STScI | SPACE TELESCOPE SCIENCE INSTITUTE

EXPANDING THE FRONTIERS OF SPACE ASTRONOMY

# Exoplanet Science with *Webb*

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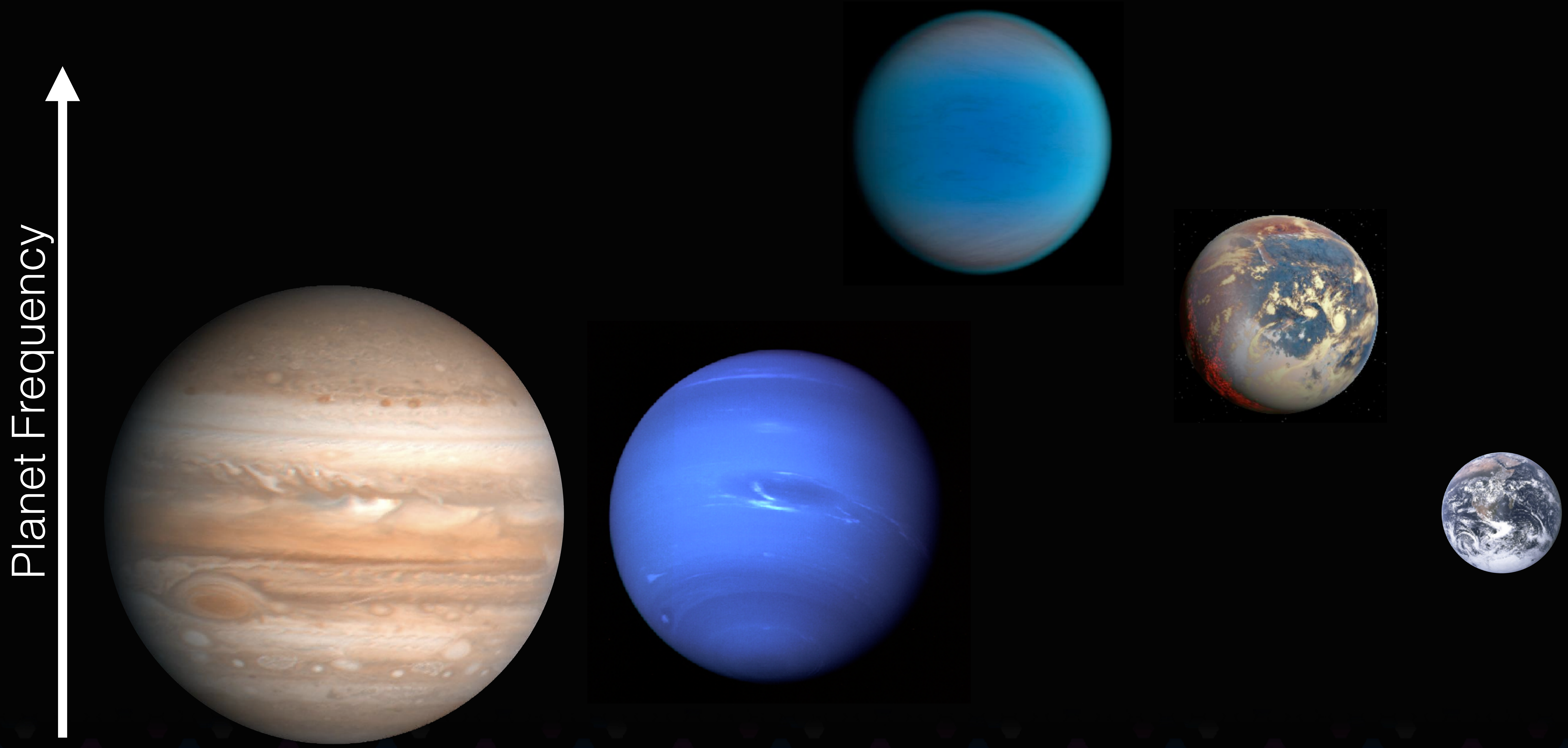
STScI JWST Project Scientist

01/08/18

# First Exoplanet Detected in 1995…..

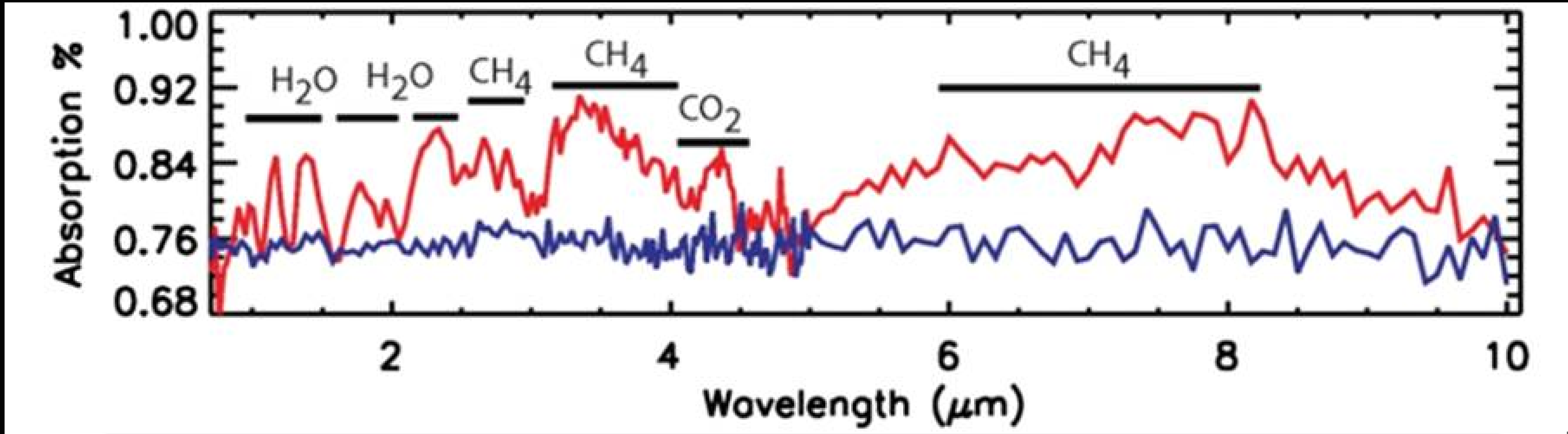



In 2018, More than 3500 Confirmed Exoplanets

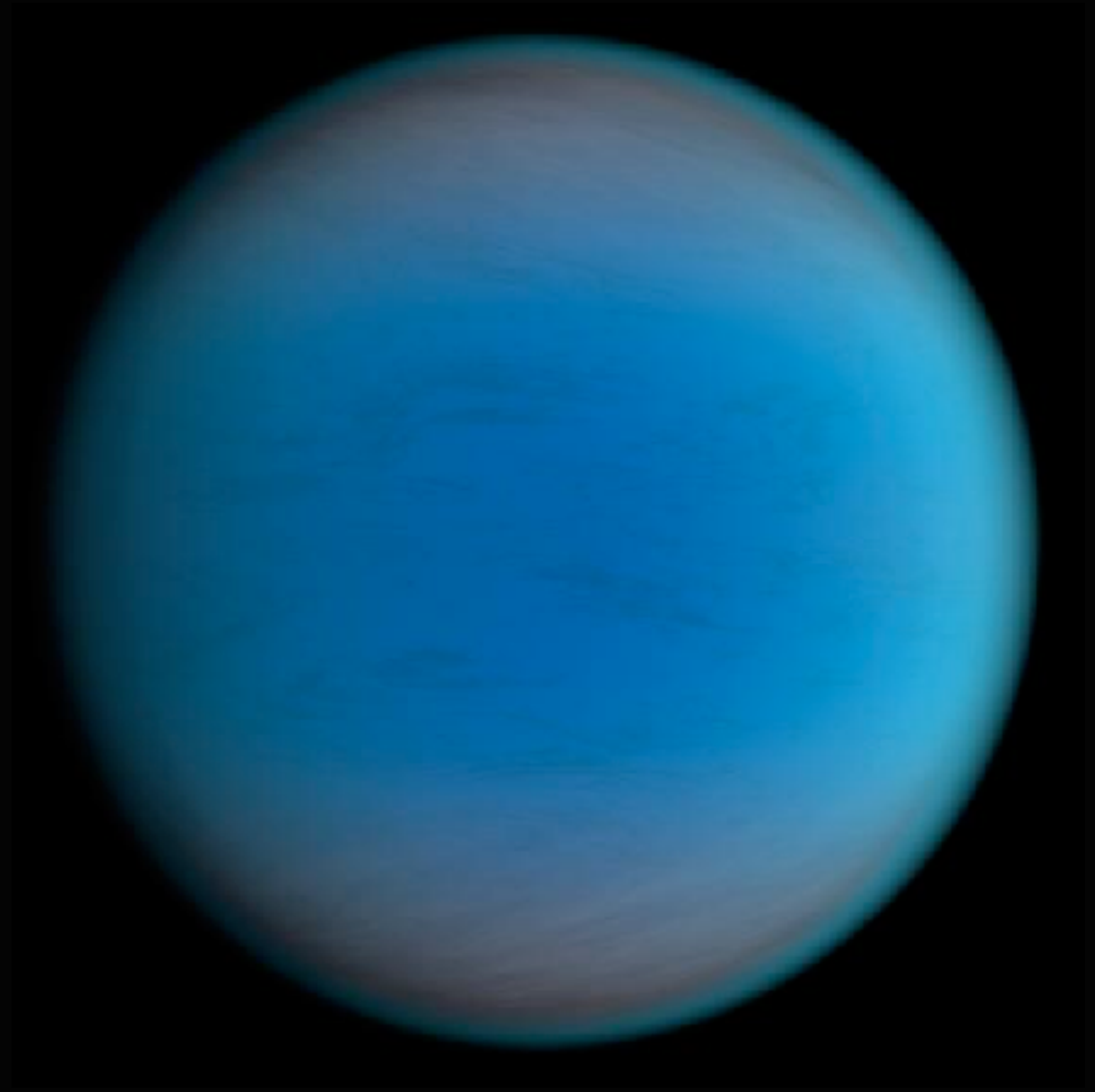
Planets not to scale

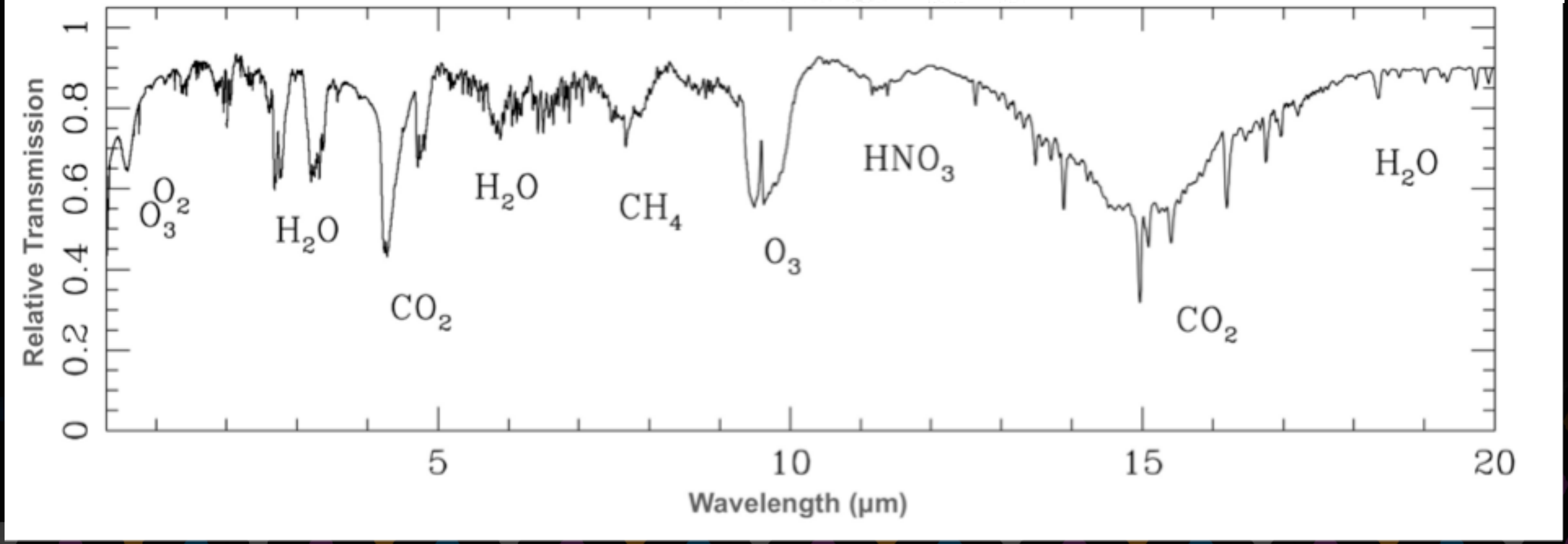

In the era of *Webb*
Potential for >300 Exoplanets with Characterization Observations
In the era of *Hubble & Spitzer*
>100 Exoplanets with Characterization Observations

# *Webb* will observe exoplanets at molecule-rich infrared wavelengths



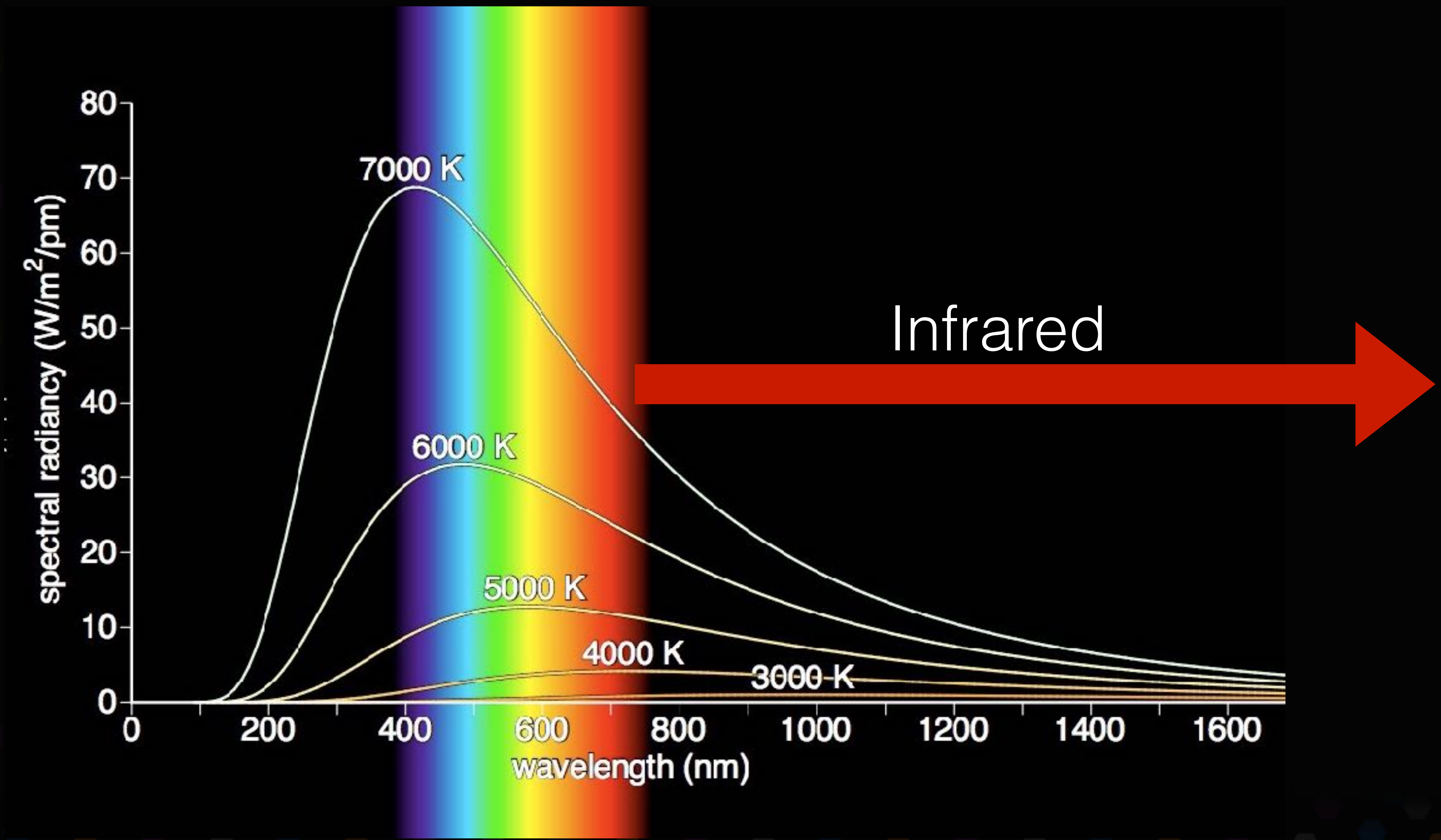

Beichman et al. (2014)

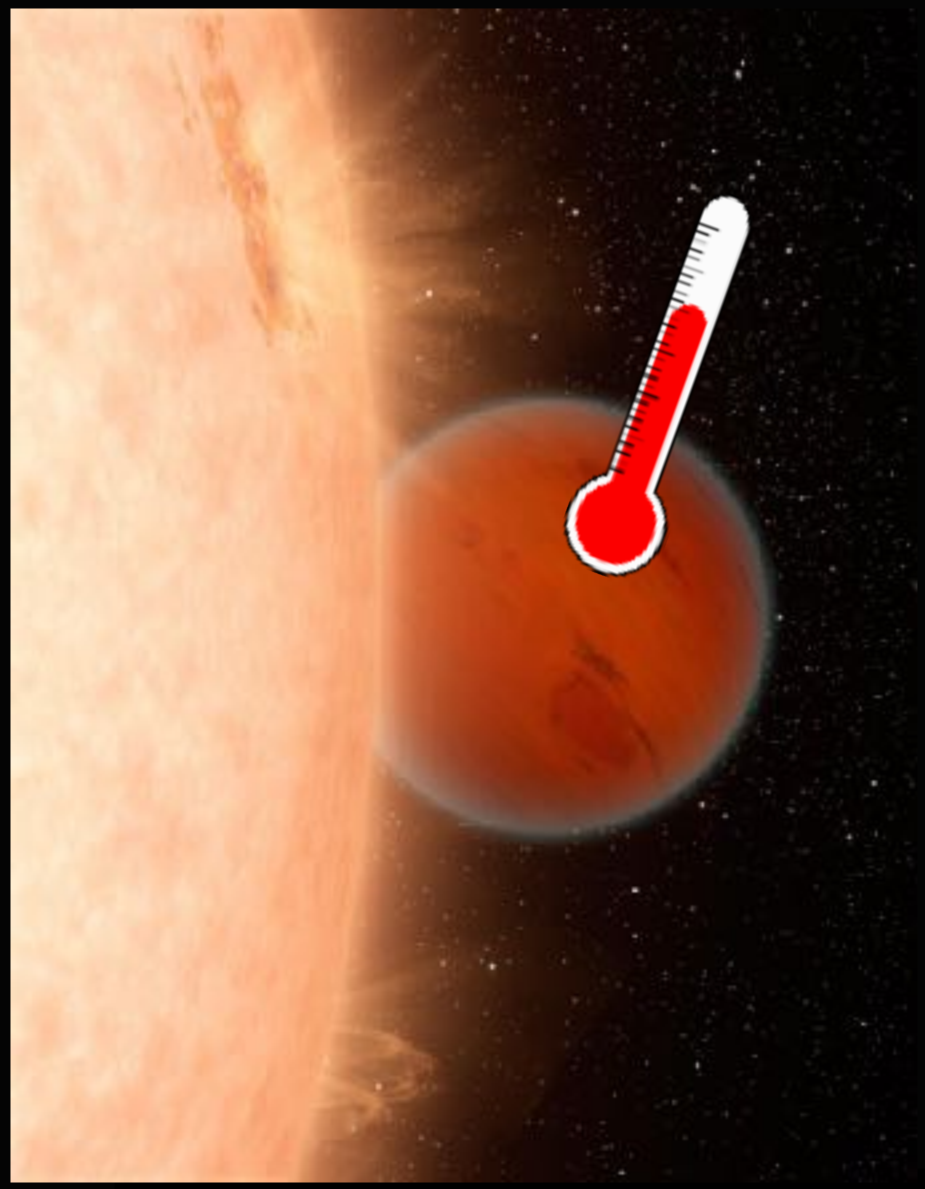


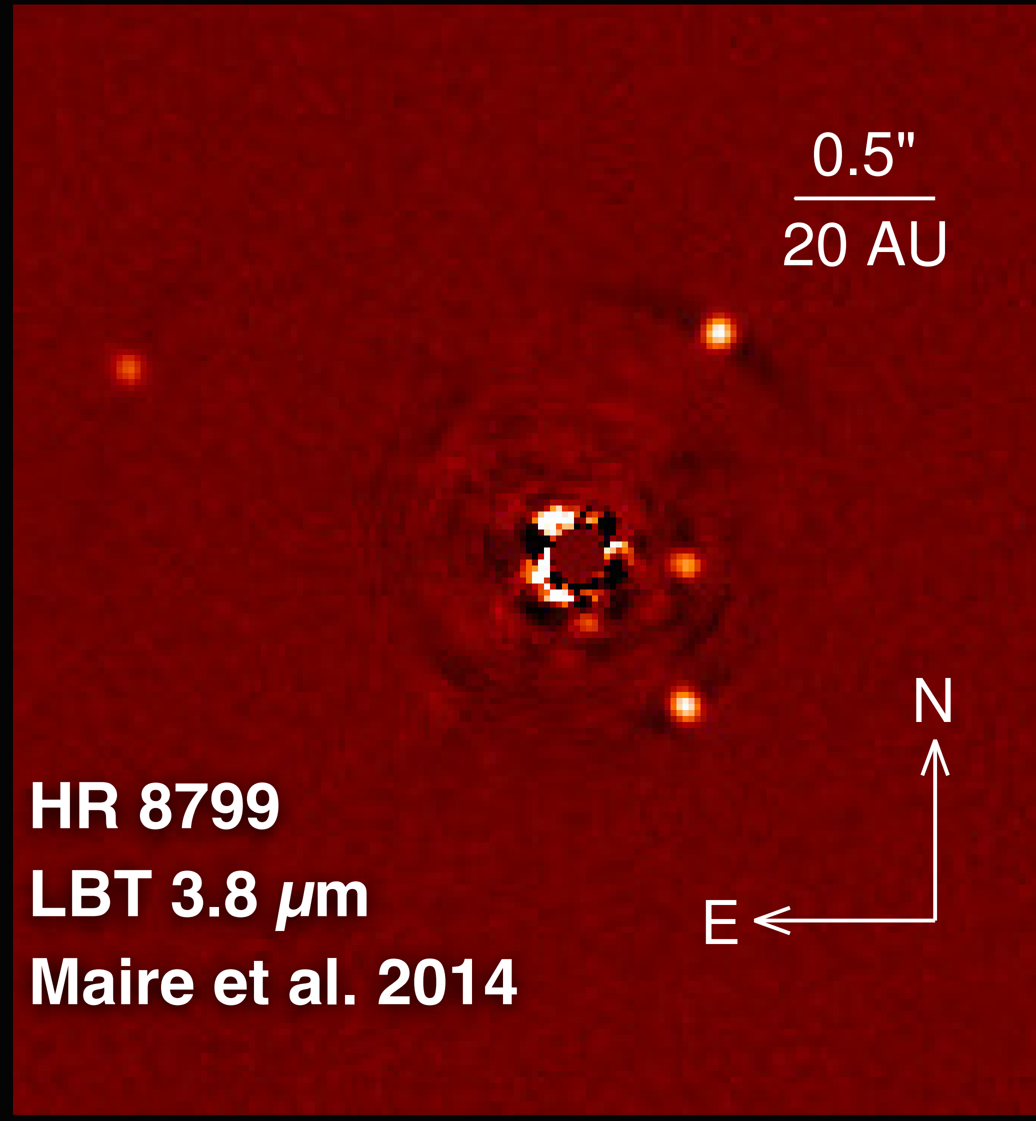


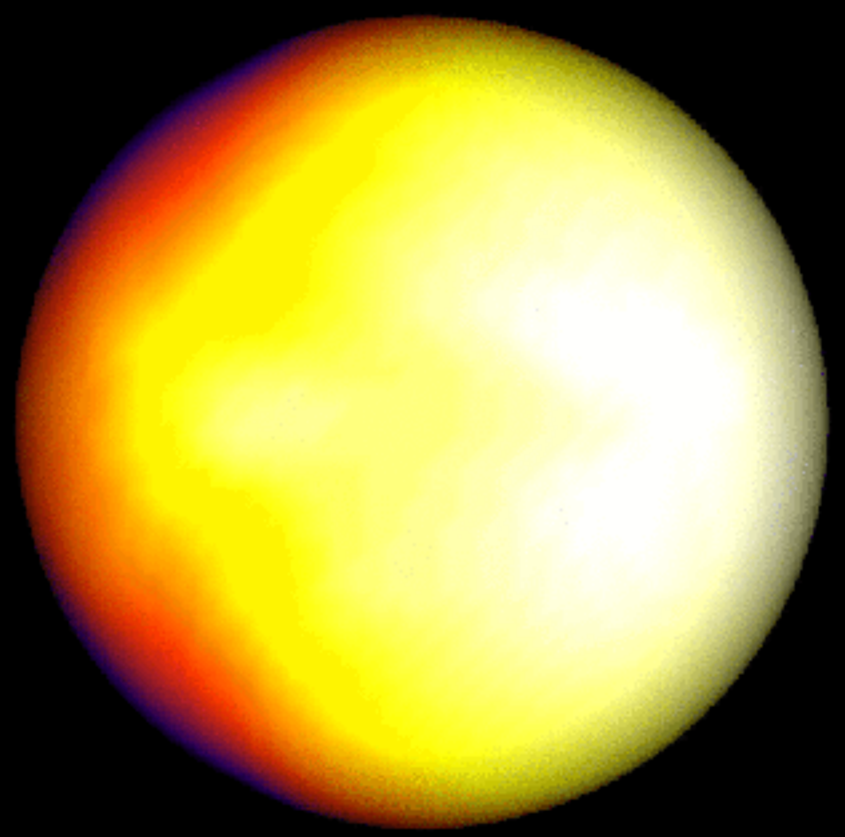

Kaltenegger and Traub (2009)

