Coronagraphic Imaging of Debris Disks from a High-Altitude Balloon Platform

Stephen C. Unwin, Wesley A. Traub, John T. Trauger, Geoffrey Bryden, John Krist
Jet Propulsion Laboratory, California Institute of Technology

David W. Stuchlik
NASA Wallops Flight Facility

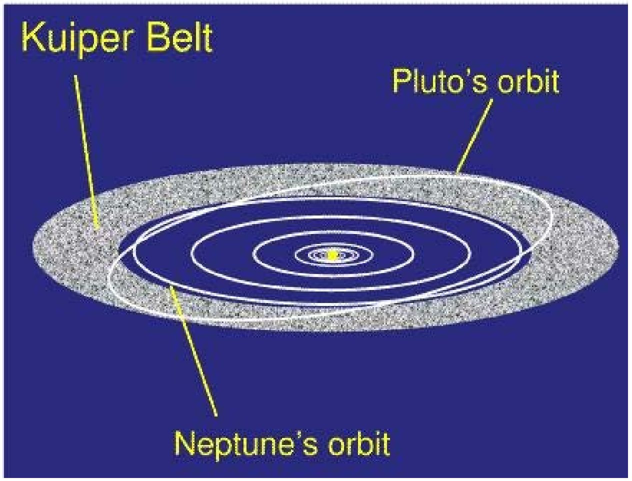
Charles F. Lillie
Lillie Consulting, LLC

220th Meeting of the American Astronomical Society, Anchorage AK
June 10-14, 2012

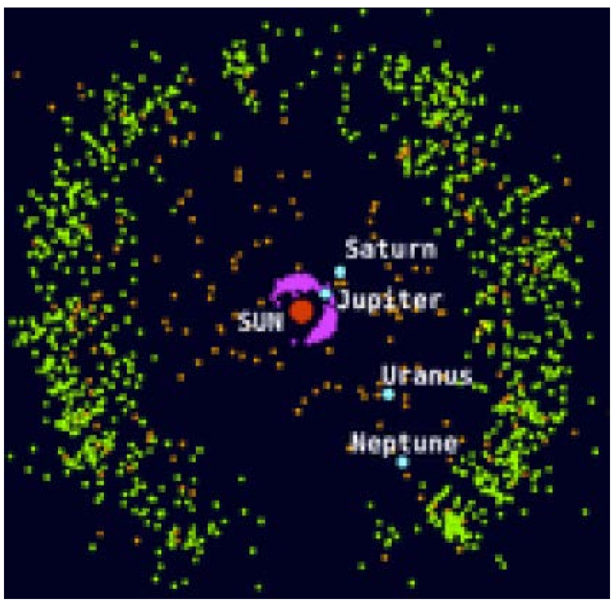
Debris Disks: Signposts of Planets, Asteroids, and Comets

- *Debris disks* are rings of micron-size dust orbiting in the outer regions of planetary systems
- Asteroid and comet collisions are the probable sources of the dust
- Radiation pressure and Poynting-Robertson drag
- Planets shepherd and sculpt the dust into a ring
- The dust ring is bright enough to be imaged, brighter than the planets themselves
- *So debris disk images are our connection to as-yet unseen planets, comets, and asteroids*

Edgeworth-Kuiper Objects/Belt: our own Debris Disk



- EKOs and dust occupy ~circular orbits just beyond Neptune
- Luminosity of EKB is ~10^{-7}, roughly same as zodiacal light
- Mass of EKB is ~0.1 Earth

