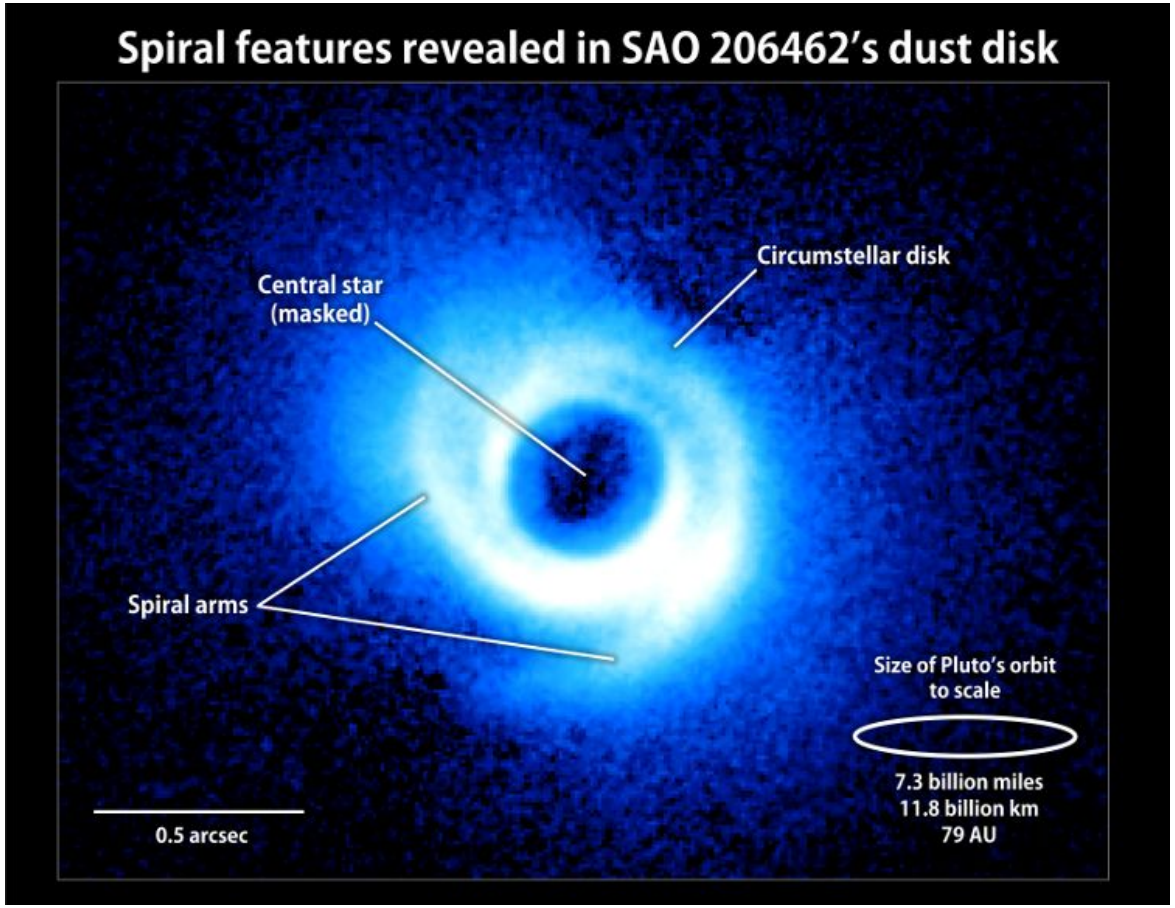
AFTA Disk Science



Tom Greene (NASA Ames)
AFTA SDT Meeting
September 9, 2013
Thanks to AFTA disk science group

Unique AFTA-C Disk Science in 2020s:

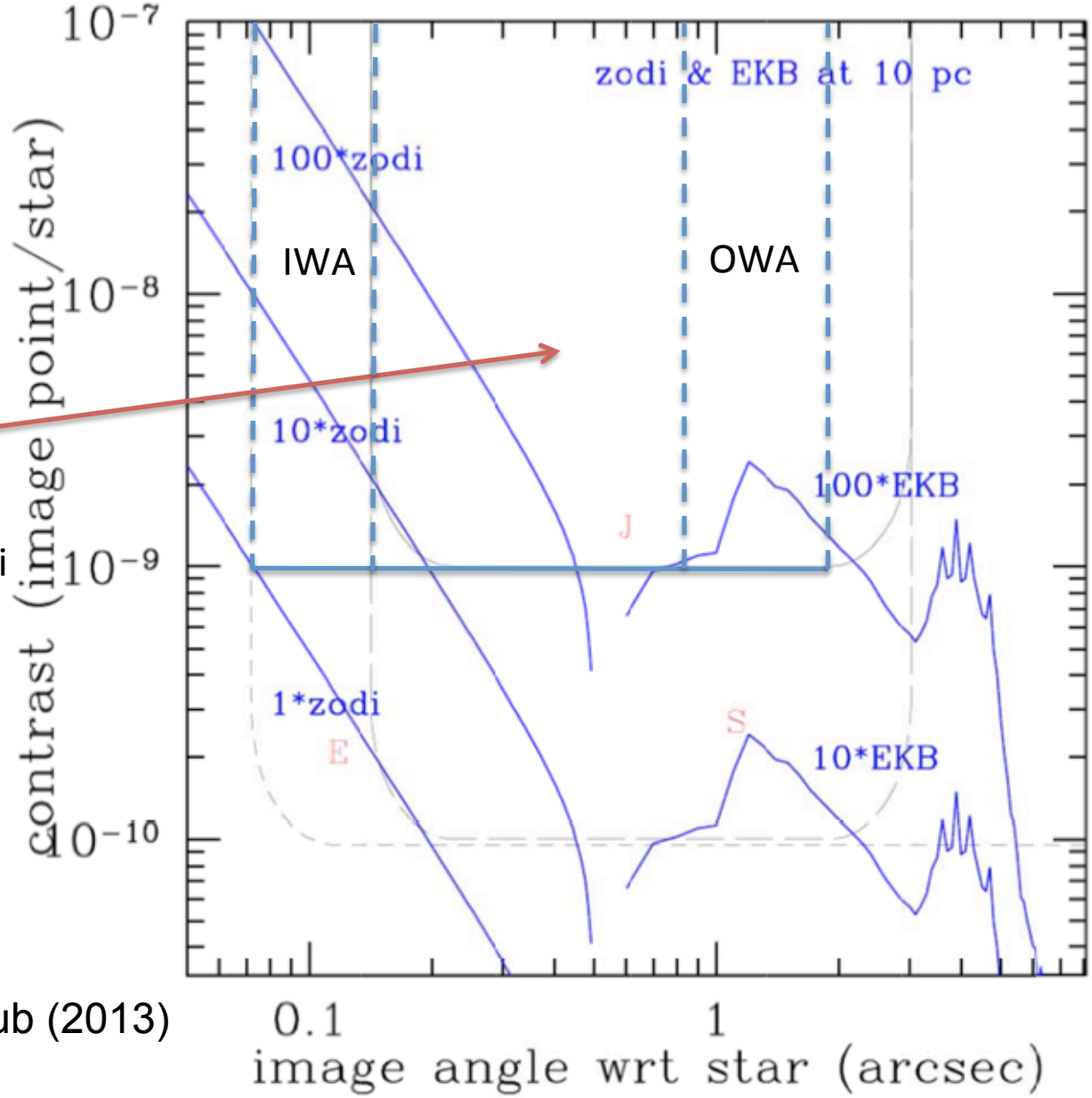
Reflected light imaging of nearby planetary systems

- Extremely sensitive, high spatial resolution imaging of zodi and Kuiper disks of nearby, mature stars
  - Can sample habitable zones of some (10-20) nearby stars
  - Find signs of un/seen planets and collisions (gaps, belts, shepherding)
  - Dust data useful for future terrestrial planet imaging
  - Sensitivity close to LBT-I with better spatial resolution:
    - AFTA visible + LBT-I MIR yield grain albedos
- Image inner regions of ~20 extreme debris disks found with HST
- Image transition disks of young stars found in mm or IR (secondary):
  - How much material is in the inner "clear" regions?
  - What are particle sizes, and how do disks clear?
- Scattered light imaging of well-studied T Tauri disks (secondary)
  - Study grain albedos and dust distributions during planet formation era

