June 3rd, 2015

SF2A 2015 - PRÉPARATION SCIENTIFIQUE JWST

OBSERVING DEBRIS DISKS & PLANETS WITH THE JWST/NIRCAM CORONAGRAPH

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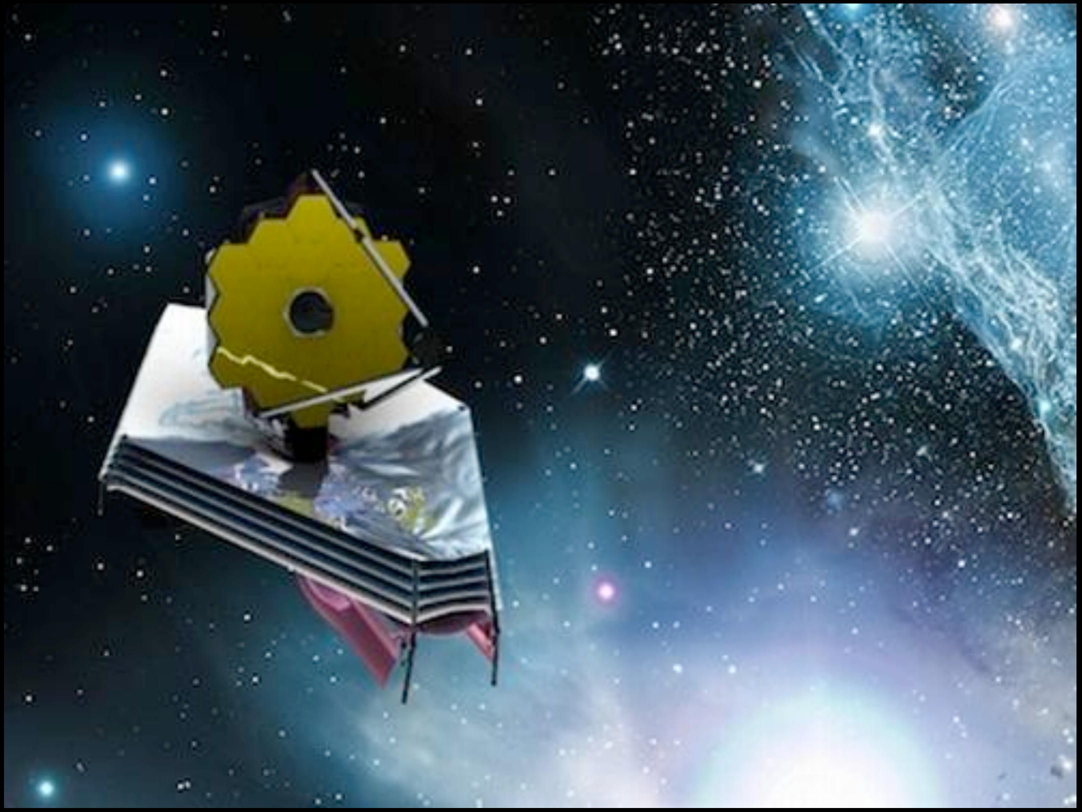


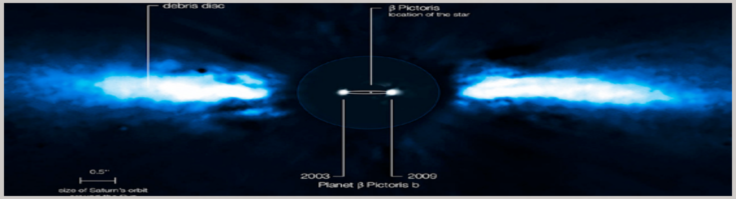
LAYOUT

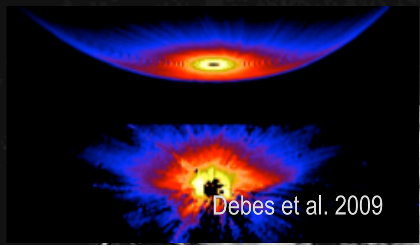
1. Dusty exoplanetary systems
2. The case of η Corvi
3. A simulator for the NIRCam coronagraph
4. Disk imaging
5. Planet imaging

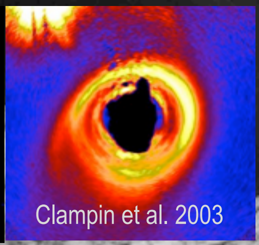
DUSTY EXOPLANETARY SYSTEMS

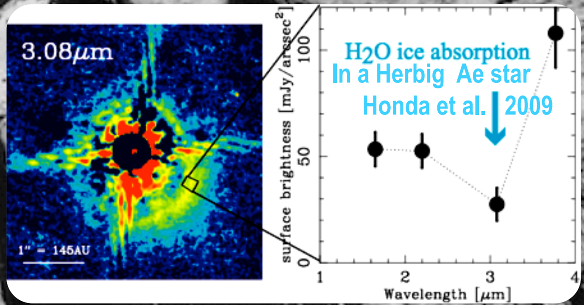
DEBRIS DISKS ARE KUIPER- AND MAIN-BELT ANALOGUES

- Optically thin disks
- Main Sequence stars (>10^7 years)
- Second-generation grains, gas poor
- Driven by photo-gravitational forces









Science questions for NIRCam:

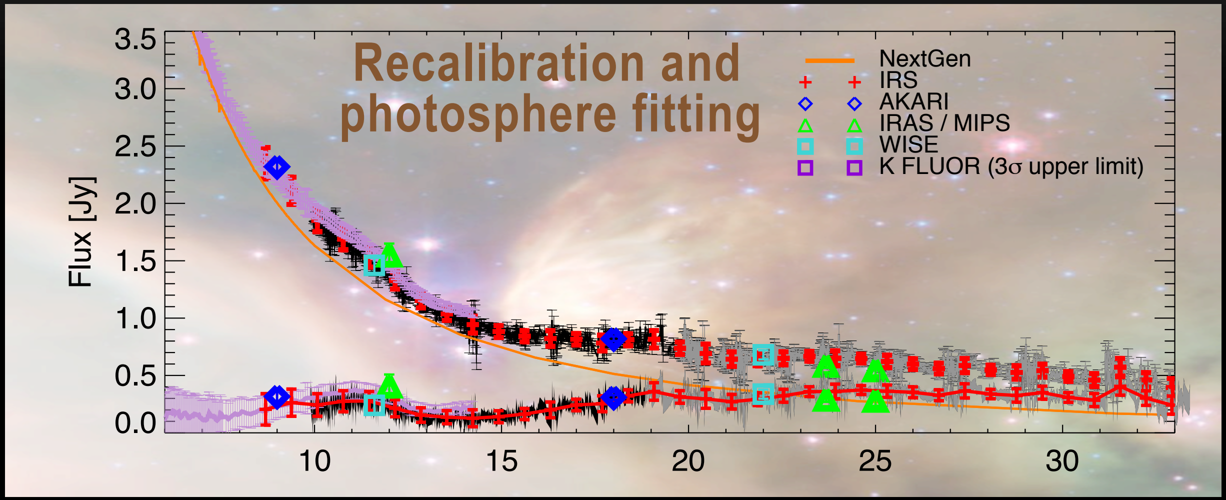
- Are there structures in disks and do they trace planets?
- Can we image disk-shaping exoplanets?
- Are there ices in exo-asteroids / exo-KBOs? Where are the icelines? (H_2O, CO, CO_2, NH_3)
- How does scattering compare to thermal emission? (dust optics & physics/dynamics, disk geometry)