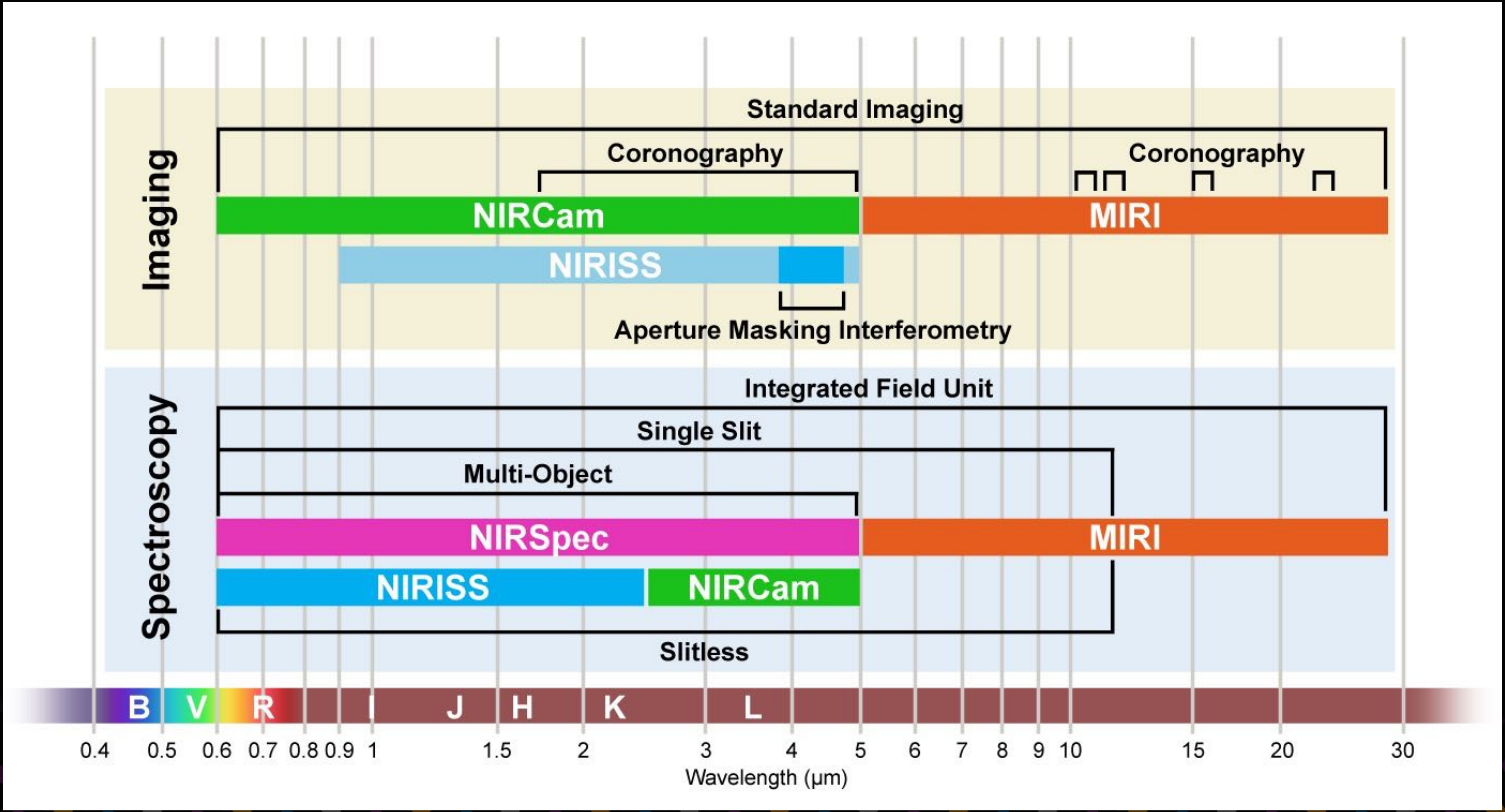
# *Webb* will observe at infrared wavelengths where exoplanets emit most of their light



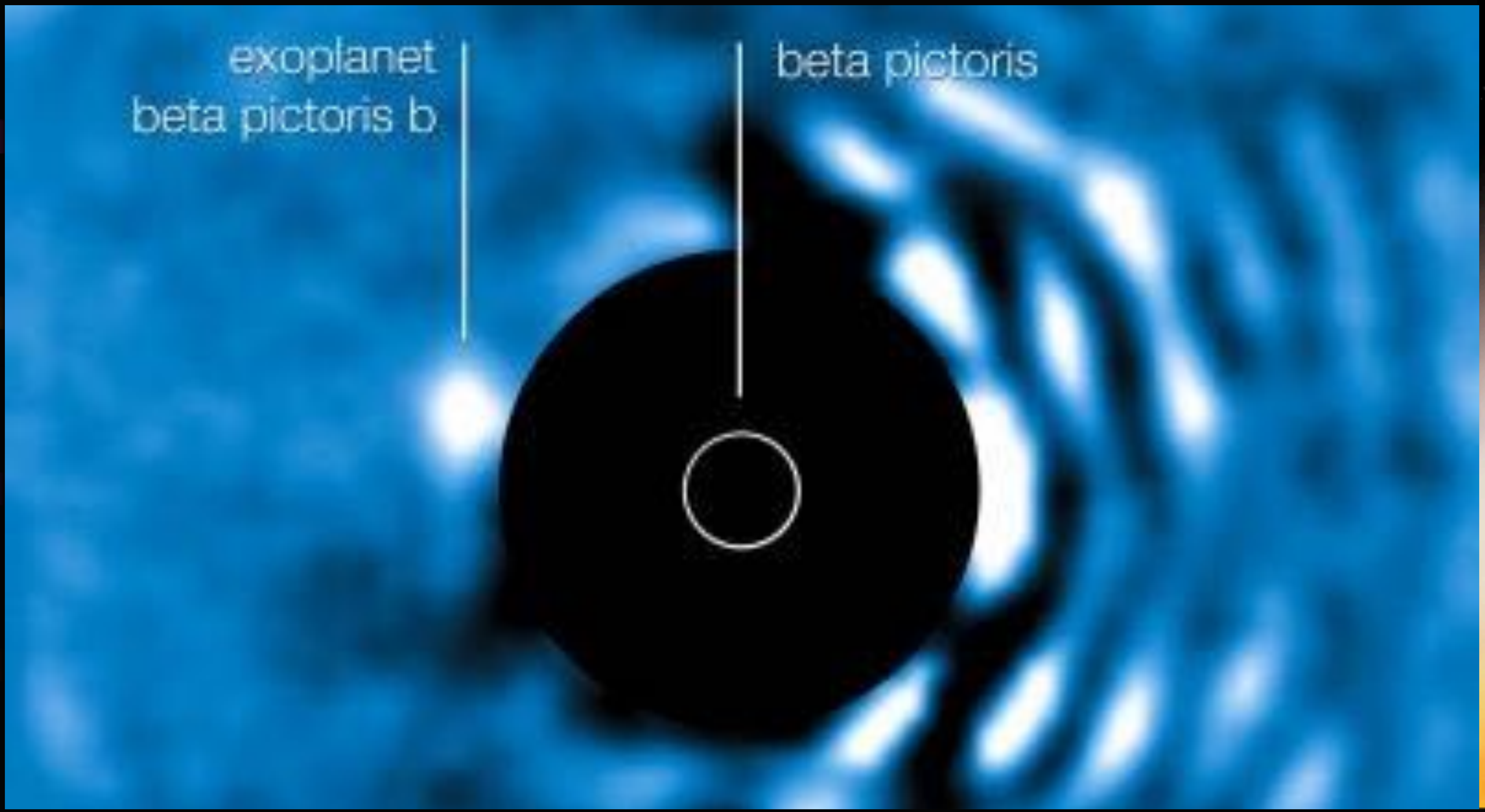


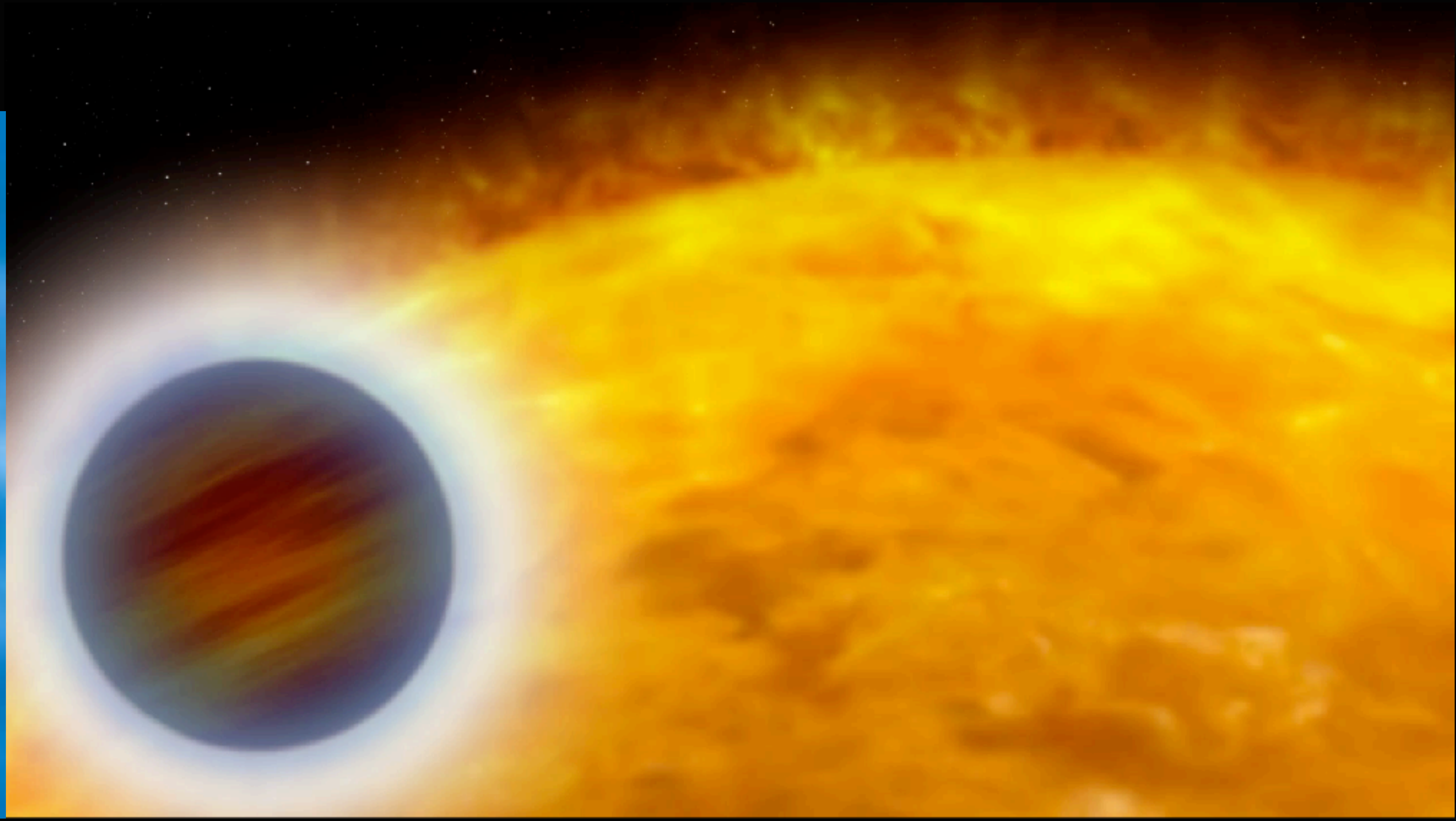


Imaging
Standard Imaging
Coronography
Coronography
NIRCam
MIRI
NIRISS
Aperture Masking Interferometry
Spectroscopy
Integrated Field Unit
Single Slit
Multi-Object
NIRSpec
MIRI
NIRISS
NIRCam
Slitless
B V R I J H K L
0.4 0.5 0.6 0.7 0.8 0.9 1 1.5 2 3 4 5 6 7 8 9 10 15 20 30
Wavelength (μm)

# *Webb* will probe exoplanets in primarily two ways…

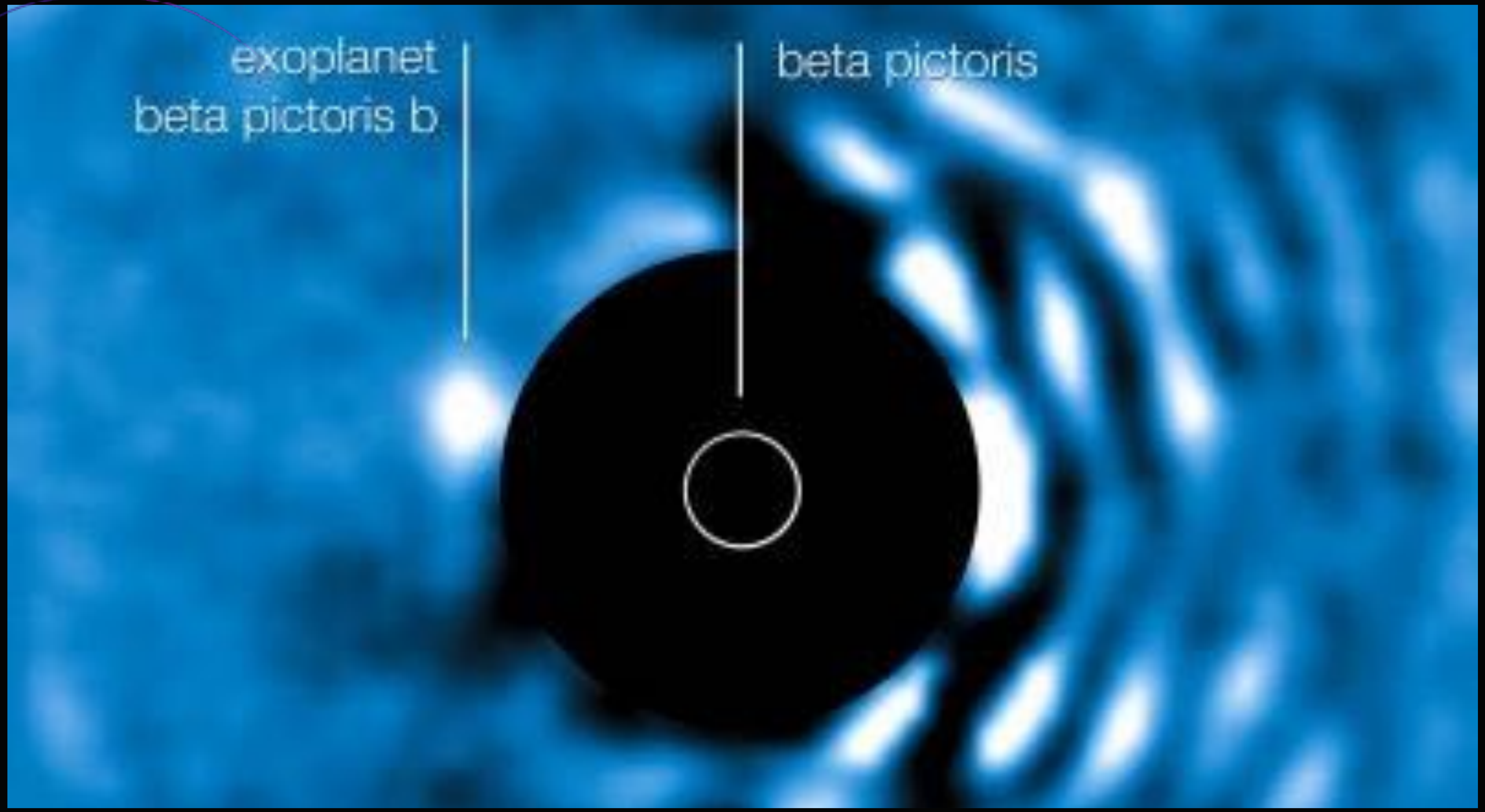



High-Contrast Imaging



High-Precision Time-Series Observations

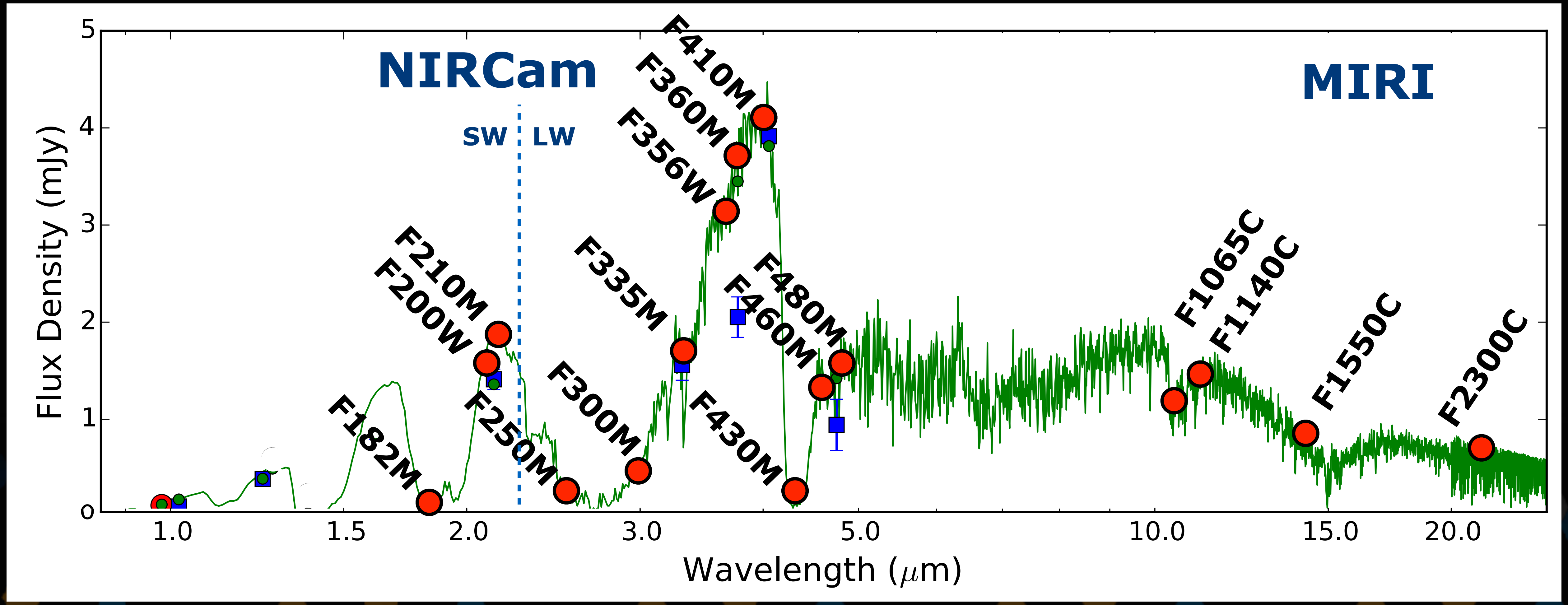
# High-Contrast Imaging with *Webb*



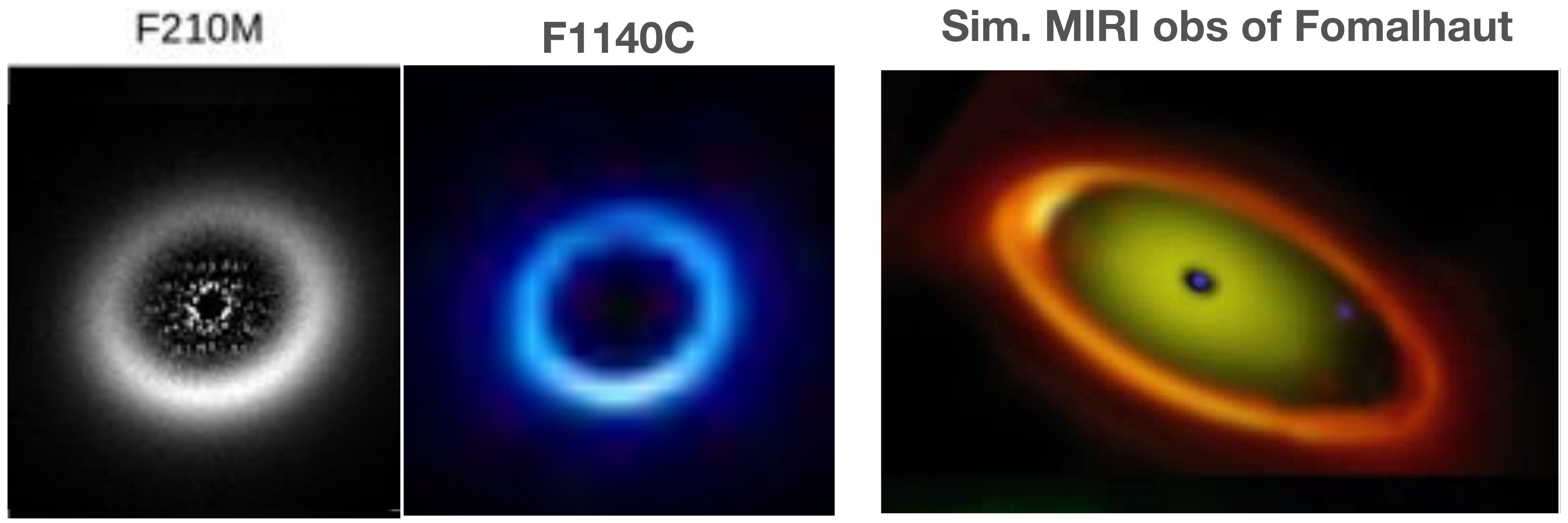

*High contrast at longer wavelengths: 3-5 μm, 10+ μm*

*Much deeper sensitivity & wider field of view than AO.*

*Options: NIRCam & MIRI coronagraphs, NIRISS AMI, or non-coronagraphic PSF subtraction with any instrument.*



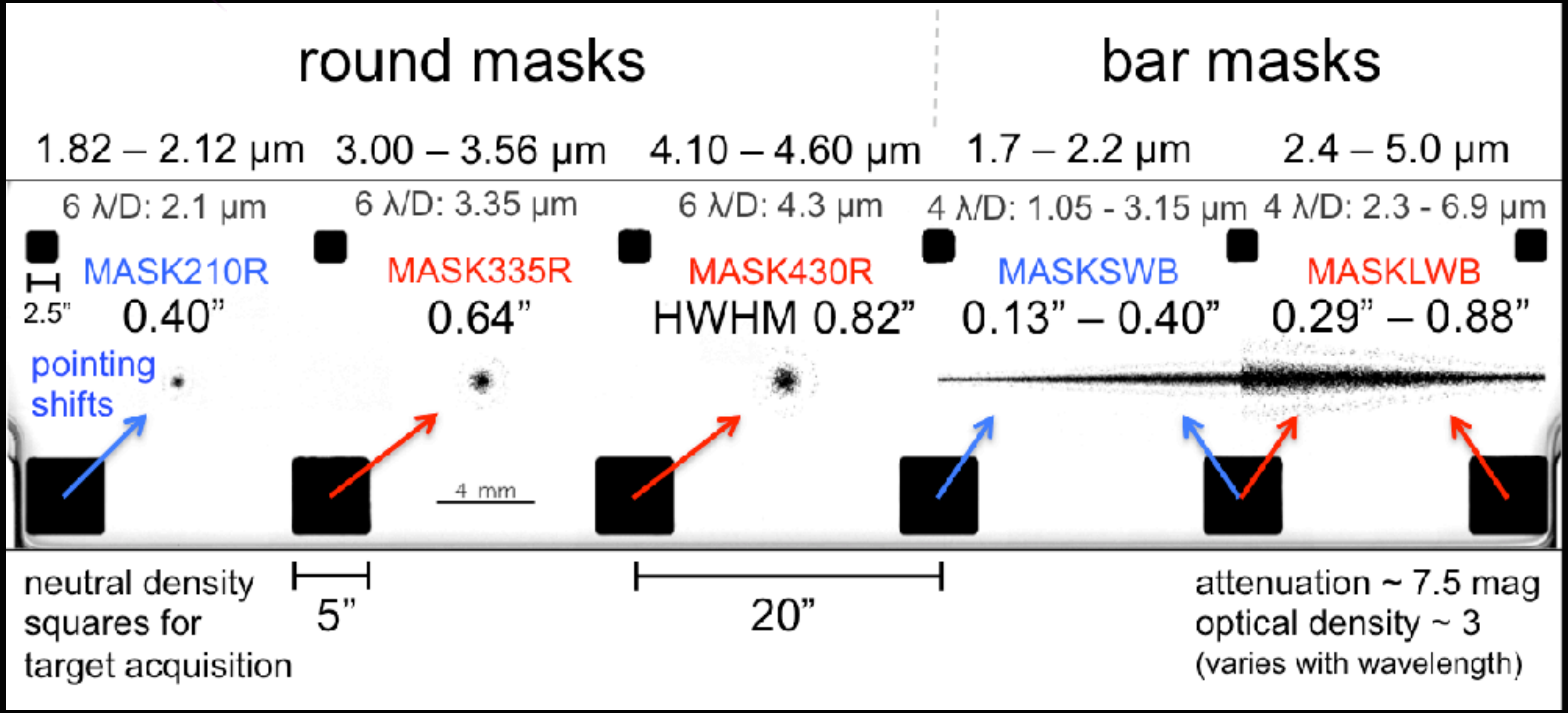

Teff = 1000 K, log(g) = 3.5 model from Barman et al.




Lebreton et al.

Stapelfeldt et al.

