Debris Disks and Exozodi Study Analysis Group

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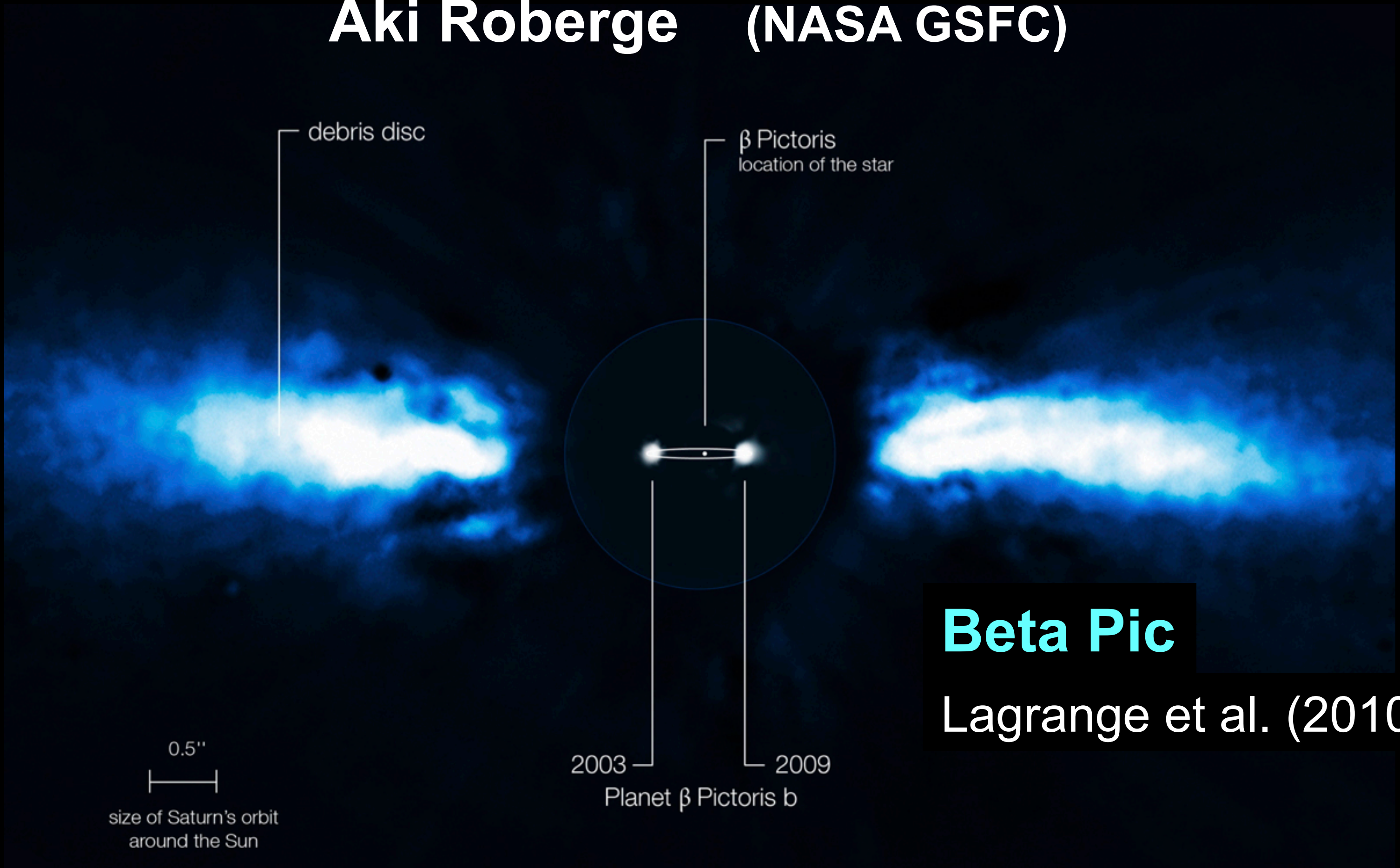

Beta Pic

Lagrange et al. (2010)

6th Exoplanet Exploration Program Analysis Group Meeting, Reno NV, Oct 13 & 14, 2012

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ExoPAG SAG 1 Report

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The Exozodiacal Dust Problem for Direct Observations of Exo-Earths

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ABSTRACT. Debris dust in the habitable zones of stars—otherwise known as exozodiacal dust—comes from extrasolar asteroids and comets and is thus an expected part of a planetary system. Background flux from the solar system's zodiacal dust and the exozodiacal dust in the target system is likely to be the largest source of astrophysical noise in direct observations of terrestrial planets in the habitable zones of nearby stars. Furthermore, dust structures like clumps, thought to be produced by dynamical interactions with exoplanets, are a possible source of confusion. In this article, we qualitatively assess the primary impact of exozodiacal dust on high-contrast direct imaging at optical wavelengths, such as would be performed with a coronagraph. Then we present the sensitivity of previous, current, and near-term facilities to thermal emission from debris dust at all distances from nearby solar-type stars, as well as our current knowledge of dust levels from recent surveys. Finally, we address the other method of detecting debris dust, through high-contrast imaging in scattered light. This method is currently far less sensitive than thermal emission observations, but provides high spatial resolution for studying dust structures. This article represents the first report of NASA's Exoplanet Exploration Program Analysis Group (ExoPAG).

