NIRCam & NIRISS on JWST: Exploring Origins & Evolution of Planetary Systems

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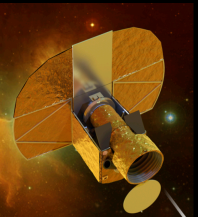
PlanetS Workshop, Bern, CH 9 May, 2017



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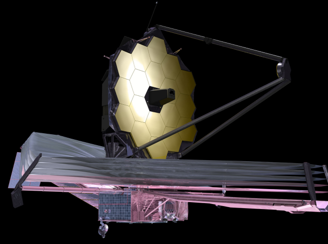
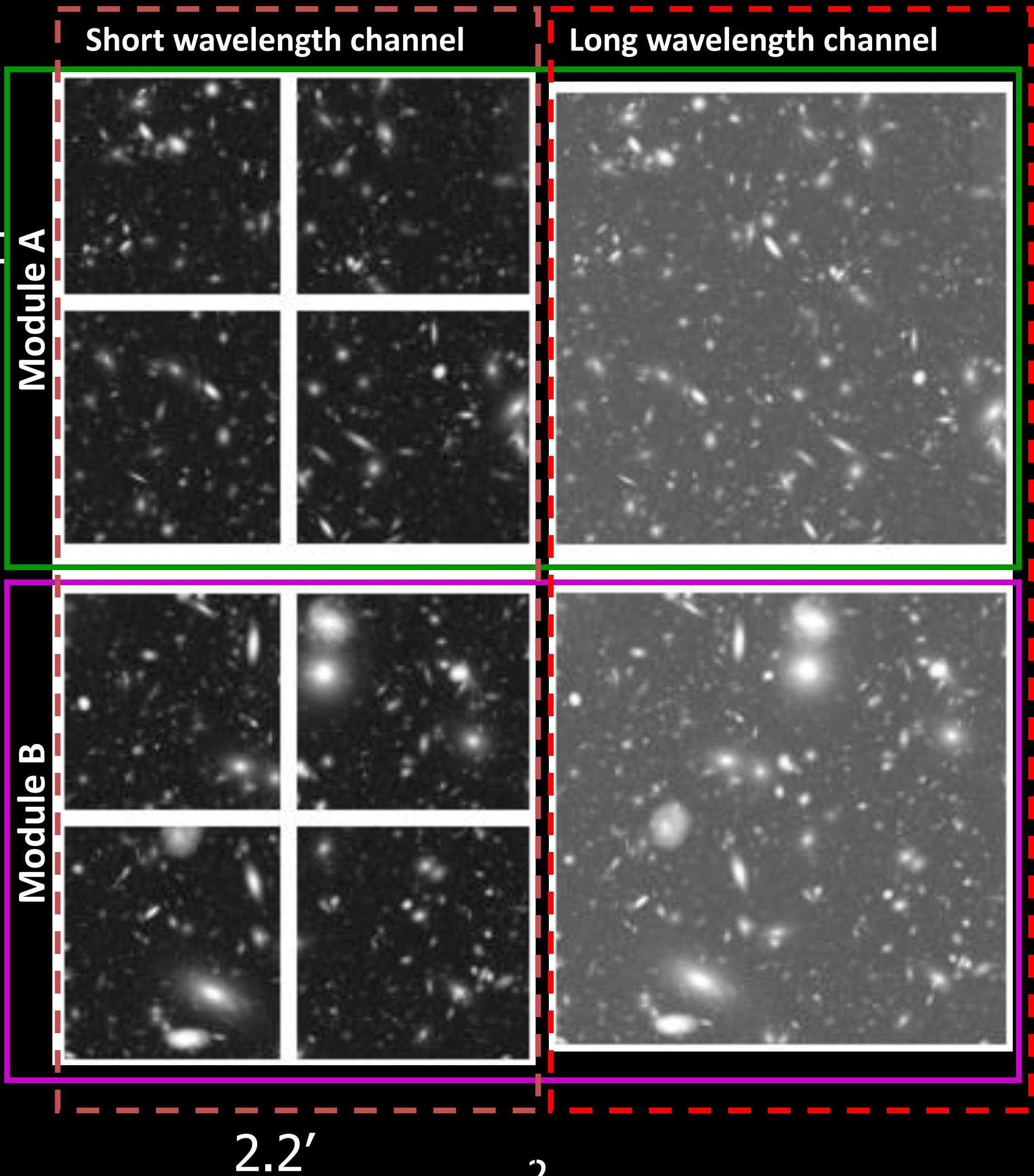
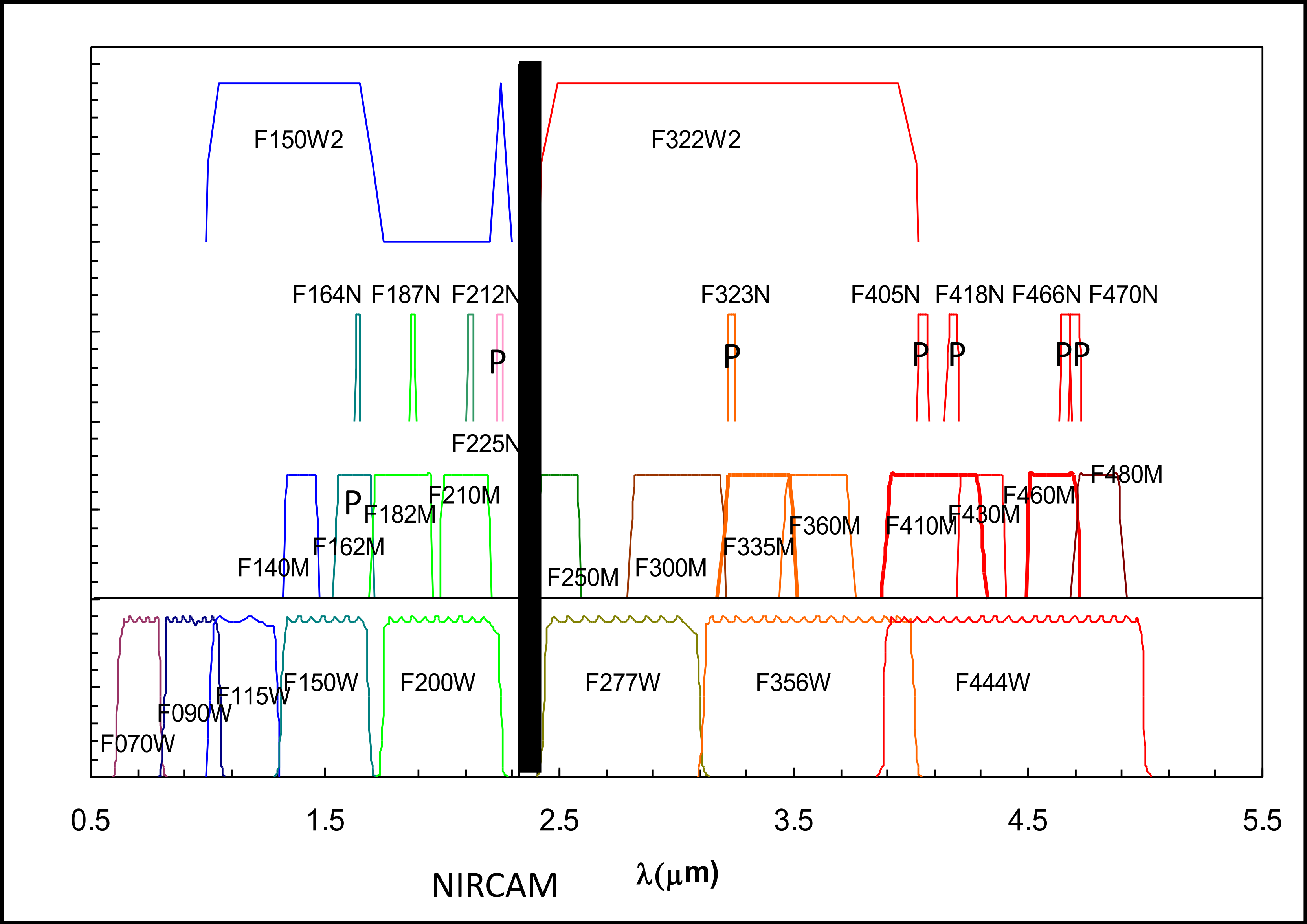