67P/Churyumov-Gerasimenko

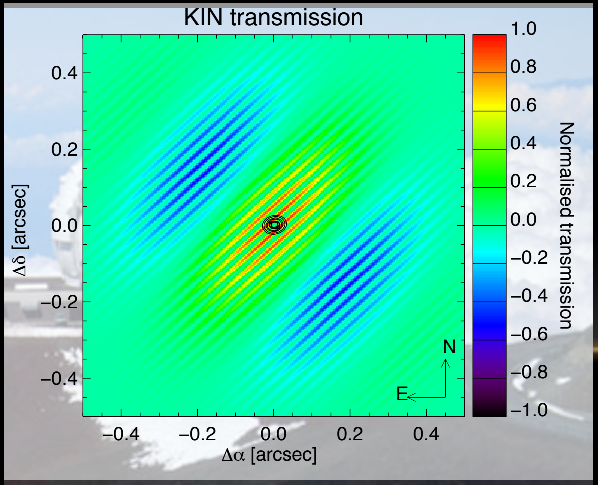
The case of η Corvi: A nearby (18.2 parsec) F2V star with huge mid- and far-infrared excess given its age of ~1.4 Gyr

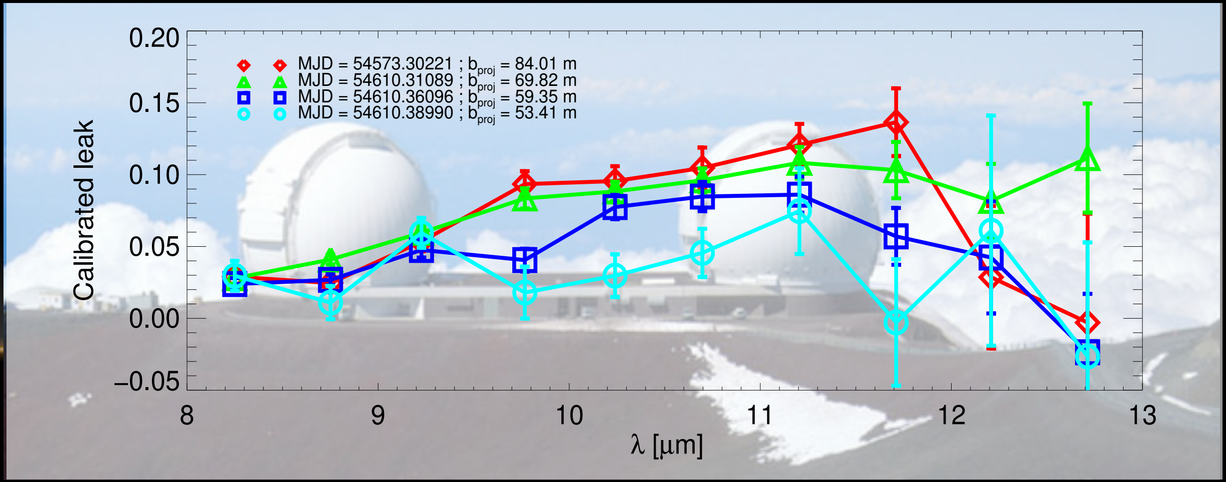
Lebreton et al., subm. to ApJ

Spitzer-IRS spectroscopy probes warm silicate dust in the inner disk



Keck Interferometer nulls across the N-band (4 baselines) pinpoint the warm dust location



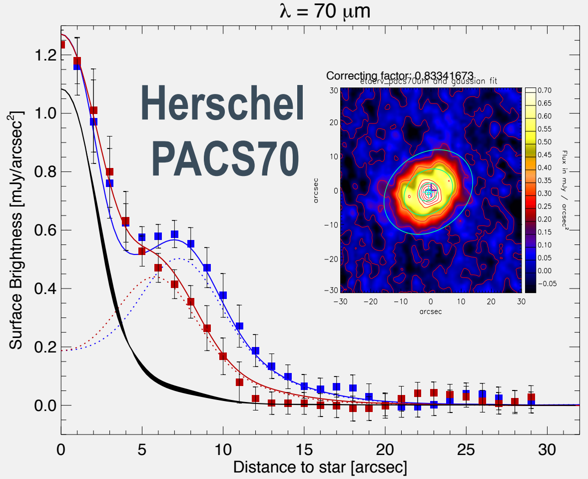


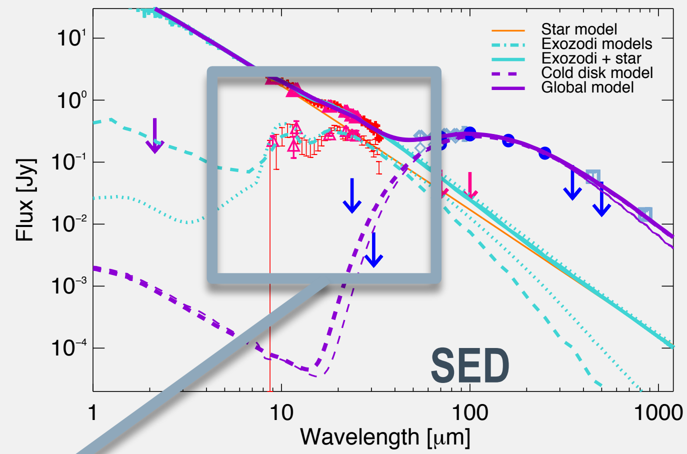
The case of η Corvi: Radiative transfer modeling of the outer belt and the inner exozodiacal disk

Lebreton et al., subm. to ApJ

- **Fit to resolved Herschel PACS 70/100/160μm imaging + SED from near-IR to mm**

  ⟶ a «classical», ice-free belt in collisional equilibrium with a mass comparable to much younger disks





Annulus
at r_0 = 133 AU
a_{min} = 5 μm
$dn(a) \propto a^{-3.5} da$
$M = (0.7\text{-}2.9) \times 10^{-2}\ M_\oplus$

- **The Keck Interferometer refines the inner dust location w.r.t unresolved Spitzer**

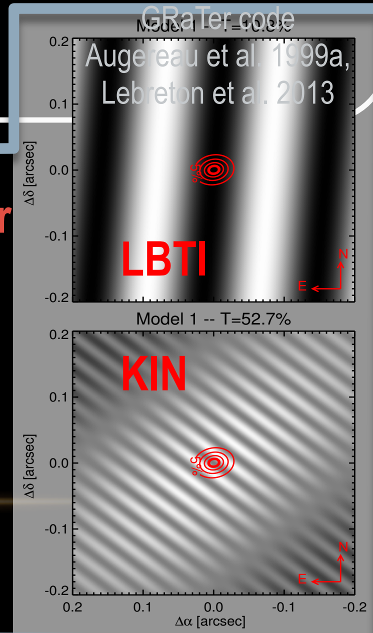
  ⟶ Inner disk (exozodi): "Abnormally" high albedo Forsterite at 0.2 AU (χ^2 = 1.7) or Olivine at 0.8 AU (χ^2 = 2.9) a_{min} ~0.8 – 1.2 um

  The mass of a 200km asteroid just in dust at 0.2 AU!

