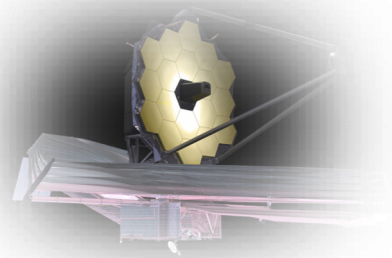
A spectroscopic phase curve of a hot Jupiter with MIRI LRS

as part of the Transiting Exoplanet Community Early Release Science Program

Nicolas Crouzet

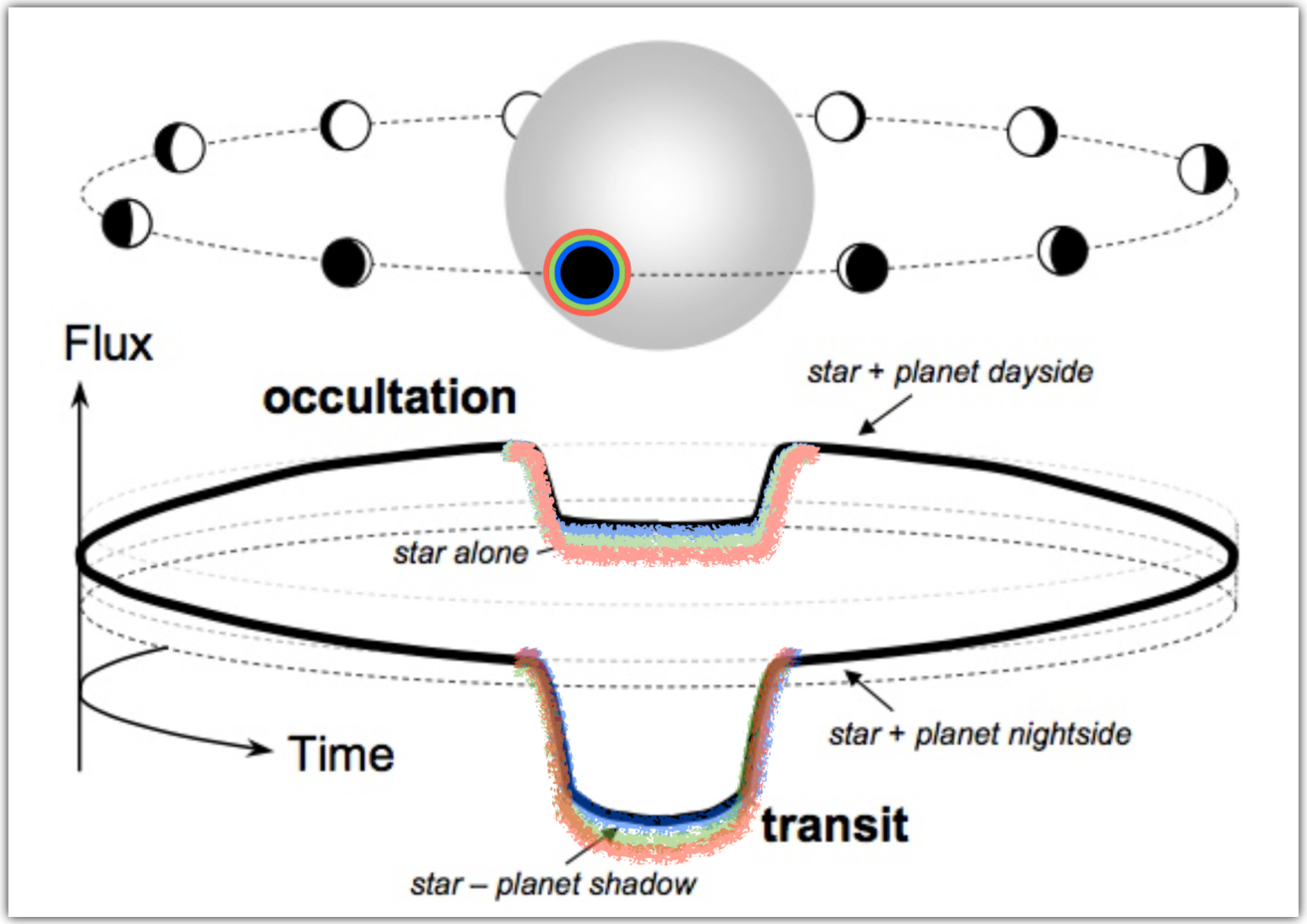
And the Transiting Exoplanet ERS team



EWASS 2018 – Liverpool – 3 April 2018

Spectroscopy of transiting exoplanets

Goal: Observe and study their atmospheres



The Transiting Exoplanet ERS program

Overview:

- Spectroscopy of **transiting exoplanet atmospheres**
- A **community program**: ~100 people
- PI: Natalie Batalha, co-PIs: Jacob Bean & Kevin Stevenson, Science council led by David Sing
- First round of ideas: *Stevenson et al. 2016, PASP 128, 4401* Program summary: *Bean et al. in prep.*
- Divided into **four sub-programs**, all in one proposal
- **78 hours** allocated

