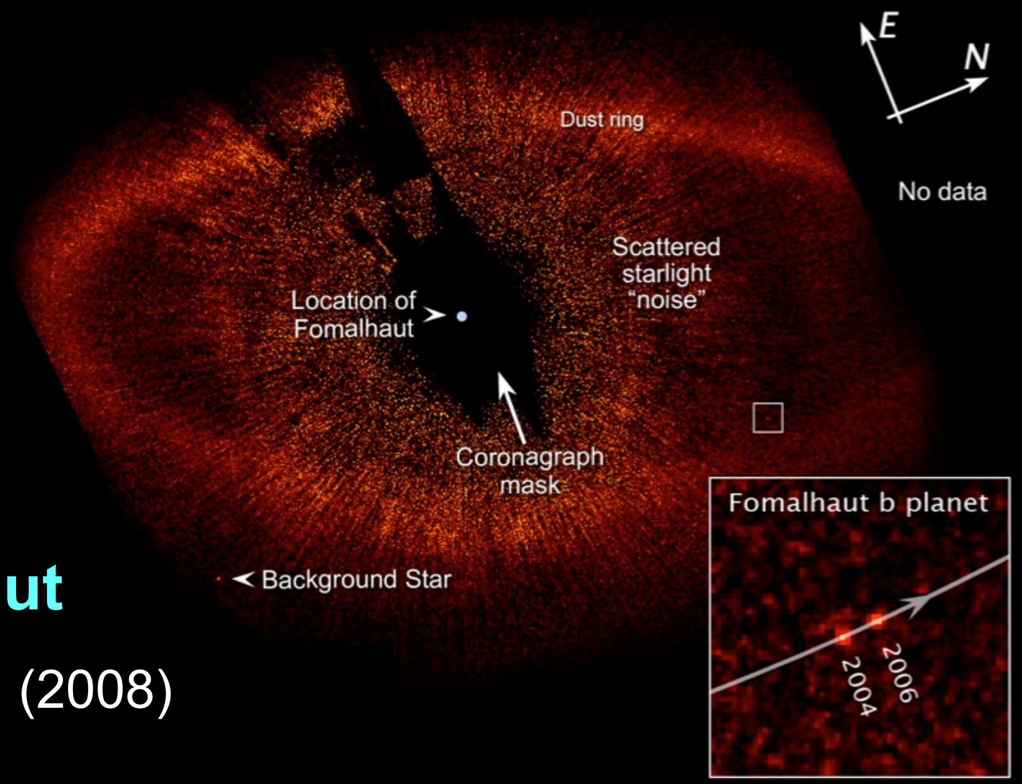
Debris Disks and Exozodi Study Analysis Group

Aki Roberge (NASA GSFC)



Fomalahut

Kalas et al. (2008)

5th Exoplanet Exploration Program Analysis Group Meeting, Austin TX, Jan 7 & 8, 2012

Current SAG Participants

Aki Roberge	(NASA GSFC)	Bruce Macintosh	LLNL)
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Jean-Charles Augereau	(Grenoble)	Charley Noecker	(NASA JPL)
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Joseph Catanzarite	(NASA JPL)	Remi Soummer	(STScI)
Christine Chen	(STScI)	Karl Stapelfeldt	(NASA GSFC)
Tom Greene	(NASA Ames)	Chris Stark	(Carnegie DTM)
Phil Hinz	(U of Arizona)	Alycia Weinberger	(Carnegie DTM)
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Casey Lisse	(JHU APL)		