  (Likely an exo-LHB: Lisse et al. 2012)

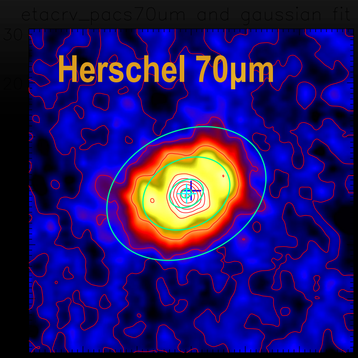
- **The first LBTI data validate our conclusions and favor a ~0.2AU location**

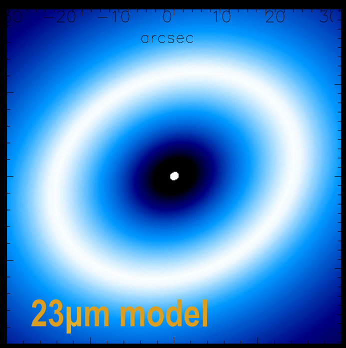
  (Defrère et al 2014)

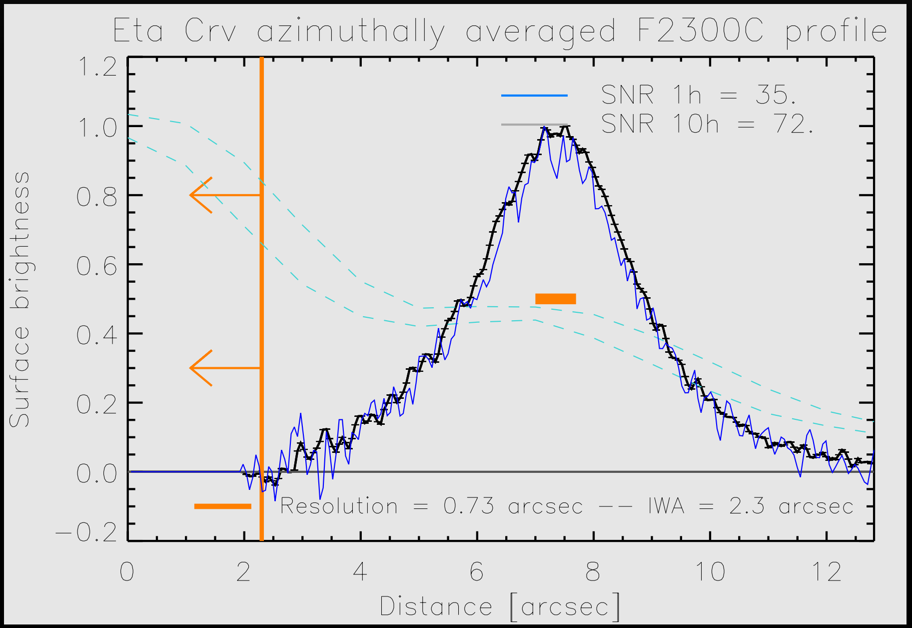


η Crv: too faint for NIRCam but a great target for MIRI

Lebreton et al., subm. to ApJ

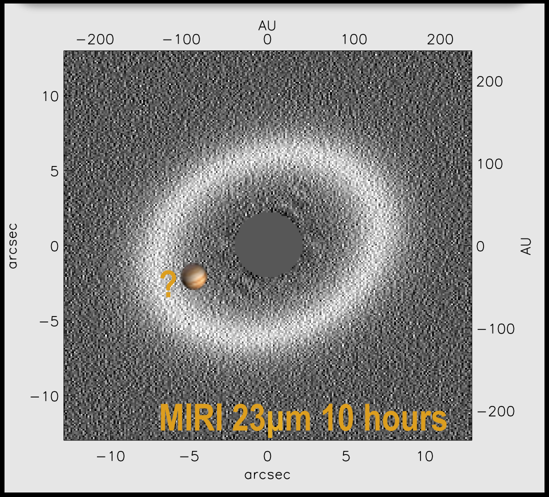






MIRI simulations

F2300C Lyot: The disk is well-detected in 1 hour (A. Boccaletti)



Planets? A companion is predicted to sculpt the belt at 5.3” (1Jupiter) to 6.5” (0.1 Jupiter)

NIRCam can detect a 2 Jupiter-mass planet in 1hour

THE NIRCAM CORONAGRAPH

NIRCam:

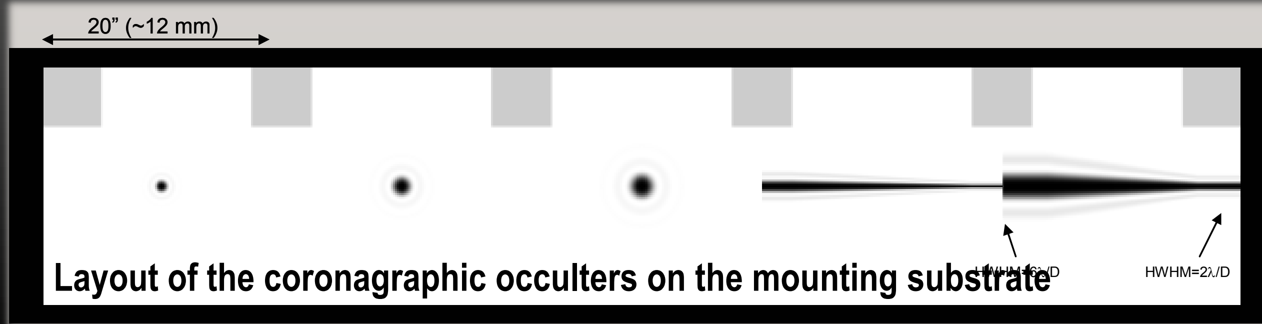
- Near-infrared imaging from 0.6 to 5µm (28 broad, medium and narrow filters)
- Angular resolution: 0.02" to 0.16"
- 2.2'x4.4' FOV, 31.7mas/pixel (SW) or 64.8mas/pixel (LW).

Coronagraph:

- ~4-6λ/D IWA (Jupiter at 4.5µm from 8.2pc)
- Suppress diffracted light ≤ 130nm WFE (throughput 18%)

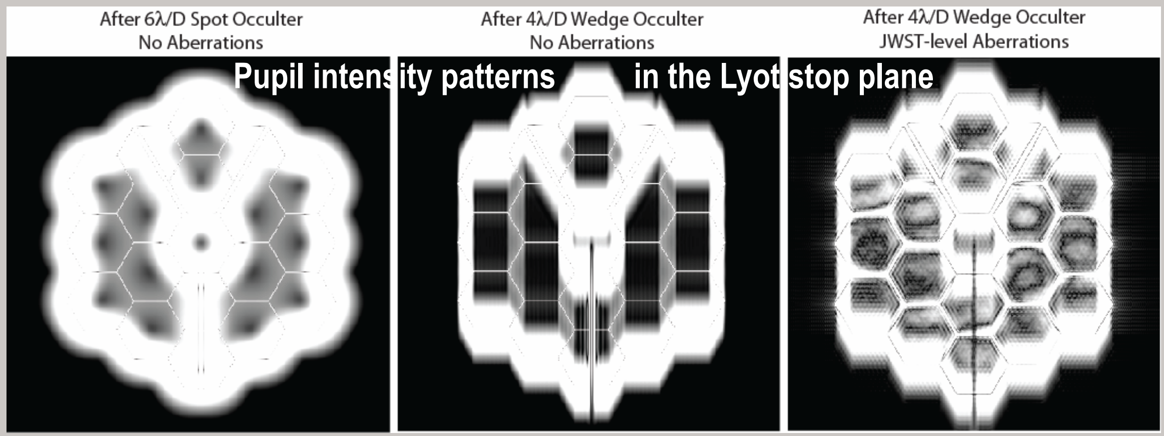
➡ **Contrast**: **10^{-5} (1") – 10^{-8} (10")**

Tolerance to 2% pupil misalignment, <20 mas pointing error



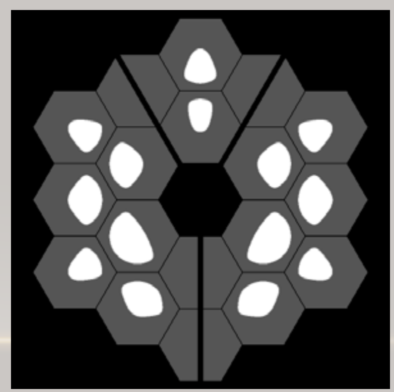
Layout of the coronagraphic occulters on the mounting substrate