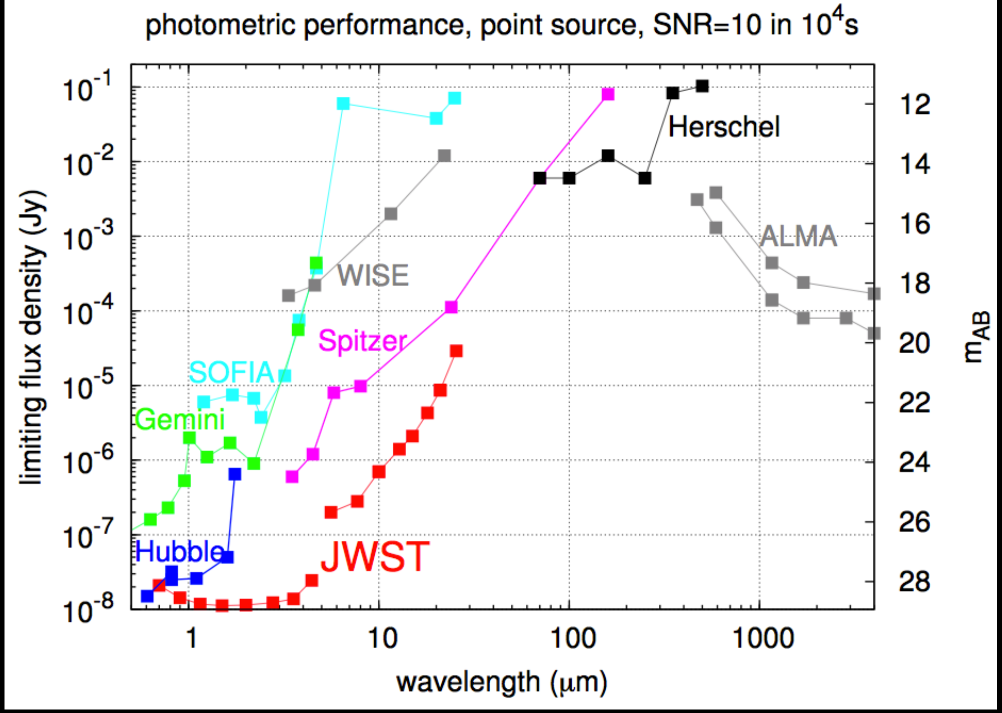
NIRCam: Simple but Powerful Capability

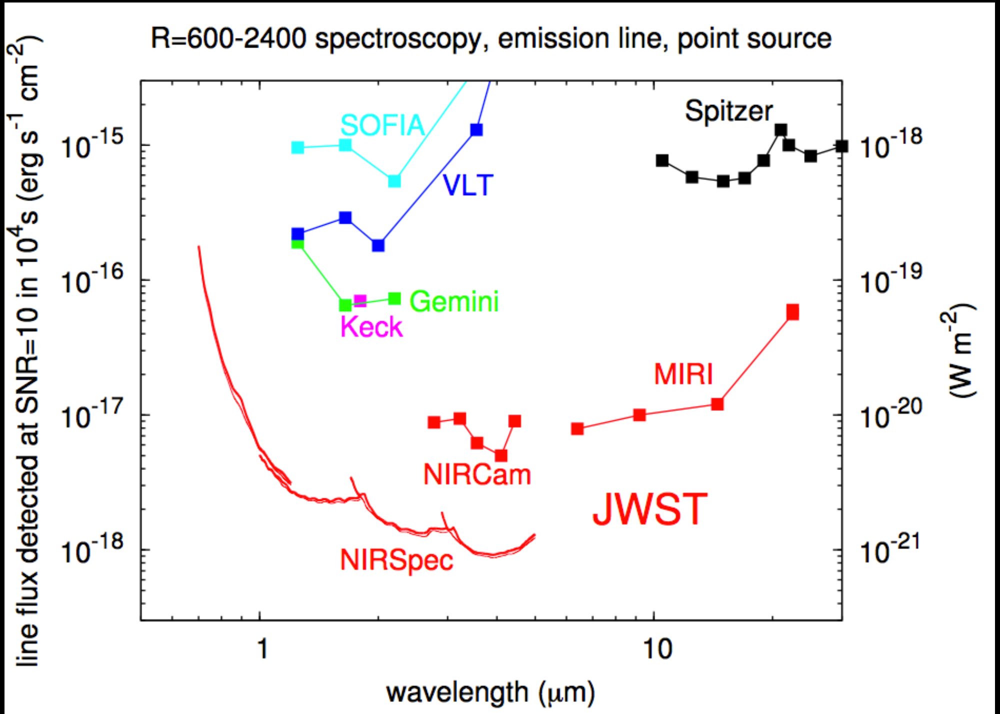
- NIRCam images 0.6 - 5μm with refractive optics
  - –Dichroic splits into short (0.6-2.3 μm) and long-λ (2.4-5 μm) sections
  - –Nyquist sampling at 2 μm (0.032"/pix) & 4 μm (0.064"/pix)
  - –2.2 arcmin x 4.4 arcmin FOV in two colors (40 Mpixels) simultaneously
- 2 redundant modules
- Coronagraphs
-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



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







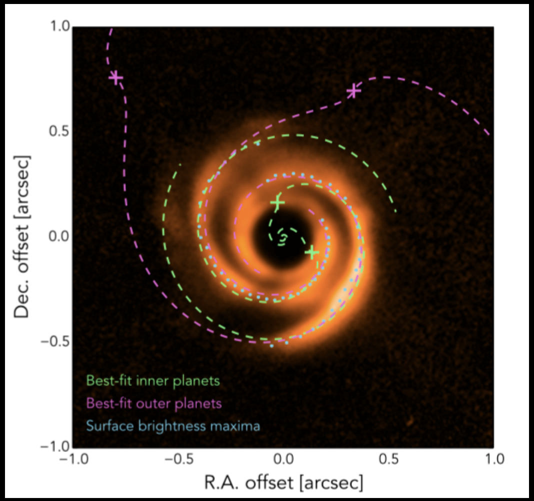
Rather Sensitive…

Star & Planet Formation

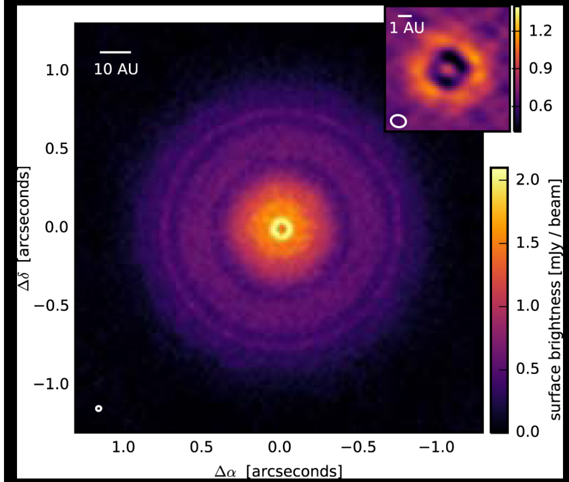
- Planetary Mass Objects:
  Star clusters (140-500 pc) to probe IMF (1 Jupiter mass)
  - — Ejected planets?
  - — Follow-up spectra NIRSPEC.
  - — Retrieval to get C/O.

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

- Forming Proto-planets:
  - — Disk asymetries.
  - — Gaps and rings.
  - — Background limited.



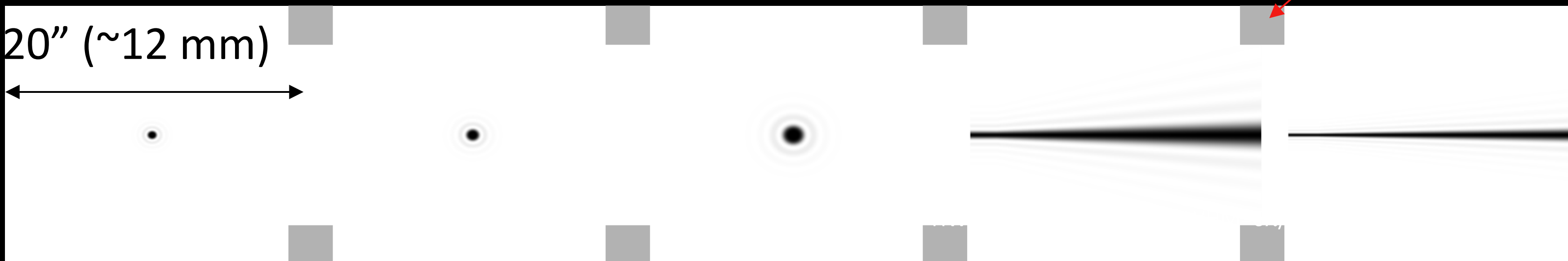
Stolker et al. (2016)



van Boeckel et al. (2016)

Lyot Coronagraphs

3" x 3" ND squares



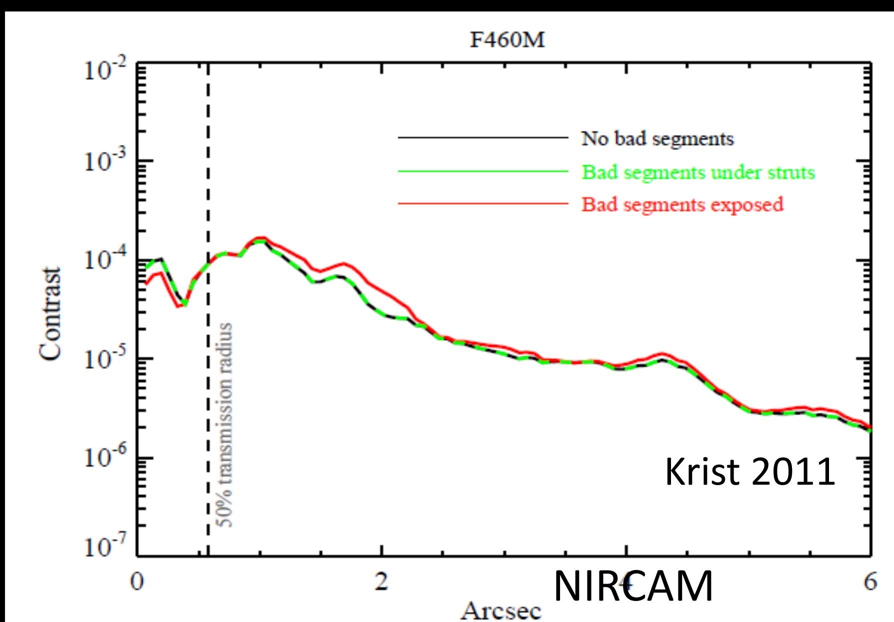
HWHM = 0.40" (6λ/D @ 2.1 μm)

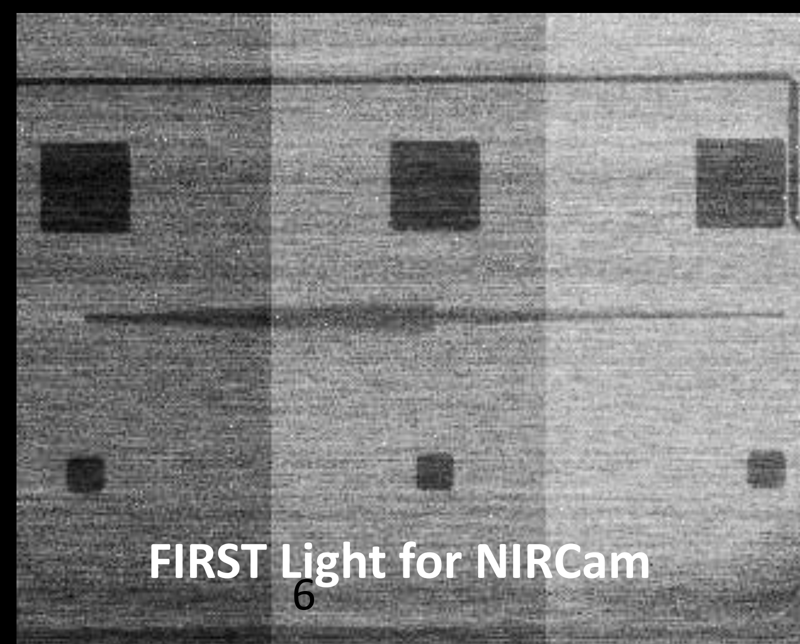
HWHM = 0.64" (6λ/D @ 3.35 μm)

HWHM = 0.82" (6λ/D @ 4.3 μm)

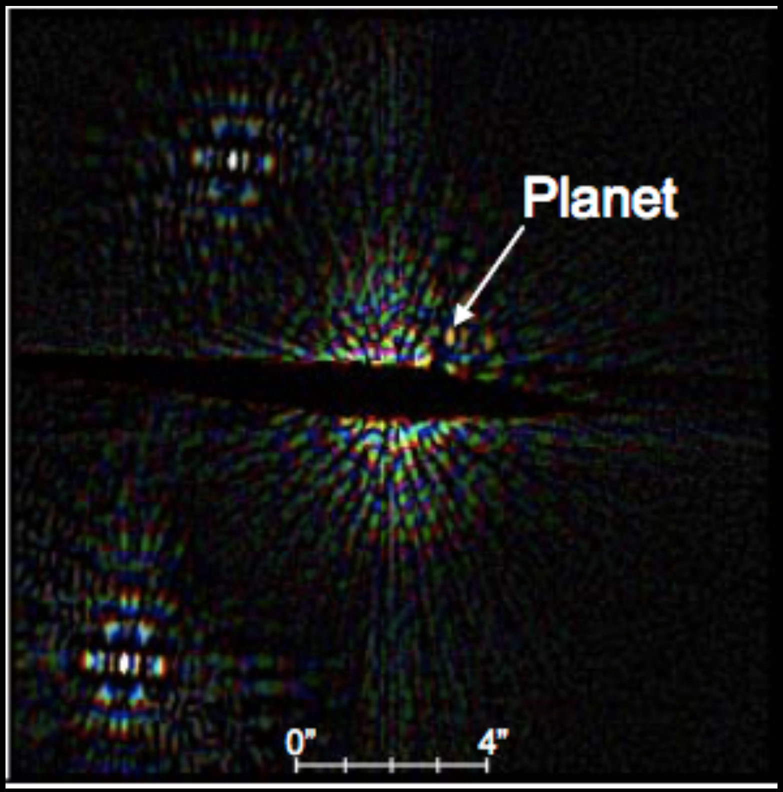
$HWHM_c$ = 0.58" (4λ/D @ 4.6 μm)