The Team

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Tsiaras Angelos
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Venot Olivia
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Wakeford Hannah R.
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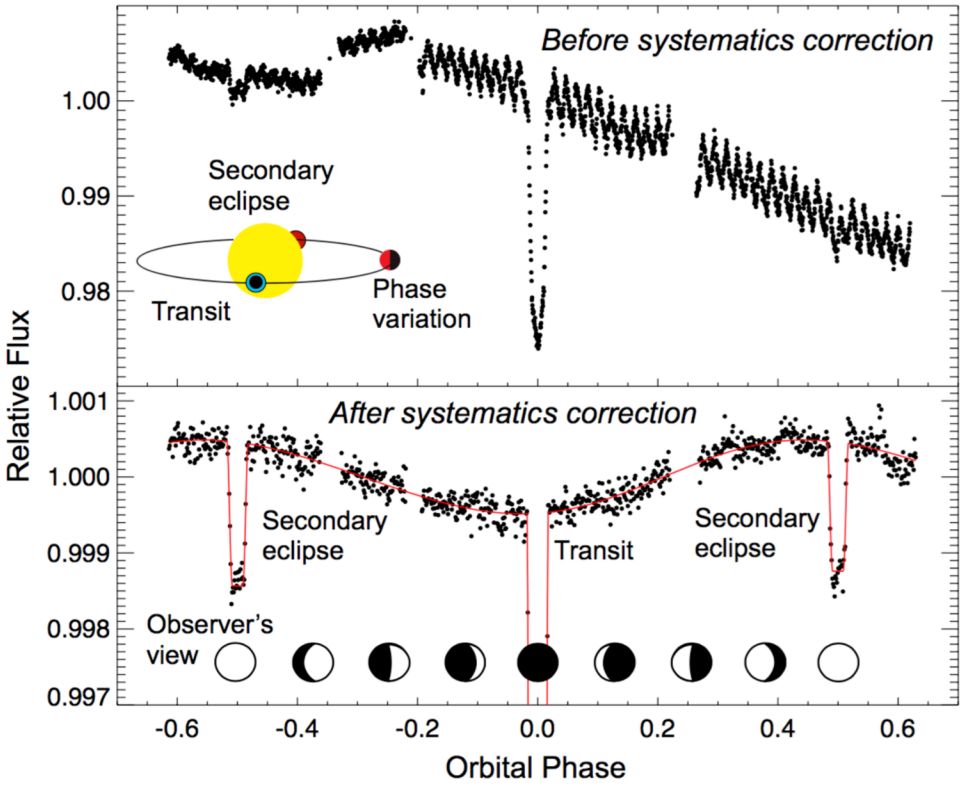
Weaver Ian
Wheatley Peter J.
Zellem Robert T.

Context

Spitzer/IRAC 4.5 µm phase curve for the hot Jupiter HD 189733b *(Knutson et al. 2012)*



Evaluating and correcting for systematic effects is essential

Our program will test transits, eclipses, and **a phase curve**

MIRI Phase Curve

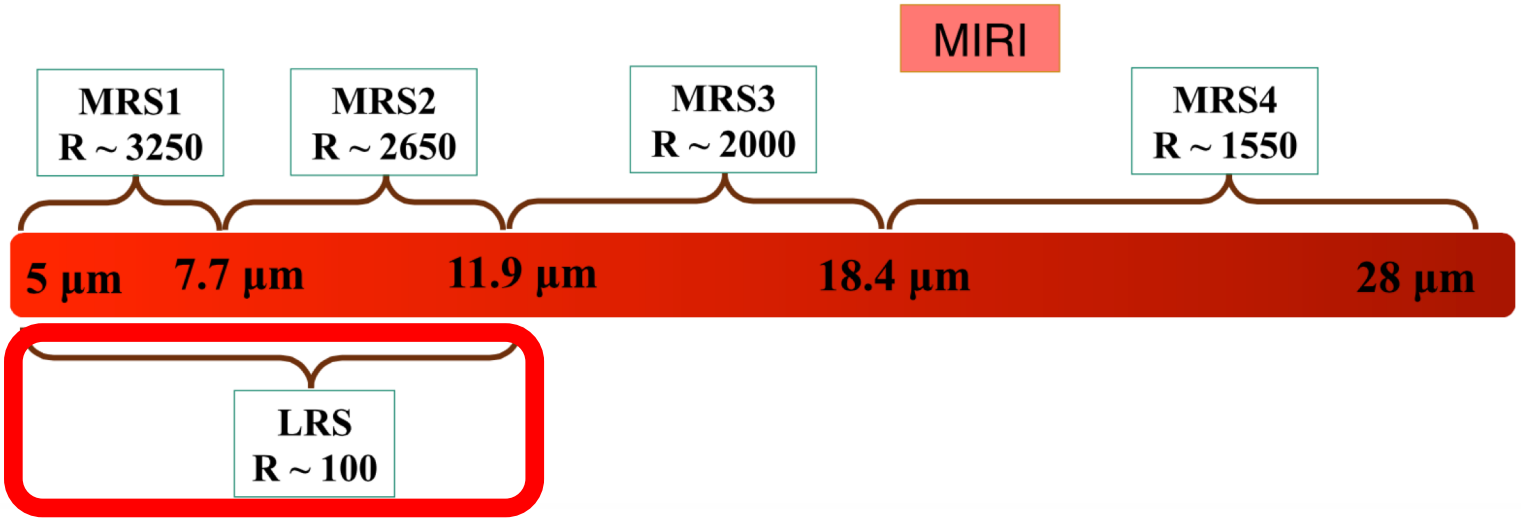
- Chairs: Laura Kreidberg, Nicolas Crouzet, Julianne Moses (48 members)

- Goals: - Extract a **spectroscopic phase curve** of a hot Jupiter in the 5 – 12 μm range

  - Determine its **atmospheric composition**, temperature structure, heat transport, chemistry, cloud properties

  - Test the **stability** of **JWST** and **MIRI LRS** over **day-long timescales**

MIRI Phase Curve



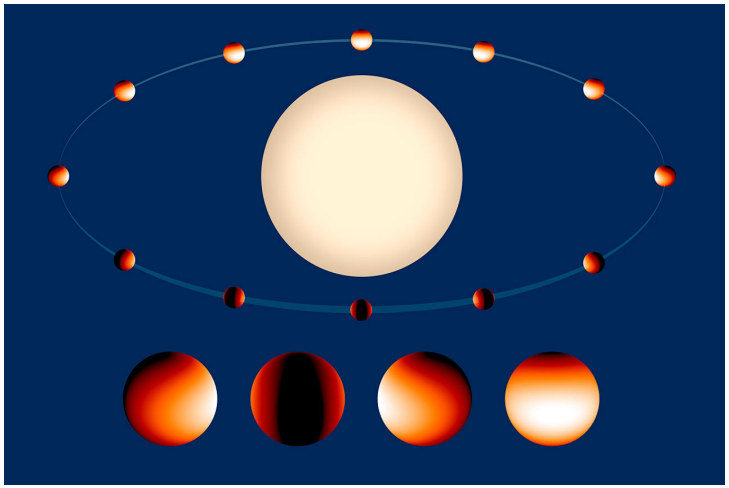
MIRI:
- Only JWST instrument at $\lambda > 5$ μm
- Si:As detectors, different from NIR detectors