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

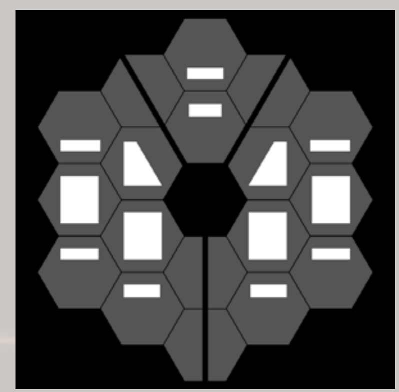


Pupil intensity patterns in the Lyot stop plane

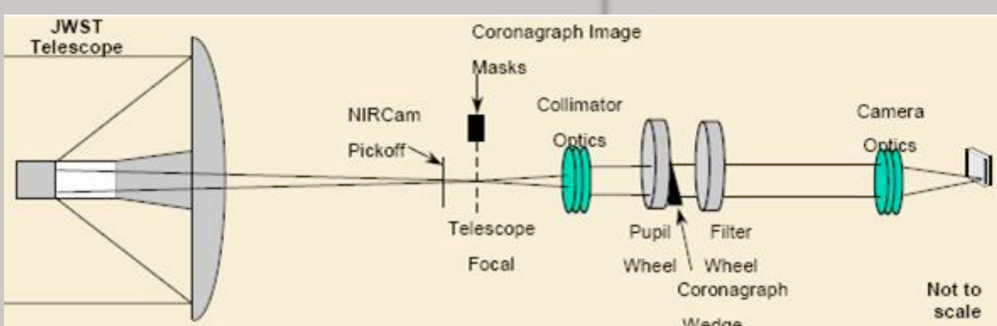
From Krist et al. 2007



Lyot stop for 6λ/D spot occulters



Lyot stop for 4λ/D wedge occulters

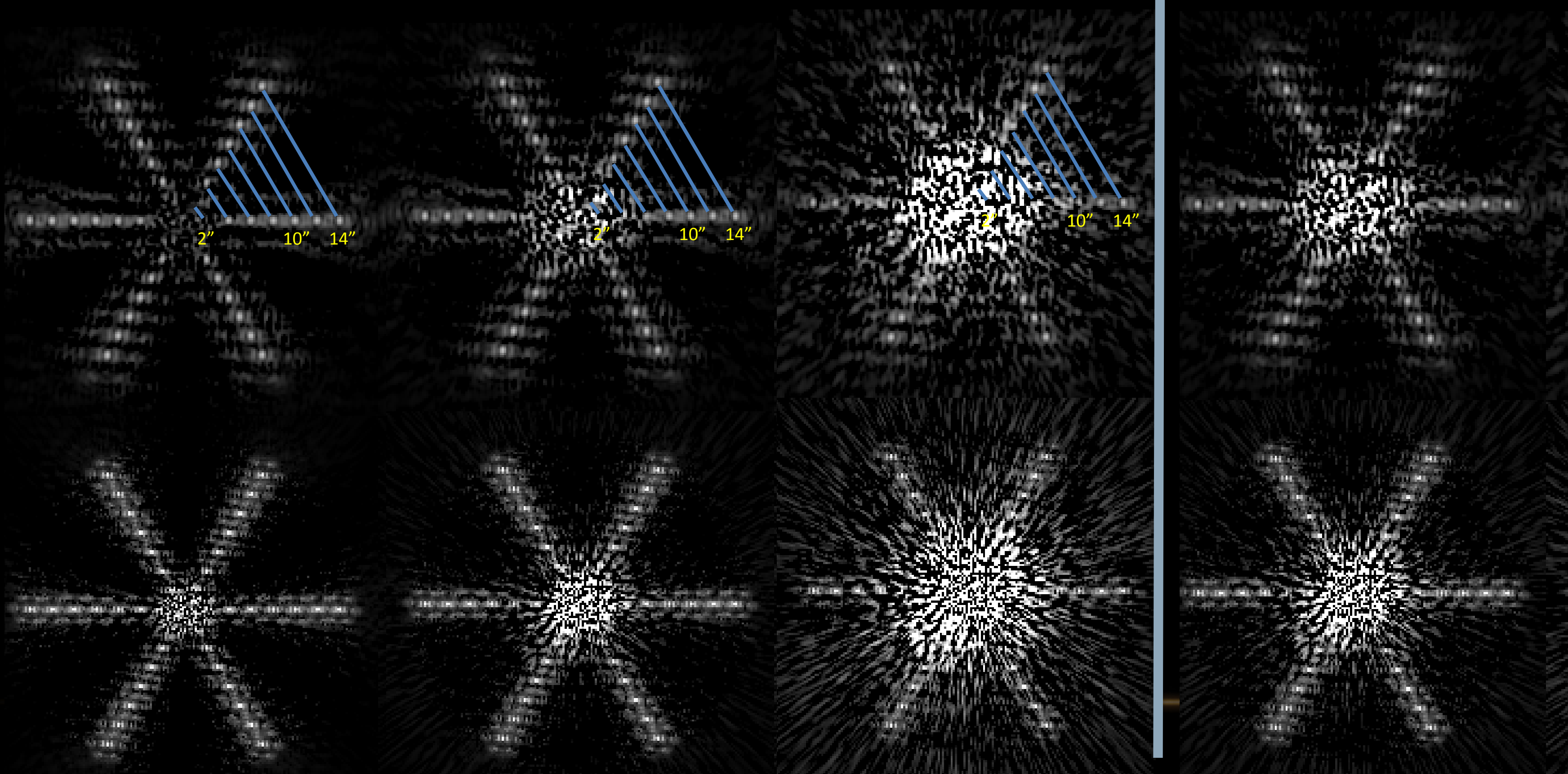


CORONAGRAPHIC PERFORMANCES VS SOURCE CONTRAST

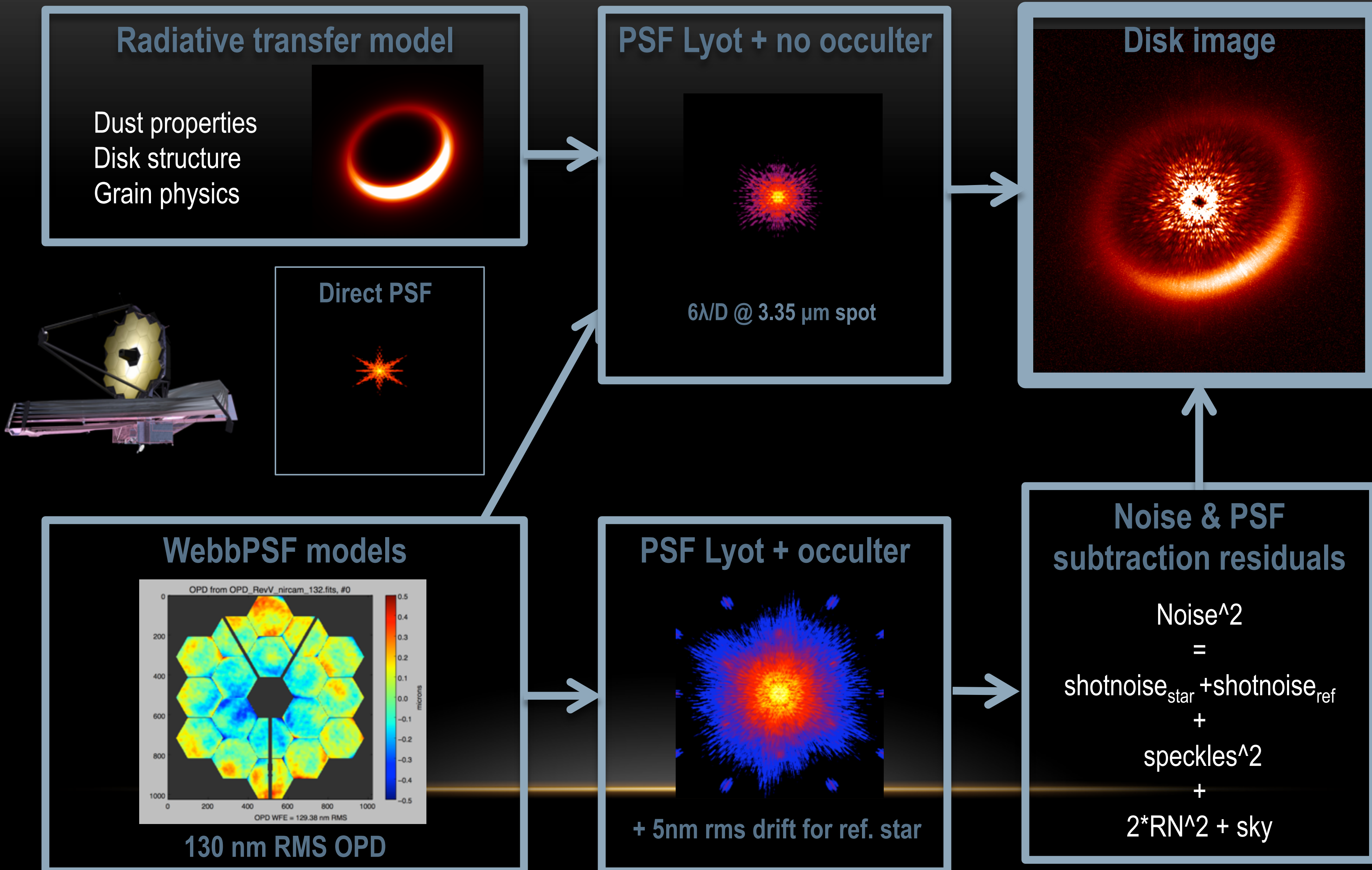
10º roll, iterative roll subtraction, 1 or 0.25 nm wavefront change between rolls

Simulations from John Krist

	10^{-6} contrast 1 nm RMS	10^{-7} contrast 1 nm RMS	10^{-8} contrast 1 nm RMS	10^{-8} contrast 0.25 nm RMS
F430M spot				
F210M spot				

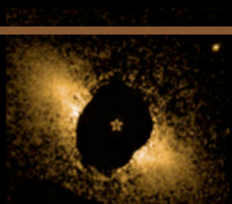


NIRCAM CORONAGRAPH SIMULATOR

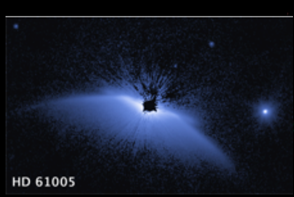


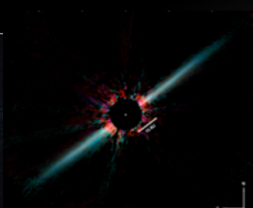
NIRCAM DEBRIS DISK SAMPLE SELECTION

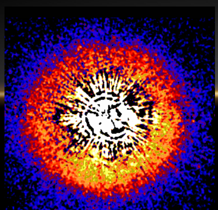
- **A limited number of debris disks** have been **spatially resolved**, most of them in thermal emission (far-IR/ mm), only **23 disks have been resolved in scattered light** (as of Jan. 2015: **HST**, ground)
- Select a limited sample of **extended, high surface brightness debris disks**
