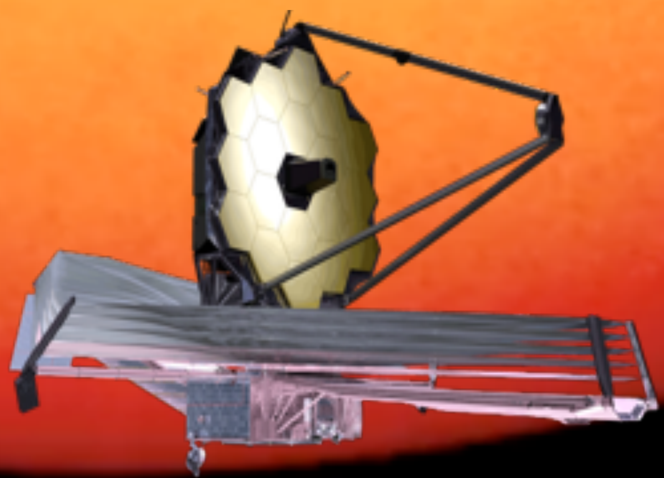
The James Webb Space Telescope:

Capabilities for Transiting Exoplanet Observations



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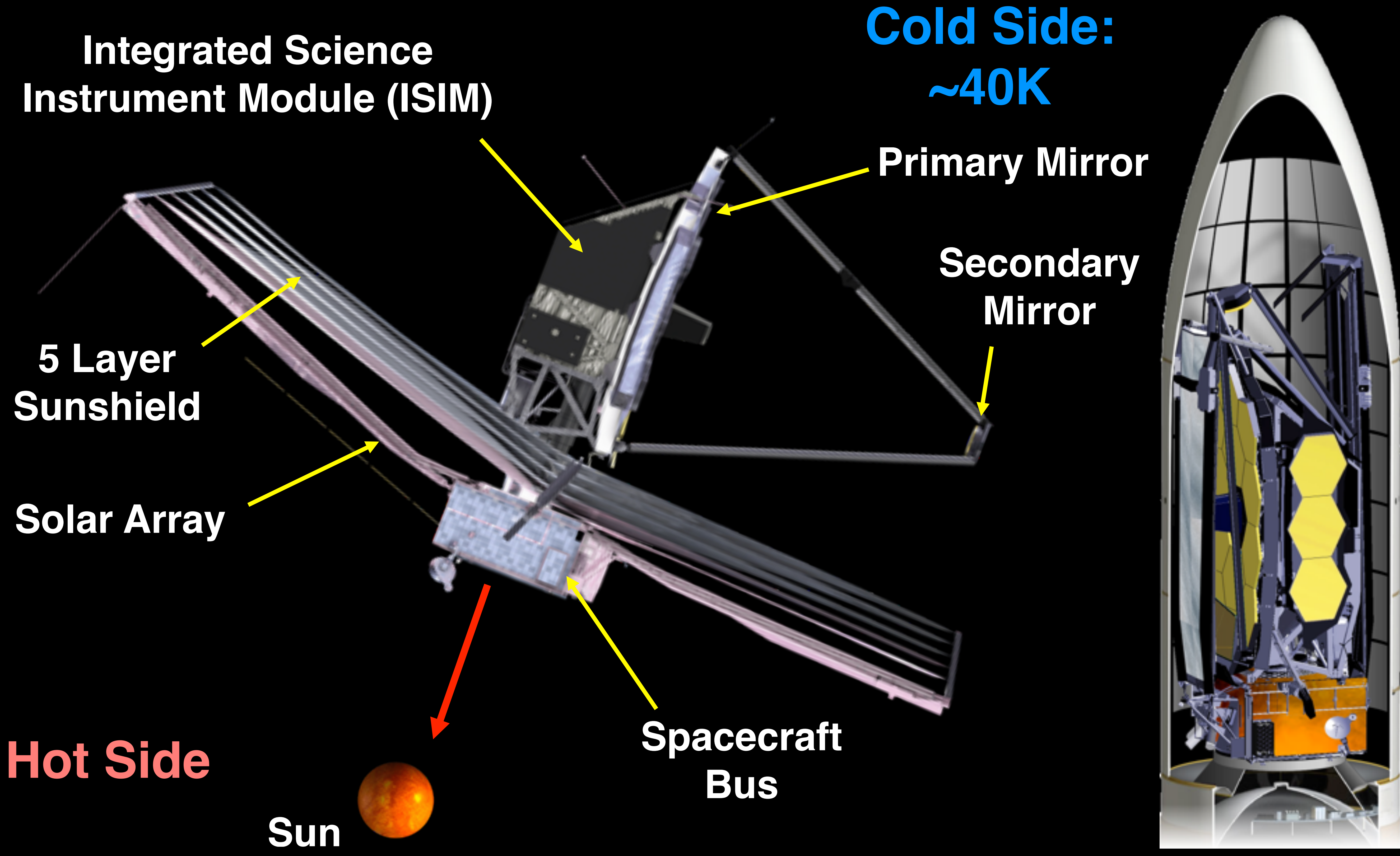
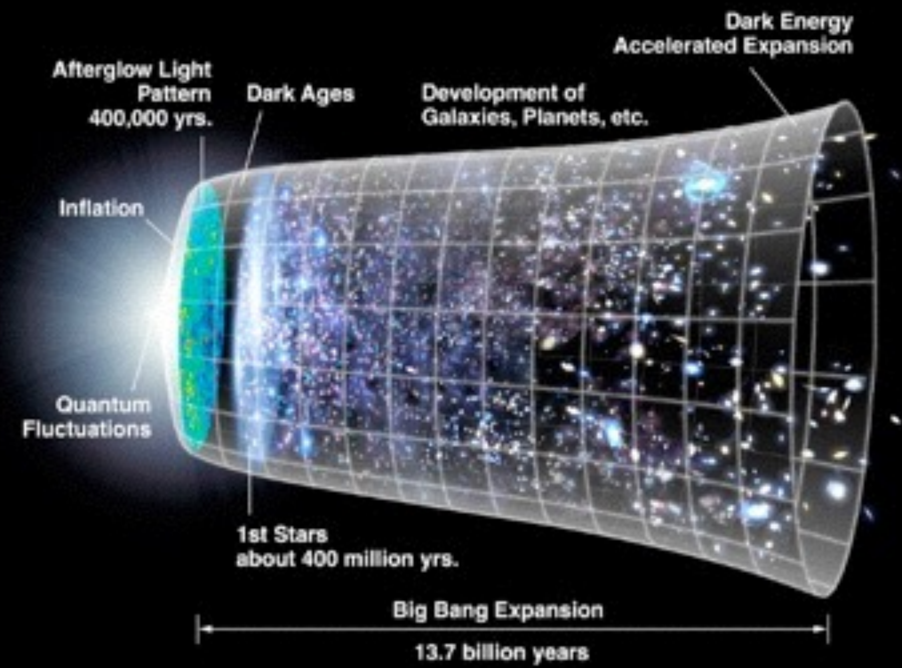
JWST: How It Works

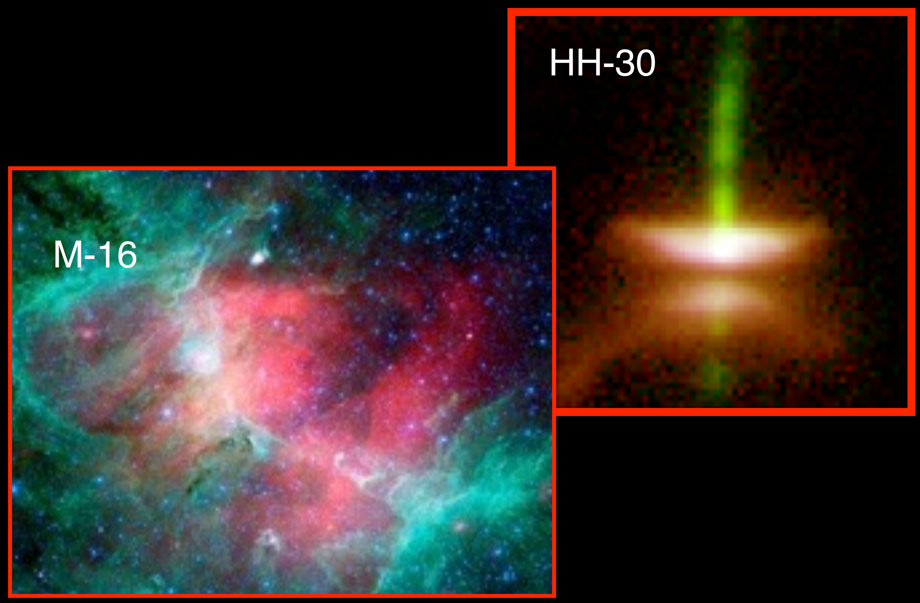


JWST Science



First Light and Re-Ionization

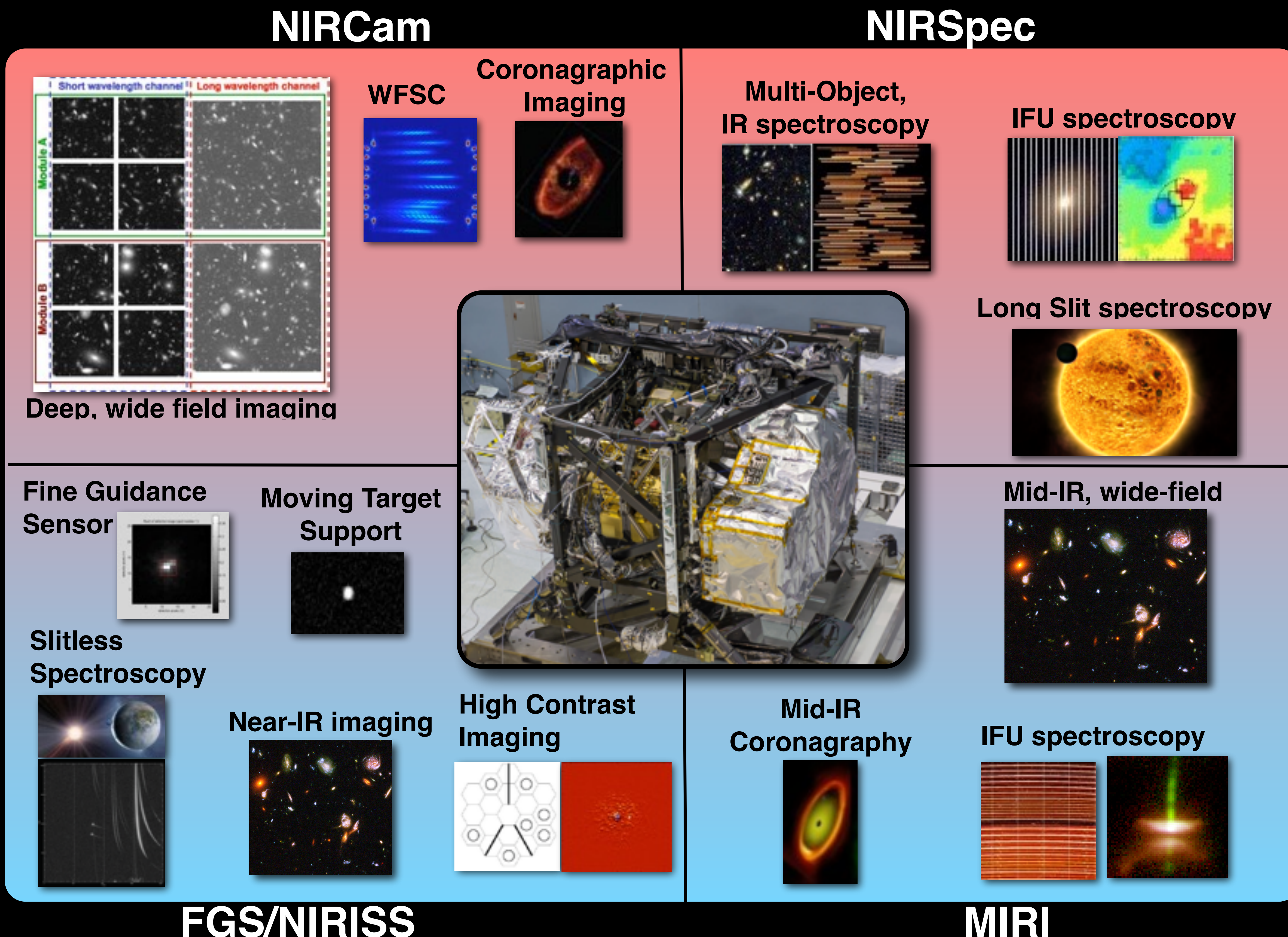
Assembly of Galaxies



Birth of stars and
proto-planetary systems

Planetary systems and the
origin of life

JWST's Science Instruments



Clampin/GSFC

Transit Science with JWST

- **Broad wavelength coverage with multiple spectroscopic capabilities including enhancements added for transit science observations**
  - ➡ Stable observing platform: L2 Orbit
  - ➡ Bright observing limits
  - ➡ Large, 6.5 meter aperture

