Debris Disk Imaging with WFIRST

Geoff Bryden
Jet Propulsion Laboratory,
California Institute of Technology

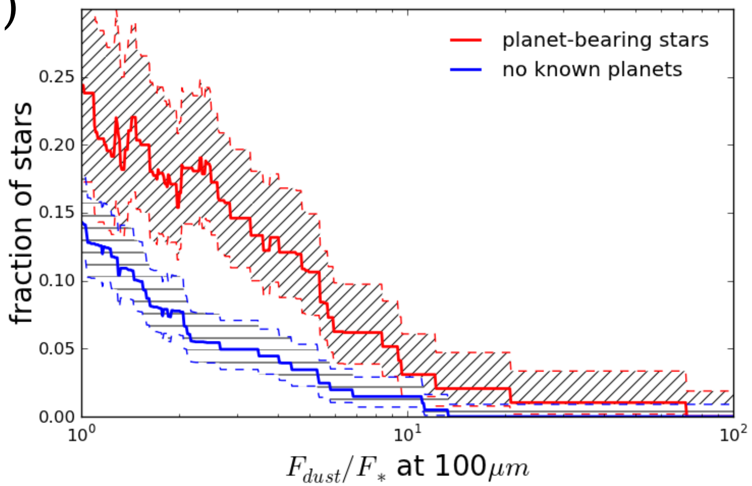
Exploring the Remnants of Planet Formation

Theories predict a variety of relationships between planets and their neighboring asteroid/Kuiper belts of debris.

- Co-dependence on initial disk conditions (Wyatt+ 2007)
- Distant secular interaction (Moro-Martin+ 2007)
- Close direct interaction (Wyatt 1999)
- Planetesimal scattering to outer disk (Lin)
- Ongoing systemwide instability (Booth+ 2009)
- Early systemwide instability (Raymond+ 2011)

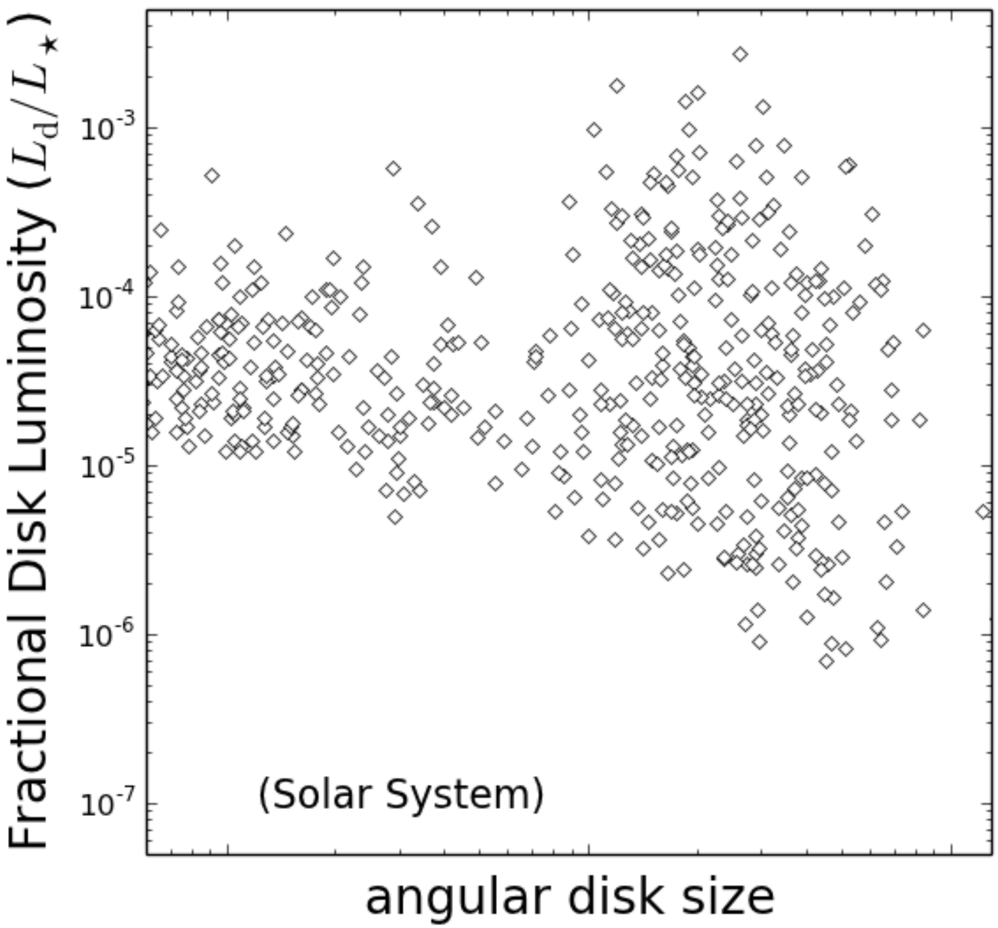
Herschel surveys reveal a strongly significant correlation between inner RV planets and cold outer debris.

Far-IR disk brightness distributions



Bryden+ 2016

Mid-IR / Far-IR Disk Detection Phase Space



Hundreds of debris disks have been discovered by infrared space telescopes (IRAS, ISO, **Spitzer**, AKARI, WISE, and Herschel) via their thermal emission.

Unresolved photometry measures each disk's fractional luminosity and dust temperature.

The dust location is ambiguous from the SED alone.