1. INTRODUCTION

Interplanetary dust interior to the solar system's asteroid belt is called the zodiacal dust, which comes from comet comae and

2009). However, a more sensitive survey for exozodiacal dust around a smaller set of nearby stars with the Keck Nulling Interferometer (KIN) found mostly nondetections (discussed further below; Millan-Gabet et al. 2011). As will be shown,

The Problem for Exoplanet Imaging

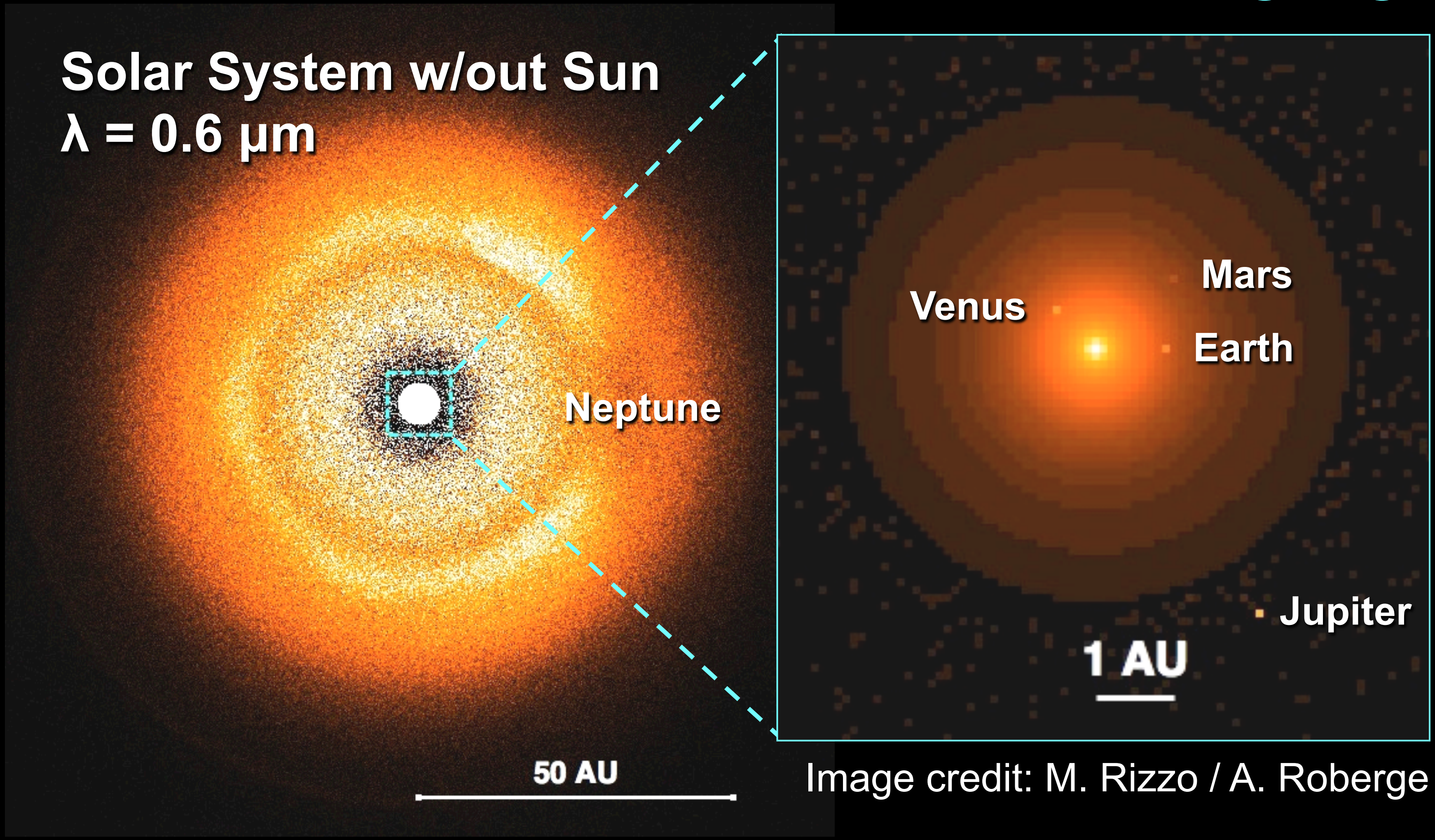


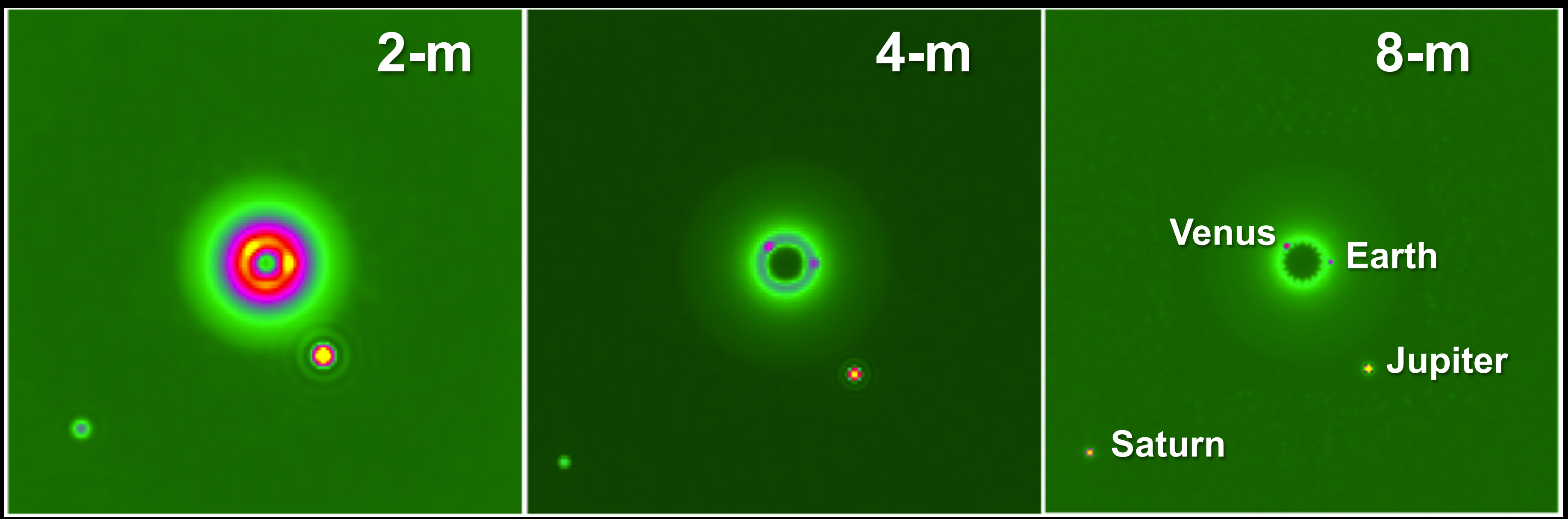
Image credit: M. Rizzo / A. Roberge

- Dust models from Kuchner & Stark (2010), Kelsall et al. (1998) + ZODIPIC

Simulated Solar System Images

Solar System at 10 pc

Model run through external occulter simulator
(no noise)



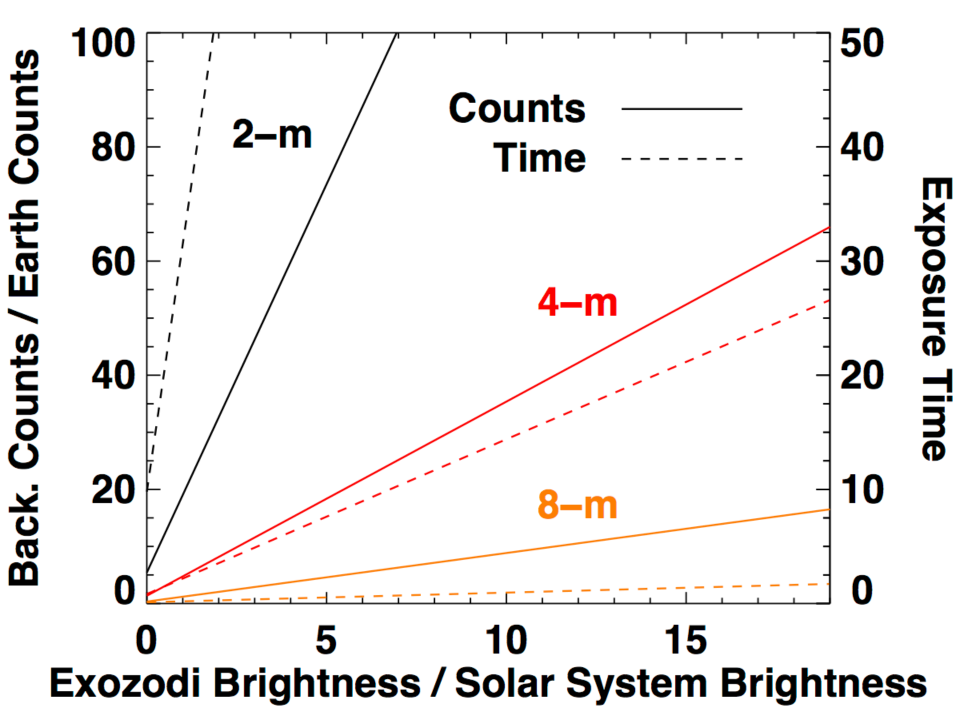
Turnbull et al. (2012)

