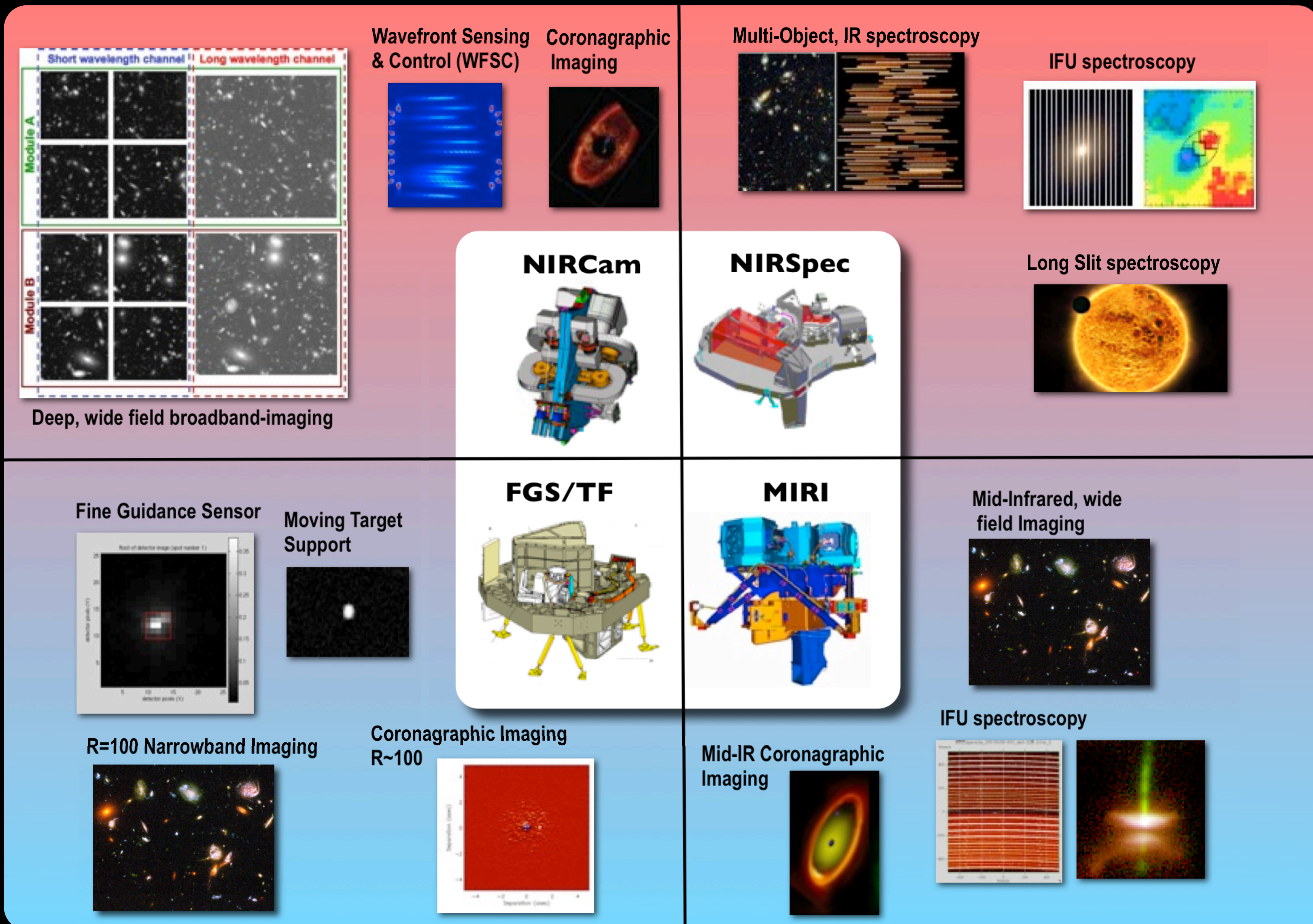
Exoplanet observations with JWST

SOFIA Community Task Force Tele-Talks
Mark Clampin
JWST Observatory Project Scientist
Goddard Space Flight Center

JWST Instruments



JWST Coronagraphs

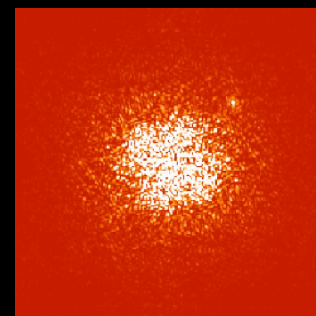
- Each JWST instrument has a high contrast imaging mode