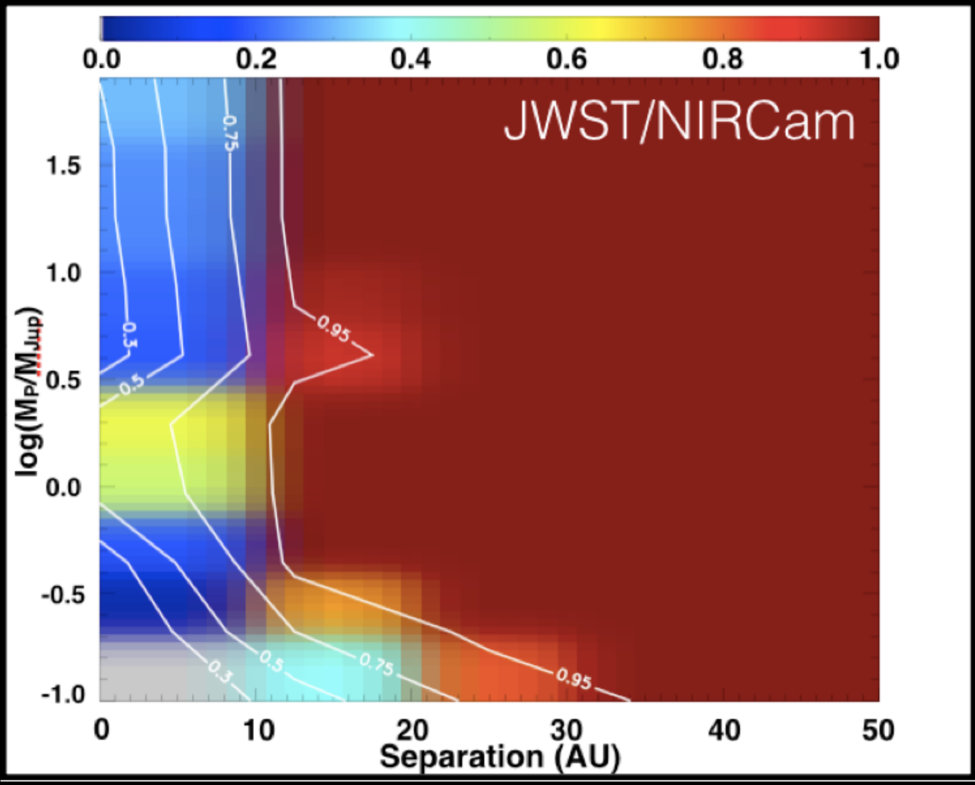
$HWHM_c$ = 0.27" (4λ/D @ 2.1 μm)





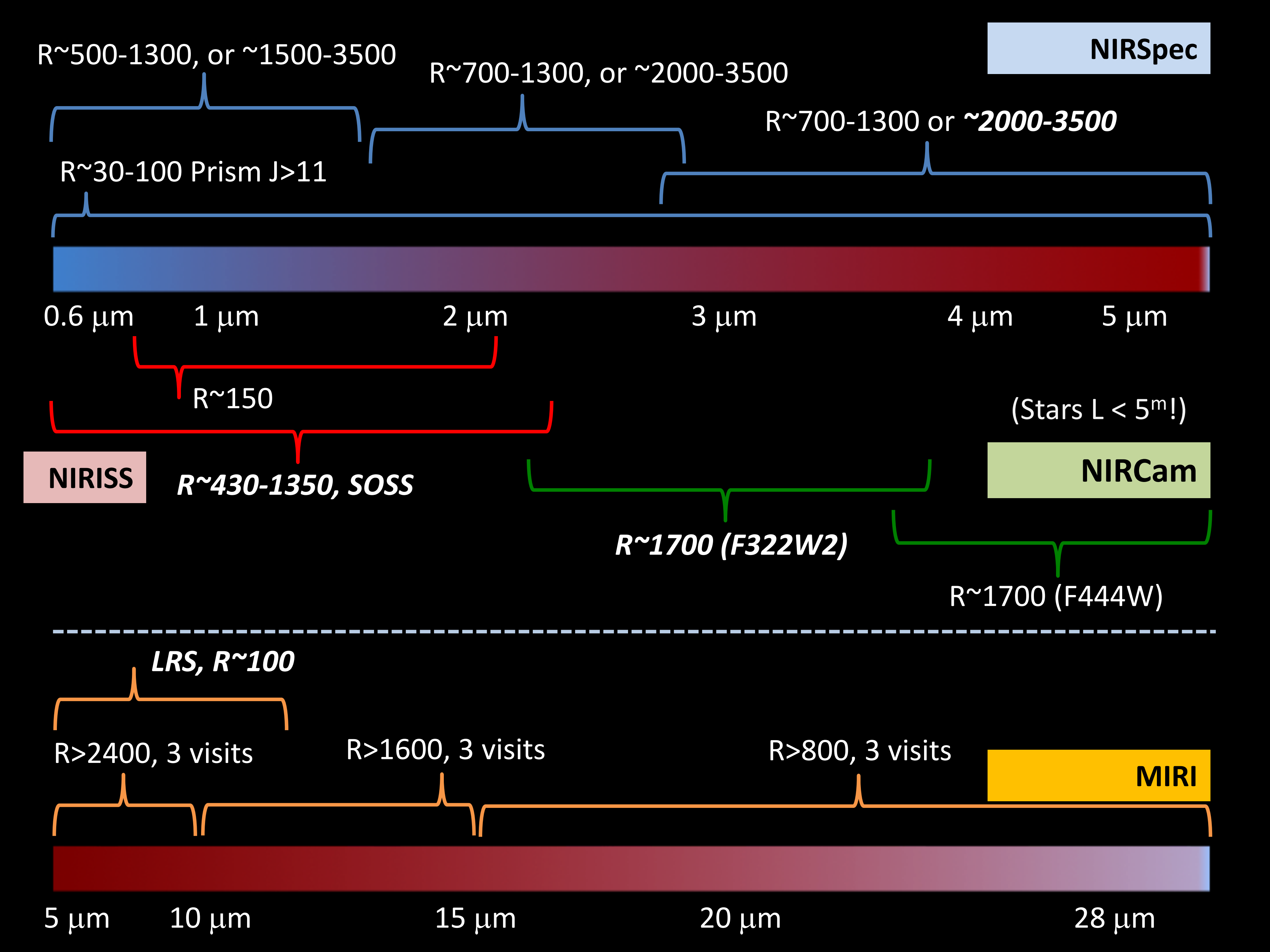
Survey of Low Mass Stars with NIRCam





Krist et al. (2007)

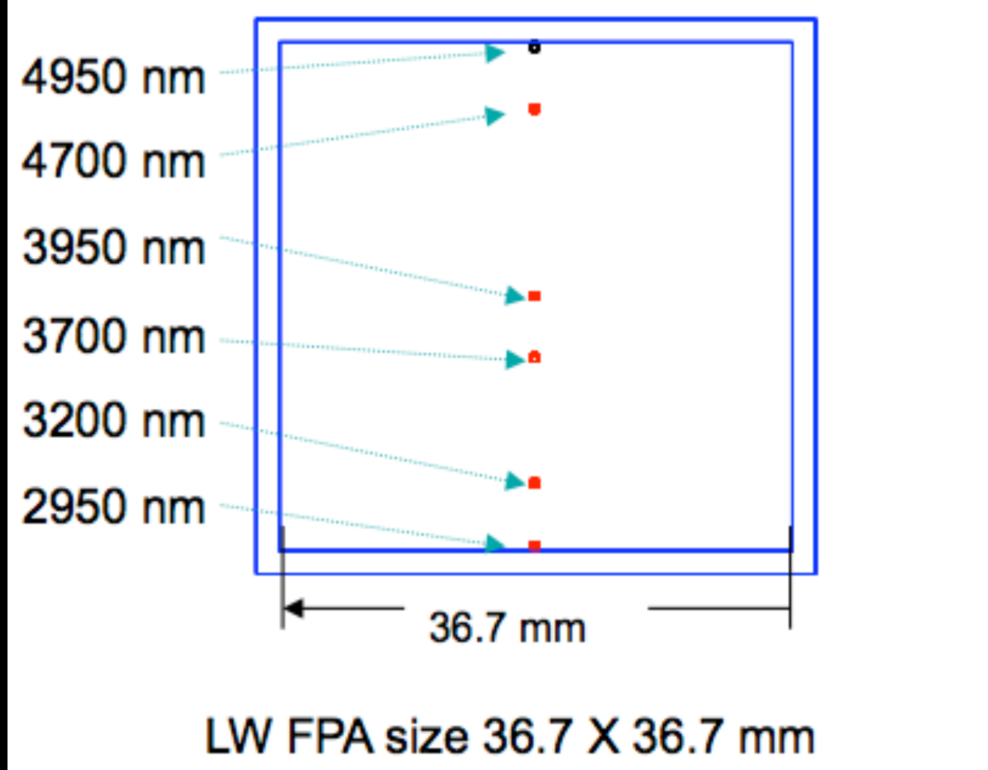
J. Schleider, M. Reggiani, NIRCamTeam



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

NIRCam 2.5 – 5 μm slitless grisms

- Grisms are in the LW pupil wheel and are used in series with a LW filter
- R = 1700
- Good spatial sampling:
- Nyquist sampled at 4 μm



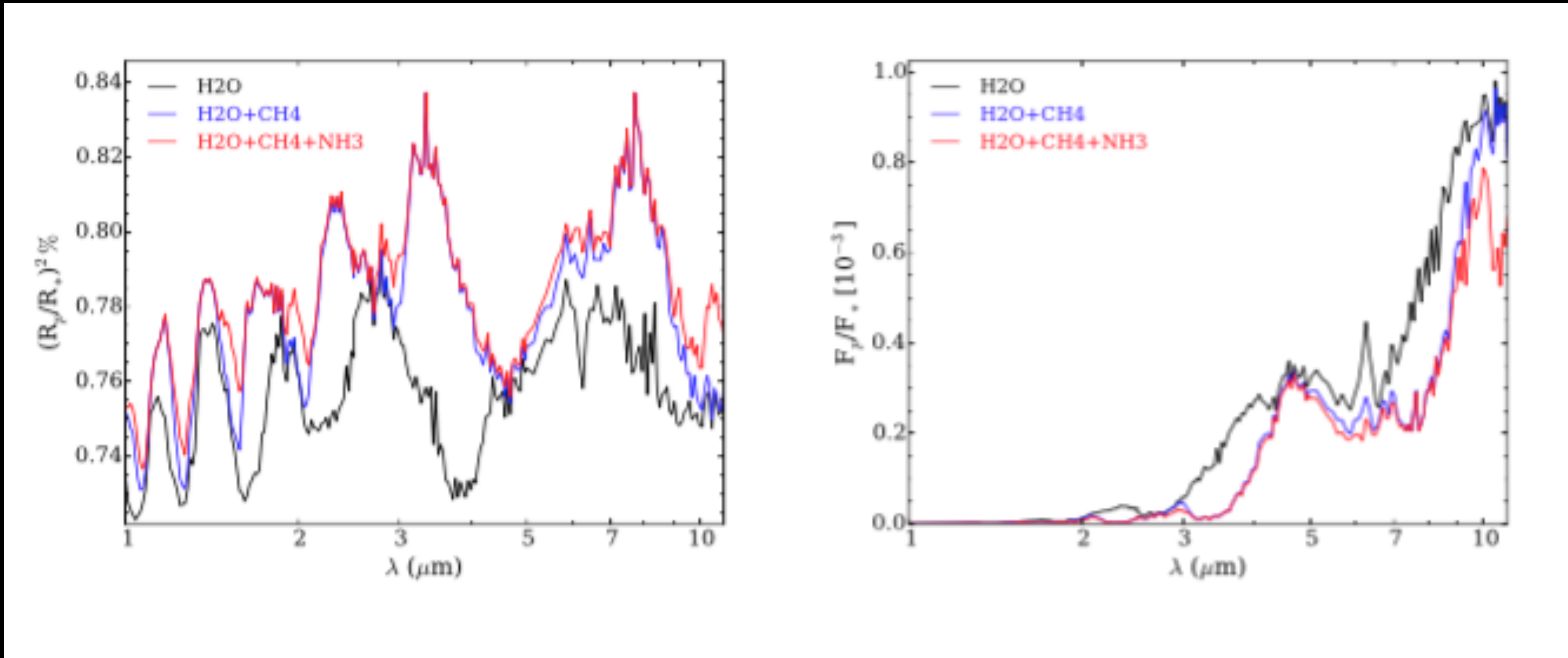
Center Field Dispersion by Grism

Some grism filter combinations

Filter	λ1	λ2	# pixels
F277W	2.42	3.12	696
F322W2	2.42	4.03	1600
F356W	3.12	4.01	885
F410M	3.90	4.31	408
F444W	3.89	5.00	1104