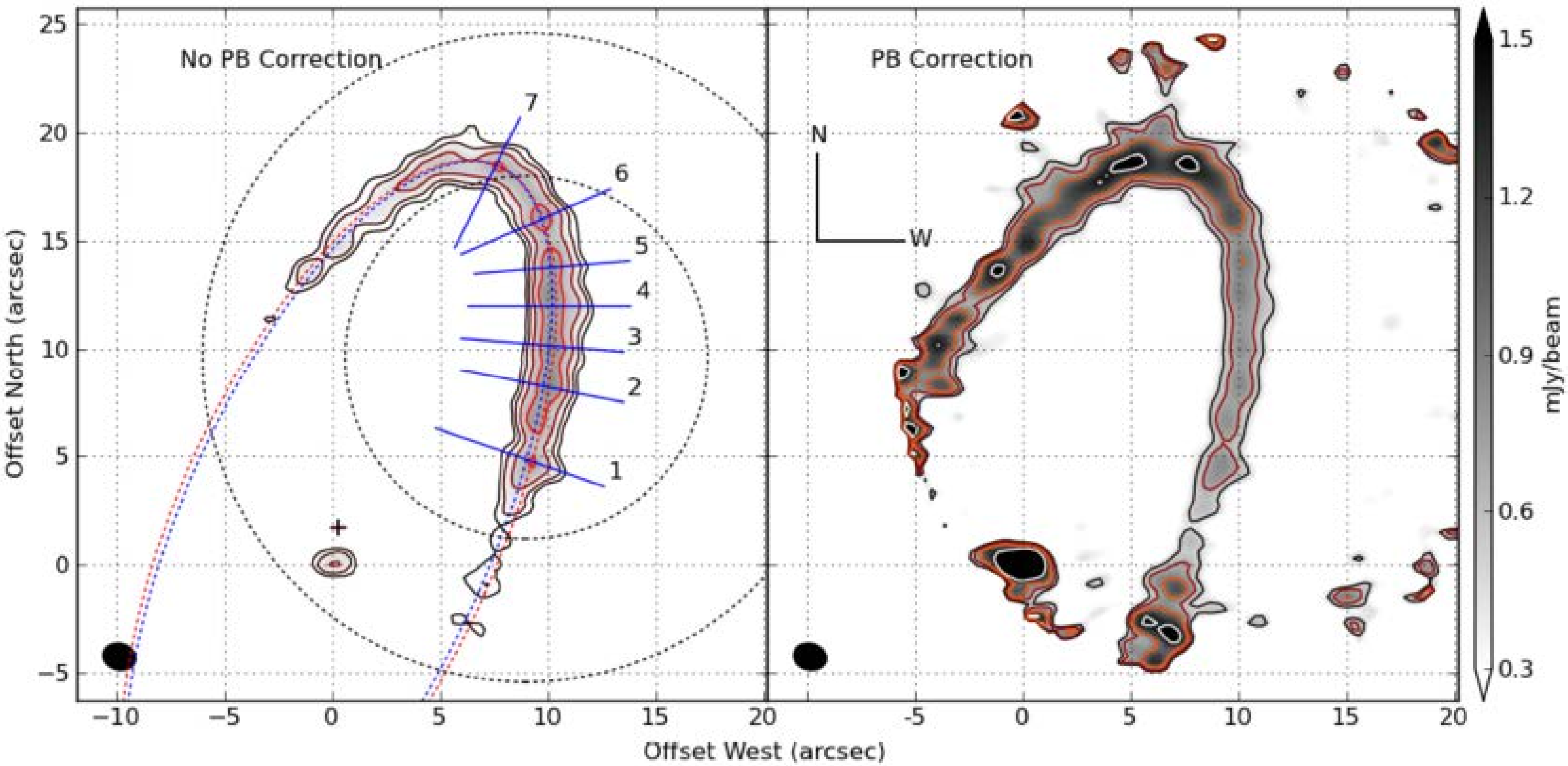


- About 1000 individual EKOs are known, incl. Pluto, total population ~10^9

Refs.: http://www.solstation.com/stars/kuiper.htm ; Vitense etal , A&A (2010, 2012)

Fomalhaut’s Debris Disk: ALMA detection

- ALMA detection at 850 μm finds sharp-edged ring at ~140 AU
- Ring width is 13-19 AU
- Consistent with 2 shepherding planets, each < 3 Earths



Boley et al., astro-ph (2012)

Science Derived From Visible & Thermal Images

- Thermal flux → # grains * area/grain * σT^4
- Thermal spectrum → T
- T + star luminosity → semi-major axis of ring (AU)
- Visible image size, a(AU) → location of comet/asteroid source of grains
- Visible image shape → width/warp → shepherd planet locations
- Visible image brightness + thermal flux + thermal spectrum → albedo
- Visible image color and albedo → type of material, size of grain, weathering
- Visible image shift → massive planet
- Visible image numbers → relative history of planetary systems

