Coronagraphic Imaging of Exoplanets with NIRCam

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For the NIRCam Team
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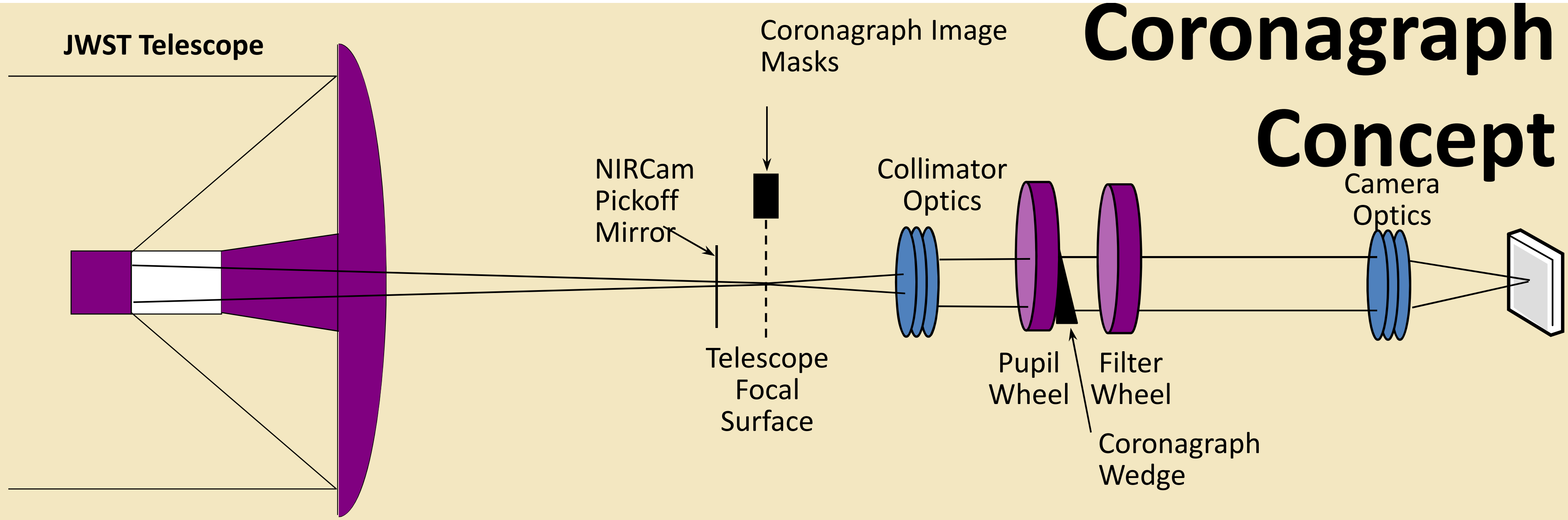
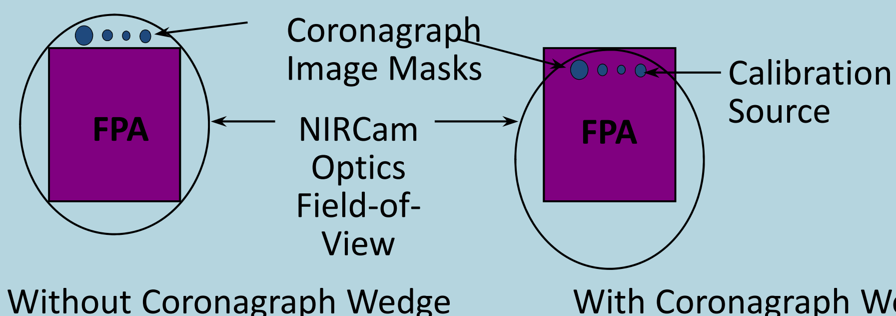
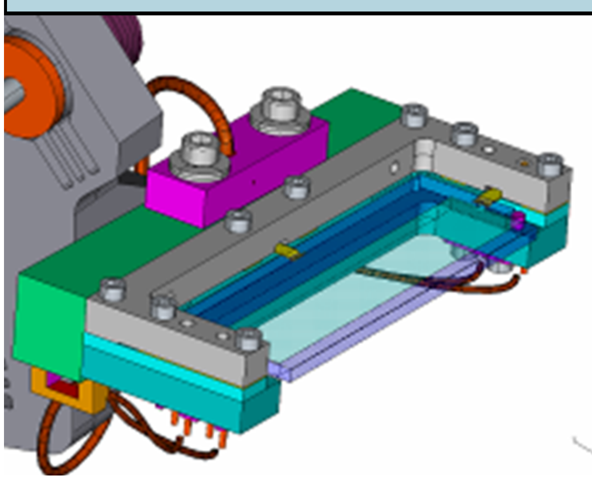
Coronagraph Concept