Impacts on Direct Observations

1. Background flux increases direct imaging & spectroscopy exposure times

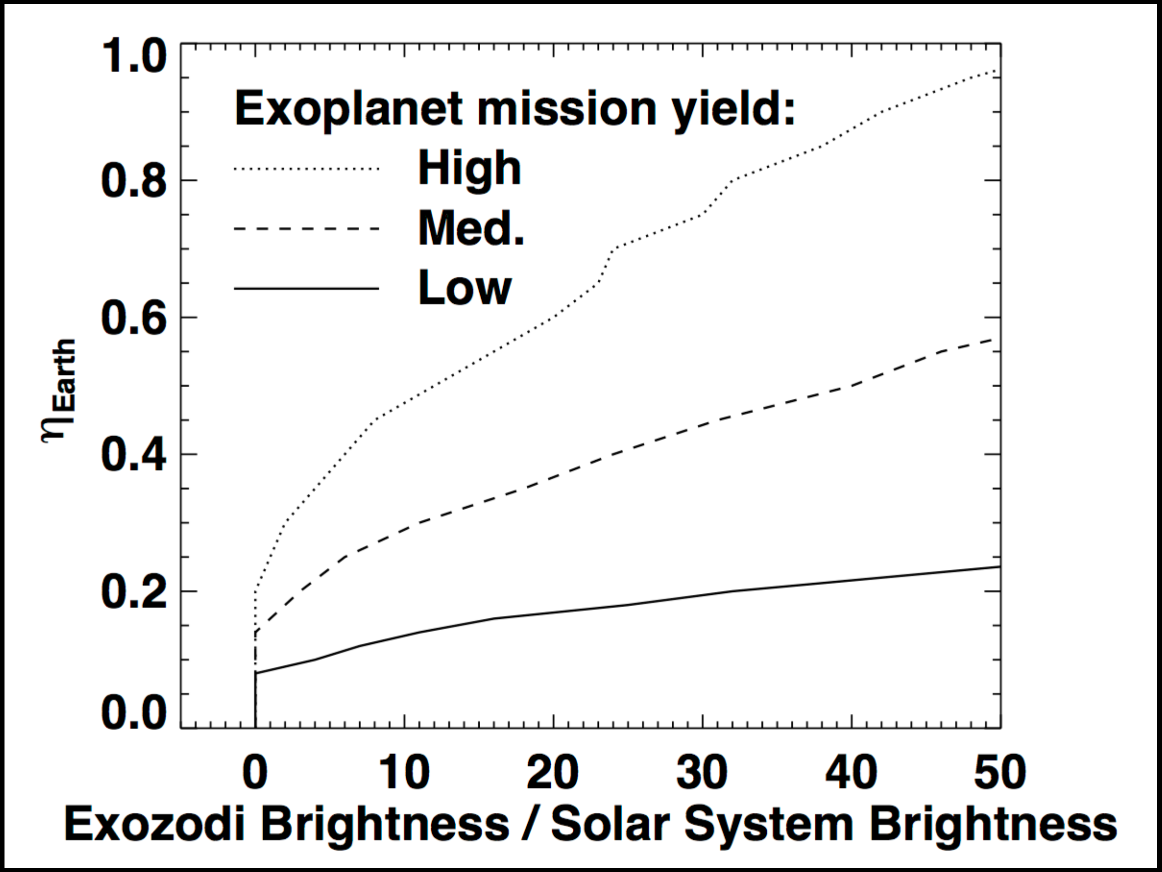
- Solar System-twin at 10 pc with 4-meter aperture: $C_{background} \sim 5 \times C_{Earth}$
- Effect is worse for smaller apertures

Roberge et al. (2012)



Impacts on Direct Observations

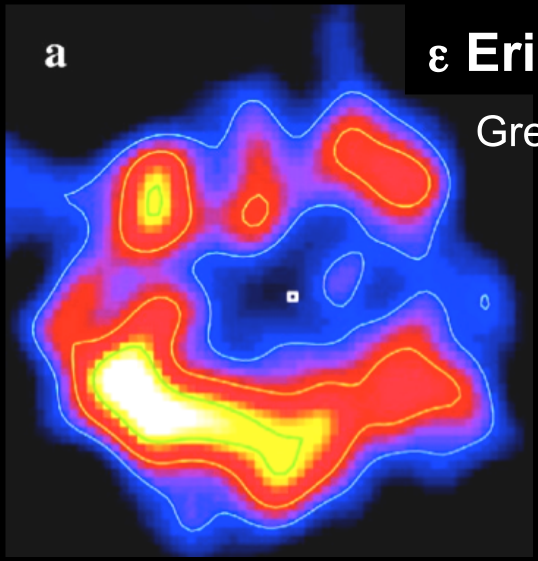
- Higher exozodi means larger η_{Earth} needed to characterize same number of planets



Roberge et al. (2012)