Low Resolution Spectrometer (LRS):
- Only mode available for time-series observations with MIRI
- 5 – 12 μm, slitless mode

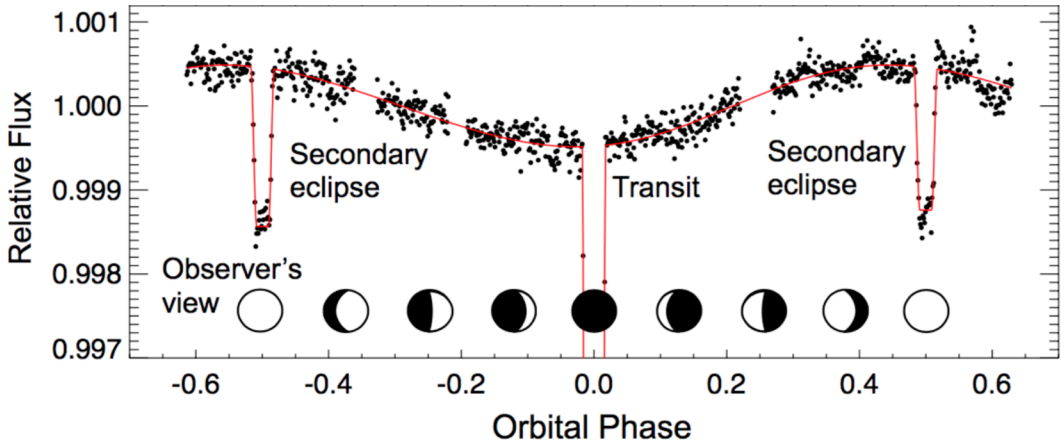
MIRI Phase Curve

- Observation:

  A **full orbit** observation of a short period hot Jupiter with **MIRI LRS**, including 2 eclipses and 1 transit

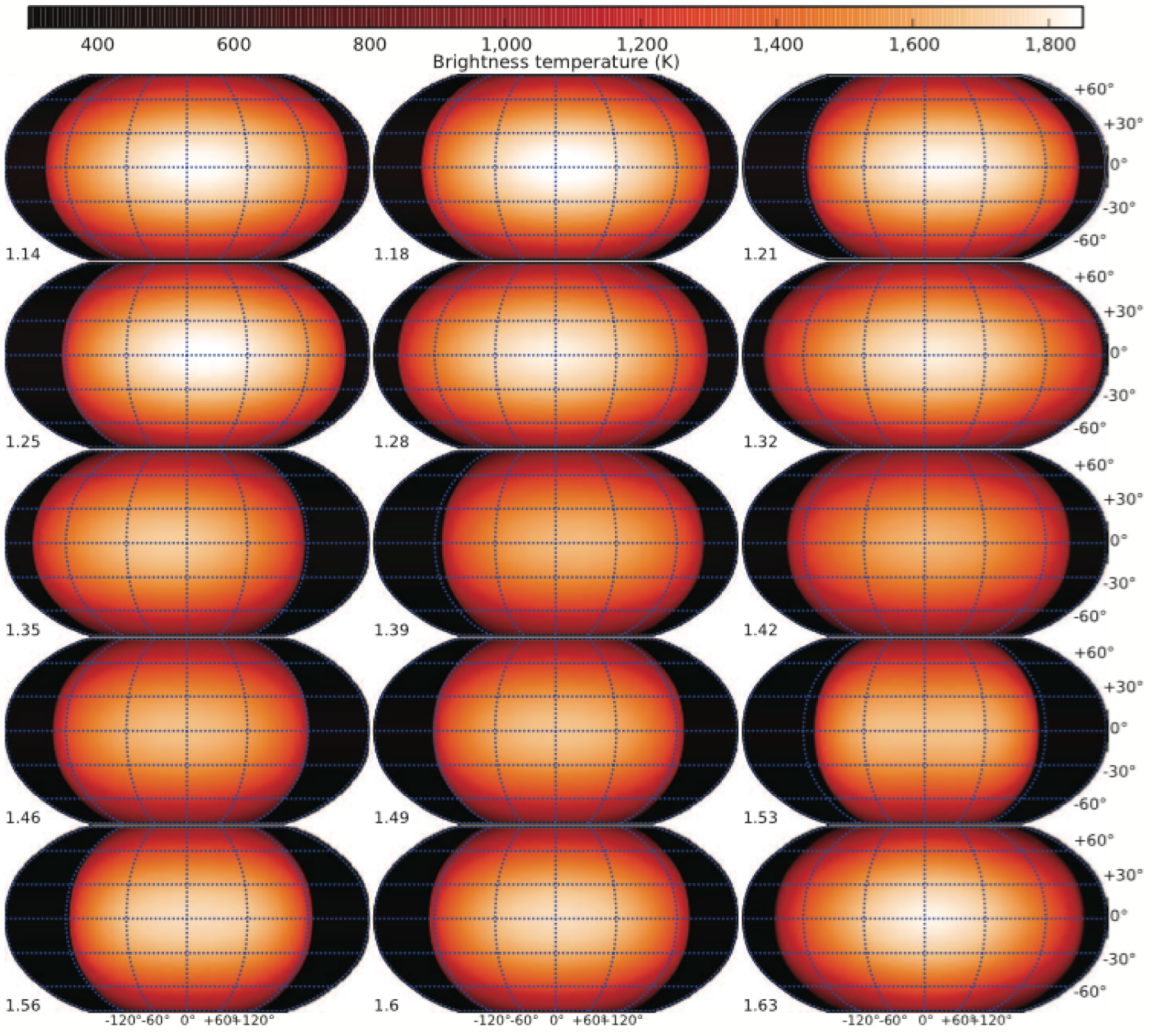


Orbit (tilted view)