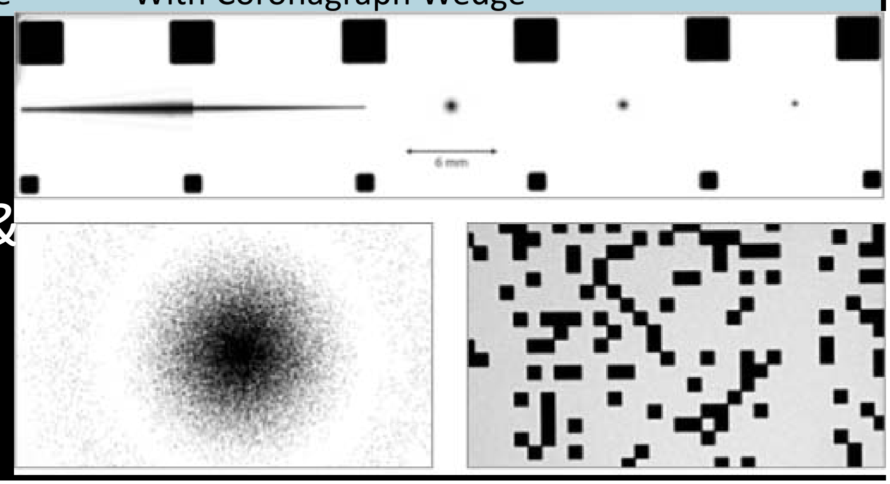




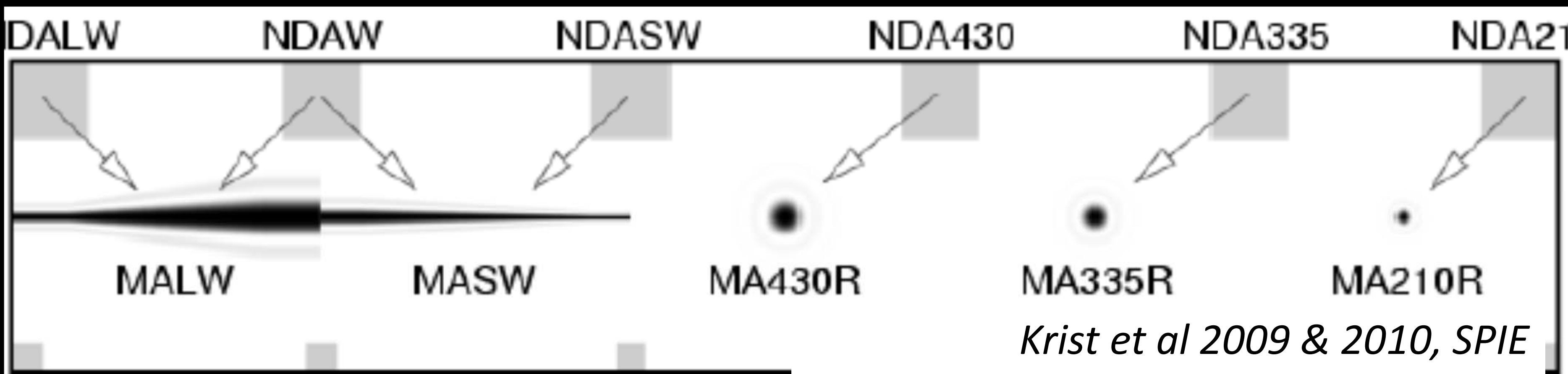
Not to scale



Krist et al 2009 & 2010, SPIE

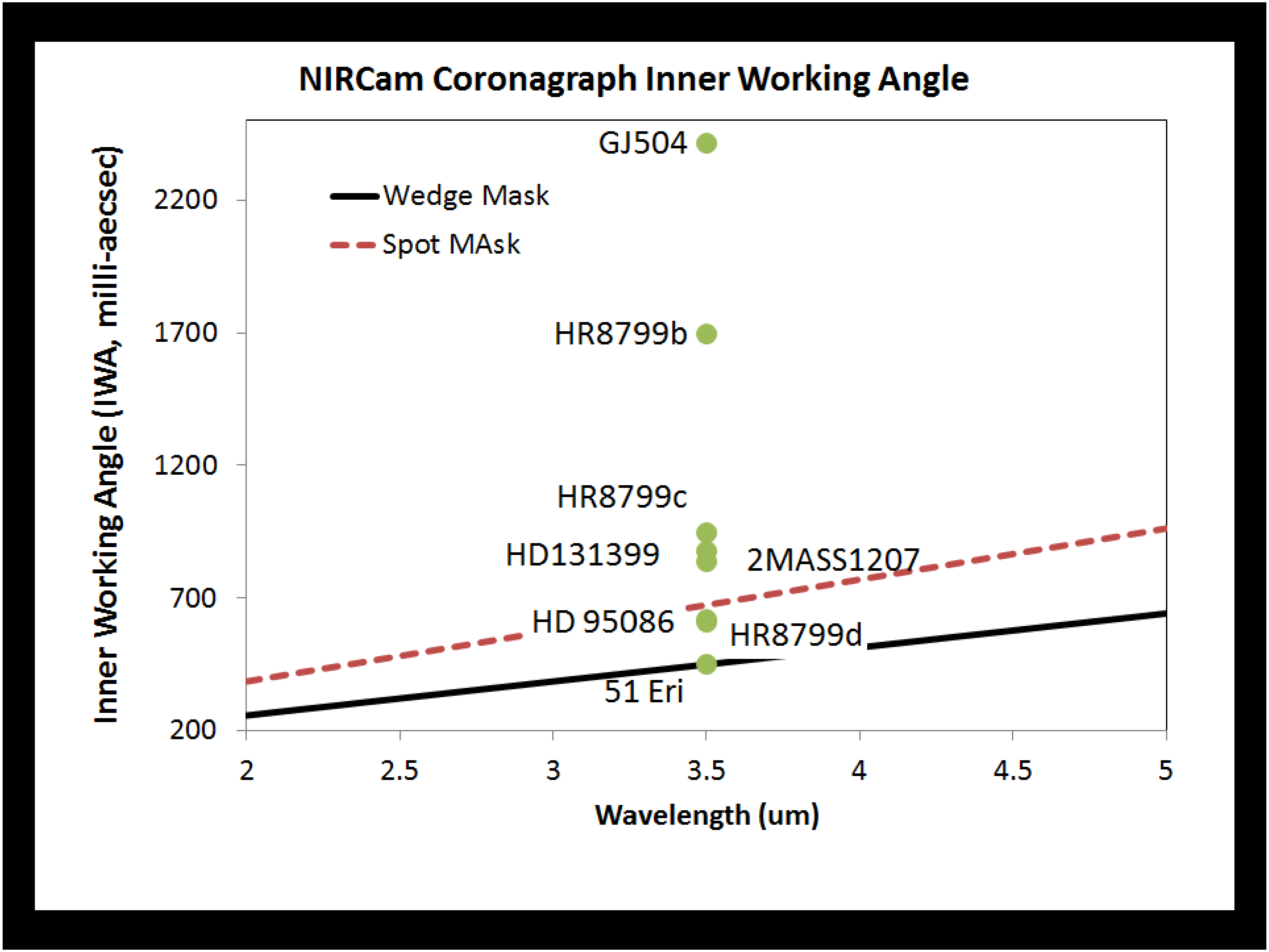


NIRCam Focal Plane Masks



$FWHM_c$ = 0.58” (4λ/D @ 4.6 μm)	**$FWHM_c$ = 0.27”** (4λ/D @ 2.1 μm	**FWHM = 0.82”** (6λ/D @ 4.3 μm)	**FWHM = 0.64”** (6λ/D @ 3.35 μm)	**FWHM = 0.40”** (6λ/D @ 2.1 μm)

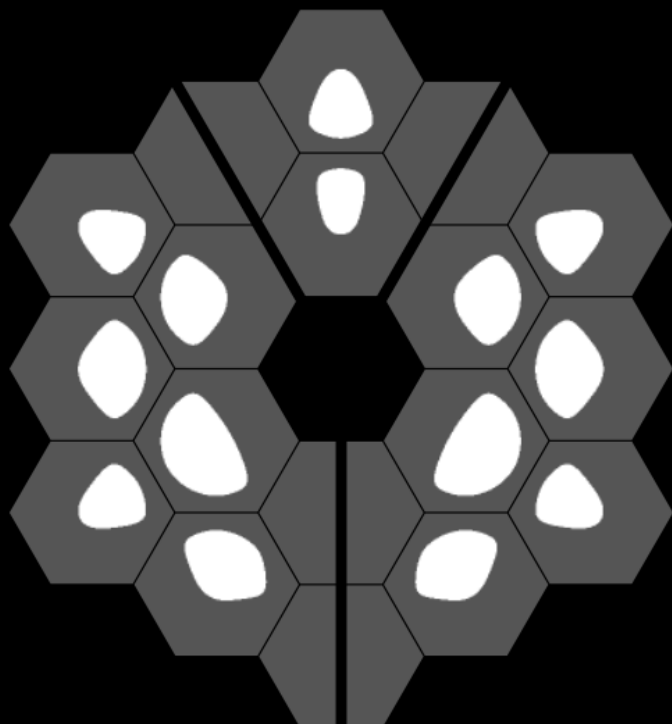
- 2 wedge-shaped masks for known geometries give best inner working angle (IWA)=4λ/D~0.13λ”
- 3 circular (sombrero) masks for 360° coverage with larger IWA= 6λ/D~0.19λ”


NIRCam Coronagraph Inner Working Angle
Wedge Mask
Spot MAsk
GJ504
HR8799b
HR8799c
HD131399
2MASS1207
HD 95086
HR8799d
51 Eri
Inner Working Angle (IWA, milli-aecsec)
2200
1700
1200
700
200
2
2.5
3
3.5
4
4.5
5
Wavelength (um)

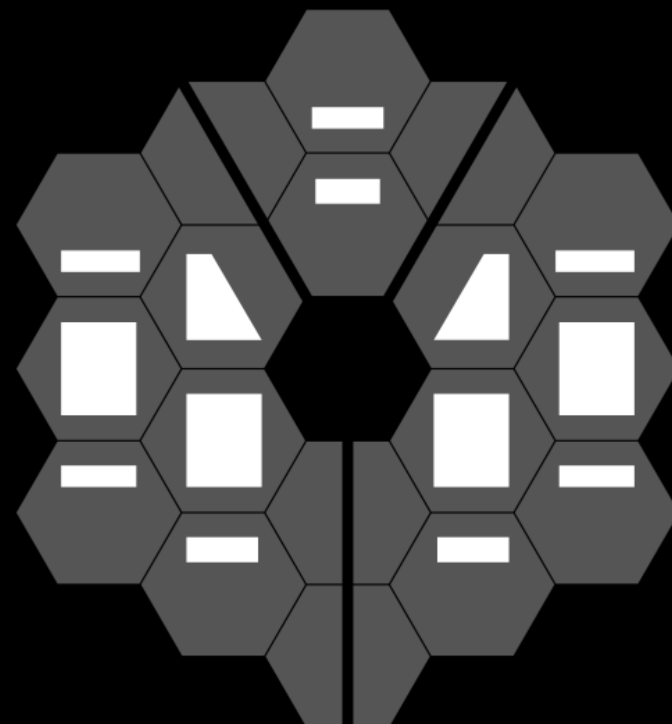
NIRCam Coronagraph Lyot Stops

Clear regions superposed on JWST pupil

Throughput ~19%.