Imaging Telescopes for Debris Disks

- Ground-based: impossible for all but ~5 disks
- Hubble: limited to handful of bright disks with contrast $> 10^{-7}$
- Spitzer: thermal photometry for most, images for a few disks
- JWST: similar to HST, plus mid-infrared images with MIRI
- Balloon-borne coronagraph: promising (see Zodiac II)

Zodiac II: Example of a Feasible Coronagraph on a Balloon Platform

Zodiac II is a 1.1-m diameter version of the concept

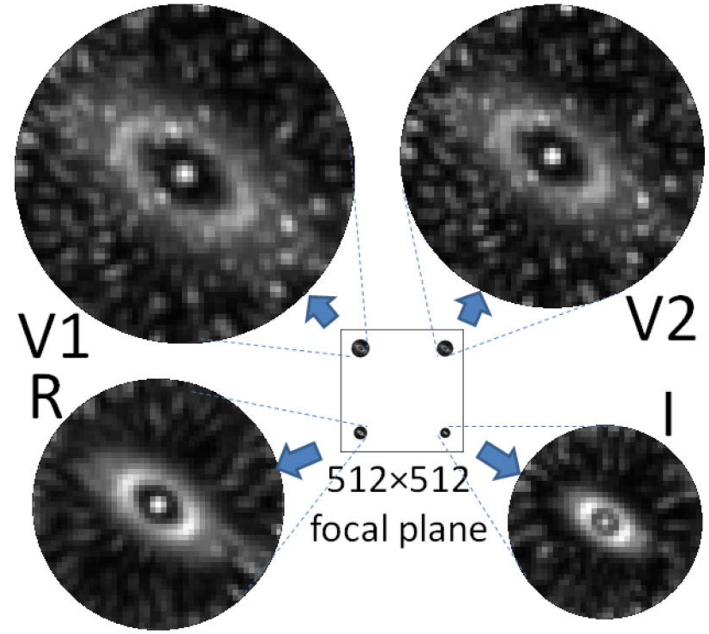
No current or planned facility can match Zodiac II performance on debris disks, by factor of 100

Instrument and Mission Design

- 1.1-m diameter telescope
  - Inner working angle 0.4 arcsec
  - Integration times up to 4 hours
- Imaging coronagraph (Band-Limited Lyot)
  - Raw contrast 10^{-7}; final contrast 10^{-8}
- Visible wavelength operation
  - Reflected light from disk: 500-990 nm
- Four spectral bands
  - Measure disk color
- Stratospheric balloon platform,
  - Seeing effects negligible at ~35 km
- Observe ~25 targets over 4 flights

