NIRCam: A Revolutionary Near-IR Capability with JWST

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Société Française d'Astronomie & d'Astrophysique (SF2A)

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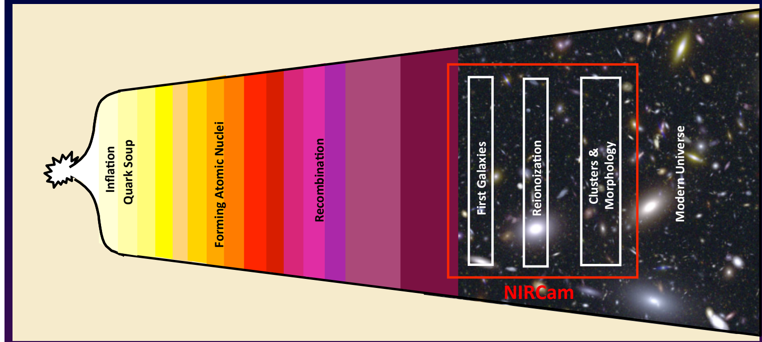
Science Goals Require 1-5 μm Performance

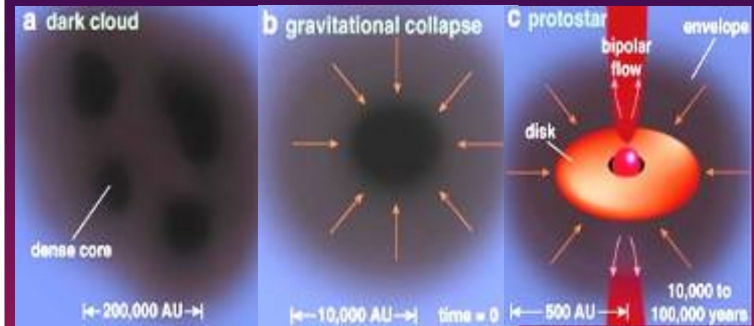


First Light and Reionization: Conduct deep surveys to find and categorize objects.

Broadband, high sensitivity, large FOV, diffraction-limited PSF, multiple broadband filters

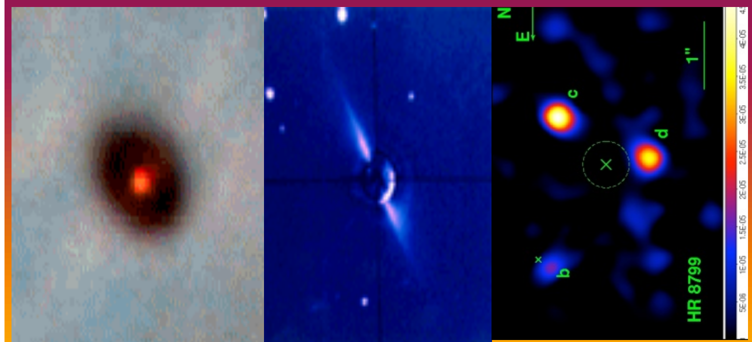
The Assembly of Galaxies: Measure shapes and colors of galaxies, identify young clusters

Broadband, high sensitivity, large FOV, diffraction-limited PSF



The Birth of Stars & Planets: Determine colors and numbers of stars in clusters, measure extinction profiles in dense clouds

Broad and narrowband filters, high sensitivity, large FOV, diffraction-limited PSF, high dynamic range



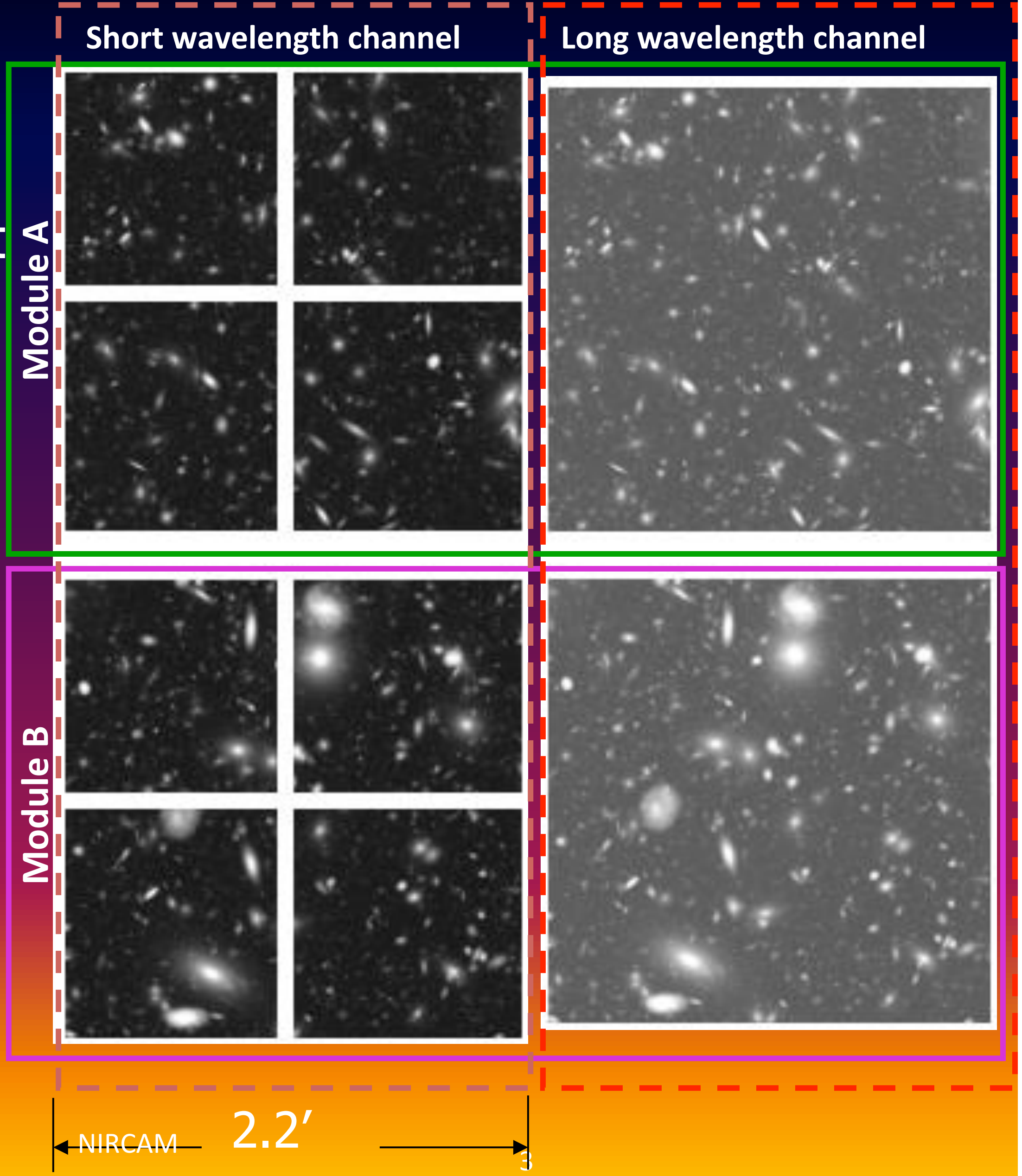
Planetary Systems and the Origins of Life:

Characterize disks and planets, classify KBOs

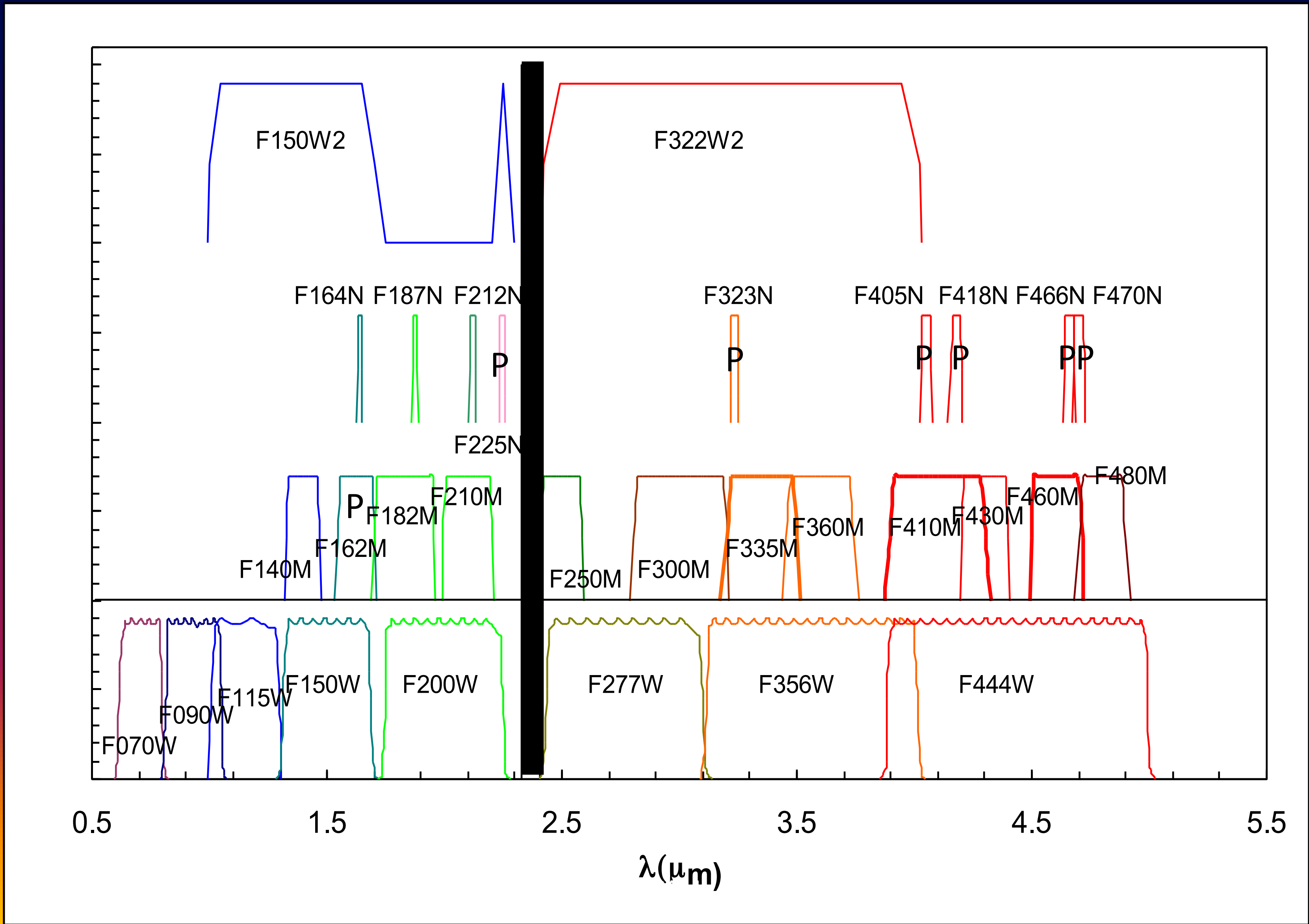
Broad and intermediate band filters, high sensitivity, coronagraphic masks, defocused images and grism spectroscopy for transits

NIRCam: Simple but Powerful Capability

- NIRCam images 0.6 - 5μm with refractive optics
  - –Dichroic splits into short (0.6-2.3 μm) and long-λ (2.4-5 μm) sections
  - –Nyquist sampling at 2 μm (0.032”/pix) & 4 μm (0.064”/pix)
  - –2.2 arcmin x 4.4 arcmin FOV in two colors (40 Mpixels) simultaneously
- 2 redundant modules
- Coronagraphs
- Grism and defocus lenses for science and WFS



NIRCam Filters Span 0.65 - 5 μm
For Photo-z , Galaxies, Stars, Planets, & ISM

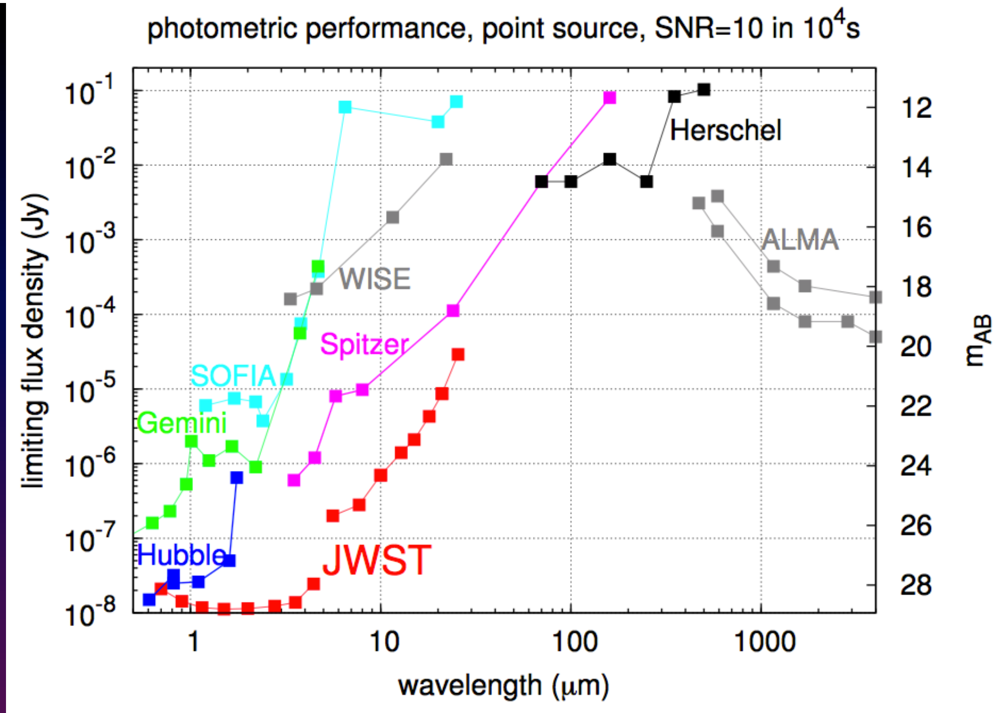


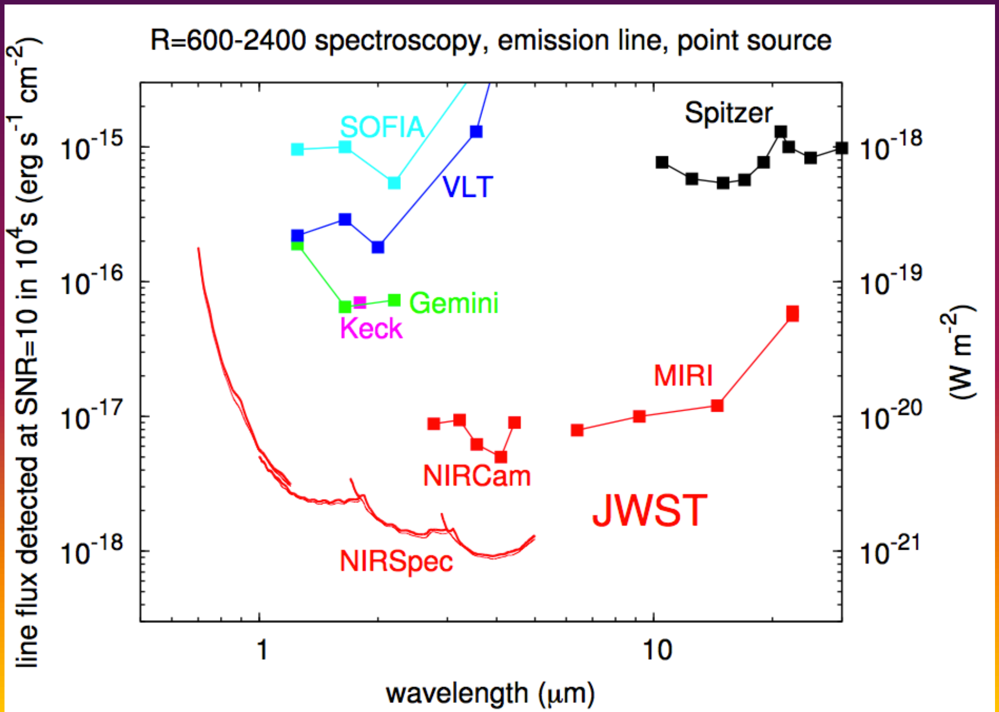
NIRCam's Revolutionary Capabilities

- Sensitivity
  - At 1-2 μm JWST is 3-4 mag more sensitive than Keck w. AO and 1-2 mag more sensitive than HST
  - At 3-5 μm JWST is 8-10 mag more sensitive than Keck and 5 mag more sensitive than Spitzer/IRAC (with no confusion limit)
- Stable high resolution PSF (<0.2" at 4.4 μm) over 4.4' field