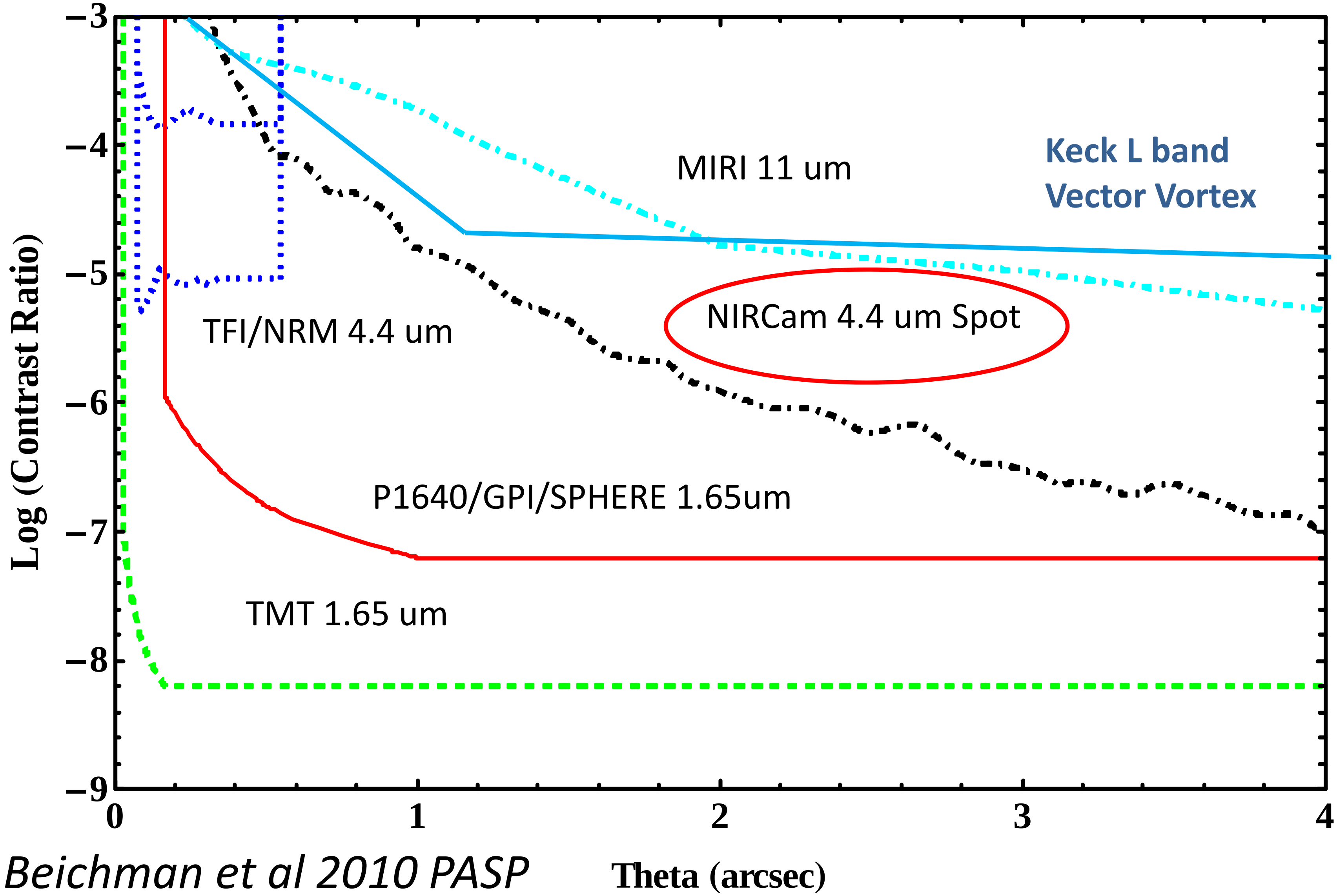
Lyot stop for
6λ/D spot occulters



Lyot stop for
4λ/D wedge occulters

Krist et al 2009 & 2010, SPIE

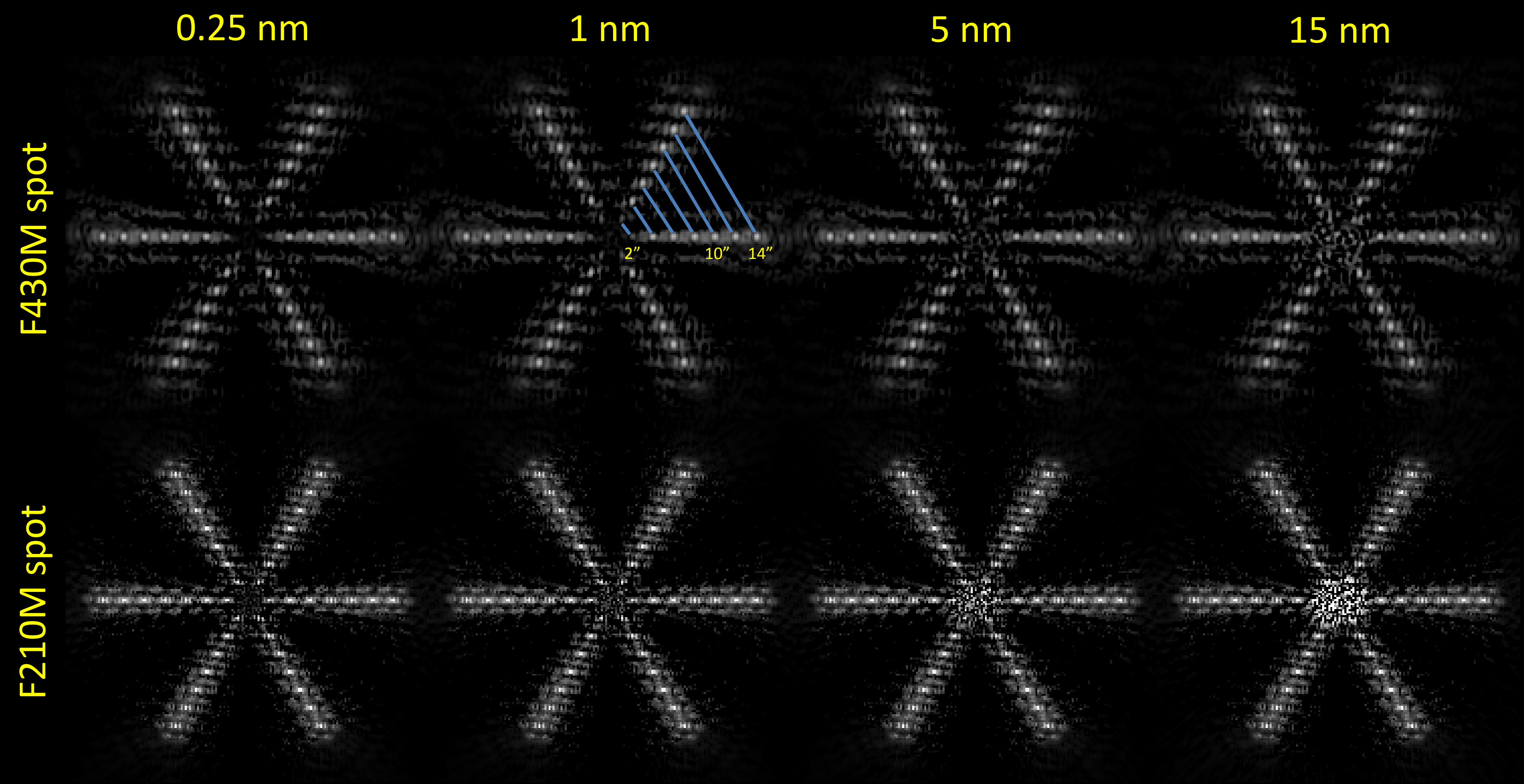
Coronagraphic Capabilities: Ground and Space