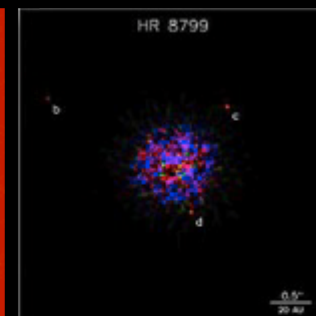
SI	Channel/Mode	λ (μm)	IWA	R (λ/δλ)	Contrast
NIRCam	Short λ Lyot Coronagraph	0.6 - 2.3	≥4λ/D	4, 10, 100	≤ 10^5
NIRCam	Long λ Lyot Coronagraph	2.4 - 5.0	≥4λ/D	4, 10, 100	~10^5
TFI	Multi-λ coronagraph	1.6 - 2.5	≥4λ/D	100	~10^6
TFI	Multi-λ coronagraph	3.2 - 4.9	≥4λ/D	100	~10^6
TFI	Non-redundant mask	1.6 - 2.5	0.5λ/D	100	~10^4
TFI	Non-redundant mask	3.2 - 4.9	0.5λ/D	100	~10^4
MIRI	Quadrant Phase Coronagraph	10.65	~3λ/D	20	~10^4
MIRI	Quadrant Phase Coronagraph	11.4	~3λ/D	20	~$5x10^5$
MIRI	Quadrant Phase Coronagraph	15.5	~3λ/D	20	~$2x10^5$
MIRI	Lyot Coronagraph	23	≥4λ/D	5	~10^5

JWST Coronagraphs

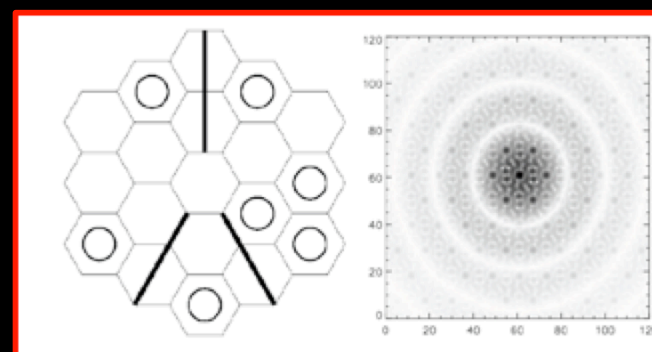
- **NIRCam**
  - Band-limited mask occulters

- **Tunable Filter Imager (TFI) Coronagraph**
  - Coronagraph: Differential Speckle Imaging
  - Contrast gain of ~10x versus NIRCam
    (Marois et al. 2008)