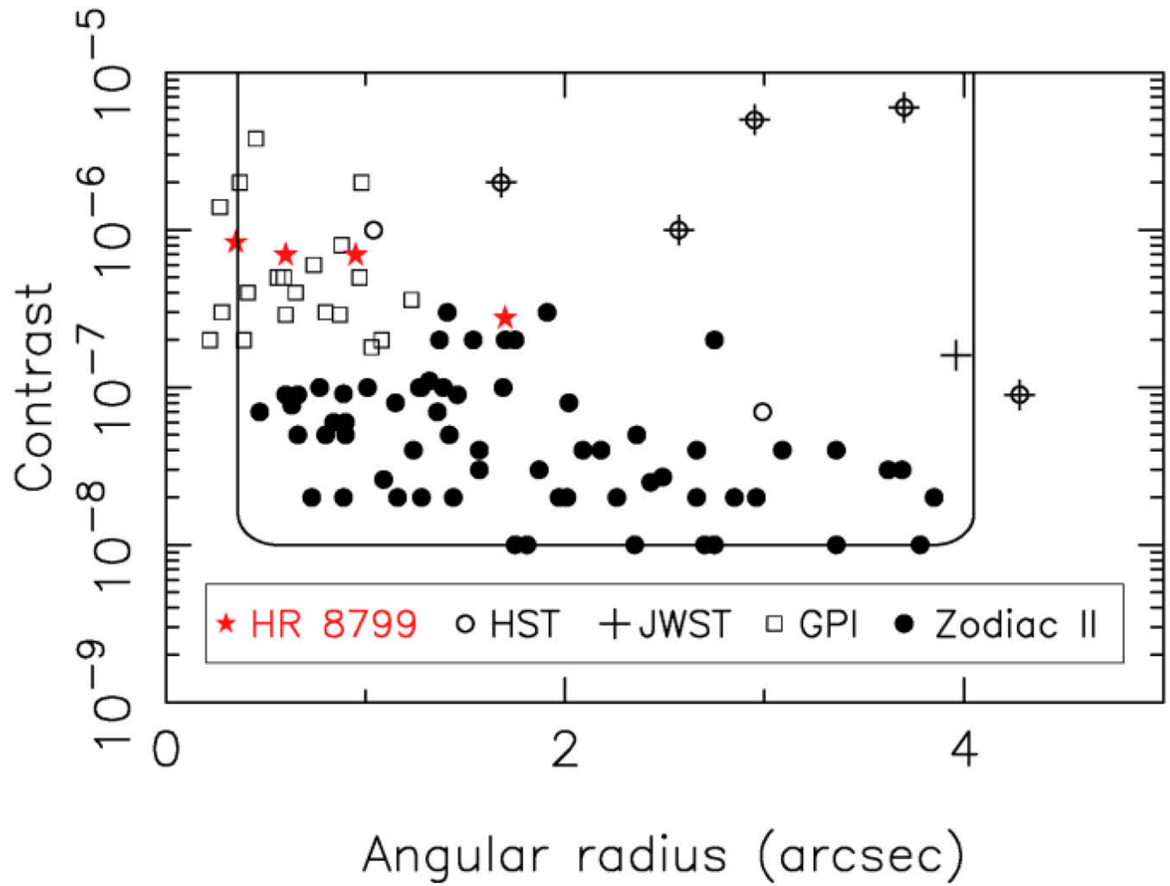
Focal plane simulation

Band	Central Wavelength	Bandwidth (FWHM)	D_{Lyot}/D_{tel}
V1	520 nm	10%	0.65
V2	580 nm	10%	0.58
R	700 nm	20%	0.48
I	900 nm	20%	0.37



- Four Zodiac II bands are recorded onto a single CCD camera
- Images are scaled to give 2.5 pixels per FWHM in each image
- Simulated disk structure (assumed two belts) surrounding a V=6 star
  - 1 hour of -1-minute-long integrations
  - Disk can be seen within each of the circular dark holes
- Integrations of 1 hour on the brightest Zodiac II targets yield SNR > 10 per pixel

Predicted Debris Disc Sizes and Contrasts



- 89 target debris disks for Zodiac II shown in the the U-shaped area
  - Complete list derived from Spitzer data
  - Inner angular limit is for V1-band; outer limit is for I-band
- Zodiac II contrast and angular resolution open up a large discovery space

Thank you!

Further references:

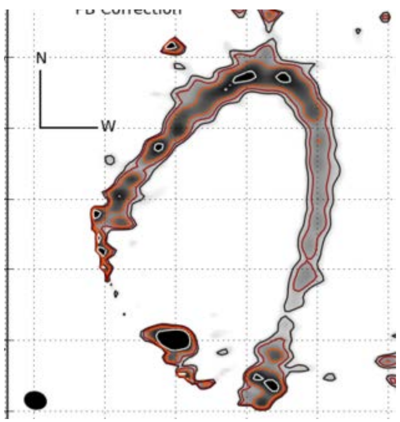
1. S. Wolf, et al, Circumstellar disks and planets, science cases for next-generation optical/infrared long-baseline interferometers, A & A (2012)

2. O. Absil and D. Mawet, Formation and evolution of planetary systems: the impact of high angular resolution optical techniques, A & A (2010)

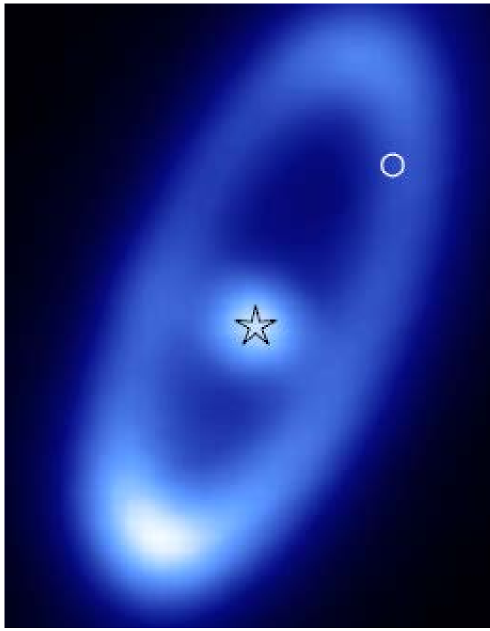
3. G. Bryden, et al, Zodiac II: debris disk science from a balloon, SPIE (2011)