Beichman et al 2010 PASP

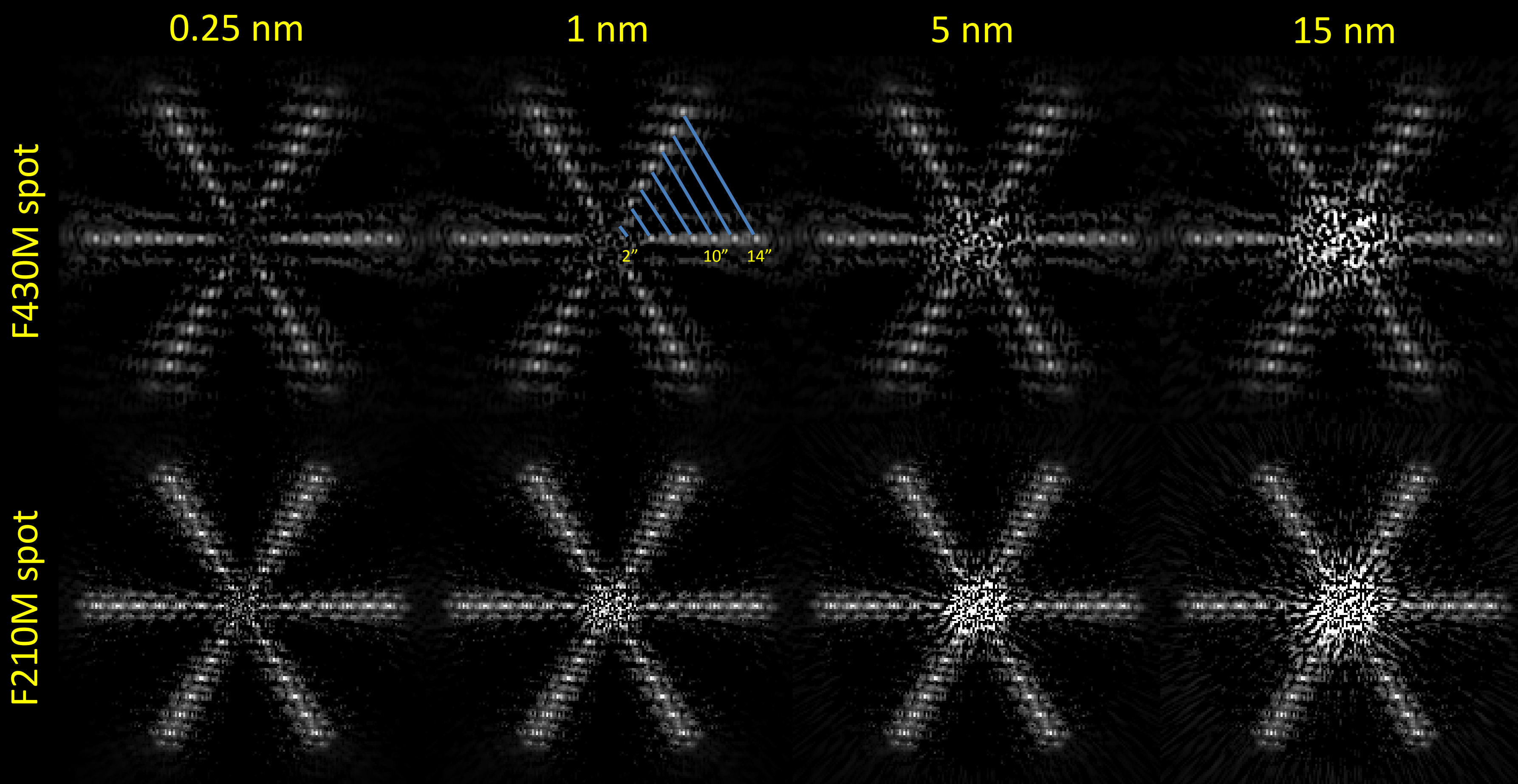
10^{-5} contrast sources, 10° roll, iterative roll subtraction

RMS wavefront change between rolls indicated



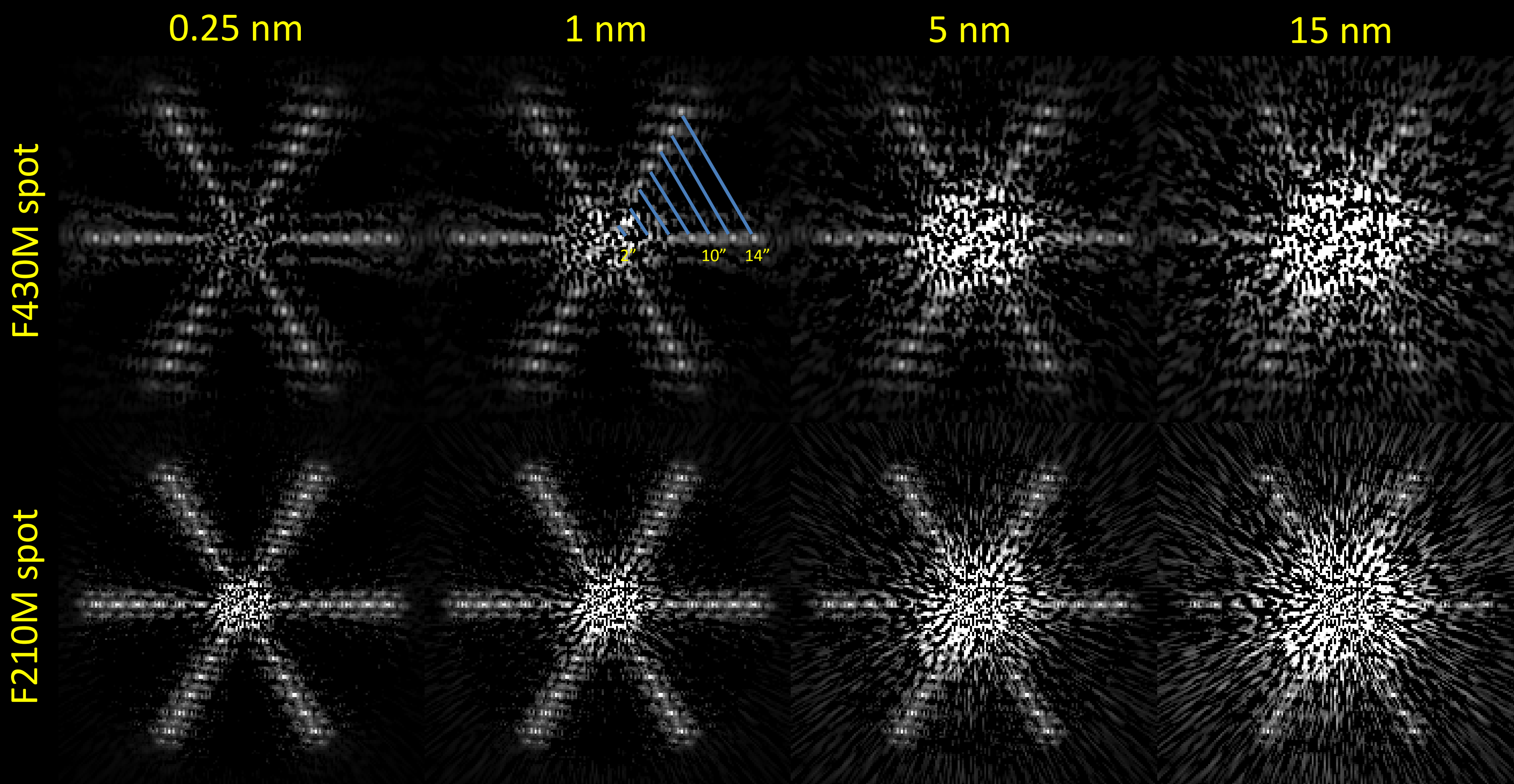
10^{-6} contrast sources, 10° roll, iterative roll subtraction