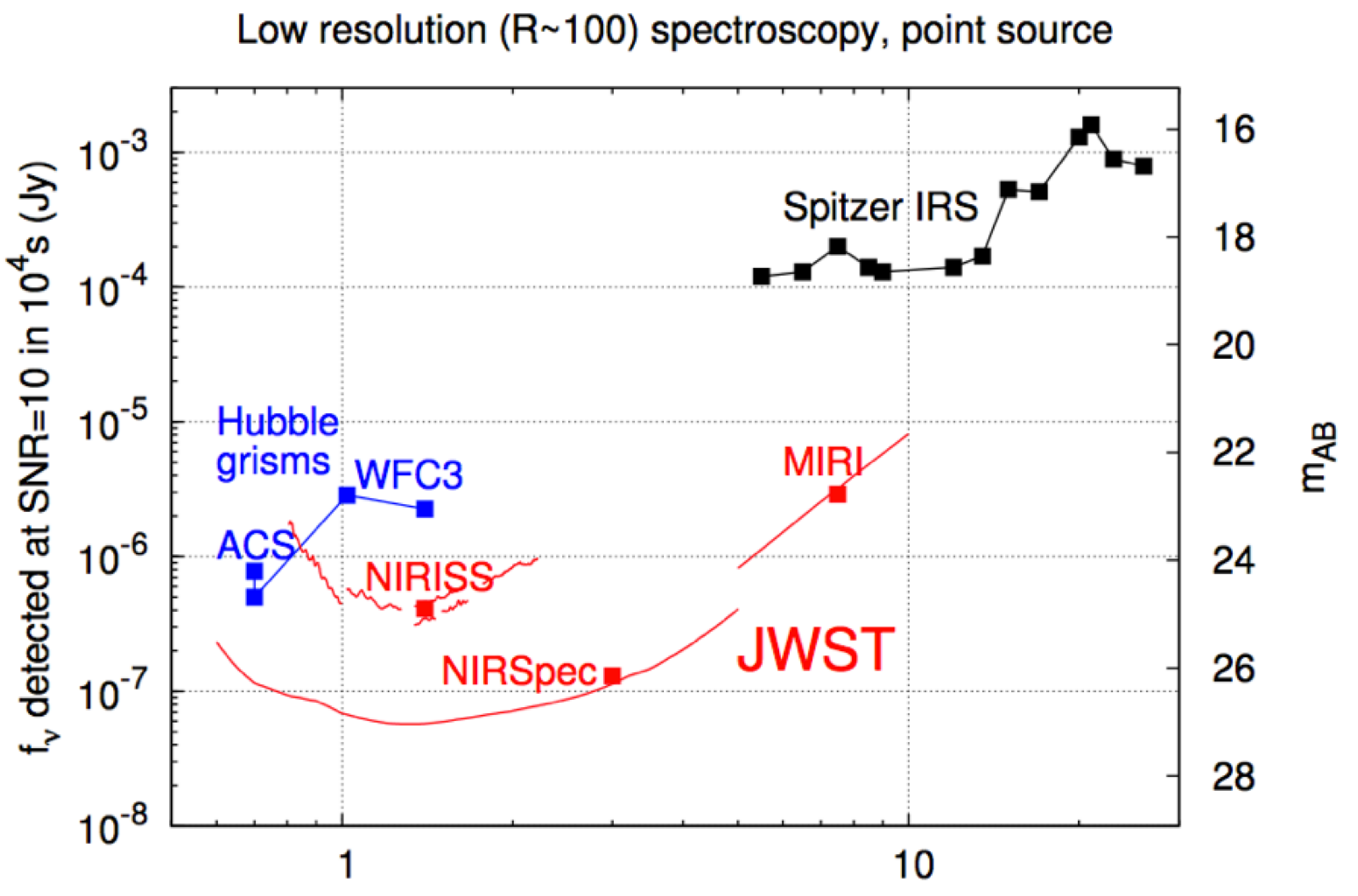
Transmission Spectroscopy

- ➡ Composition
- ➡ Scale height
- ➡ Clouds
- ➡ Planetary mass

Emission spectroscopy

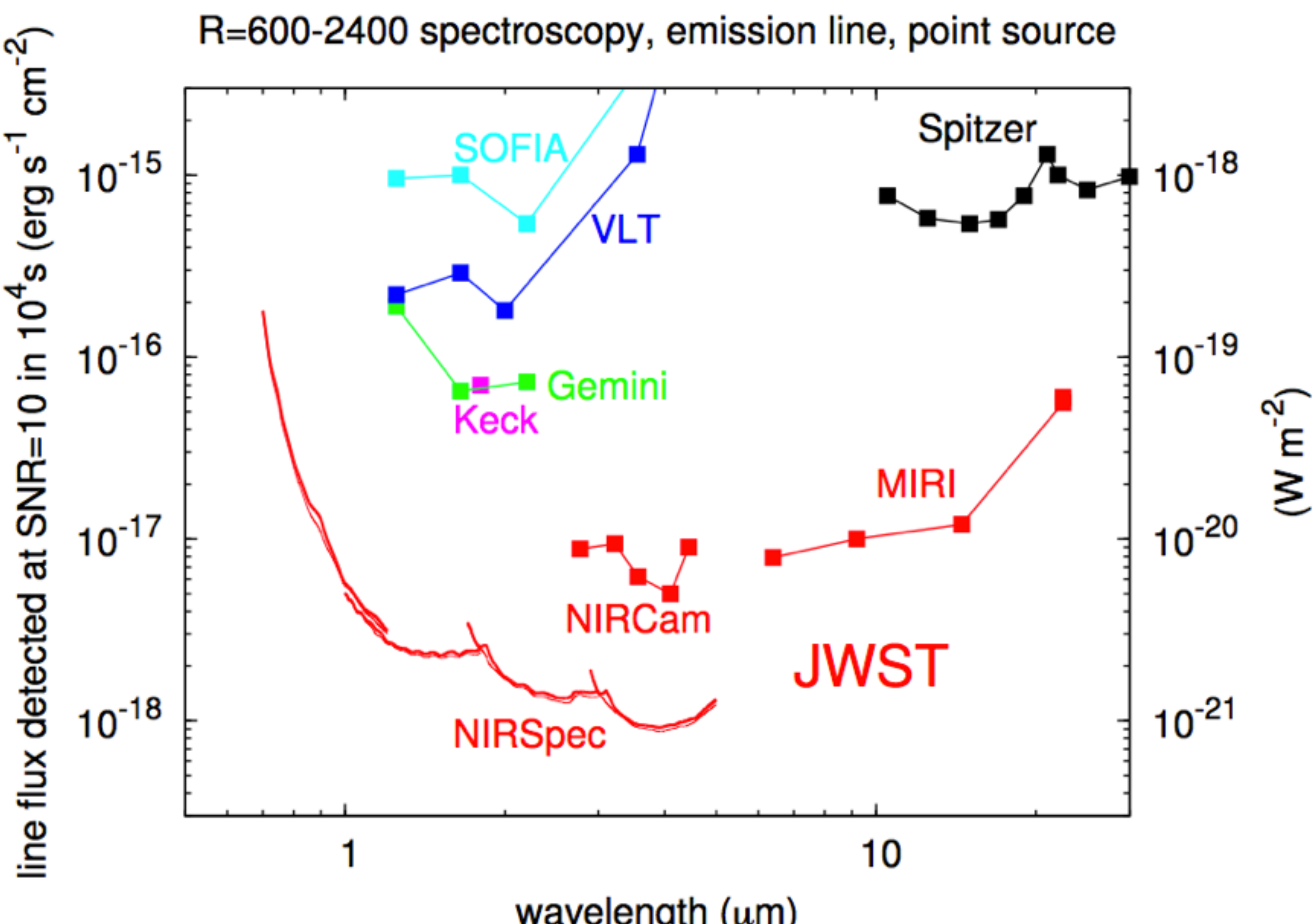
- ➡ Composition
- ➡ Atmospheric structure (T-P profile)
- ➡ Global energy budget
- ➡ Clouds

Observatory Sensitivity: Spectroscopy



www.stsci.edu/jwst/science/sensitivity

Observatory Sensitivity: Spectroscopy



www.stsci.edu/jwst/science/sensitivity

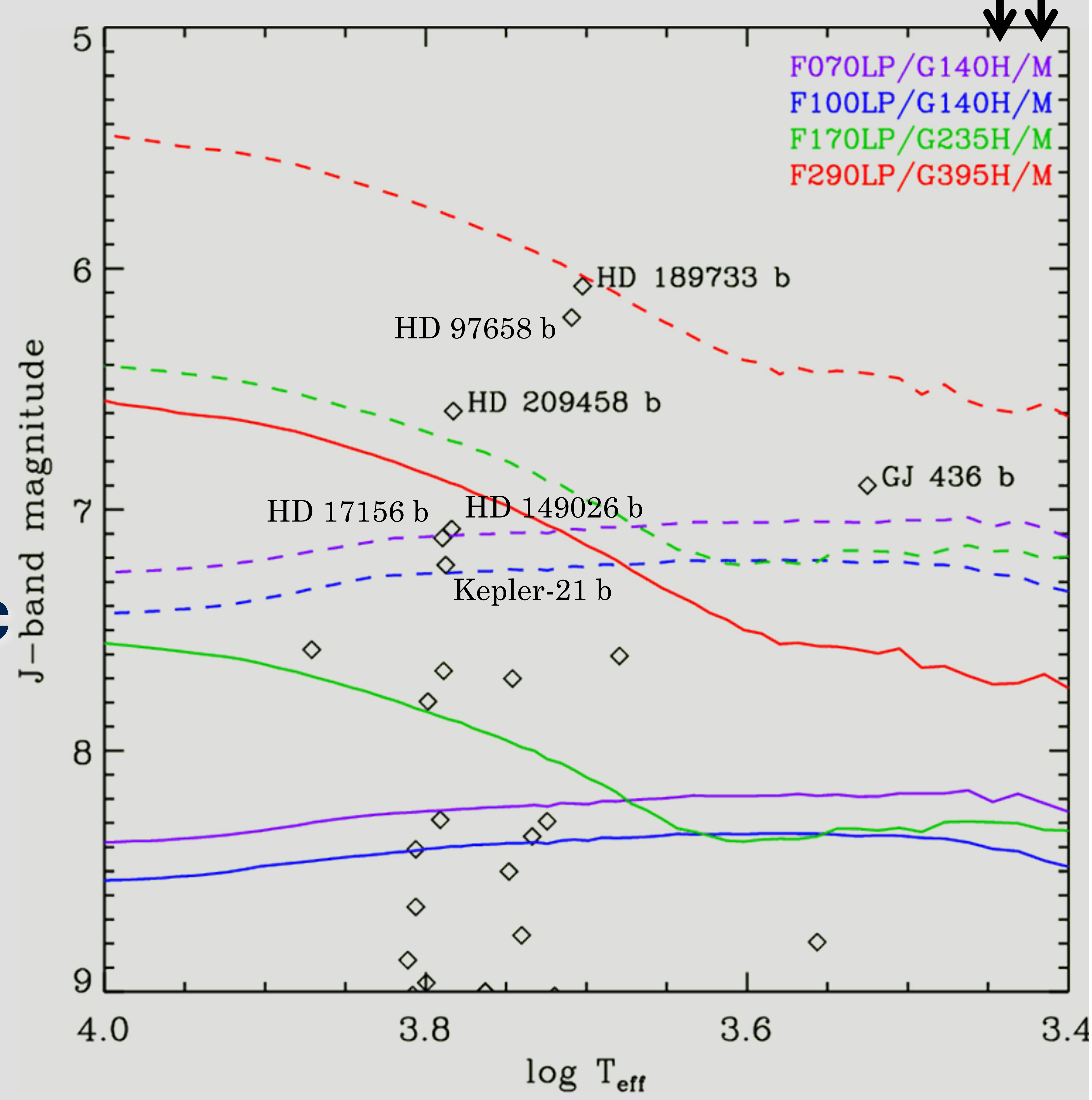
Near-IR Spectrograph (NIRSpec)