AFTA can detect zodiacal and Kuiper Belts

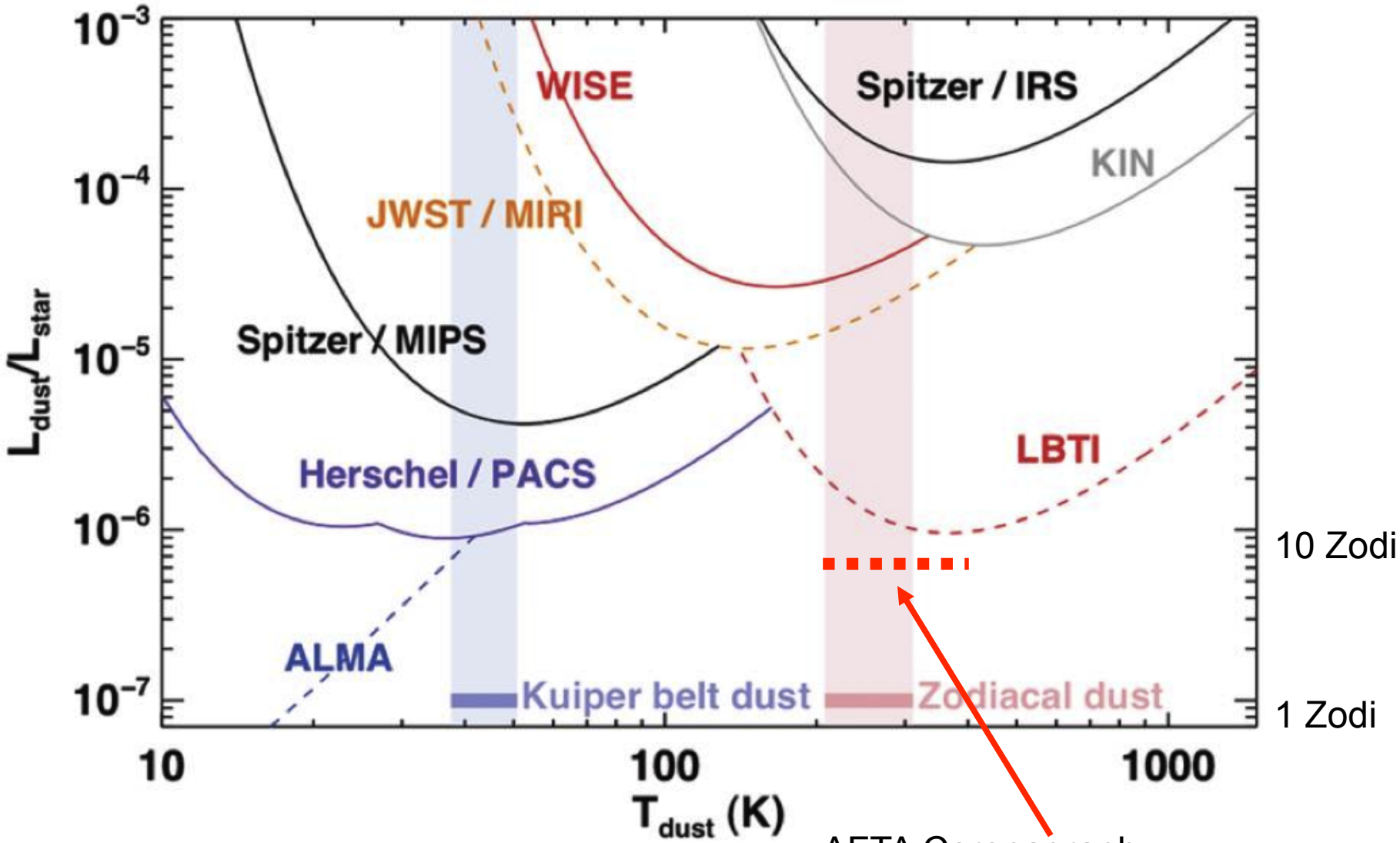
AFTA Niche:

- Small IWA good for zodi
- Current OWA is set by 48 x 48 DMs and is not great



Adapted from W. Traub (2013)

Excellent Exozodi sensitivity



Adapted from Roberge et al. (2012)