Backup charts

Fomalhaut's debris disk, multi-wavelength images

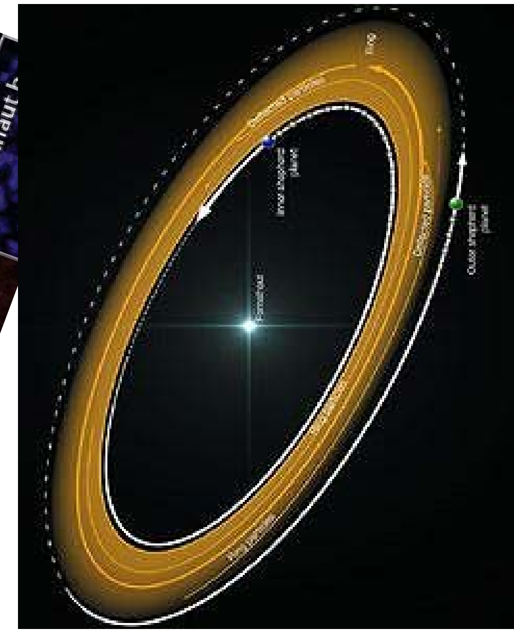


850 µm
ALMA



70 µm
Herschel

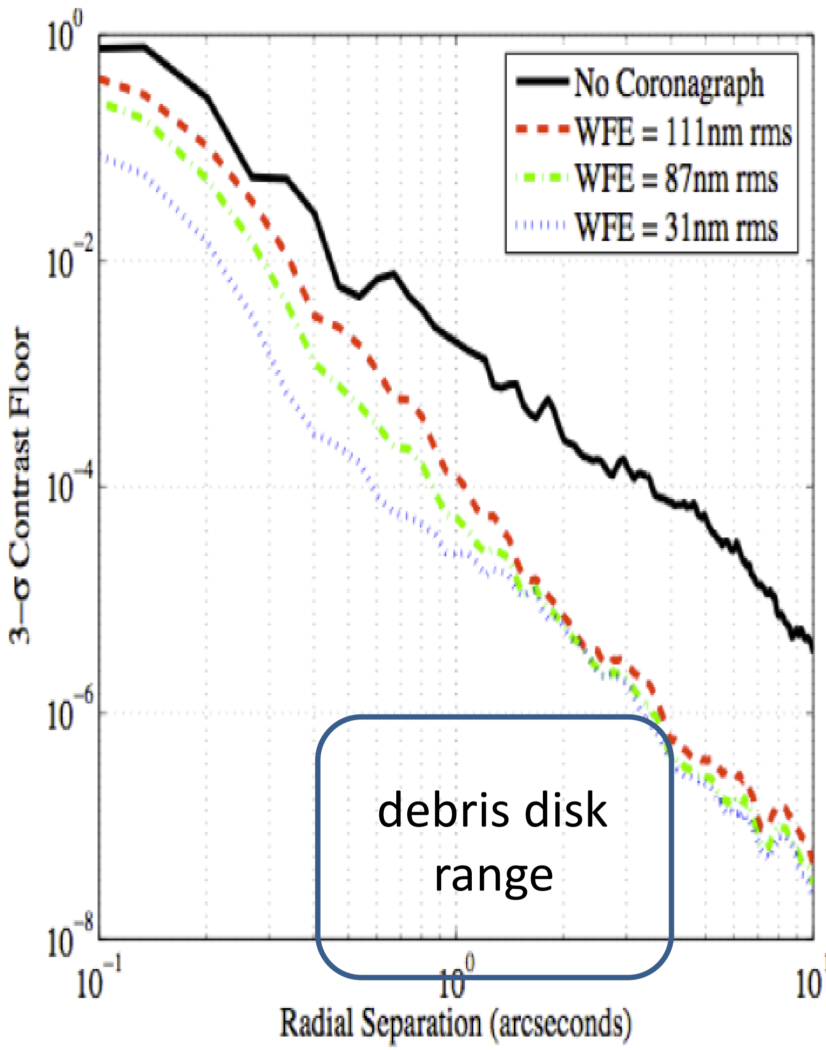
0.6 µm
HST



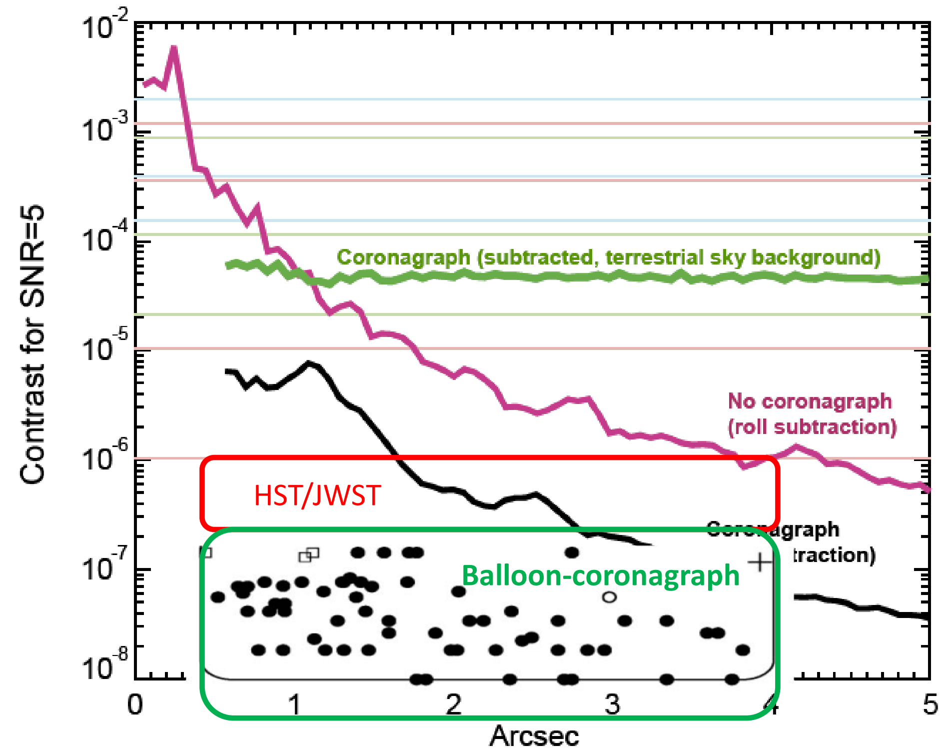