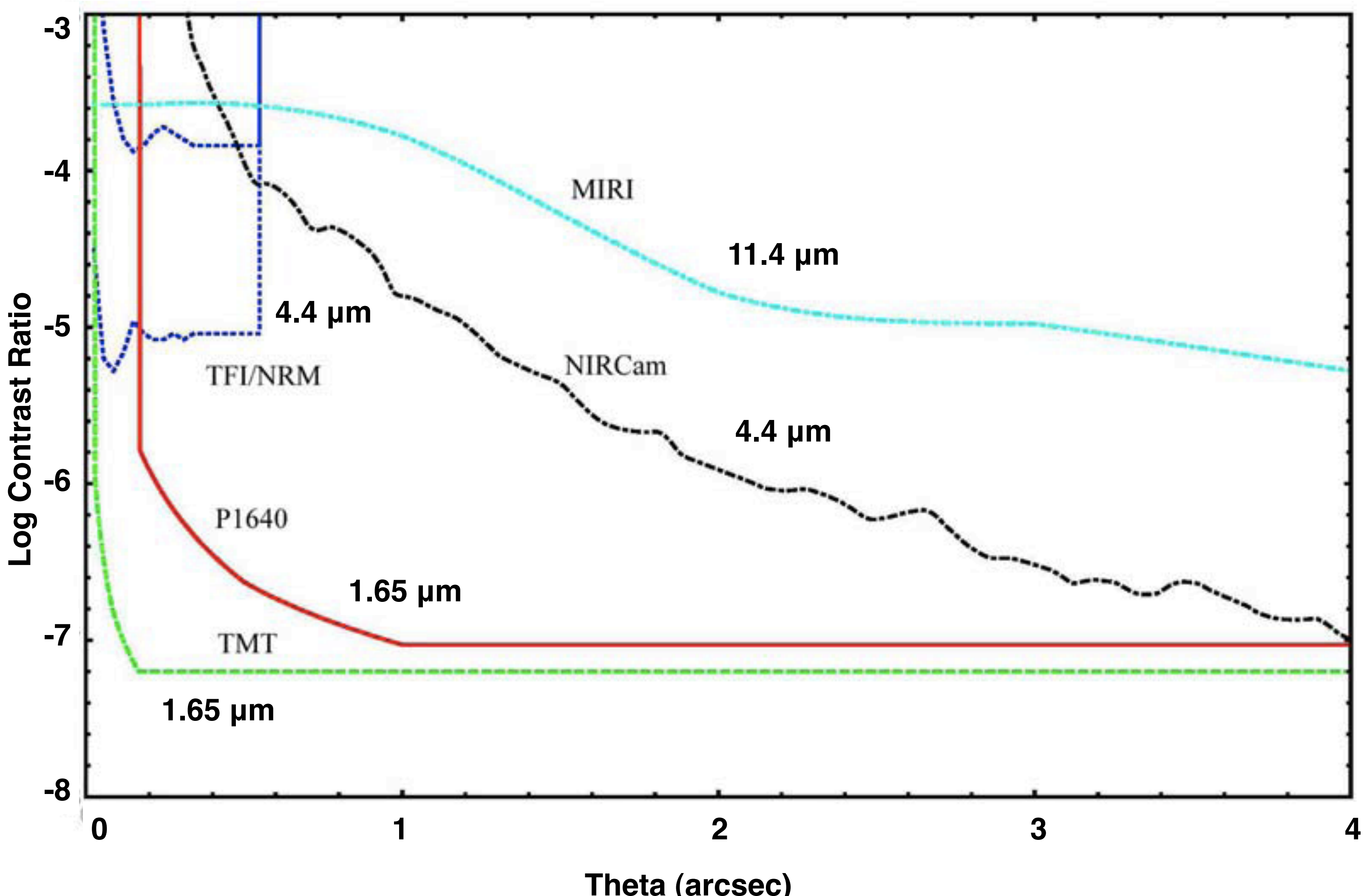


- **Non-redundant Mask**
  - Wavelength range: 1.5-2.5, 3.1-5.0 μm
  - Closure Phase Imaging
  - Trades inner working angle of 0.5 λ/D against contrast



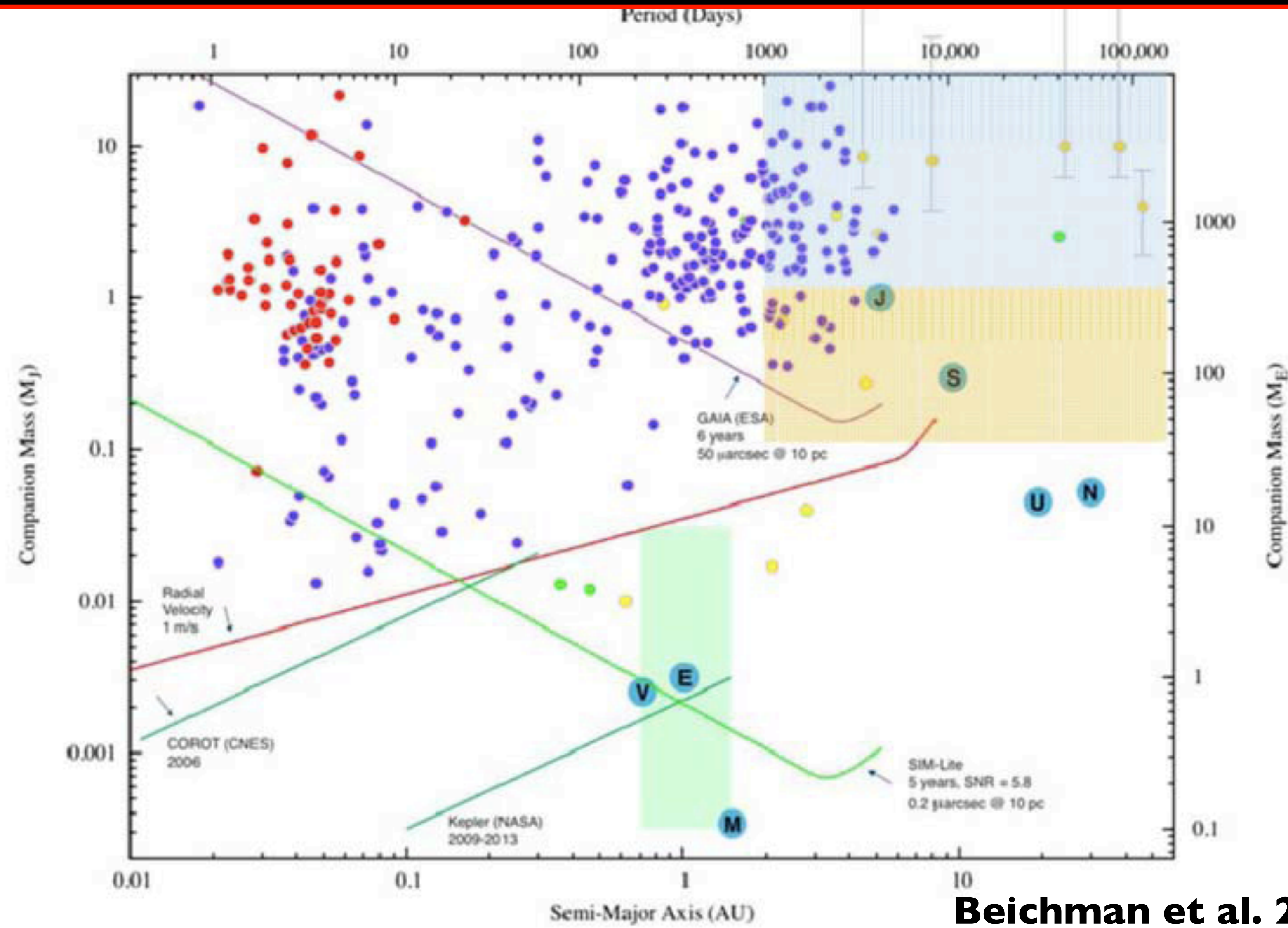
- **MIRI**
  - 3 Quadrant Phase
  - 1 Lyot