Phase curve

Spectroscopic phase curves **before** the ERS: WASP-43b observed with HST WFC3



Stevenson et al. 2014

Brightness temperature maps between 1.1 - 1.7 μm

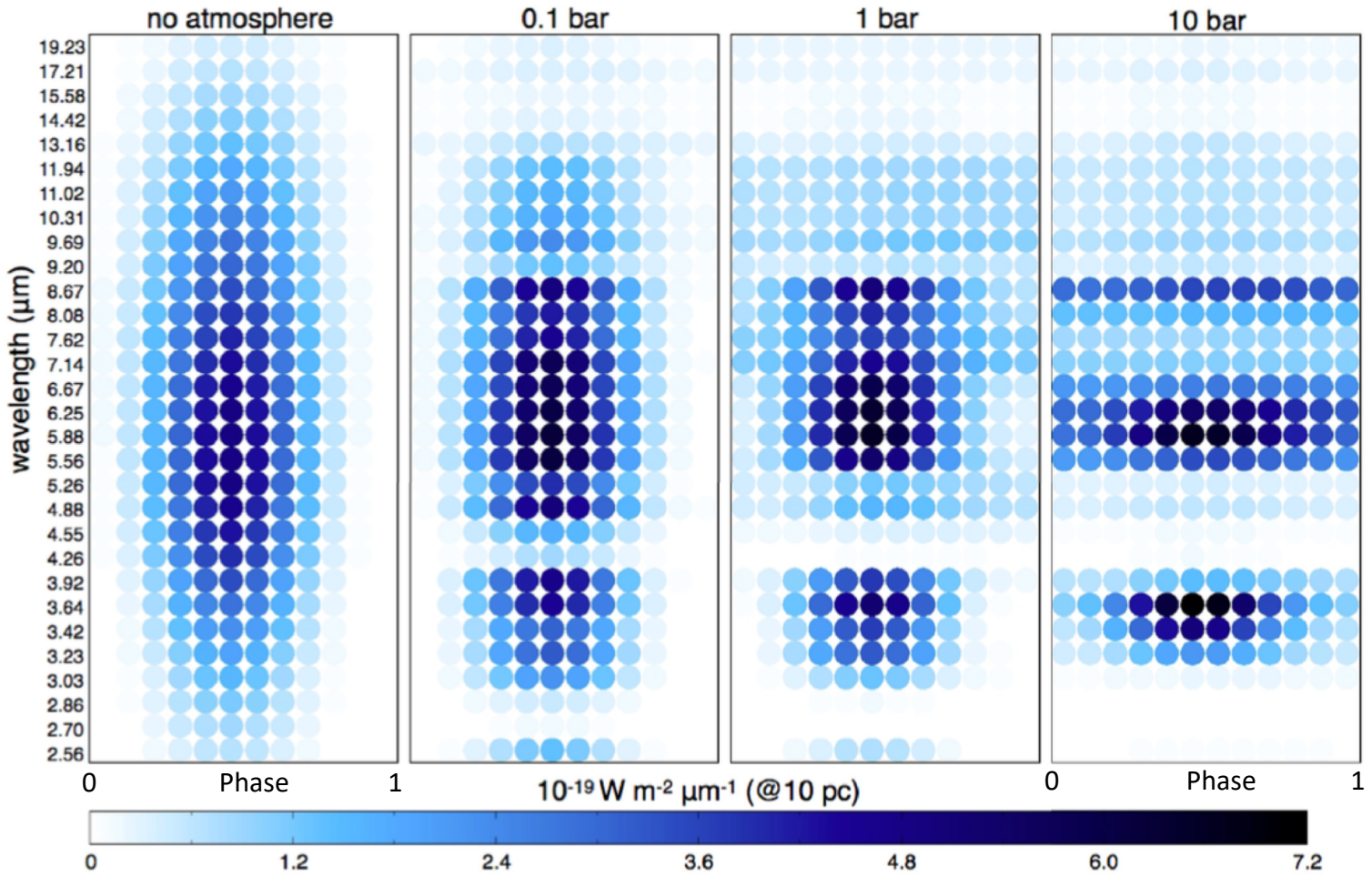
Reconstruct the **atmospheric structure** and **composition** in **altitude** and **longitude**

Measure the 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.