- **Follow-up observations of HST disks**: comparable contrast & resolution but in the 2-5 µm range with excellent PSF stability
- Disk stars are **great targets for planet detection** down to (sub-)Neptunian masses

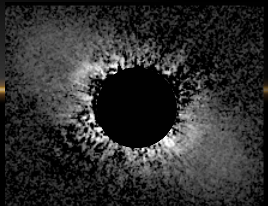


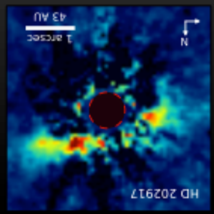
Star	Spectral Type	fdisk/f*	Age [Myr]	Typical radius [arcsec]	Perturbing planet separation [arcsec] 0.1 Mj	1 Mj	10 Mj
HD10647	F8.5V	4.0E-04	1400	4.76	4.32	3.97	3.44
HD181327	F5.5V	6.0E-03	12	1.72	1.57	1.45	1.26
HD32297	A7V	2.0E-03	30	1.05	0.96	0.89	0.79
The Moth	G8Vk	2.5E-03	90	1.77	1.59	1.45	1.25
AU mic	M1Ve	7.6E-03	12	3.53	3.11	2.80	2.35
HD107146	G2V	1.0E-04	140	4.56	4.12	3.78	3.26
HR4796A	A0V	5.0E-03	8	2.10	1.95	1.82	1.62
HD92945	K6	7.7E-04	294	2.09	1.87	1.71	1.46

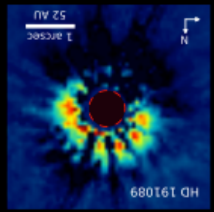


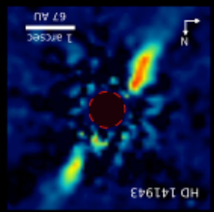


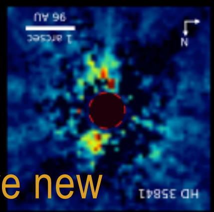








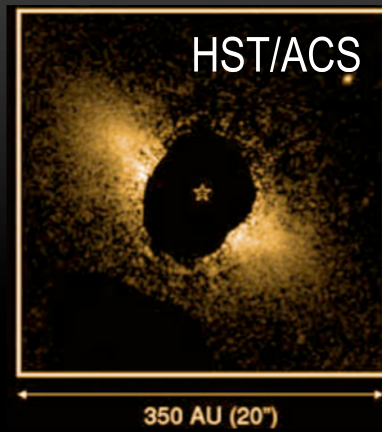


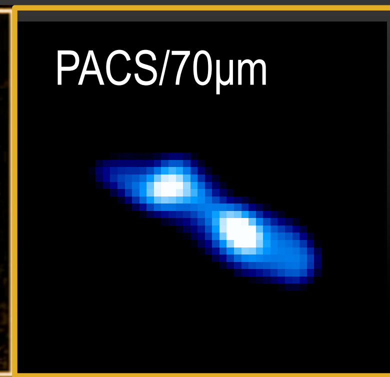


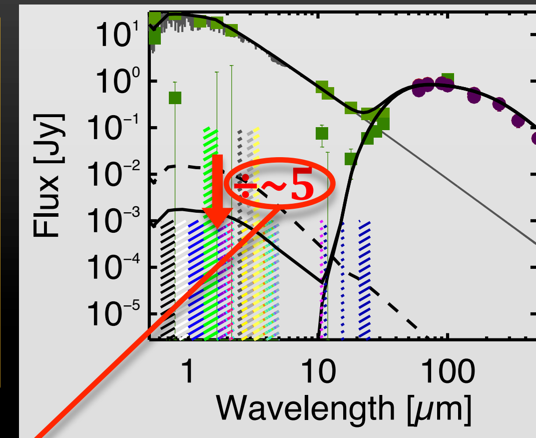
+ more new candidates from the HST archive

SIMULATIONS FOR NIRCAM GTO TARGETS: EXAMPLE OF Q[1] ERI

q[1] Eri (HD10647):
a 1.4Gyr debris belt (~4.8")
around a F8V star at 17.4 pc
hosting a Jupiter-mass planet
(M.sin(i)=0.93 M_J, b=2.03AU, e = 0.1)