Impacts on Exoplanet Imaging

2. Dust structures (produced by exoplanets) may cause confusion

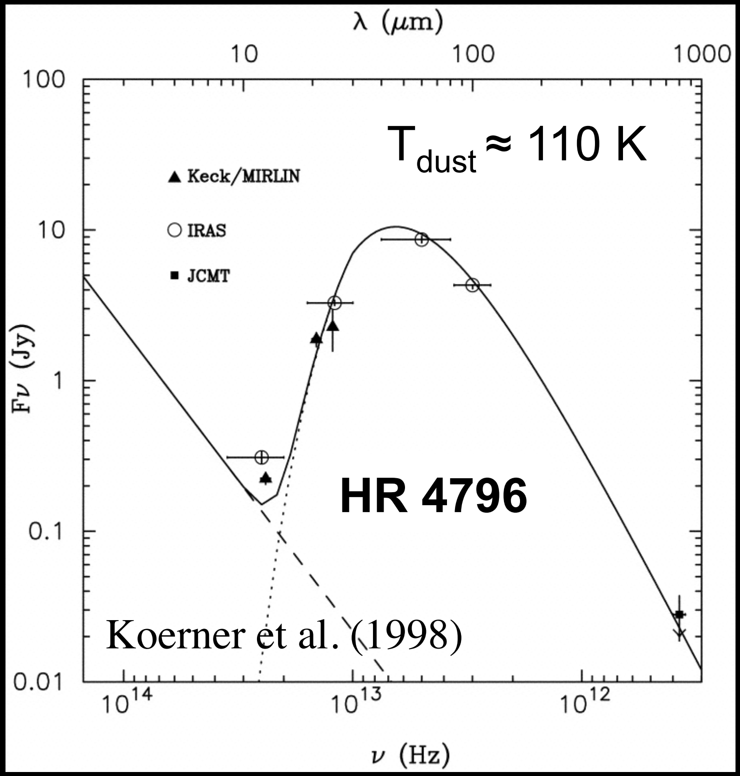


Clumps
ε Eridani @ 850 μm
Greaves et al. (2005)

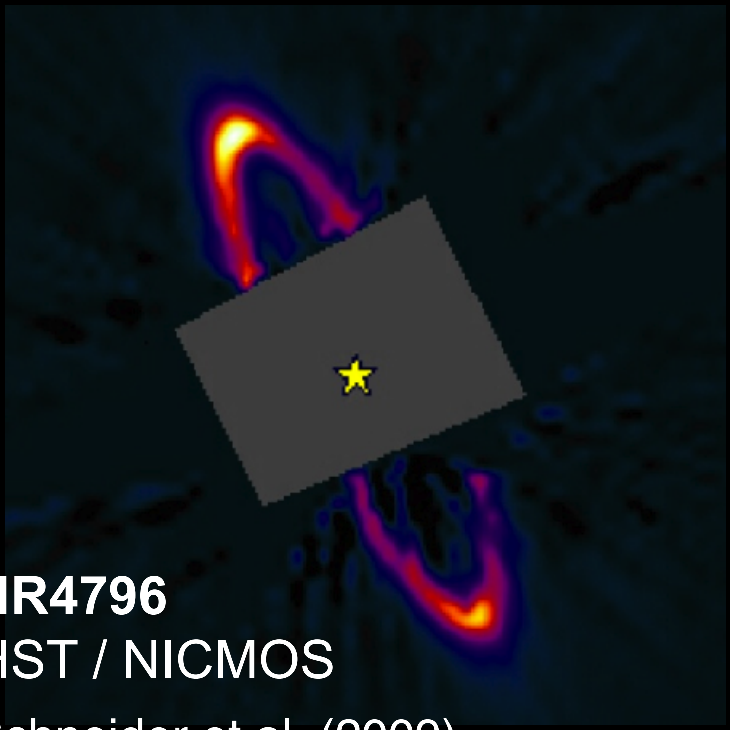
- Possible solutions:
  - Advanced image analysis techniques, possibly with detailed exozodi modeling
  - Multi-color and/or multi-epoch imaging, direct spectroscopy

Observing Debris Dust

Thermal emission



Scattered light



HR4796
HST / NICMOS
Schneider et al. (2009)

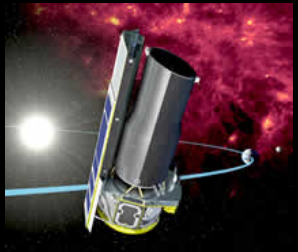
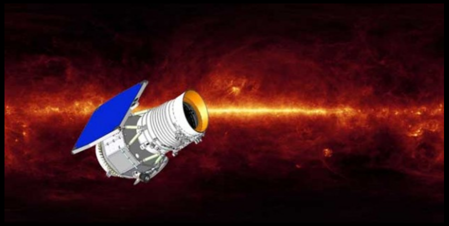
1. Fractional dust luminosity (L_{dust}/L_{star}) ➔ dust abundance
2. Dust temperature (T_{dust}) ➔ distance