- Developed by European Space Agency and GSFC (MSA)
  - Operating wavelength: 0.6 – 5.0 µm
  - **1.6” x 1.6” fixed slit for transit spectroscopy**

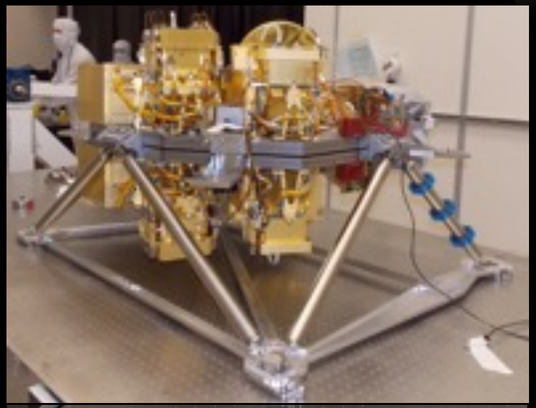
NIRSpec Optical Configurations

Grating	Filter	Wavelengths	Resolution	
PRISM	CLEAR	0.6 – 5.0	30 – 300	“100”
G140M	F070LP	0.7 – 1.2	500 – 850	
	F100LP	1.0 – 1.8	700 – 1300	“1000”
G235M	F170LP	1.7 – 3.0		
G395M	F290LP	2.9 – 5.0		
G140H	F070LP	0.7 – 1.2	1300 – 2300	
	F100LP	1.0 – 1.8	1900 – 3600	“2700”
G235H	F170LP	1.7 – 3.0		
G395H	F290LP	2.9 – 5.0		

NIRSPec Bright Limits



Near-Infrared Camera (NIRCam)

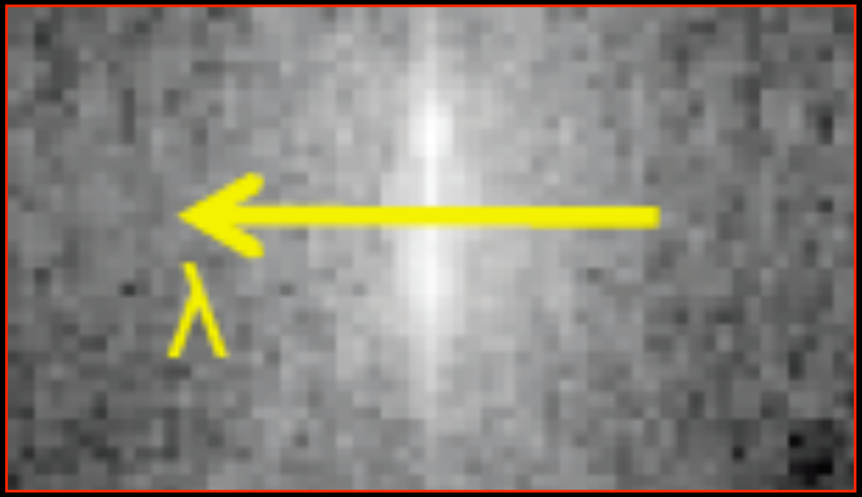


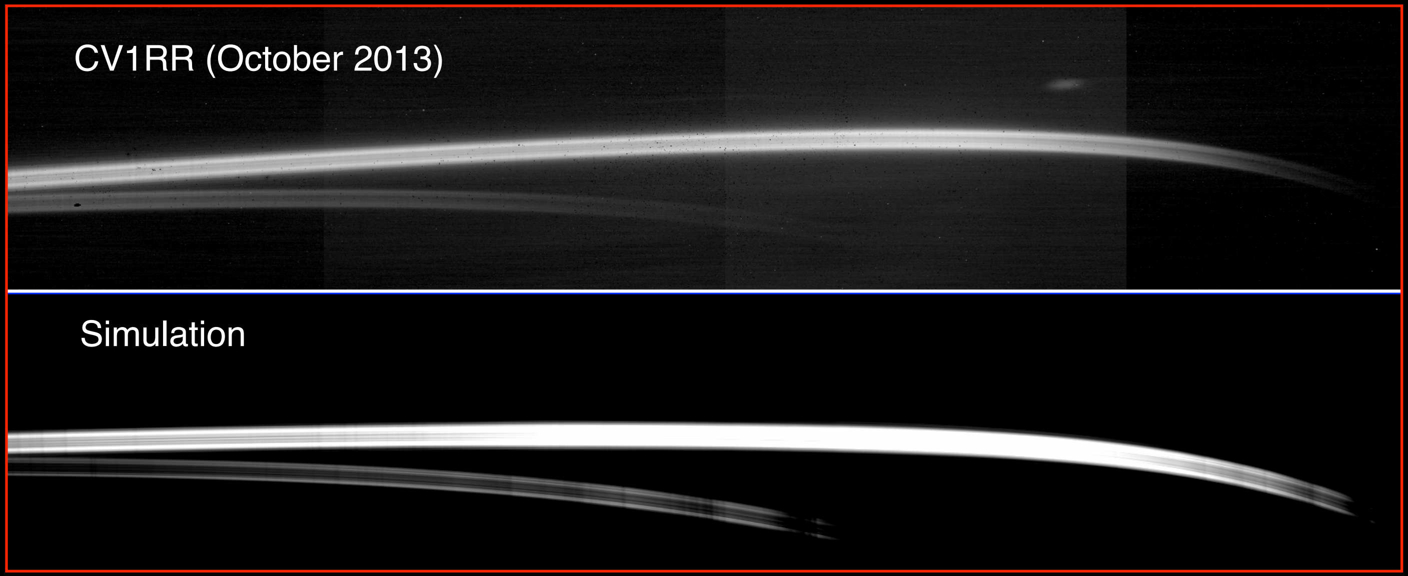
- **Operating wavelength**: 0.6 – 5.0 µm
- **Spectral resolutions**: 4, 10, 100
- **Dichroic**: 0.6-2.3 µm & 2.4-5 µm channels
- **Nyquist sampling:** @ 2 µm (0.032”/pix) & 4 µm (0.064”/pix)
- **Detector sub-arrays**: rapid readout ➠ brighter targets

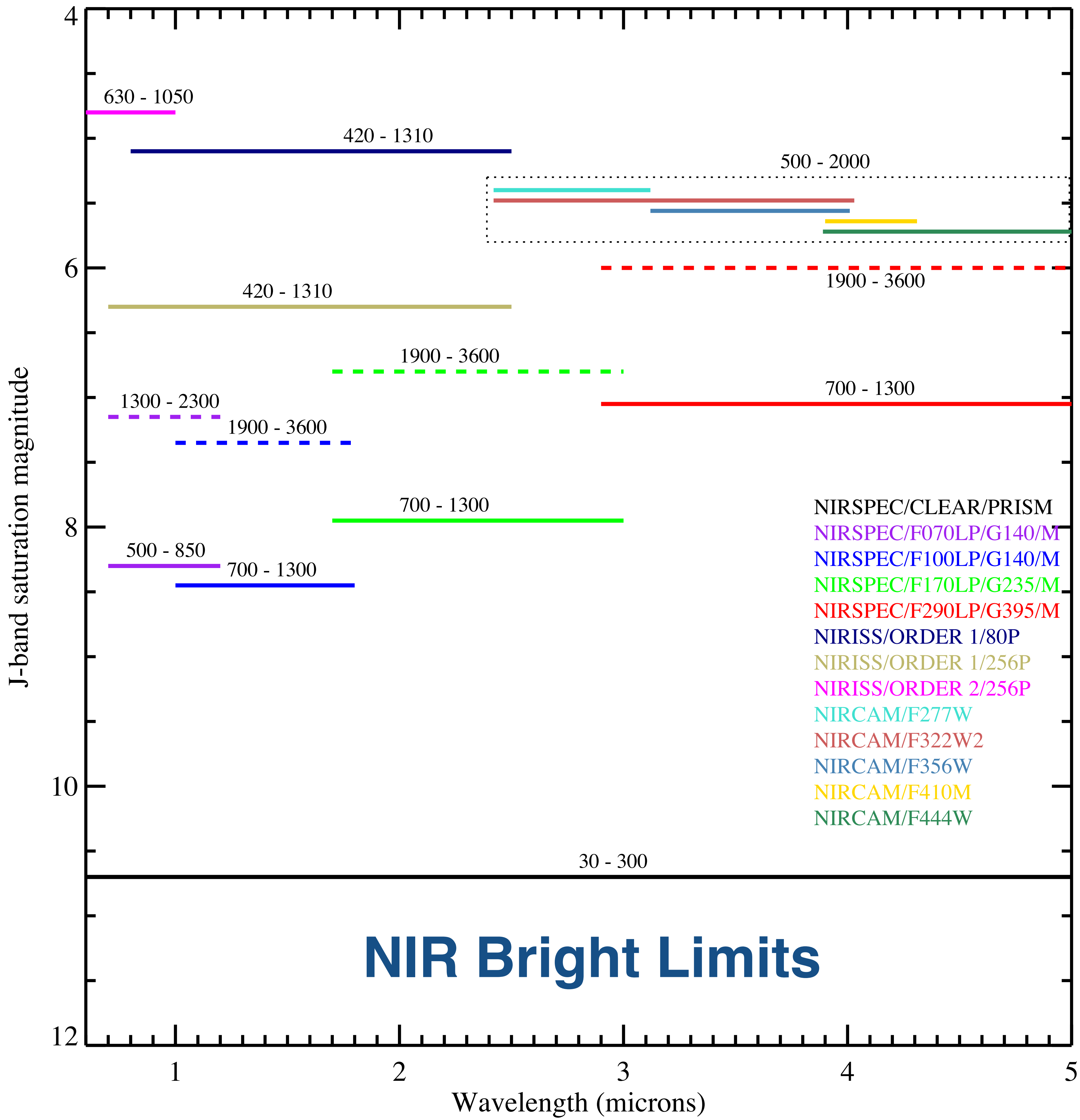
- **Transit Photometry**: 4λ, 8λ, 12λ defocused imaging
  - **A**void saturation of bright targets for light curves
  - 8λ gives K=4 saturation limit w/160x160 subarray, versus K=9 imaging saturation limit w/64x64 subarray
- **Transit Spectroscopy:** Slitless spectroscopy R~1700 w/ filters
  - ➡ F322W2: 2.42 µm - 4.03 µm
  - ➡ F444W: 3.89 µm - 5.00 µm

FGS/NIRISS

- Fine Guidance Sensor/Near-Infrared Imager & Slitless Spectrograph
- Developed by the Canadian Space Agency
- Operating wavelength: 0.8 – 4.8 µm
  - ➠ Broad-band guider operates in closed loop with fine steering mirror
  - ➠ Exoplanet grism : R700, 0.6 µm- 3 µm w/Defocused Image
    - ➠ bright targets