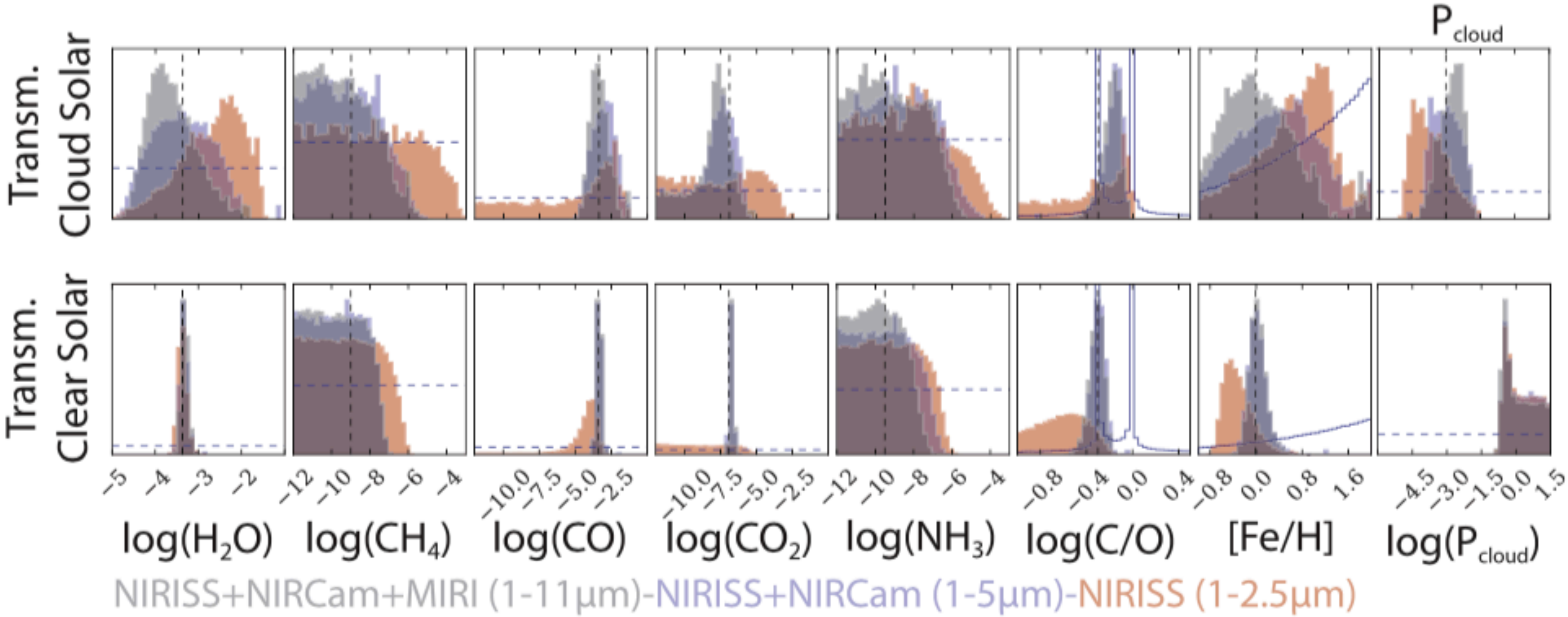
- 2 grisms per module in perpendicular orientations

Molecular Features in Cool Planets



- T < 1200 K have CH_4, NH_3, H2O
- Important to cover CO & CO_2 (NIRCam) also to assess chemistry and get complete elemental inventory

Characterization from TRANSIT spectroscopy



Greene et al. 2016

- Red histogram is NIRISS only, with restricted wavelength range of 1-2.5 um

NIRCAM GTO: *Preliminary*

- Planet Formation and Evolution:
  - End of the IMF versus ejected planets (16 hours).
  - Forming proto-planets in circumstellar disks (14 hours).
- Exoplanet Imaging & Characterization:
  - Coronagraphic Imaging of Young Planets (35 hours).
  - Spectroscopy of Widely Separated Systems (24 hours).
  - Y Dwarf Characterization (28 hours)
  - M dwarf Imaging Survey (36 hours).
- Transit Spectroscopy of Mature Planets: 155 hours
  - 2.4-12 microns NIRCam/MIRI program.
  - 600 K < T < 1200 K
  - 7-200 Mearth
  - < 3 to > 10 Rearth.

https://confluence.stsci.edu/display/STUCP/JWST+Guaranteed+Time+Observers+Cycle+1+Plans

NIRCAM GTO: *Preliminary*

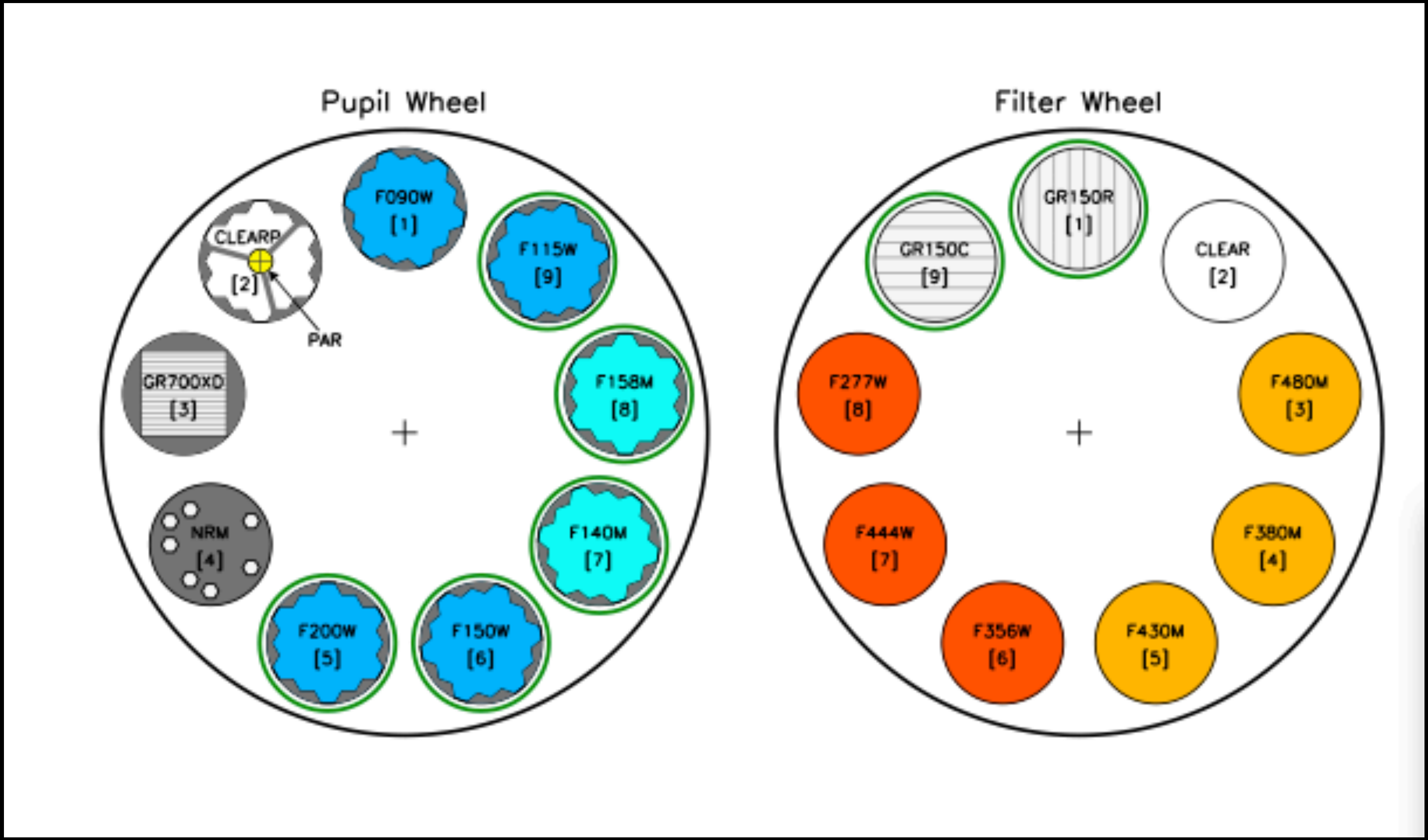
Name	K(mag)	T_{eq}(K)	$R_p(R_\oplus)$	$M_p(M_\oplus)$	T_{14}(hrs)	Geometry	Visits	Grism Filter	Obs Time/w NIRCam
HD189733b	5.5	1190	12.5	360	1.82	Emission	1	F322W2	7.8
HD189733b	5.5	1190	12.5	360	1.82	Emission	1	F444W	7.8
WASP-80b	8.4	850	10.7	180	2.11	Emission	1	F322W2	8.7
WASP-80b	8.4	850	10.7	180	2.11	Emission	1	F444W	8.7
WASP-80b	8.4	850	10.7	180	2.11	Transmission	1	F322W2	8.7
WASP-80b	8.4	850	10.7	180	2.11	Transmission	1	F444W	8.7
HAT-P-19b	10.5	1010	12.7	93	2.84	Emission	1	F322W2	10.8
HAT-P-19b	10.5	1010	12.7	93	2.84	Emission	1	F444W	10.8
GJ 436 b	6.1	700	4.2	22	0.76	Emission	3	F322W2	14.3
GJ 436 b	6.1	700	4.2	22	0.76	Emission	3	F444W	14.3
HAT-P-26b	9.6	1000	6.2	19	2.46	Transmission	1	F322W2	9.7
HAT-P-26b	9.6	1000	6.2	19	2.46	Transmission	1	F444W	9.7
GJ 3470b	8.0	700	4.1	14	1.92	Transmission	1	F322W2	8.1
GJ 3470b	8.0	700	4.1	14	1.92	Transmission	1	F444W	8.1
GJ 1214b	8.8	600	2.6	6.5	0.88	Transmission	1	F322W2	10.2
GJ 1214b	8.8	600	2.6	6.5	0.88	Transmission	1	F444W	10.2

https://confluence.stsci.edu/display/STUCP/JWST+Guaranteed+Time+Observers+Cycle+1+Plans