- To participate, email Aki.Roberge@nasa.gov

The Problem for Exoplanet Imaging

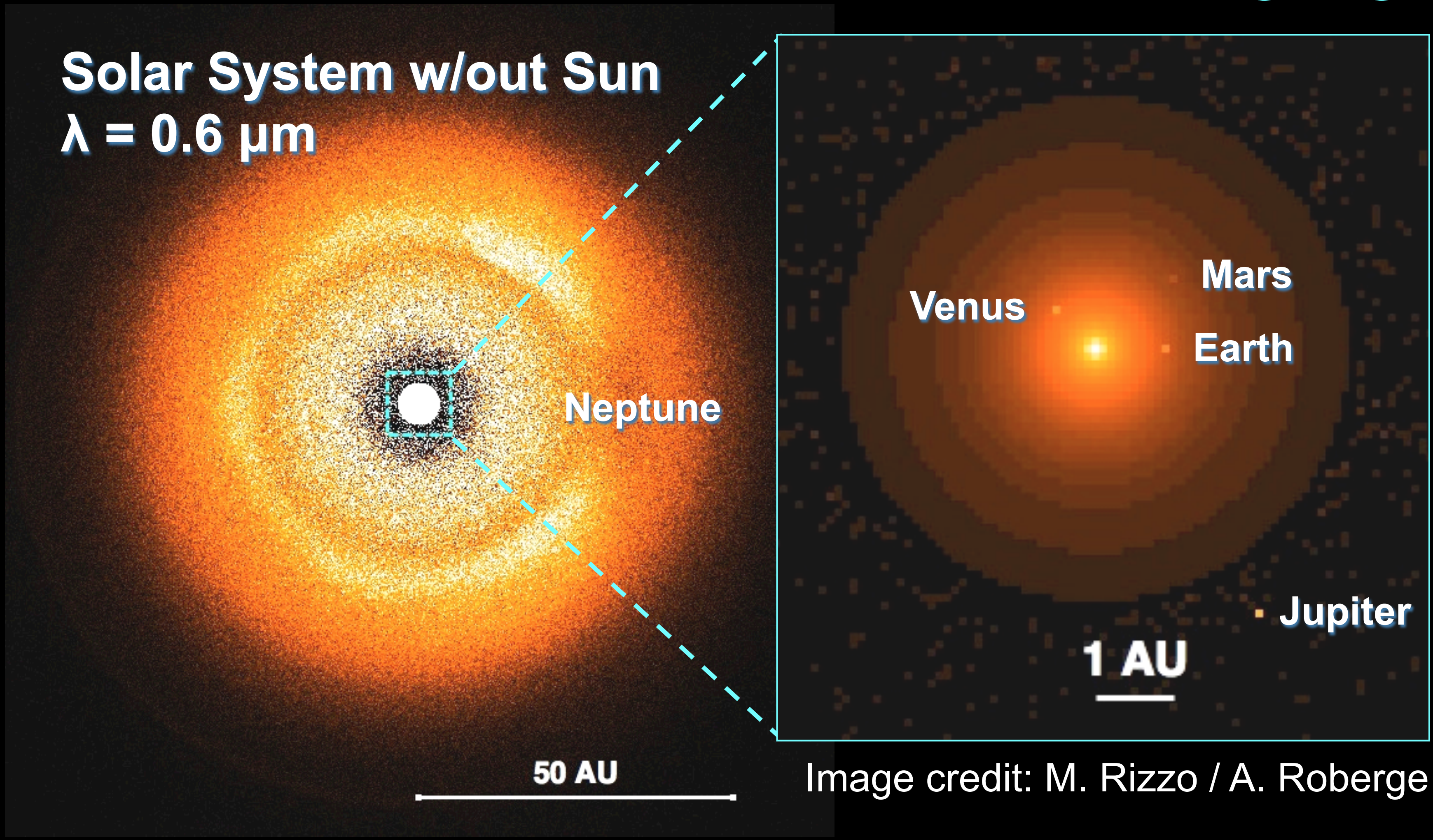


Image credit: M. Rizzo / A. Roberge

- 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)