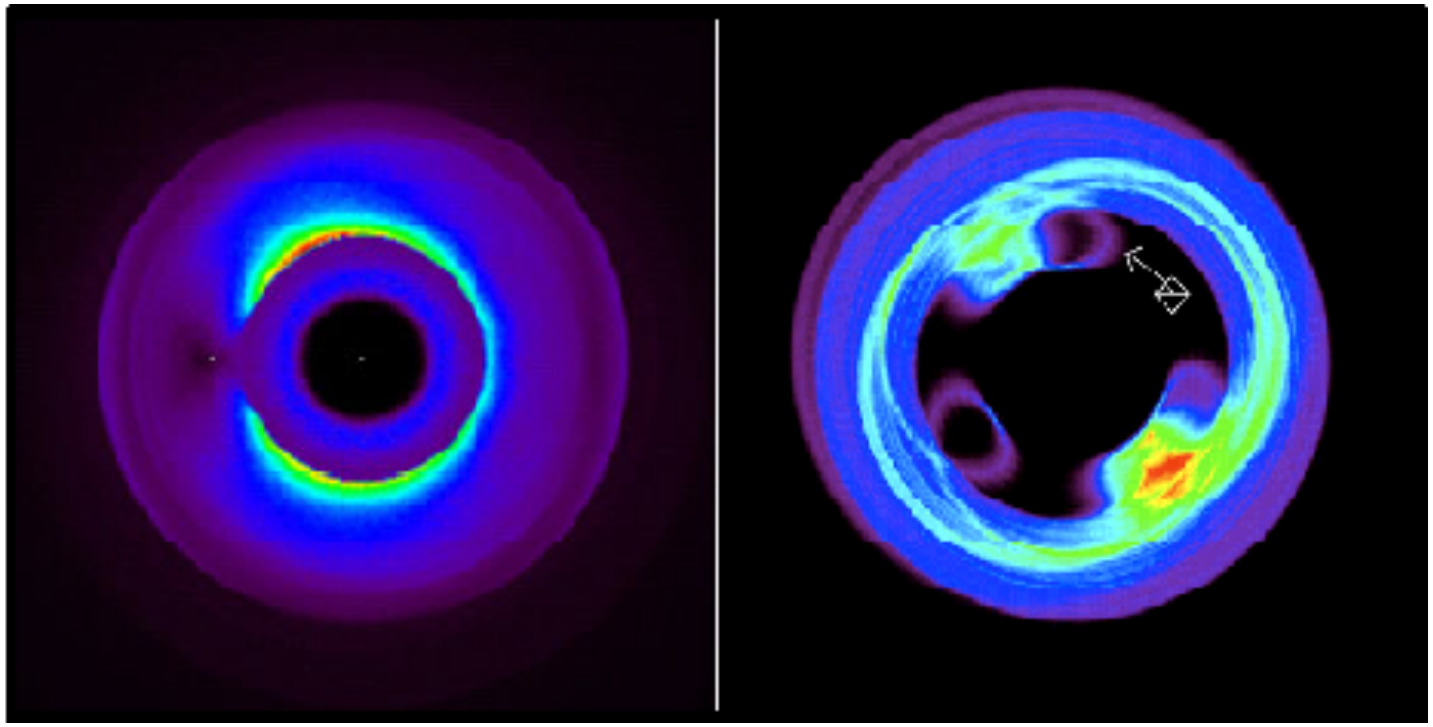
AFTA Coronagraph
5 zodi ~ 1E-9 star outer HZ at 10pc

Broad (disk) science goals & comments

- Observe and understand the planetary systems of nearby stars: planets, disks, and interactions between them
- Characterize the extents, densities, colors, and morphologies of the disks to understand their origins and evolutionary progress

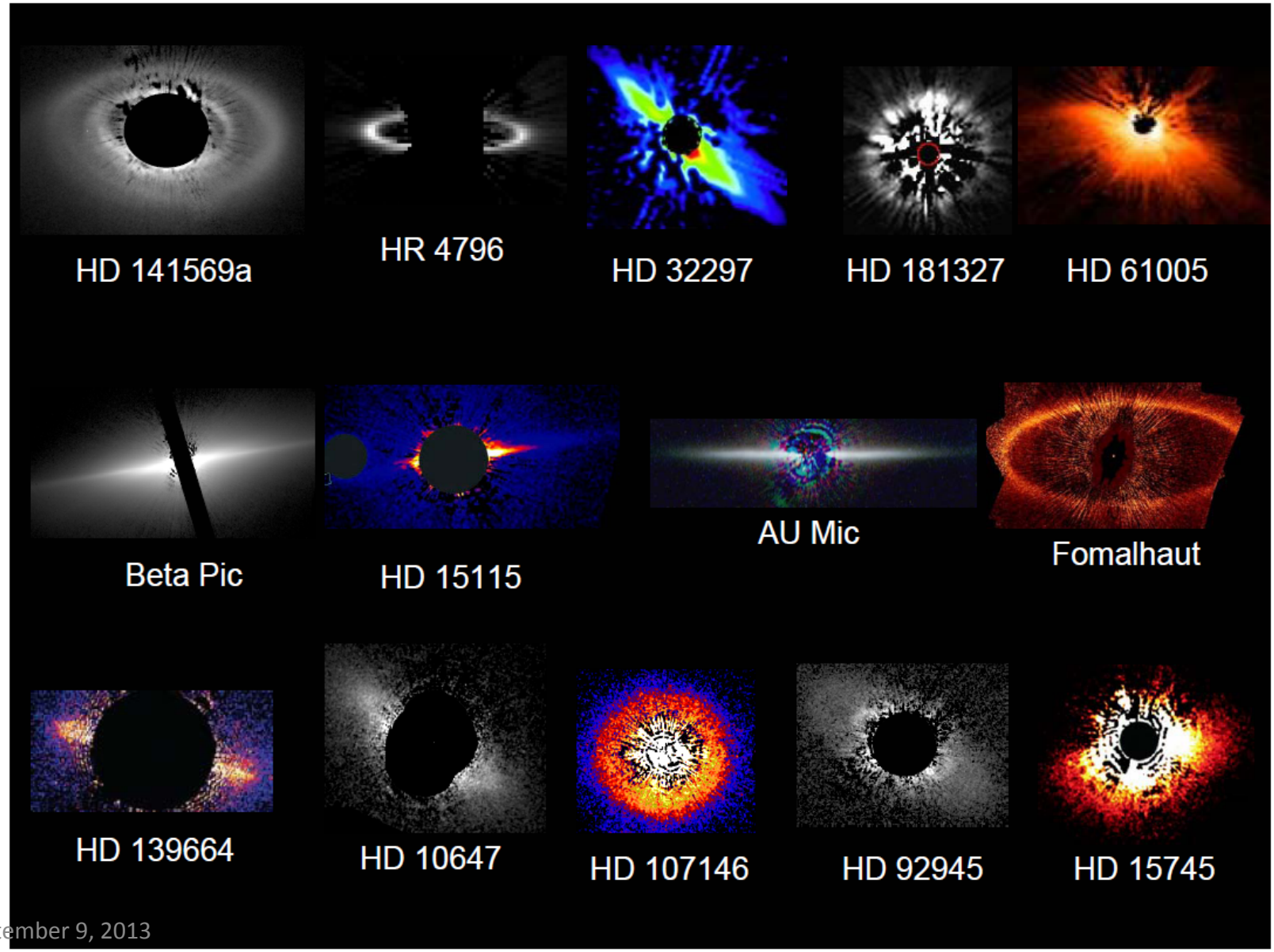
  - THESE GOALS REQUIRE SENSITIVE IMAGING IN AT LEAST 2 BROADBAND FILTERS (polarimetry is TBD – more later)
  - THE DISK IMAGING SAMPLE MAY BE IDENTICAL TO THE EXOPLANET SURVEY SAMPLE
  - DISK SENSITIVITY DEGRADES GRACEFULLY WITH CONTRAST PERFORMANCE (MORE GRACEFUL THAN PLANET IMAGING)
  - OUTER WORKING ANGLE IS A CONCERN: WHAT IS UNCORRECTED PERFORMANCE?