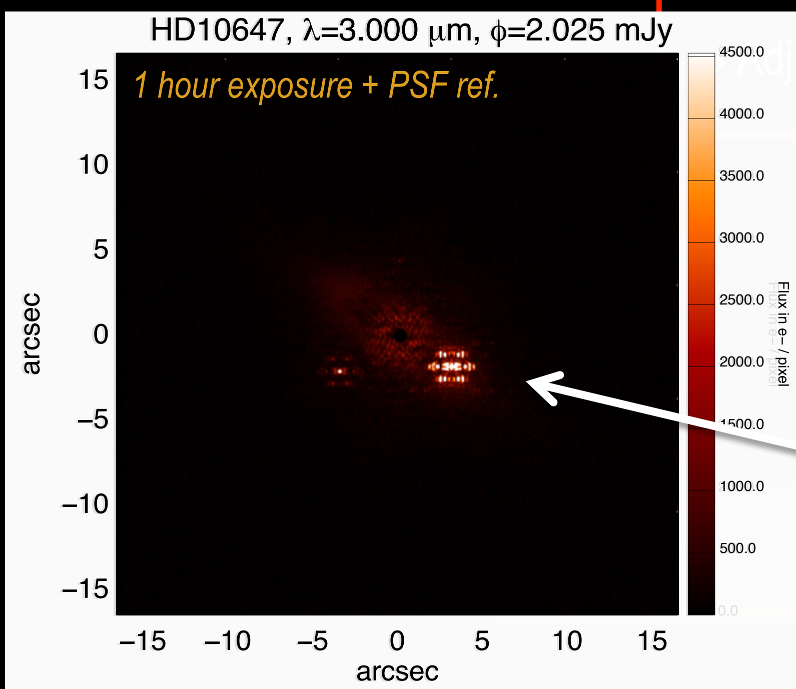


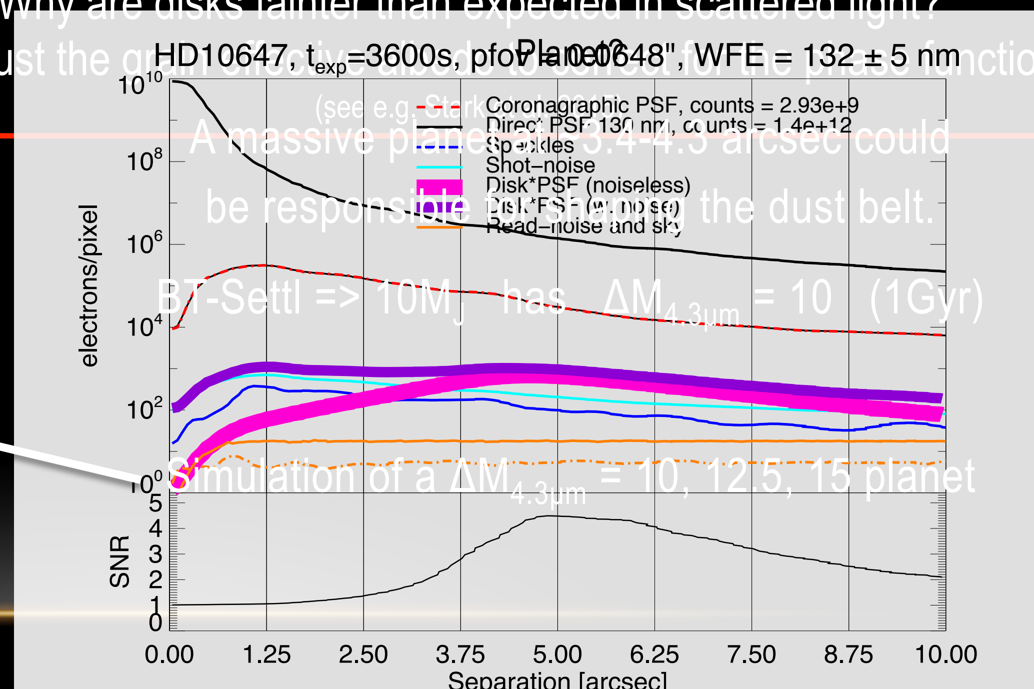
Why are disks fainter than expected in scattered light?
→ Adjust the grain effective albedo to correct for the phase function
(see e.g. Stark et al. 2014)

Planet?
A massive planet at 3.4-4.3 arcsec could be responsible for shaping the dust belt.

BT-Settl => 10M_J has $\Delta M_{4.3\mu m}$ = 10 (1Gyr)

Simulation of a $\Delta M_{4.3\mu m}$ = 10, 12.5, 15 planet

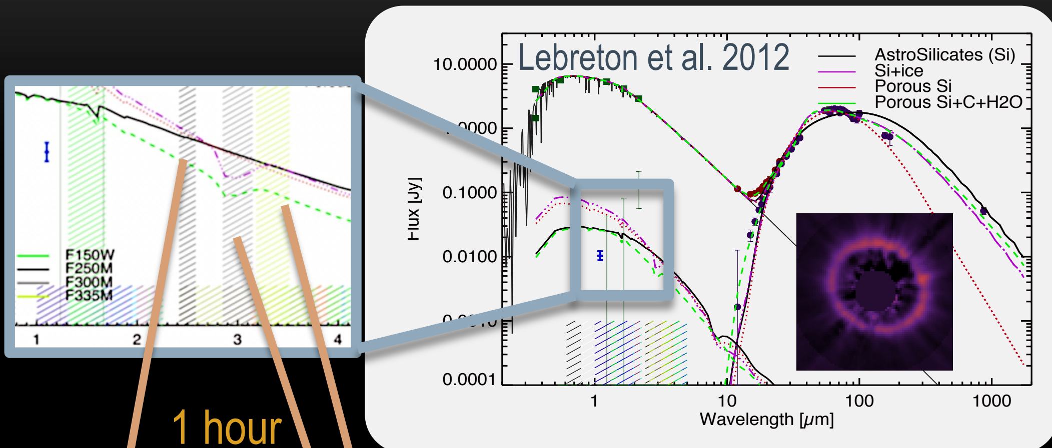




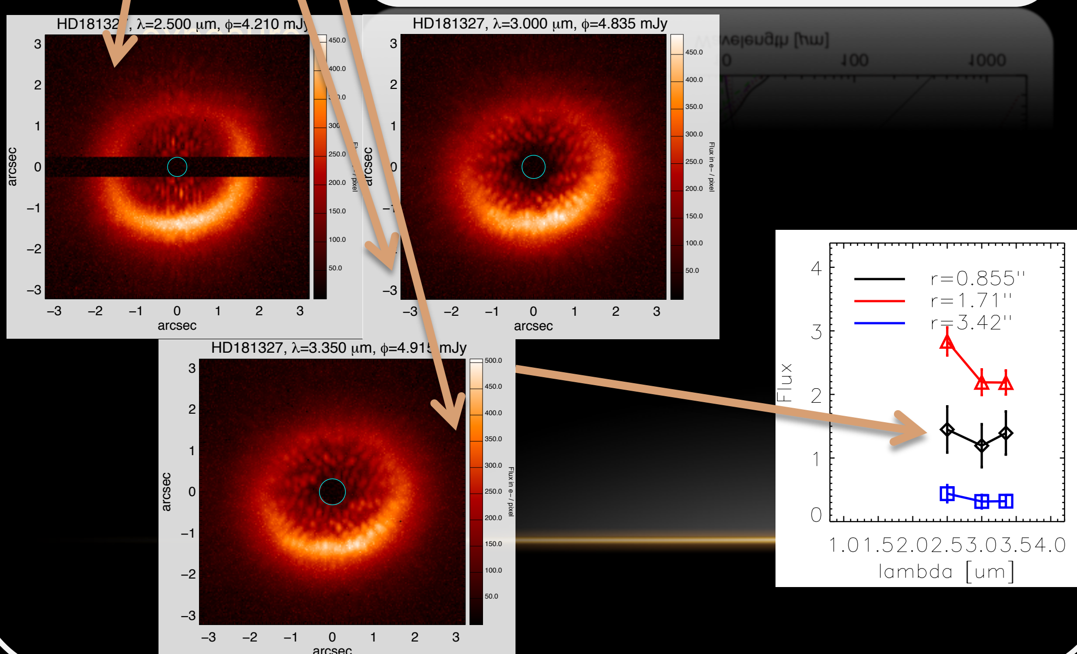
SIMULATIONS FOR THE YOUNG EXO-KUIPER-BELT OF HD181327

Coordination with MIRI (IWA MIRI 1λ/D ~ NIRCam 4λ/D)