JWST Coronagraph Performance



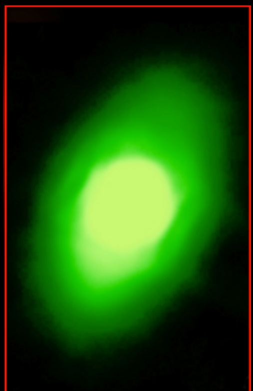
Beichman et al. 2009

Coronagraph Discovery Space

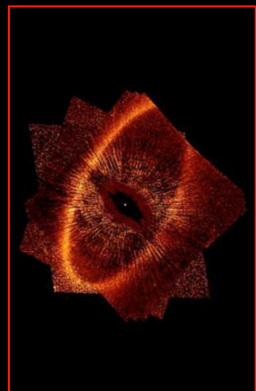


Beichman et al. 2009

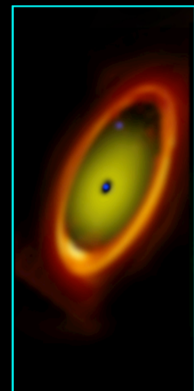
Disk Characterization



Spitzer (24 μm)

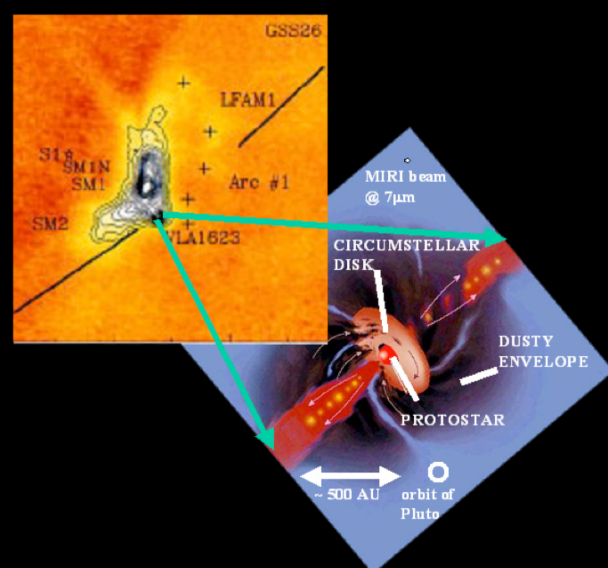


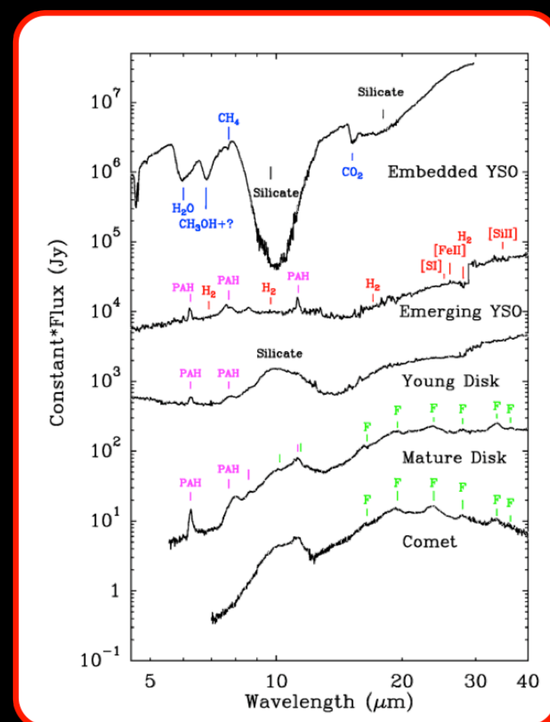
ACS (Visible)