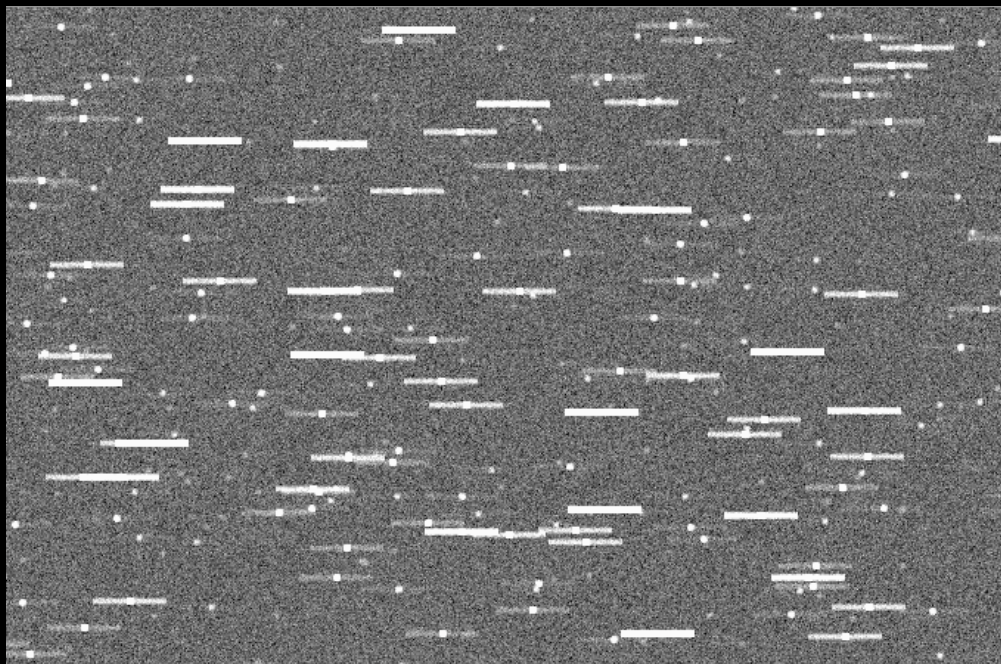
NIRISS Observing modes

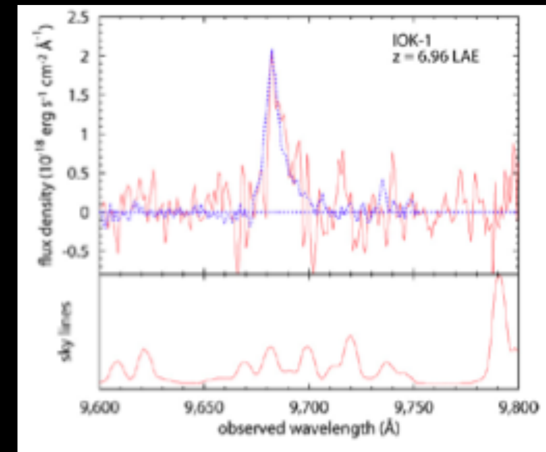
- Wide-Field Slitless Spectroscopy (WFSS)
  - Wavelength range: 1 – 2.5 µm
  - Spectral resolution: 150
  - Line flux sensitivity: (10σ 10^4s): 5×10^{-21} W m^{-2} at 1.5 µm with F150W filter.
  - Spectro-photometry accuracy: 10%
- Single-Object Slitless Spectroscopy (SOSS)
  - Wavelength range: 0.6 – 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)

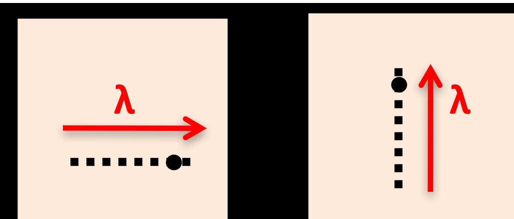
Wide-Field Slitless Spectroscopy (WFSS)

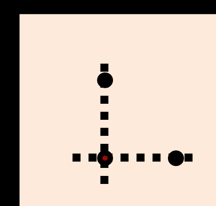


WFSS mode uses two grisms with orthogonal dispersion





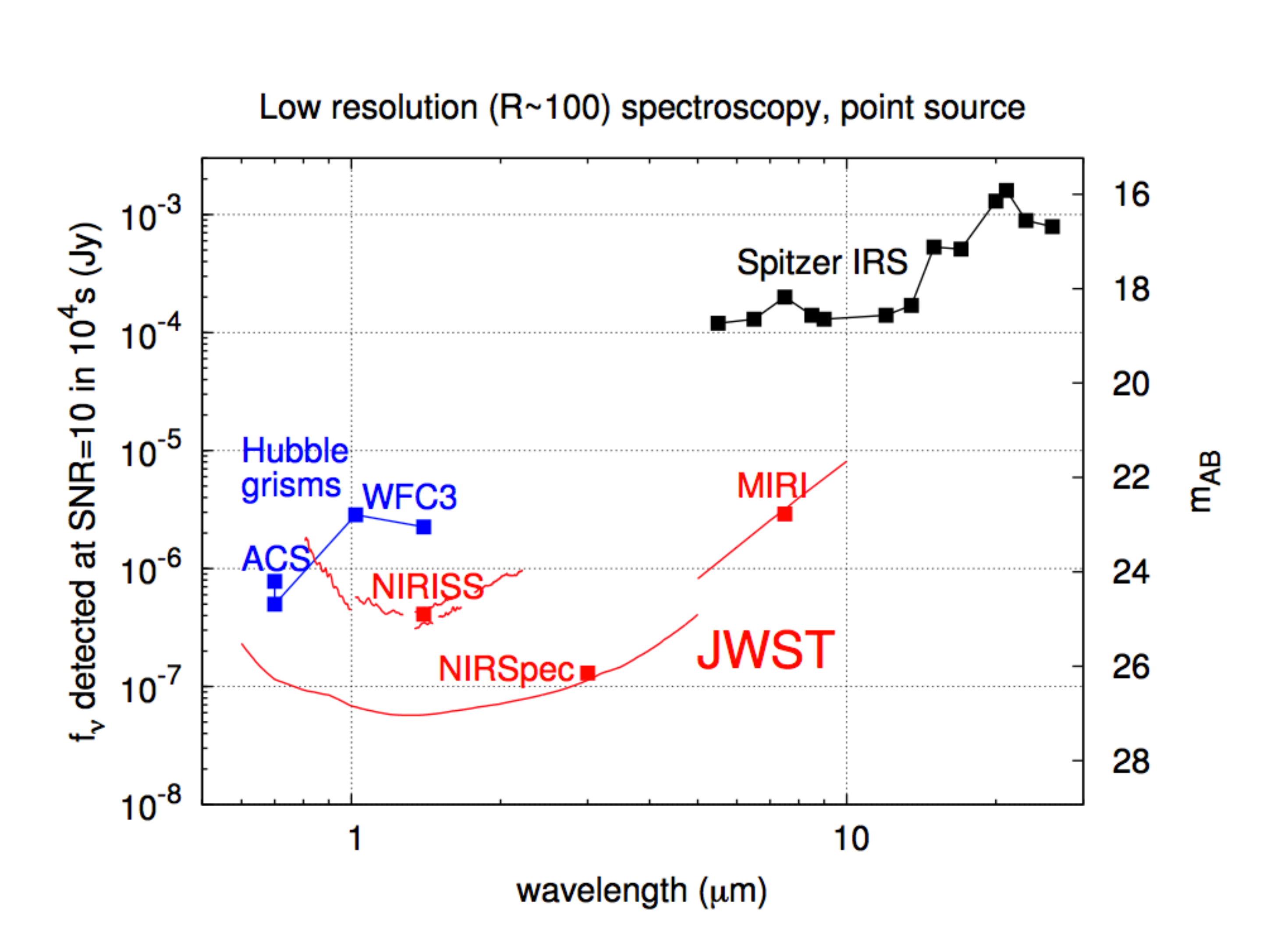




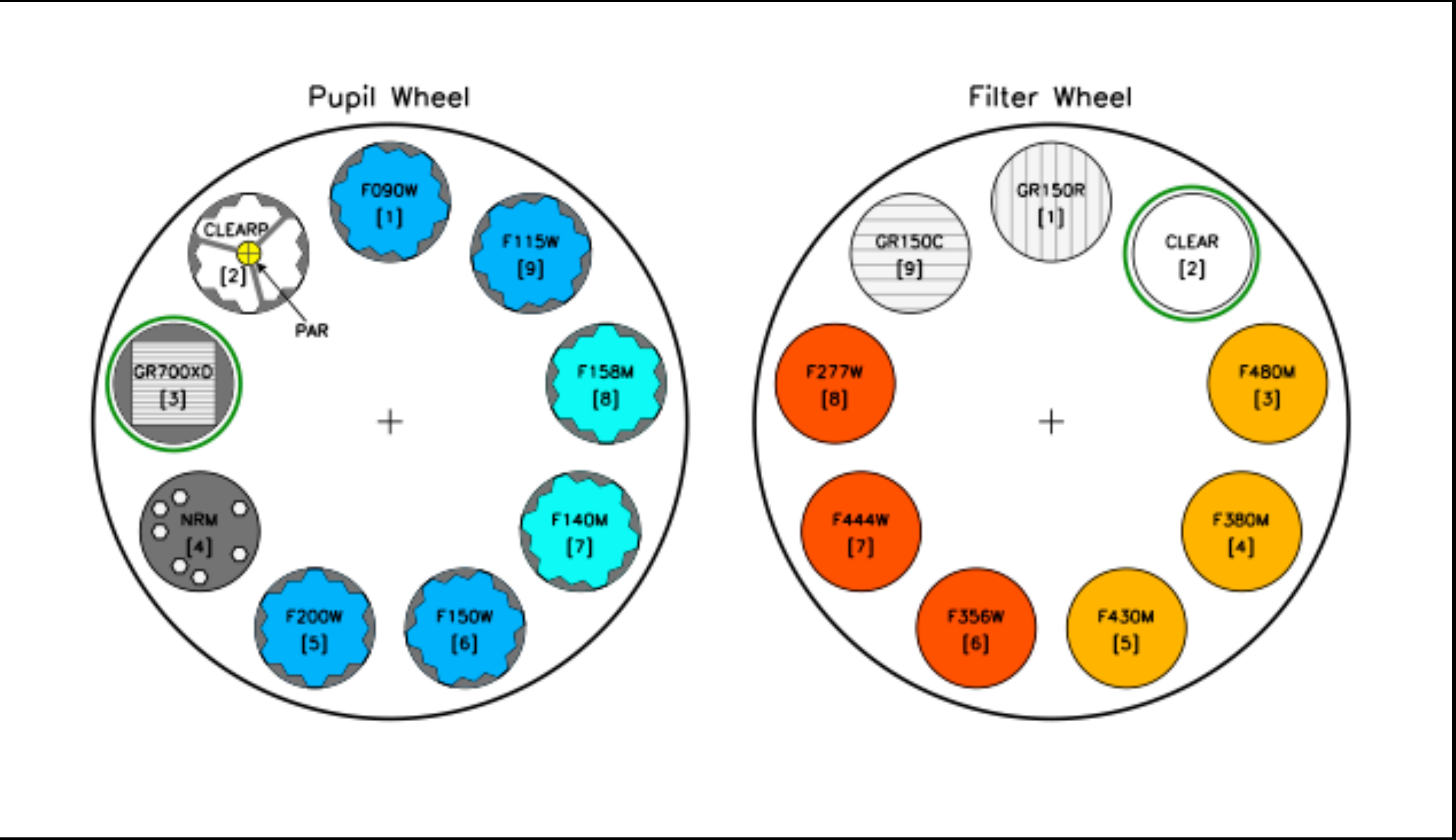
Spatial location at intersection point

- 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

NIRISS vs HST & NIRSPec

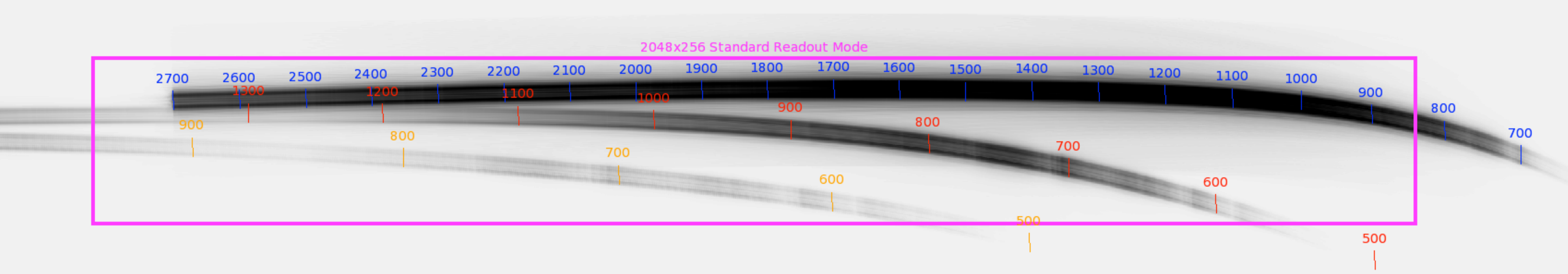


Single-object slitless Spectroscopy (SOSS)