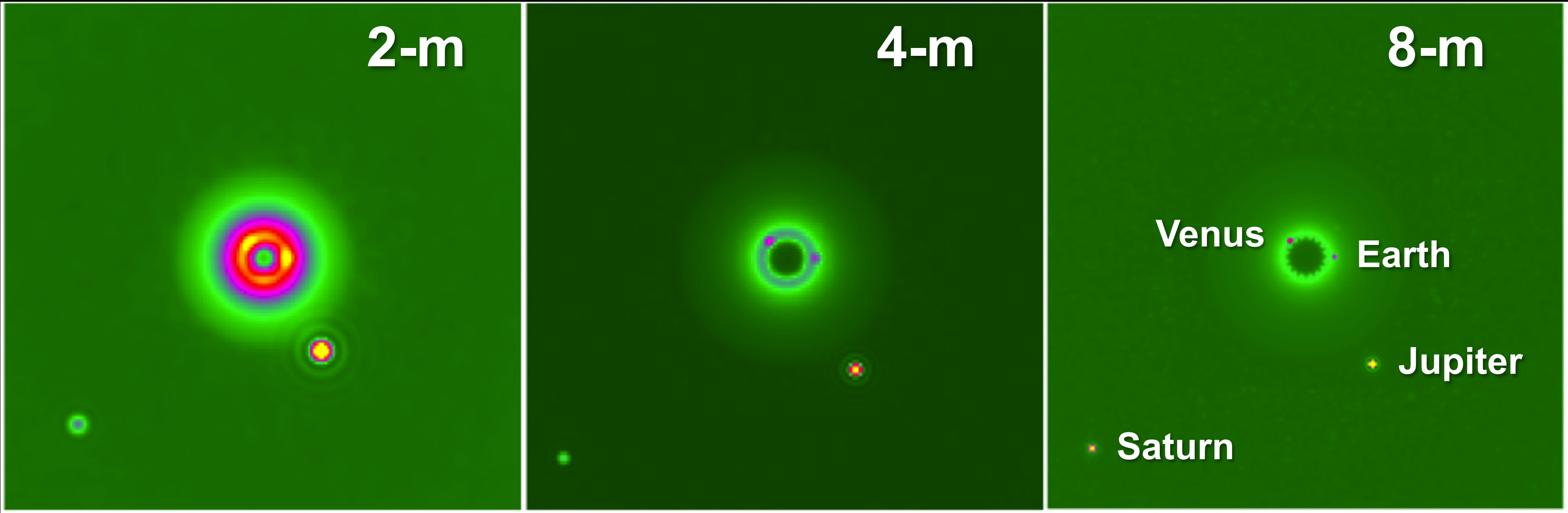
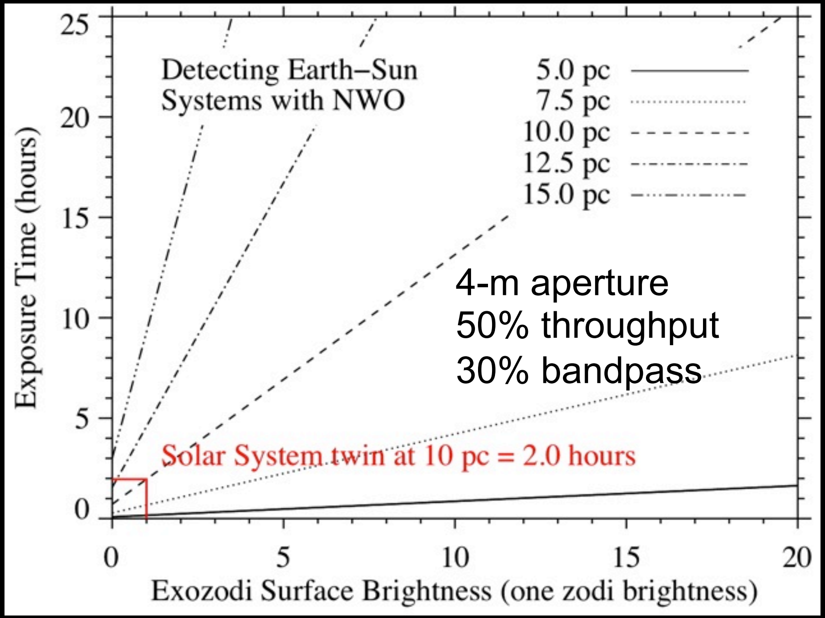