JWST (20 μm)

- Disk morphology:
  -- scattered light & emission
- Indirect evidence of exoplanets
  - e.g. Kalas et al. (2008), Stark and Kuchner (2008)
- Spatially resolved spectroscopy
  - Disk mineralogy
- Characterize circumstellar disk evolution during the critical 5 – 30 Myr period in dense clusters out to 2kpc and down to ≤1 $M_\odot$
- Hot gas phase chemistry in future habitable zones of low mass young stars





JWST is Optimum for Transit Science

- SWG review of capabilities for transit science ➠ Report
- Low background: L2 orbit & cryogenic telescope
- Apertures: Slitless and/or large slit spectroscopy
- Long dwell times: L2 orbit
- Image quality:
  - Stable PSF (also, OTE has many Degree of Freedom)
  - Pointing: Detailed error budget
- Detectors
  - Sub-arrays and "NIR direct to digital" readout (ASIC)
- Ground-testing: 3 instrument characterization phases

JWST Transit Science Instrument Modes

	Instrument Mode	λ (μm)	R (λ/δλ)	FOV	Application
Imaging	NIRCam	0.6 - 2.3 2.4 - 5.0	4, 10, 100 4, 10, 100	2 x (2.2' x 2.2') 2 x (2.2' x 2.2')	High precision light curves of primary and secondary eclipses
	NIRCam (Defocused)	0.6 - 2.3	4, 10, 100	Defocused images radius = 0.74" radius = 1.42" radius = 2.11"	High precision light curves of primary and secondary eclipses for - bright targets that need to be defocused to avoid rapid saturation - reduction of flat field and pointing errors
	MIRI	5 - 28	4 - 6	1.9' x 1.4'	High precision light curves of secondary eclipses
	TFI	1.6 - 2.6 3.2 - 4.9	100	2 x (2.2' x 2.2') 2 x (2.2' x 2.2')	High precision light curves of primary and secondary eclipses - bright targets that need to be defocused to avoid rapid saturation
Spectroscopy	NIRCam	2.4 - 5.0	1700	2 x (2.2' x 2.2')	Transmission and emission spectroscopy of transiting planets
	NIRSpec	1.0 - 5.0	100, 1000, 2700	1.6" x 1.6"	Transmission and emission spectroscopy of transiting planets
	MIRI-LRS	5 -11	100	Slitless	Emission spectroscopy of transiting planets - Low spectroscopy
	MIRI-MRS	5.9 - 7.7 7.4 - 11.8 11.4 - 18.2 17.5 - 28.8	3000 3000 3000 3000	3.7" x 3.7" 4.7" x 4.5" 6.2" x 6.1" 7.1" x 7.1"	Emission spectroscopy of transiting planets - suitable for specific spectral features e.g. CO_2 @ 15 μm

- **NIRCam Defocused imaging for transit photometry: 4λ, 8λ, 12λ waves**

NIRCam Capabilities

- **High precision two-channel photometry**
  - → Primary transits (short-λ) & Secondary transits (long-λ)
  - Precision terrestrial planet light curves
  - Exoplanet mass and radii (w/radial velocity)
  - Transiting timing – detection of unseen planets
  - Detection of moons, trojans and planetary rings
  - Reflectance/Thermal phase variations across the whole light curve: exoplanet atmospheric dynamics
- **Long-λ spectroscopy (2.4 - 5.0 μm)**

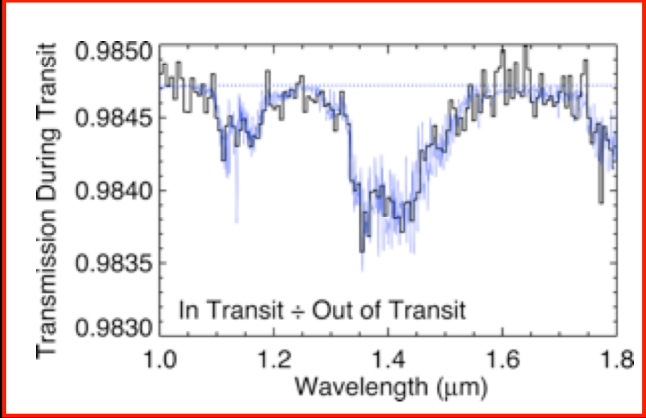
  Primary and secondary transits of hot Jupiters (R≤1000)