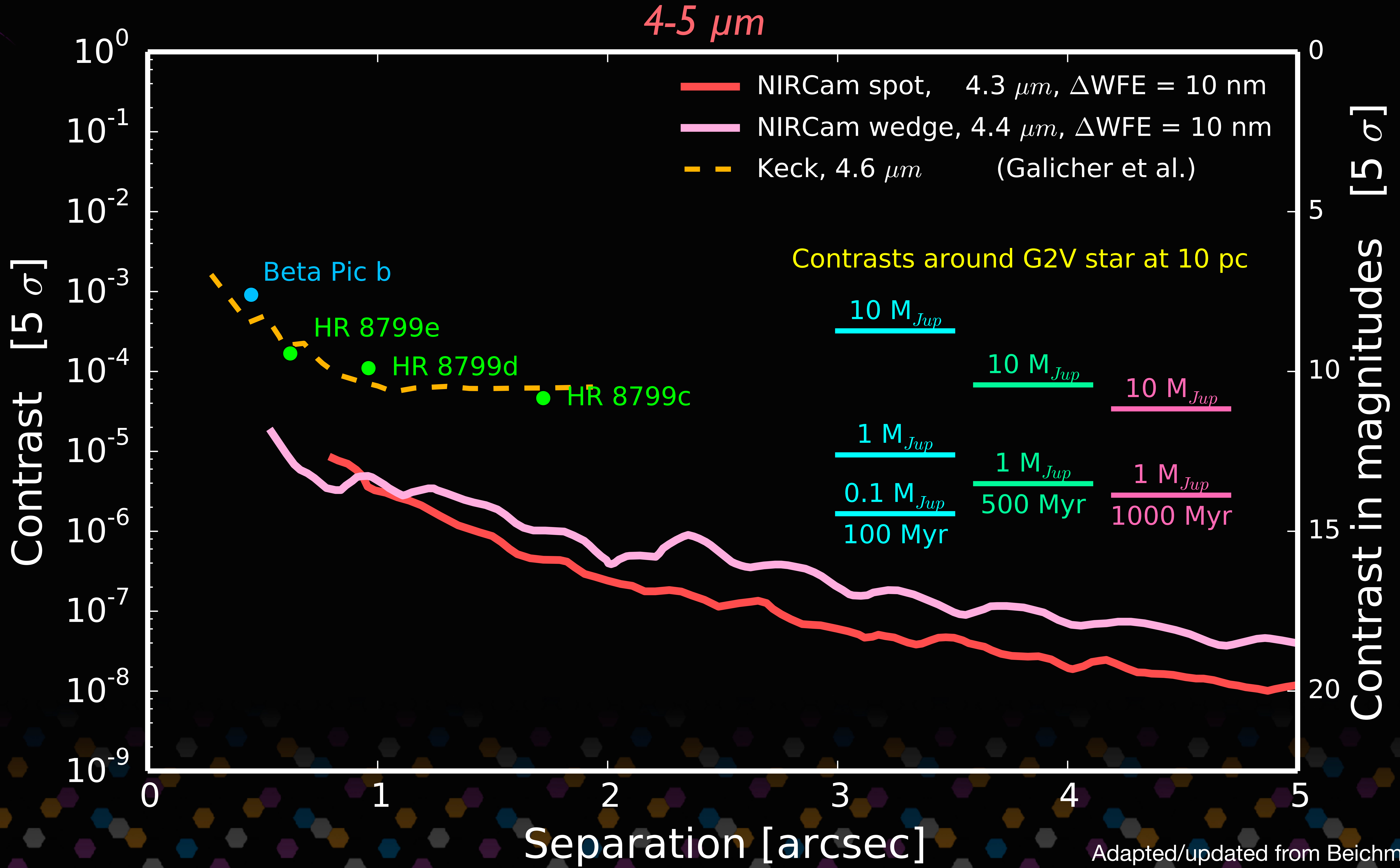
# NIRCam Coronagraphs




| | Name | Shape | Inner Working Angle | Wavelength Range |
|---|---|---|---|---|
| SW channel | MASK210R | round | 0.40" | 1.8 - 2.2 µm |
| | MASKSWB | bar | 0.13 - 0.40" | 1.8 - 2.2 µm |
| LW channel | MASK335R | round | 0.63" | 2.5 - 4.1 µm |
| | MASK430R | round | 0.81" | 2.5 - 4.6 µm |
| | MASKLWB | bar | 0.29 - 0.88" | 2.5 - 4.8 µm |

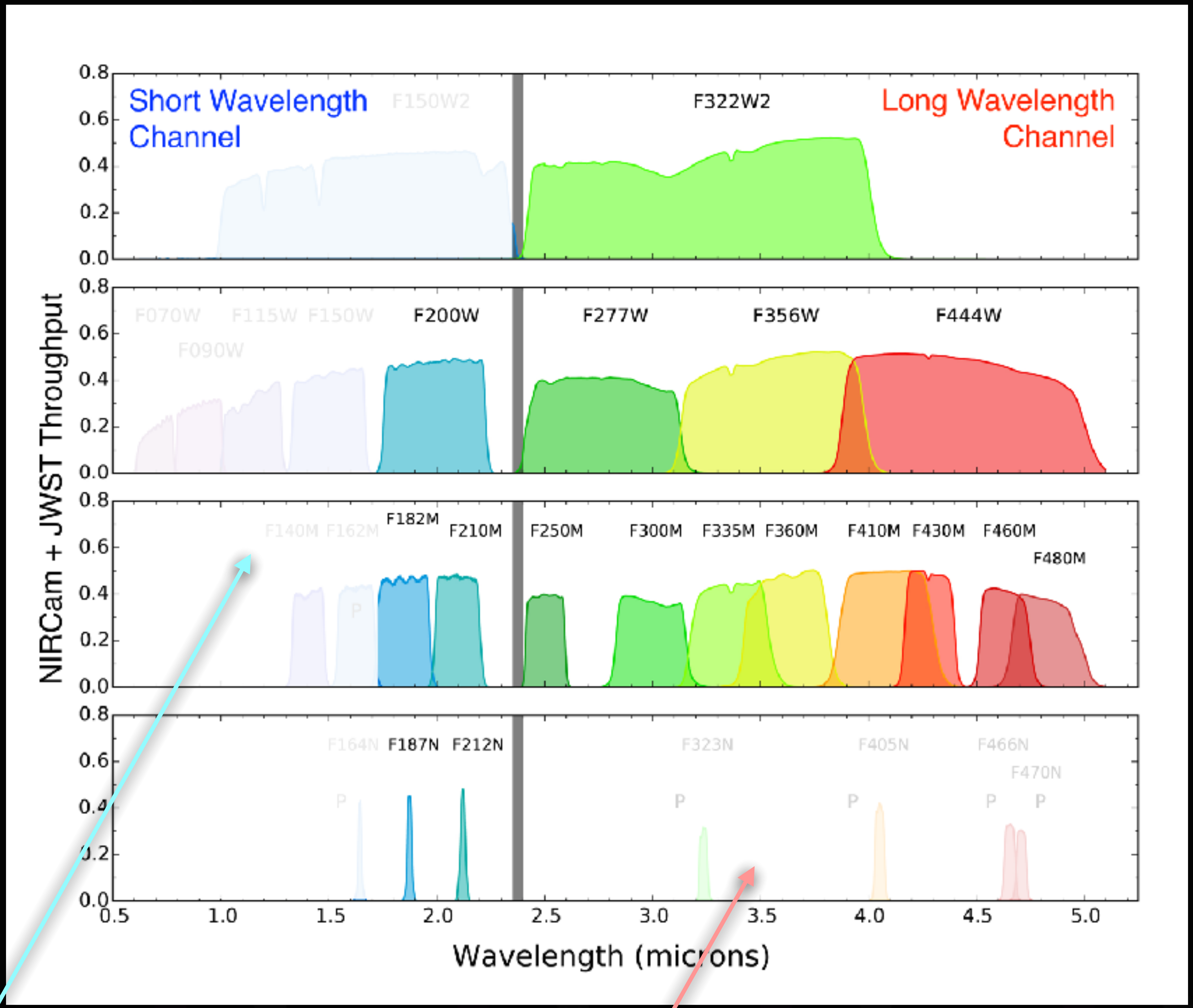
- 5 Lyot coronagraphs, pseudo band-limited with soft-edged grayscale occulters.
- Round occulters provide 360º azimuthal coverage for disk observations and planet searches. Relatively large (HWHM = 0.4-0.8"): optimized for 6 λ/D at λ= 2.1, 3.3, 4.3.
- Bar occulters provide allow selection of inner working angle to match wavelength. Optimized for 4 λ/D. Each filter has its own location along the wedge.
- Lyot stops suppress PSF wing diffraction. Throughput = 19%.
- coronagraph optics are outside the FOV during normal imaging observations.

# NIRCam contrasts: below $10^{-5}$ at 1”, $10^{-7}$ at 4”




Adapted/updated from Beichman et al. 2010

# Most NIRCam filters are available for coronagraphy

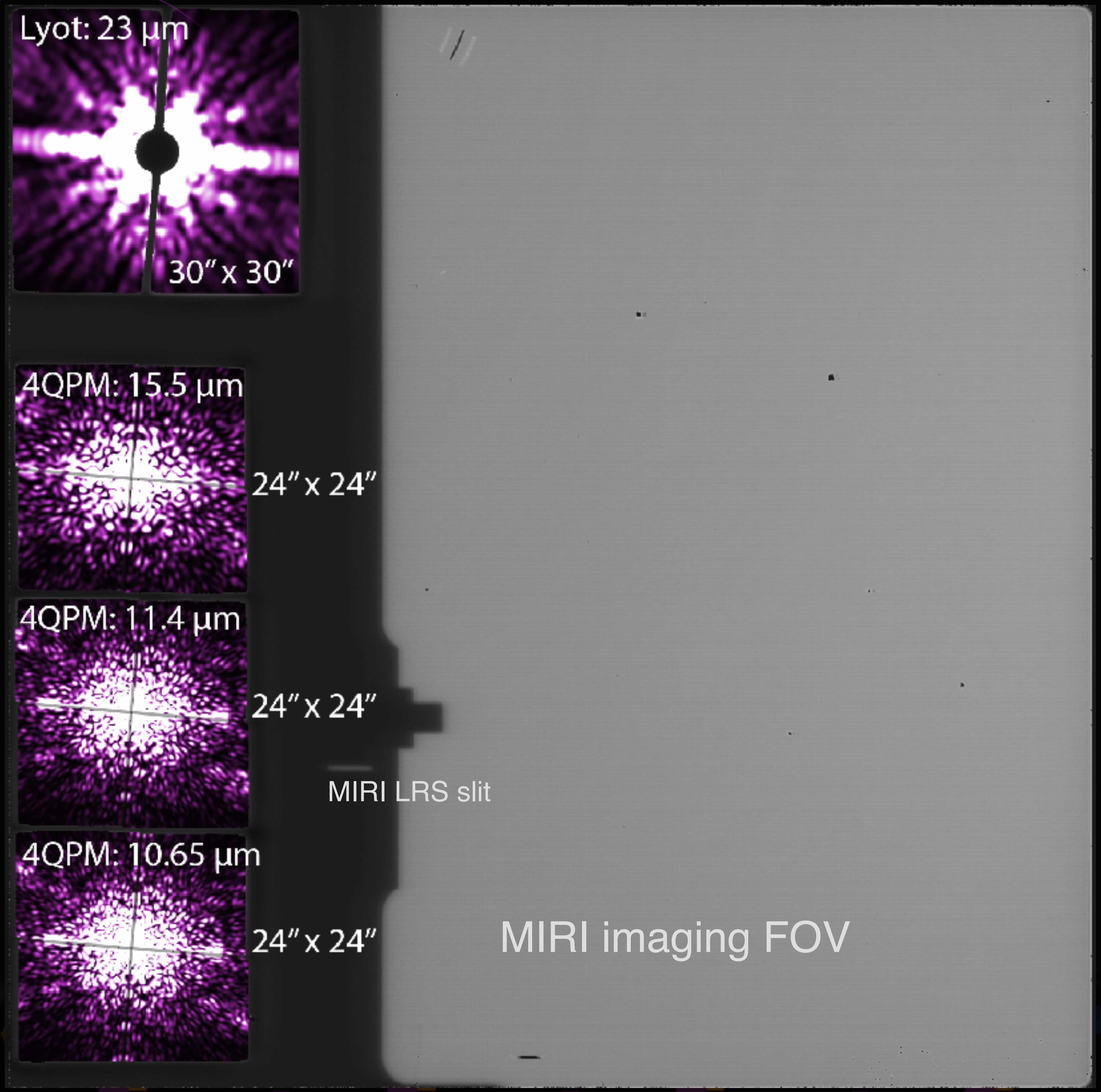



SW filters below 1.8 μm unavailable.
Coronagraph mask anti-reflection coating has low throughput for λ < 1.8 μm

LW narrow band filters unavailable.
These are installed in same pupil wheel as the coronagraph Lyot stops.

| Filter | |
|---|---|
| F182M | H2O, CH4 |
| F187N | Paschen Alpha |
| F200W | continuum |
| F210M | H2O, CH4 |
| F212N | H2 |
| F250M | continuum, CH4 |
| F277W | continuum |
| F300M | H2O ice |
| F322W2 | double-wide, max sensitivity |
| F335M | PAH, CH4 |
| F360M | continuum |
| F410M | continuum |
| F430M | CO2, N2 |
| F444W | continuum |
| F460M | CO |
| F480M | CO |

# MIRI Coronagraphs

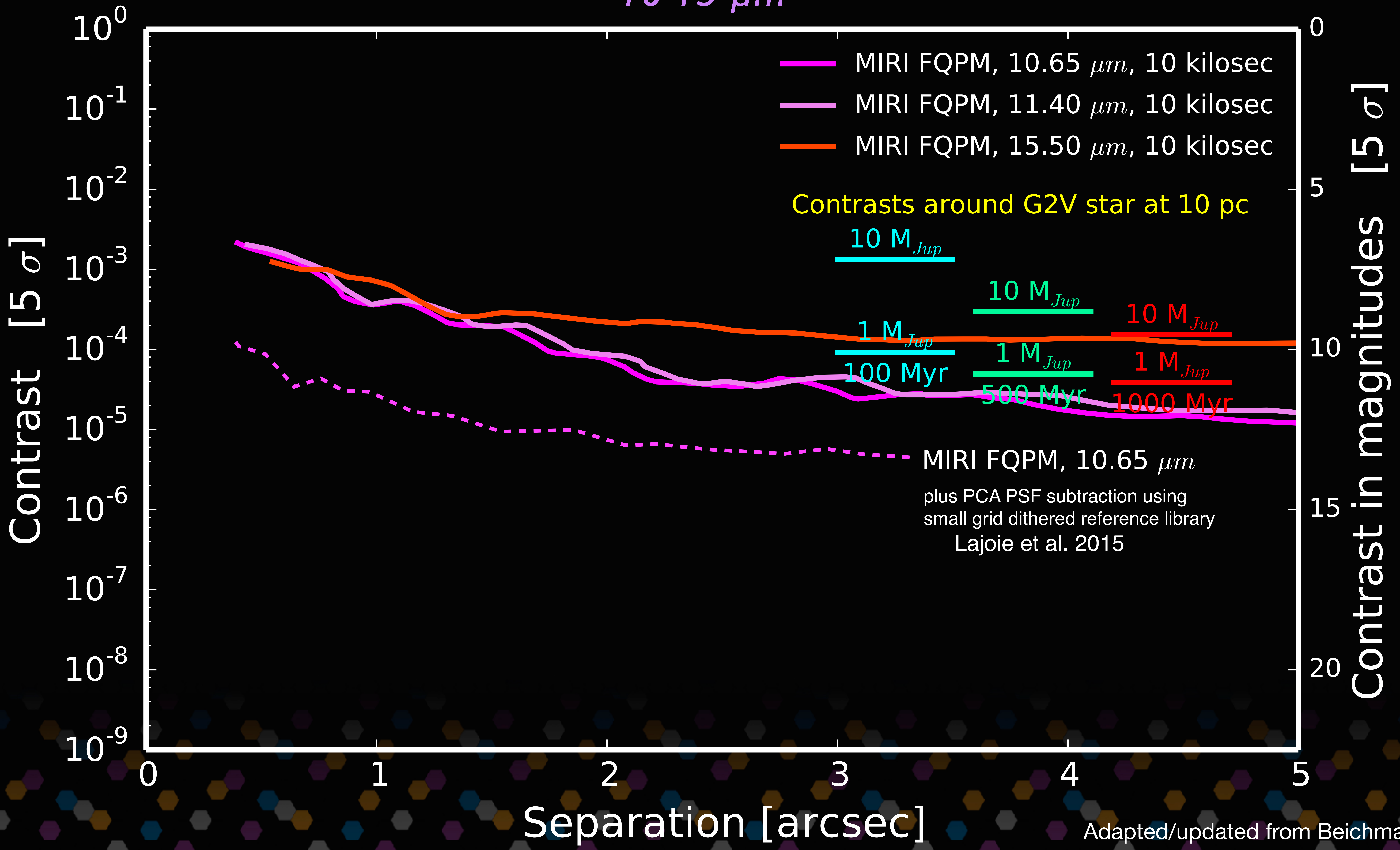



- 3 four-quadrant phase mask coronagraphs, at fixed filters: 10.65, 11.4, 15.5 *µ*m. These provide good contrast down to 1 λ/D, but are relatively narrow band. (R~20)
- One Lyot coronagraph. The occulter is relatively large (optimized for 3 λ/D at 23 *µ*m; r=2.16") but broader bandwidth (R~5) optimized for sensitivity to disks.
- Coronagraph masks are always in the FOV, along left side of MIRI imager detector.

| Name | Type | Inner Working Angle | Bandwidth |
|---|---|---|---|
| F1065C | FQPM | 0.33" | 0.75 µm |
| F1140C | FQPM | 0.36" | 0.8 µm |
| F1550C | FQPM | 0.49" | 0.9 µm |
| F2300C | Lyot | 2.16" | 5.5 µm |

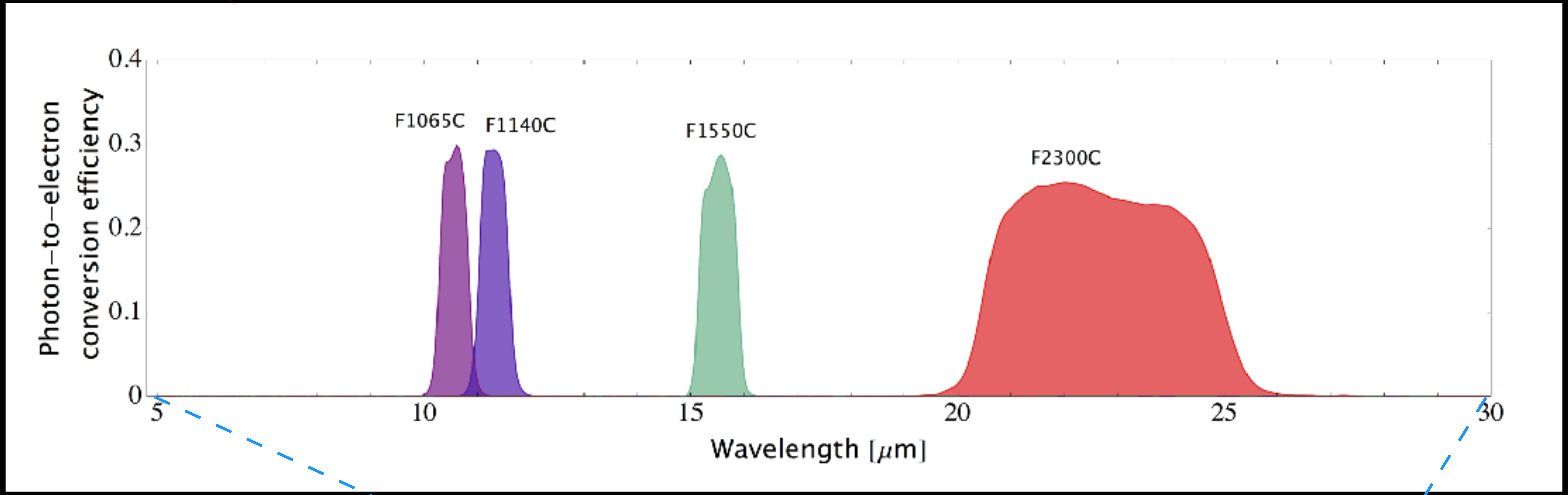
# MIRI contrasts: $10^{-4}$ to $10^{-5}$ for r > 1”

*10-15 μm*

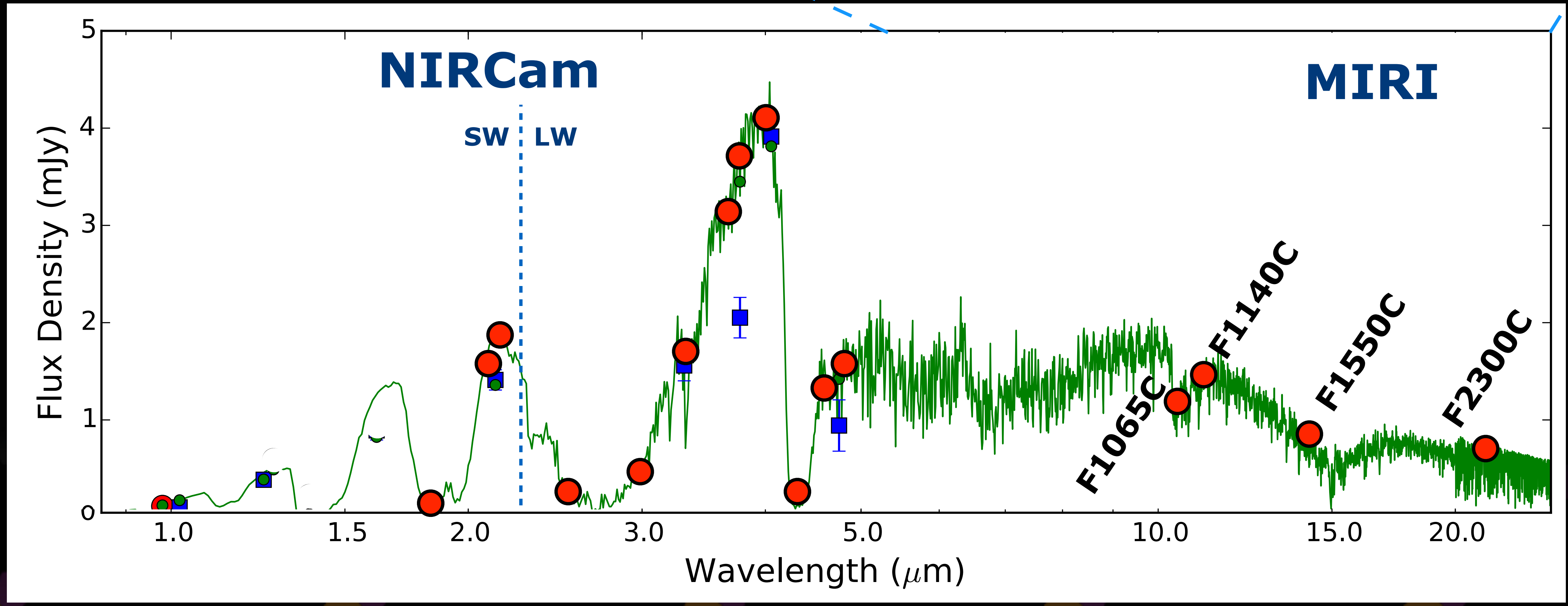



Adapted/updated from Beichman et al. 2010

# MIRI Filters for Coronagraphy




| Filter | |
|---|---|
| F1065C | Ammonia |
| F1140C | Continuum (planets); Si, PAHs (disks) |
| F1550C | Continuum |
| C2300C | Continuum, especially for disks |




Teff = 1000 K, log(g) = 3.5 model from Barman et al.

- Ammonia feature at 10.65 $\mu m$ is main spectral feature at 5-20 $\mu m$ for cool exoplanet atmospheres (T~ 200-500 K).
- Continuum slope from 11.4 - 15.5 measures planet temperature.
- These filters also suitable for studies of circumstellar disks and AGN.