JWST/ NIRCAM	Point Source	Keck NIRC-2 with NGS AO	Point Source	WFC3/IR or IRAC	Point Source
F115W	27.5 mag	J (Strehl=0.2)	24.4 mag	F110W	26.5
F150W	27.5 mag	H (Strehl=0.3)	23.9 mag	F160W	25.5
F200W	27.3 mag	Ks (Strehl=0.5)	23.7 mag		
F300W	26.1 mag	L' (Strehl=0.6)	18.1mag	IRAC 3.6	21.2
F444W	25.1 mag	M (Strehl=0.6)	15.6 mag	IRAC 4.5	20.4

(Vega mag, 5σ, 1hr)

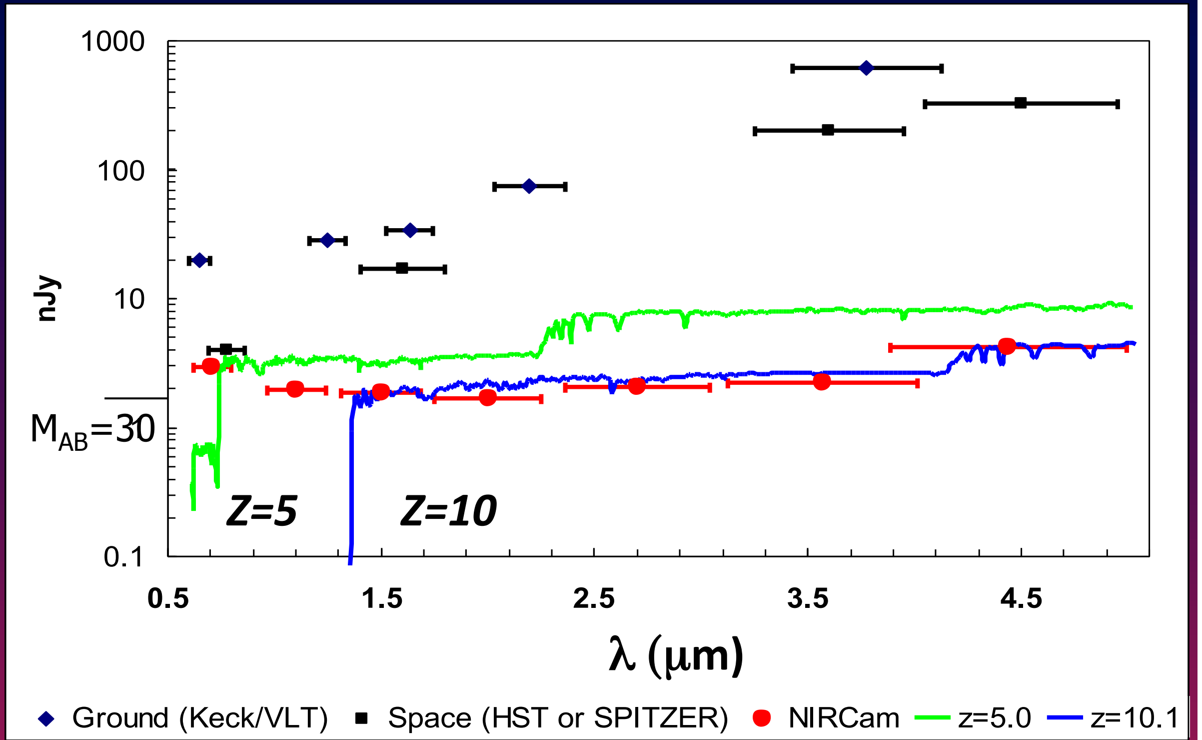




Sensitivity is superb!

Key Science Programs: First Light

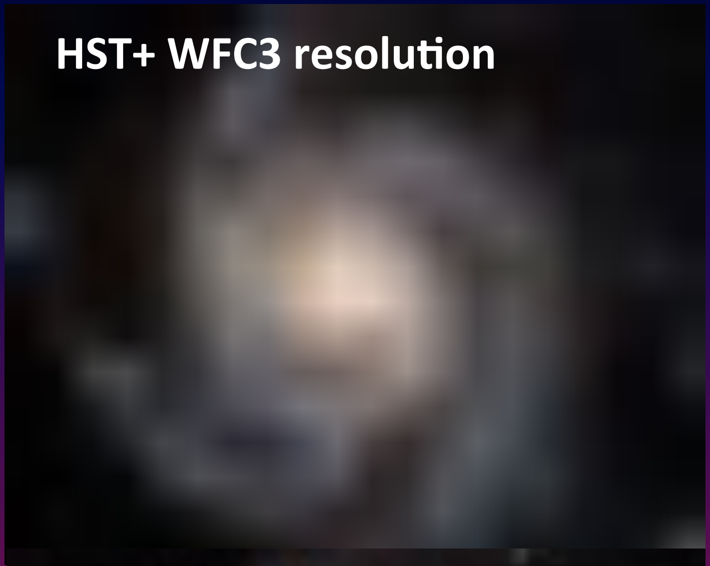
- NIRCam is 100x more sensitive Spitzer for ultra-deep surveys for youngest galaxies (z~10)
- Multi-Filter set for ~4% photometric redshifts for >98% of galaxies in multi-color survey.



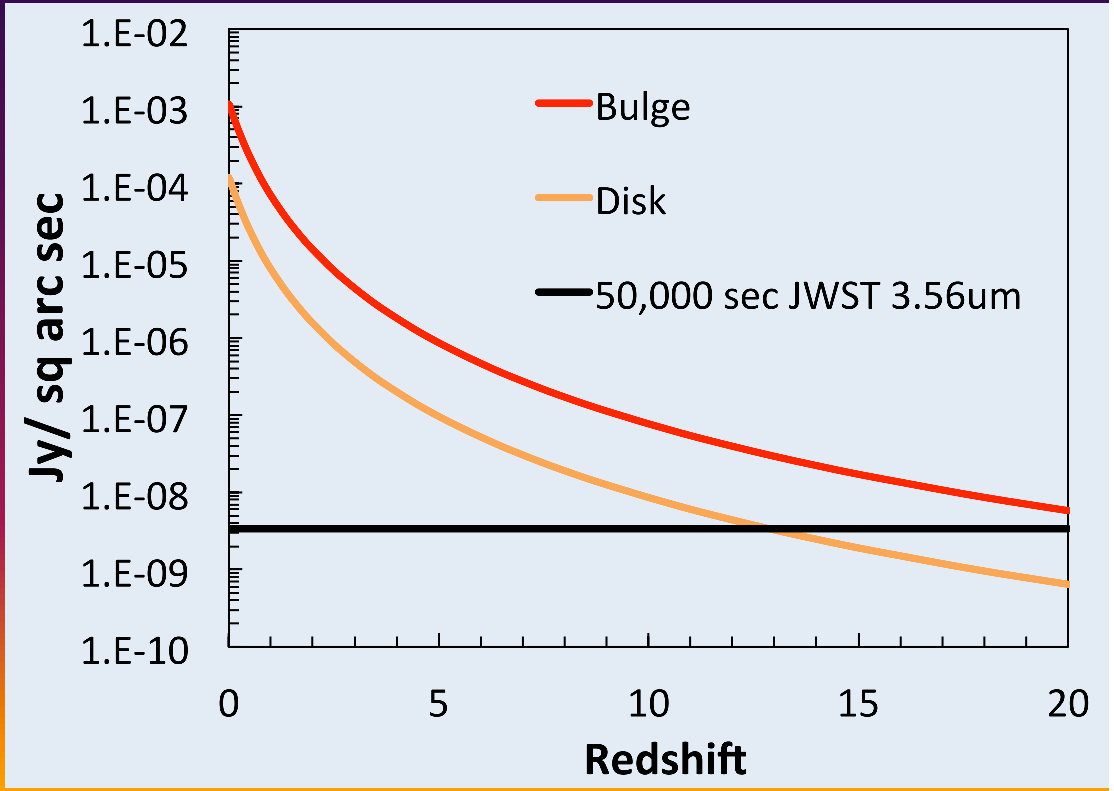
The z=10 galaxy has a mass of $4\times10^{8}M_{Sun}$

(5 hrs/filter with 10 hrs at 4.5 microns)

Key Science Programs: Assembly of Galaxies



- NIRCam's combination of sensitivity and angular resolution will reveal how galaxies develop their characteristic shapes.

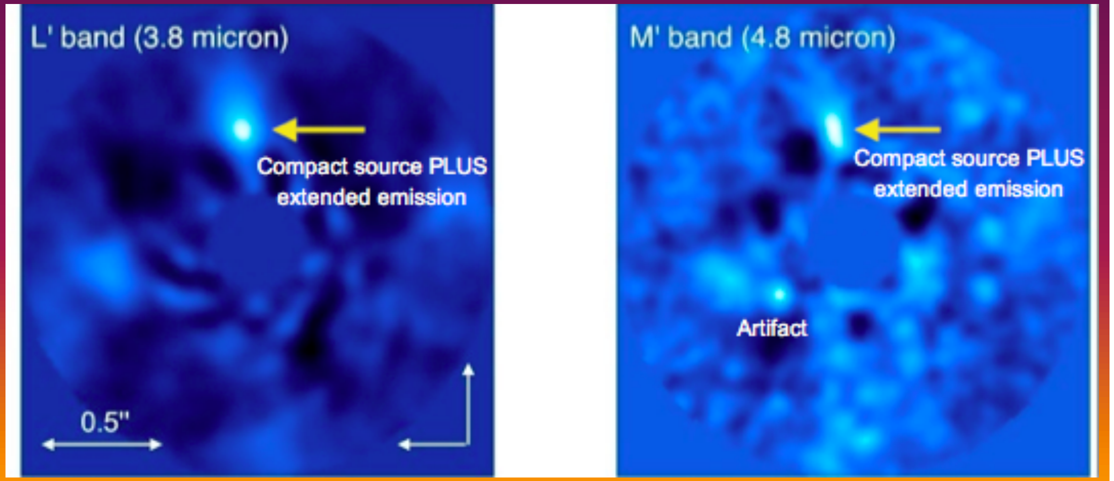


Key Programs: Star & Planet Formation

- Star formation: Near & Far
  - Star clusters (140-500 pc) to probe IMF (1 Jupiter mass)
  - Local group to study extreme star formation
  - Extinction mapping to study cloud structure & composition.

e.g. NGC 2024
(Meyer et al. 2008)
Image D. Thompson

- Planet-forming Disks:
  - Forming protoplanets
  - Image disk asymmetries.
  - Map dust, ice distribution

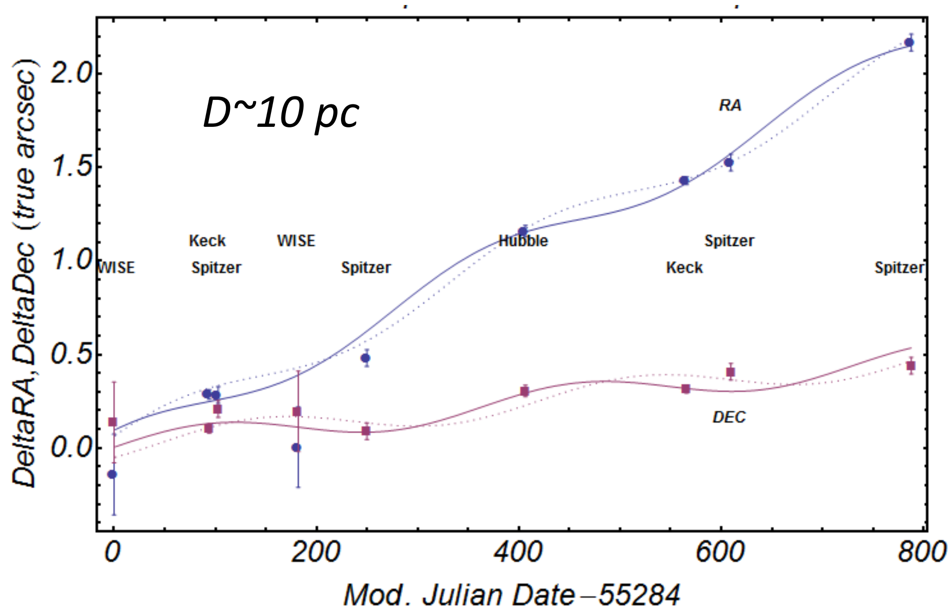


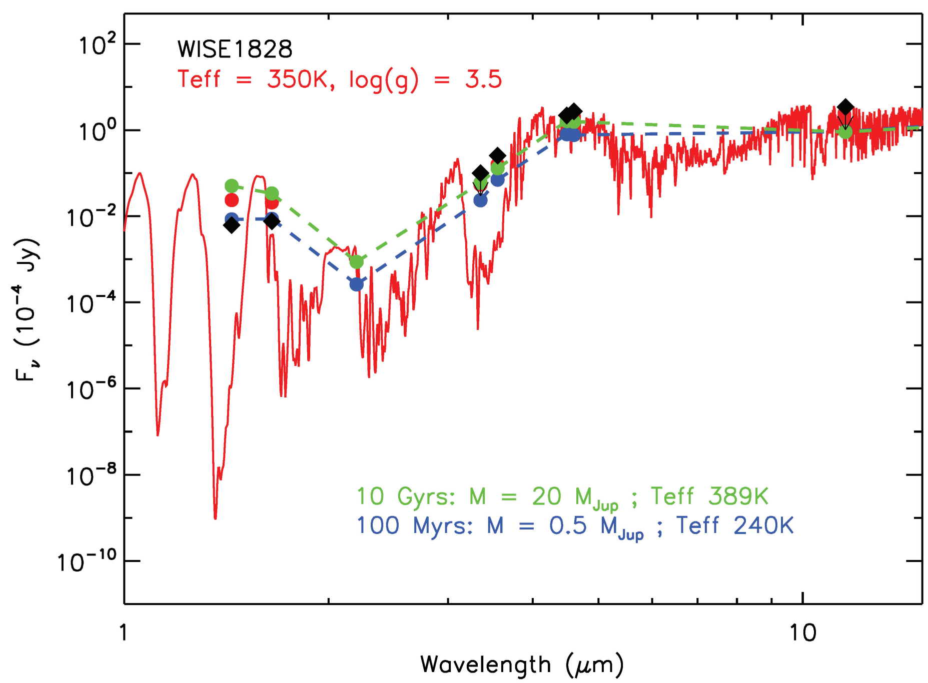
HD 100546 b (Quanz et al. 2015)

Nearby Y Dwarfs: BD or Planets?