Disk – planet Interactions



Model scattered-light surface distributions for debris disks under the dynamical influence of a co-orbiting planet. Left: 1 Earth-mass planet at 1 AU (Kuchner et al 2007), Right: Debris disk model for the Vega system from which a Neptune-mass planet at 65 AU (that migrated outward from 40 AU ofver 50 Myr) has been inferred (Wyatt 2003).

HST has imaged ~2 dozen debris disks, > 1000 zodi



AFTA Exozodiacal / Debris Disk Science

- What is the amount and distribution of the debris
  - How much dust? Indicative of planetary content & collisions
  - What is going on in inner solar systems – within HST masks?
  - All the way into the habitable zone? How far out?
- What large-scale structures are present?
  - Brightness distribution indicative of collisions within an asteroid belt?
  - Evidence of seen or unseen planets sculpting gaps or shepherding disks?
- What are the sizes and compositions of the dust grains?
  - Photometry of 2+ well-separated wavelengths give some constraint on size distribution and composition (mid-IR helps)
  - Polarimetry may be useful, but unknown whether mature disks have polarized (small) grains
  - Polarimetry can help distinguish dust clumps from planets

Exozodiacal Dust Imaging Feasibility

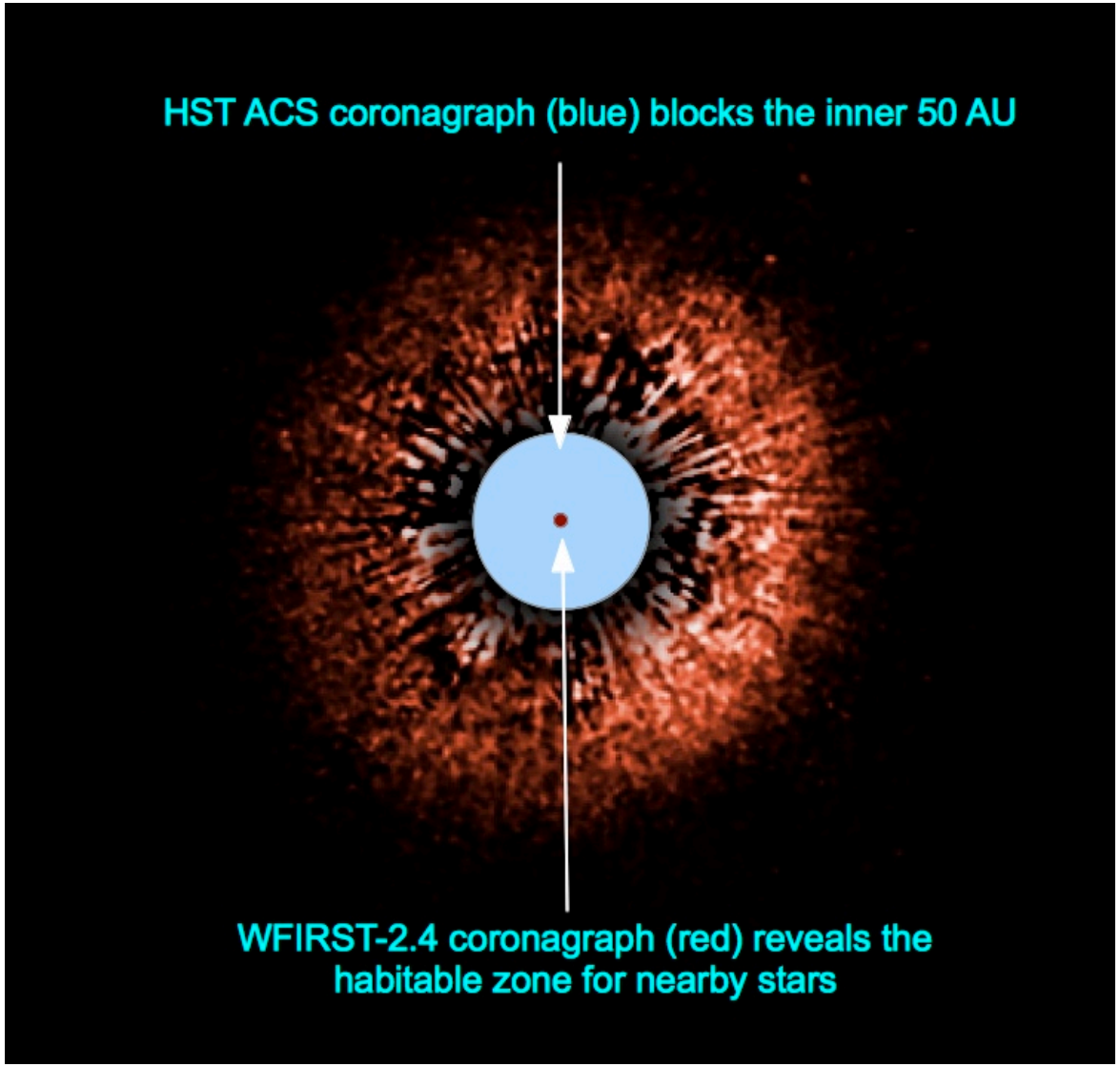
- Most sensitive visible dust imaging yet and high resolution
- Searching for planets around nearby stars should reveal disks in the same images
- Exozodi sensitivity per res. element is not a strong function of distance due to IWA and $r^{-2.x}$ disk flux dropoff:

  5 zodi Exozodi ~ 1E-9 star at 10 pc at 1.6 AU (3.5 λ/D)
- ~10 hr exposure time for SNR ~10, R=10 res el. (5 zodi, 10pc)

  - Res. element is 50 mas V band or 0.5 AU at 10 pc
  - Trace disks to large radii if you bin azimuthally
- 2x higher spatial resolution than LBT-I: locate the dust!

