS
- Instrument simulations: **Pandexo** software tool *(Natasha Batalha)*

  MIRI LRS observing mode





6 μm 8 μm 10 μm 12 μm

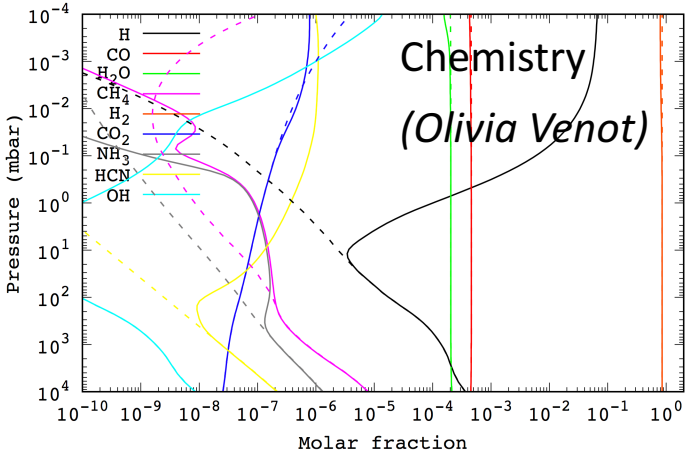
Only phase curve is shown (no transit/eclipse)

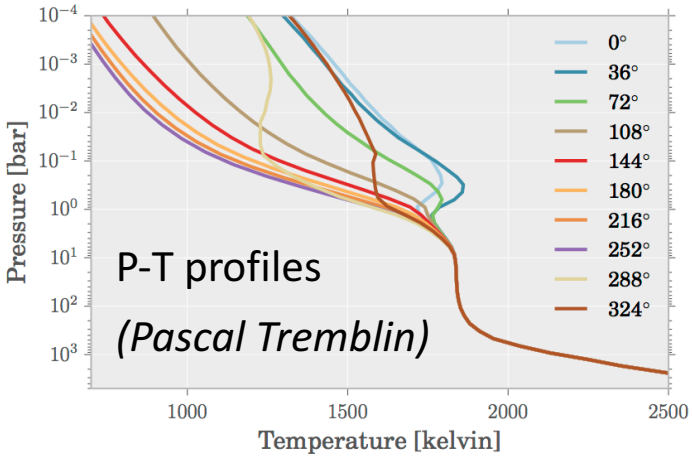
Program 2: “MIRI Phase Curve”

Focus group 1: Atmospheric modeling

Goal: **Model WASP-43b’s atmosphere** as completely as possible, gathering a broad range of expertise

- *Phase-resolved chemical composition*
- *Thermal structure in longitude & altitude*
- *Bond albedo, energy budget*
- *Cloud coverage and composition (dayside & nightside)*
- *Cloud microphysics & grain size*
- *Disequilibrium chemistry*
- *Eclipse mapping*





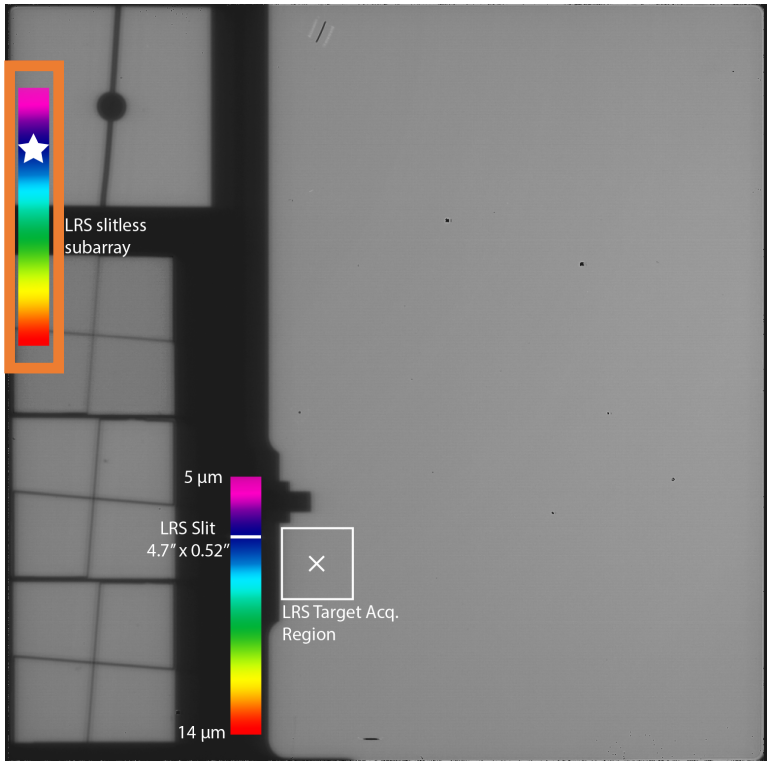
Program 2: “MIRI Phase Curve”