# *Webb* High-Contrast Imaging Summary

**NIRCam**
1-5 μm

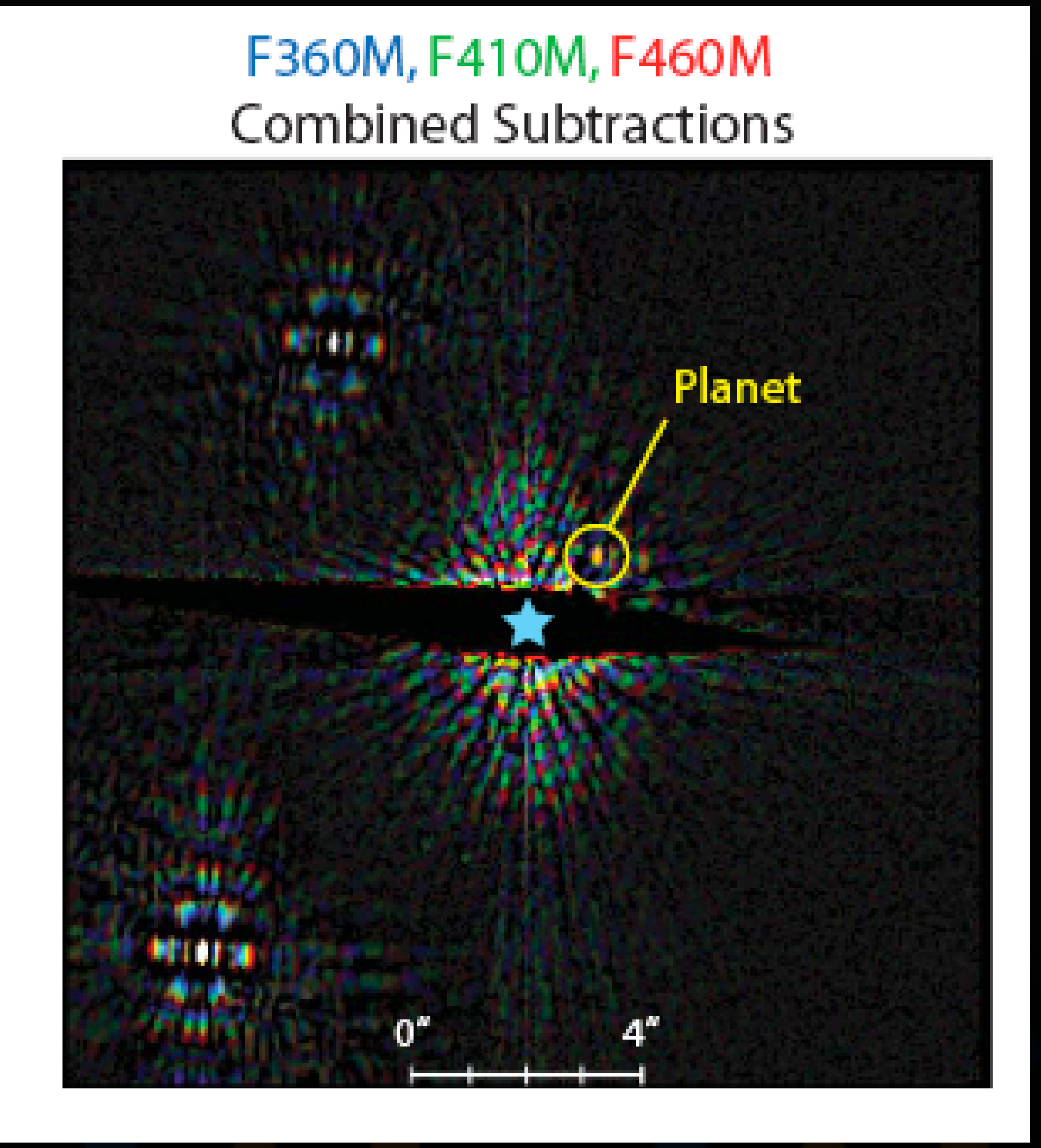
5 coronagraph options
IWA 0.3 - 0.4'' (3λ/D)
Contrasts 1e-5 - 1e-6

**MIRI**
5-27 μm

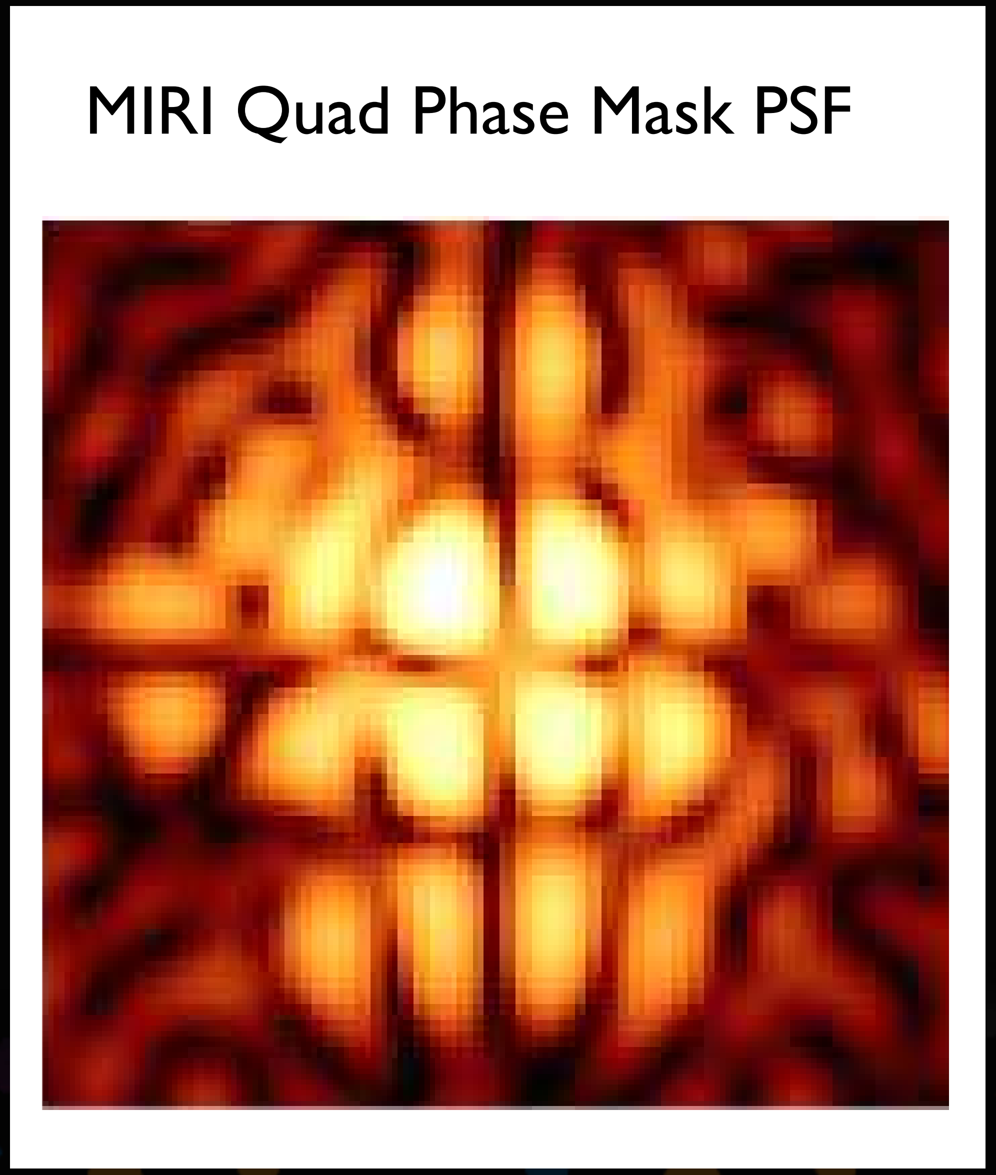
4 coronagraph options
IWA 0.3 - 0.5'' (1λ/D)
Contrasts 1e-3 - 1e-4

**NIRISS**
2.7-5 μm

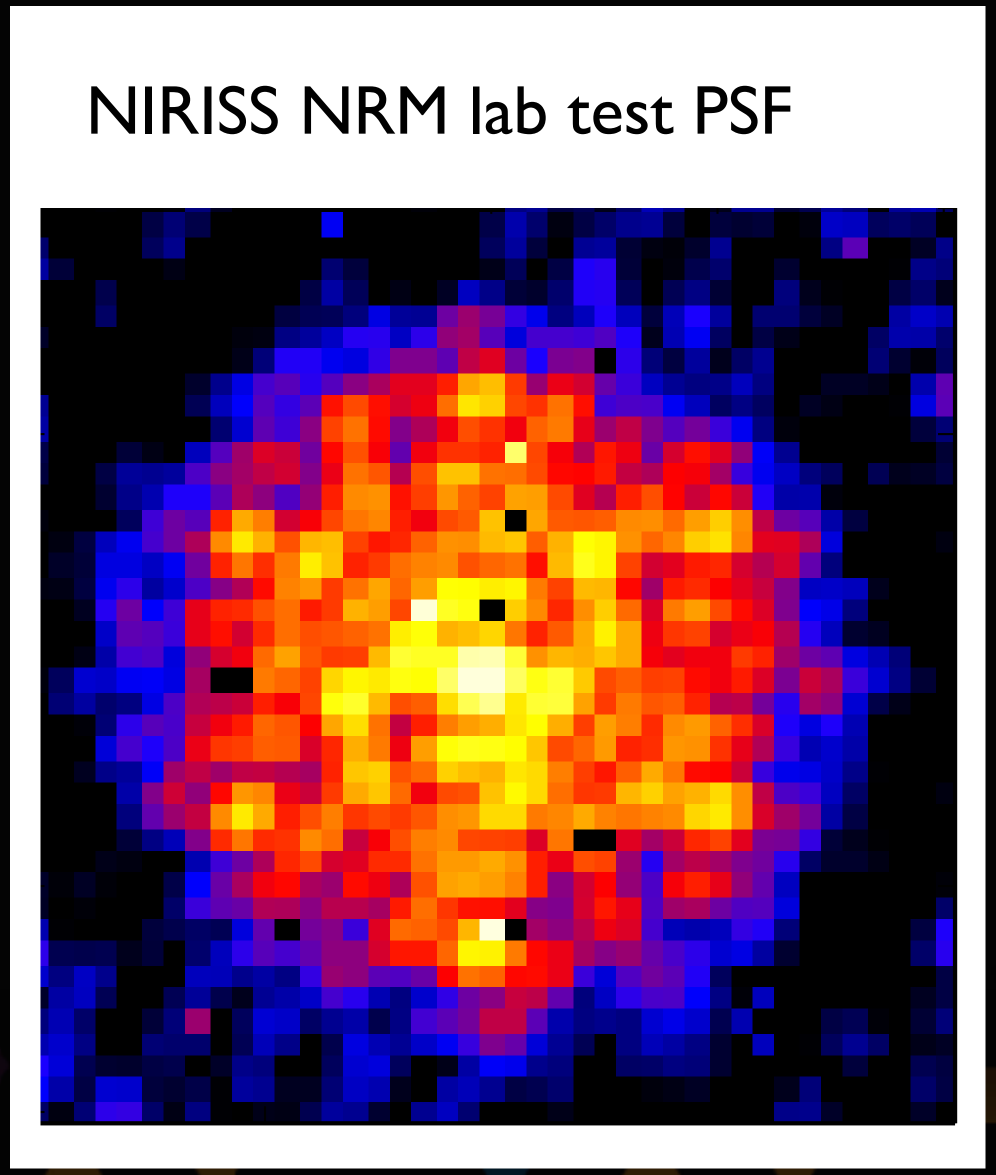
Aperture Masking Interferometry
IWA 0.04 - 0.07'' (λ/2D)
Contrasts 1e-3 - 1e-4



Simulation by John Krist

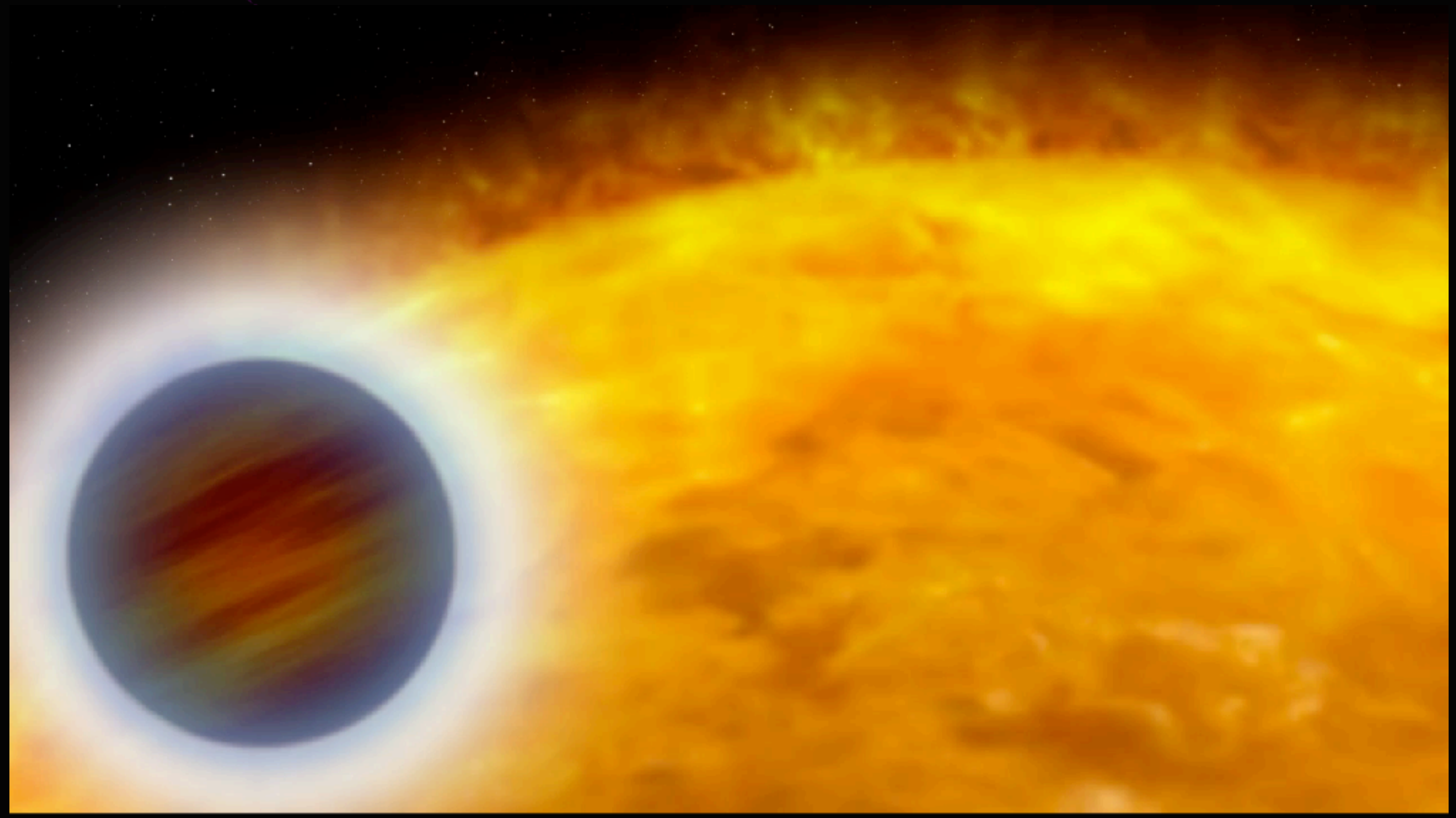


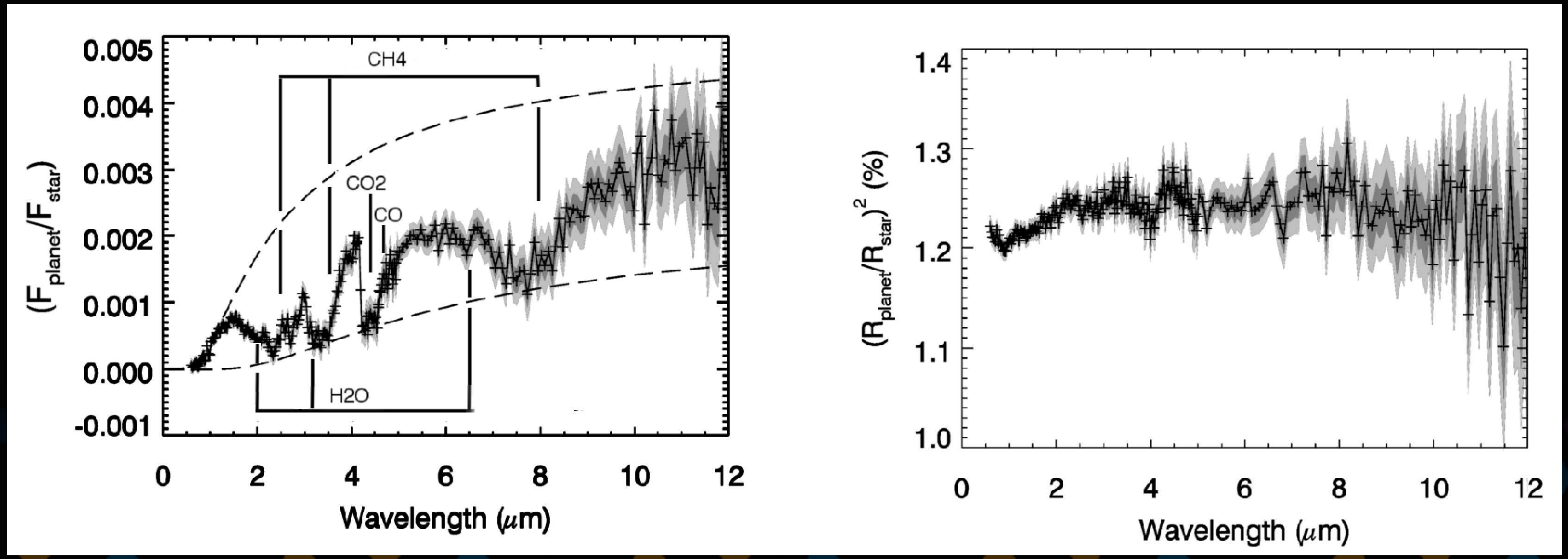
Simulation from Lajoie et al. 2014



Data courtesy of Greenbaum & Martel

# High-Precision Time-Series Spectroscopy and Imaging with *Webb*






Barstow et al. (2015)

*Time-series modes exist for all four of Webb's instruments:*

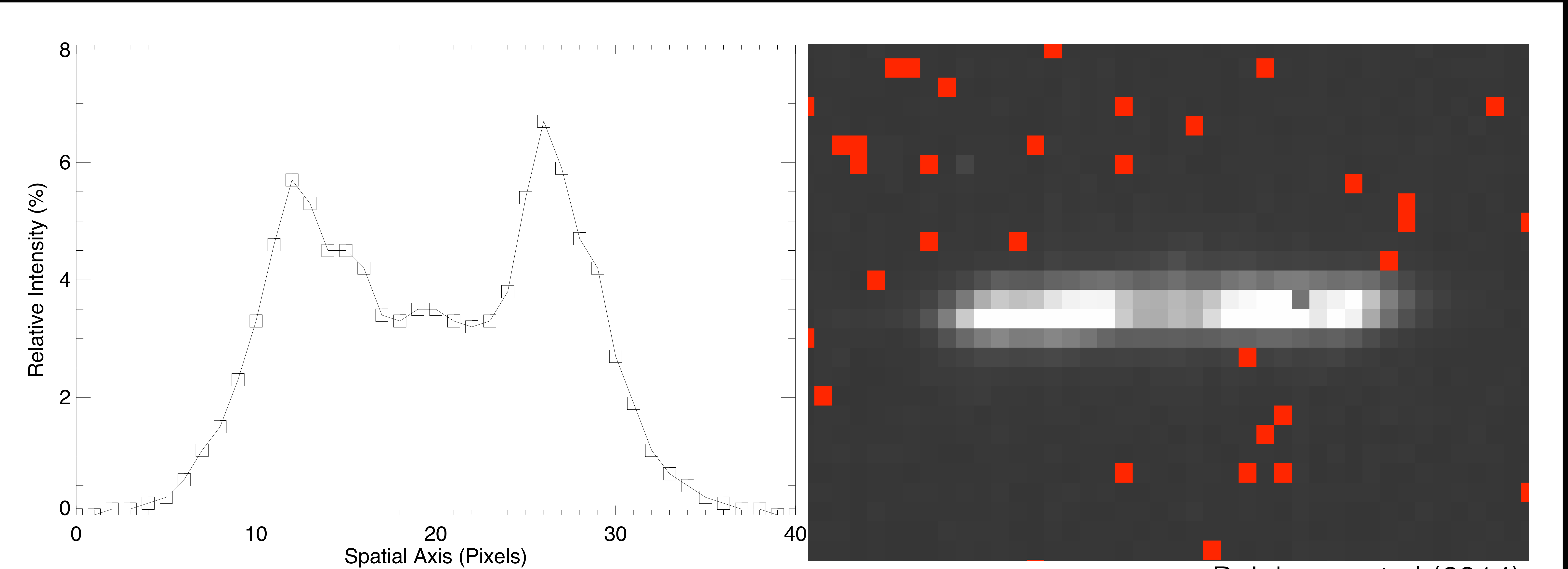
- *Dithers disabled by default*
- *Exposures can exceed 10,000 seconds*
- *Subarrays for bright targets*

*Spectroscopy available from 0.6-12 microns, enabling exploration of a broad range of molecular signatures and more!*

*Probes exoplanets at wavelengths beyond 5 microns for the first time since the end of the Spitzer Cryogenic Mission!!!!!*

# NIRISS Single-Object Slitless Spectroscopy (SOSS)
## 0.6 - 2.8 microns

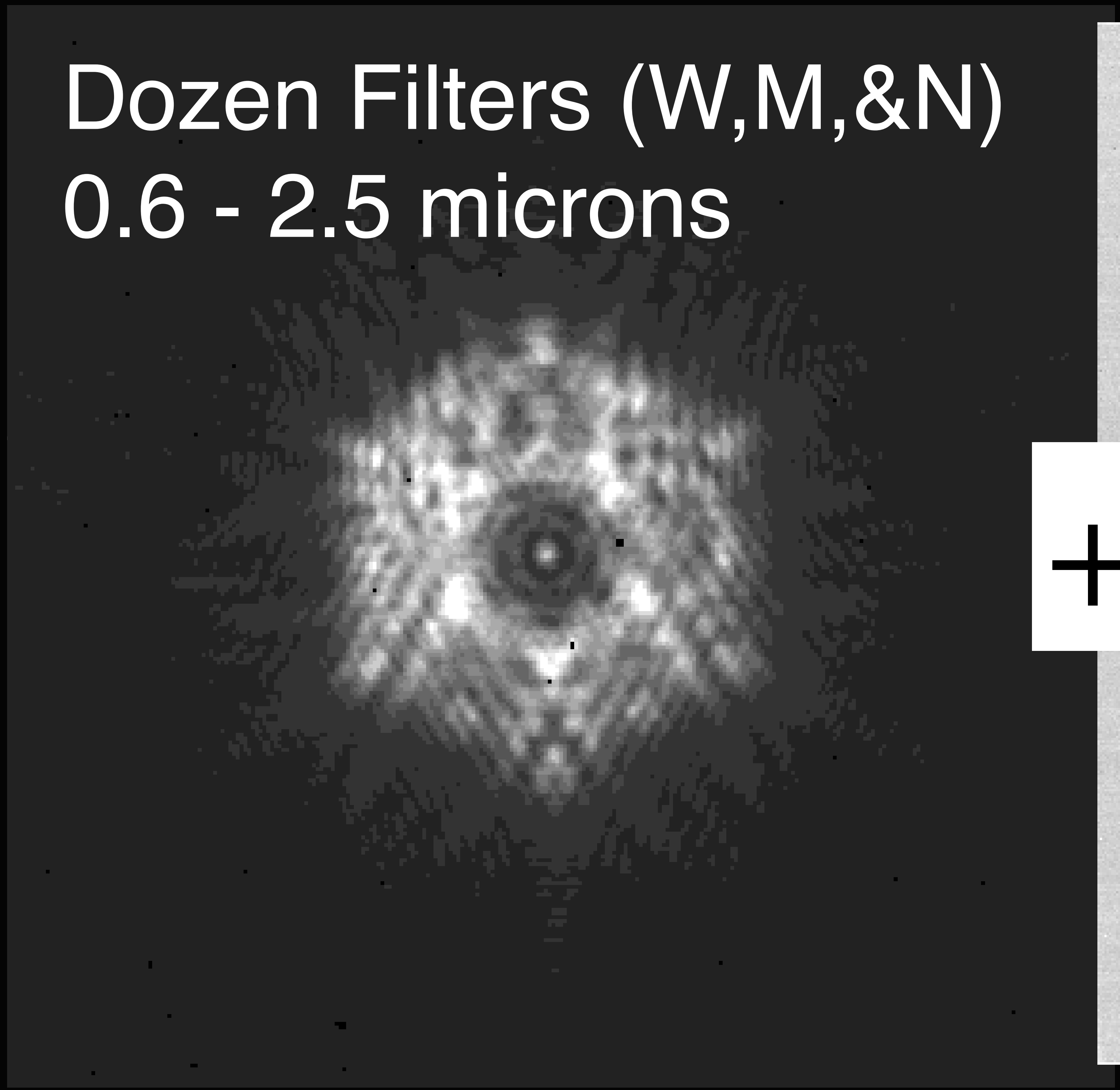
First space-based instrument mode designed specifically for high-precision time-series observations of exoplanets!