  - LBT-I resolution is ~10 μm / 20-m = 100 mas

Search inner regions of bright known disks



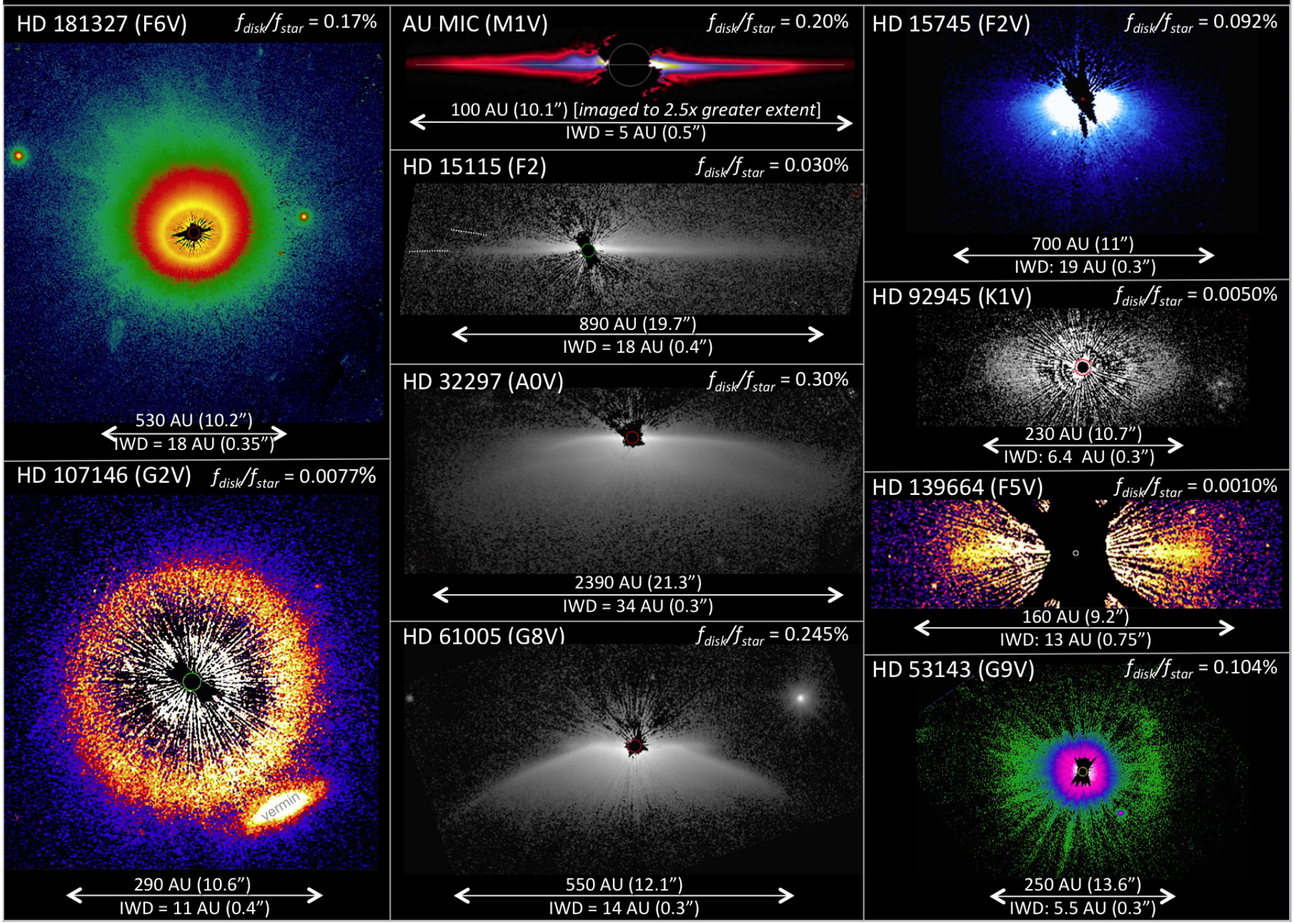
http://hubblesite.org/newscenter/archive/releases/2004/33/image/c/

AFTA will:

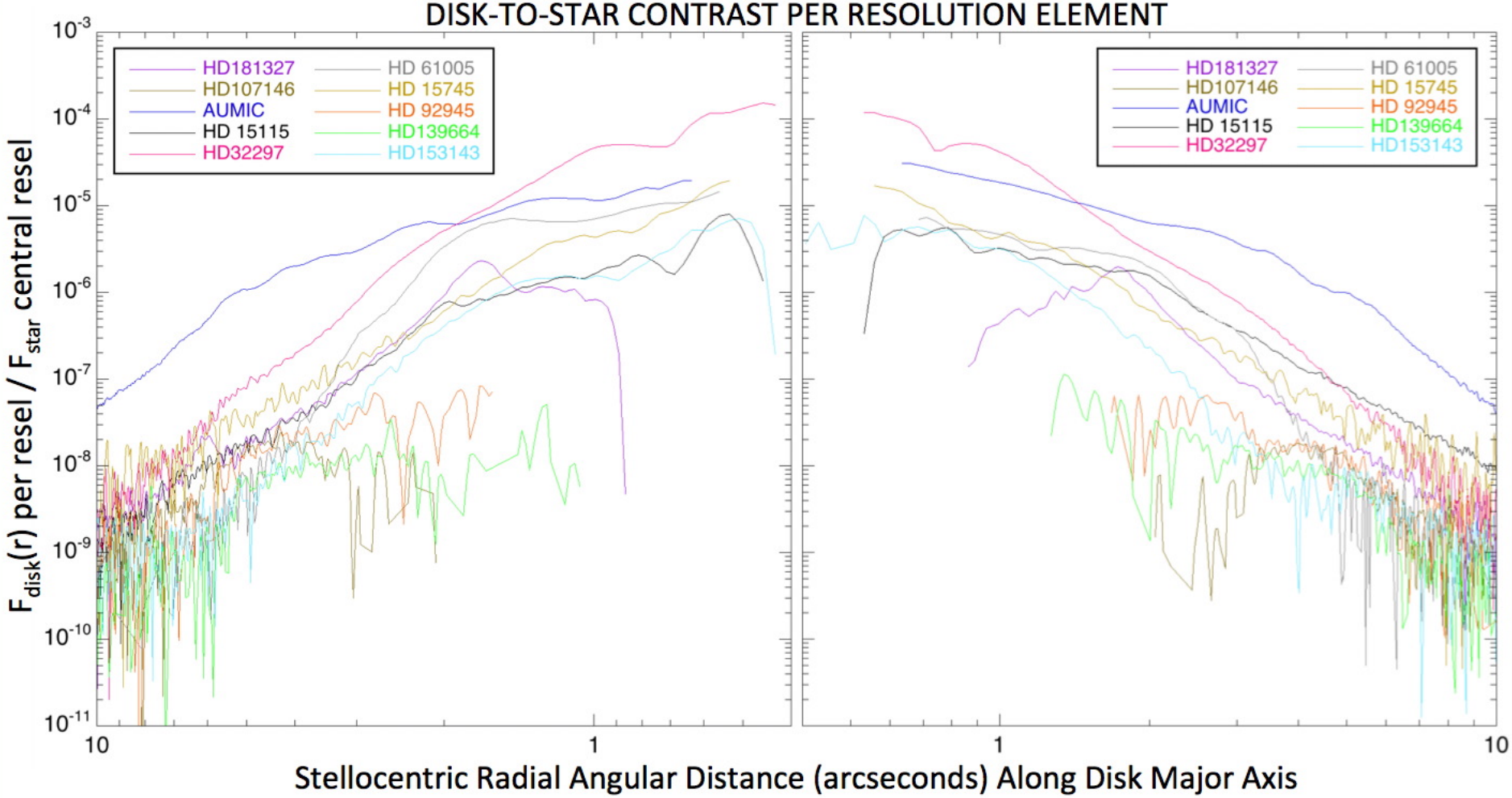
- Measure the amount and distribution of circumstellar dust.
- Measure the large scale structure of disks, revealing the presence of asteroid belts and gaps due to unseen planets.
- Measure the size and distribution of dust grains.
- Provide measurements of the zodiacal cloud in other systems.