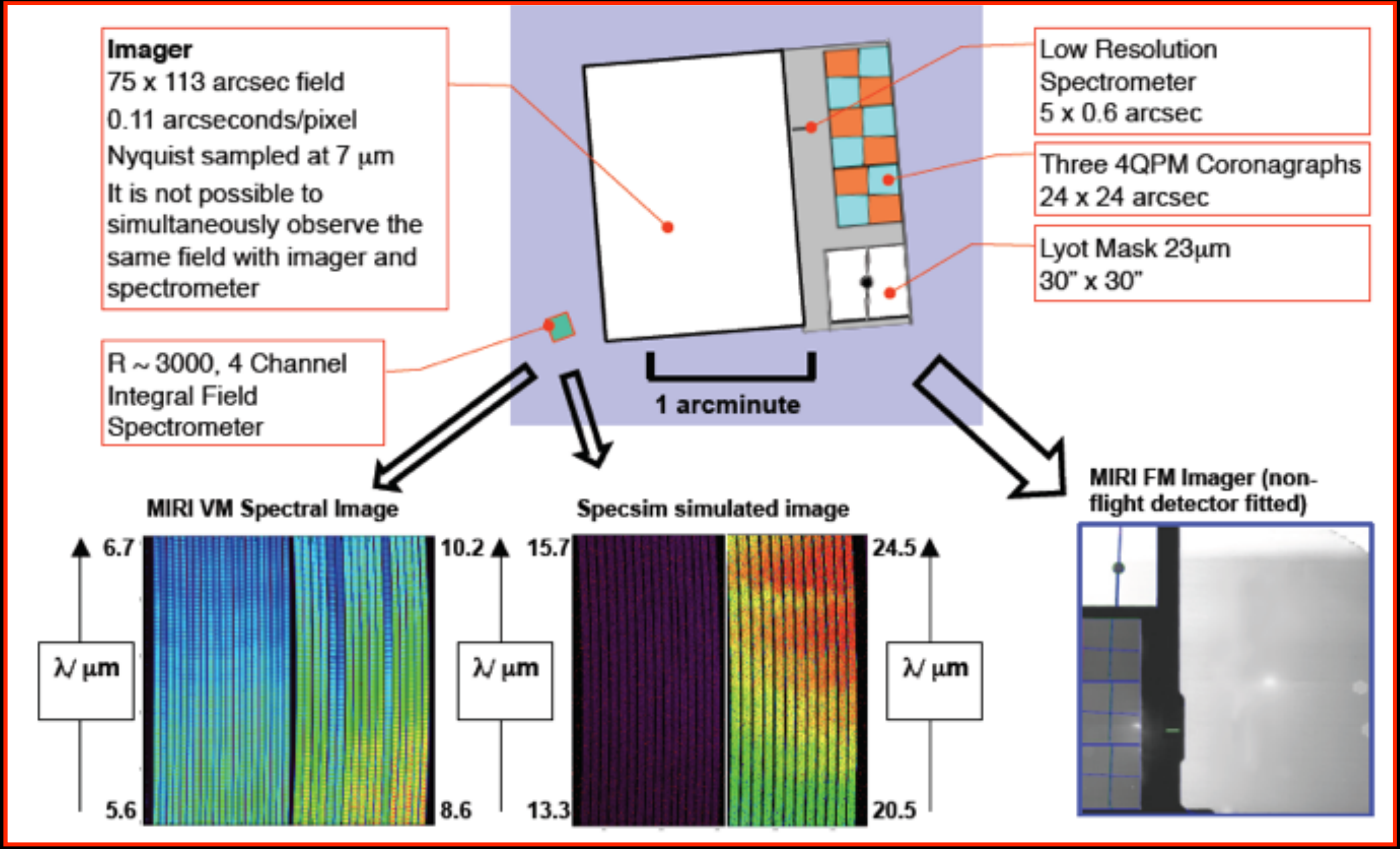




NIR Bright Limits

Mid-Infrared Imager (MIRI)

- Developed by the MIRI European Consortium & JPL
- Operating wavelength: 5 – 29 µm
  - ➠ R ~ 100 slitless spectroscopy
  - ➠ R ~ 3000 spectroscopy via integral field units



MIRI Bright Limits

Mode	Disperser/Filter	Brightest Observable with subarray G0 (K mag)	Brightest Observable with subarray M5 (K mag)
Imaging	F770W	5.86	6.28
Imaging	F1130W	3.31	3.75
Imaging	F1500W	3.43	3.86
Spectrograph	Band2C	3.74	4.09
LRS	PRISM	4.41	4.83

Operational Concerns

- **Decorrelation of pointing**
  - ➡ **JWST pointing specified for short wavelengths (~7 mas)**
  - ➡ FGS provides telemetry: guide star centroids every 60 sec
  - ➡ New calibration mode defined for transit and coronagraphs
    - ➡ Fine steering mirror offsets permit a star to be scanned around a detector pixel to calibrate pixel response function (~mas steps)

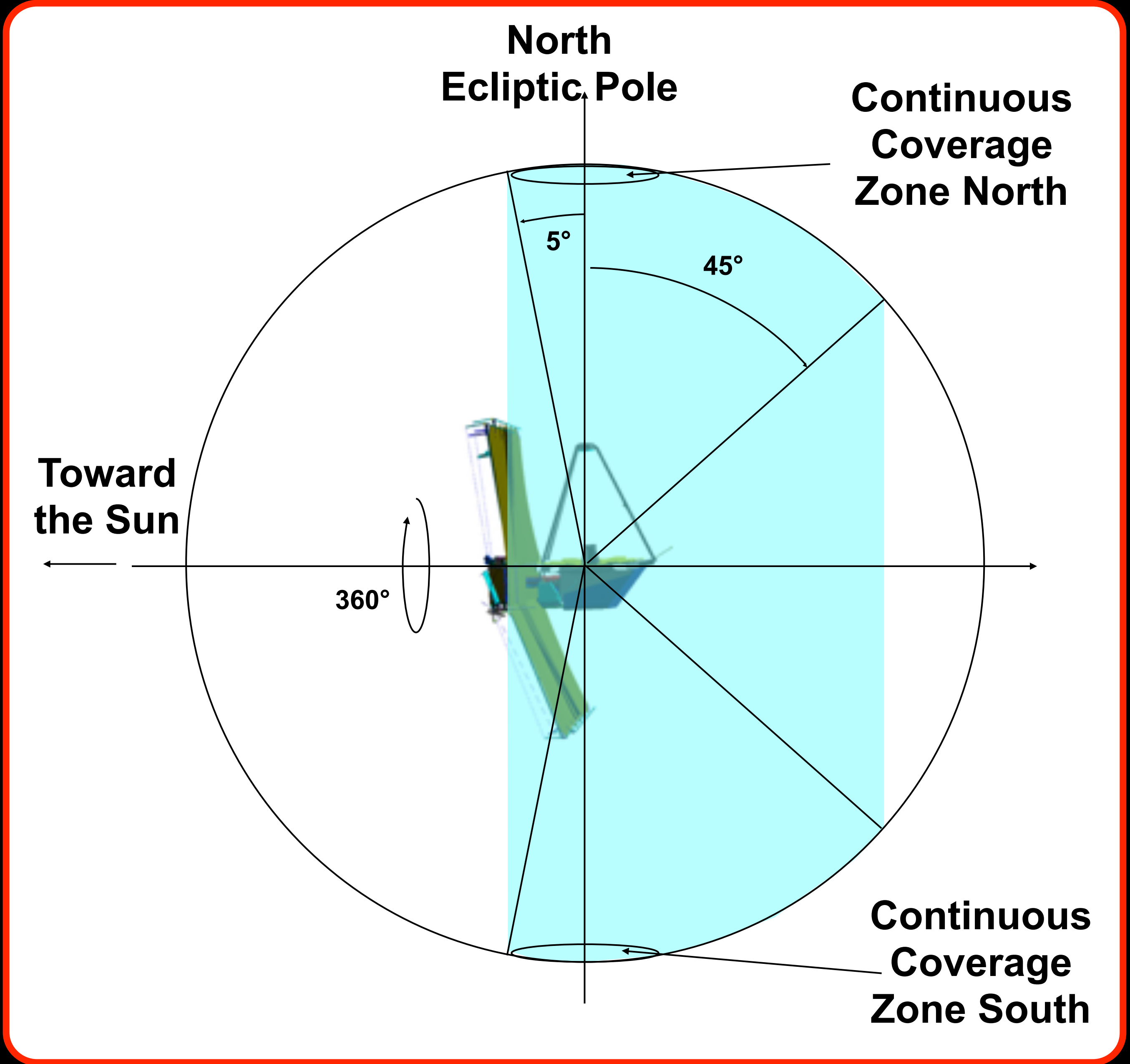
- **Thermal stability: JWST is designed to be stable. Verification planned for commissioning**
- **Antenna re-point every 10k sec produces 0.1” jitter for ~1 min**
- **Momentum unloading and stationkeeping burns likely limit maximum pointed observing time T ≤ 50 hrs**
  - ➡ Momentum unloads more frequent: driven by science program

JWST: Observing Constraints

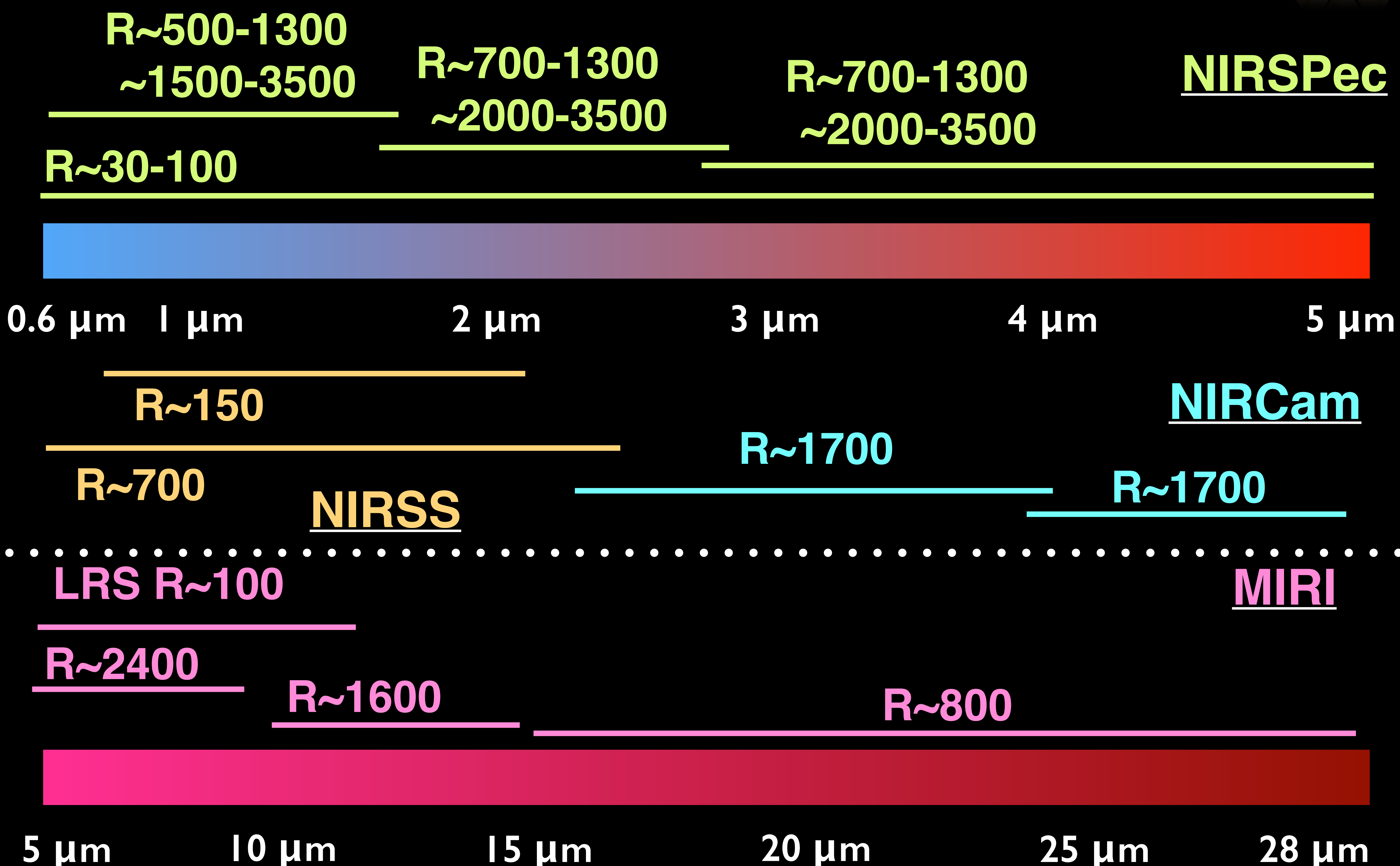
- **Sun angle constraints:** instantaneous coverage over 35% of sky