  Secondary transits of hot earths R~50

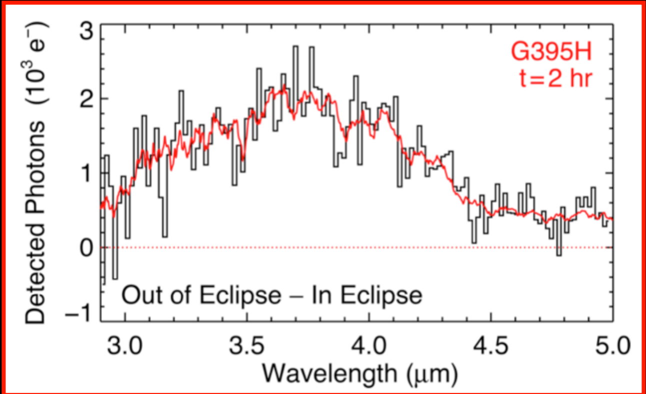
NIRSpec Science

- Recently added 1.6’x1.6” slit for transits
- Short-λ and Long-λ spectroscopy
  - Primary and secondary transits
  - Hot Jupiters: NIRSpec can obtain spectra at a range of spectral resolutions. For the bright host stars it can conduct high precision transit spectroscopy (GKM stars) to characterize spectral features
  - Hot-Neptunes: NIRSpec can obtain transit spectra at a range of spectral resolutions. For the bright host stars it can conduct high precision transit spectroscopy (GKM stars) to characterize spectral features
  - Superearths: NIRSpec can obtain emission spectra of superearths, and detect spectral features in transmission for some atmospheric compositions (M star hosts)

NIRSpec Transit Spectrum for HD 209458 at K=12



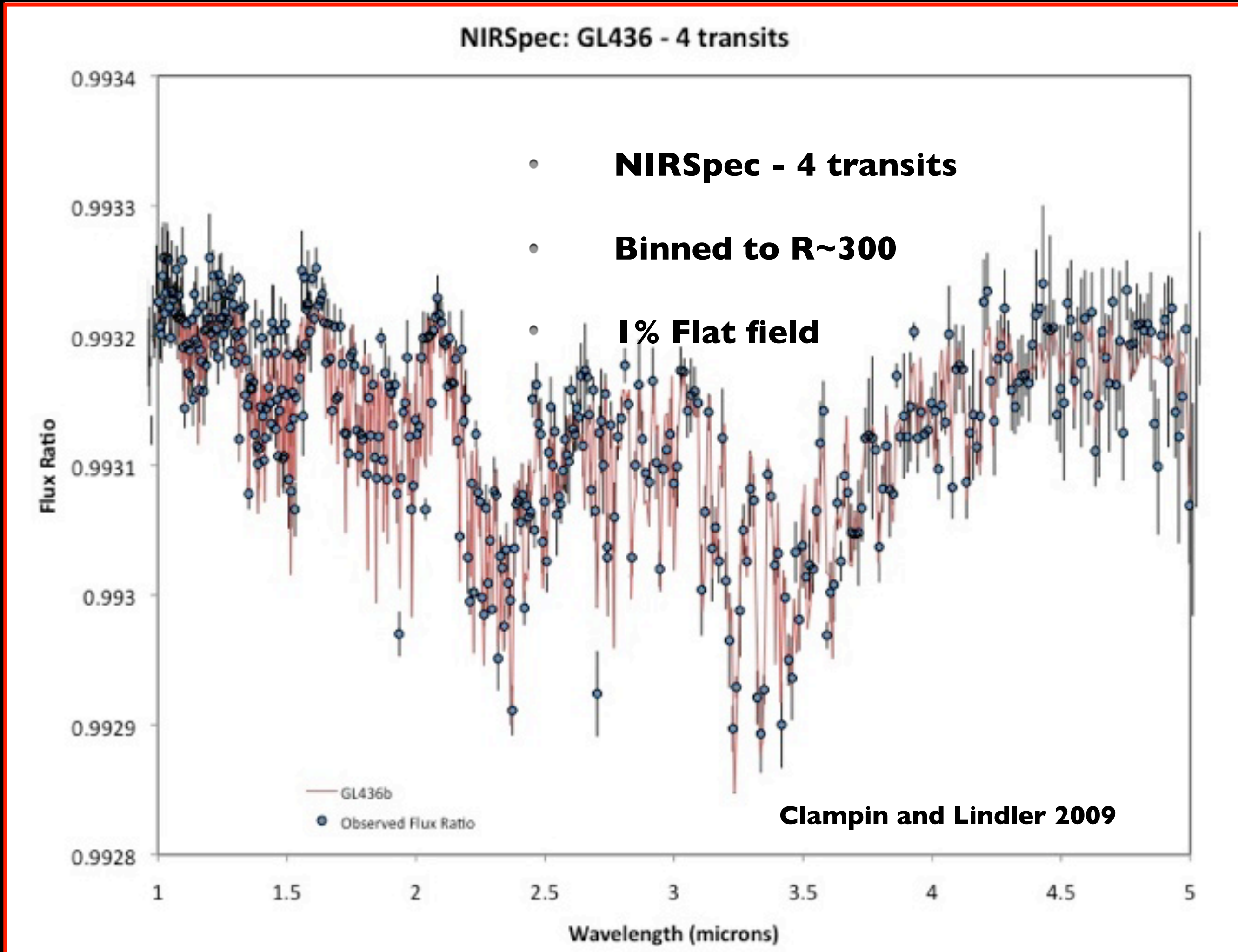
NIRSpec Emission Spectrum for HD 209458 at K=12