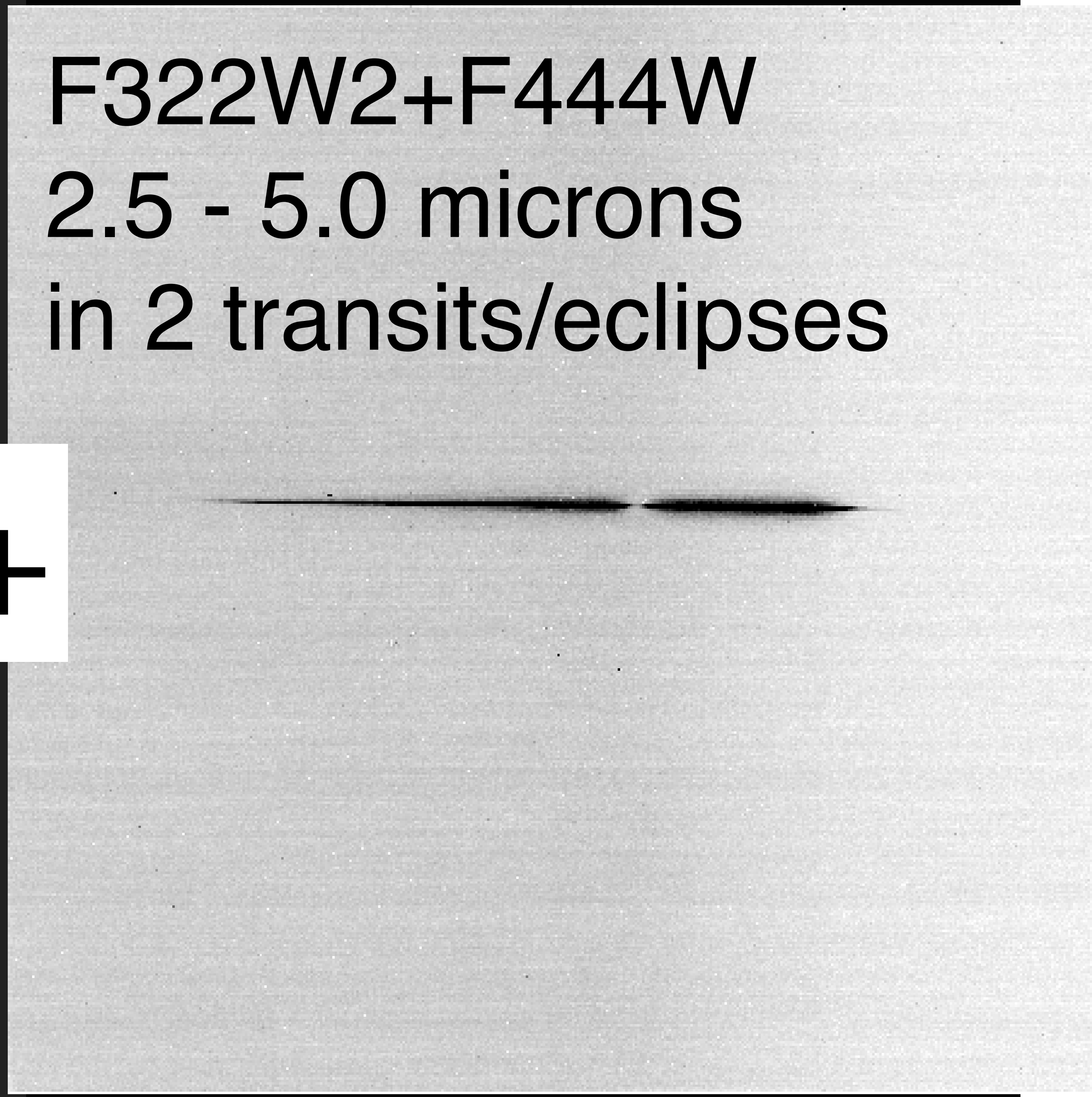
Beichman et al (2014)


Saturation Limits: J~7.2 (256 x 2048 subarray) J~6.2 (96 x 2048 subarray)

# NIRCam Photometry & Slitless Grisms
# 0.6 - 5 microns

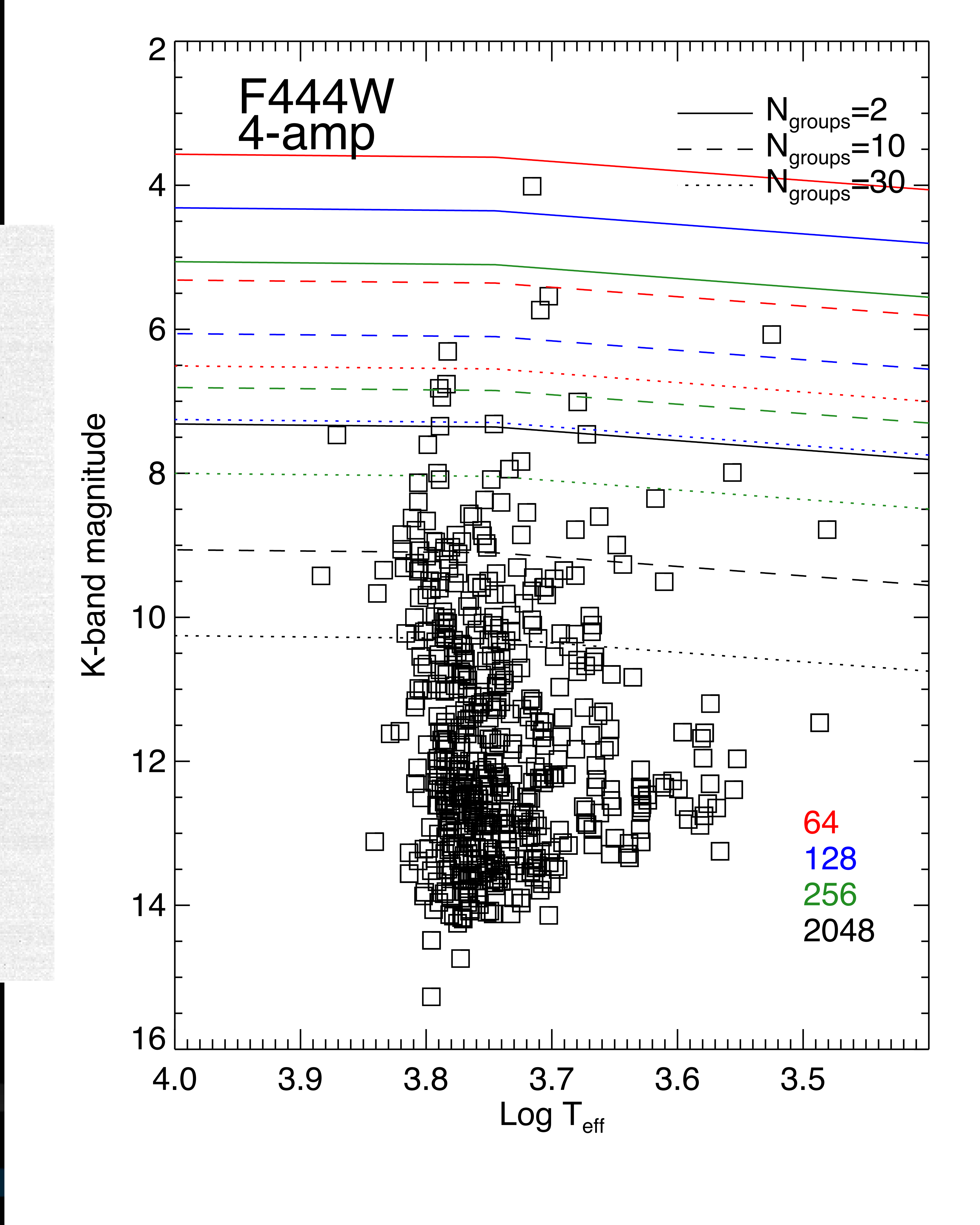



+

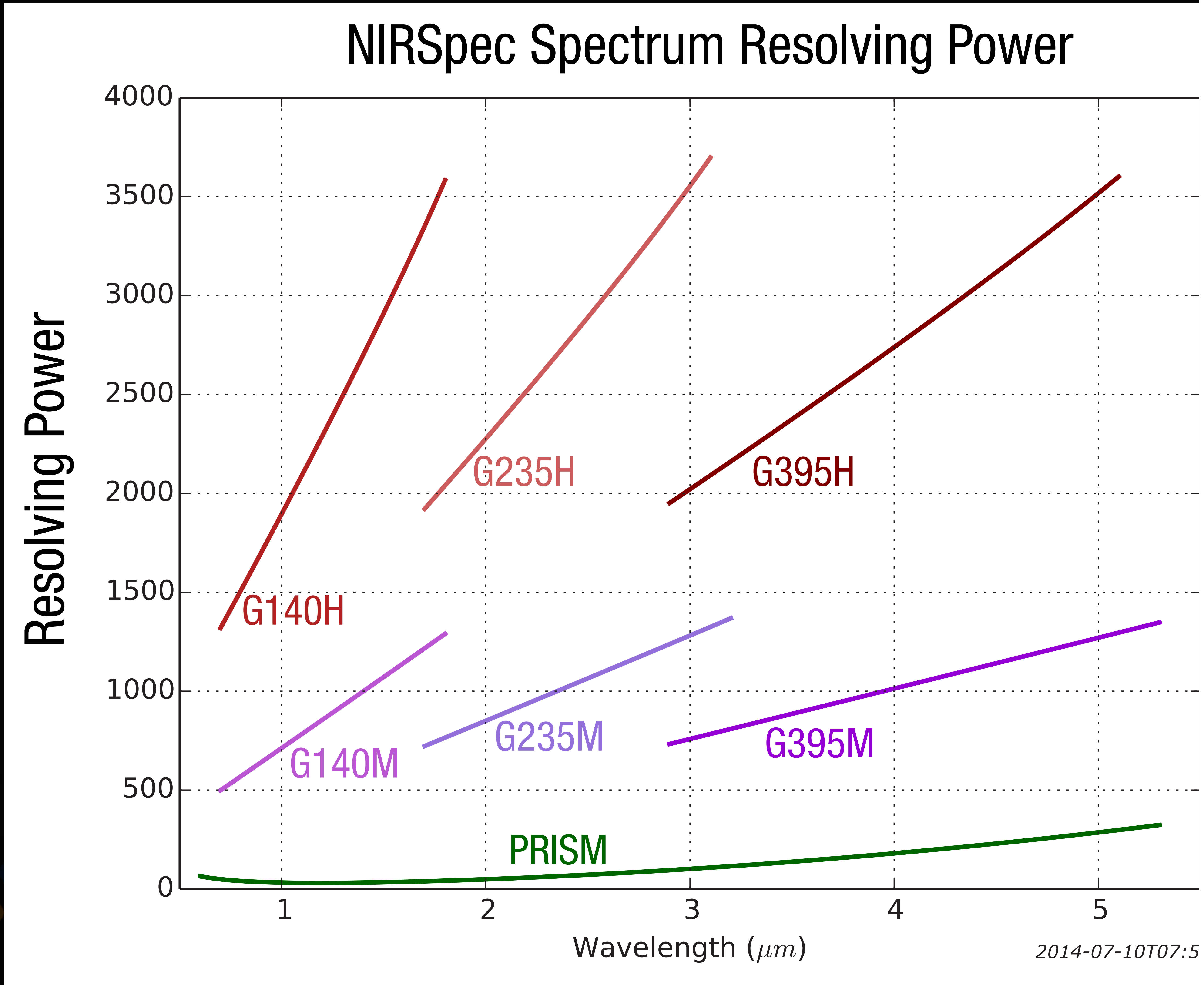


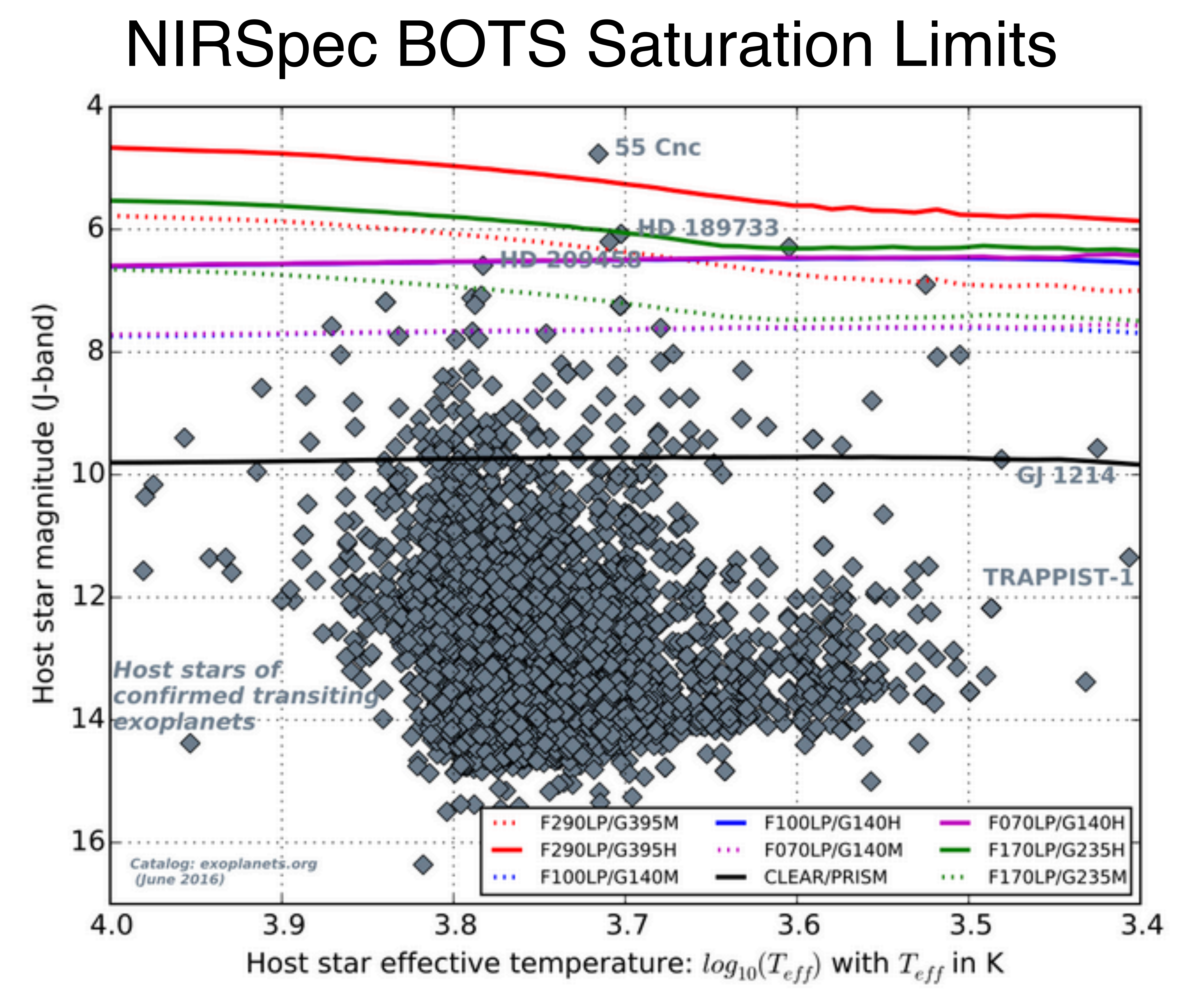

J~4 bright limit

R ~ 1400

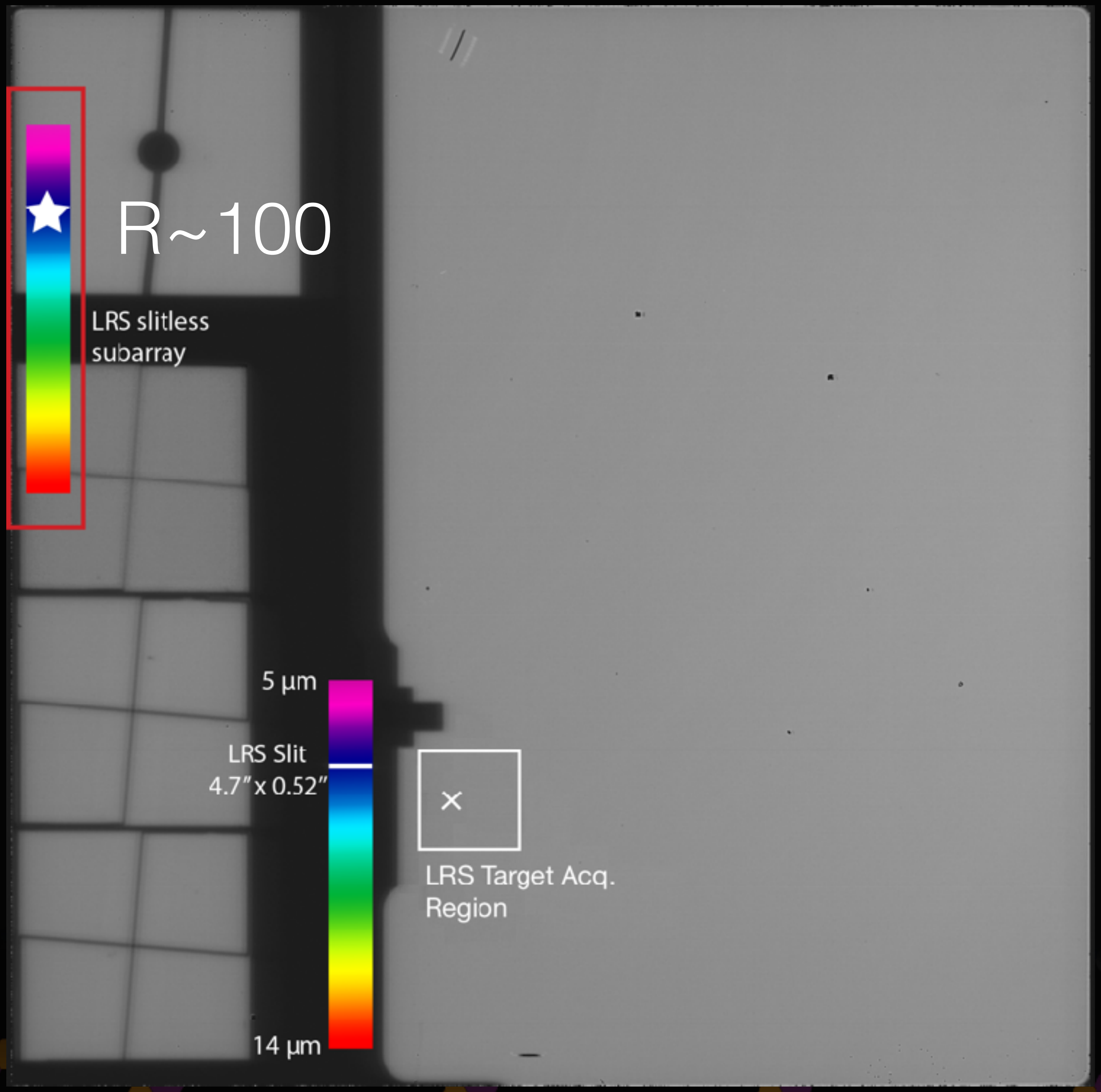


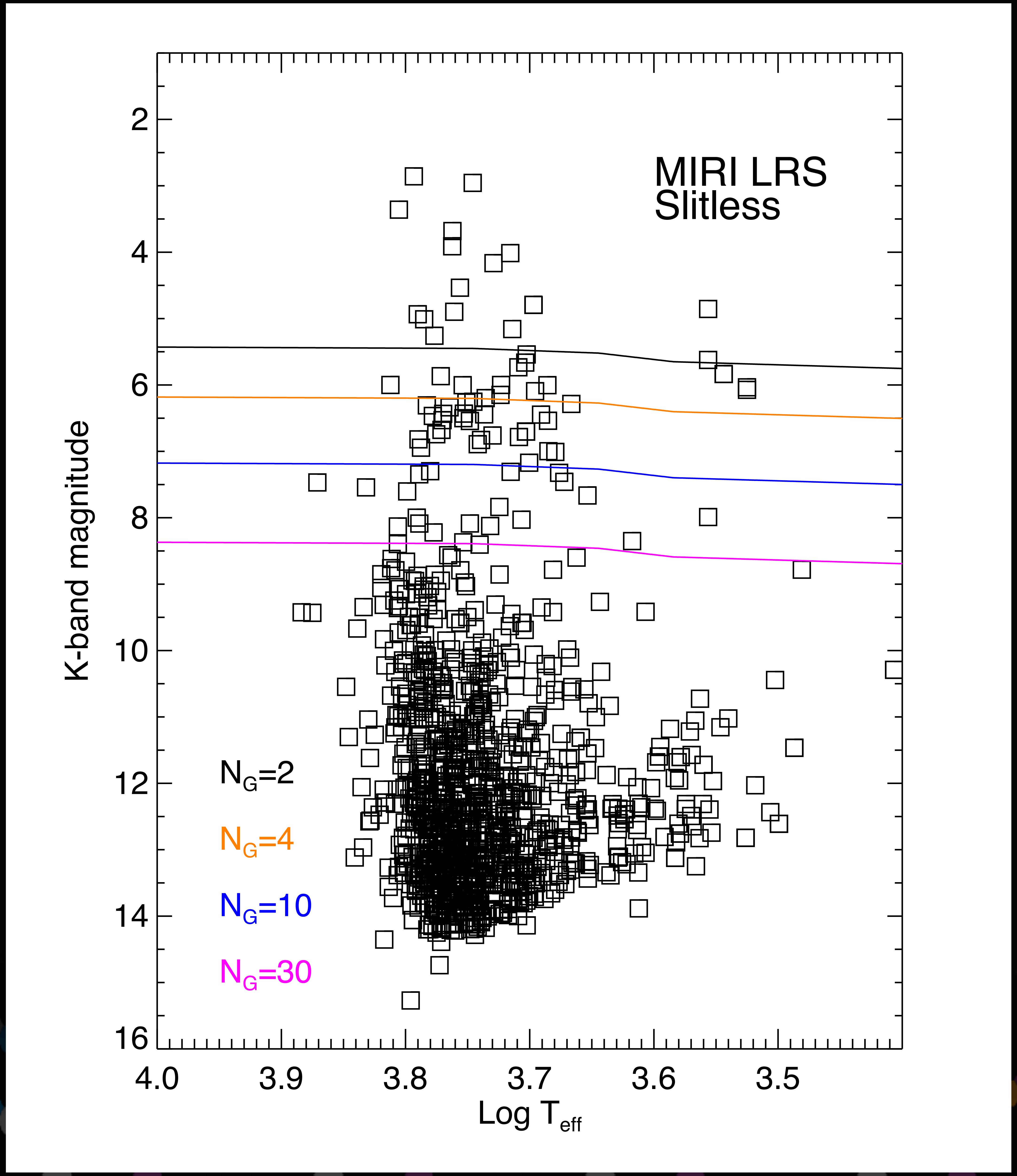
# NIRSpec Fixed “Slit” (1.6” x 1.6” aperture)
# 0.6 - 5 microns



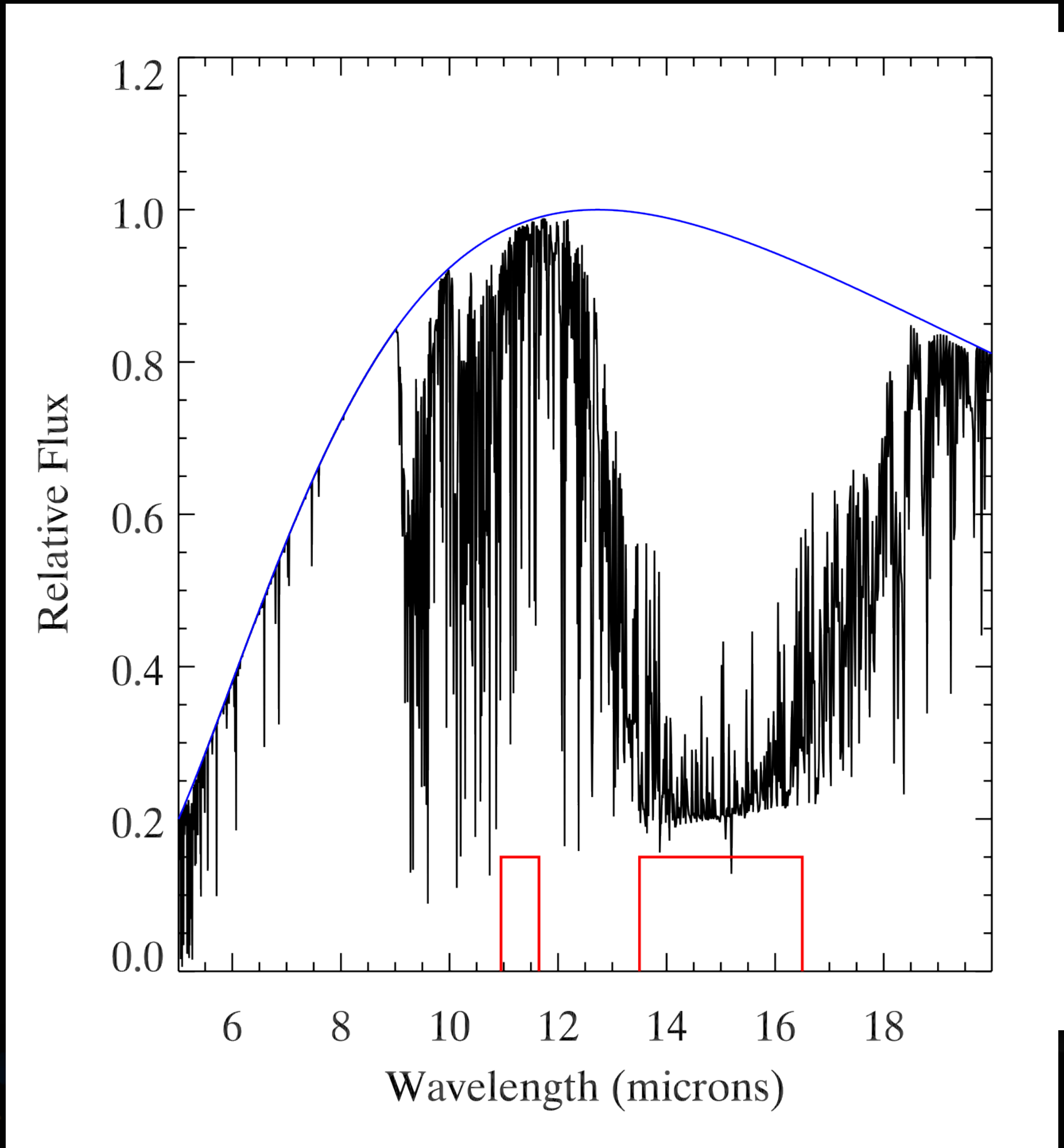



# MIRI Slitless Low-Resolution Spectroscopy (LRS)
# 5 - 12 microns



# *Webb* Photometric Modes for Time-Series Observations

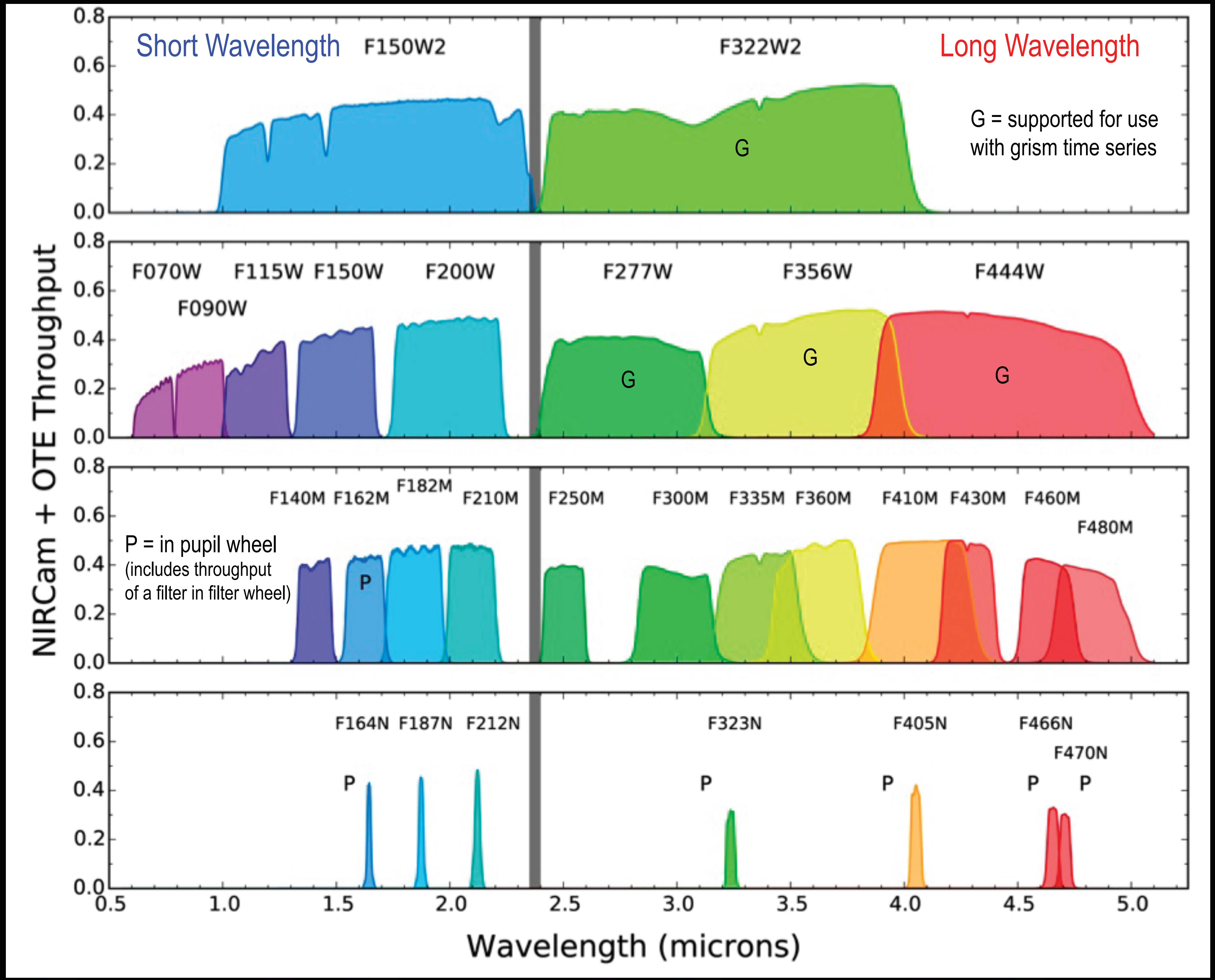



Deming et al. (2009)