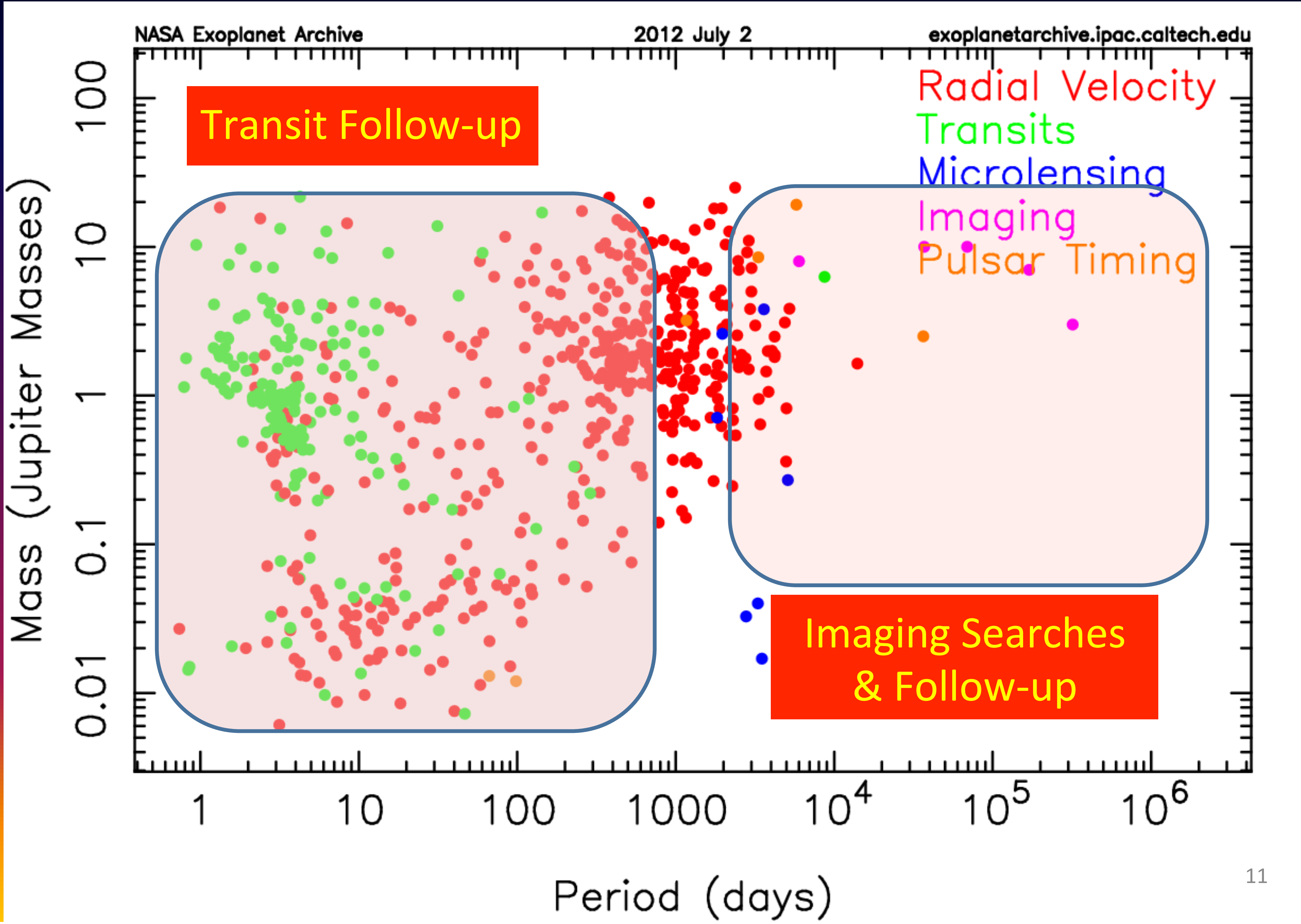
- WISE & Spitzer objects
  - T < 500 K
  - Mass ~1-20 M_{Jup}
  - Ages ~0.1-5 Gyr
  - Distances < 20 pc
- Astrometry and binarity
  - 100-200 mas parallax.
  - 10s mas orbital motions
- Bright sources (≥100 μJy)
  - Grism and NIRSpec spectra
  - Compare with spectra of bound objects.

NIF



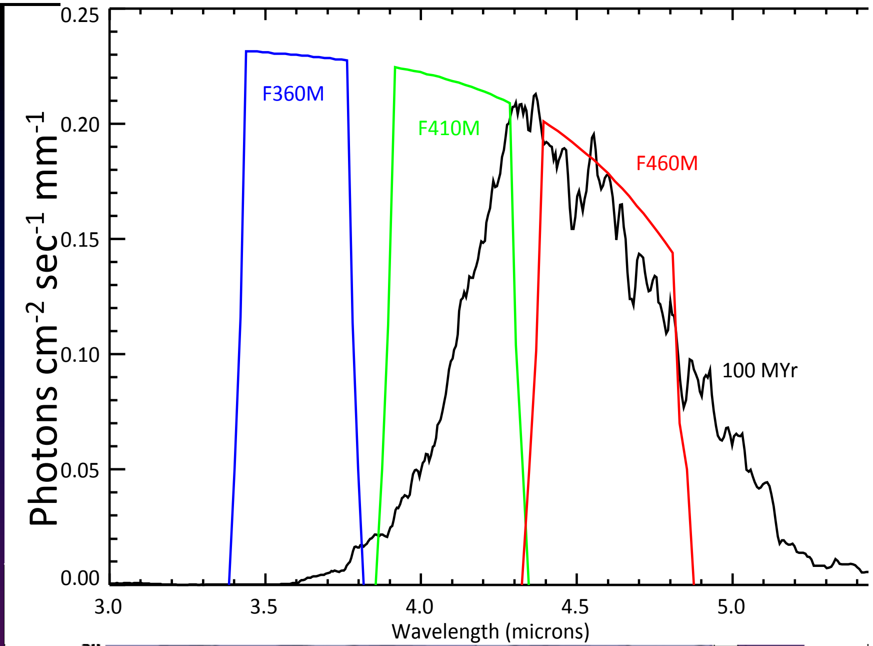


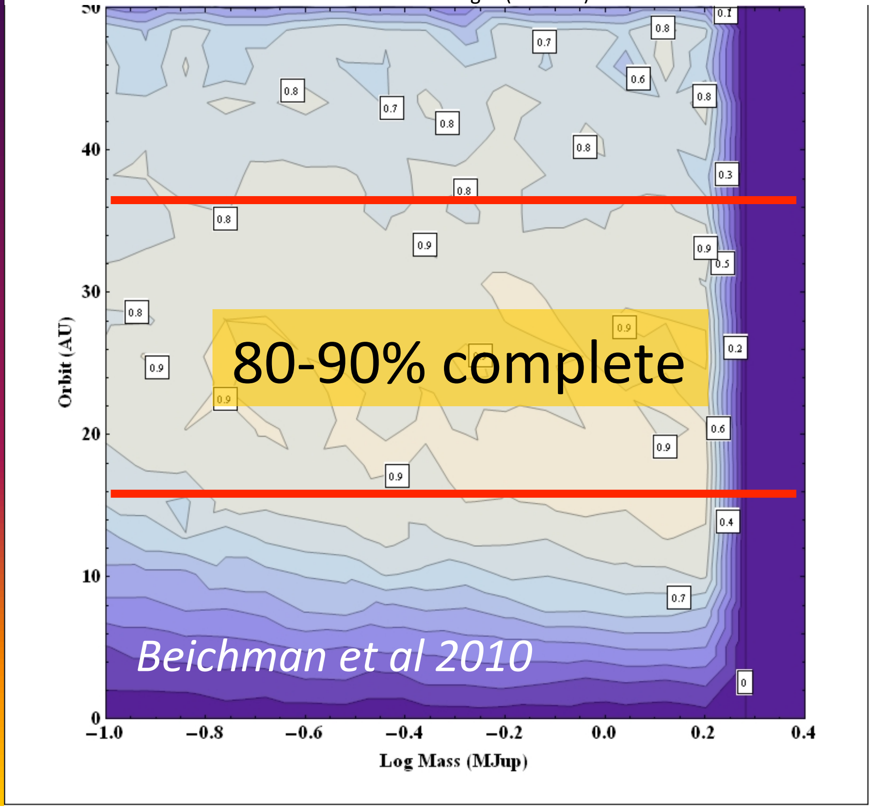
Key Science Programs: ExoPlanet Science



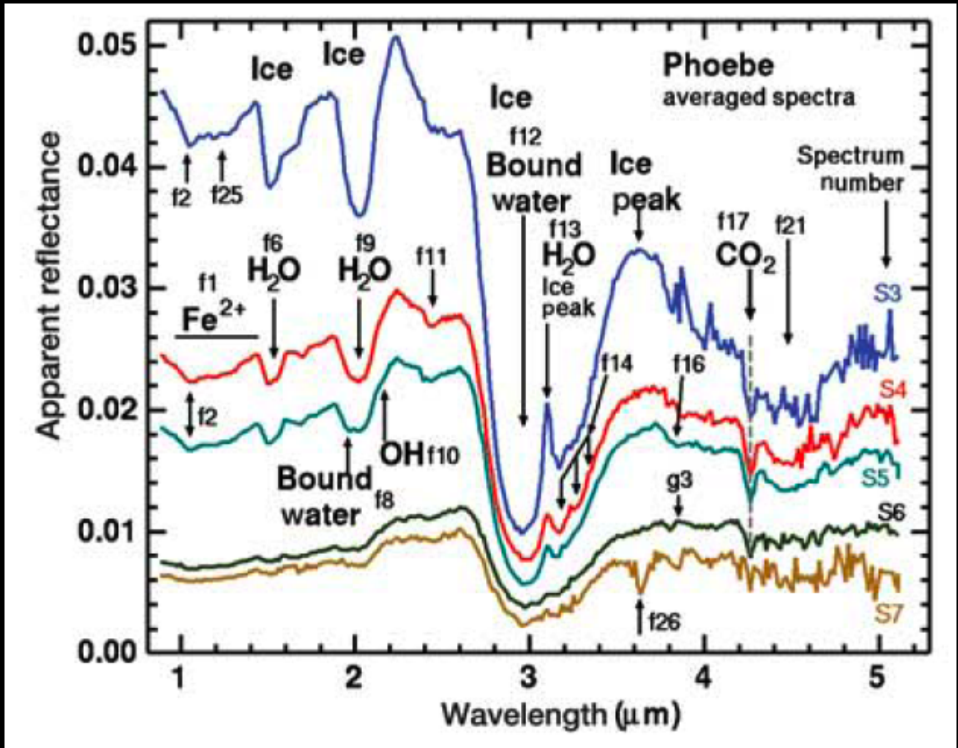
NIRCam Planet Imaging

- NIRCam super-sensitive at large inner working angles.
- Survey nearby young late-type stars for planets M≥ 0.1 Mjup > 15 AU
- Characterize well-known systems
  - Complete SEDs (NIRCam + MIRI)
  - Refine orbits w. HST, ground-based
  - Search for additional planets (≥M_{Saturn})
  - Investigate interactions with rings, incl rings inferred from Spitzer SED