Focus group 2: MIRI technical challenges

Goals: - **Identify MIRI challenges** for time-series observations of transiting exoplanets, evaluate and correct for them
- Measure the **noise floor**

- *MIRI detectors are different (Si:As)*
- *Actively cooled*
- *Less stable than HST, Spitzer*
- *Several causes of non-linear behavior (ramp, memory effects)*
- *Evaluate background and stability*
- *Use of the reference pixels*

MIRI focal plane



Program 2: “MIRI Phase Curve”

Focus group 3: Target selection

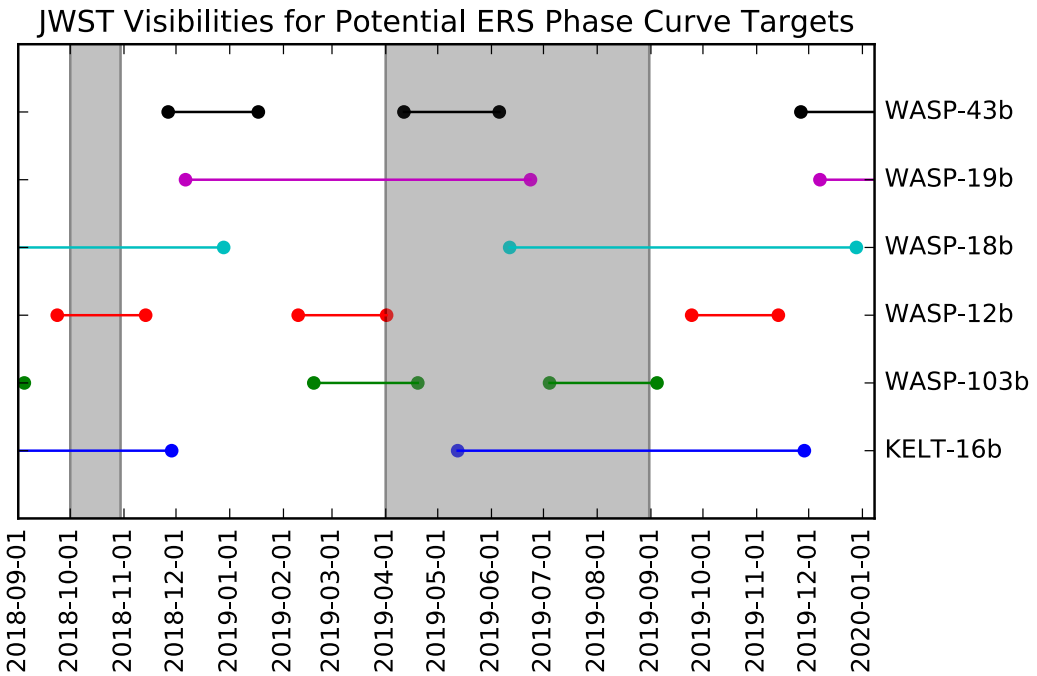
Goals: - Measure / account for WASP-43 **stellar variability**
- Identify one or several **backup targets**

WASP-43:

- T_{eff} = 4500 +/- 100 K
- *Age* < 1 Gyr
- P_{rot} = 15.6 +/- 0.4 days
- *log(R’_HK)* = -4.2 +/- 0.1
  ~ HD 189733

Disentangle:

- *planet’s phase curve*
- *instrument trends*
- *stellar variability*



Kamen Todorov & Jonathan Fraine

Program 3: “Data challenge”

Chair: **Zach Berta-Thomson**, Co-Chair: **Mike Line**

A transverse program to:

- **Prepare tools** to enable quick and accurate analysis and interpretation of the data, make them available to the community.
- Assess the achieved precision, **identify the major systematic noise** sources, their quantitative impact, and potential avenues for mitigating them.
- Internally **validate the scientific conclusions** drawn from JWST data through comparison of results by different team members, and **determine best practices** and required ingredients for JWST analyses.
- **Inform** the planning and selection of future JWST exoplanet programs.

Program 4: “Science Near the Noise Floor”

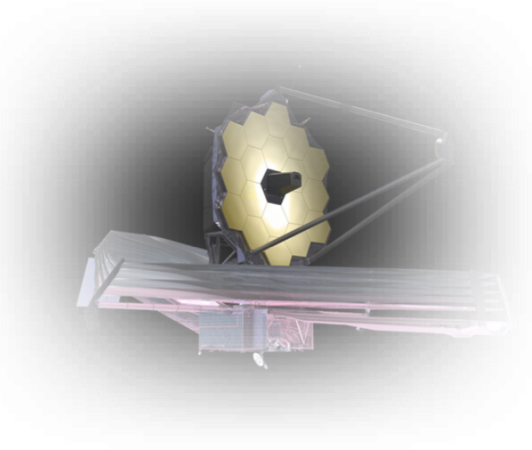
Chair: **Björn Benneke**, Co-Chair: **Jacob Bean**