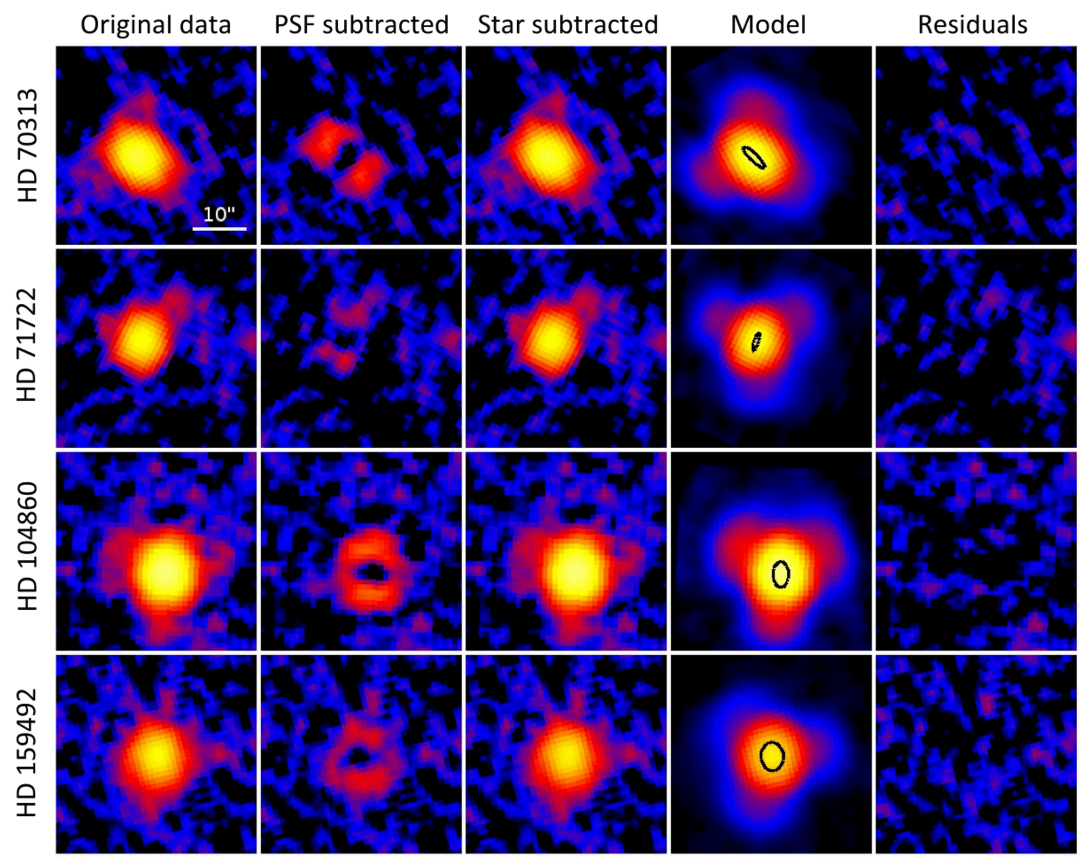
above: summary of known debris disks,
e.g. Chen+ 2014 compilation of >500 disks with Spitzer mid-IR spectra

Herschel–Resolved Disks

Herschel has (marginally) resolved many debris disks.

Model fits measure the disk
- radius
- inclination
- position angle

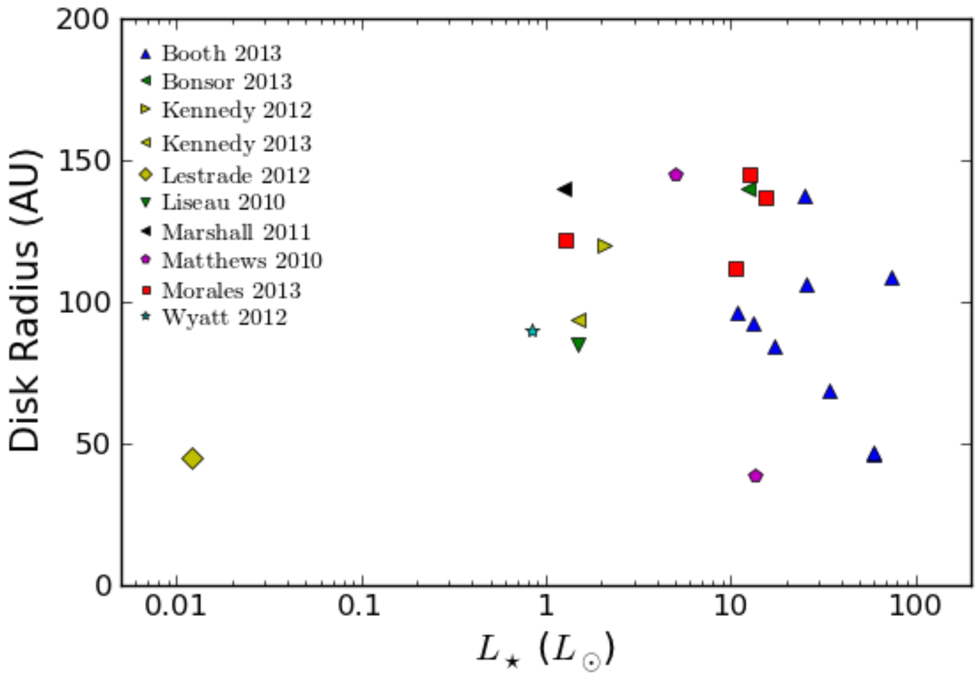
Disk shapes are usually consistent with a thin ring, but overall provide little information about the disks' radial profiles.