RMS wavefront change between rolls indicated



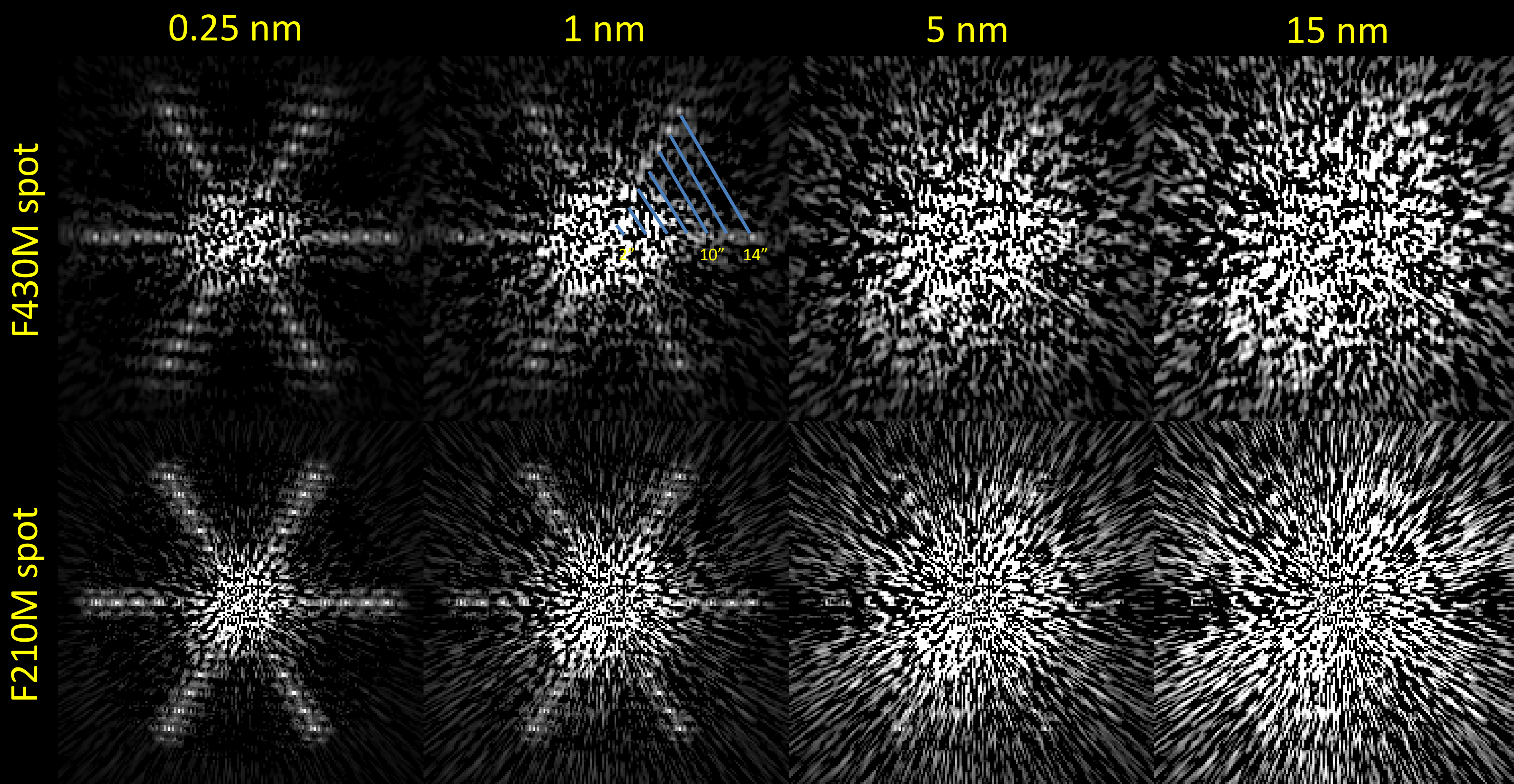
10^{-7} contrast sources, 10° roll, iterative roll subtraction