Key Program: Properties of Kuiper Belt Objects

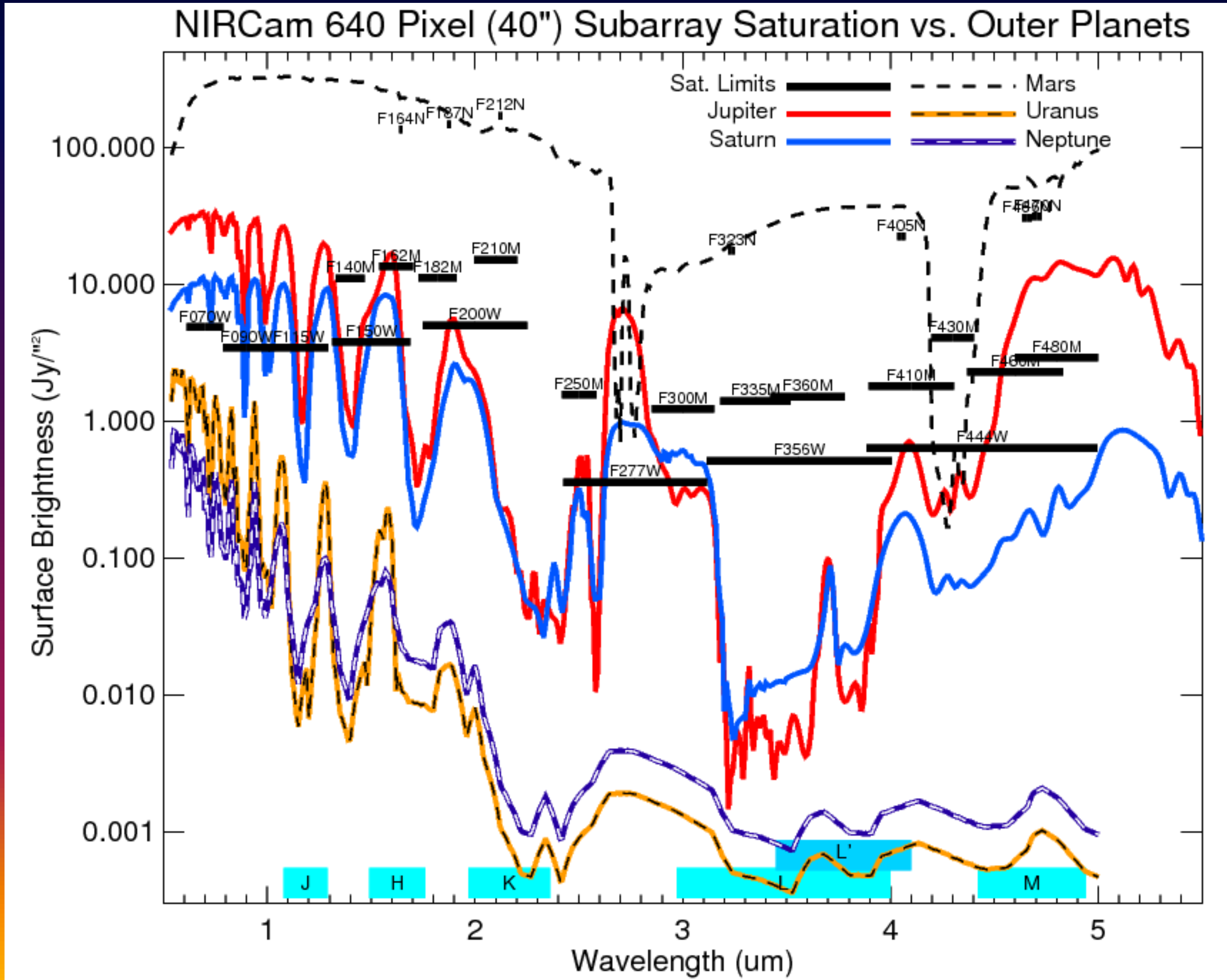


Spectra from D = 220 km "KBO", Clark et a 2005

Phoebe

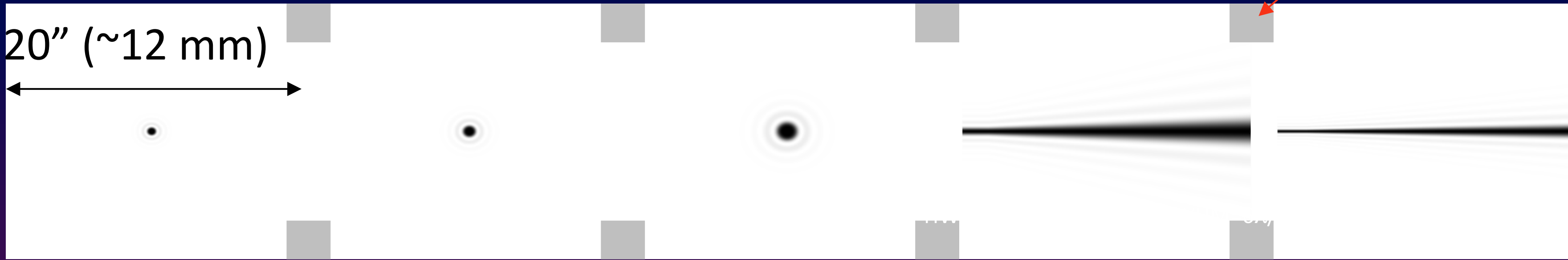
- Spectrophotometry of several KBOs d>100 km at R~100.
- Astrometry for binaries ➔ mass & density

JWST Will Study Outer Planets (Even Mars!)

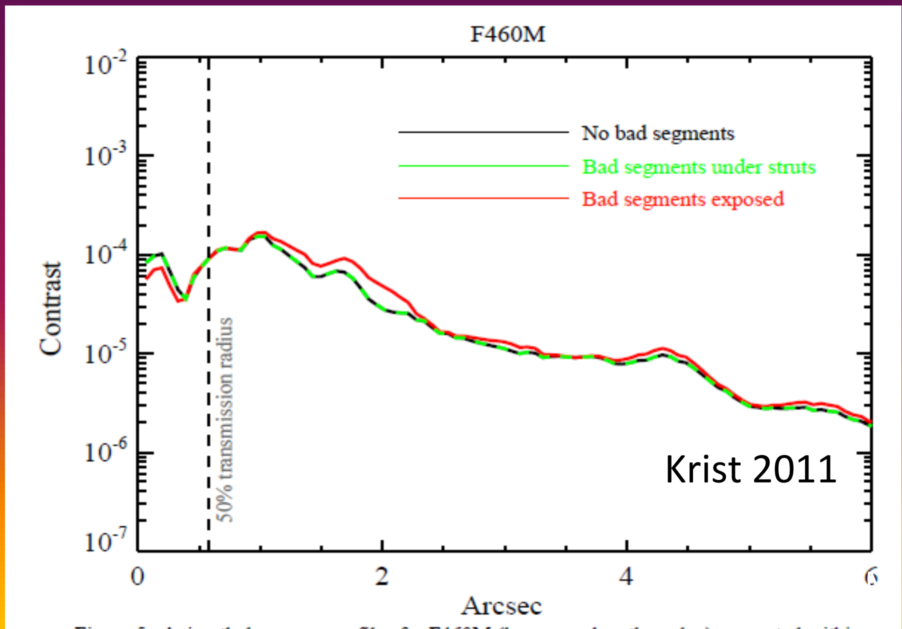


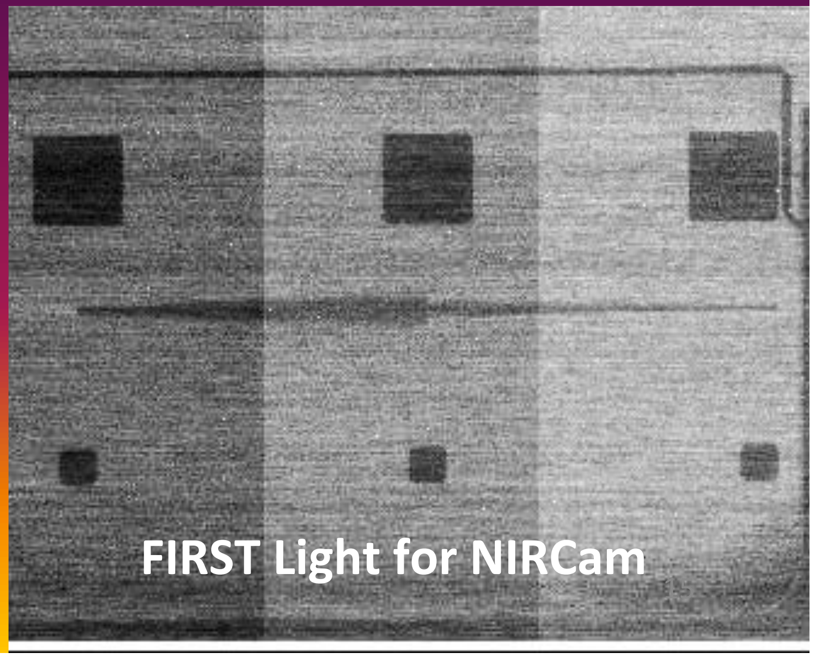
Coronagraph Status

3" x 3" ND squares



HWHM = 0.40" (6λ/D @ 2.1 μm) | HWHM = 0.64" (6λ/D @ 3.35 μm) | HWHM = 0.82" (6λ/D @ 4.3 μm) | $HWHM_c$ = 0.58" (4λ/D @ 4.6 μm) | $HWHM_c$ = 0.27" (4λ/D @ 2.1 μm)



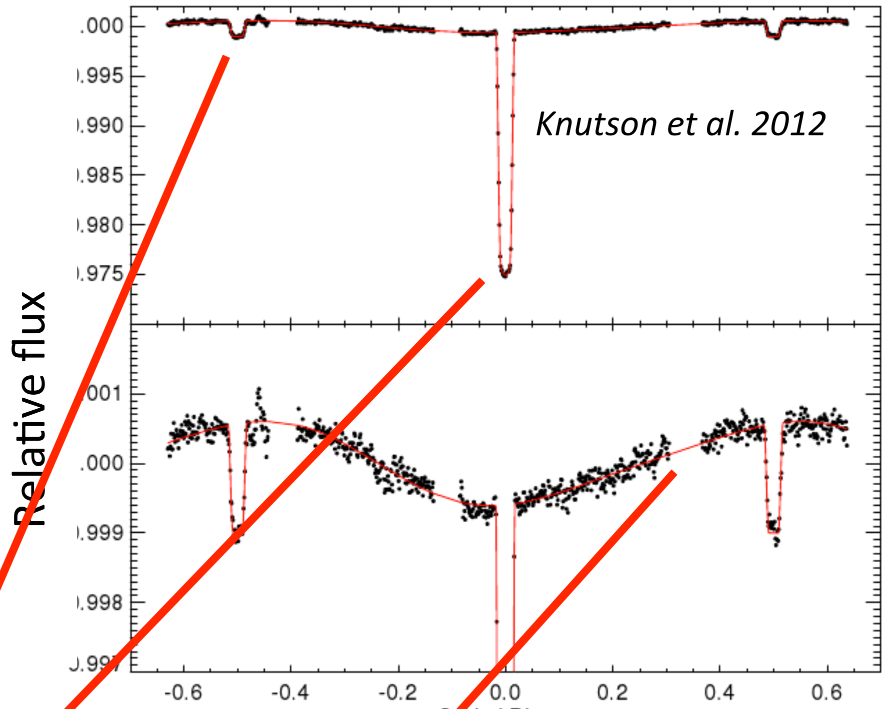


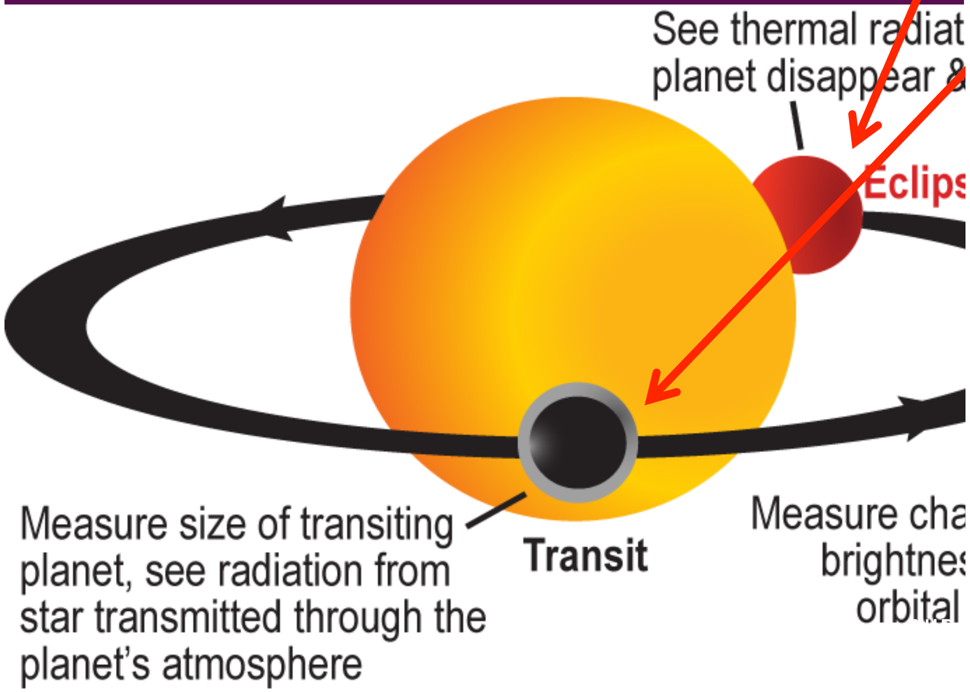
JWST Transit Science

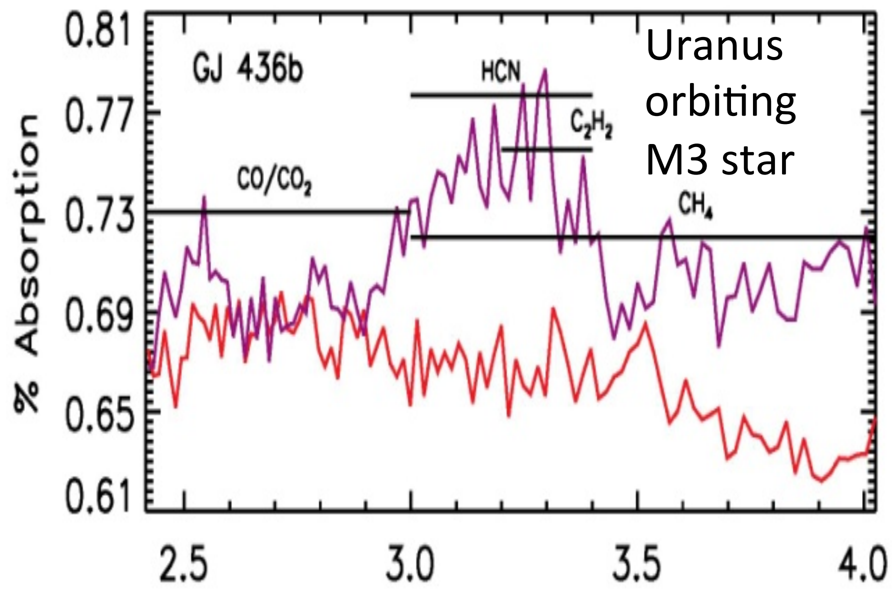
• Revolution in transit observations: 7.6xSNR(Spitzer), 2.7xSNR(HST)