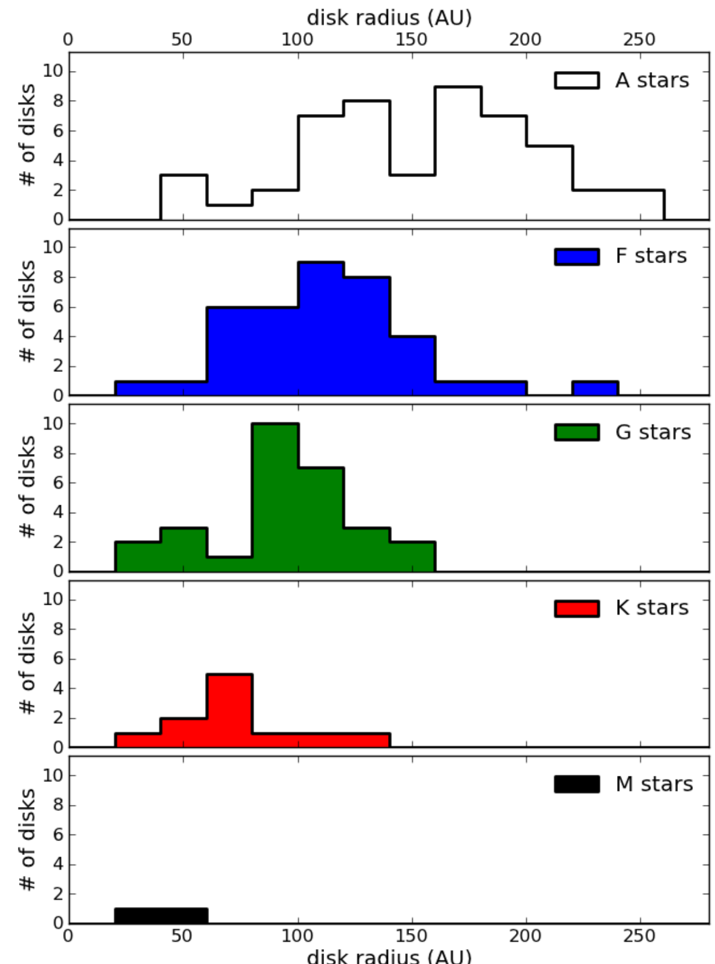
Morales+ 2013

Over 100 Disks Resolved by Herschel

From detailed modeling of individual systems

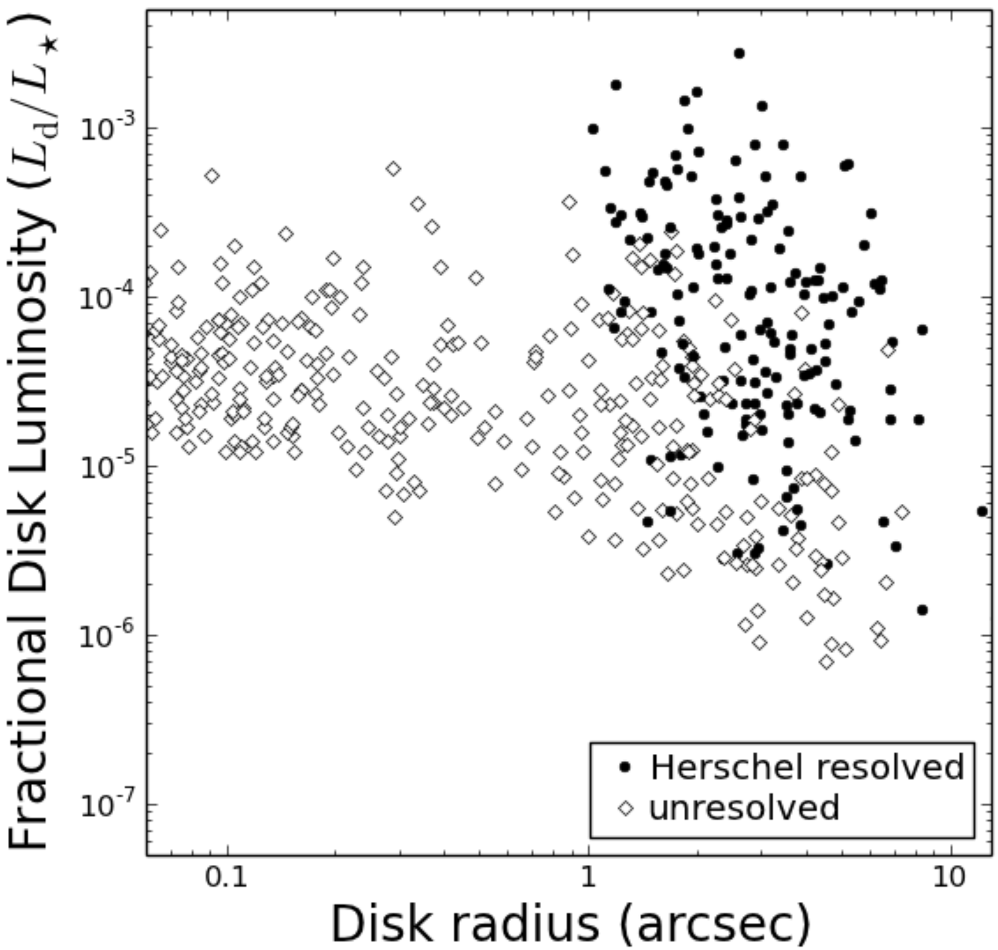


To statistical trends within a large sample



Bryden+ 2016

Herschel Disk Imaging Phase Space

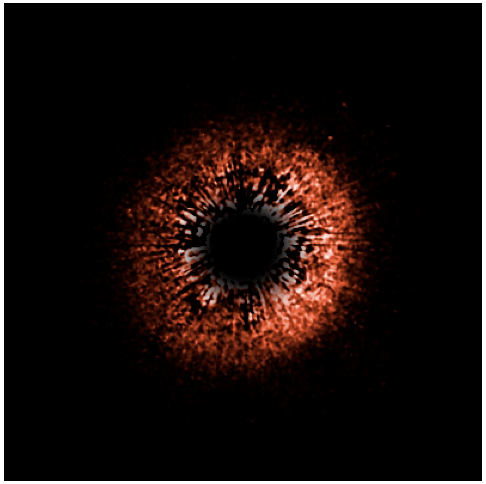


Herschel-resolved disks provide a scale for unresolved disks.

These disks, however, are only marginally resolved.

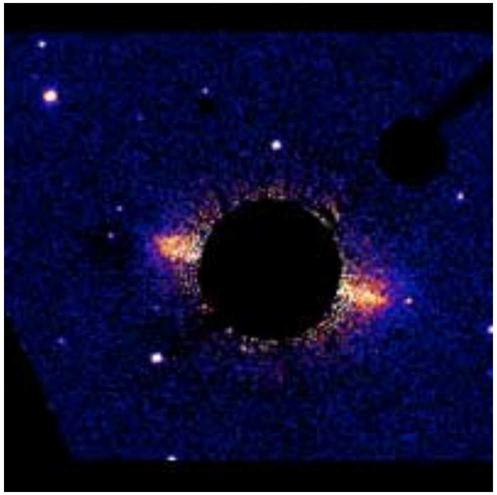
Moving from thermal emission in the far-IR (~100 μm) to optical observations of scattered light provides ~100x better resolution. (but requires high contrast!)

Hubble Debris Disk Imaging

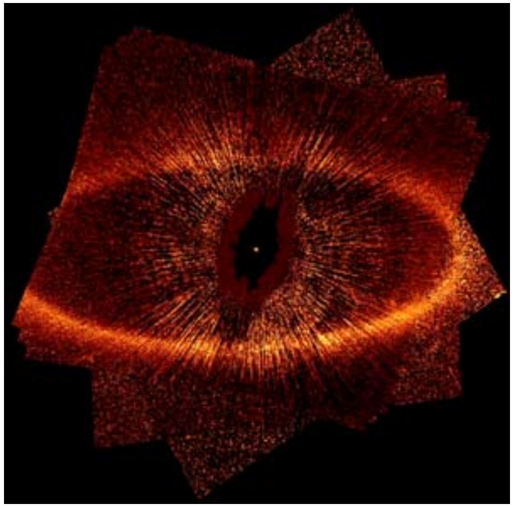


HD 107146; Ardila+ 2004

Hubble imaging at much higher resolution reveals a variety of disk structures:

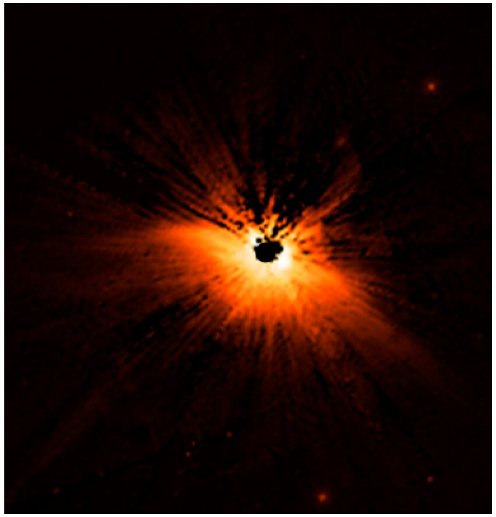


HD 15115; Kalas+ 2007



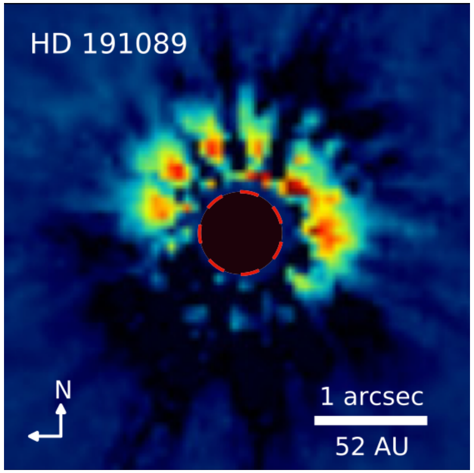
Fomalhaut; Kalas+ 2005

- broad belts & narrow rings
- sharp edges & diffuse halos
- offsets, warps, and other asymmetries



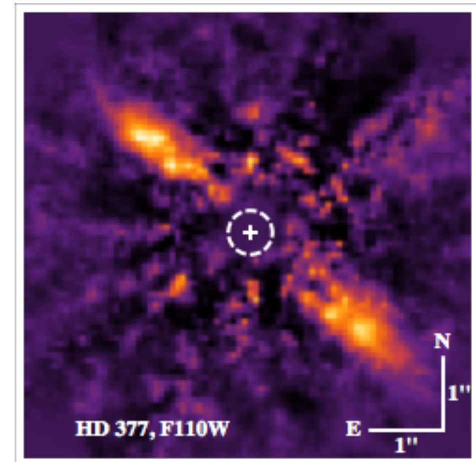
HD 61005; Hines+ 2007

Hubble Debris Disk Imaging

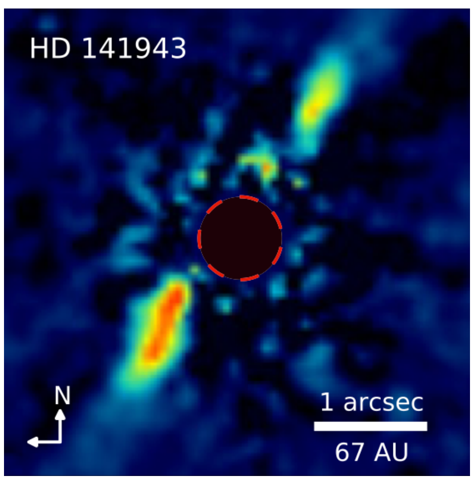


HD 191089; Soummer+ 2014

ALICE
"Archival Legacy Investigation of Circumstellar Environments"
(Soummer, Choquet, Pueyo, Perrin, Chen,…)

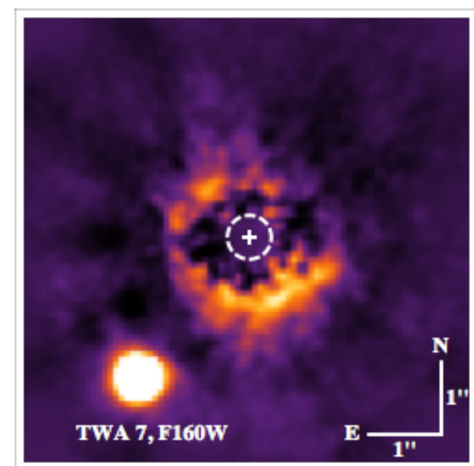


HD 377; Choquet+ 2016



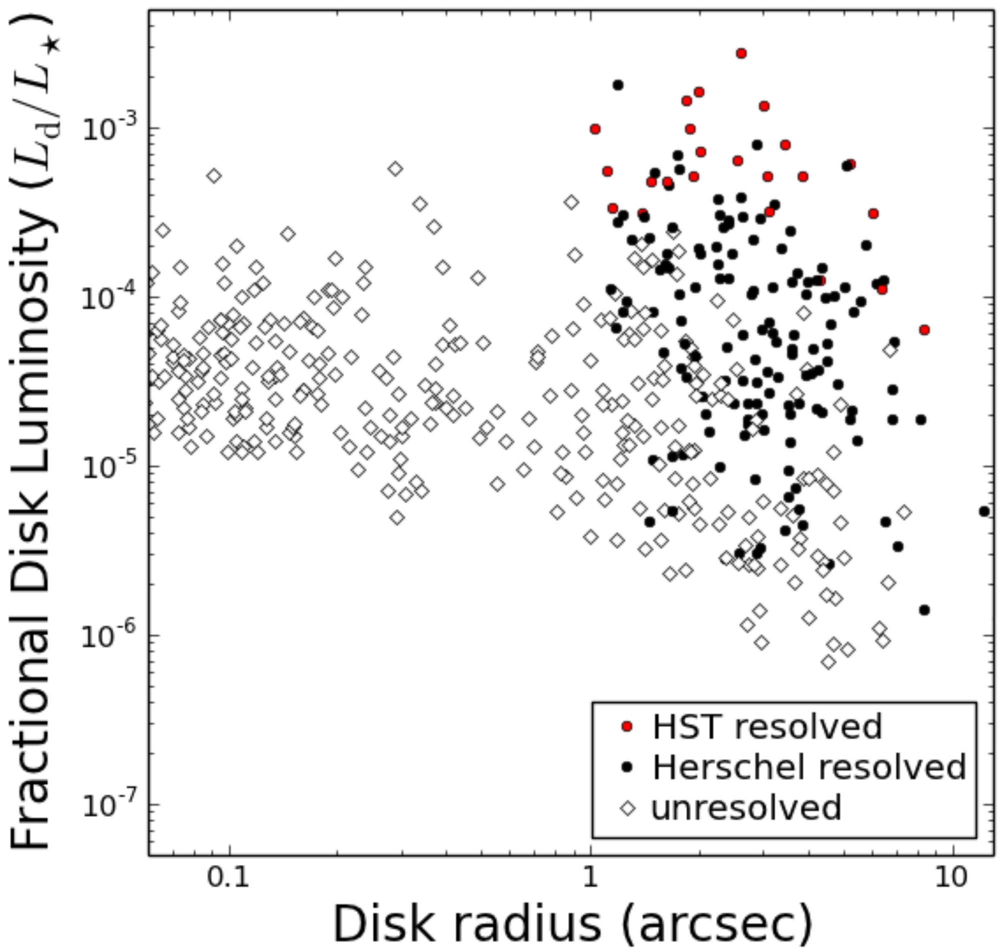
HD 141943; Soummer+ 2014

Re-analysis of HST/NICMOS archival images reveals **9 new debris disk images,** increasing the total to 31 disks imaged in scattered light.