Image credit: T. Glassman

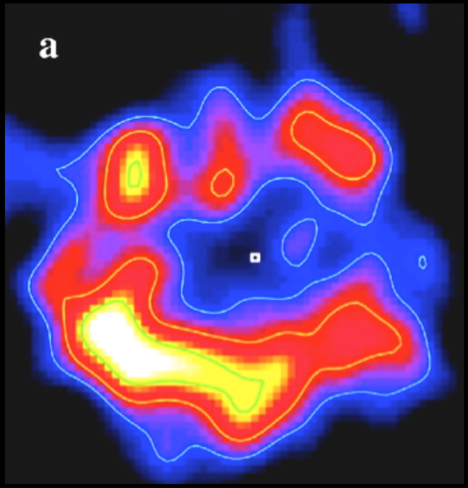
Impacts on Exoplanet Imaging

1. Background flux linearly increases imaging & spectroscopy exposure times



A. Roberge

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



Clumps

ε Eridani @ 850 μm

Greaves et al. (2005)

Report on Dust Sensitivities

NASA ExoPAG Study Analysis Group #1: Debris Disks & Exozodiacal Dust

Sensitivity of Current & Upcoming Facilities to Exozodiacal Dust

Aki Roberge (NASA GSFC), Christine Chen (STScI), Rafael Millan-Gabet (Caltech),
Karl Stapelfeldt (NASA GSFC), Olivier Absil (Université de Liège),
Geoffrey Bryden (NASA JPL), & the NASA ExoPAG SAG #1 Team

January 4, 2012

This document addresses Task #2 of the ExoPAG Debris Disks & Exozodiacal Dust Study Analysis Group: **Collect reliable information on the expected sensitivity of all current & upcoming facilities to debris dust at different distances from various types of nearby stars.**

1 Introduction

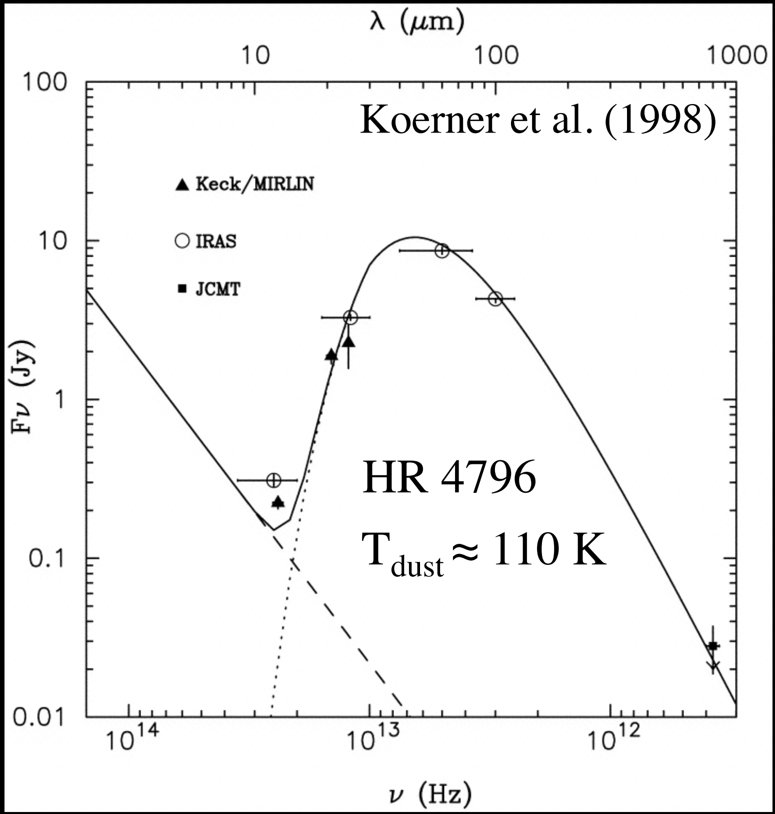
Interplanetary dust interior to the Solar System's asteroid belt is called the zodiacal dust, which comes from comet comae and asteroid collisions, just like the dust in any debris disk. At least 13% of nearby solar-type stars harbor cold, outer debris dust denser than the dust in the Solar System's Kuiper belt (Beichman et al., 2006a). Sensitive new far-IR surveys probing for cold dust down to the Solar System Kuiper belt level find a detection rate of about 25% (e.g. Eiroa et al., in preparation). Unfortunately, we know little about warmer exozodiacal dust in the inner reaches of nearby systems. In both images and spectra, background flux from the local zodiacal dust and the exozodiacal dust will likely dominate the signal of an Earth-analog exoplanet, even if exozodiacal