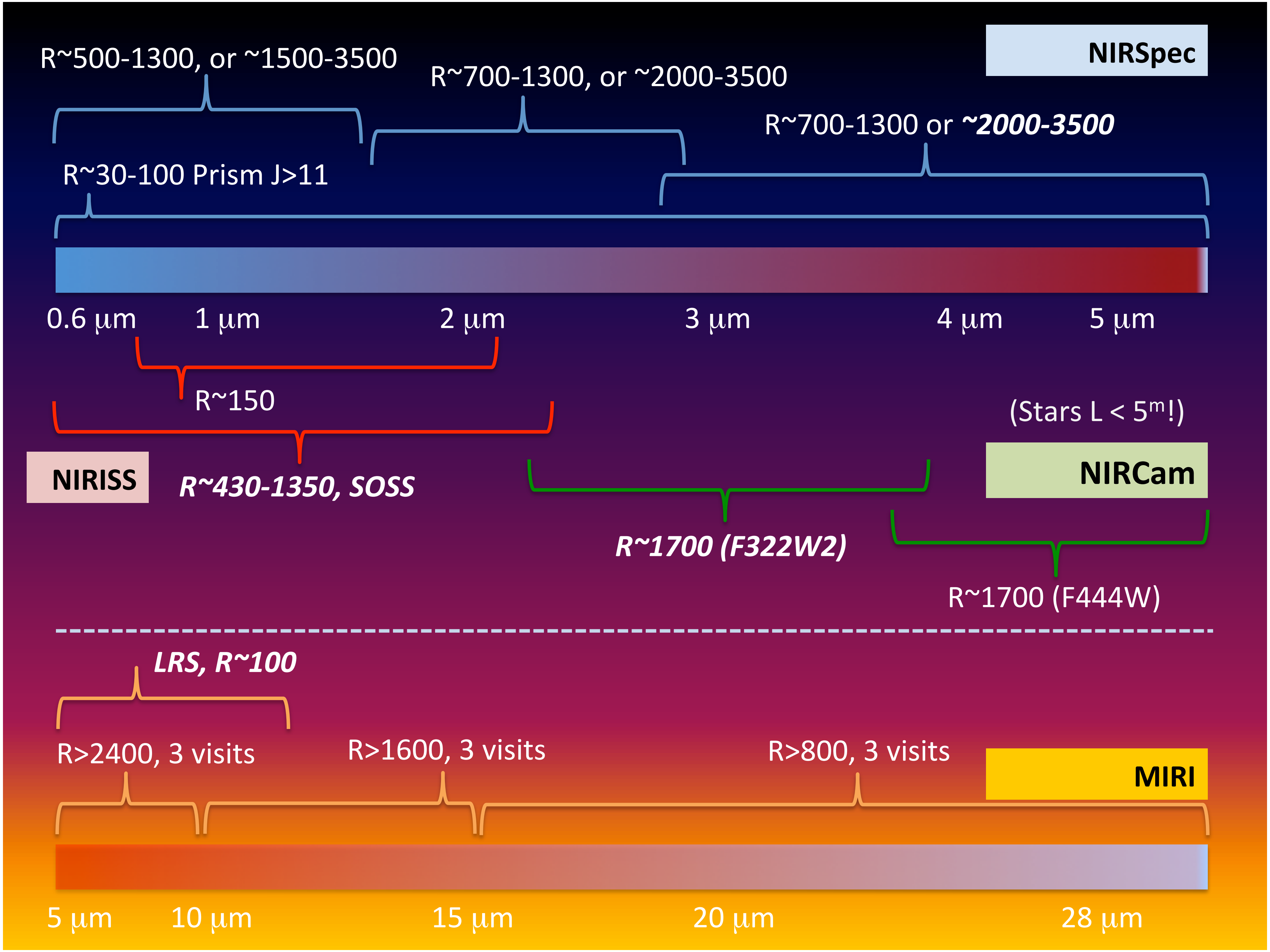
• Wide spectral coverage (0.5-20 μm) and resolution (R~5-2,000).

•Characterize atmospheres, e.g. metallicity & photochemsitry

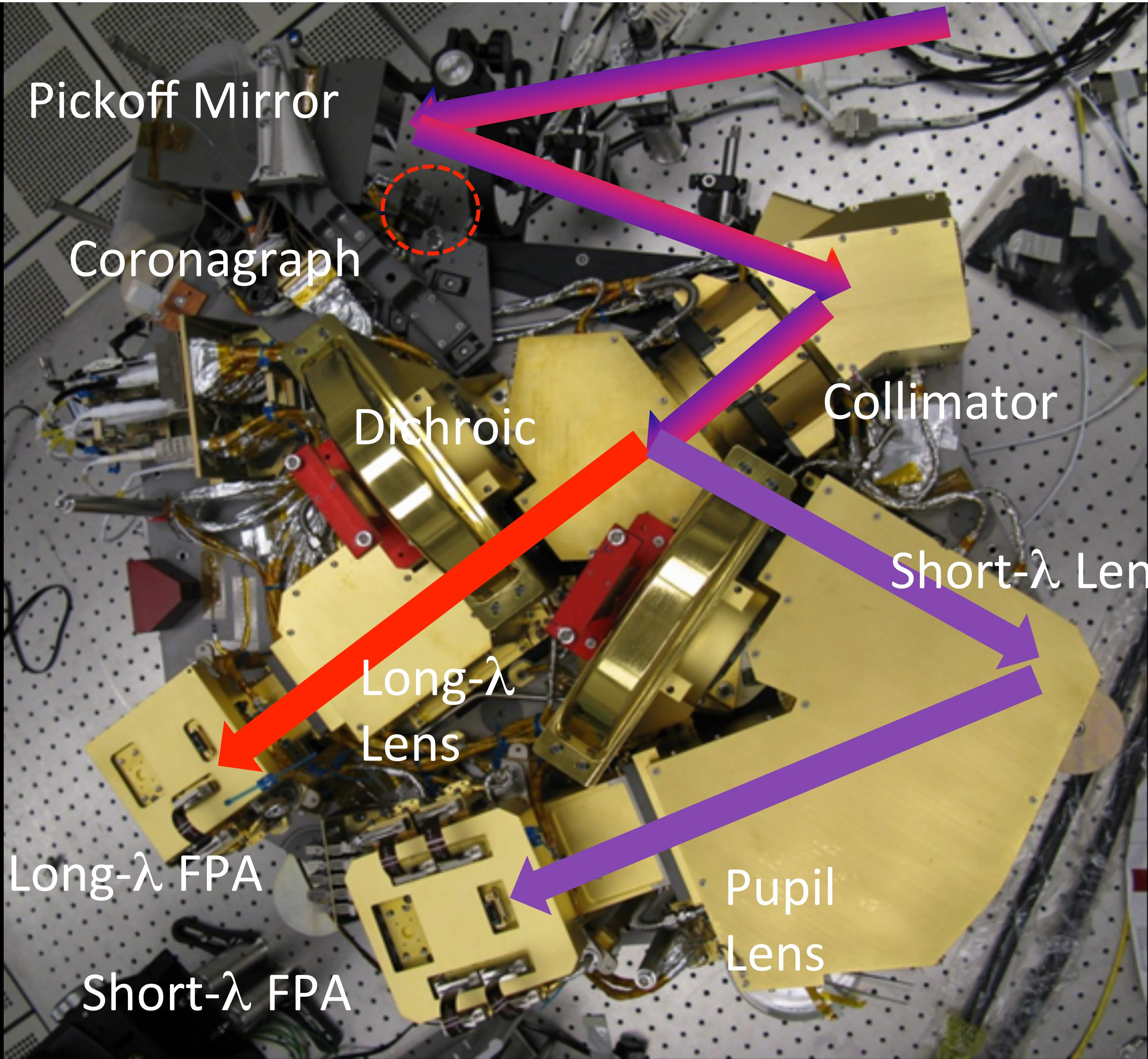




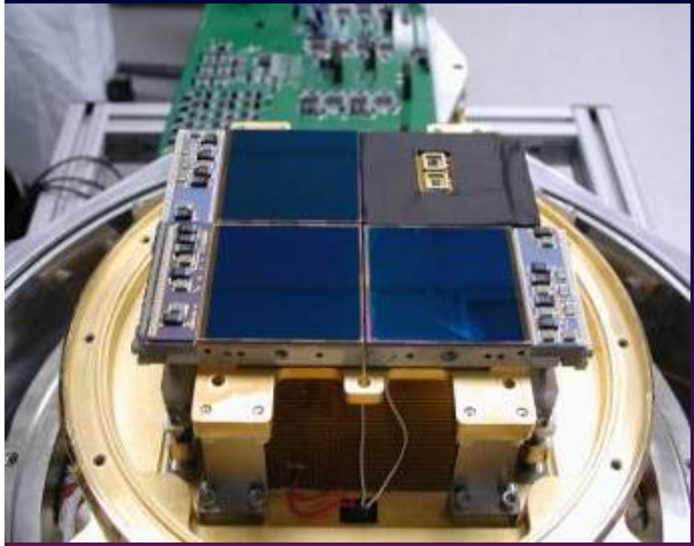




NIRSpec
R~500-1300, or ~1500-3500
R~700-1300, or ~2000-3500
R~700-1300 or ~2000-3500
R~30-100 Prism J>11
0.6 μm
1 μm
2 μm
3 μm
4 μm
5 μm
R~150
(Stars L < 5m!)
NIRISS
R~430-1350, SOSS
NIRCam
R~1700 (F322W2)
R~1700 (F444W)
LRS, R~100
R>2400, 3 visits
R>1600, 3 visits
R>800, 3 visits
MIRI
5 μm
10 μm
15 μm
20 μm
28 μm

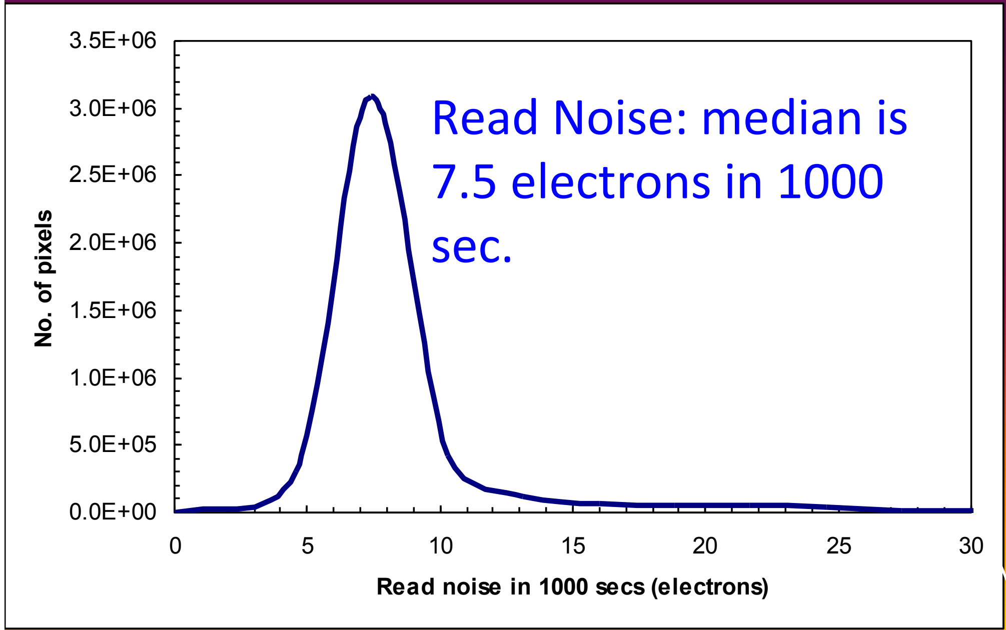

Pickoff Mirror
Coronagraph
Dichroic
Collimator
Short-λ Lens
Long-λ
Lens
Long-λ FPA
Pupil
Lens
Short-λ FPA

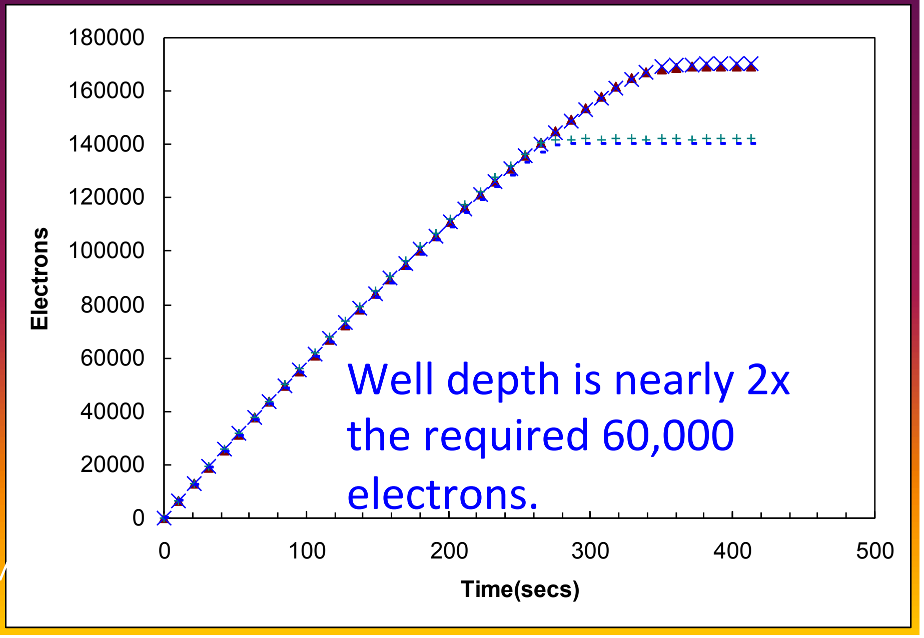
JWST HgCdTe 1-5 μm Detectors



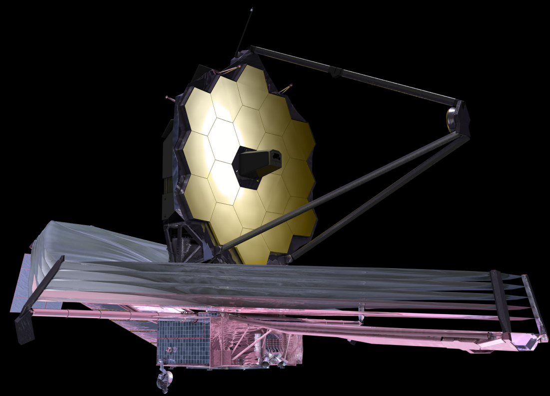
- NIRCam/NIRSpec/FGS use similar detectors.
- NIRCam uses 2.5 μm & 5.2 μm cut-off format 2040x2040 and reference pix.
- Current@37K ~.005 e/sec & QE > 80% @0.6–5 μm

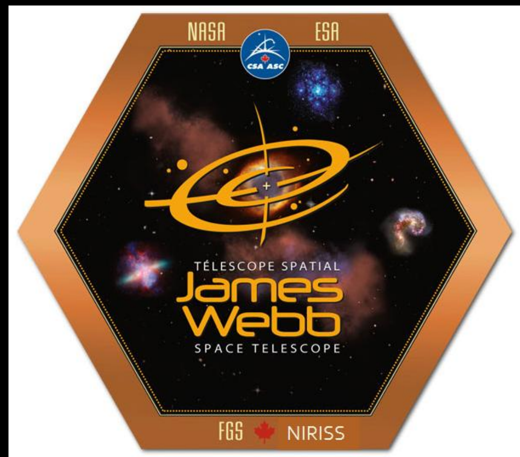
Problems along the way, but now on track!





NIRCam is Back in ISIM!





The Near-Infrared Imager and Slitless Spectrograph

NIRISS science team

- **René Doyon (PI), U. de Montréal**
- David Lafrenière, (exoplanet team leader), UdeM
- Chris Willott, (high-z galaxy team leader), NRC-Herzberg
- Robert Abraham, U. of Toronto
- John Hutchings, NRC-Herzberg
- Ray Jayawardhana, York University
- Doug Johnston, NRC-Herzberg
- Laura Ferrarese, NRC-Herzberg
- Lisa Kaltenegger, Cornell
- *Mike Meyer, ETH, Switzerland*
- Judith Pipher, U. of Rochester
- Neil Rowlands, COM DEV
- Marcin Sawicki, St-Mary's
- Anand Sivaramakrishnan, STScI

Focus on high-redshift galaxies and exoplanet science.