TWA 7; Choquet+ 2016

HST/JWST Disk Imaging Phase Space



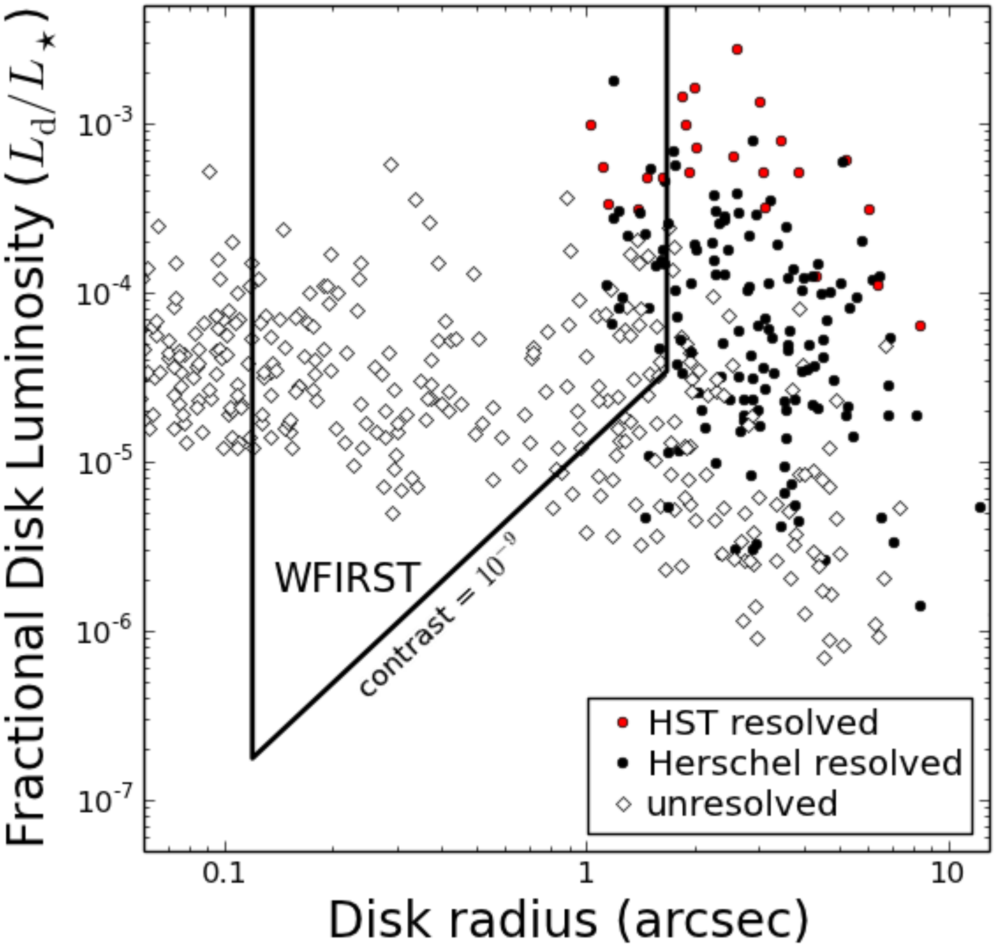
HST can only image the largest and best contrast disks.

JWST capabilities are similar to HST (Mawet+ 2012)

Desired capability:

- fainter disks
- closer to central star

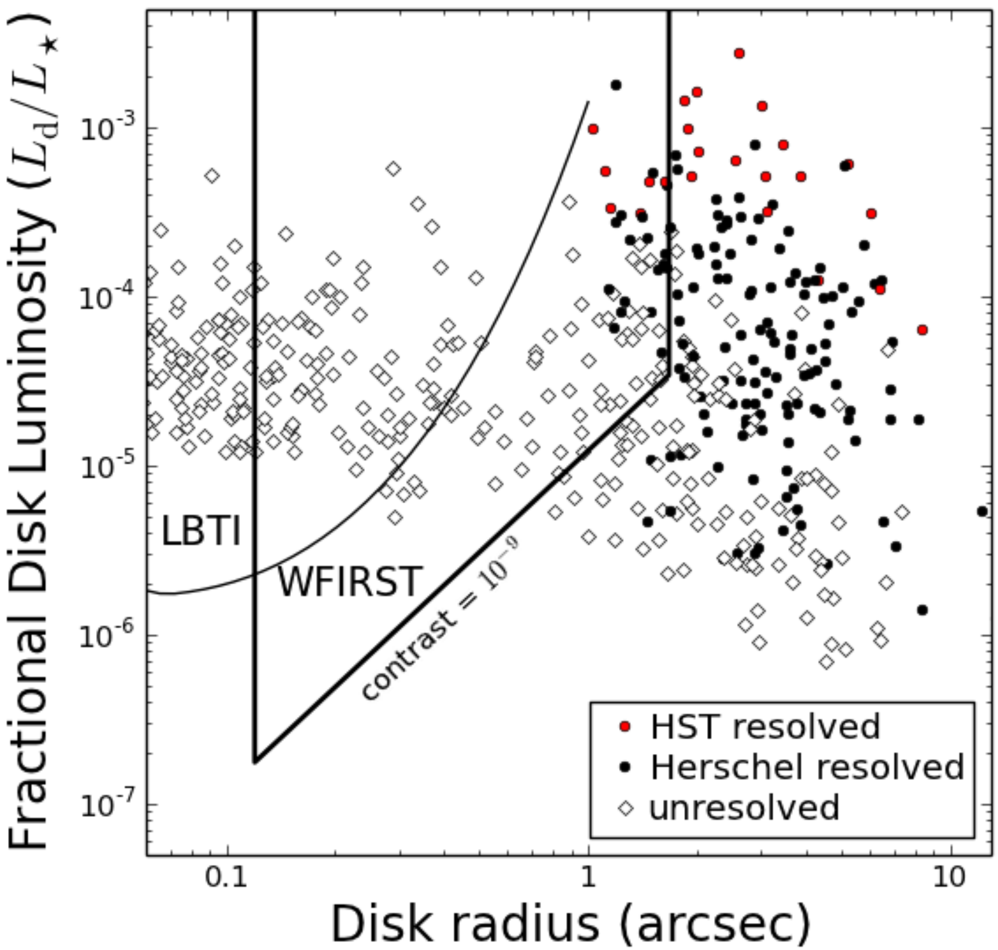
WFIRST
Disk Imaging Phase Space



WFIRST will dramatically increase the number of disks resolved in scattered light.