Simulations by Jeff Valenti (NIRSpec Science Team)

GJ436: Simulated Transmission Spectrum

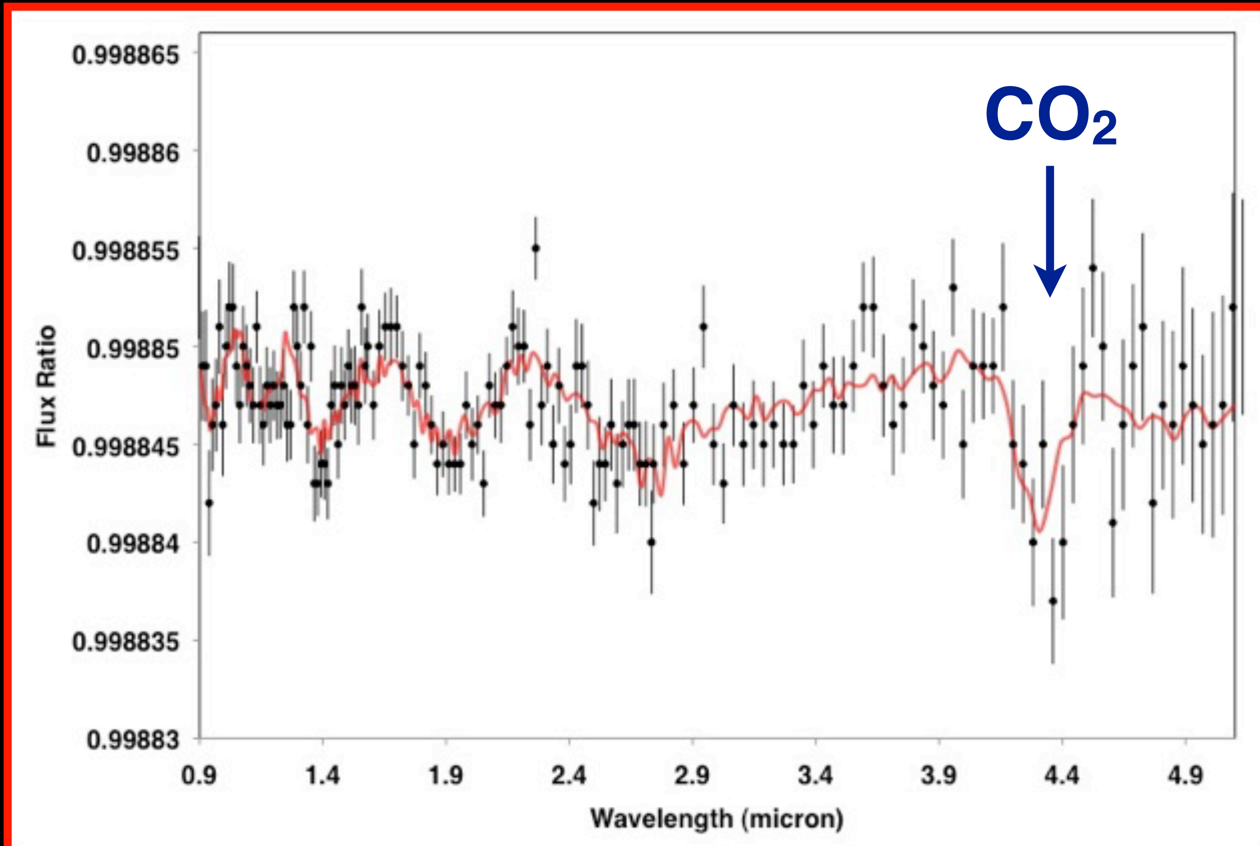
- High precision spectra of gas and ice giants