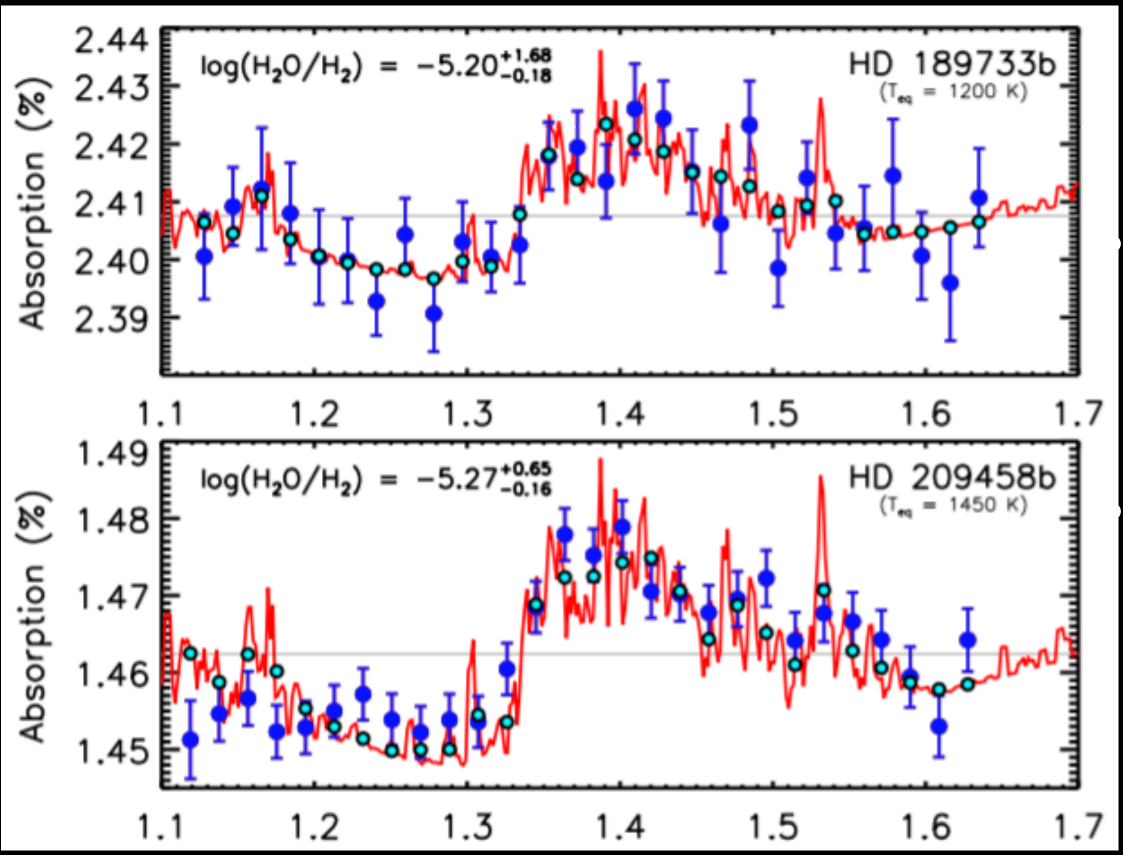


SOSS Observing modes

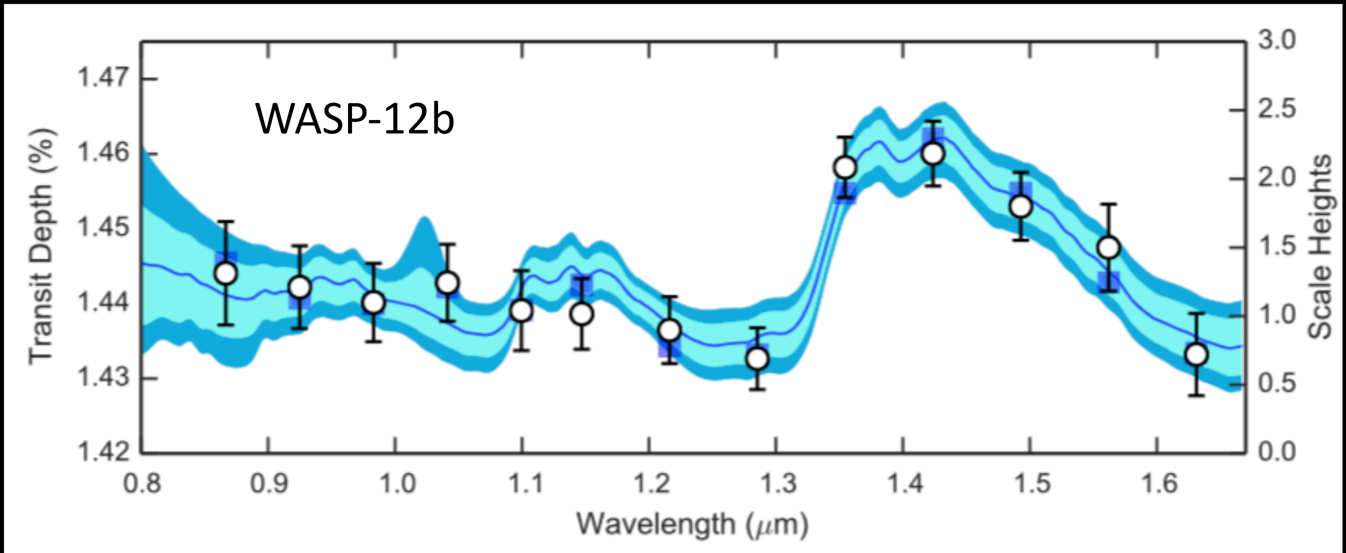
- Standard Mode:
  - Wavelength coverage: 0.6-2.8 µm
  - Subarray: 256x2048 (order m=1 and 2)
  - Saturation limit: J=8.0 (CDS; 70 000 e-), 33% efficiency
- Bright mode
  - Wavelength coverage: 1.05-2.8 µm
  - Subarray: 80x2048 (m=1 only)
  - Saturation limit: J=6.8



Madhusudhan et al. 2015



- Current precision of 30-100 ppm at R~20-70
- **NIRISS=**
  - **same precision**
  - **R~500-1500 (gain 10X)**
  - **0.6-2.8 um (gain 2-3X)**