WFIRST will easily detect disks at Spitzer/Herschel contrast levels (L_{disk}/L_{star}~10^{-5}), potentially pushing down to disks as faint as the Solar System's.

LBTI
Disk Imaging Phase Space



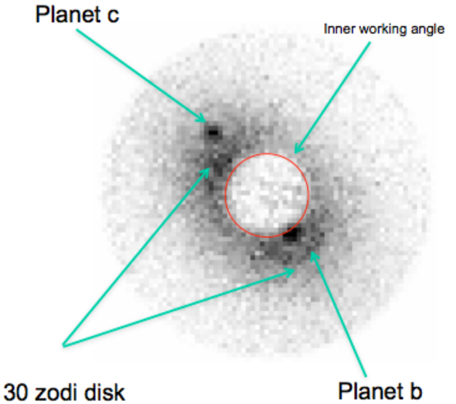
HOSTS
"Hunt for Observable Signatures of Terrestrial Systems"
(PI: Phil Hinz)

LBTI probes the thermal emission from dust in the habitable zones of nearby stars.

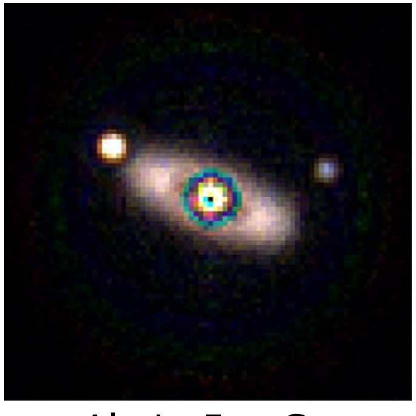
First science result – detection of eta Crv dust inside of 0.1" (Defrere+ 2015)

LBTI/WFIRST are complementary. All LBTI detections of warm dust should be followed up with WFIRST imaging.

Detailed Simulations of WFIRST Disk Observations



47 UMa; WFIRST-AFTA
Greene 2015


Altair; Exo-C
Stapelfeldt 2015

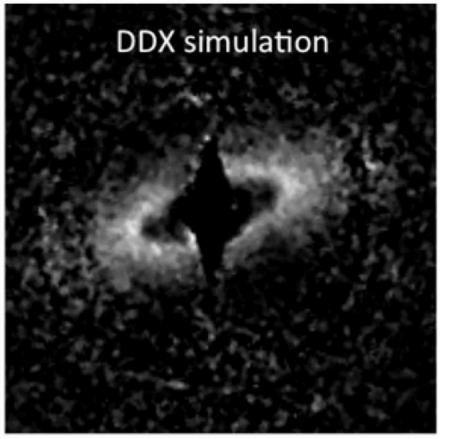
see G. Schneider's 30 page AFTA 'quick study' on circumstellar disks (2014)

and

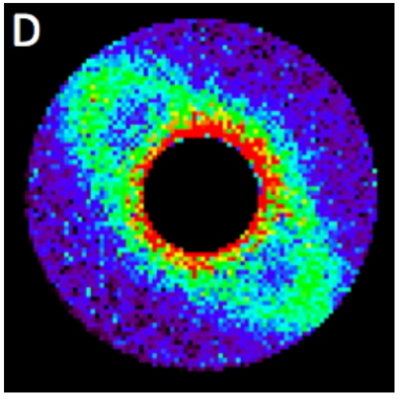
C. Chen's WFIRST Preparatory Science (WPS) program modeling the dust in systems with known planets

Quantification of WFIRST's expected science yield requires both a detailed instrument model and realistic data analysis.

Success metric depends on science goal.



49 Ceti; DDX balloon
Bryden 2013



eps Eri; WFIRST-AFTA
Schneider 2014

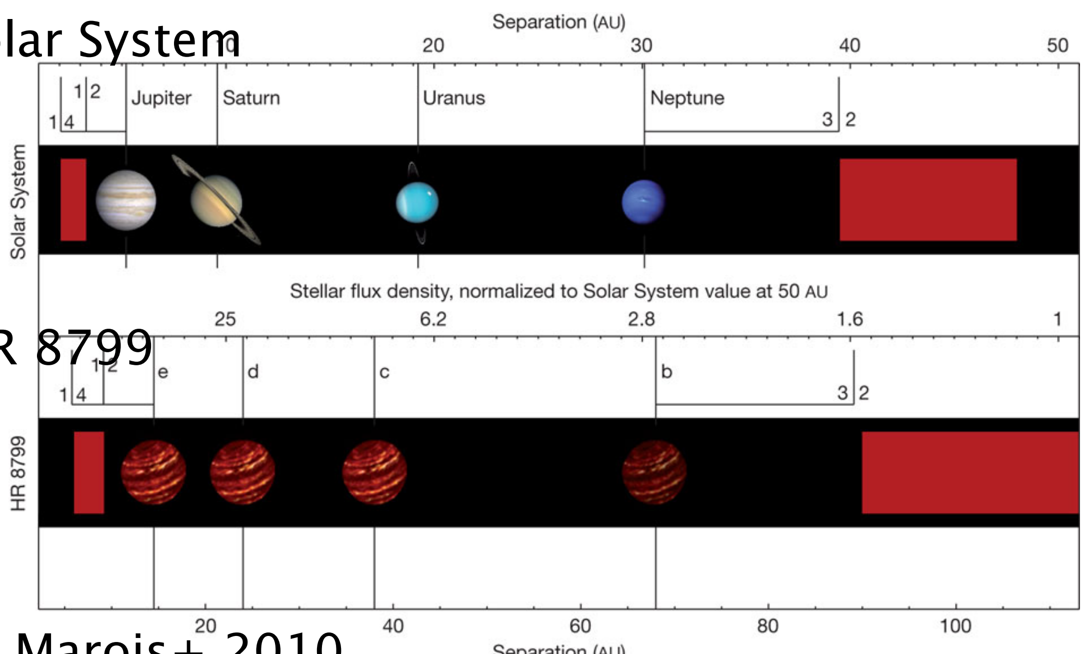
Goal 1: System Architecture

With ~100x better resolution than Herschel, WFIRST will easily measure each disk's radial profile and will thereby distinguish between single or multiple belts of material.

WFIRST will also probe the low levels of residual dust flowing between the dominant belts, e.g. by P–R drag.