RMS wavefront change between rolls indicated

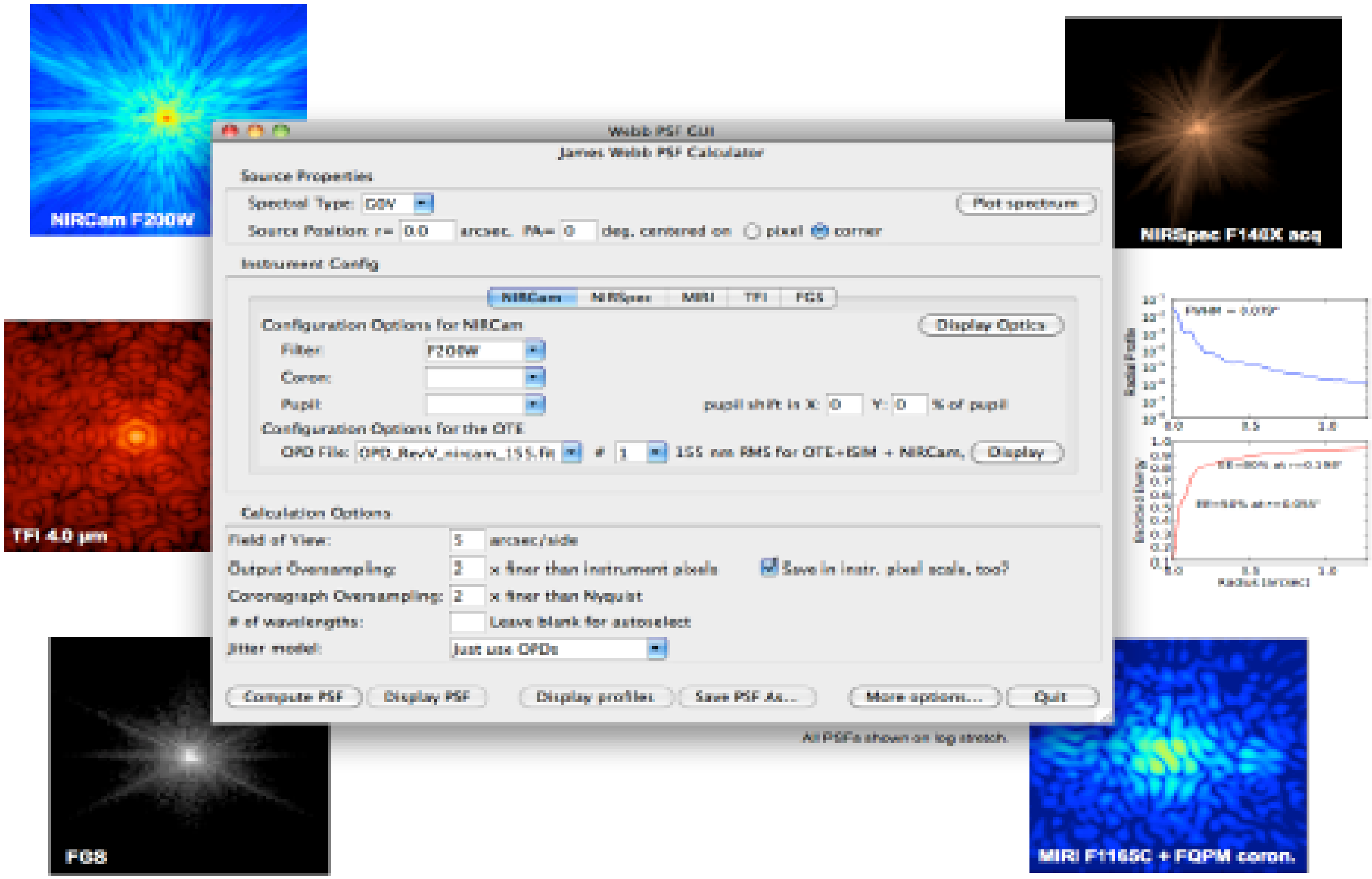


10^{-8} contrast sources, 10° roll, iterative roll subtraction

RMS wavefront change between rolls indicated



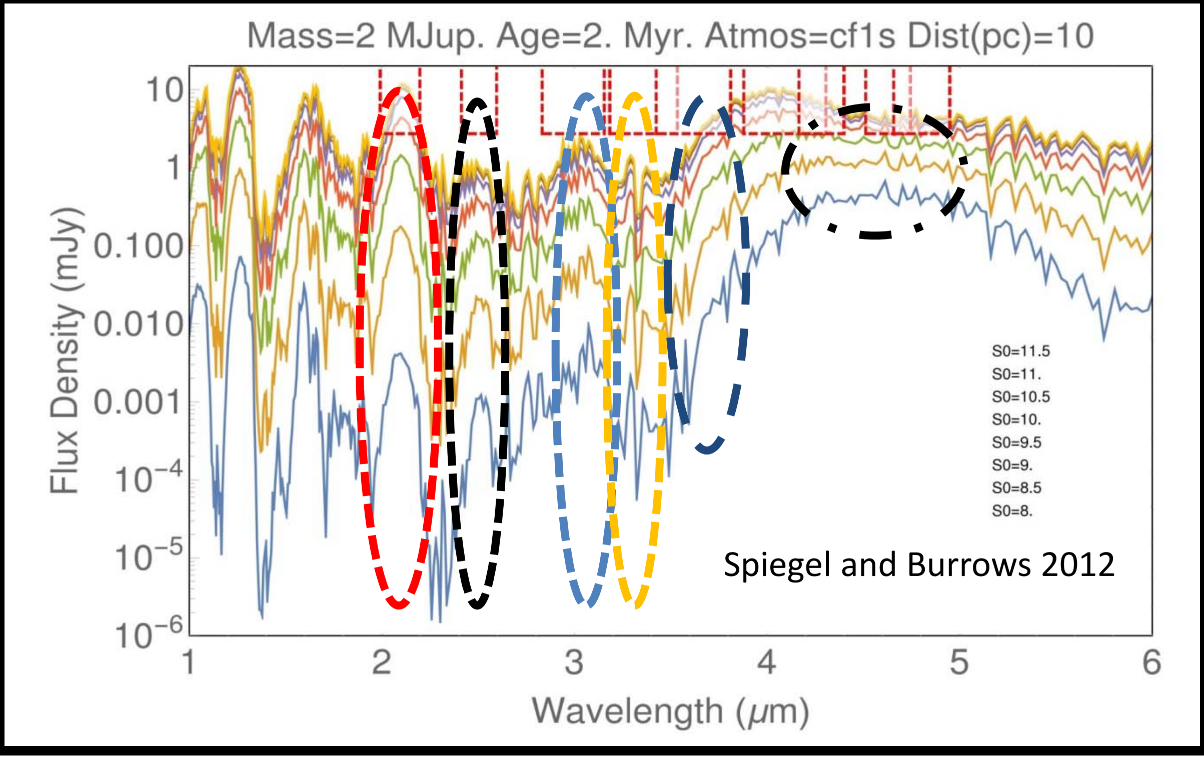
PSF Simulation Tools



http://www.stsci.edu/~mperrin/software/webbpsf.html

Illustrative Coronagraphic Observations

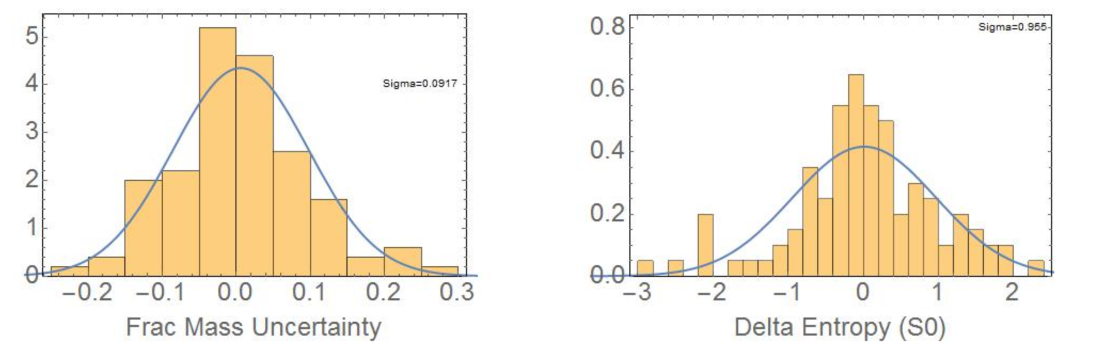
- Observe ~5 known planetary systems with the NIRCam and MIRI coronagraphs to recover physical and atmospheric properties
  - Mass, Radius, Teff, Luminosity, Clouds, Composition Initial Entropy
- Search for lower mass planets down to ~0.1-0.3 MJup
- Select targets in angular separation range 0.4”-3”, masses<13 M_{Jup}