Debris disk around the young (~100 Myr), nearby (28 pc) sun-like (G2 V0) star HD 107146 (Ardila et al. 2004)

The HST/GO 12228 Debris Disk Sample (G. Schneider & the HST GO/12228 Team)



DEBRIS DISK MAJOR AXIS OPTICAL SURFACE BRIGHTNESS
DISK-TO-STAR CONTRAST PER RESOLUTION ELEMENT



G. Schneider and the HST/GO 12228 Team – 04 Sep 2013

Draft AFTA Disk Science Objectives

- Search for low surface density circumstellar disks around a sample of several dozen nearby stars
- Measure the location, density, and extent of dust particles around nearby stars in order to identify planetesimal belts and understand delivery of volatiles to inner solar systems
- Detect and measure substructures within dusty debris that can be used to understand the locations of planitesimals (i.e., asteroids) and influences of seen and unseen planets
- Image the inner regions of bright debris disks detected by HST but occulted by its larger coronagraphic masks
- Understand the time evolution of circumstellar disk properties around a wider star sample at greater distances, using data from other facilities as needed.

Strawman AFTA Disk Observations

- Search for disks in coronagraphic images of nearby stars: same sample used for planet search
  - Ideal if both planets and disks detected together: Do planets shepherd disks, what are other influences?
- Ideal to survey ~40 high nearby systems in 2 well-separated broadband colors with high sensitivity (10 disks to 10 zodi)
  - Want reasonable statistics
  - Want IWA to reach HZ of ~10 disks, OWA to reach Kuiper belts (50+ AU)
  - Surface brightness constrains particle surface densities and hence mass (adding mid-IR to measure albedos helps)
  - Colors constrain grain compositions
- Image many of the ~20 HST debris disks in 2 colors (medium depth)
- Still evaluating utility of polarization measurements:
  - Are mature disks expected to be polarized? Not if small grains gone
  - What spectral bandwidth is needed for polarization measurements?
  - Will polarized signals be measured accurately through the instrument?
  - Can polarized measurements boost the final measured contrast?

Disk Instrument Requirements Drivers

- Final contrast:
  - 1E-9 is good for 10 zodi disks; graceful science falloff if worse
- Inner working angle (IWA):
  - 3 λ/D gives ~150 mas in red, samples solar HZs to ~6.5 pc (~10)
  - 2 λ/D gives ~100 mas in red, survey solar HZs out to 10pc (3.4 x the volume of 3 λ/D)
- OWA: Should be ~2 arcsec to survey Kuiper belt regions at 10 pc. This is an issue for 48x48 element DMs
- Spectral range: 400 – 900+ nm is important and useful for disk colors
- Polarization is TBD
- No requirements on disk spectroscopy, but it would be useful to image gas in younger disks (details not worked out, not requirements driver)