Solar System

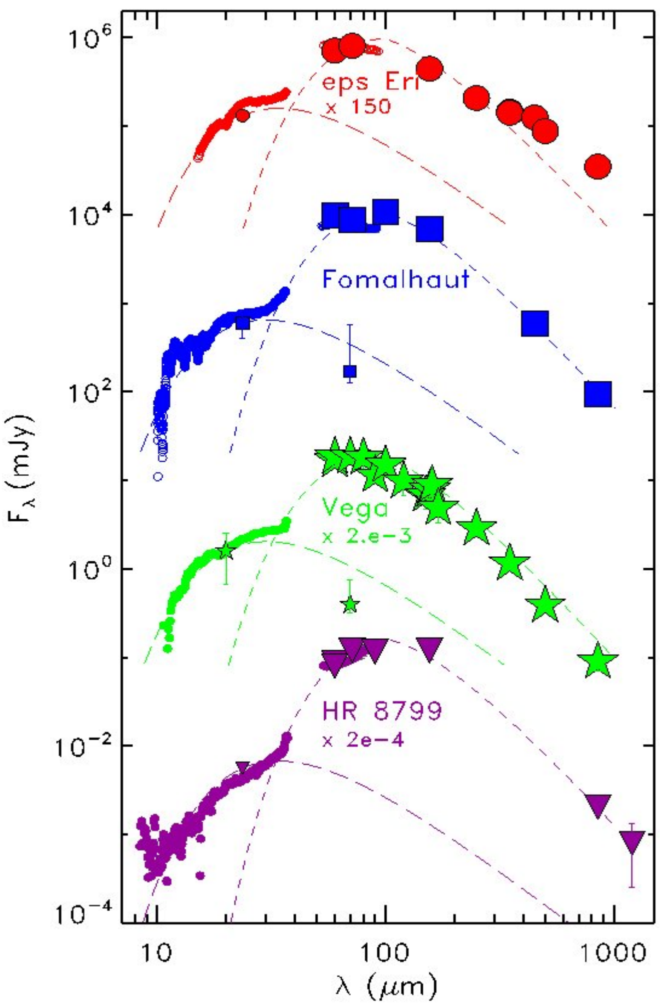
HR 8799



Marois+ 2010

Two–belt architectures may suggest the presence of intermediate planets.

Goal 1: System Architecture

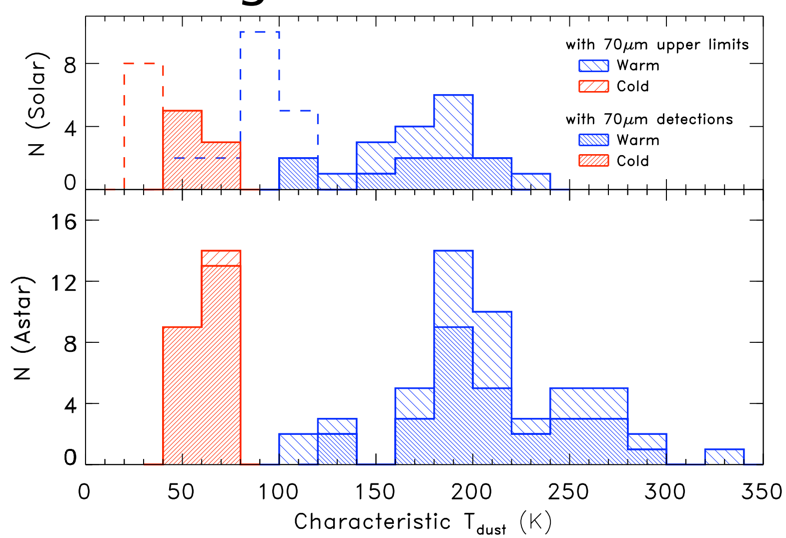


Su+ 2013

SED analysis of unresolved disks finds that two-belt systems are common.

Chen+ (2014) find **2/3 of ~500 disks** with Spitzer spectra are best fit with a two-belt architecture reminiscent of the Solar System's asteroid/Kuiper belts.

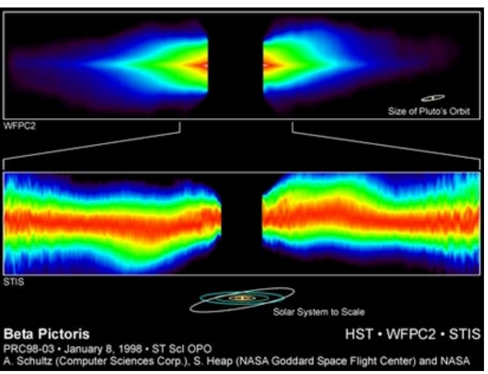
Morales+ (2011) identify a break at a fixed temperature, not at a fixed location, a possible signature of the ice line.



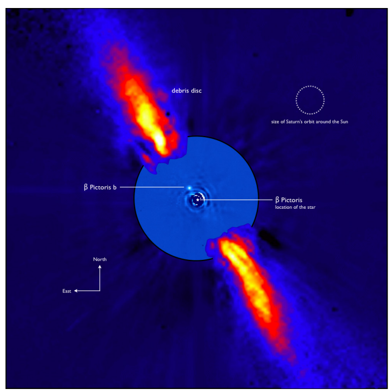
Goal 2: Planet-Induced Structure

Warp

beta Pic b –
planet mass/semi-major axis predicted by Mouillet (1997) based on inner disk warp