Saturation Limits

| µm | Jy | M |
|---|---|---|
| 5.6 | 0.42 | 6.1 |
| 7.7 | 0.24 | 6.0 |
| 10.0 | 0.52 | 4.7 |
| 11.3 | 2.25 | 2.8 |
| 12.8 | 0.95 | 3.5 |
| 15.0 | 1.23 | 2.9 |
| 18.0 | 2.2 | 1.9 |
| 21.0 | 2.2 | 1.5 |
| 25.5 | 6.4 | 0.0 |
| Glasse+ 2015 | | G2V |

MIRI




NIRCam

# *Webb* TSO Target Acquisition Strategies


TA offset and saturation are proven strategies leveraged by *Spitzer* and *Hubble*

With FGS alone positional errors range from 0.5-1 arcsec (a few pixels)

# *Webb* High-Precision Time-Series Spectroscopic Modes

**NIRISS**
0.6-2.8 microns

**Slitless Spectroscopy**
J > 6, R~700

**NIRCam**
2.5-5 microns

**Slitless Spectroscopy**
K > 3.5, R~1450

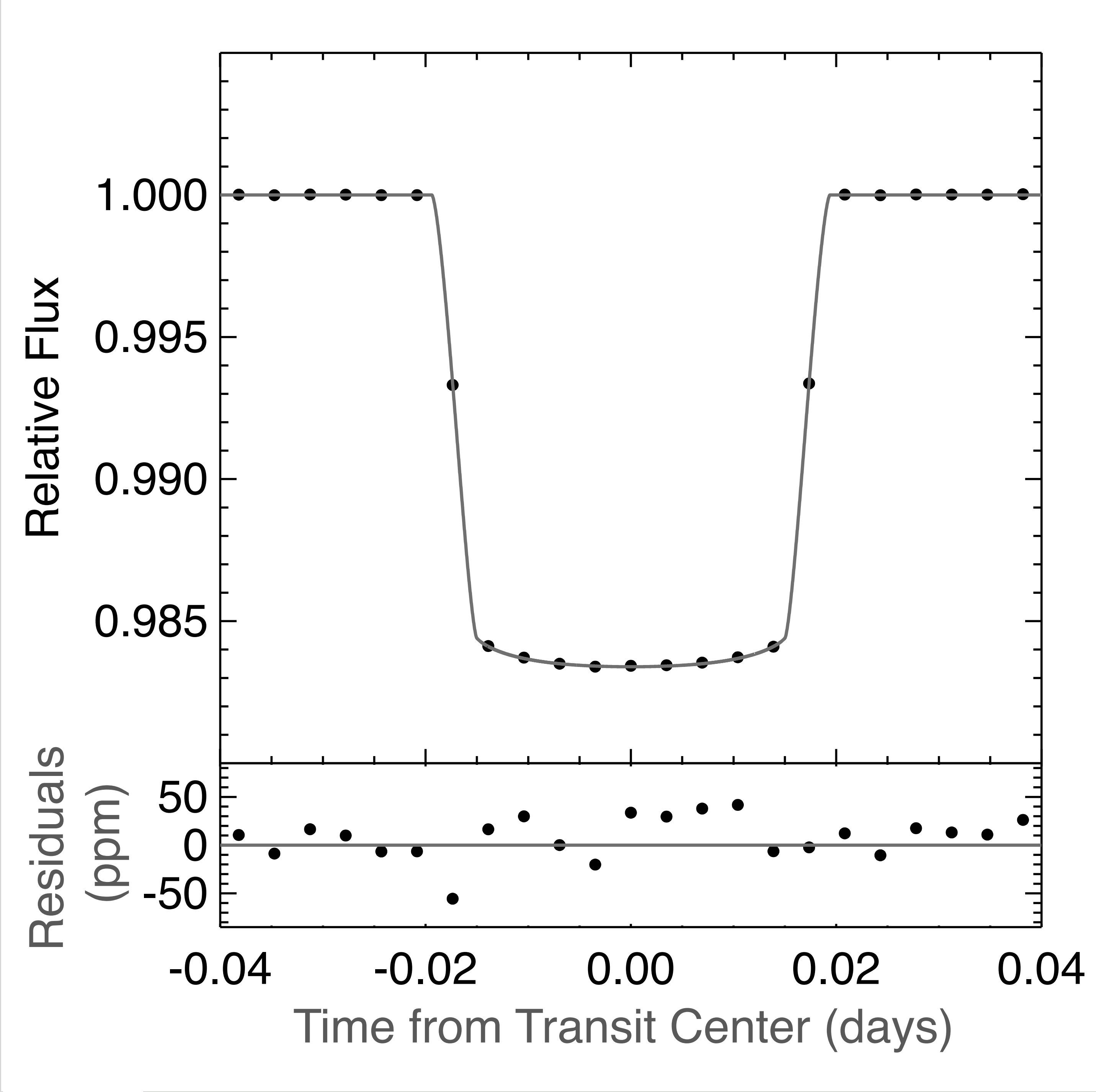
**NIRSpec**
1-5 microns

**1.6” x 1.6” large aperture**
J > 5, R~2700
J > 6, R~1000
J > 9.5, R~100

**MIRI**
5-12 microns

**Slitless Spectroscopy**
K > 5, R~100

Exoplanet Transit Time Series




Single Transit/Eclipse
Precisions ~30-100 ppm

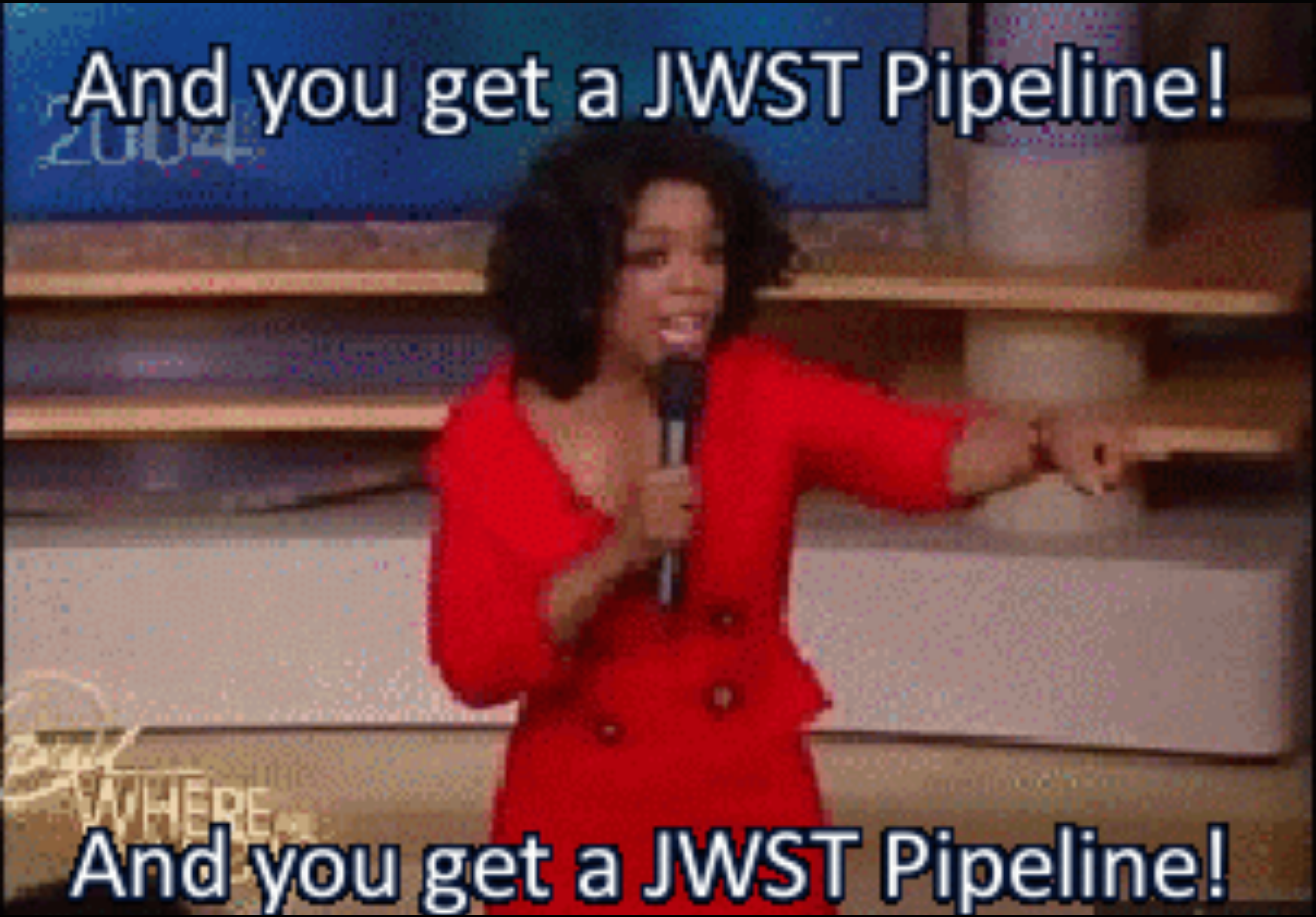
# *Webb* Pipeline & Data Products


Written in python, based on astropy

Users can replace specific modules

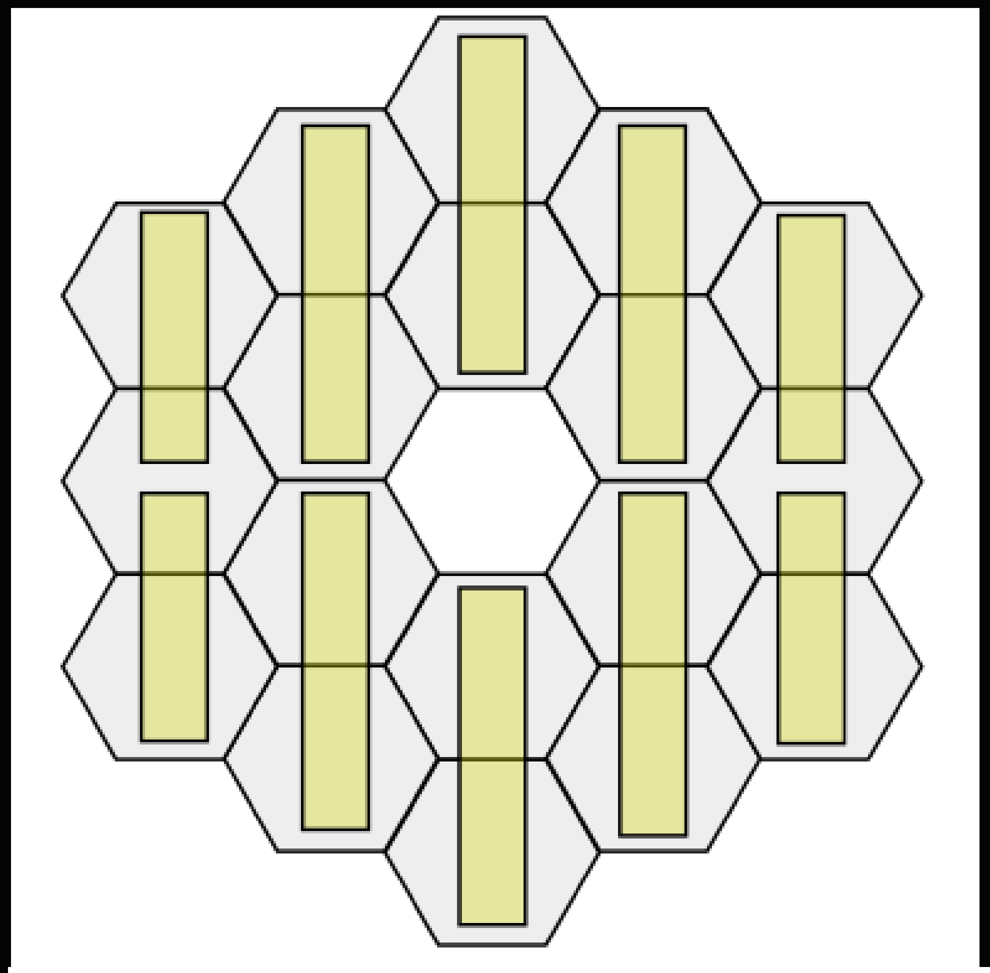
Will be freely available (github)

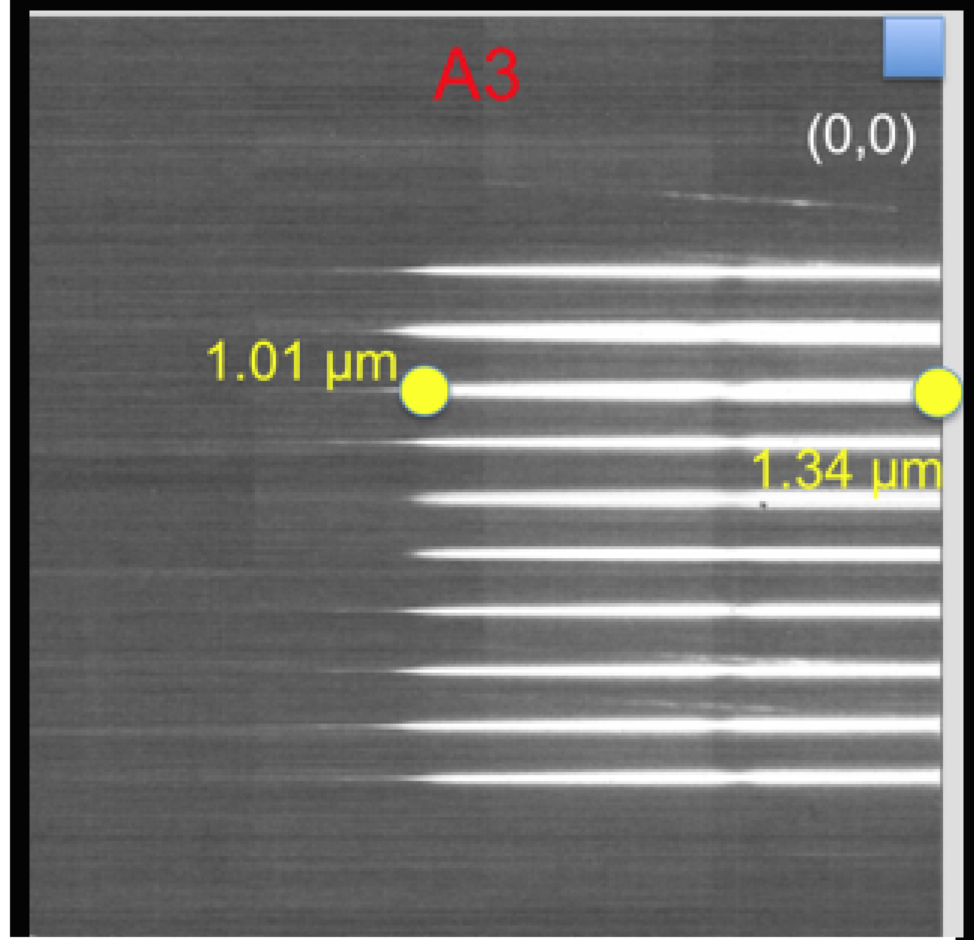
Users can rerun all or part of pipeline

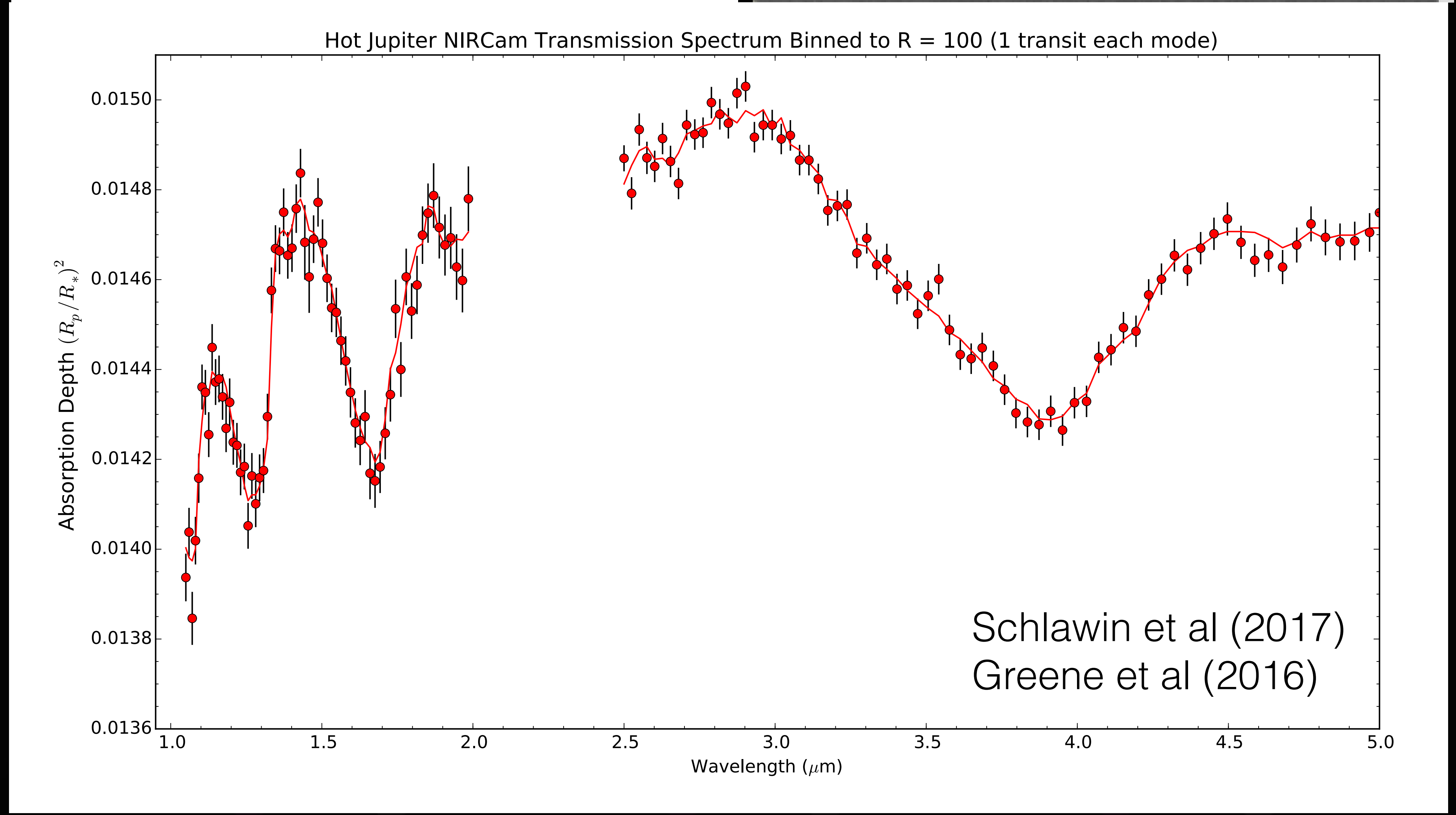

And you get a JWST Pipeline!
And you get a JWST Pipeline!

# Coming Soon to a *Webb* near you…

- NIRCam simultaneous short wavelength (SW) and long wavelength (LW) coronagraph mode
- 100% efficiency read modes (read-reset) for NIRISS and NIRSpec
- NIRCam Dispersed Hartmann Sensor (DHS) SW+ LW Grism Spectroscopy
- NIRISS SOSS+F277W calibration option
- Target Acquisition (TA) enhancements for NIRCam, MIRI, and NIRSpec





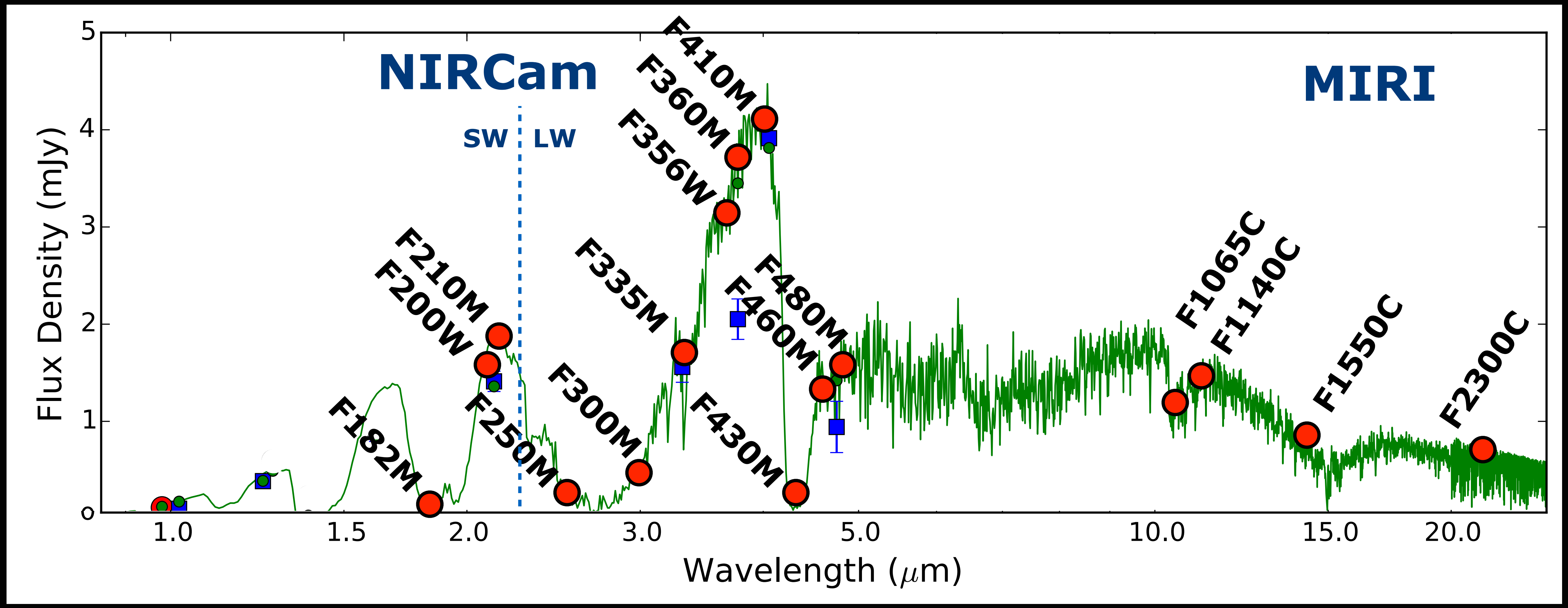

All require onboard-script recertification and other ground system work. Prioritization set with input from JSTUC in February 2018.

# Now that you've met JWST's exoplanet modes and features…

Let's talk science!!!!

# *Webb* will probe self-luminous exoplanets, brown dwarfs and disks to provide critical insights into planet formation and evolution

## Exoplanet and brown dwarf atmospheres




Teff = 1000 K, log(g) = 3.5 model from Barman et al.