Detailed disk model across the ice 3μm feature



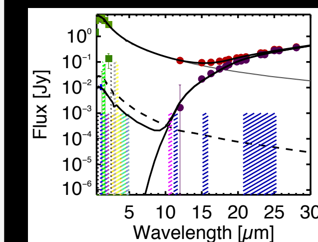
1 hour

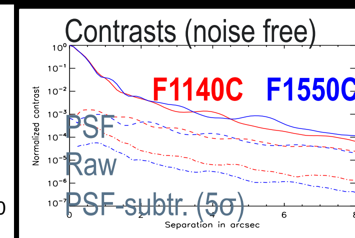


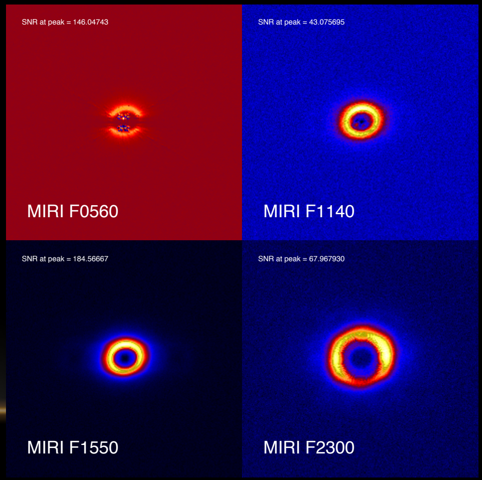
MIRI simulations:

Scattered vs. thermal light

A. Boccaletti's simulations →

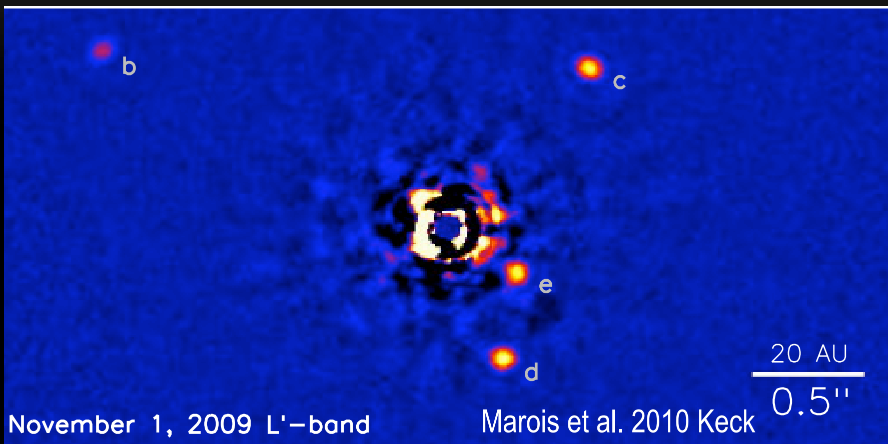


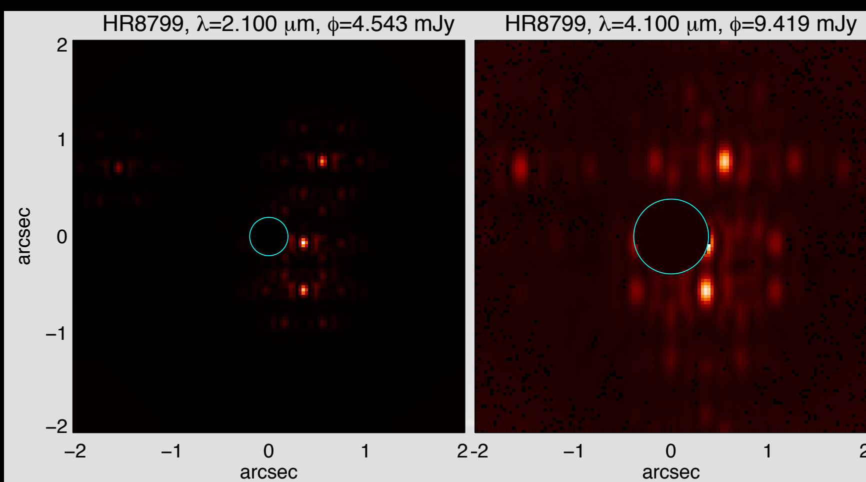




EXOPLANET DIRECT IMAGING SIMULATIONS

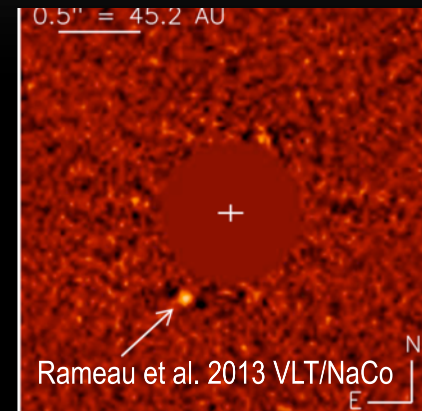
HR 8799 b, c, d, e

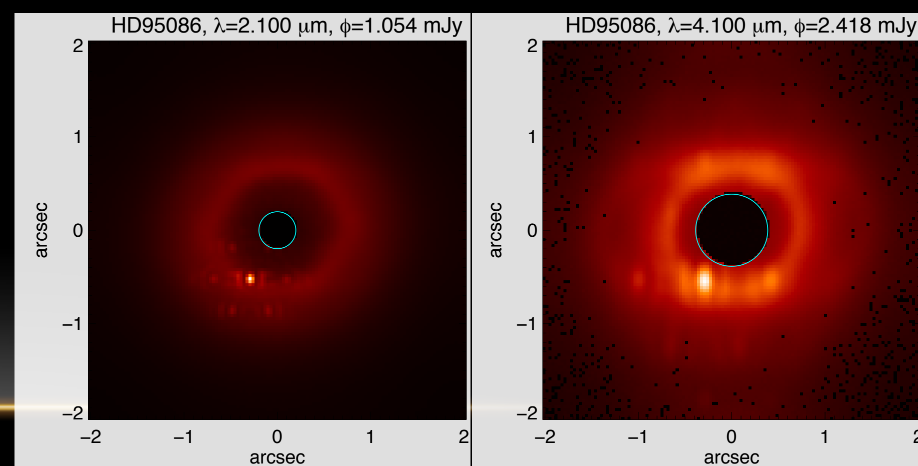




HD 95086

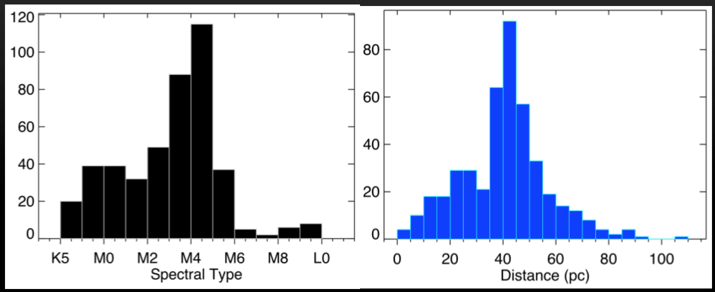
R = 0.6 arcsec, Δmag ≥ 9.2 (L' 3.8 um)





A SURVEY OF LOW MASS PLANETS ORBITING M STARS IN WIDE ORBITS (with J. Schlieder, C. Beichman, M. Meyer)

- **NIRCam spot coronagraph at 4.4 μm:** excellent **sensitivity to planets >10 AU and M>0.1 M_{jup}** down to M^{*}_{F440W} = 23.5 mag
- Sample of 440 late K and M stars in various associations with known distances and ages (Schlieder et al.)