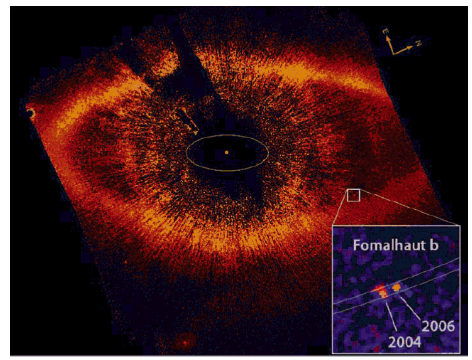
Heap+ 2000



Lagrange+ 2009

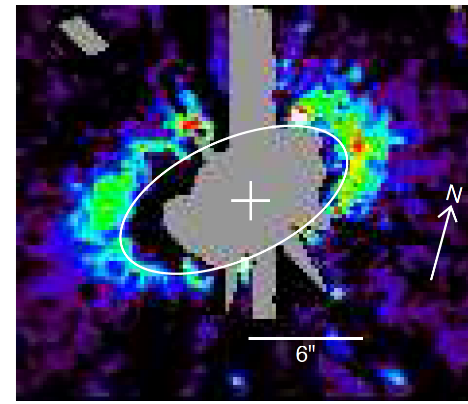
Sharp-edged offset rings

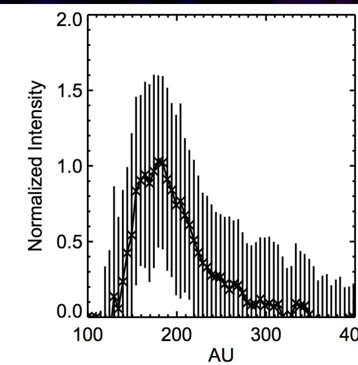
Fomalhaut



Kalas+ 2005

HD 202628





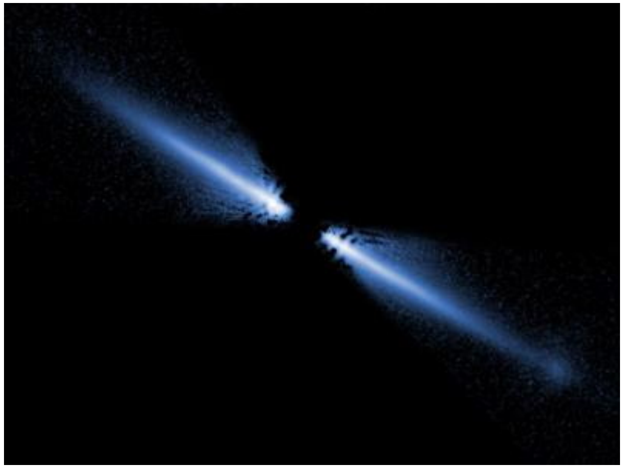
~2-Gyr-old, G2V star
e=0.18, a=158 AU
Krist+ 2012

Goal 3: Disk Physics

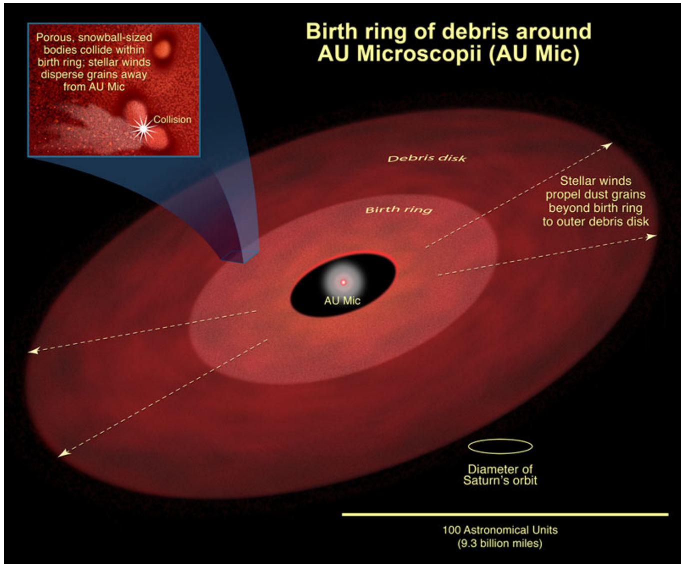
High-resolution disk images help to determine how dust is created and transported within each system.

Measurables:
  dust distribution, disk morphology, color, albedo
→ Constraints on grain size and composition

A new regime of disk physics:
Known disks are dominated by collisions and blowout. WFIRST will be able to image fainter disks where P-R drag is dominant, as in the Solar System. Resonant capture of dust is expected.



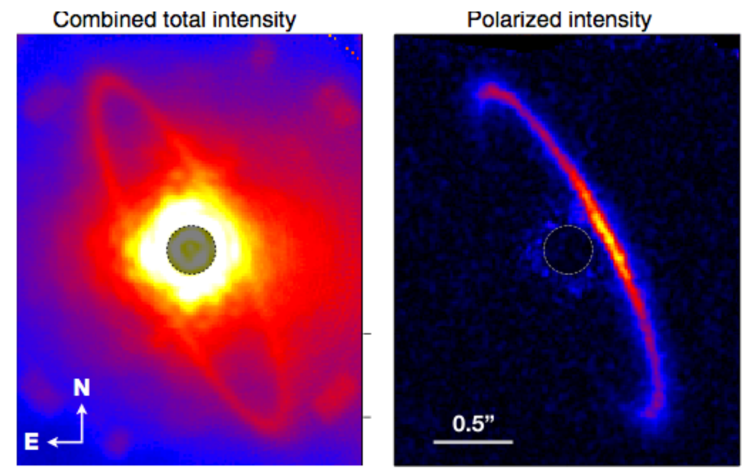
AU Mic's blue disk, indicative of small grains
Krist+ 2005

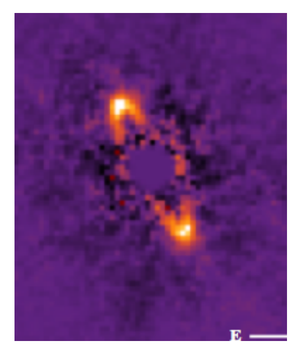


Polarization

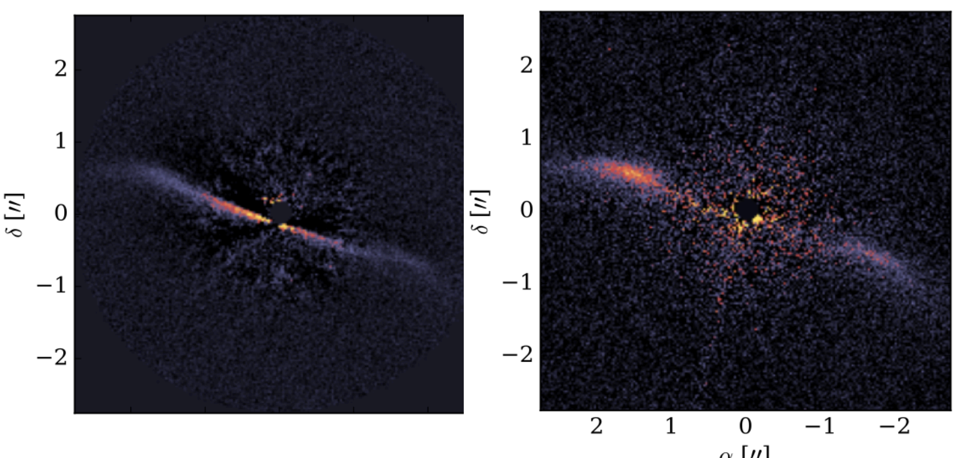
Images in polarized light provide a unique probe of dust scattering, enabling new insight into dust properties and disk geometry.

HR 4796A
GPI total & polarized intensity
Perrin+ 2015





HST-NICMOS
PCA by E. Choquet



HD 61005 (“the Moth”)
VLT/SPHERE total & polarized intensity
Olofsson+ 2016

Summary

A dedicated WFIRST survey can resolve many known debris disks.

WFIRST's planet imaging survey will meanwhile image many new disks around nearby stars.

These high-resolution images will:

- Determine the prevalence of two-belt planetary system architectures like the Solar System's.
- Reveal the presence of unseen planets via their influence on disk structure.
- Explore the physics and evolution of debris disks by characterizing the dust size and disk morphology.