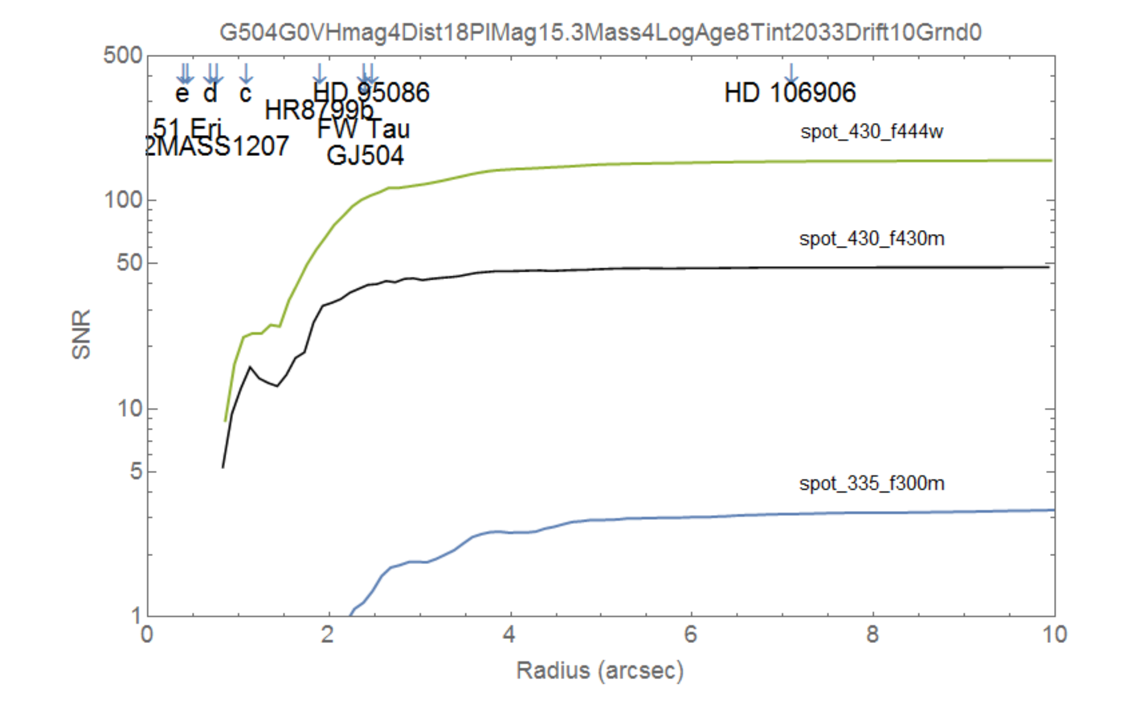


Coronagraphic Observations -2

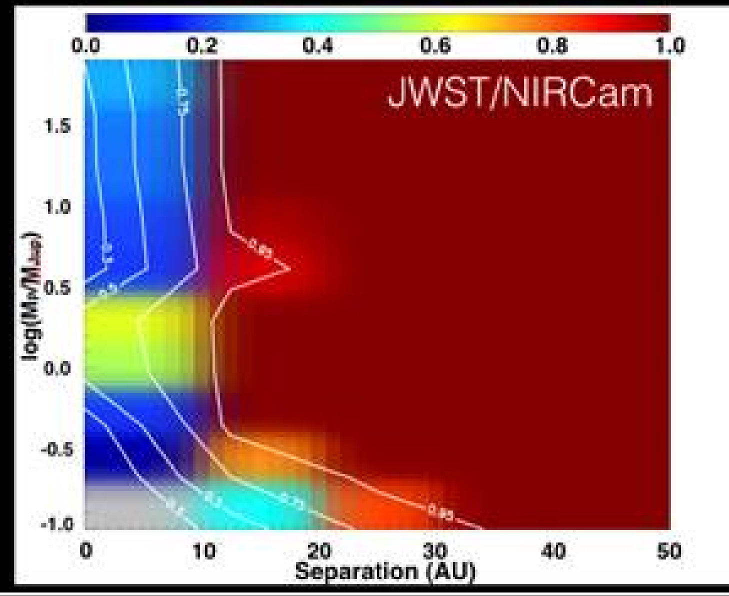
- Monte Carlo analysis over broad range of masses, ages, shows NIRCam (F210M, F250M, F300M, F335M, F430M) + MIRI (F1065C, F1140C, F1550C) yields masses, radii, entropy, etc to 10% for known planets.

- Are systems like HR8799 the exception or rule?
- Use JWST's sensitivity to probe to lower masses outside of ~1-2" in F444W where planets brightest and F322W2 to reject stars & galaxies

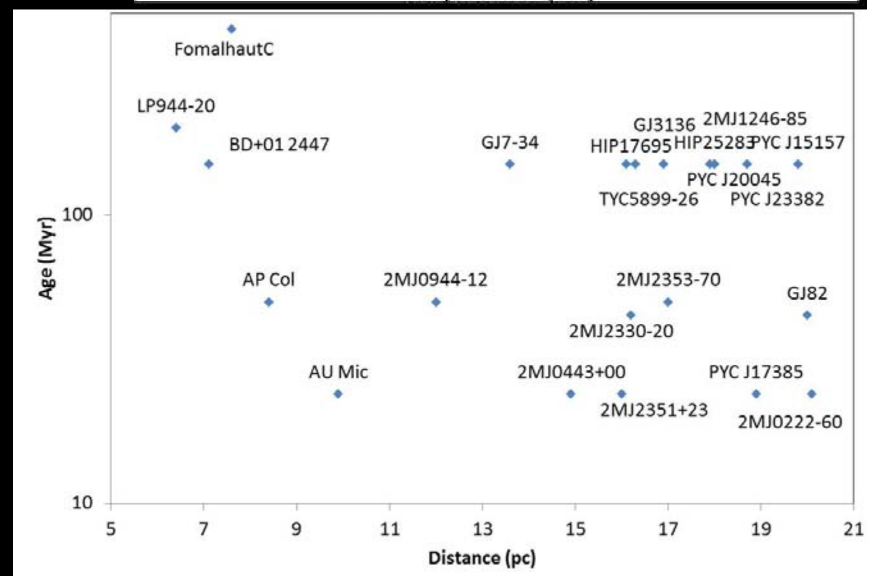




M Star Survey



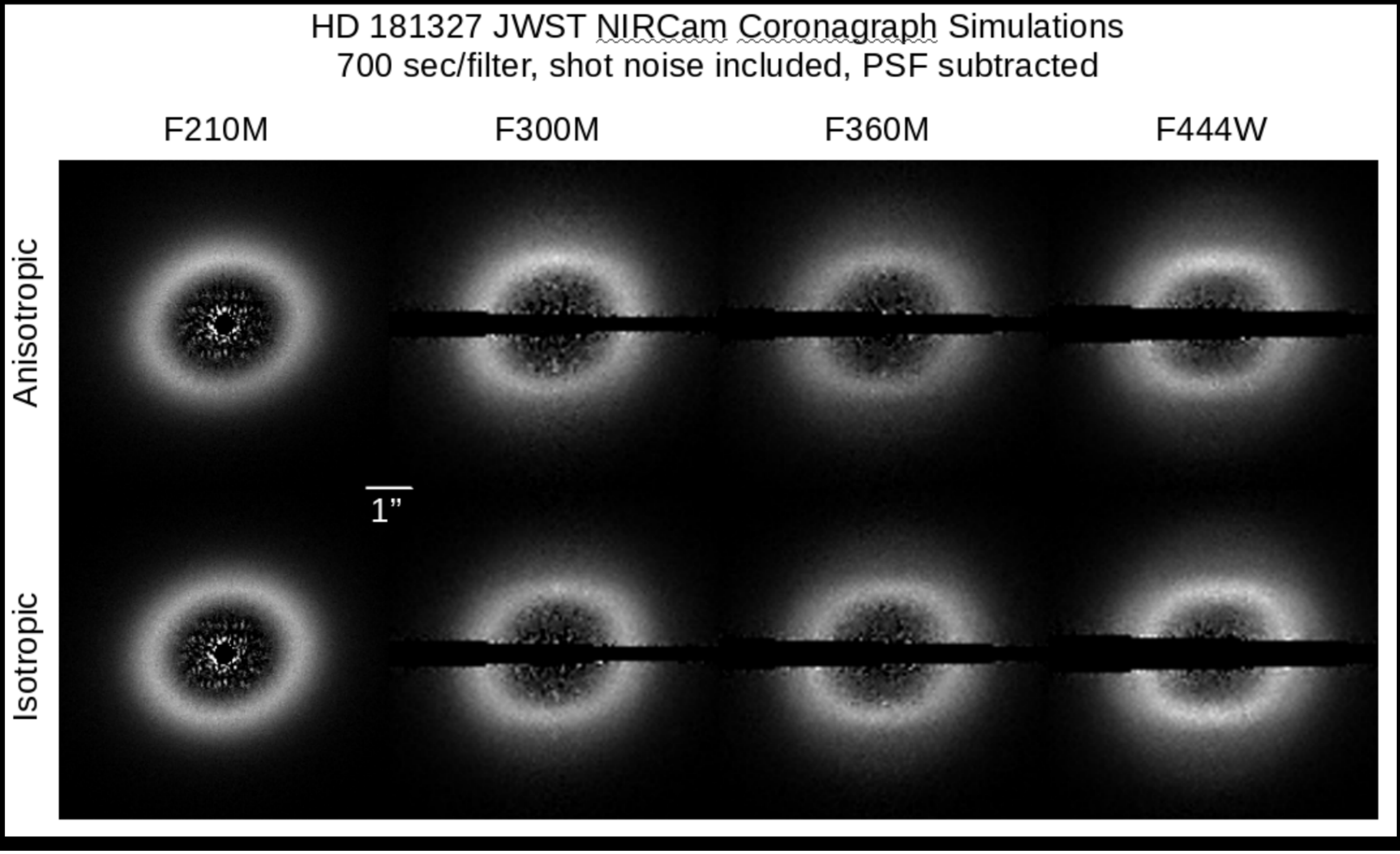
- Kepler and microlensing suggest many small planets orbiting M stars
- NIRCam coronagraphy can reach Saturn - Uranus masses for <150 Myr planets within 15 pc.
- Probe 10-15 AU: CO snow line favored for ice giant formation
- Survey ~15 objects at F322W2 and F444W at 3.5 hr/obj
- Use entire sample to create reference star library



Dist (pc)	Med Spec Type	Min Age (Myr)	Med Age (Myr)	MaxAge (Myr)	WISE W2 (Mag)
16.25	M4	24	150	440	7.26

Disk Imaging

- JWST wavefront error (132 nm) precludes more sensitive searches for debris disks compared with HST
- Ultimate performance depends on stability between target and reference stars (5-10 nm?)