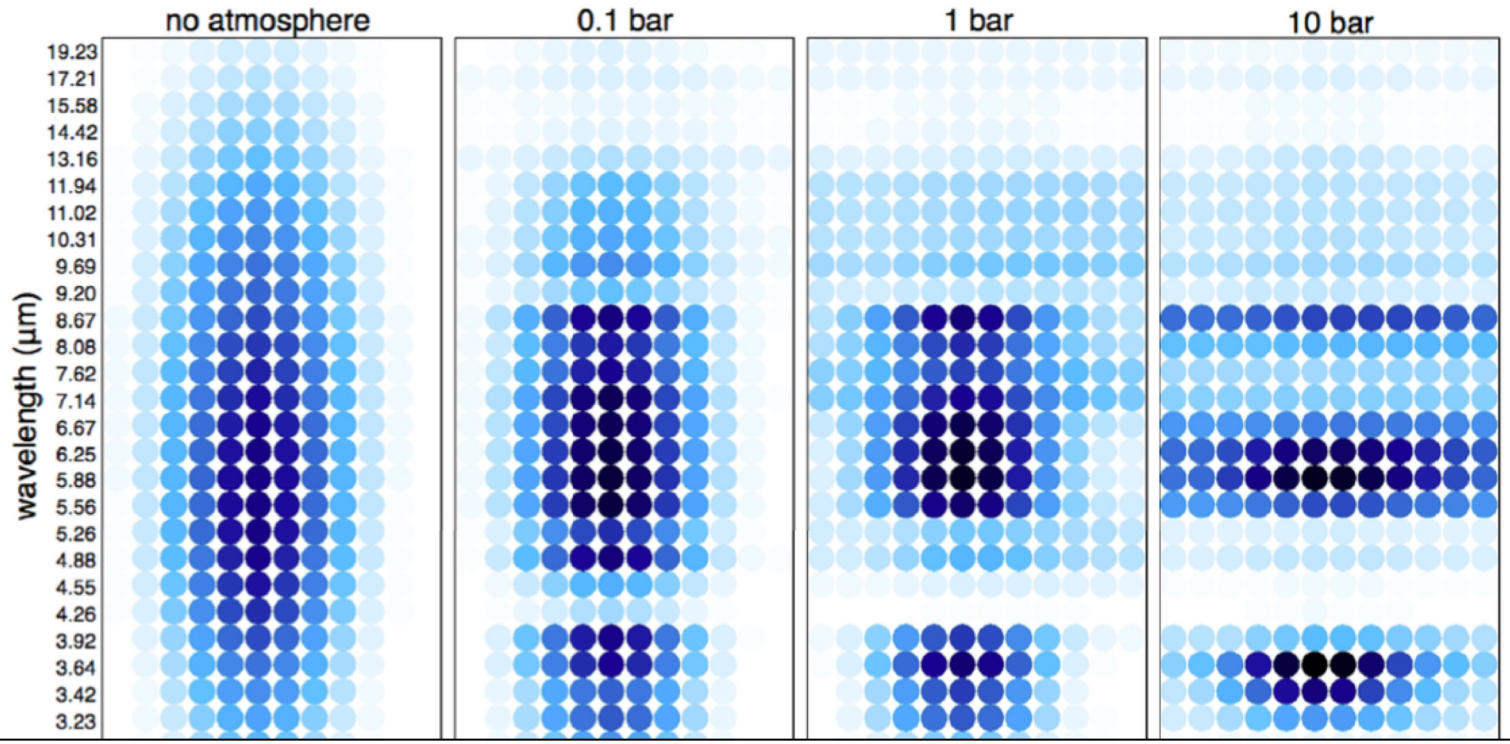


Model of a Super Earth emission *(Selsis et al. 2011)*

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.



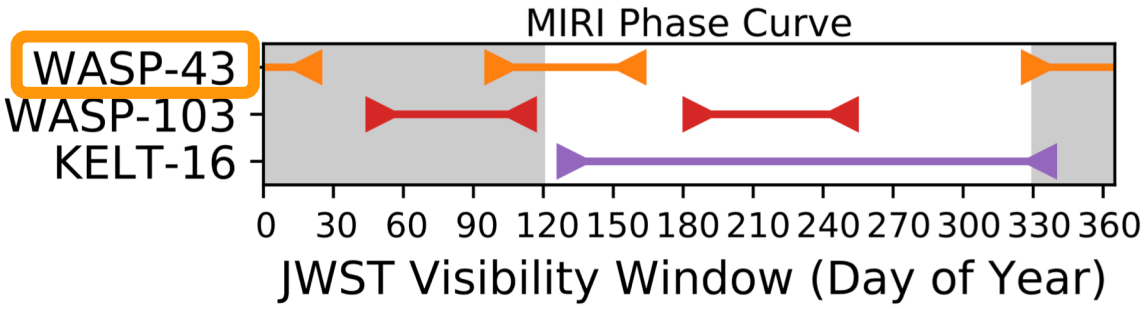
Can **differentiate** between **no atmosphere** and a **thick atmosphere** (challenging for transit spectroscopy: spectral features are absent or weak)

We need MIRI wavelengths for these systems

Should be evaluated first on a hot Jupiter

Focus group: Target selection

Goals: - Identify the main target and backup targets
- Measure and account for **stellar variability**



The star WASP-43:

- T_{eff} = 4520 +/- 120 K (K7V)
- *Age* < 1 Gyr
- P_{rot} = 15.6 +/- 0.4 days
- *log(R'_HK)* = -4.2 +/- 0.1
  ~ HD 189733

The planet WASP-43b:

- A very short period hot Jupiter
  (P = 19.5 h, T_{eq} ~ 1440 K, δ_e ~ 0.44 %)
- Good visibility window
- HST WFC3 spectroscopic phase curves
  (*Stevenson et al. 2014*)

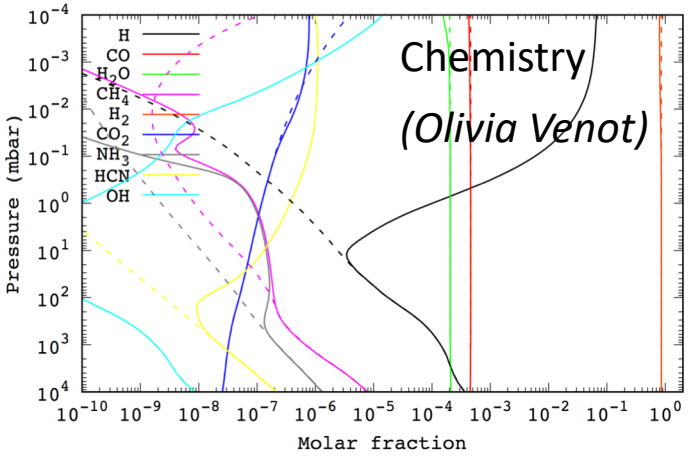
We must disentangle:

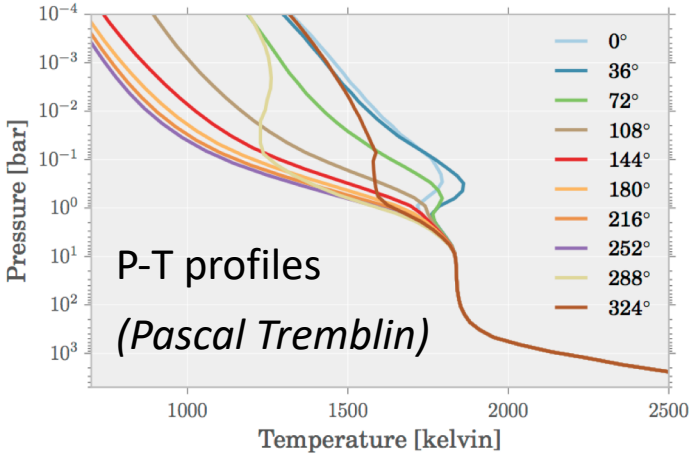
- Planet's phase curve
- Instrument trends
- Stellar variability