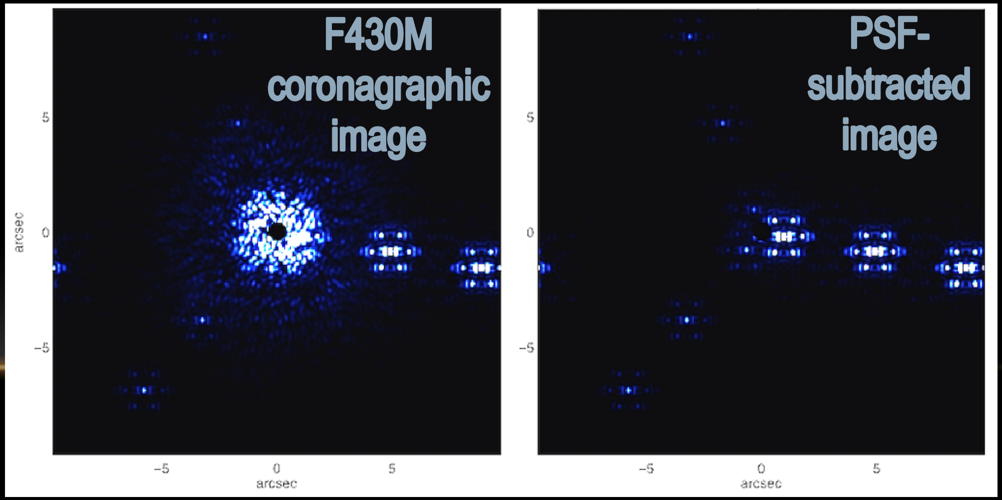


- Cold star CONDO03 models. MC simulations assuming every system has 1 planet: 10% inside 5 AU, remainder between 5-200 AU. Masses 0.1<M< 5 M_{jup}.
- **376 stars have P>25% of detecting a planet. Top 25 stars: P = 57%.**
- **A survey of top 25 would yield 14 planets** down to 0.1M_{Jup} at 10 AU (MIRI: 11 planets. NIRISS: 10 planets. GPI: 5 planets)

NIRCam average planet:
⟨Mass⟩= 0.45 MJup
⟨Age⟩ = 65 Myr,
⟨SMA⟩ = 59 AU

Simulated images of BD+012447 (M2.5, 130 Myr AB Doradus, 7.1 pc)

0.5, 1, and 5 M_{Jup} planets at 1", 5", and 9"



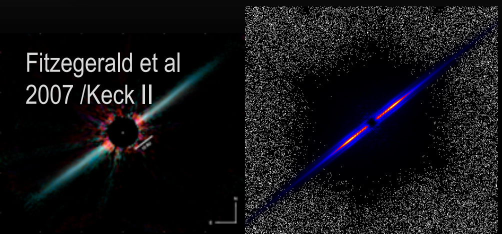
CONCLUSIONS

Detailed models of η Corvi (soon in ApJ):

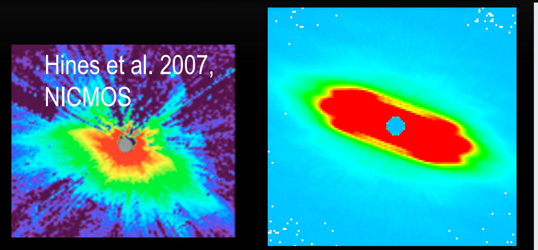
- A massive 133AU-wide exo-Kuiper Belt (Herschel)
- Its inner exozodiacal disk is closer than previously thought (0.2 AU: KI, LBTI, IRS) and abnormally bright (high-albedo forsterite)
- Good candidate for MIRI imaging

NIRCam coronagraphic imaging of extrasolar Kuiper Belts

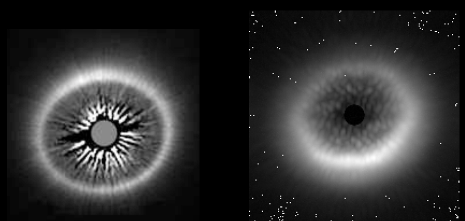
- **Follow-up of HST disks at new λ**
  - Science driver for NIRCam and MIRI collaborative program
- **Understanding material properties**
  - Scattered vs. thermal light
  - A census of ices / ice lines
- **Probing dust structures**
  - Collisions & dynamics
  - Shepherding planets
  - Planet direct imaging



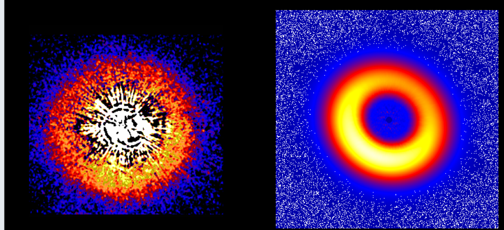
AU Mic, M1Ve, F_{disk}/F_{star}=7.7e-3
91pc, 35AU



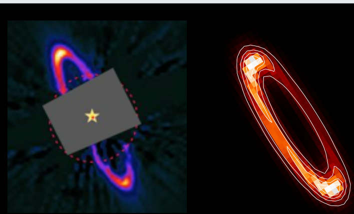
The Moth, G8Vk, F_{disk}/F_{star}=2.5e-3
4.5pc, 61AU



HD181327, F5.5V, F_{disk}/F_{star}=6.0e-3
51.8 pc, 90 AU



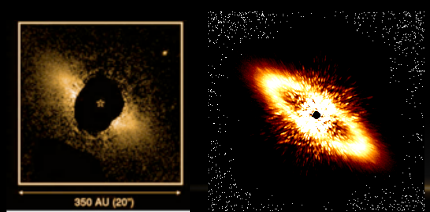
HD 107146, G2V, F_{disk}/F_{star}=1.0e-4
28.5pc, 130AU



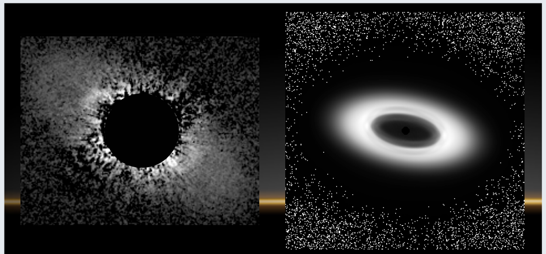
HD 4796A, A0V, F_{disk}/F_{star}=5.0e-3
67pc, 140AU

Obs | Models
(in prep for PASP)

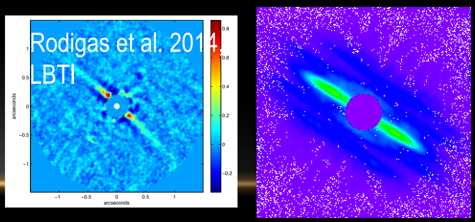
→ Simulations are being performed for a sample of 8 objects (~50 hours)



HD 10647, G2V, F_{disk}/F_{star}=1.0E-4
17.4pc, R~75AU



HD 92945, K6V, F_{disk}/F_{star}=7.7E-4
21.55pc, 45AU



HD 32297, A7V, F_{disk}/F_{star}=7.6e-3
105pc, R ~120AU