## Debris disk dust composition and ices

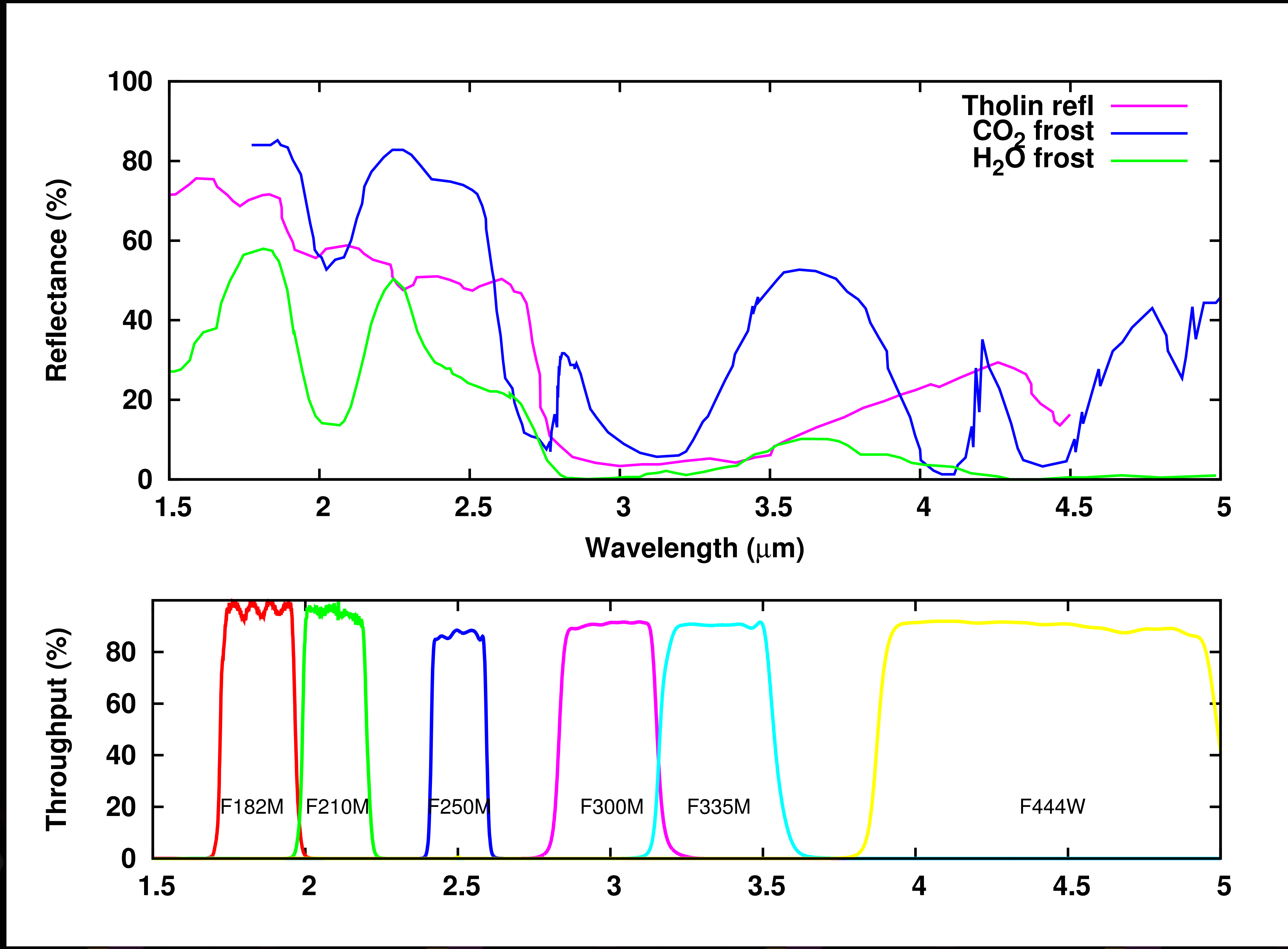
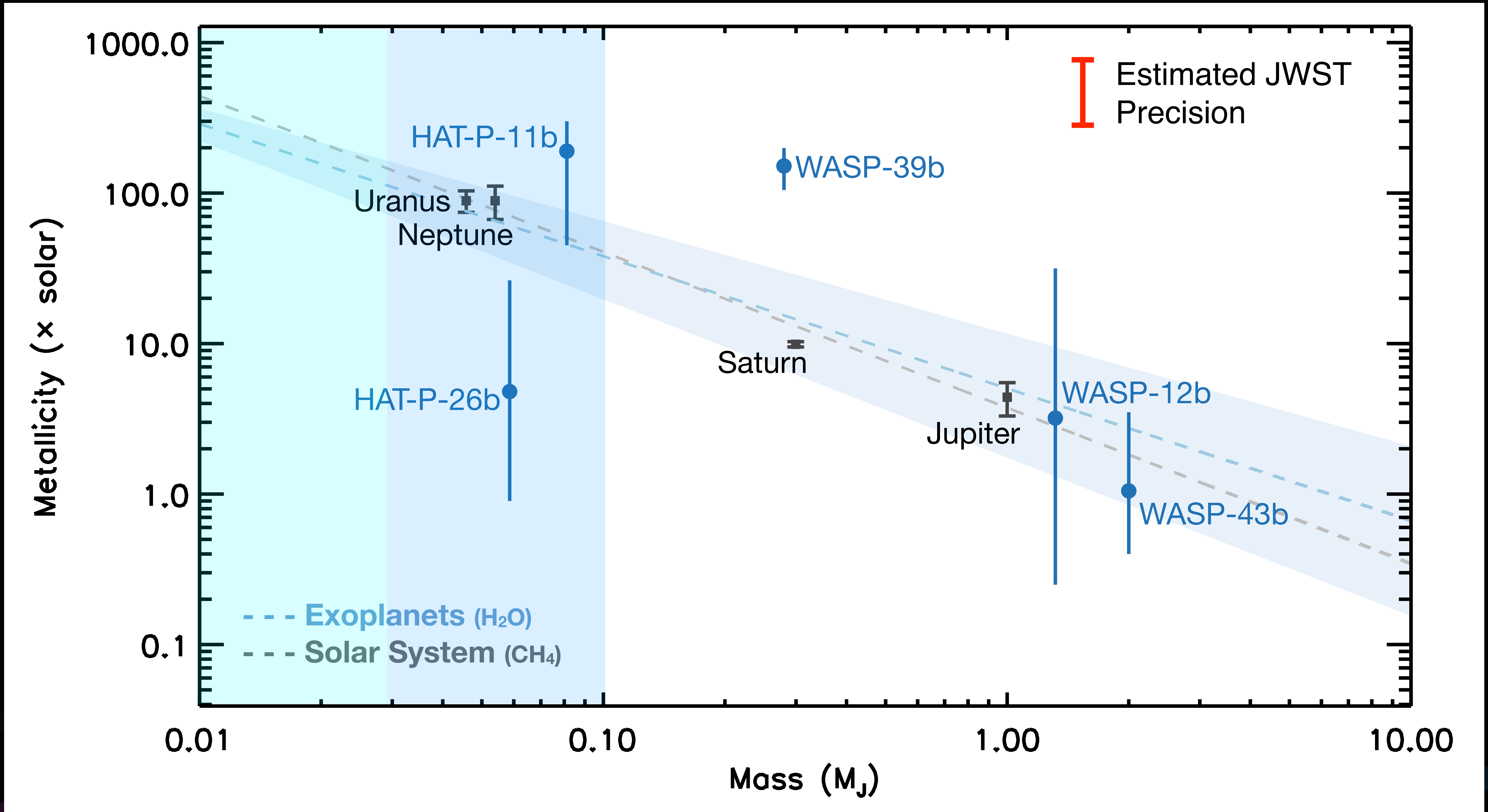
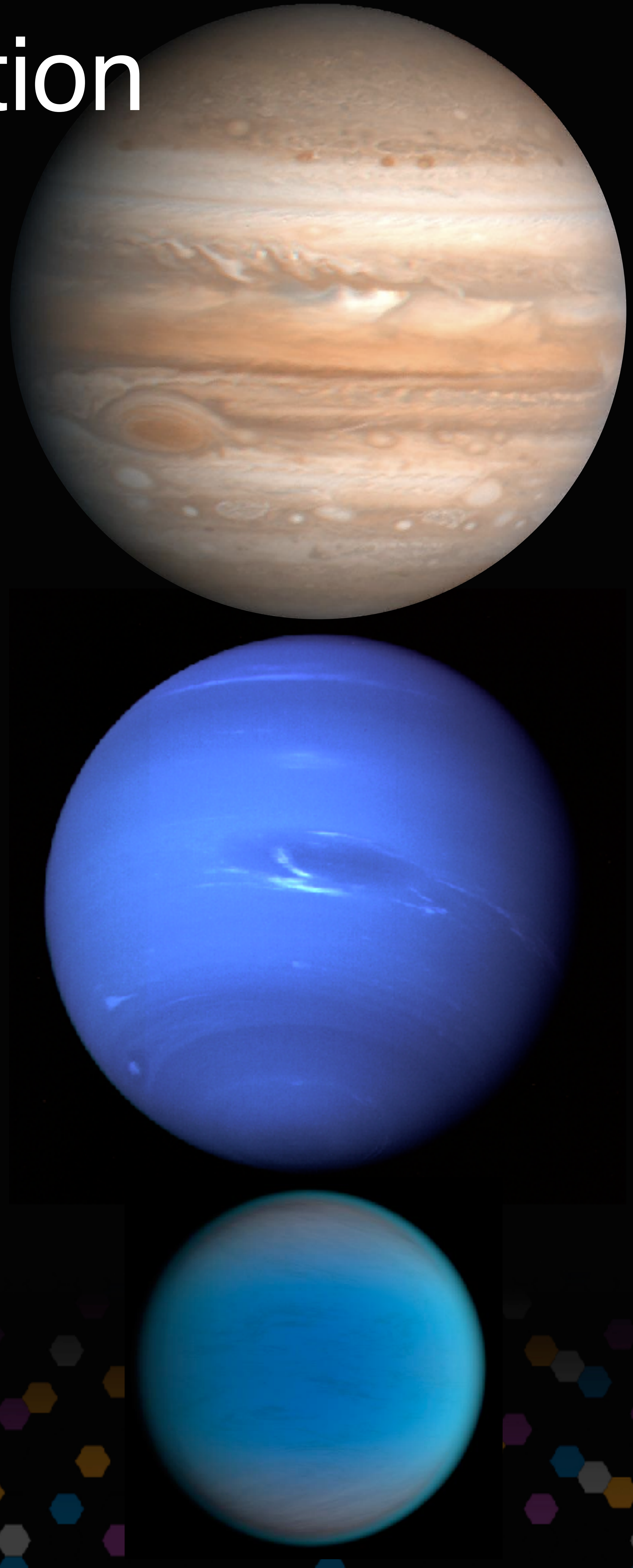



Figure courtesy Andras Gaspar et al. (NIRCam GTO)

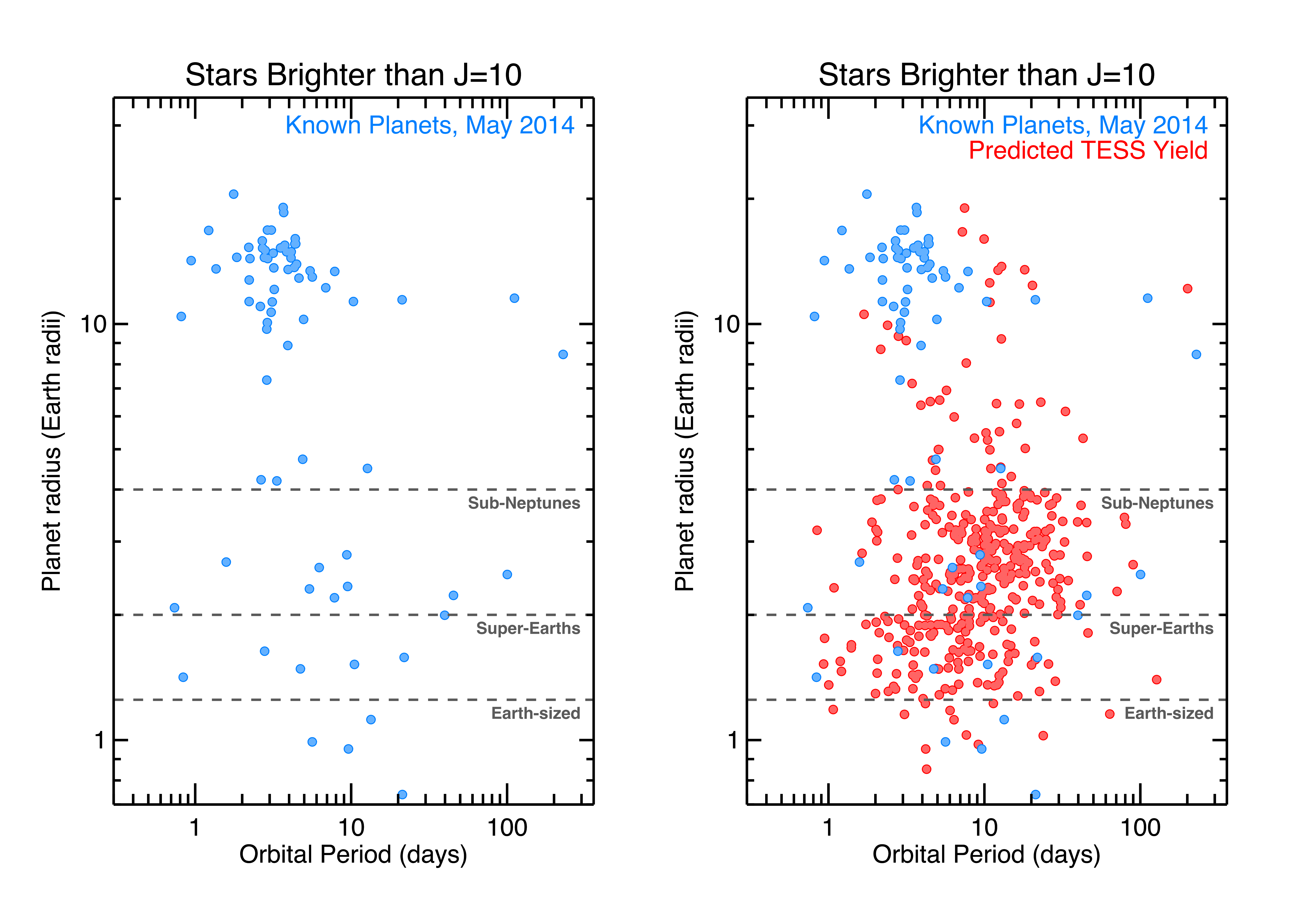
# *Webb* will provide compositional information for a large sample of giant exoplanets



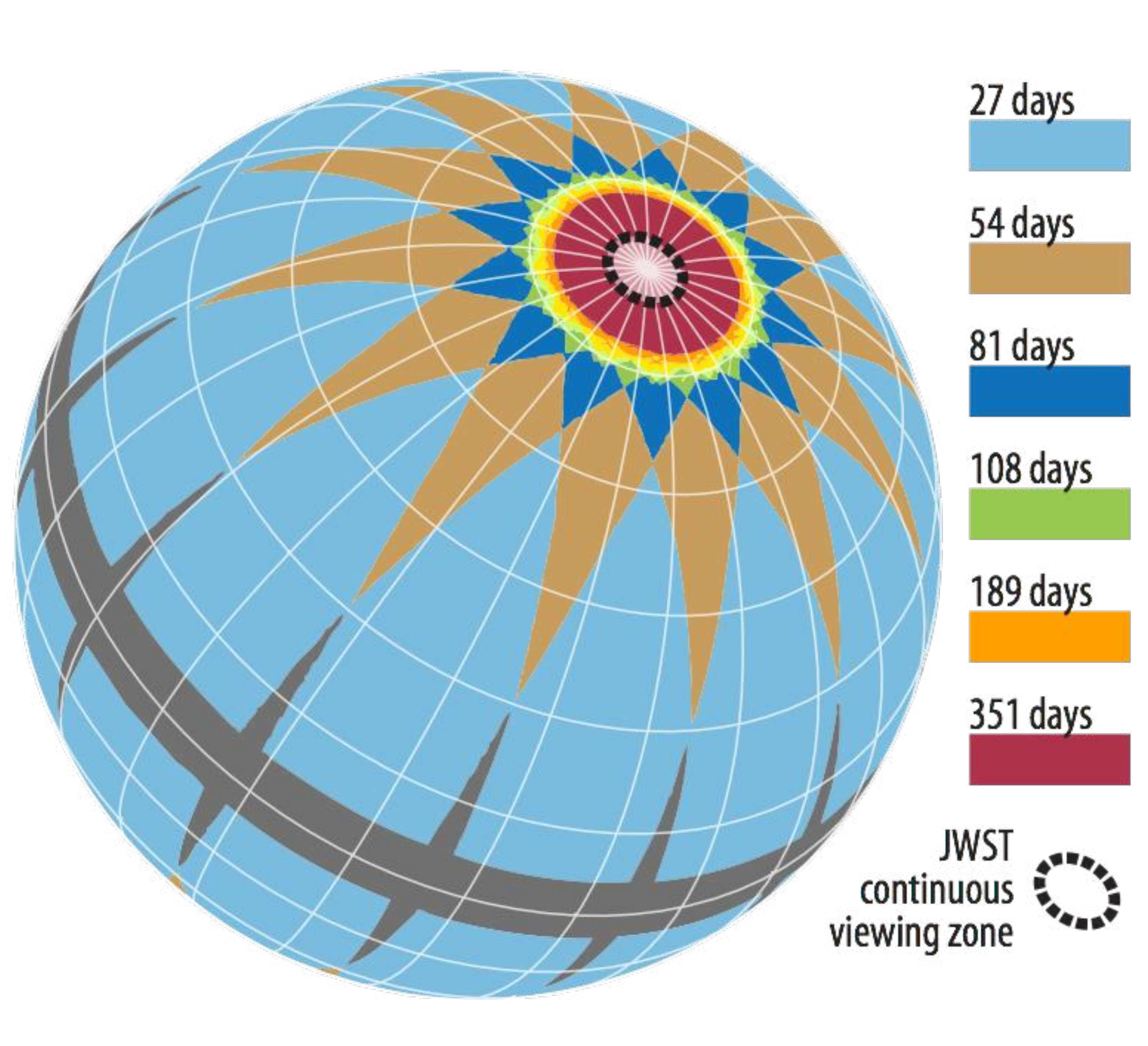



Wakeford et al. (2018)
Greene et al. (2016)

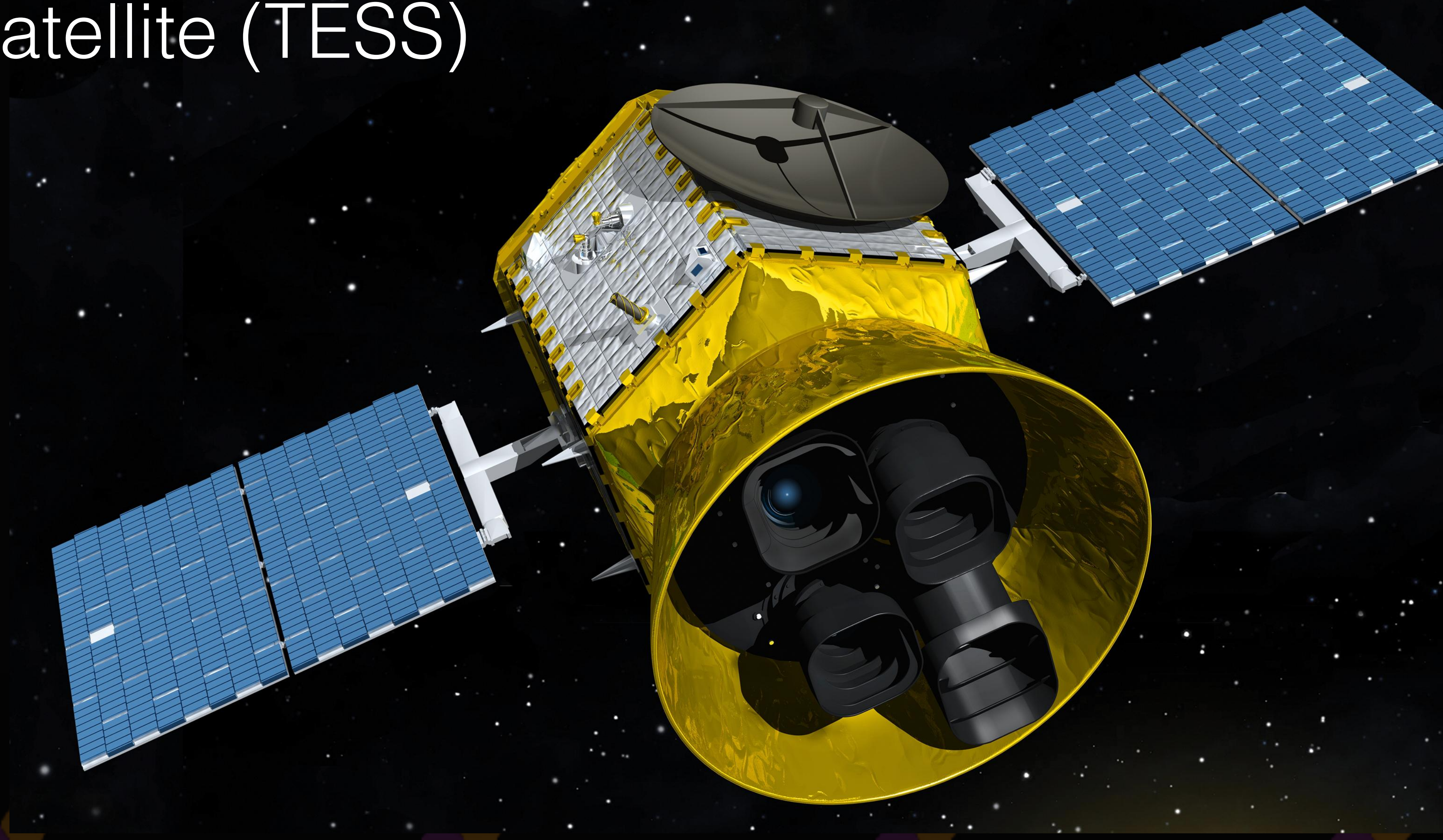
# *Webb* will help to determine the nature of Super-Earths and Mini-Neptunes




Ricker et al. (2014)

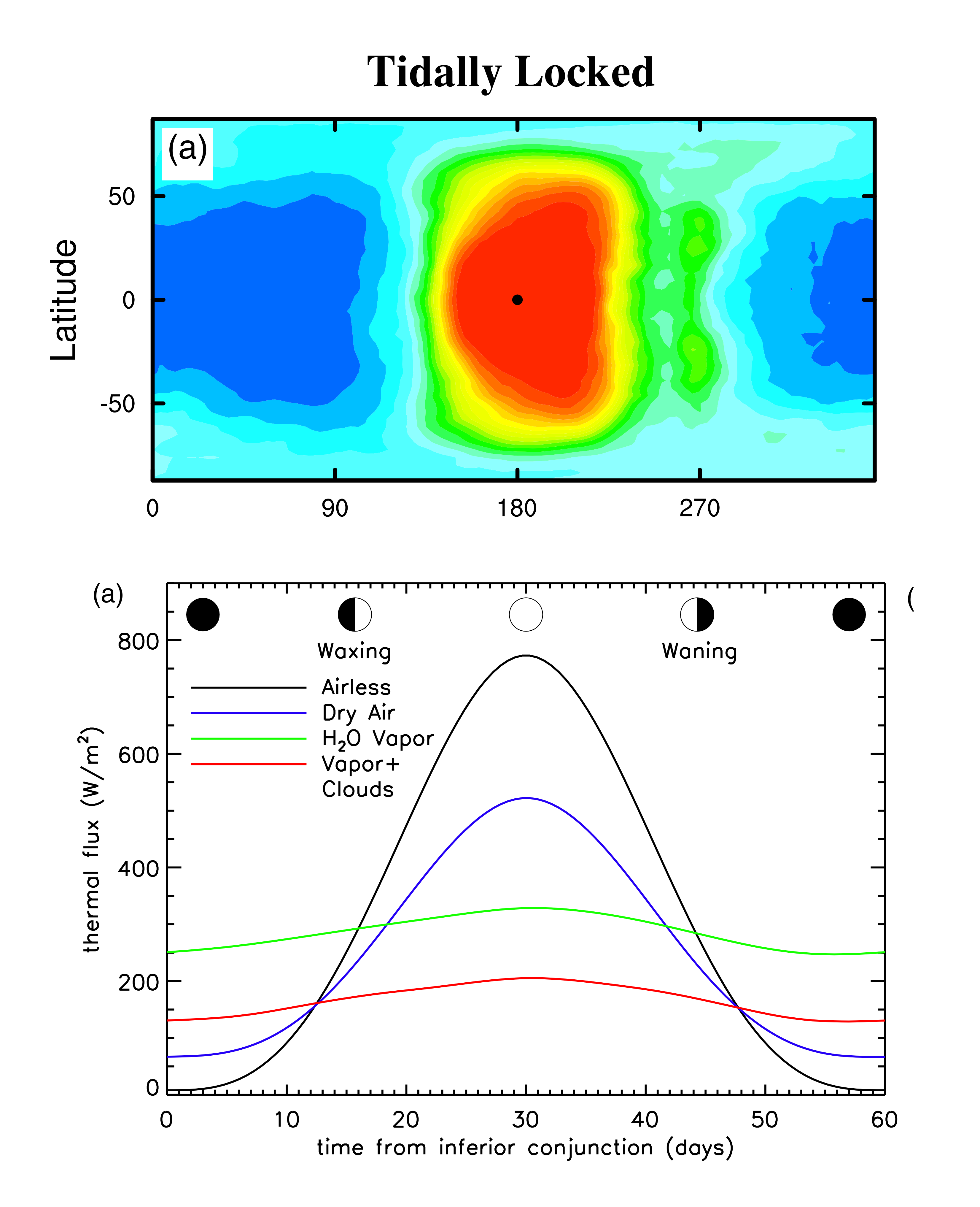



Transiting Exoplanet Survey Satellite (TESS)