- **Field of Regard is an annulus with rotational symmetry about the L2-Sun axis, 50° wide**

- **The observatory will have full sky coverage over a sidereal year**

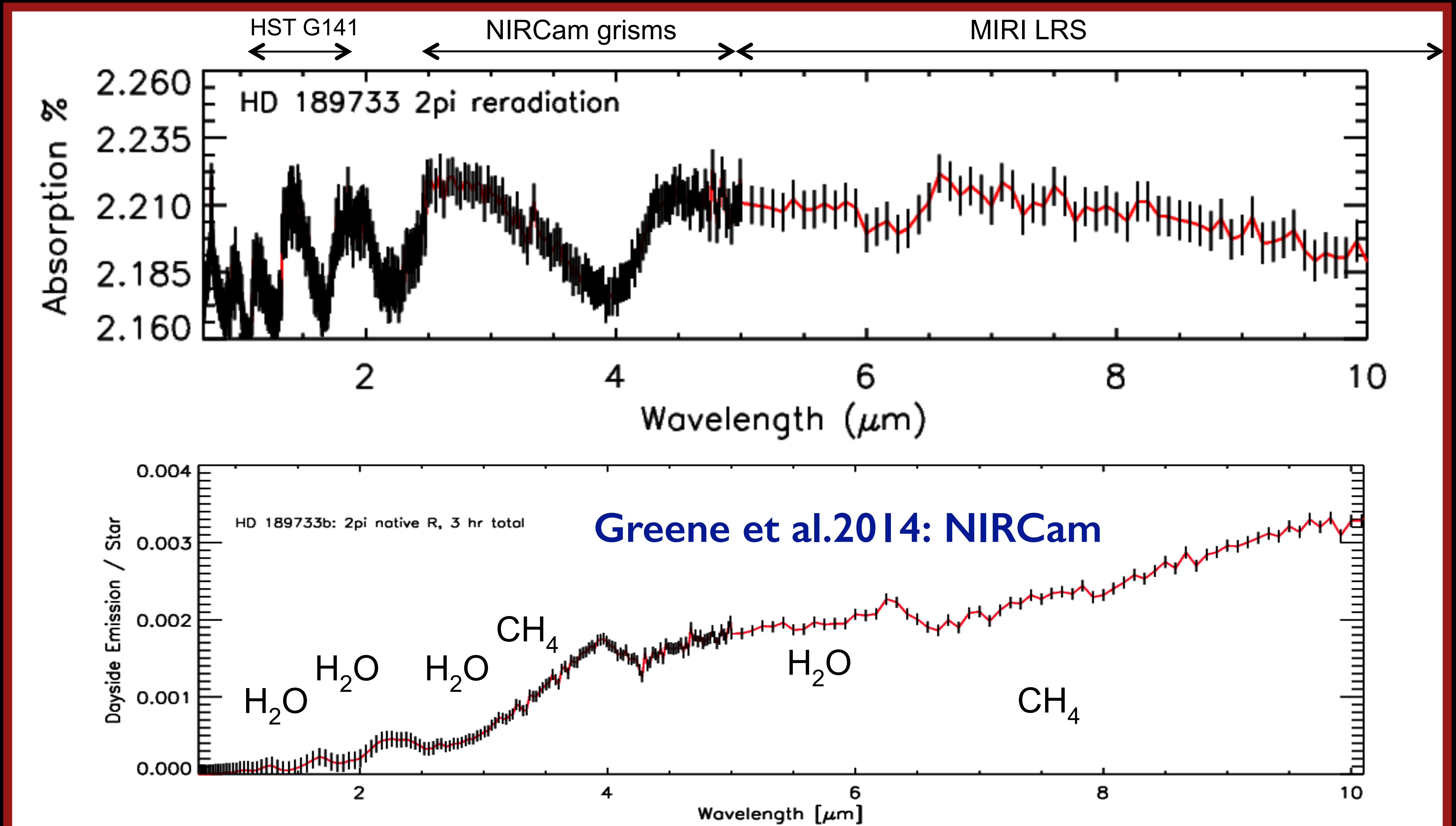


Which Mode Do I Use?

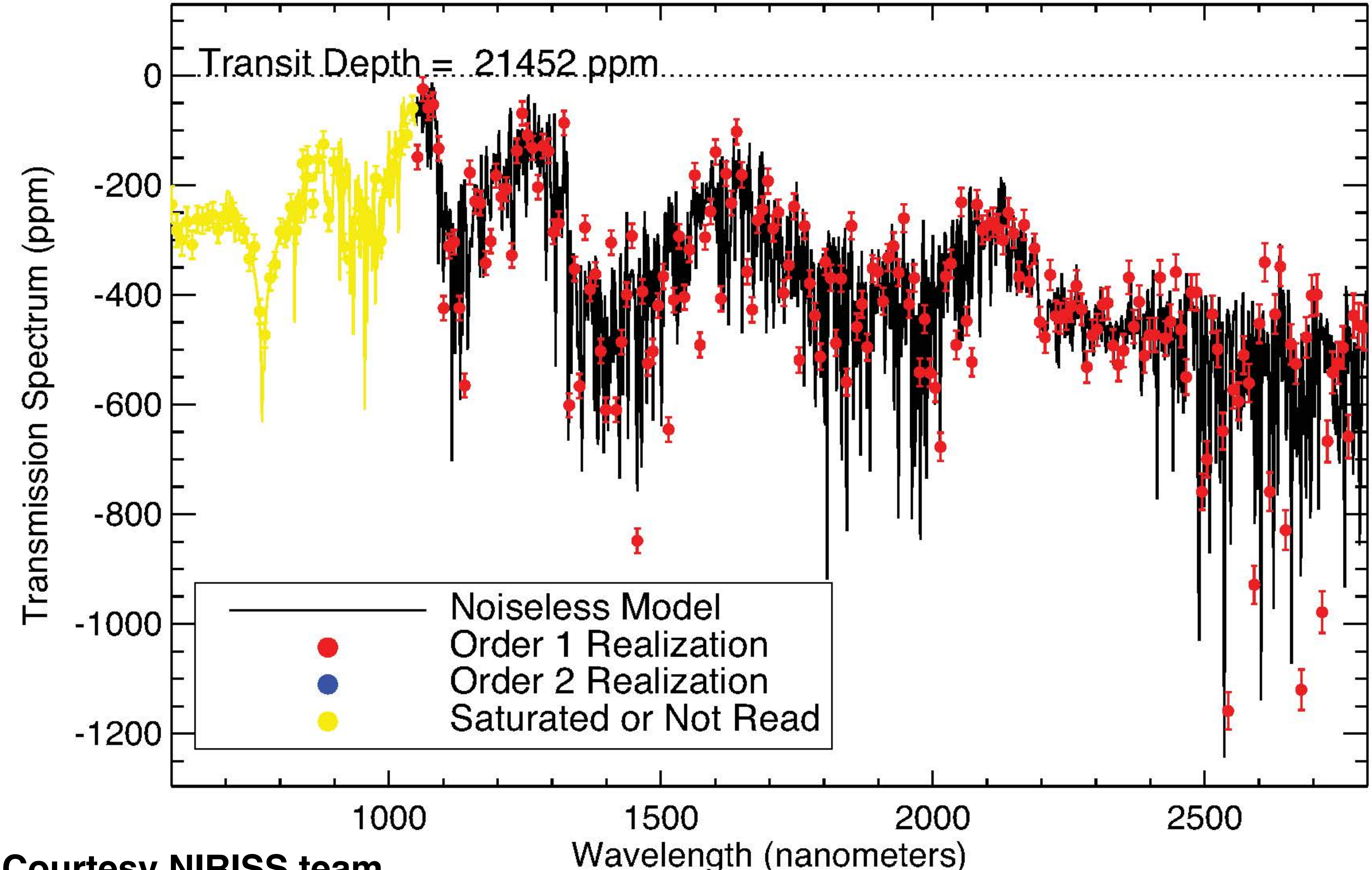


Gas Giants

- **Gas Giant Planets: Comparative planetology programs**
  - ➡ Single transit, high fidelity spectra of transiting gas giants
  - ➡ Multi-λ coverage provides context: breaks model degeneracies