Model GJ436 provided by Sara Seager

Intermediate Superearth

- **True Superearths are challenging**

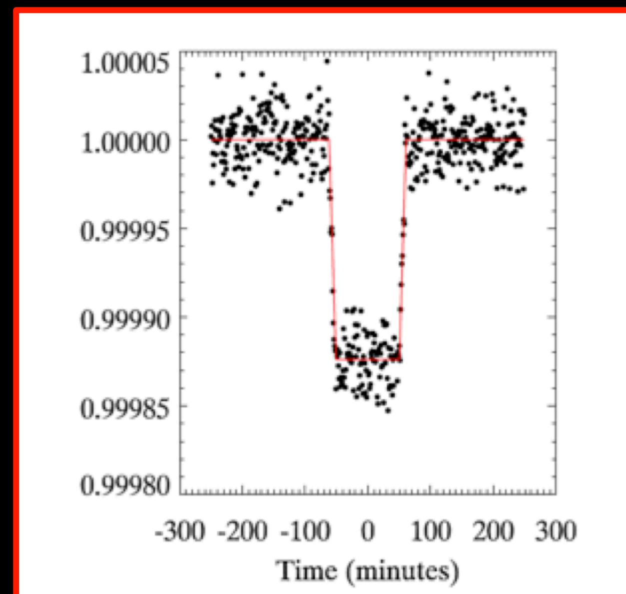


- **NIRSpec - 100 transits, Binned to R=100**
- **For multi-transit observations: sky location will be important**

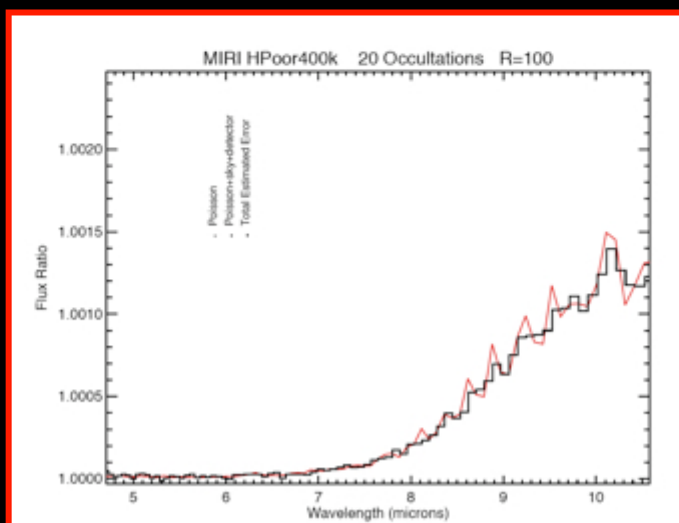
MIRI Science

- **MIRI slitless spectroscopic mode (Low Resolution Spectrograph)**
  - Detection of R~100 hot-Jupiter emission spectra in a single transit
  - Detection of small (1-2 R_{Earth}) planets transiting G, K & M stars

- **MIRI Medium Resolution Spectrograph**
  - Best applied to detection of specific spectral features e.g. CO_2 feature at 15 μm



Secondary Eclipse of a hot (T~500K) exo-Neptune observed at 15 µm (Deming et al. 2009)



JWST Transit Science Summary

Observation	Targets	R	Science
Transit light Curves	Gas giants Intermediate planets Superearths	5 5 5	- Exoplanet properties e.g. Mass, radius -> Physical structure - Confirmation of Terrestrial planet transits - Transit timing: detection of unseen planets
Phase light curves	Gas giants Intermediate planets	5 5	- Day to night emission mapping: dynamical models of Exoplanet atmospheres
Transmission Spectroscopy	Gas giants Gas giants Intermediate planets Superearths planets	3000 100-500 100-500 ≤100	Spectral line diagnostics - atmospheric composition e.g. C, CO_2, CH_4 - follow-up of survey detections: TESS & Kepler
Emission Spectroscopy	Gas giants Gas giants Intermediate planets Superearths planets	3000 100-500 100-500 ≤100	- Spectral line diagnostic - Planet temperature measurements - follow-up of survey detections: TESS & Kepler

- Characterization of habitable superearths
  - e.g. Kaltenegger & Traub, 2009, Palle et al. 2009, Deming et al. 2009
  - Spectral characterization of habitable superearths with late type parent stars will require ≥ 100 transits (spectroscopy or filter-imaging)

Collaborators

- JWST Science Working Group
  - JWST Science Instrument Teams:
    inc. Tom Greene, John Krist, Chas Beichman
  - JWST Transit Working Group
- Eliza Miller-Ricci (MIT), Sara Seager (MIT) and Dimitar Sasselov (CfA)
- Drake Deming (GSFC)
- Don Lindler (SigmaSpace)

- Web Site: http://jwst.gsfc.nasa.gov/