schematic
w/ planets

Refs.: Boley et al., astro-ph (2012); Acke et al. A&A (2012); Kalas et al. (2008)

JWST imaging of debris disks



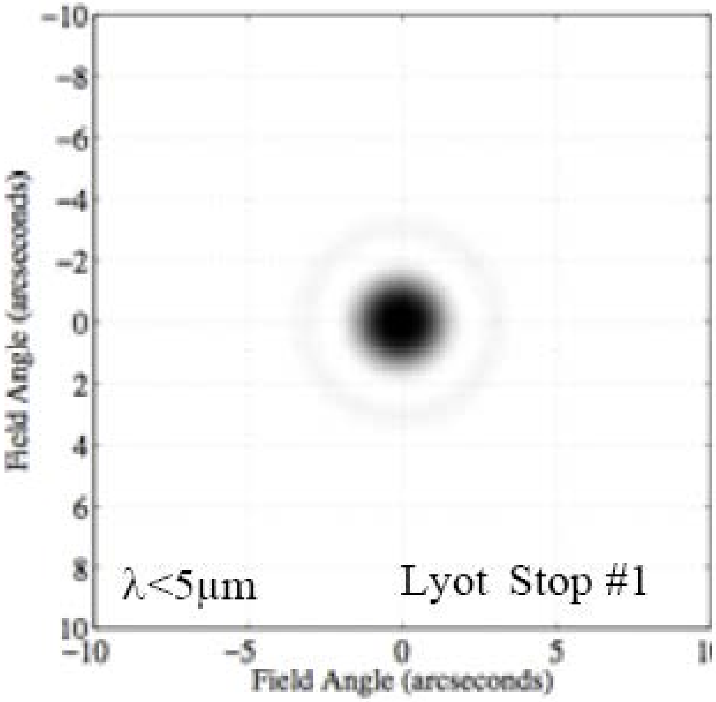
3-σ az-averaged visible contrast, NIRCAM occulter (colors)