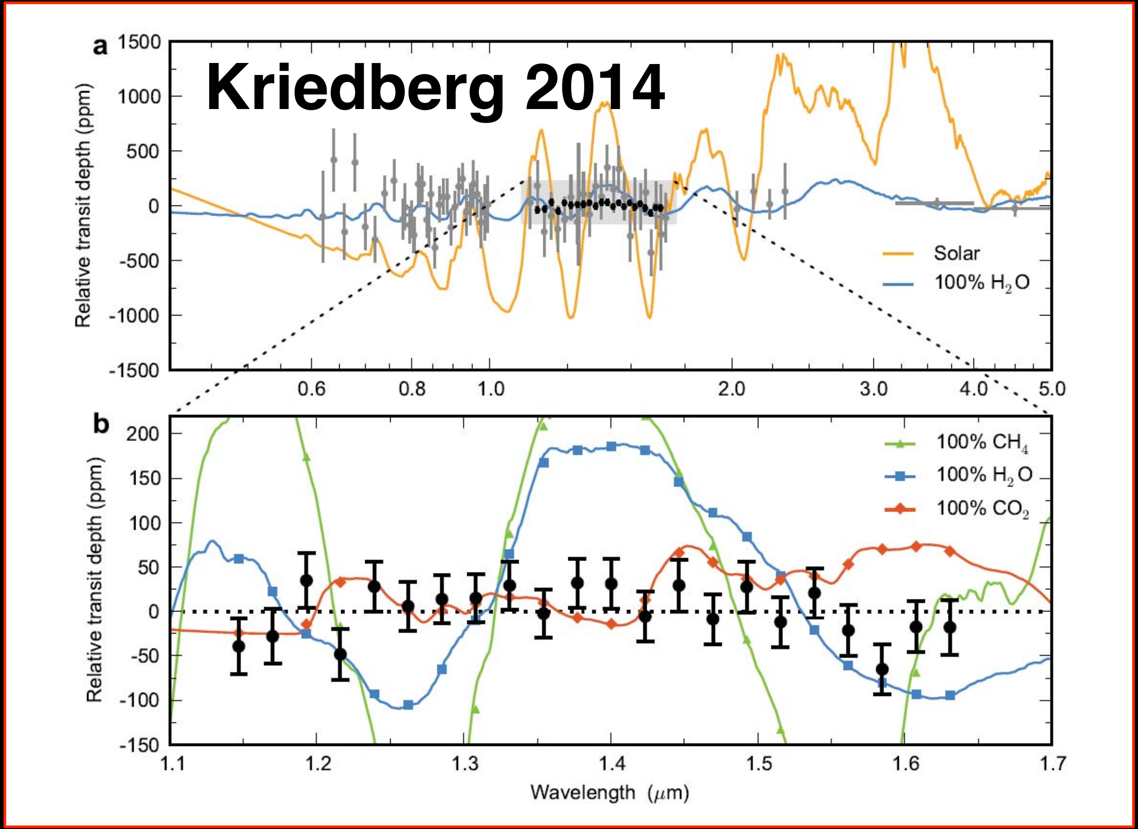
Simulated NIRISS HD 189733 Observation

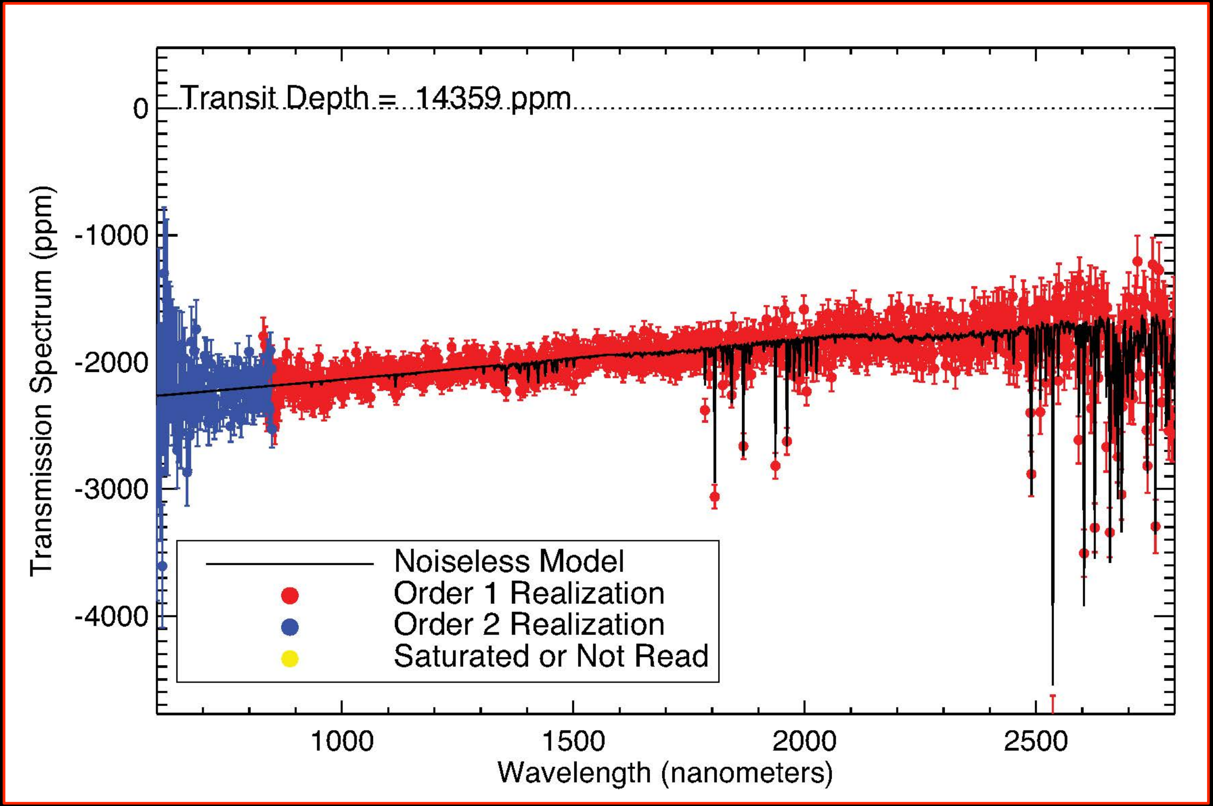


Courtesy NIRISS team

Superearths

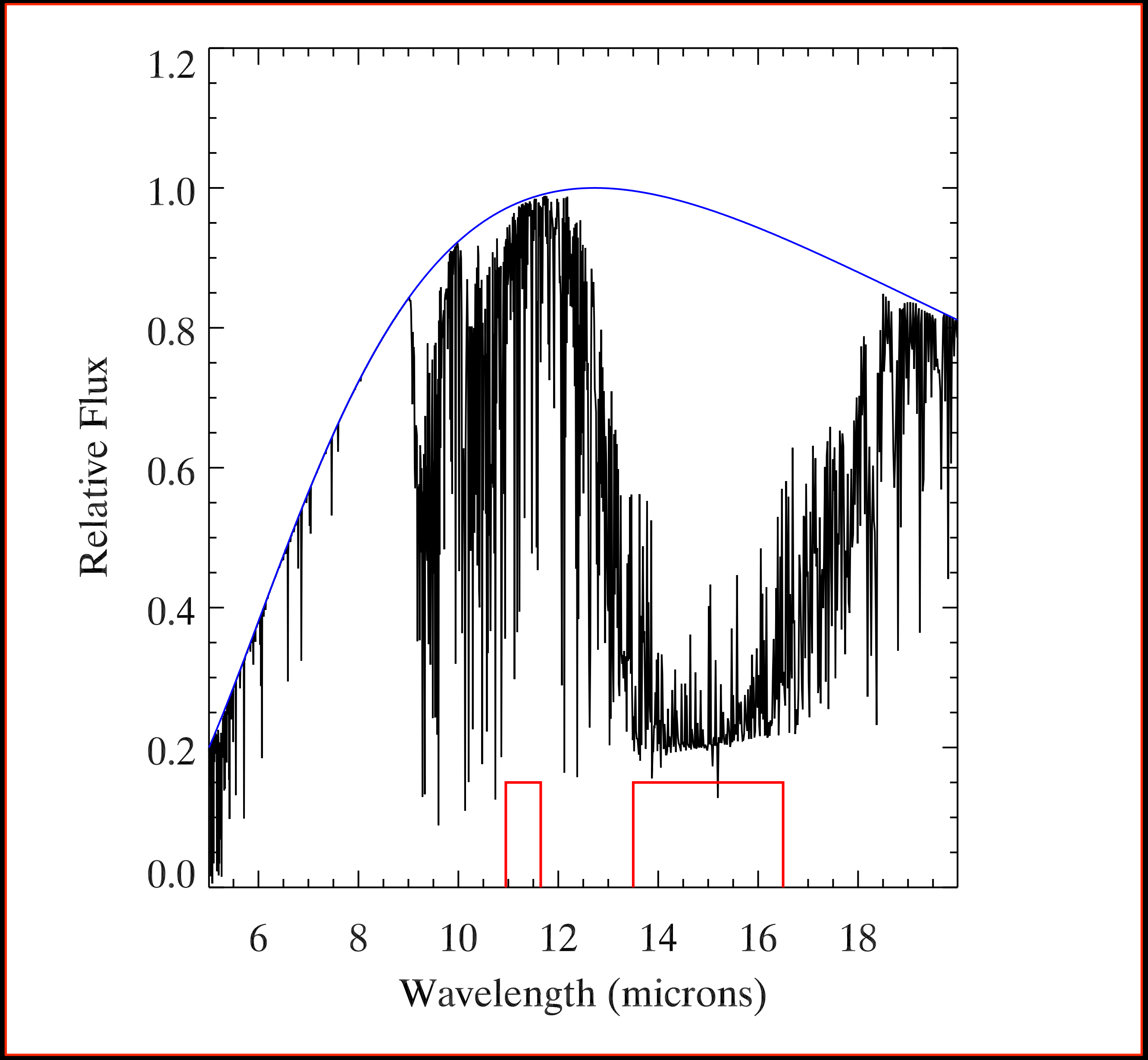
- Survey properties of super earths and mini-Neptunes
  - ➡ Core composition
  - ➡ NIR and MIR
- GJ 1214 has a flat spectrum
  - ➡ Clouds become transparent at long-λ
  - ➡ High resolution NIRISS observations could capture lines penetrating the haze (Beichman et al. 2014)





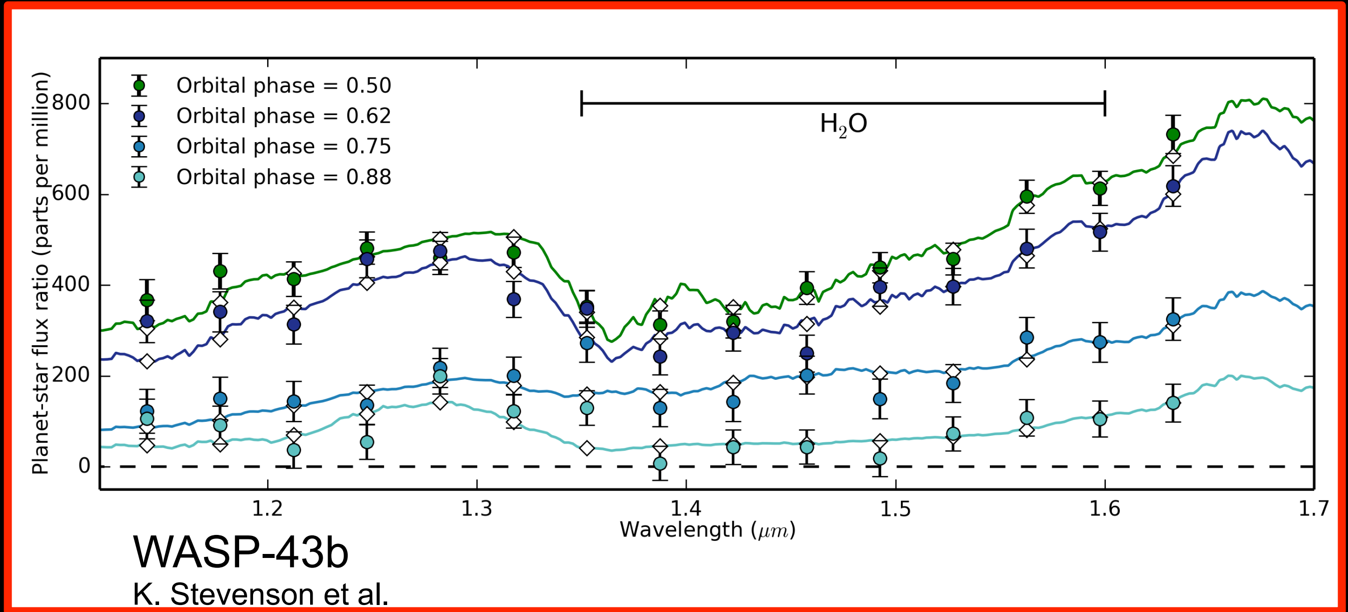
MIRI Broadband Imaging

- Filter imaging is also possible e.g. 12 μm - 28 μm MIRI bandpass of MIRI
- Deming et al. 2009 simulated a broad band detection of CO_2 in super earth emission, with M dwarf parent star
- Detection of CO_2 feature in ~50 hr for ~300-400K 2 R⊕ planet around M5 star at 10 pc



Exoplanet Climates

- Full phase curve spectroscopic mapping
  - ➡ Atmospheric circulation
  - ➡ Atmospheric structure
    - ➡ T/P profiles
  - ➡ Composition



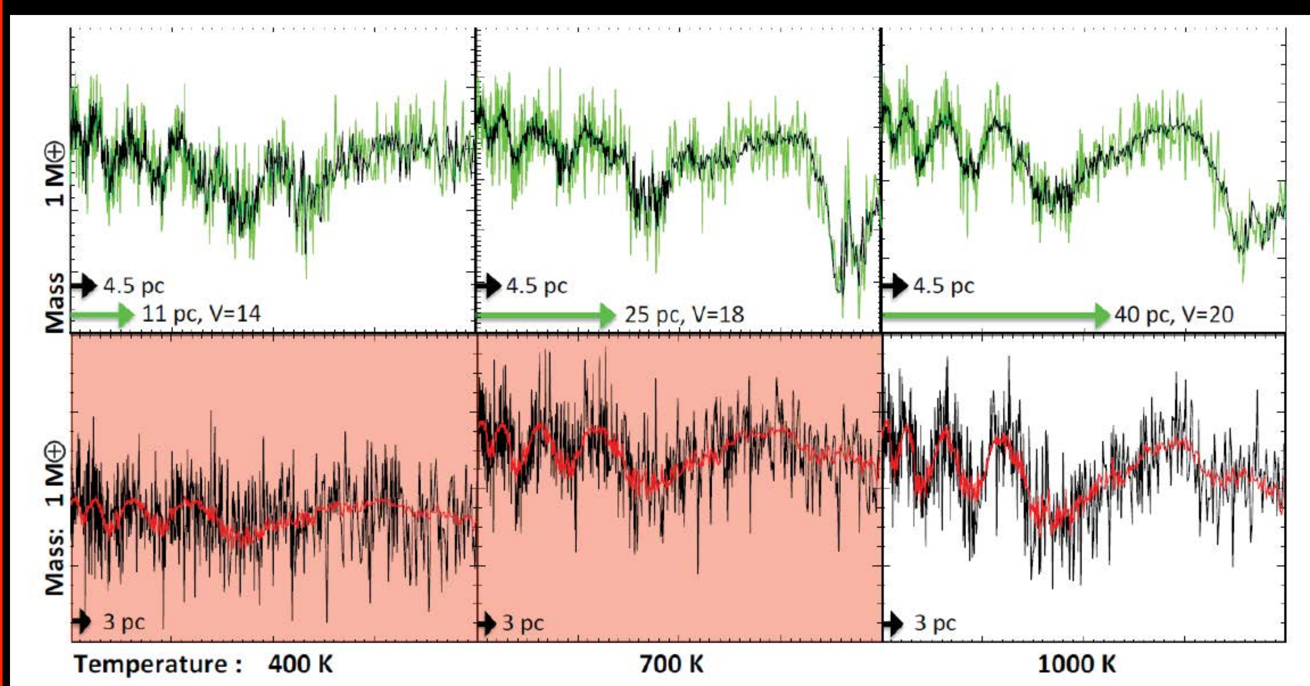
Full phase curve spectroscopy: Wasp 43b - Stevenson et al. 2014