FGS/NIRISS overview

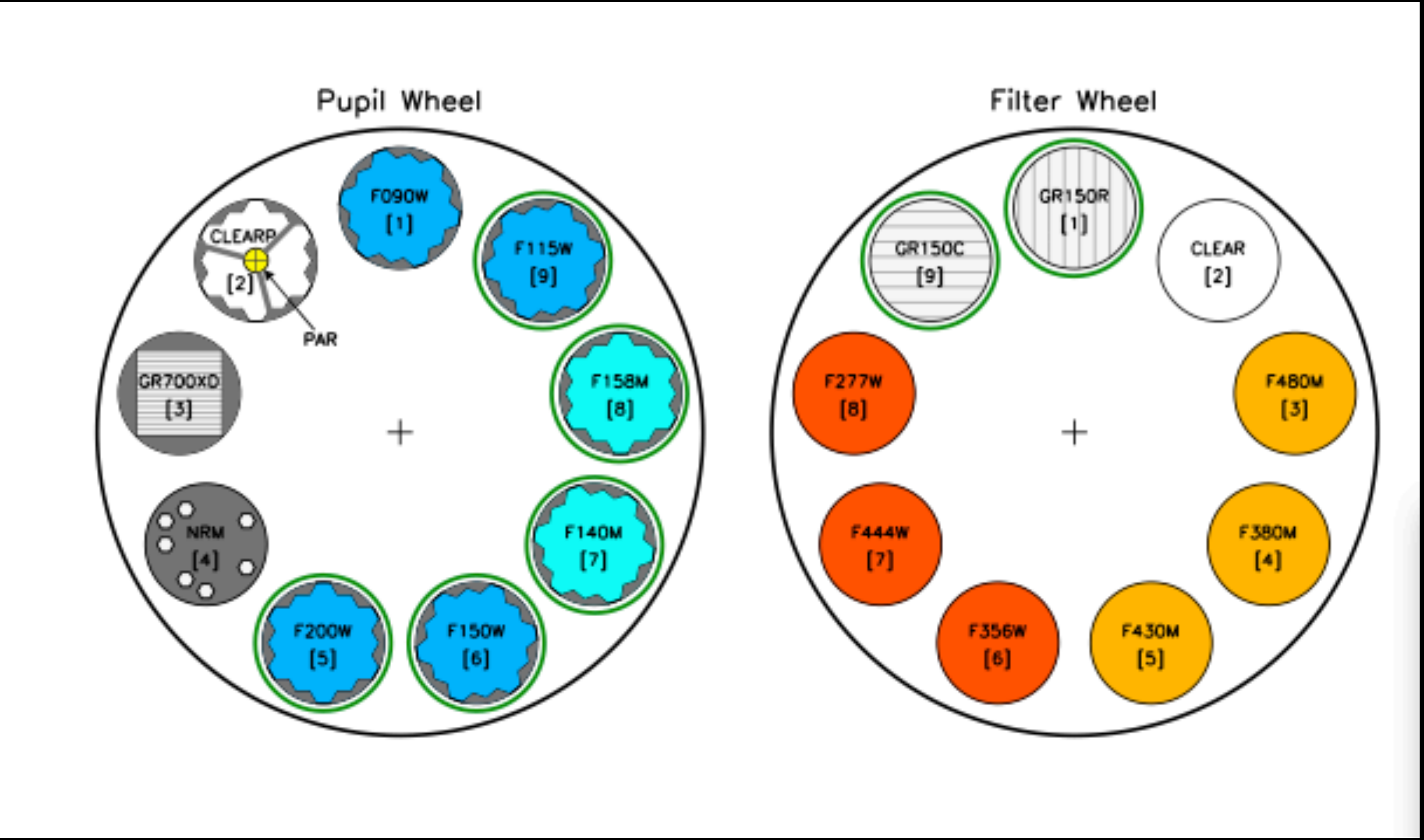
Two instruments in one box from the Canadian Space Agency

- FGS (Fine Guidance Sensor)
  - Provides fine guiding to the observatory
  - 0.6-5 µm IR camera. No filters, single optical train with two redundant detectors each with a FOV of 2.3'x2.3'
    - Noise equivalent angle (one axis): 4 milliarcsec
    - 95% sky coverage down to J_{AB}=19.5
- NIRISS (Near-Infrared Imager and Slitless Spectrograph)
  - 0.6-5 µm IR camera.
  - 4 modes: imaging, wide-field slitless spectroscopy, single object slitless spectroscopy, high-contrast imaging.

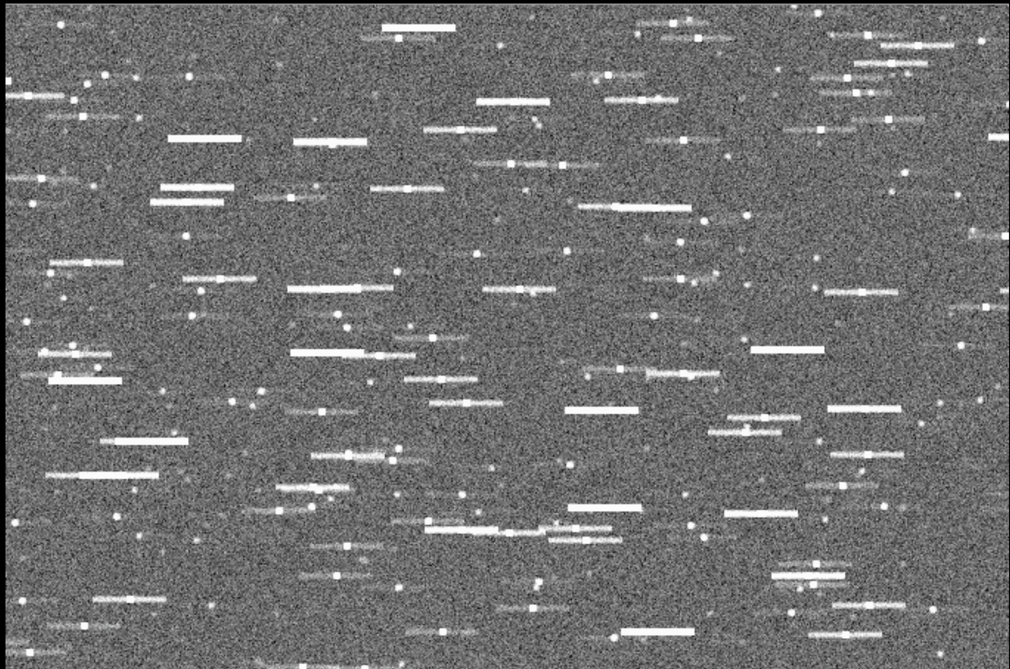
NIRISS Observing modes

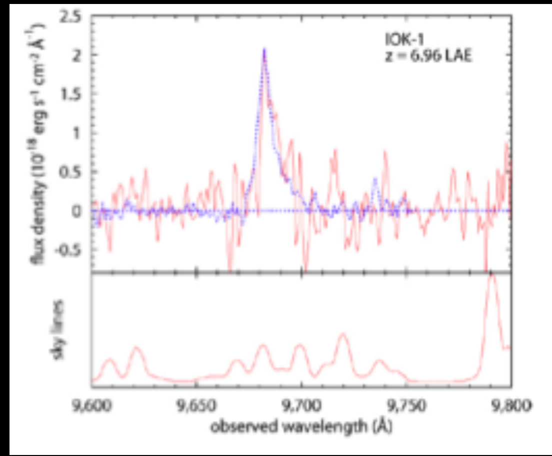
- Wide-Field Slitless Spectroscopy (WFSS)
  - Wavelength range: 1 – 2.5 µm
  - Spectral resolution: 150
  - Line flux sensitivity: (10σ 10^4s): $5x10^{-21}$ W m^{-2} at 1.5 µm with F150W filter.
  - Spectro-photometry accuracy: 10%
- Single-Object Slitless Spectroscopy (SOSS)
  - Wavelength range: 0.6 – 2.5 µm
  - Spectral resolution: 700 at 1.25 µm
  - Brightness limit: J=6.9-8
- Aperture Masking Interferometry (AMI, high-contrast imaging)
  - Wavelength range: 3.8 – 4.8 µm.
  - Three medium-band (5-8%) filters.
  - Contrast: 10^{-4} between 70 and 500 mas on 5th star at 4.8 um.
- Broad-band imaging (BBI; parallel mode only)
  - 7 NIRCam filters: F090W, F115W, F150W, F200W, F277W, F356W, F444W
  - Open (for use potentially in guide mode)

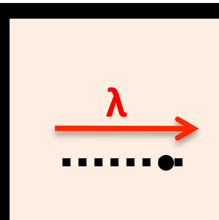
Wide-Field Slitless Spectroscopy (WFSS)

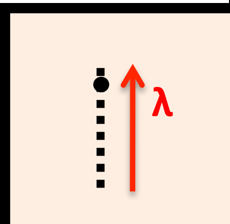


WFSS mode: two grisms with orthogonal dispersion

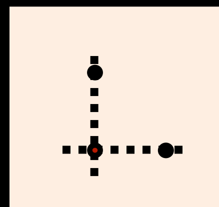






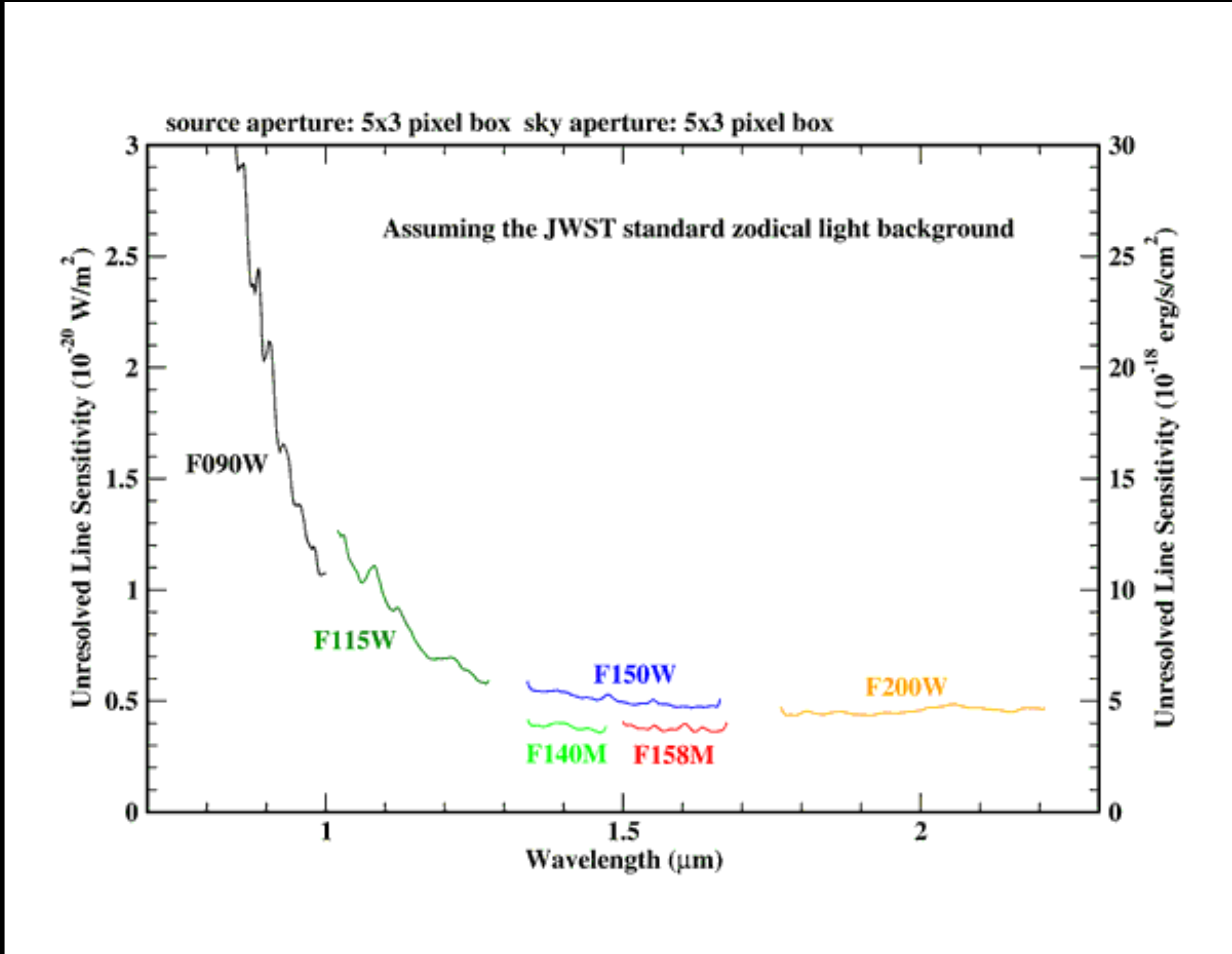


- A spectrum for every source in the field of view.
- No need for deep pre-imaging for selecting objects.
- Slitless mode is less efficient compared to slit mode as background is higher but enables 1000s spectra to be recorded.
- Very successful mode on HST WFC3