Debris Disk Parameters

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

- Solar System defines "1 zodi"
  - 1 zodi is $L_{dust}/L_{star} = 10^{-7}$
  - HR4796 : ~ 50,000 zodis

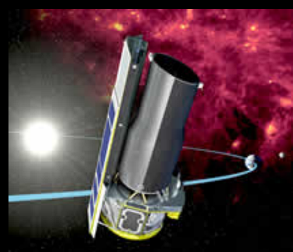
HR4796
HST / NICMOS
Schneider et al. (2009)



Unresolved Thermal Emission

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

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



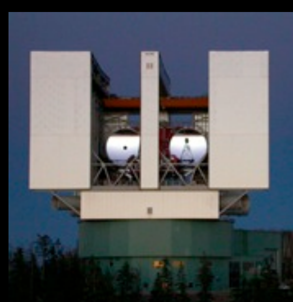


Table 1: Detection of dust thermal emission: data for various telescope facilities

Telescope / Instrument	Operation Dates	$\lambda_{\rm obs.}$ (μm)	$T_{\rm peak}$ [a] (K)	Resol. [b] ($''$)	Uncertainty [c] (1σ)	$\sigma_{F_{\rm dust}/F_\star}$ [d]	Ref.
KIN	2005 –	8.5	432	… [e]	0.3% leak error [f]	0.003	1
Spitzer/IRS	2003 – 09	10	367	2.4	1.5% of star flux	0.015	2
LBTI	2012 –	10	367	… [e]	0.01% leak error [f]	0.0001	3
WISE/W4	2009 – 11	22.1	166	12	3% of star flux [g]	0.03	4
JWST/MIRI	2018 – 23	25.5	144	0.9	2% of star flux	0.02	5
Spitzer/MIPS	2003 – 09	70	52	18.0	15% of star flux	0.15	6
Herschel/PACS	2009 – 13	70	52	5.2	1.61 mJy	0.04 [h]	7
	2009 – 13	100	37	7.7	1.90 mJy	0.1 [h]	7
	2009 – 13	160	23	12.0	3.61 mJy	0.4 [h]	7
ALMA	2012 –	1250	3	0.02	0.1 mJy	0.7 [h]	8

[a] Temperature for which the dust blackbody emission peaks at the observation frequency. Instrument is most sensitive to dust near this temperature.

[b] FWHM of the instrument point-spread function at the observation wavelength.

[c] Photometric uncertainty at the observation wavelength.

[d] Photometric uncertainty relative to the stellar flux at the observation wavelength.