Unresolved Thermal Emission

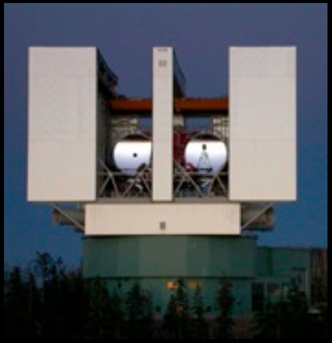
$$\frac{L_{\rm dust}}{L_\star} = \left(\frac{F_{\rm dust}}{F_\star}\right) \frac{kT_d^4\left(e^{h\nu/kT_d}-1\right)}{h\nu T_\star^3},$$

Star is Rayleigh-Jeans,
Dust is single-temp. blackbody
(~ ring-like disk)

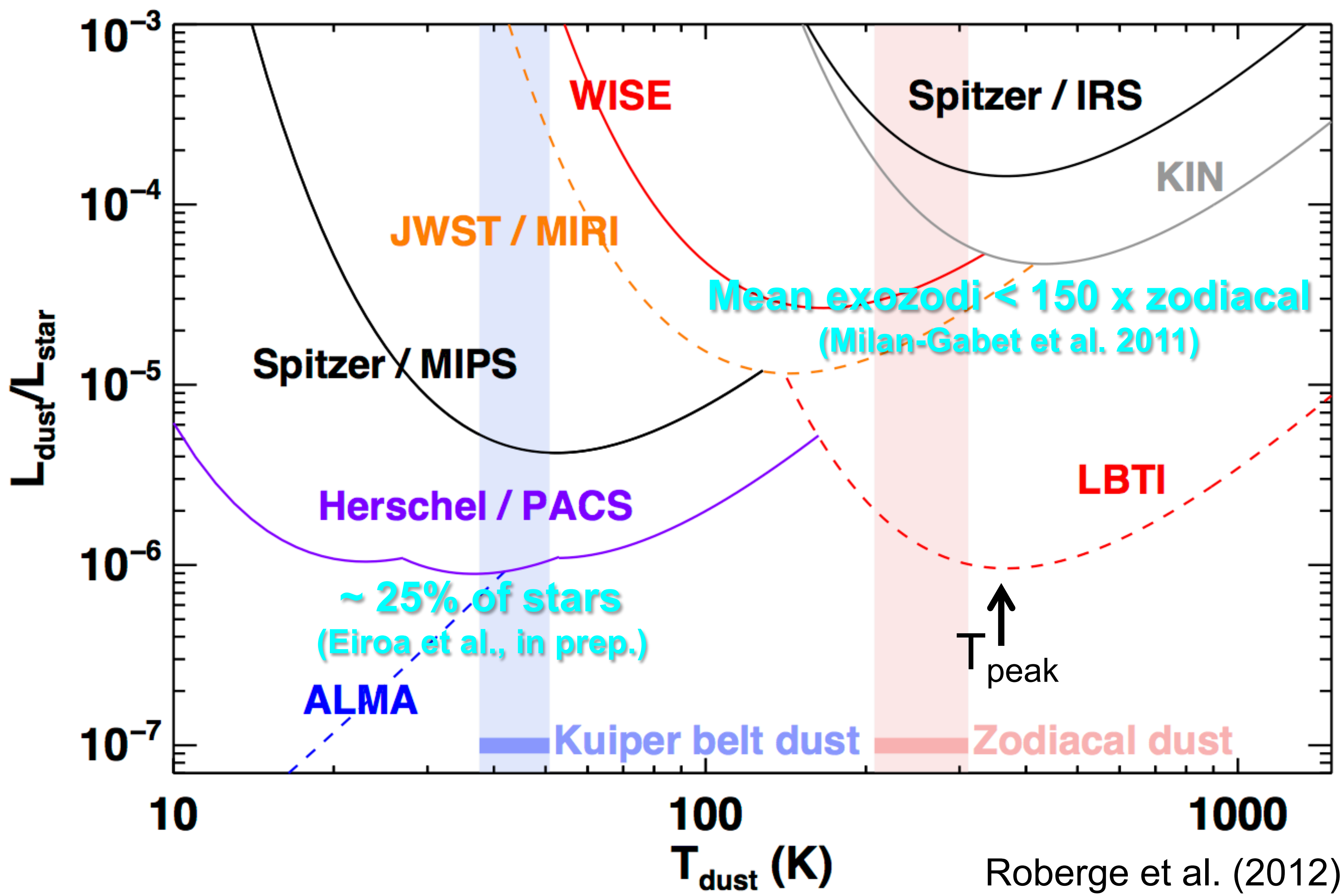
Previous & Current Facilities


Upcoming Facilities



Sensitivity Curves

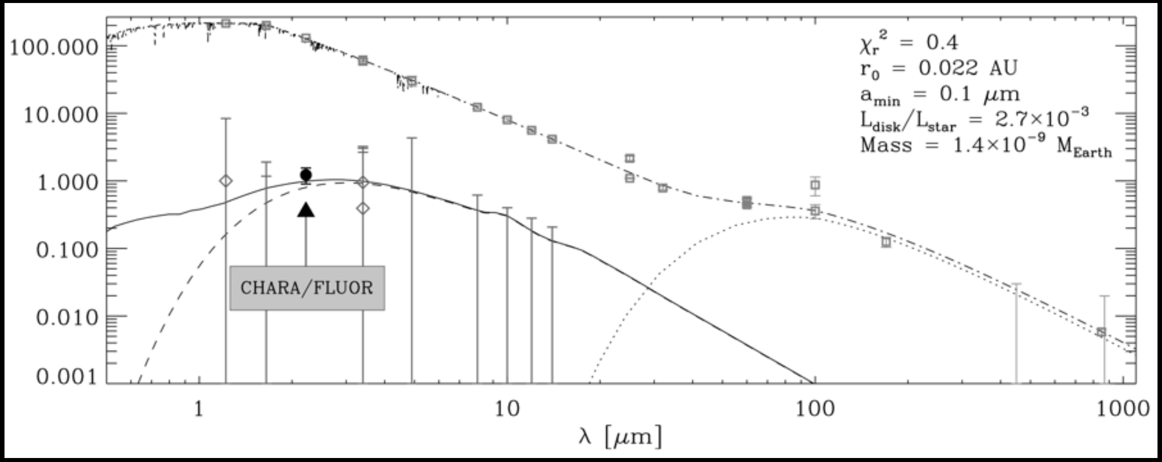


Roberge et al. (2012)

Sensitivity Curves cont'd

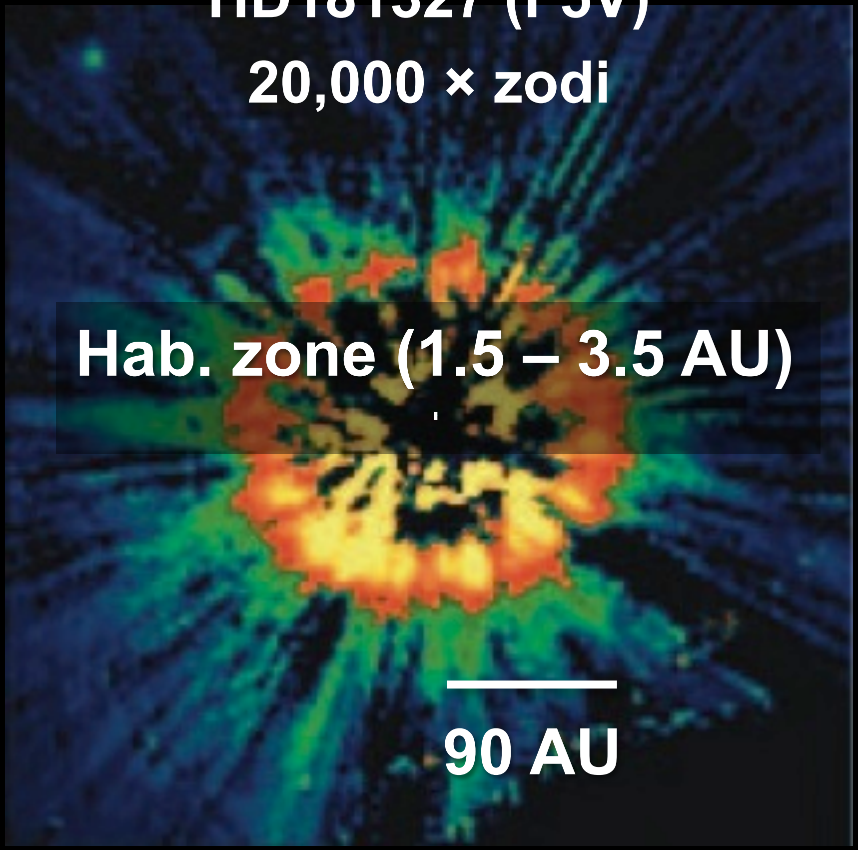
1. JWST/MIRI sensitivity achievable for more distant stars, due to large collecting area
2. Only ALMA can resolve clumps from Earth-mass planet
3. Sensitivity to large amounts of hot (~ 1700 K) dust with new near-IR instruments: VLTI/VINCI, CHARA/FLUOR, Palomar Fiber Nuller

Tau Cet (di Folco et al. 2007)



High-Contrast Imaging in Scattered Light

- Far less sensitive than unresolved thermal emission
- No access to habitable zone, but unique information on dust structures at large distances



Schneider et al. (2006)

New Techniques & Coronagraphs

- Better starlight removal techniques: Angular differential imaging, chromatic differential imaging, polarization differential imaging
- New instruments: Subaru / HiCIAO, VLTI / SPHERE, Gemini S / GPI