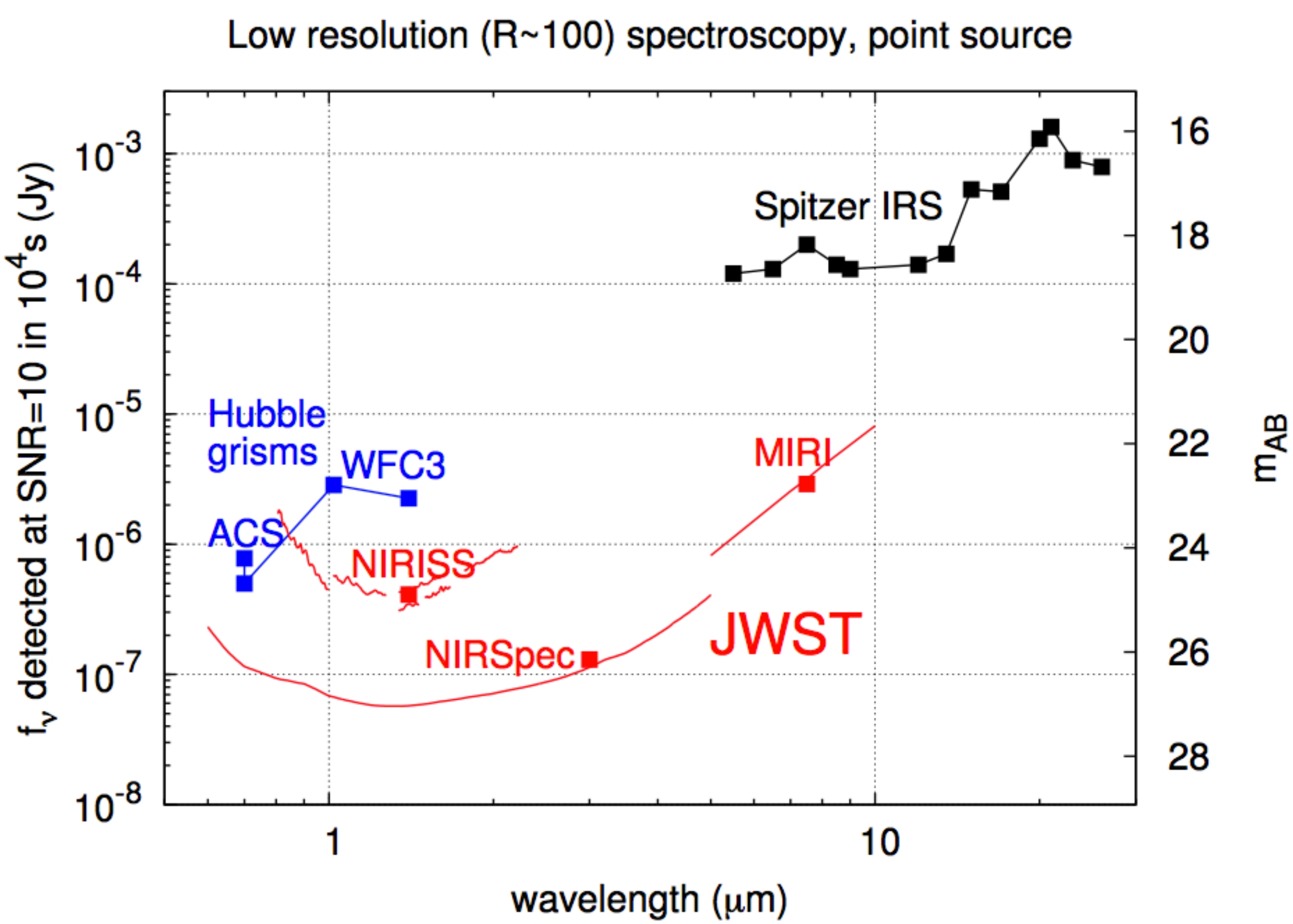


Spatial location
at intersection point

WFSS sensitivity



NIRISS vs HST & NIRSpec

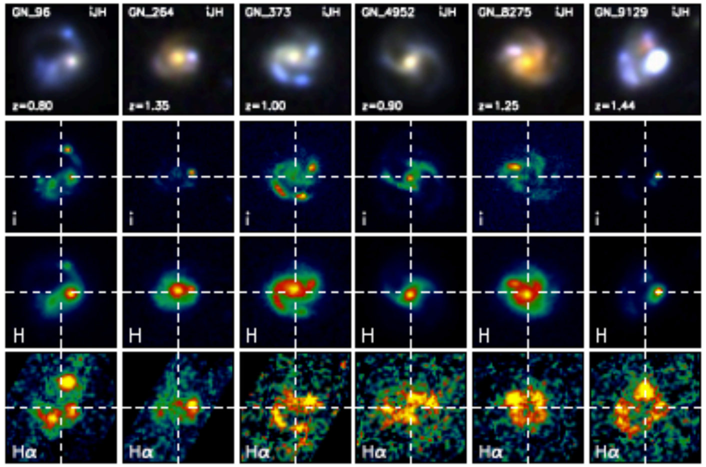


JWST Key Extragalactic Science

What is NIRISS Wide-Field Slitless Spectroscopy capable of?

Observables:

- Redshift -> distance, geometry, mergers
- Emission line luminosity -> star formation rate, IGM absorption
- Absorption line strength -> age - more difficult, can be done if bright or in a stack.
- Emission line map -> star formation map
- Emission line ratios -> metallicity, reddening
- Continuum spectral shape -> stellar population

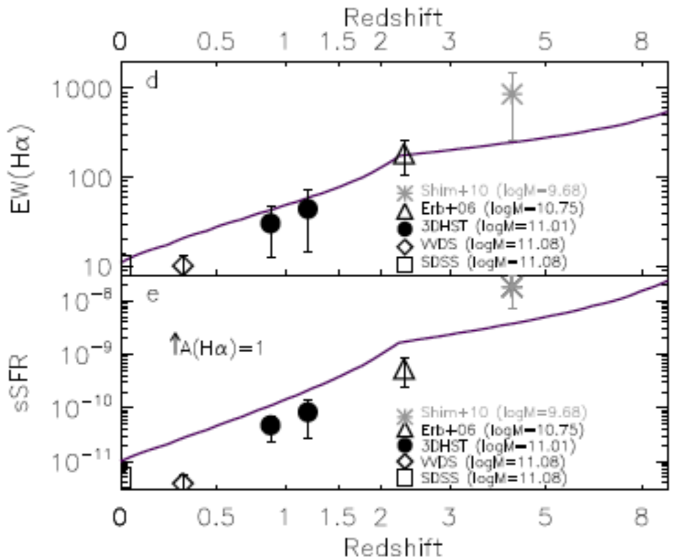


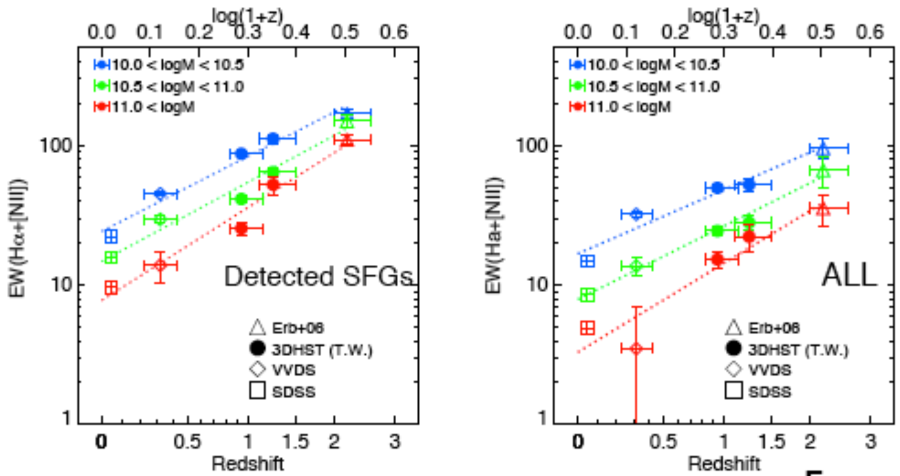
Wuyts et al. 2013

JWST Key Extragalactic Science

What is NIRISS Wide-Field Slitless Spectroscopy capable of?

Rest-frame equivalent width of emission lines increases rapidly at higher redshift due to higher specific star formation rate





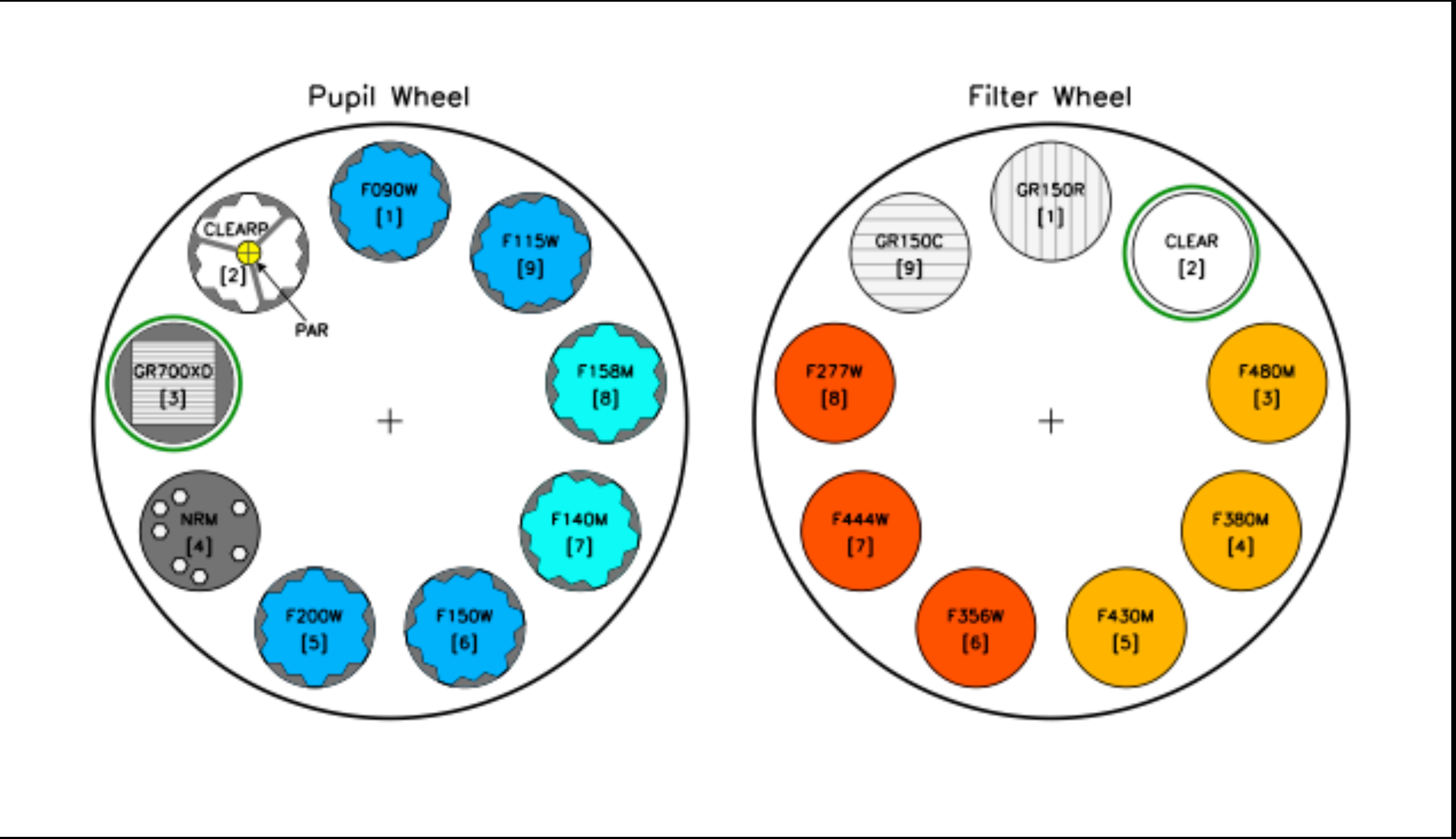
Fumagalli et al. 2012

[OIII] lines increase with decreased metallicity.

Our simulated NIRISS observations show emission lines in a large fraction of galaxies.

Potentially thousands of redshifts per field - huge multiplexing.

Single-object slitless Spectroscopy (SOSS)

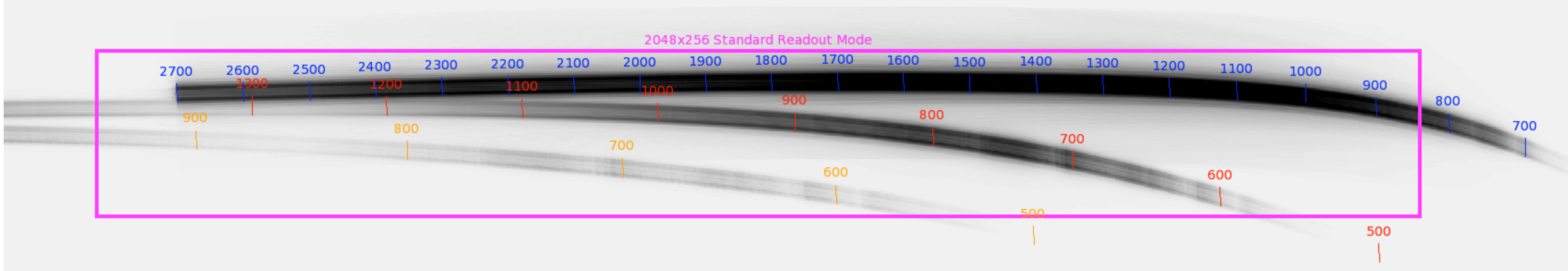


NIRISS SOSS mode

- Specifically optimized for transit spectroscopy
- Broad simultaneous wavelength range: 0.6-2.8 um
  – Cross-dispersed (order 1 and 2), no filter.
- Spectral resolution: 700 @ 1.2 um in first order
- Grism with built-in defocussing weak lens to increase dynamic range and minimize systematic ''red noise'' due to undersampling and flatfield errors
- Optical implementation to the successful « scanning mode » used on HST

SOSS Observing modes

- Standard Mode:
  - Wavelength coverage: 0.6-2.8 µm
  - Subarray: 256x2048 (order m=1 and 2)
  - Saturation limit: J=8.0 (CDS; 70 000 e-), 33% efficiency
- Bright mode
  - Wavelength coverage: 1.05-2.8 µm
  - Subarray: 80x2048 (m=1 only)
  - Saturation limit: J=6.8