Focus group: 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*



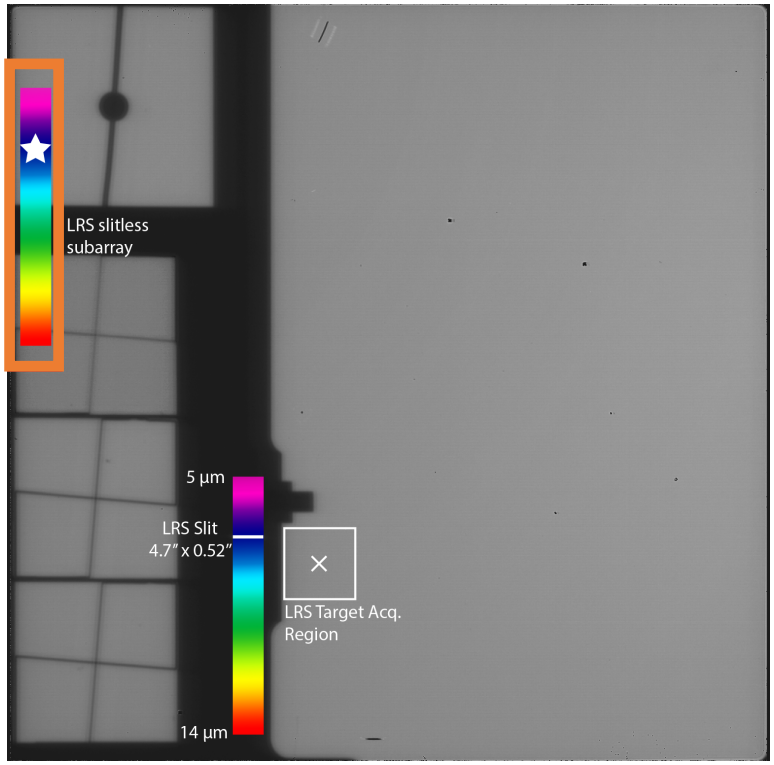


Focus group: MIRI technical challenges

Goals: - **Identify MIRI challenges** for time-series observations over 30 hours
- Measure the **noise floor**

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

MIRI focal plane

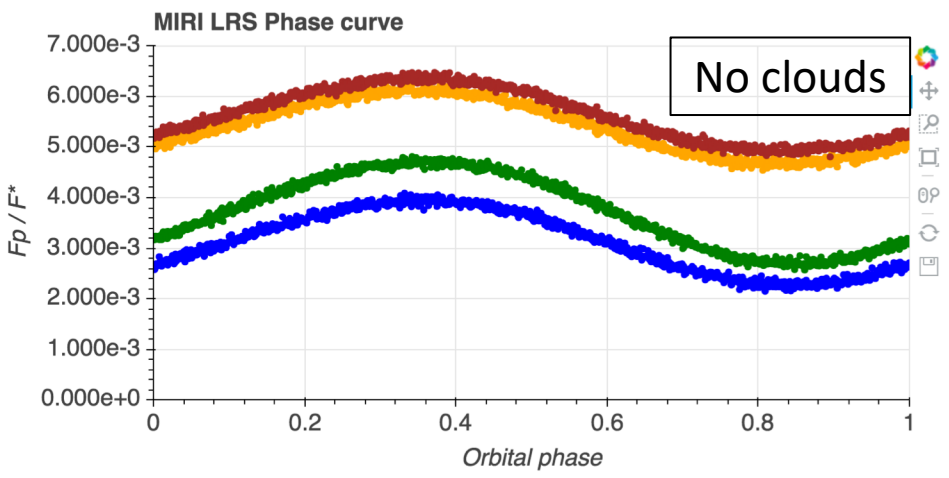


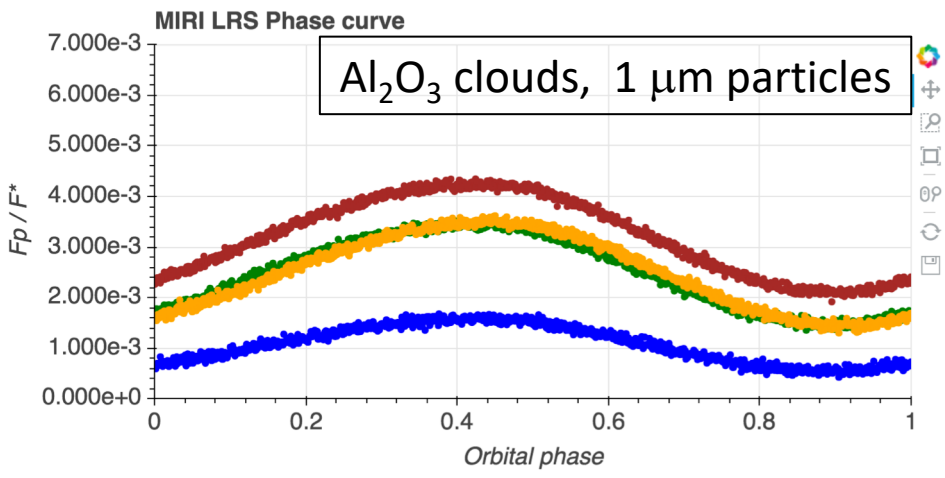
Simulations

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

  Type of clouds: Al_2O_3, $CaTiO_3$, Cr, Fe, $MgSiO_3$, MnS
- Instrument simulations: **Pandexo** *(Natasha Batalha)*