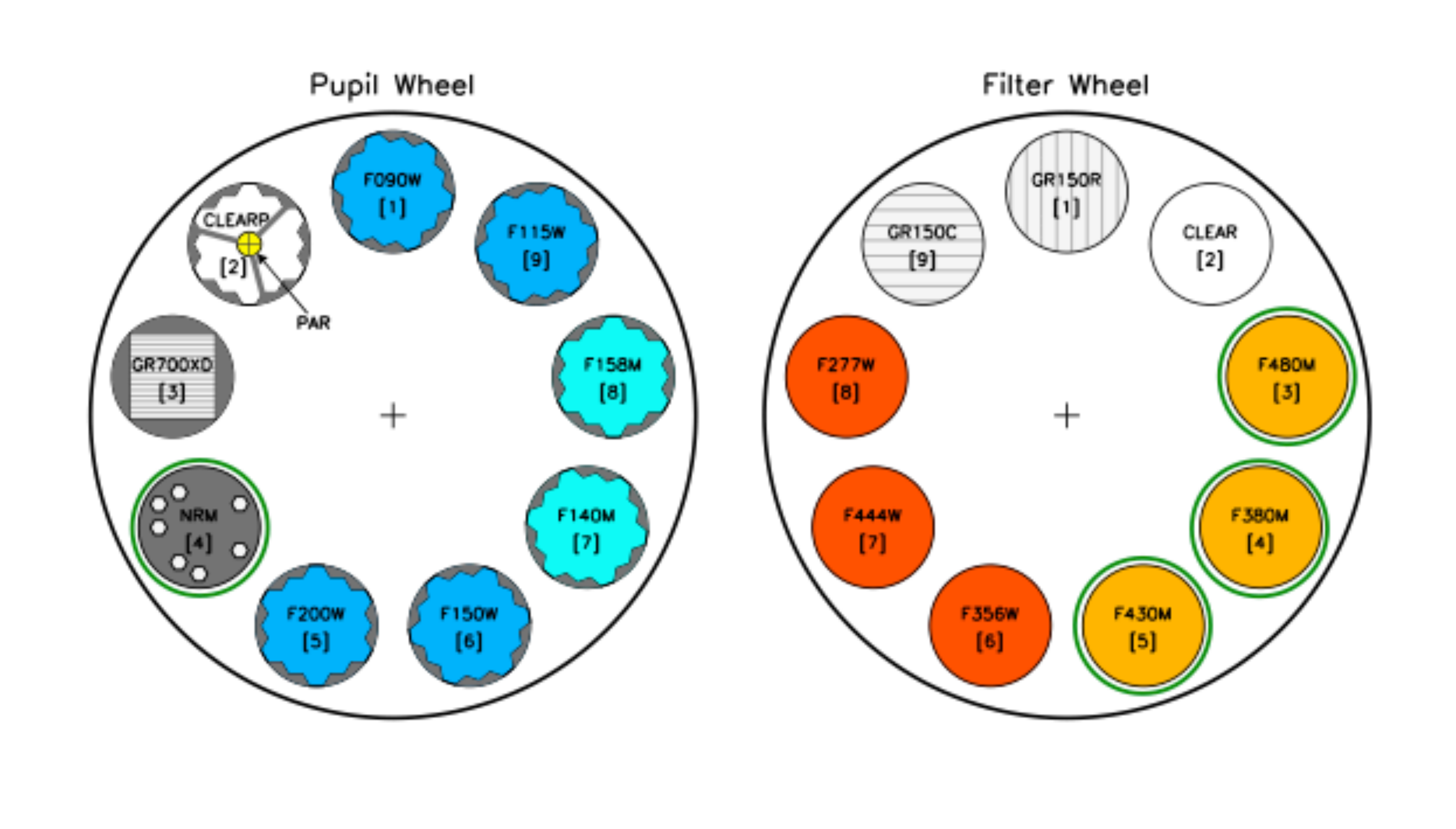
Kreidberg et al. 2015

Transit spectroscopy: possibilities

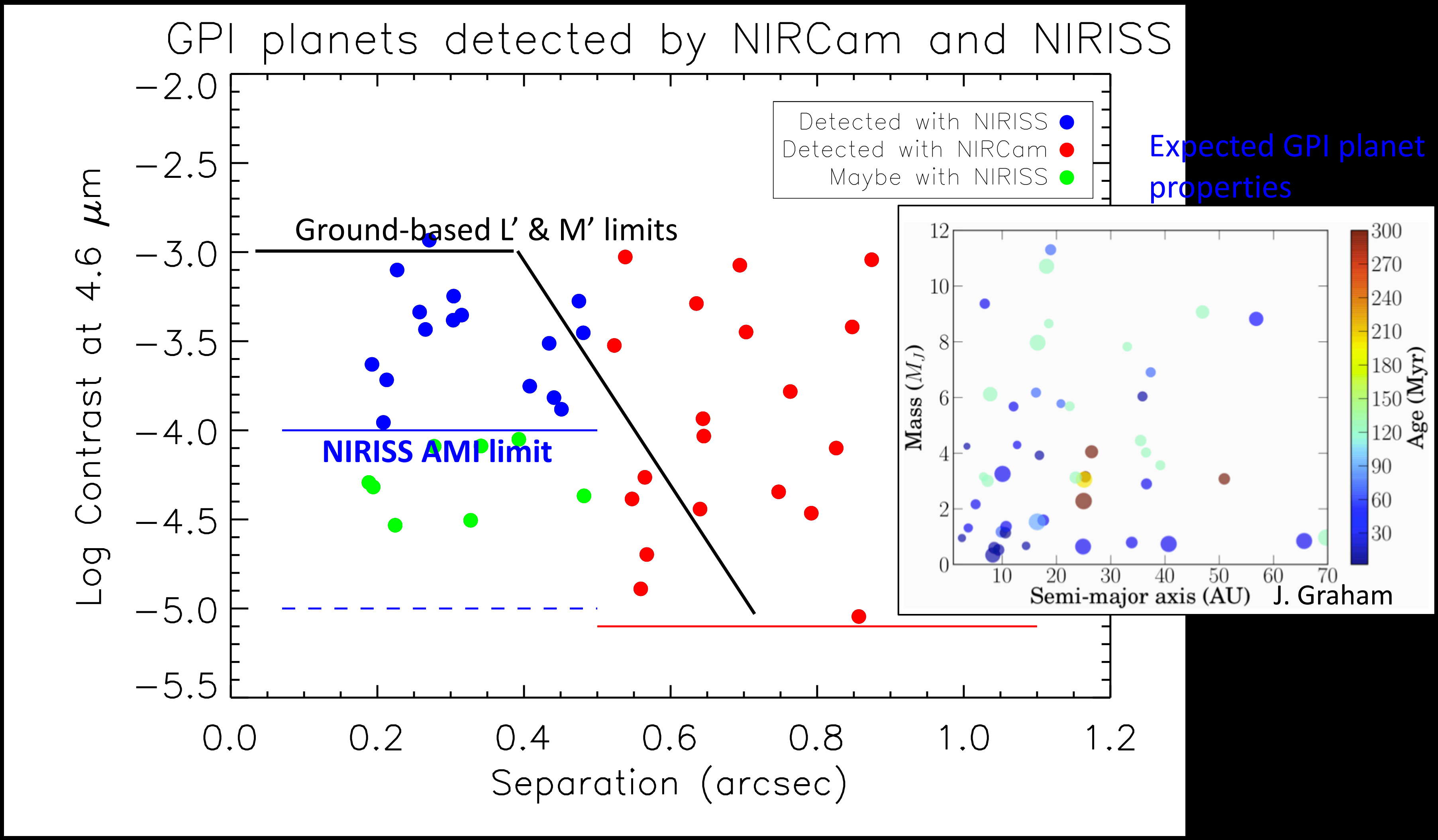
Host	Name	T_p (K)	ρ (g/cm³)	$R_\star$ ($R_\odot$)	Δf/f (ppm)		
					H_2-rich μ=2	H_2O-rich μ=18	Earth μ=29
Hot Jupiters/Neptunes							
G0V	HD209458b	1130	0.37	1.14	**700**	-	-
M3V	GJ436b	700	1.5	0.42	**800**	-	-
Super Earths							
M4V	GJ1214b	600	2	0.2	**2300**	**250**	**160**
K1V	HD97658b	800	3.4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

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

Aperture masking inteferometry (AMI)



Discovery Space for NIRISS AMI



J. Graham

NIRISS GTO: *Preliminary*

- Planet Formation and Evolution:
  - Rogue Planets in Young Clusters (WFSS, 19 hours).
  - Forming proto-planets in circumstellar transitional disks (AMI, 10 hours).
- Exoplanet Imaging & Characterization:
  - Architectures of Known Systems (AMI, 7 hours).
  - T Dwarf Variability (SOSS, 4 hours)
  - Y dwarf Imaging (AMI, 3 hours).
- NEAT Transit Survey: 204 hours

Name	J (mag)	M_p ($M_{\rm Jup}$)	R_p ($R_{\rm Jup}$)	$\log g_p$ ($cm\ s^{-2}$)	T_{eq} (K)	T_{14} (h)	$t_{\rm obs}$ (h)	Notes
GJ 3470b	8.79	0.043	0.346	2.9	600	1.9	6.31	
GJ 436b	6.90	0.0726	0.3767	3.106	680	0.761	3.67	
HAT-P-1b	9.16	0.531	1.242	2.935	1320	2.784	16.72	Tr + ecl
HD 209458 b	6.59	0.689	1.359	2.969	1450	3.065	18.03	Tr + ecl
WASP-39b	10.66	0.284	1.27	2.646	1120	2.803	8.41	
WASP-43b	10.0	1.78	0.93	3.709	1350	1.16	27.7	Phase
WASP-69b	8.03	0.259	1.057	2.762	960	2.230	7.07	
WASP-76b	8.54	0.92	1.83	2.85	2160	3.694	20.94	Tr + ecl
WASP-121b	9.63	1.183	1.865	2.973	2360	2.887	17.20	Tr + ecl
USco1610-1919b	11.1	...	0.45	...	900	4.08	11.37	
TRAPPIST-1 system	11.35	~0.003	0.0936	~3	340	0.696	35.2	10 visits
GJ 1132 b	9.25	0.005	0.1036	3.09	580	0.783	18.6	5 visits
K2-18 b	9.76	...	0.2	...	270	2	13.1	2 visits

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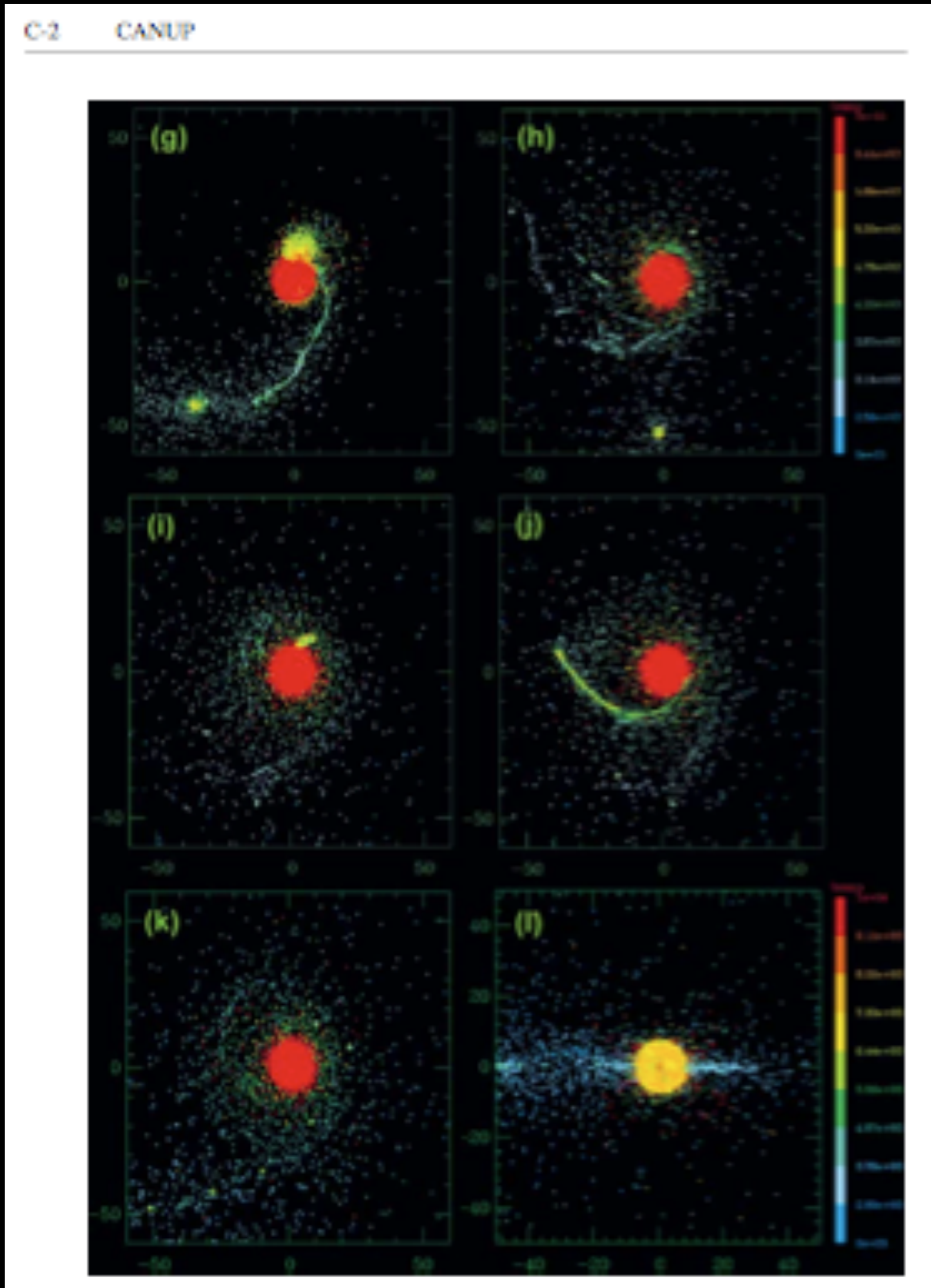
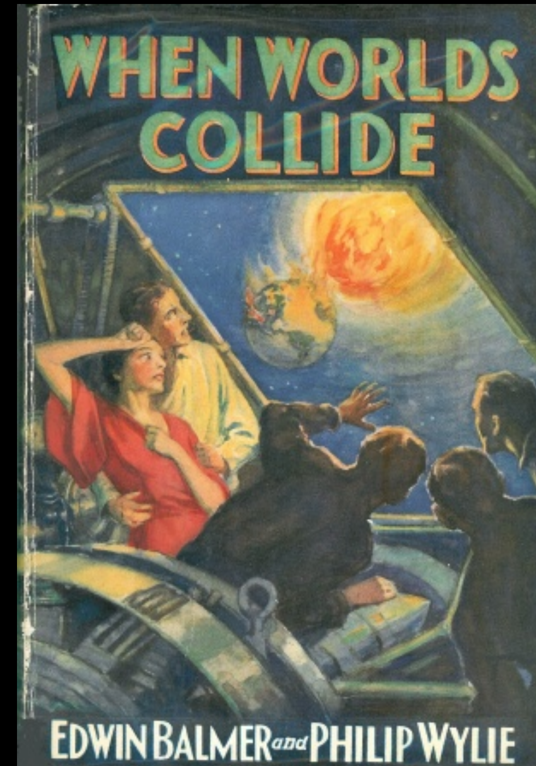
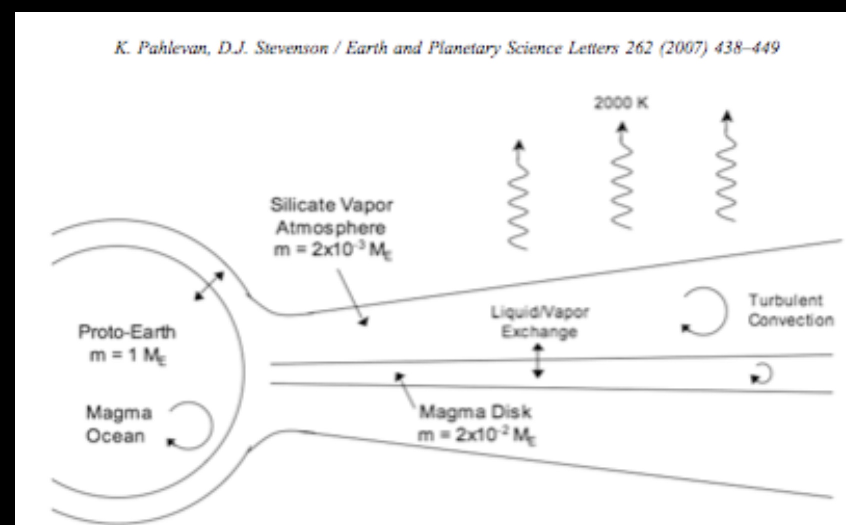
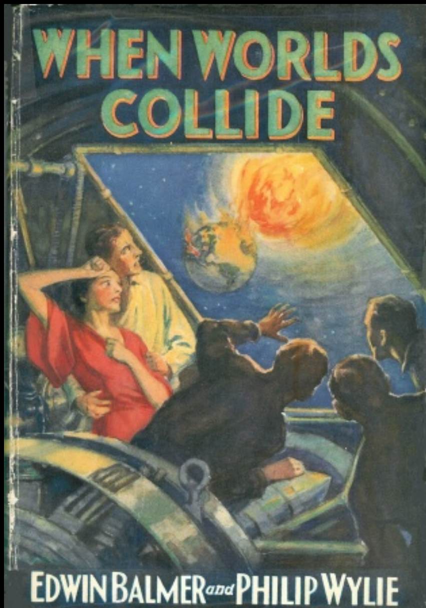