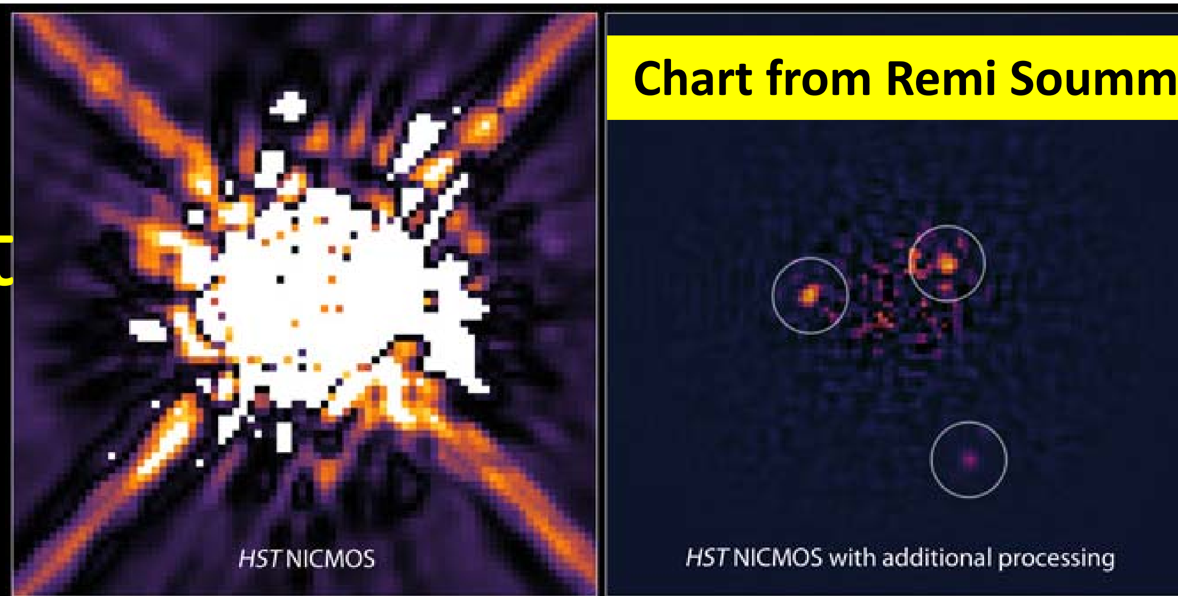
Use APT 24.3 to Define Program & Estimate Overheads (!)

- NIRCam: 5 medium + 2 wide filters, 2 rolls, one ref star
- MIRI: 3 4QPM filters, One ref. star

				Time to complete Observing Sequence (minutes)					
Instrument	**Star**	**Observation**	**Filters**	**Science**	**Instr OH**	**Slew**	**Obs OH**	**Total**	**Effic**
NIRCam	Reference	LongBar	5	33	18	15	11	77	43%
NIRCam	Reference	Short Bar	1	33	18	3	9	62	52%
NIRCam	Reference	Long Spot	2	26	18	2	7	53	49%
MIRI	Reference	F1550C-Ref	1	29	18	4	8	60	49%
MIRI	Reference	F1140C-Ref	1	29	18	2	8	57	51%
MIRI	Reference	F1065C-Ref	1	29	18	2	8	57	51%
MIRI	Target	F1065C	1	29	18	15	10	72	40%
MIRI	Target	F1550C	1	29	18	2	8	57	51%
MIRI	Target	F1140C	1	29	18	2	8	57	51%
NIRCam	Target+5deg	+5 Deep Search	2	33	18	3	9	63	52%
NIRCam	Target+5deg	+5Long Bar	5	33	19	2	9	62	53%
NIRCam	Target+5deg	+5 Short Bar	1	26	18	0	7	51	51%
NIRCam	Target-5deg	-5 Short Bar	1	26	18	4	8	56	46%
NIRCam	Target-5deg	-5 Deep Search	2	33	18	0	8	59	55%
NIRCam	Target-5deg	-5 Long Bar	5	33	19	0	8	60	55%
Total (hours)				**7.5**	**4.6**	**0.9**	**2.1**	**15.0**	**50%**

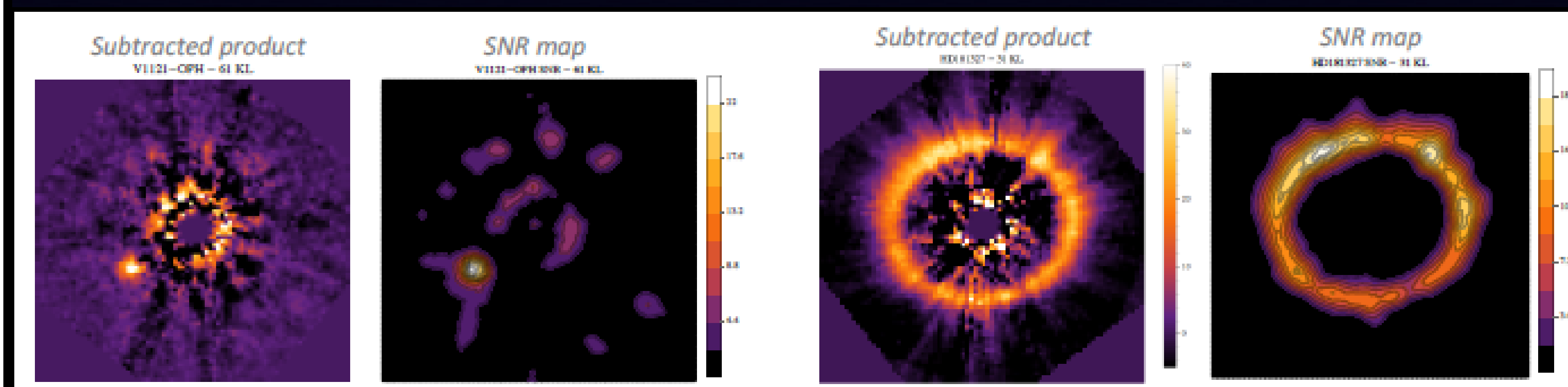
Pipeline Image Processing Built on HST Experience

Chart from Remi Soummer



NASA, ESA, and R. Soummer (STScI)

- JWST will accumulate PSF references for LOCI, KLIP, PCA, etc. Individual ref stars may be non-proprietary
- Generate pipeline subtracted images as high level product



Conclusions

- NIRCam coronagraphic capabilities are limited by telescope wavefront error --- large by standards of Extreme AO or future observatories
- NIRCam's coronagraphic power comes from JWST's WF stability (10 nm?) and low background at λ>2.4 μm and θ>1"
- Acquisition overheads are significant but APT and ETC tools will help with observation planning
- STScI will provide PSF library and advanced data processing