- Superearth & mini-neptune phase curves
  - ➡ Establish presence of an atmosphere on rocky planets
  - ➡ JWST will be able to measure the broad-band phase curves of hot super-Earths and mini-Neptunes down to ≤ 4 R⊕

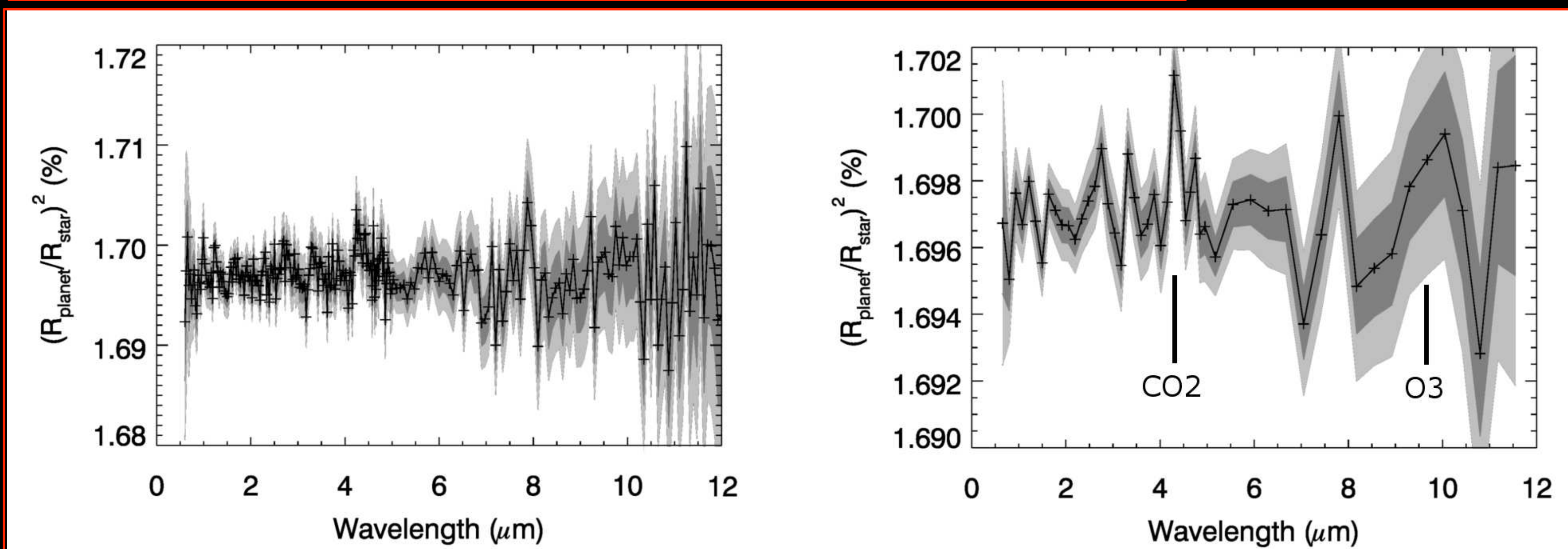
- Secondary eclipse mapping e.g. Knutson et al. 2007

Earths?

- **Earths around M stars will be very challenging: Targets**
  - Need to achieve ≤10 ppm performance over multiple transits e.g. Deming et al. 2009, Batalha et al. 2013, & Barstow et al. 2015



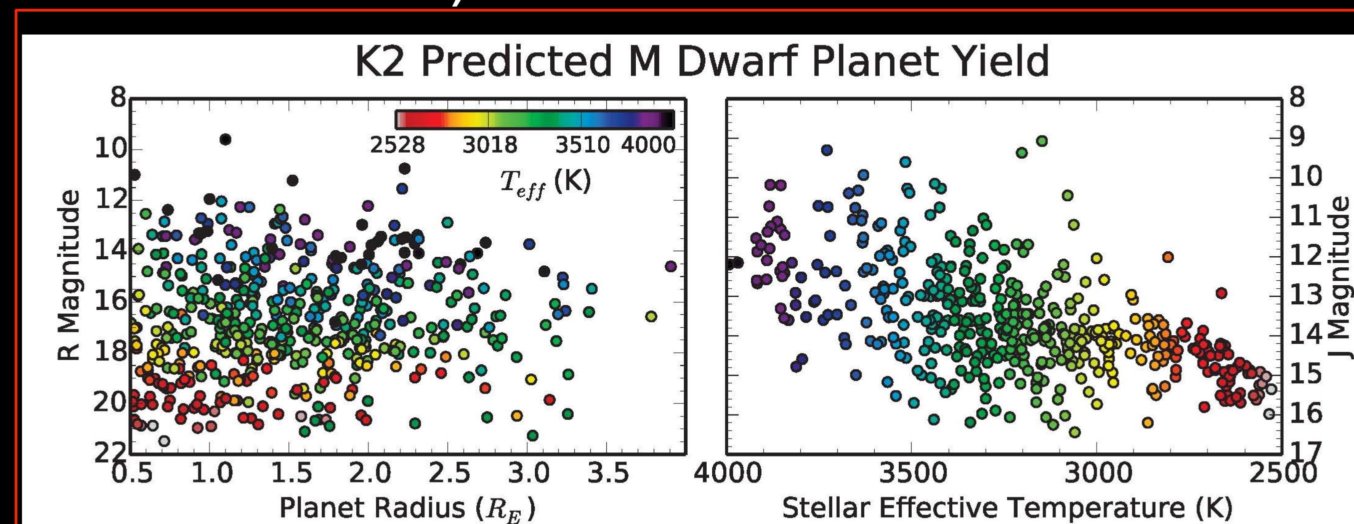
Batalha et al. 2013 show 25 transit observations with NIRSpec for 1,4 and 10 M⊕ planets at a variety of equilibrium temperatures.



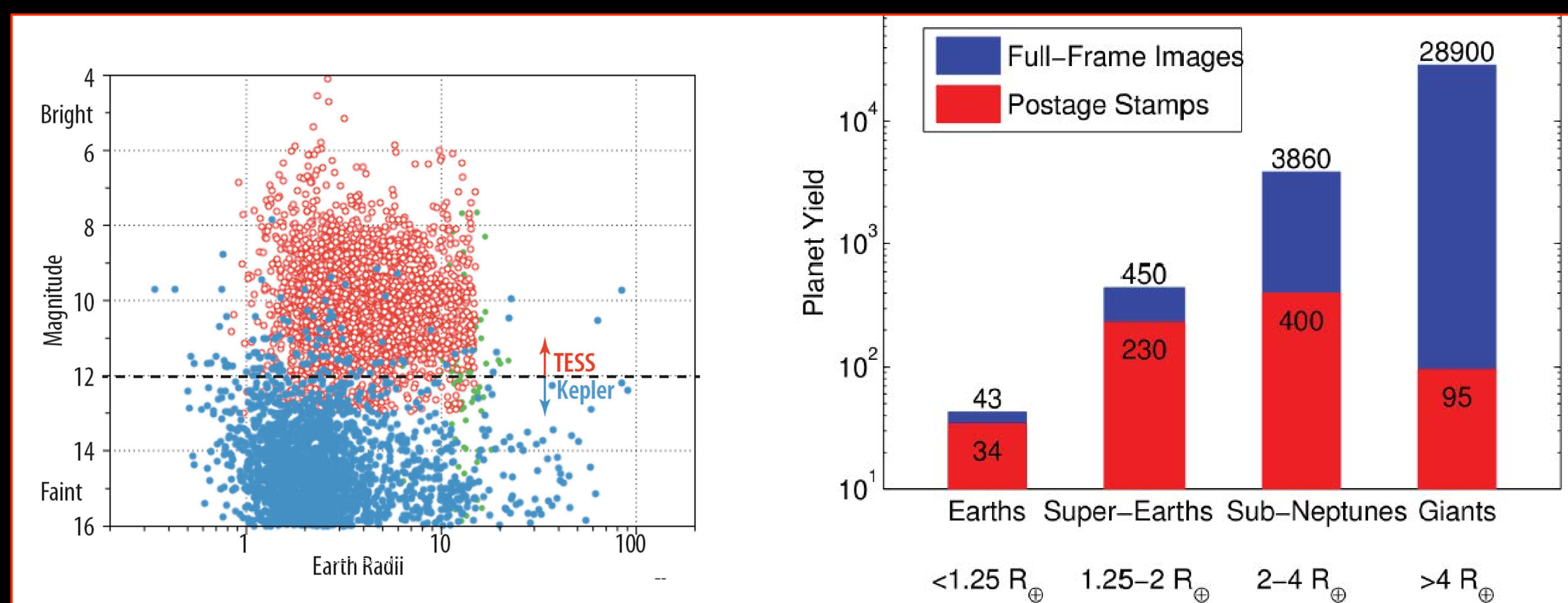
Barstow et al 2015 30 transits show detection of ozone band at 9.6 μm after binning by 5x. The CO_2 band at 4.3 μm is also detected

Targets for JWST

- Numerous ground-based surveys targeting bright, low-mass stars, including MEarth (Nutzman & Charbonneau 2008), NGTS (Chazelas 2013) and MASCARA (Snellen et al. 2012).
- K2 survey prediction by Crossfield from (Beichman et al. 2014)



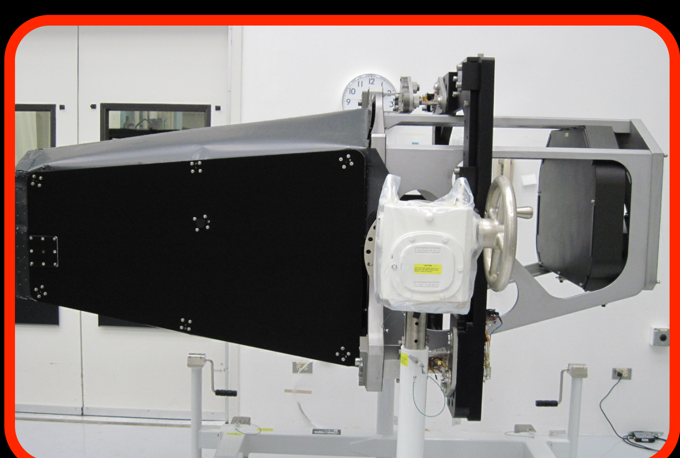
- TESS yield prediction from Sullivan et al. (2014) from both observing modes (stamps & full frame)