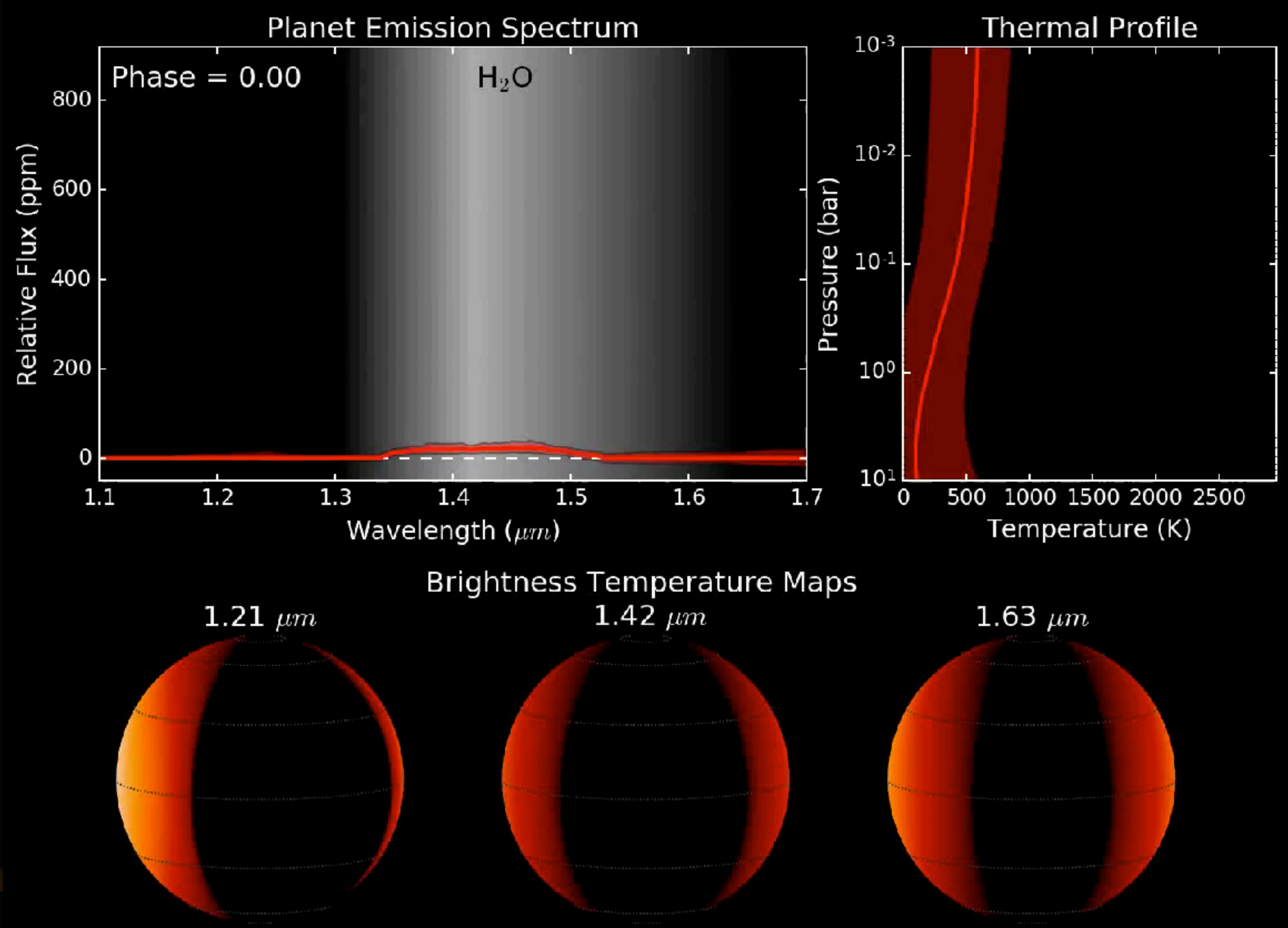


Launch in 2018

# *Webb* will allow us to probe the climates of distant worlds

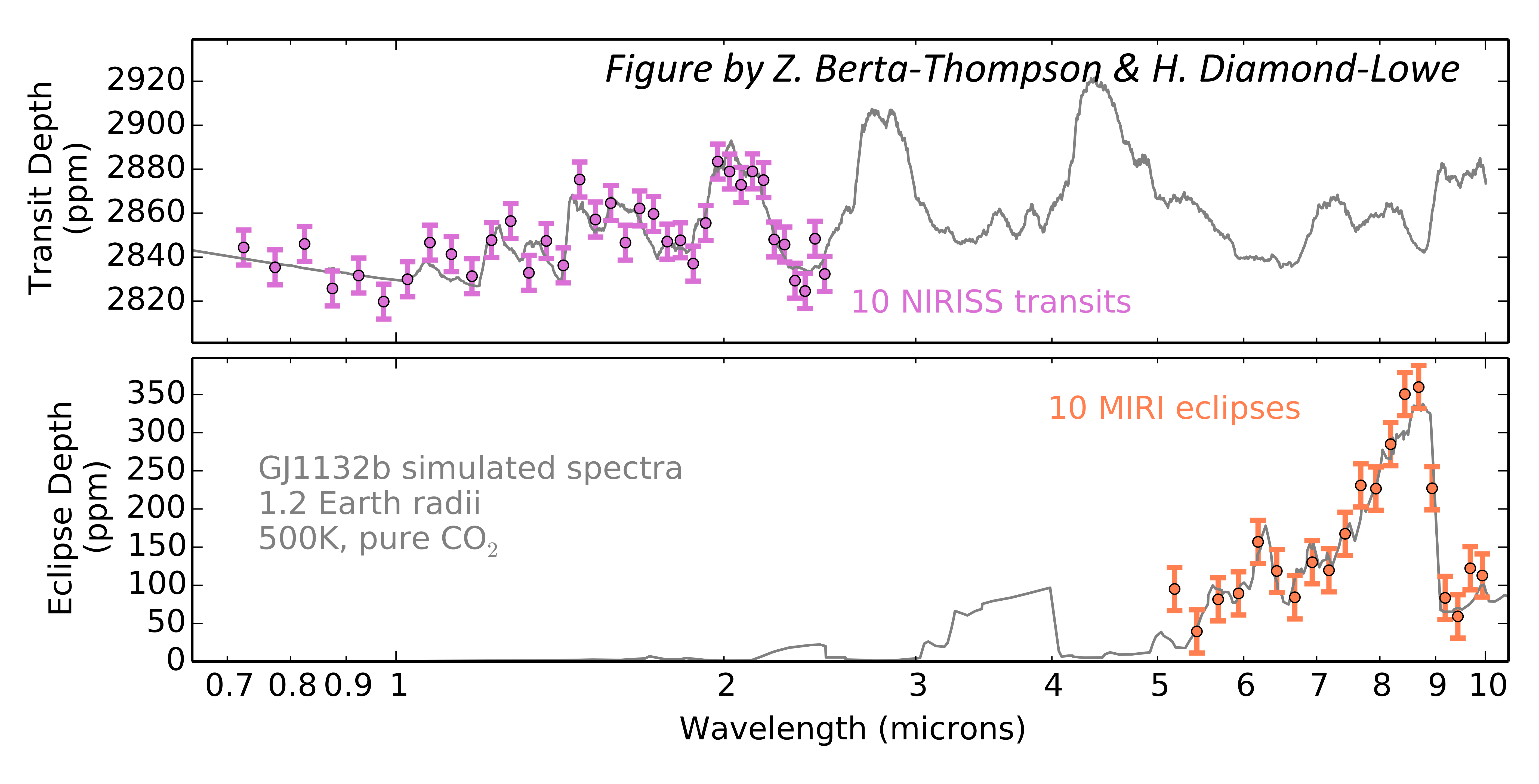



Yang et al. (2016)

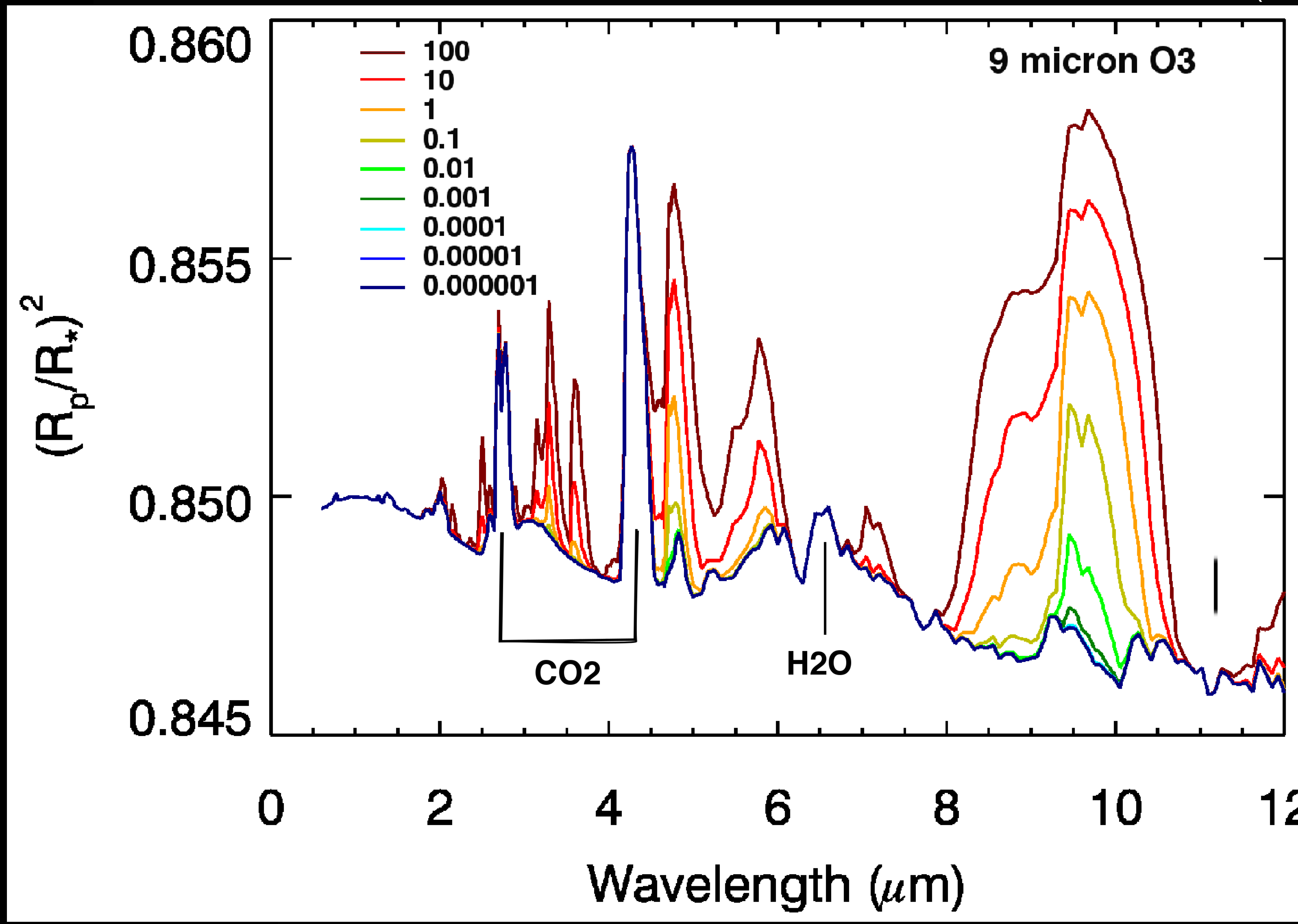


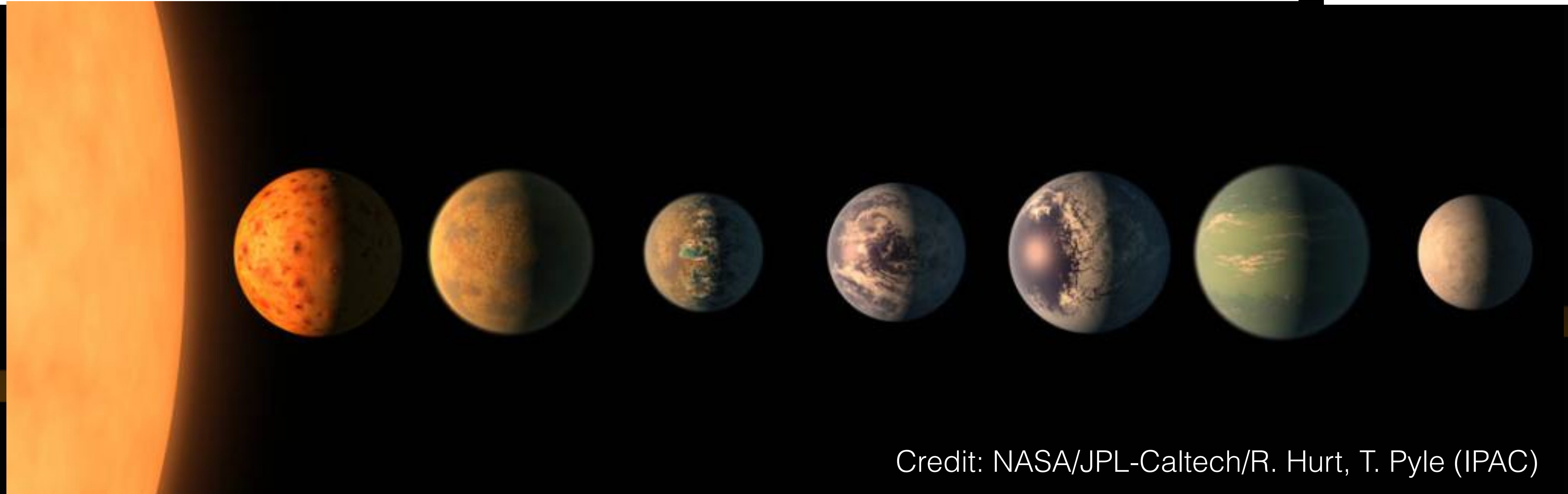

K. B. Stevenson (2014)

# *Webb* will give us important insights into rocky planet atmospheres beyond our Solar System




Barstow et al. (2016)



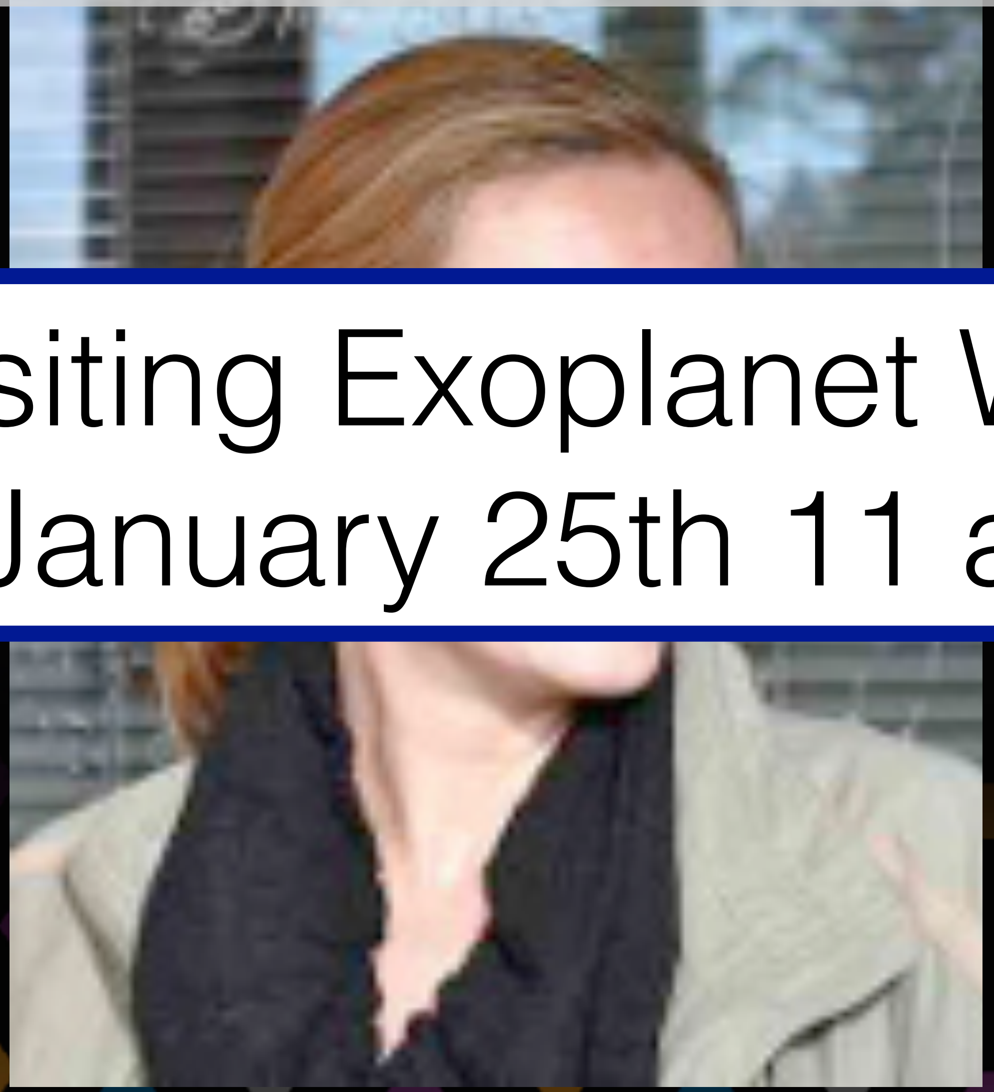



The Seven Earth-Sized Planets of TRAPPIST-1

Credit: NASA/JPL-Caltech/R. Hurt, T. Pyle (IPAC)

# *Webb* Exoplanet Team @ STScI

Nikole Lewis & Jeff Valenti
JWST Project & Mission Scientists



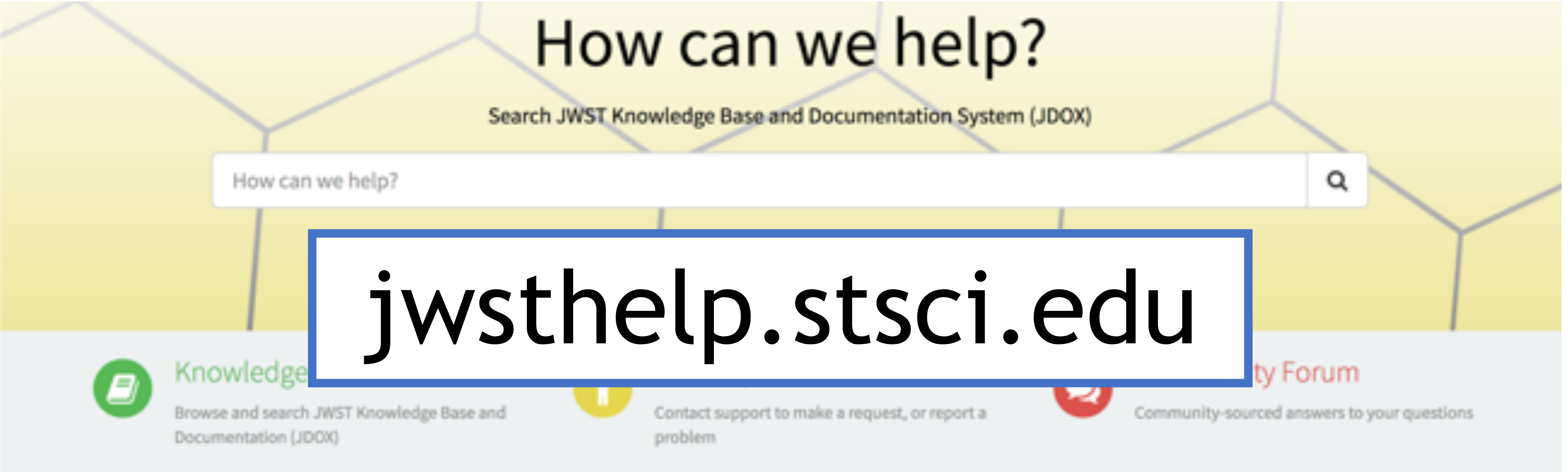
Kevin Stevenson & Sarah Kendrew
JWST Transiting Exoplanet
Working Group Lead & Deputy

Laurent Pueyo & Julien Girard
JWST Coronagraphy
Working Group Lead & Deputy

JWST Transiting Exoplanet WG Telecon
Thursday January 25th 11 am - 12 pm

And Many More…

# *Webb* Cycle 1 Science Timeline




jwsthelp.stsci.edu

commissioning (6 mo)

Cy 1 Science Observations Begin

Supplemental GO Call

*2017* *2018* *2019* *2020*

Director's Discretionary Early Release Science (DD ERS)

General Observers (GO)

Guaranteed Time Observers

Approximate given three month launch window

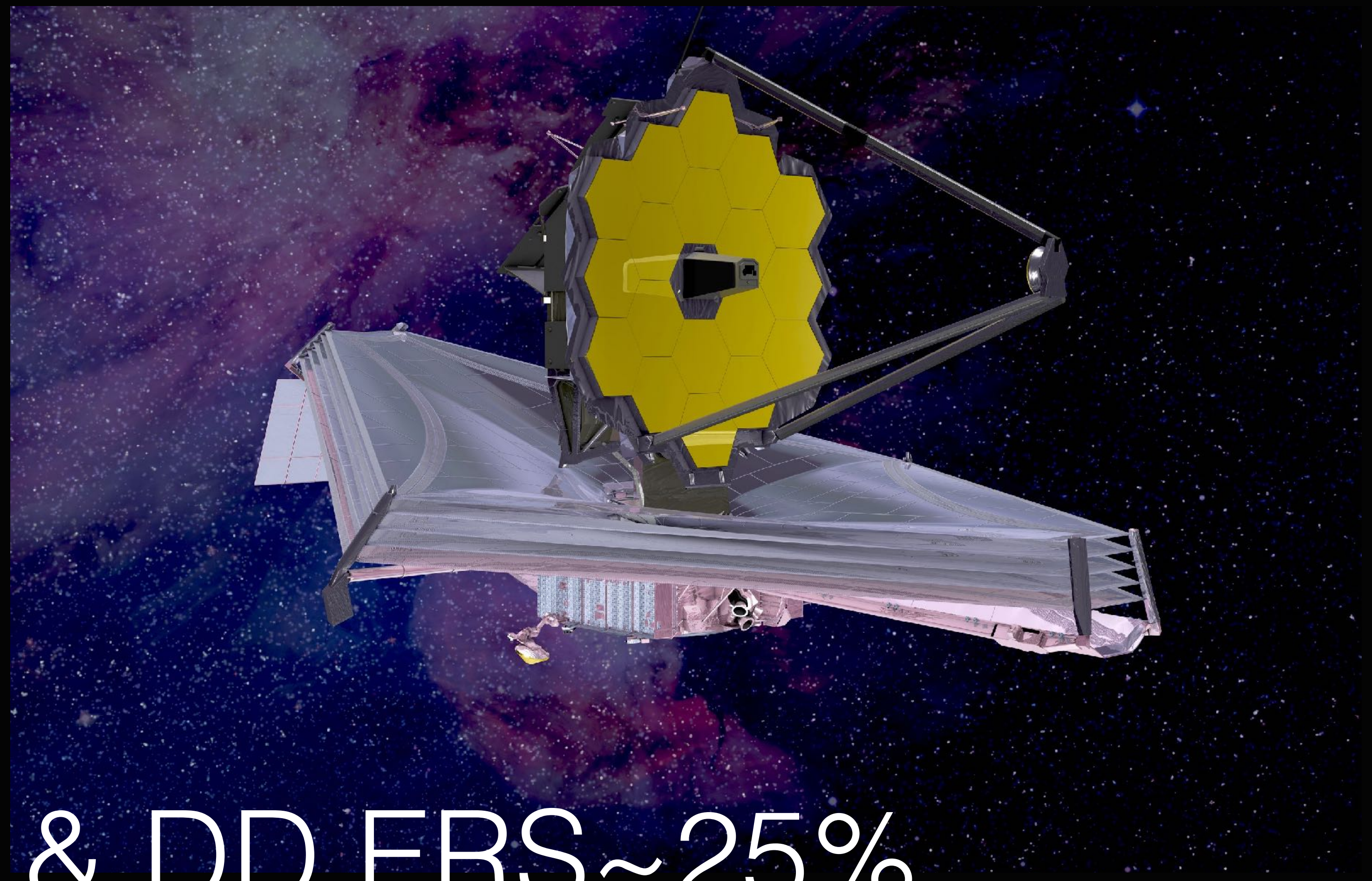
JWST Cycle 1 GO Deadline
April 6th, 2018 8pm ET

# The Future of Exoplanets with Space-Based General Purpose Observatories is Bright!

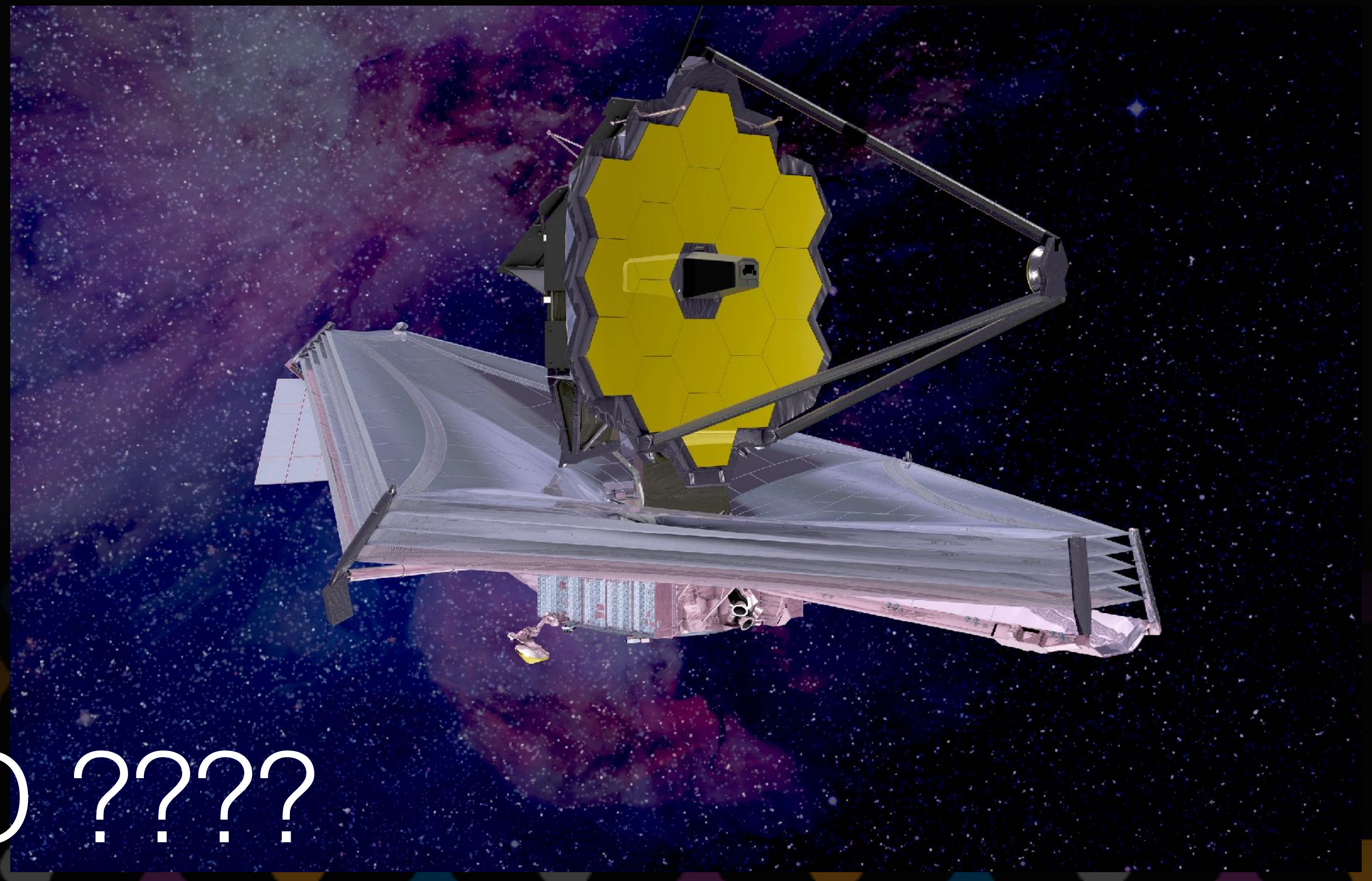
20% - 40%

10% - 20%


JWST Cycle 1 GO Deadline
April 6th, 2018 8pm ET



GTO & DD ERS~25%



GO ????