- Goals: - Provide representative data of a bright star and secondary eclipse at $\lambda < 5$ μm
  - Push photon noise to 20 ppm noise floor to test stability

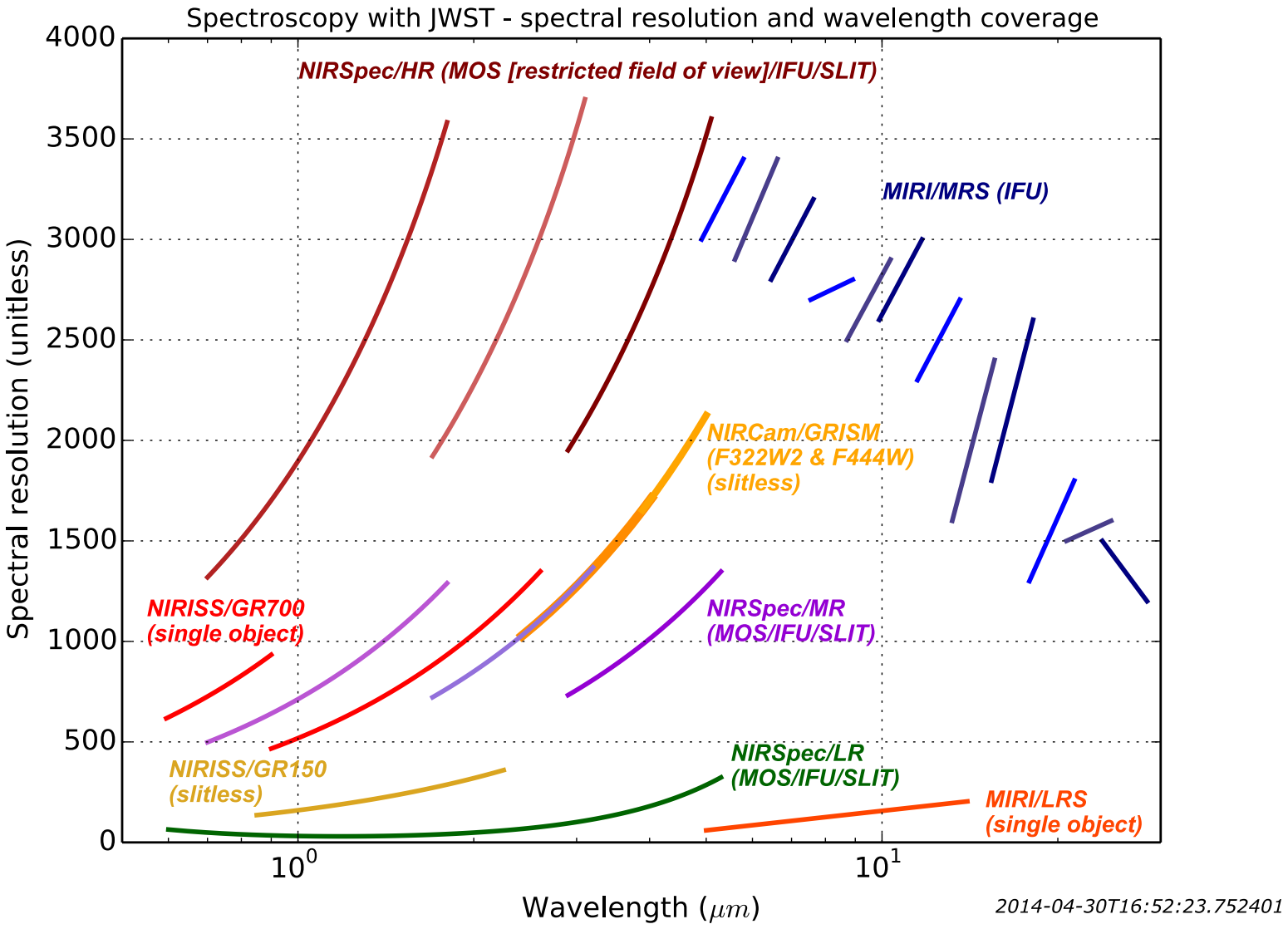
- Observations: Single observation of previously measured secondary eclipse of a planet orbiting relatively bright ($6 < K < 8$) star with NIRISS and/or NIRCam

Conclusion

- JWST will offer **unique capabilities** for transiting exoplanet spectroscopy
- JWST **ERS program**: engage the community and evaluate JWST
- The transiting exoplanet community will submit a **collaborative proposal**
- **Four sub-programs** have been chosen and are being designed:
  "Transmission Spectroscopy", "MIRI Phase Curve",
  "Data challenge", "Science Near the Noise Floor"
- Proposal submission deadline: **August 18**, 2017
- Data and tools will be **available to the community**
- Everyone is welcome to contribute!!



The JWST modes for spectroscopy



Spectroscopic performance