  MIRI LRS observing mode





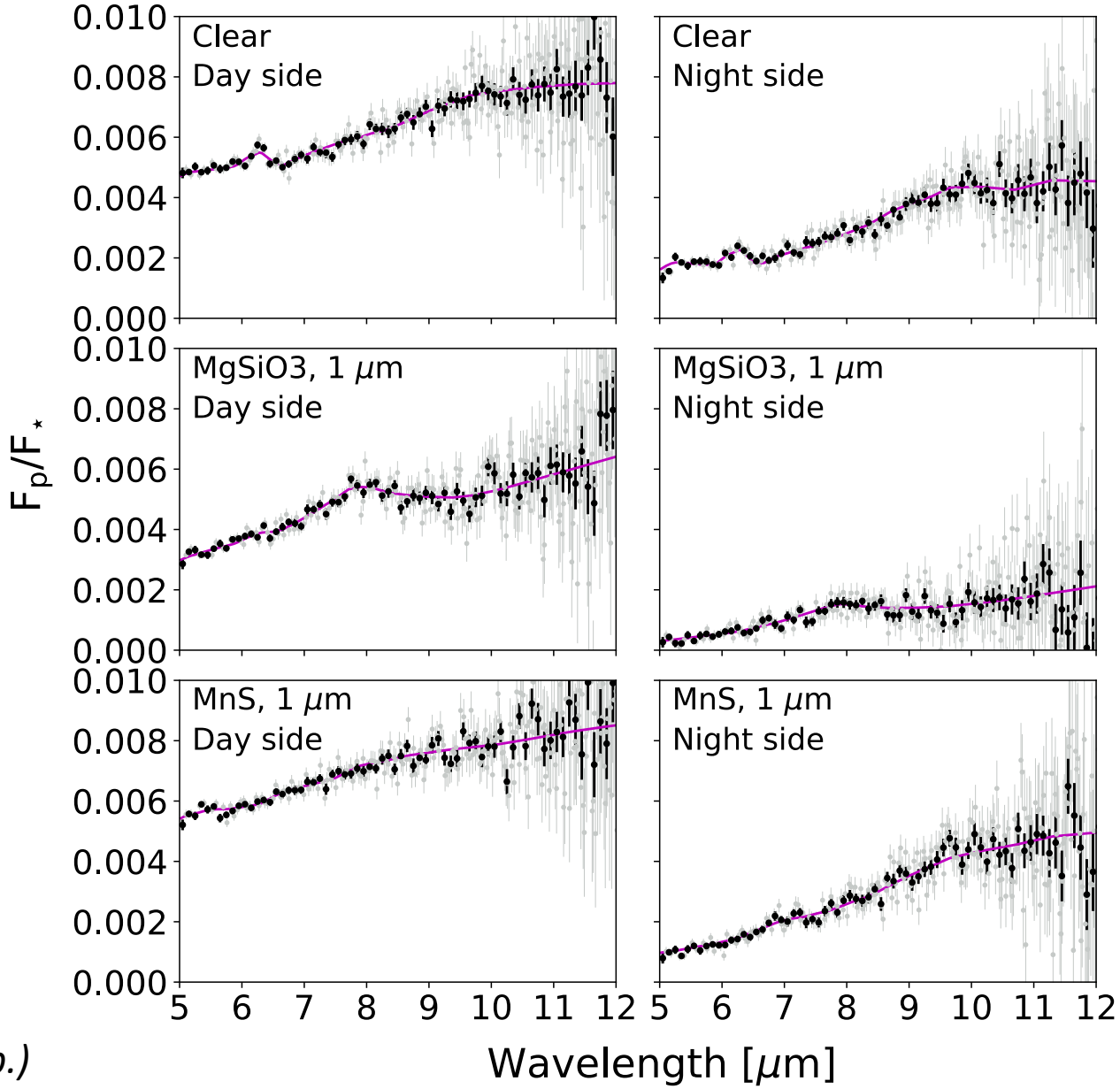
6 μm 8 μm 10 μm 12 μm

Only the **phase curve** is shown

Simulations

- **Emission spectra**

  Day side & Night side



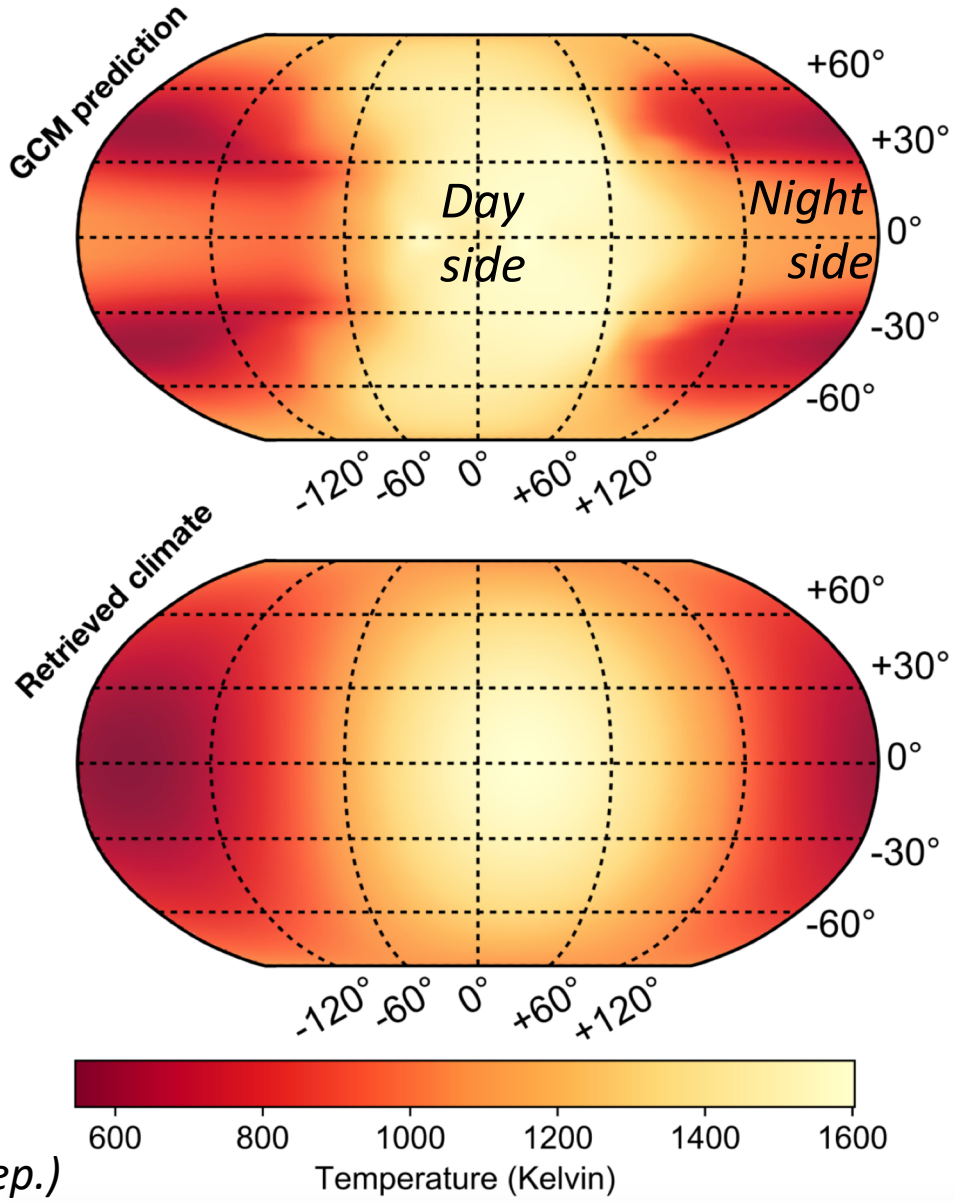
(Venot et al. in prep.)