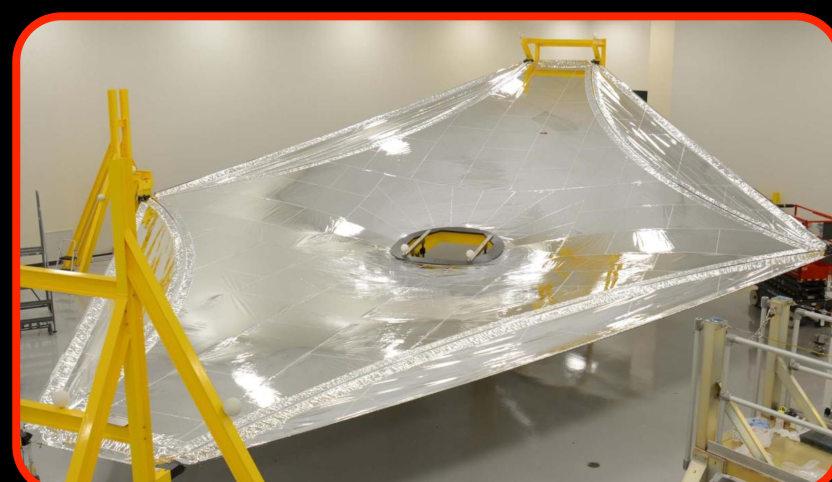
JWST Status: Integration

Telescope Mirrors

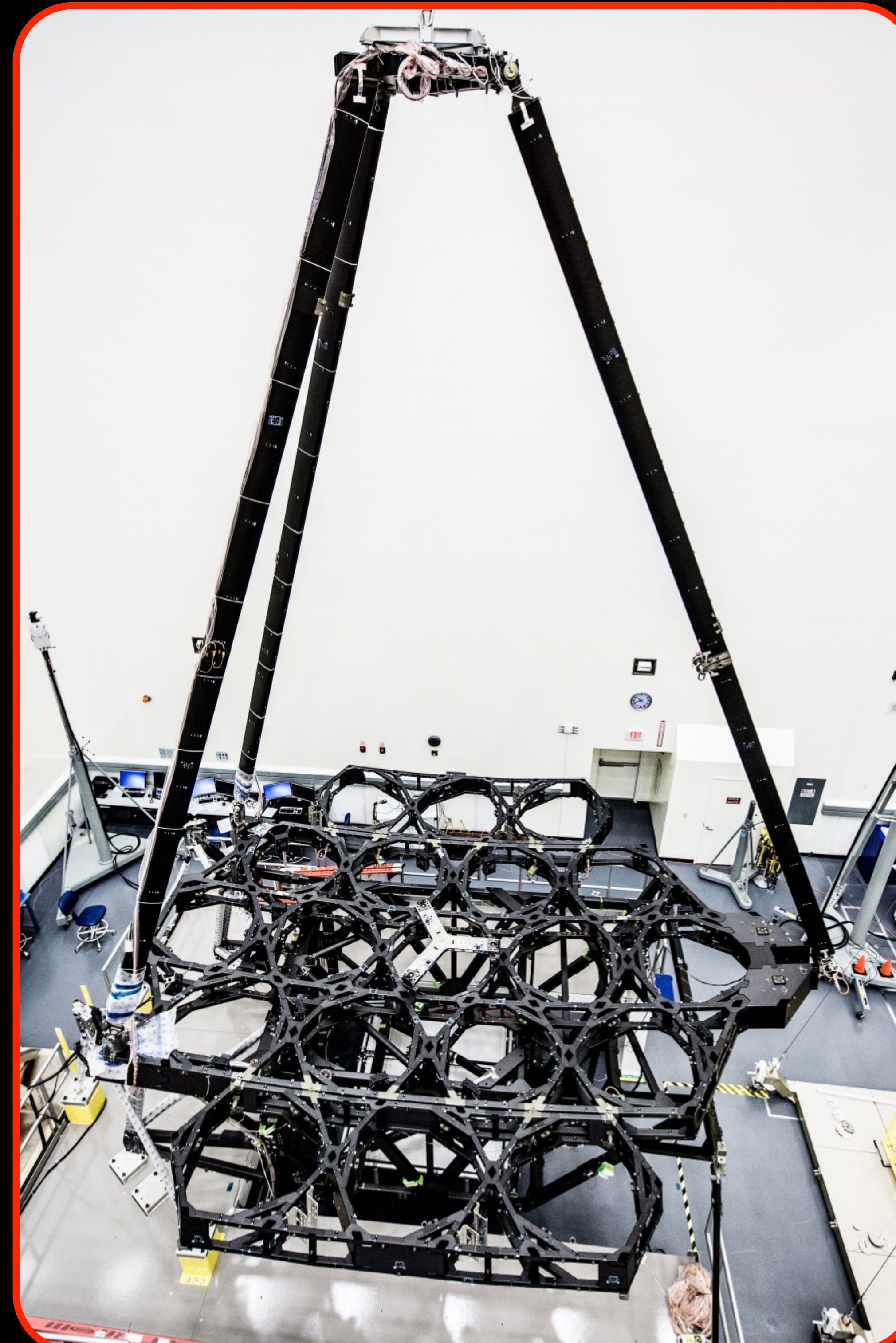
Science Instruments



Aft-Optics Bench



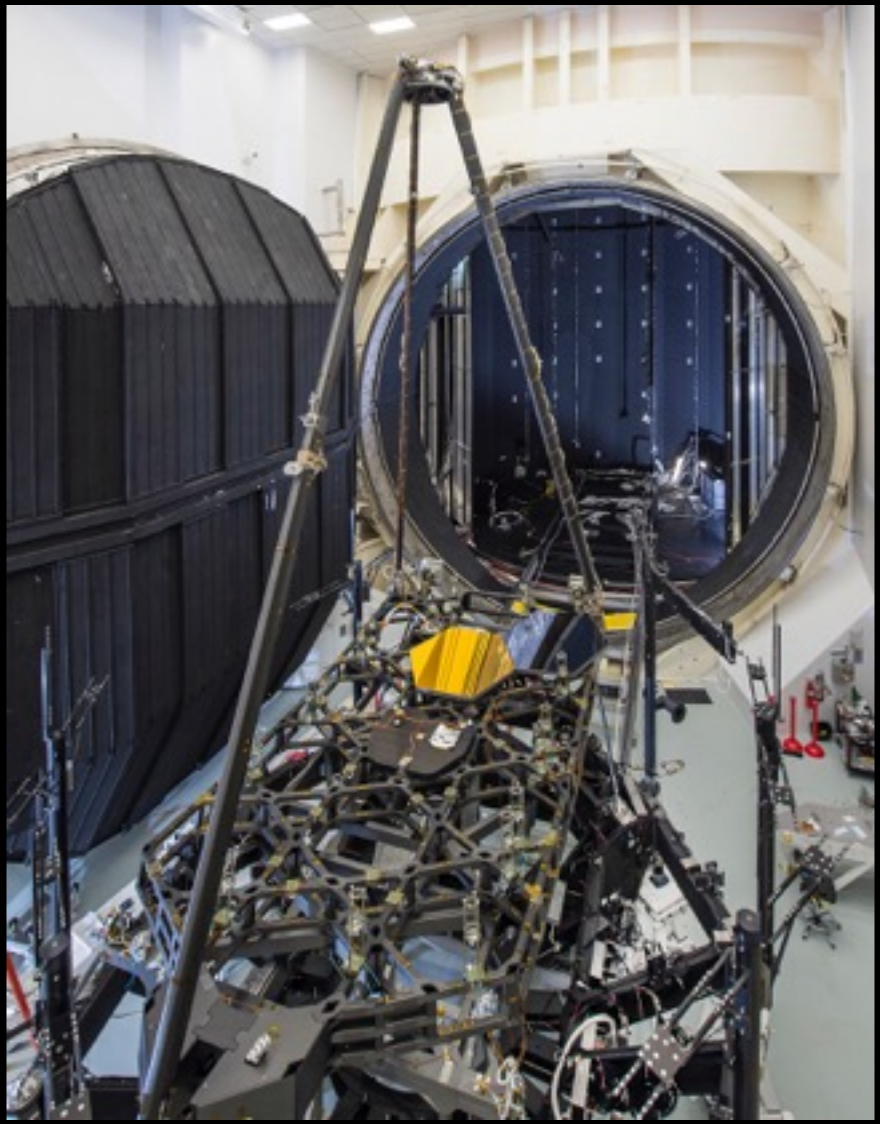
Sunshield Membrane

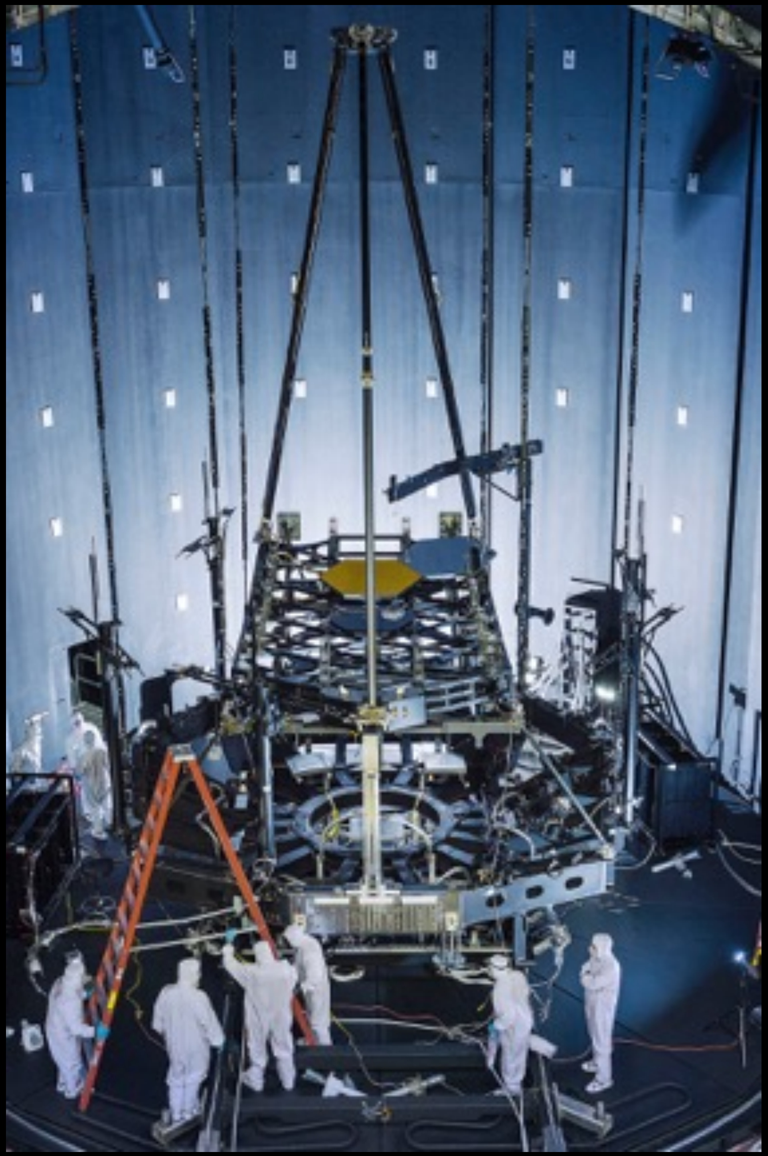


Telescope Structure

JWST Status: Integration and Test

- Instruments enter last (3/3) cryo-test later this year
- First Chamber-A cryogenic test of pathfinder completed
  - Demonstrated phasing of two mirrors at 40K





Summary

- JWST provides **m**ultiple, capabilities with R of 5 – 3000, across a wavelength range of 0.6 - 29 µm
- JWST exoplanet focus will center on transit studies of Hot Jupiters & Neptunes and Superearths.
  - ➡ Detailed high-R studies will require several visits for 0.6 - 29 µm
  - ➡ Bright limits compatible with space and ground-based surveys
  - ➡ Numerous operational capabilities to support transit observations
  - ➡ M stars Super earth characterization will be challenging for the smallest planets, & will require significant allocations of time
- Science Operations:
  - Follow HST program model
  - Need coordinated and focused effort by exoplanet community to win JWST time & fully exploit the capabilities of JWST

Thanks/Contacts

- SWG working on new white paper describing Exoplanet Spectroscopy
- Don Lindler
- NIRCam: Chas Beichman, Marcia Rieke
- MIRI: Tom Greene, George Rieke
- NIRISS/ Rene Doyon
- STScI: Jeff Valenti
- J. Lunine
- S. Seager, E. Kempton, L. Kaltenenggar, A. Mandell & Natasha Batalha