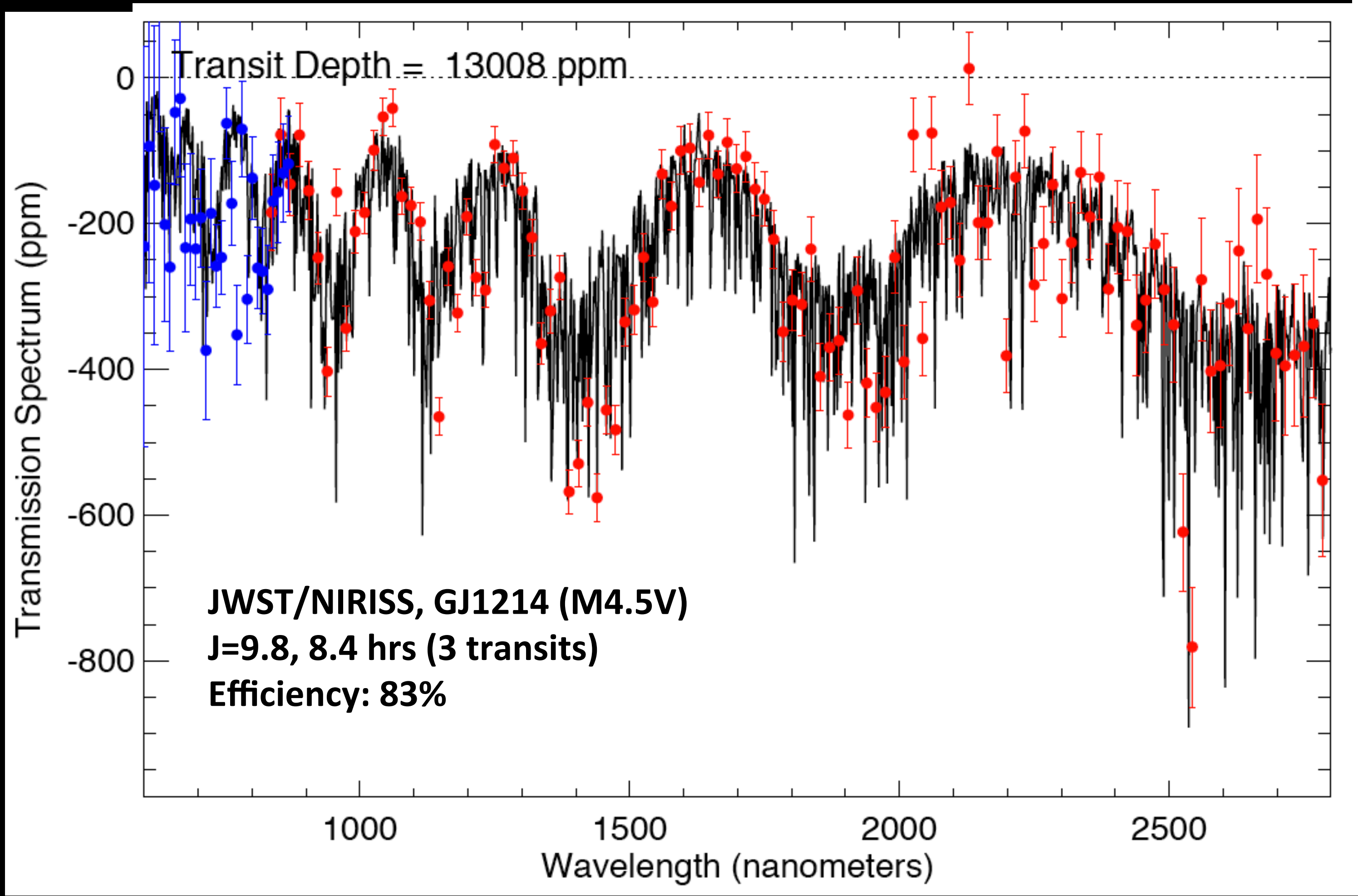


Transit spectroscopy: possibilities

Host	Name	T_p (K)	ρ (g/cm³)	$R_\star$ ($R_\odot$)	Δf/f (ppm)		
					H_2-rich μ=2	H_2O-rich μ=18	Earth μ=29
Hot Jupiters/Neptunes							
G0V	HD209458b	1130	0.37	1.14	**700**	-	-
M3V	GJ436b	700	1.5	0.42	**800**	-	-
Super Earths							
M4V	GJ1214b	600	2	0.2	**2300**	**250**	**160**
K1V	HD97658b	800	3.4	0.7	**150**	**20**	**10**
Earths							
M3V	TESS-xxx	600	5.5	0.2	-	**95**	**60**
M3V	TESS-xxx	300	5.5	0.2	-	**50**	**30**

$$\frac{\Delta f_{\rm atm}}{f} \propto \frac{R_{\rm pl} H_{\rm atm}}{R_\star^2} \rightarrow \frac{\Delta f_{\rm atm}}{f} = 615 \left(\frac{T_{\rm pl}}{1000\ K}\right)\left(\frac{\rm u}{\mu}\right)\left(\frac{1\ g/cm^3}{\rho}\right)\left(\frac{R_\odot}{R_\star}\right)^2 \rm ppm$$

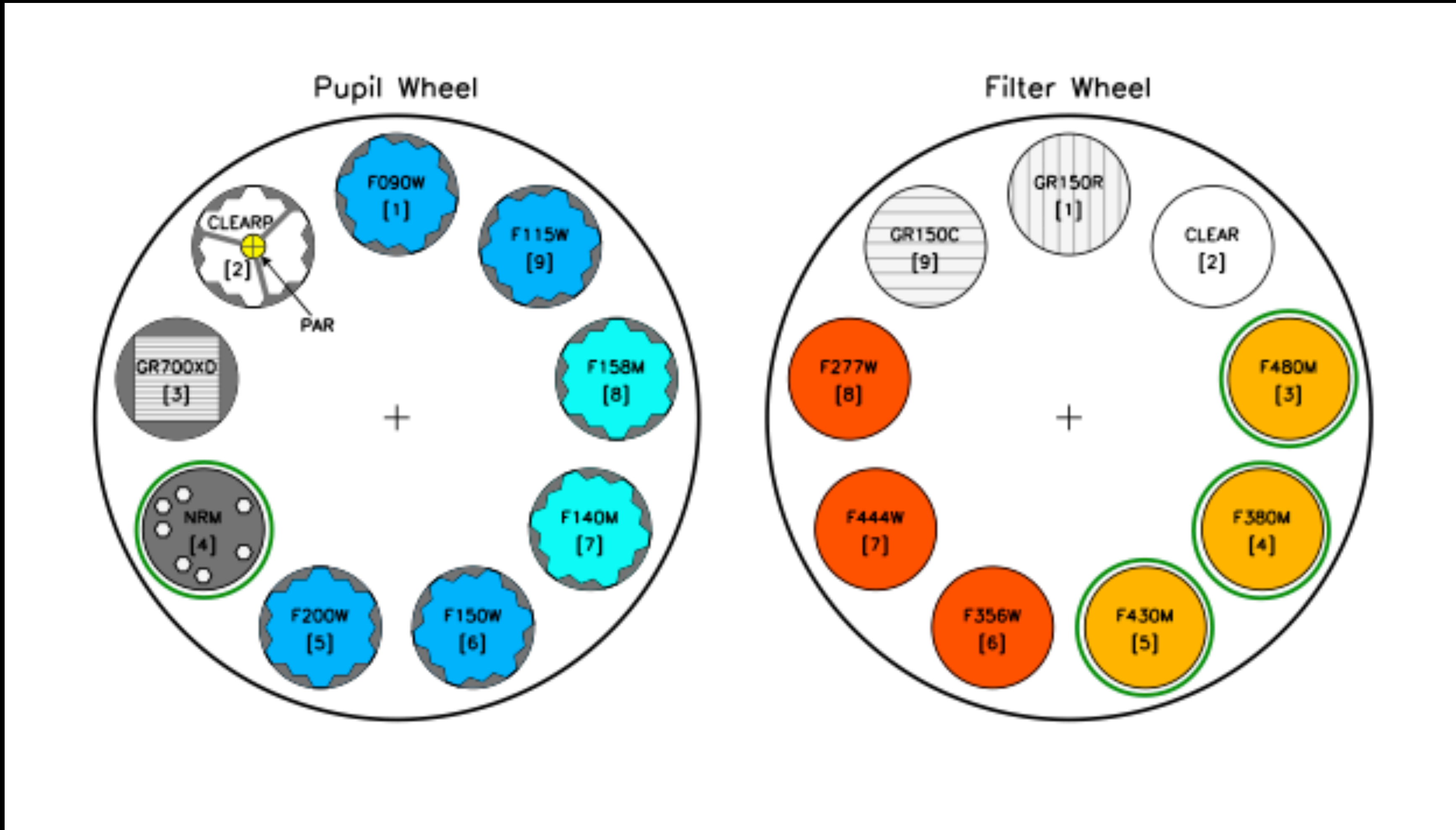
Super-Earth (GJ1214-like, water-rich, no clouds)



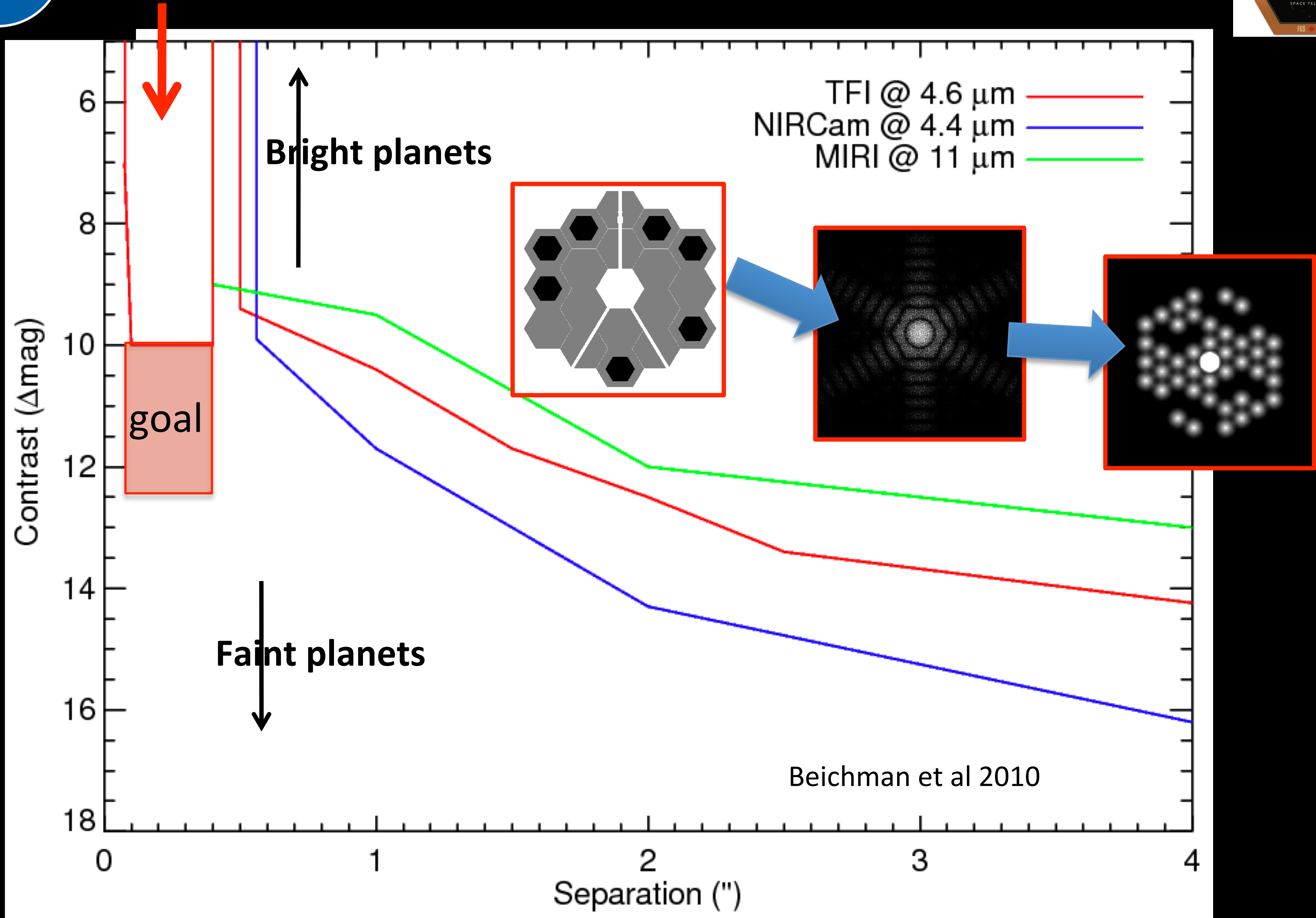
Noise level: 25 – 100 ppm

Model courtesy of J. Fortney

Aperture masking inteferometry (AMI)



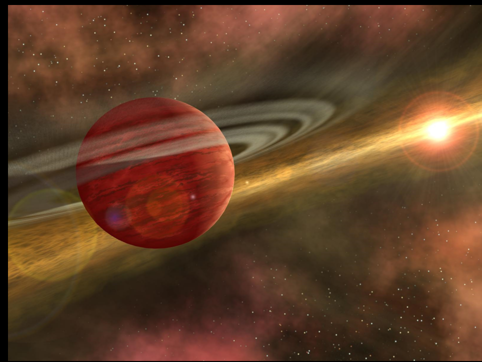
NIRISS Non-Redundant Mask will push JWST's angular resolution to its limit



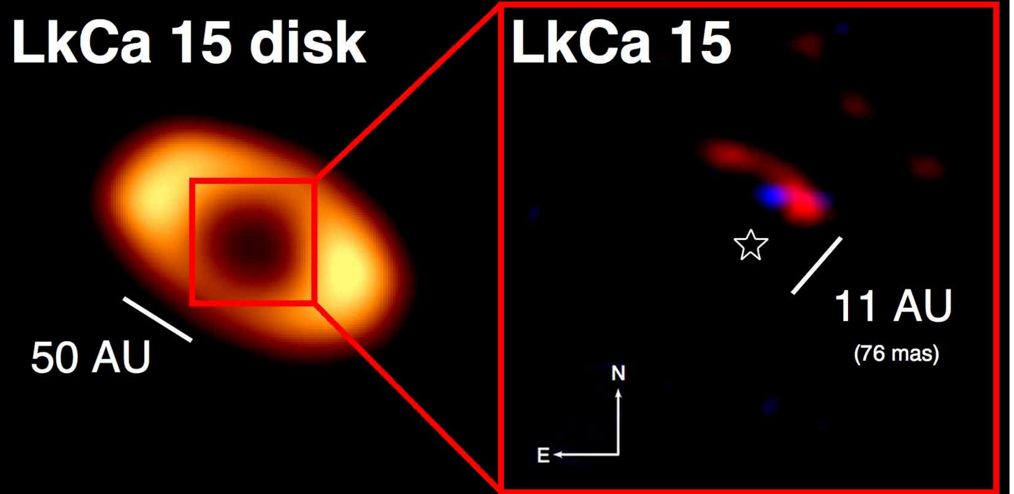
Search for giant planets in SFRs

- Do gas giant planets form in < 1-5 Myr?

- Nearby (150 pc) star forming regions enshrouded in gas and dust…
  - **I > 12 Not amenable to xAO**
  - **Excellent JWST targets!**



- **NIRISS AMI**
  - **1-2 M_{Jup} at 10-60 AU**
- **NIRCam**
  - **0.1 M_{Jup} at >120 AU**



Kraus et al. 2012

JWST/ELT Complementary Capabilities

Physical Resolution:		15 pc	50 pc	150 pc	450 pc
JWST	1.65 μm	1 AU	3 AU	10 AU	30 AU
	10 μm	7 AU	20 AU	60 AU	180 AU
ELT	1.65 μm	.2 AU	.5 AU	1.5 AU	5 AU
	10 μm	1 AU	3 AU	10 AU	30 AU

Spectral Resolution :

R = 100 (molecular features)	JWST
R = 1000 (atomic features)	JWST
R = 10,000 (30 km / sec)	ELT
R = 100,000 (3 km / sec)	ELT

Field of View:

2' (star clusters within 1 kpc)	JWST
1.5" (circumstellar disk at 150 pc)	ELT

Executive Summary: Two Powerful Capabilities

NIRCam: 1-5 micron wide-field diffraction-limited imaging.

- 1-2.5/2.5-5 micron simultaneous imaging
- Two-arm redundant capabilities (wider-field).
- Large diverse filter set for all science areas.
- Classical Lyot coronagraphy.
- Slitless grism spectroscopy from 2.5-5 microns.

NIRISS: special features for first-light and exoplanets.

- Slitless wide-field spectroscopic survey mode.
- Single-object slitless spectroscopy for exoplanets.
- Non-redundant mask imaging beyond diffraction-limit.
- Additional field of view in parallel mode.

Merci beaucoup!