Simulations

- **Predicted temperature map** from the nominal cloud-free, solar composition GCM *(Kataria et al. 2015)*

- Spherical harmonic map **retrieved from simulated phase curve** observations

- Additional information in latitude from eclipse mapping *(T. Louden)*



(Bean et al. in prep.)

Allocated JWST time

Transiting Exoplanets ERS program: **78.1 hours**

- Panchromatic Transmission: 39.6 hours
- MIRI Phase Curve: 29.4 hours
- Bright star secondary eclipse: 9.1 hours

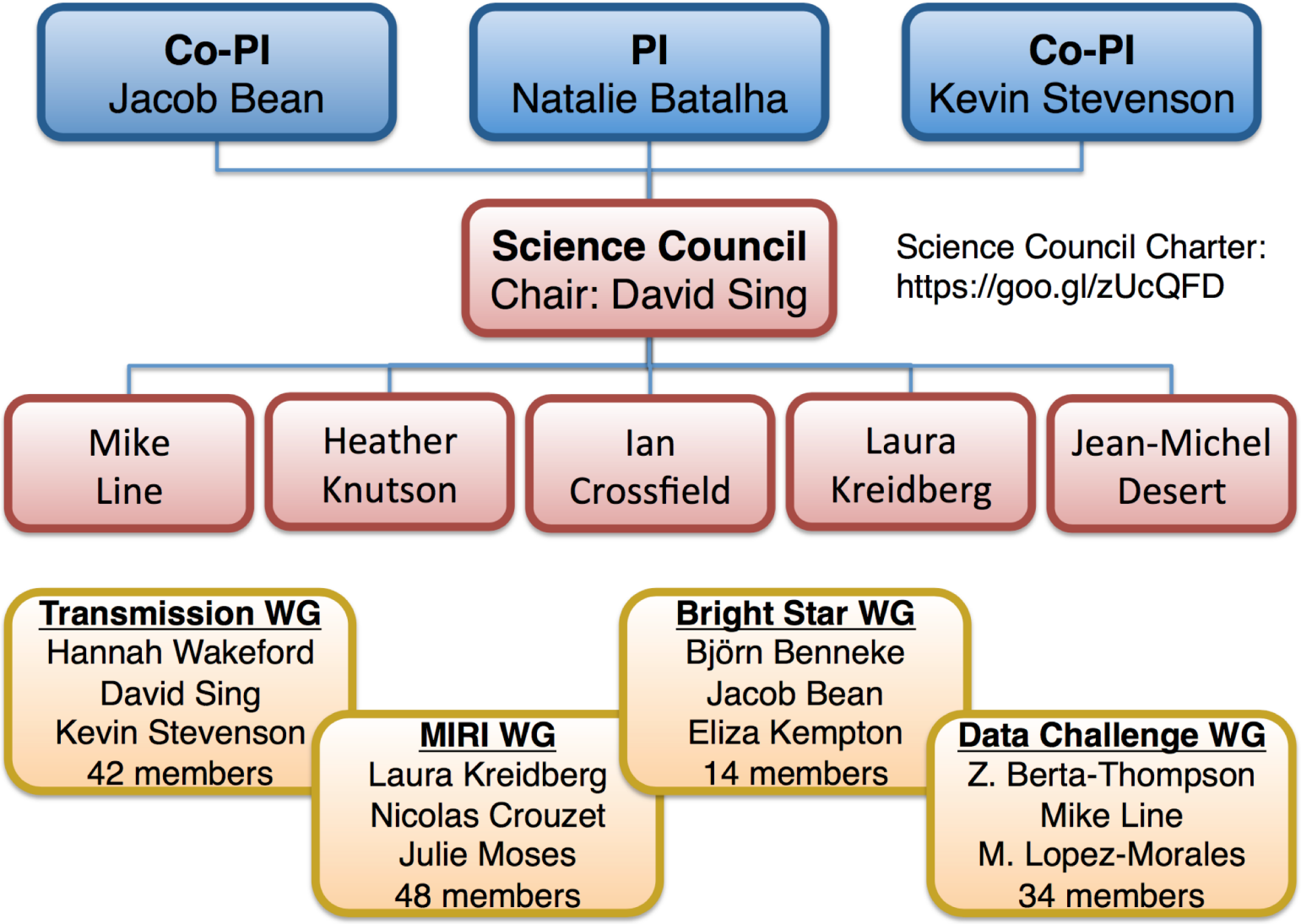
Requested: 78.1 hours

Science time: 52.1 hours

Conclusion

- JWST will offer **unique capabilities** for transiting exoplanet spectroscopy
- **Collaborative** ERS program for transiting exoplanets: four sub-programs including a **spectroscopic phase curve** of a hot Jupiter with MIRI LRS
- Target: WASP-43b, **30 hour observation**
- Retrieve its **atmospheric composition**, temperature structure, heat transport, chemistry, cloud properties
- Test the **stability** of JWST and MIRI LRS over 30 hours
- Data and tools will be **available to the community**
- Everyone is **welcome to contribute**!

Management Team



Spectroscopic modes for transiting exoplanets