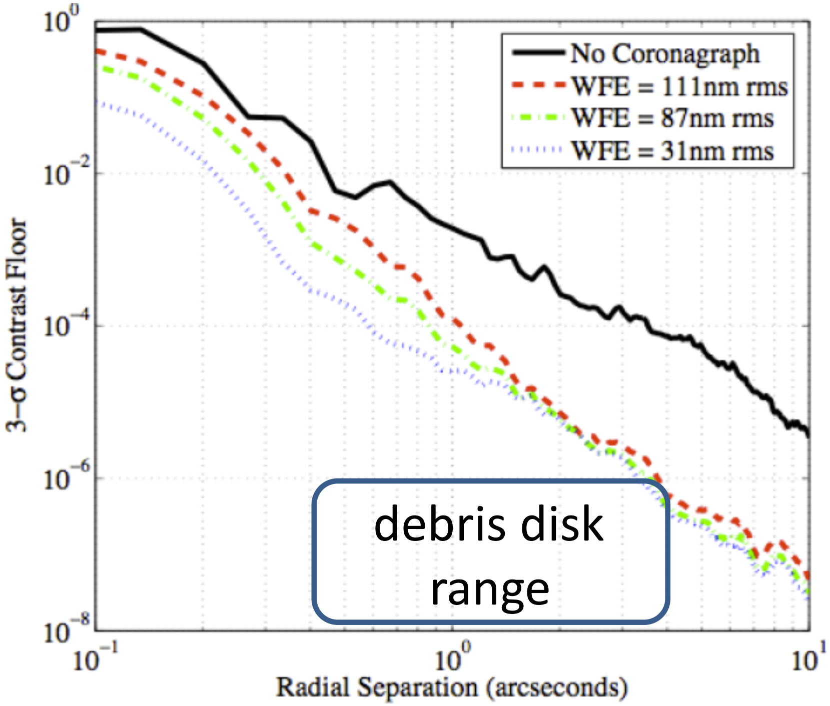


5-σ az-averaged mid-IR contrast, MIRI on JWST, HST/JWST and balloon-coron. regions outlined

Refs.: Green et al, SPIE (2005); Krist et al, SPIE (2007)