TABLE 2

HIGH-CONTRAST OPTICAL/NIR IMAGING OF DUST SCATTERED LIGHT: INSTRUMENT PERFORMANCE

Facility/instrument	Operation dates	IWA[a] (″)	Contrast[b] at 1″	Faintest disk imaged: ID	Faintest disk imaged: $L_{dust}/L_\star$	Refs.
HST/STIS	1997–2004, 2009–	0.5	3×10^{-3}	HD 202628	1×10^{-4}	1, 2
HST/NICMOS	1997–1999, 2002–2008	0.5	10^{-5}	HD 181327	2×10^{-3}	3, 4
HST/ACS	2002–2007	1	10^{-5}	Fomalhaut	8×10^{-5}	5, 6
Subaru/HiCIAO	2010–	0.15	$10^{-4.8}$[c]	HR 4796A	5×10^{-3}	7, 8
Gemini S/GPI	2012–	0.08	$\sim 10^{-6}$ to 10^{-7}[c]	...	...	9
JWST/NIRCam	2018–2023	0.3	$\sim 10^{-5}$[c]	...	...	10
JWST/NIRISS	2018–2023	0.1	$\sim 10^{-4}$ to 10^{-5}[c]	...	...	11

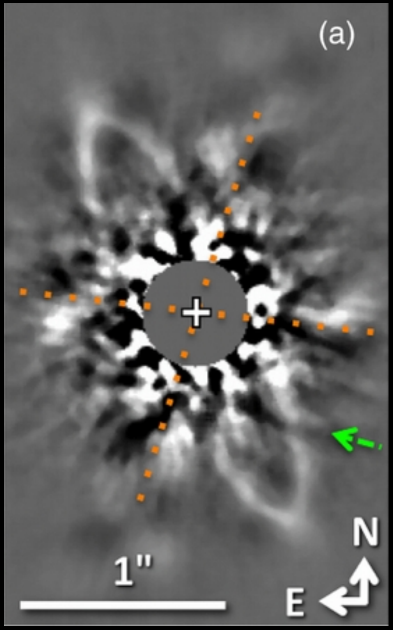
[a] Inner working angle (smallest achievable).

[b] Relative to peak of unobscured PSF, with reference PSF subtracted.

[c] Assuming a point source. Will probably be worse for extended sources like disks.

REFERENCES.—(1) Space Telescope Imaging Spectrograph (STIS) Instrument Handbook, version 10.0, http://www.stsci.edu/hst/stis/documents/handbooks/currentIHB/cover.html; (2) Krist et al. (2012); (3) Schneider & Hines (2007); (4) Schneider et al. (2006); (5) Advanced Camera for Surveys (ACS) Instrument Handbook, version 10.0, http://www.stsci.edu/hst/acs/documents/handbooks/cycle19/cover.html; (6) Kalas et al. (2005); (7) Suzuki et al. (2010); (8) Thalmann et al. (2011); (9) GPI World Wide Web page, http://planetimager.org/pages/gpi_tech_contrast.html; (10) Krist et al. (2007), (11) Space Telescope Science Institute NIRISS Web page, http://www.stsci.edu/jwst/instruments/niriss/ObservationModes/ami.

HR4796 w/ HiCIAO (Thalmann et al. 2011)



Large Binocular Telescope Interferometer

- NASA-funded instrument (PI: Phil Hinz, Arizona)
  - 3 – 5 µm camera (LMIRCam) and 8 – 13 µm nulling interferometer (NOMIC)

- Key Science: **sensitive exozodi survey using** NOMIC

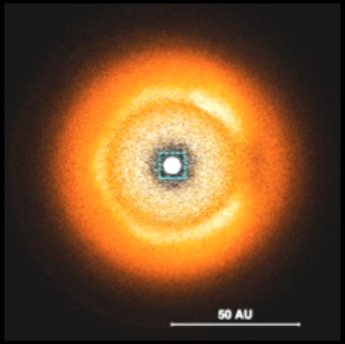
"The Hunt for Observable Signatures of Terrestrial Systems" (HOSTS)

LBTI Status Report

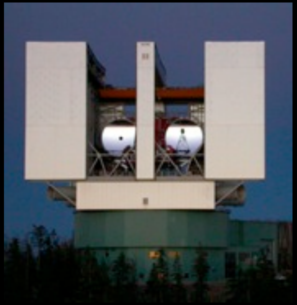
- LMIRCam producing early science
- NOMIC commissioning in progress
- Exozodi Key Science Team selected, June 2012 ↓
- Instrument Status Review, Sept. 2012
- Operational Readiness Review, Dec. 2012
- Science operations planned for ~ Q1 2013

Summary

- Effects of exozodiacal dust on direct imaging
  1. Background flux leading to increased noise
  2. Dust structures causing confusion with unresolved exoplanets



- Only facility sensitive enough to approach Solar System zodiacal dust level in habitable zones of nearby stars = LBTI



- High-contrast scattered light imaging of disks
  – Far less sensitive than unresolved thermal emission
  – Provides unique information on dust structures at large radii