C-2 CANUP
(g)
(h)
(i)
(j)
(k)
(l)


WHEN WORLDS COLLIDE
EDWIN BALMER and PHILIP WYLIE

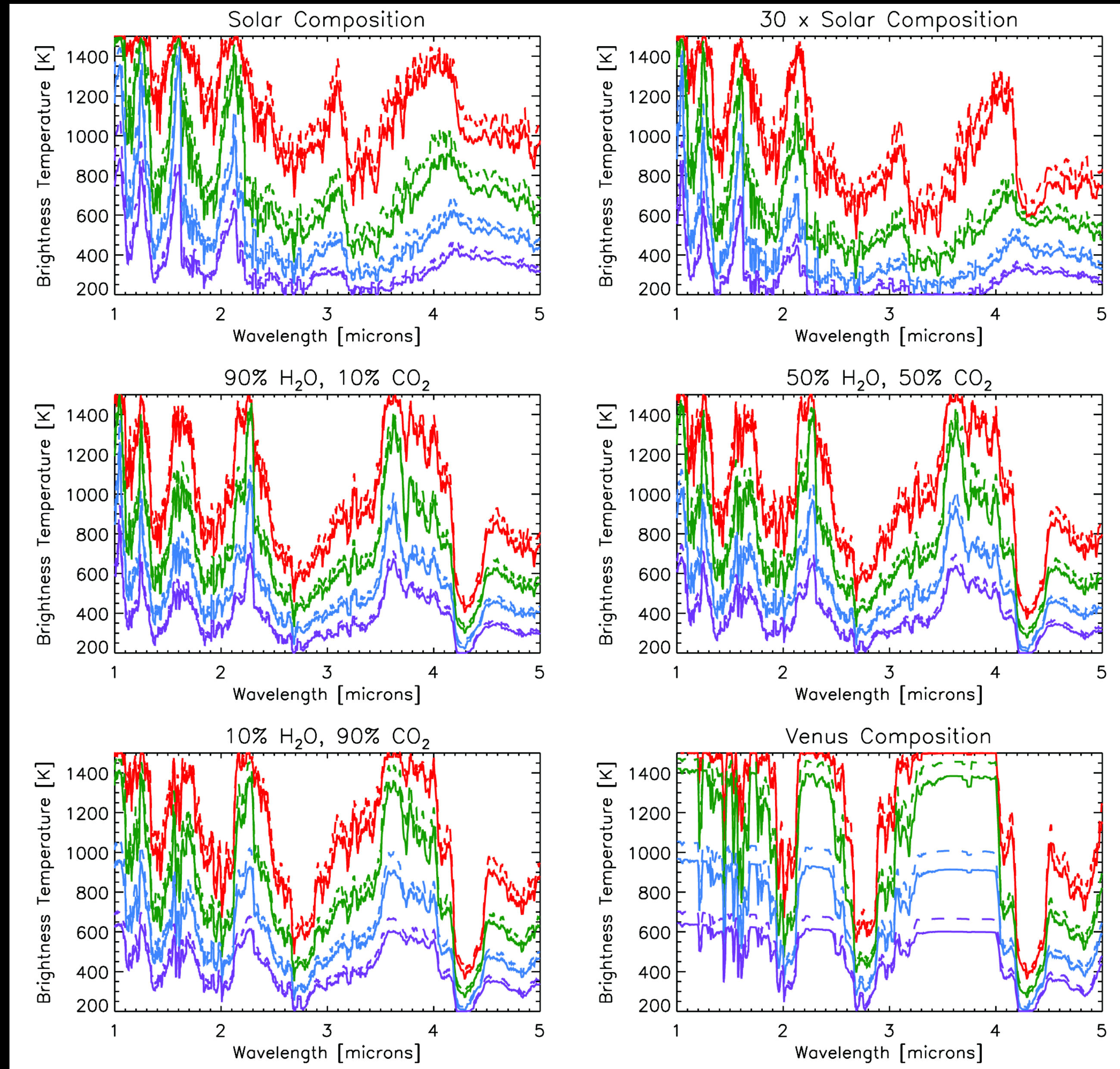

K. Pahlevan, D.J. Stevenson / Earth and Planetary Science Letters 262 (2007) 438–449
2000 K
Silicate Vapor
Atmosphere
m = 2x10^-3 M_E
Liquid/Vapor
Exchange
Turbulent
Convection
Proto-Earth
m = 1 M_E
Magma
Ocean
Magma Disk
m = 2x10^-2 M_E

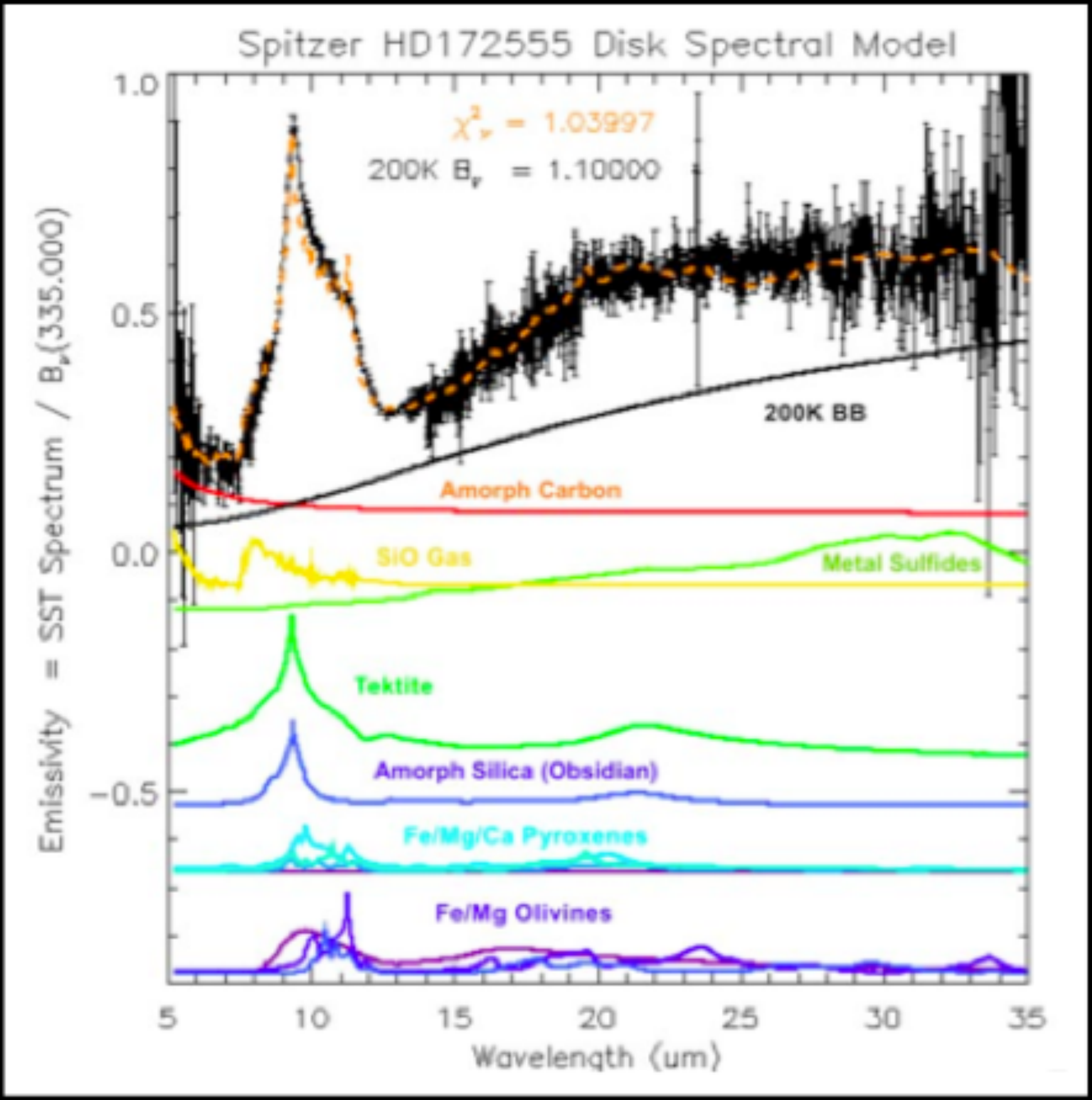


Hot Protoplanet Collision Afterglows

Miller-Ricci, Meyer, Seager, & Elkins-Tanton (2009).

cf. Lupu et al. (2014).





Hot 'PCA's with NIRCam/TFI/MIRI

Non-equilibrium dust signature (too much)

Unusual mineralogy.

Transients are *rare* in Spitzer samples (< 1%?).

Collisions < 10 AU likely to melt embryos and < 50 AU embryos reach 500 K!

Wyatt et al. (2007); Lisse et al. (2009); Meyer et al. (in prep)