JWST imaging of debris disks

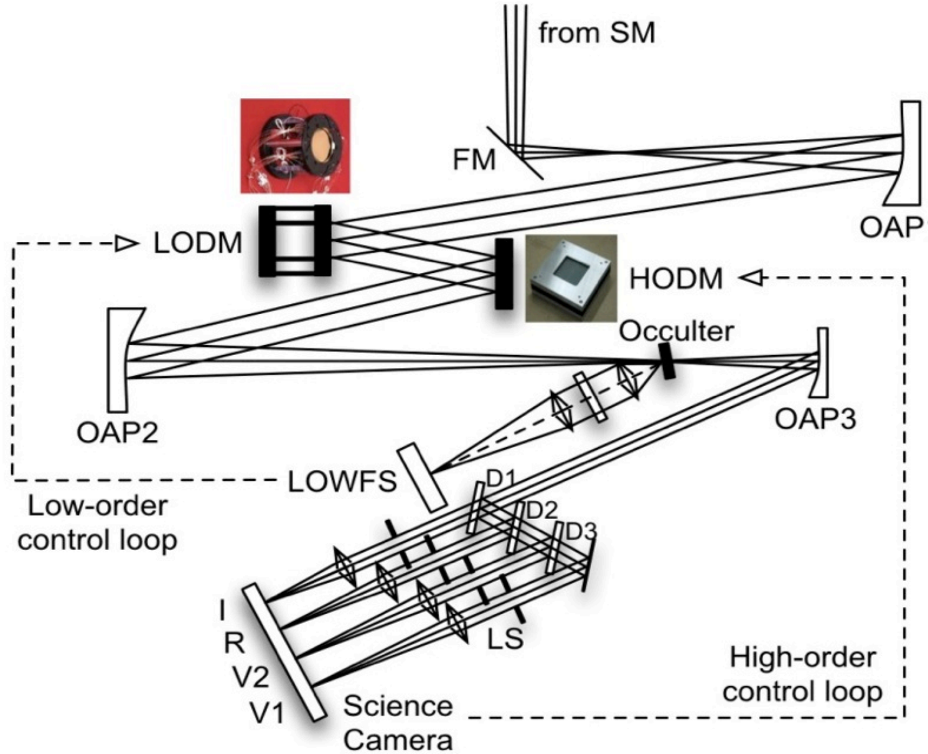




- (left) NIRCAM occulter 1.25 arcsec radial sombrero, with F480M
- (right) 3-σ envelope to the azimuthally averaged contrast, for no coronagraph (black), and for occulter (colors)
- Result: The contrast & radius of known and expected debris disks is *outside the range of sensitivity of JWST*

Ref.: adapted from Green et al, SPIE (2005)

Coronagraph

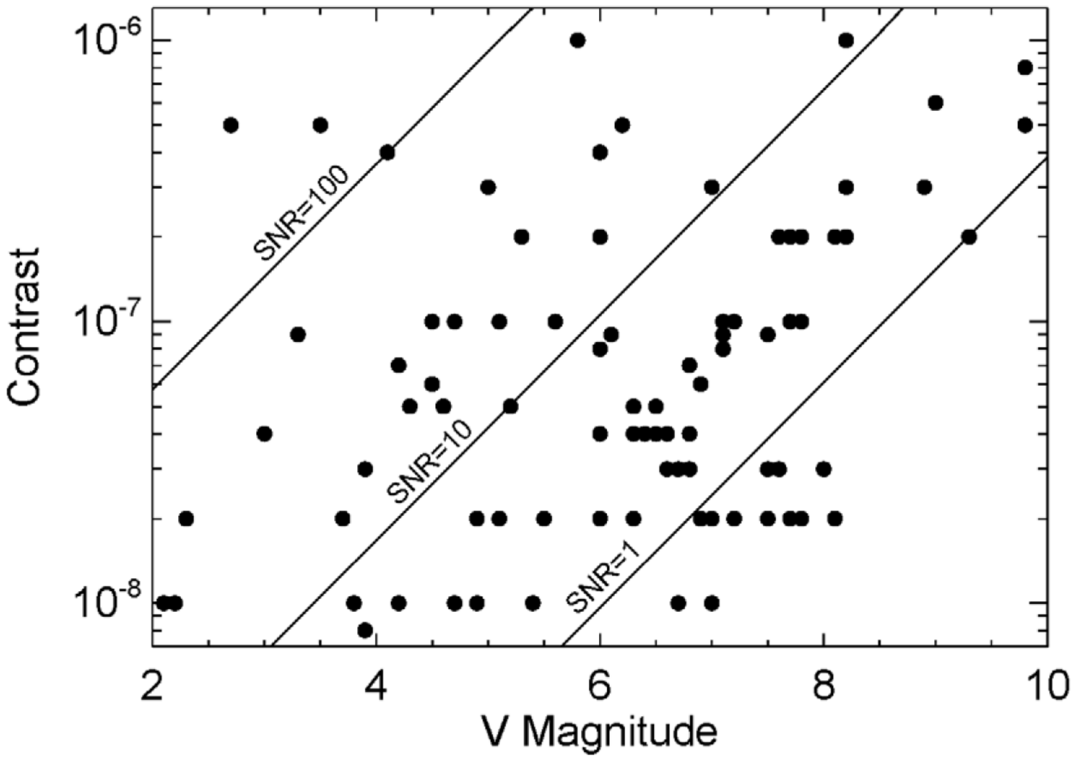


Coronagraph schematic showing optical path and control loops

- The low-order modes are measured by a LOWFS using light reflected off the occulter. These modes are corrected by the LODM.
- The high order deformable mirror is adjusted based on science camera images of the residual speckles.
- Dichroics (D1, D2, D3) split the beam into 4 wavelength bands that pass through individual Lyot stops (LS) before reaching the single science camera.

Sensitivity

- SNR per resolution element
- 1 hour integration
- V1 (520 nm) band



Signal-to-noise ratio (SNR) for our target debris disks vs. stellar magnitude and disk contrast