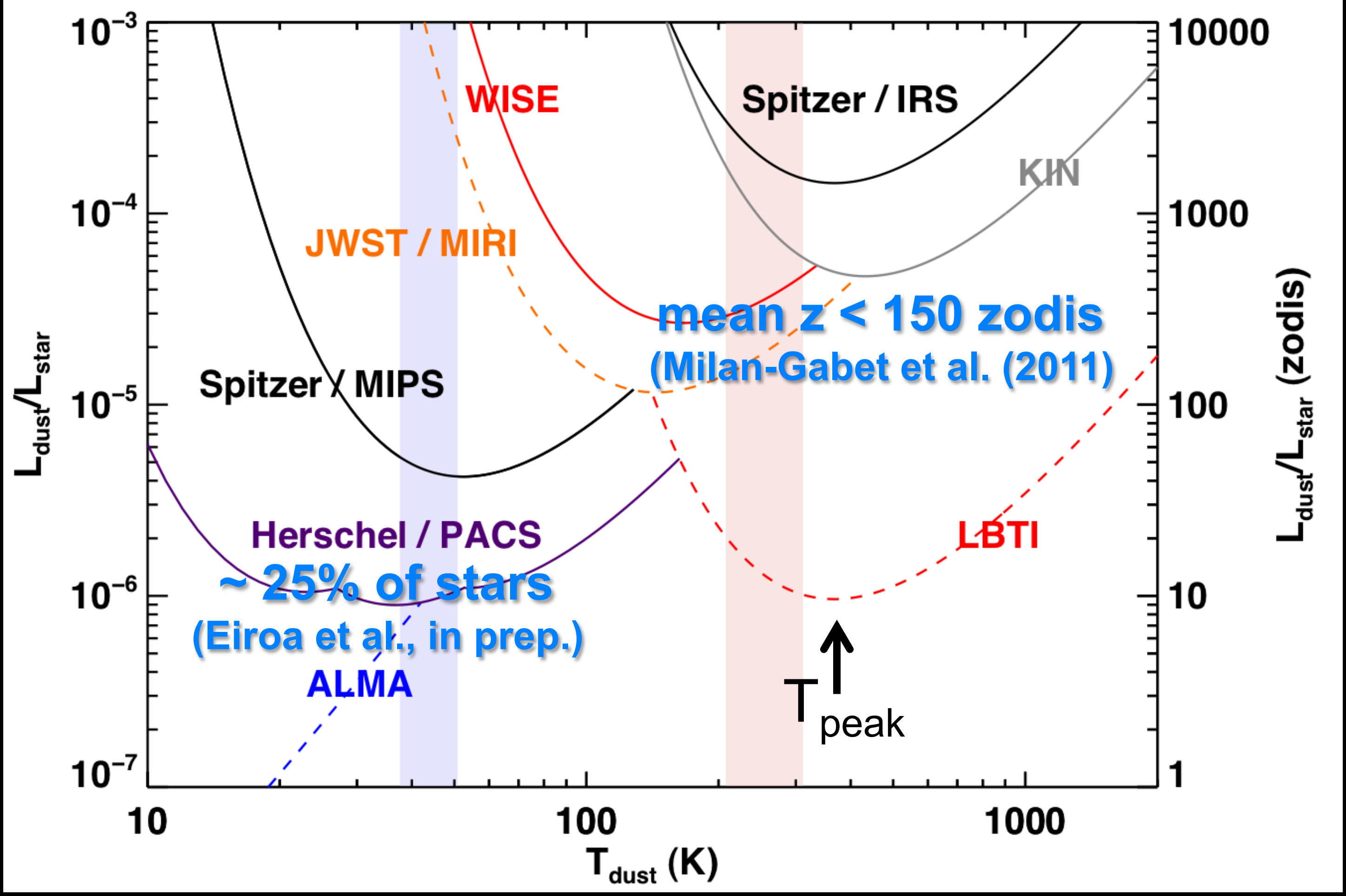
[e] Not applicable for dust clumps. Spatial resolution in radial direction only. [f] Null leakage error.

[g] Preliminary value, applicable only for best cases (D. Padgett, personal communication).

[h] Calculated assuming the photometric uncertainty in the previous column and $F_\star$ at the observation wavelength for a Sun-like star at 10 pc.

References: [1] Millan-Gabet et al. (2011); [2] Beichman et al. (2006b); [3] Hinz et al. (2008); [4] User's Guide to the WISE Preliminary Data Release; [5] Estimated final absolute photometric accuracy (C. Chen, personal communication); [6] Bryden et al. (2006); [7] Sensitivity of PACS scan map with on-source integration time ≈ 360 sec, calculated with HSPOT v6.0.1; [8] Expected full array sensitivity in Band 6 with integration time of 60 sec, ALMA Early Science Primer, v2.2 (May 2011).

Sensitivity Curves



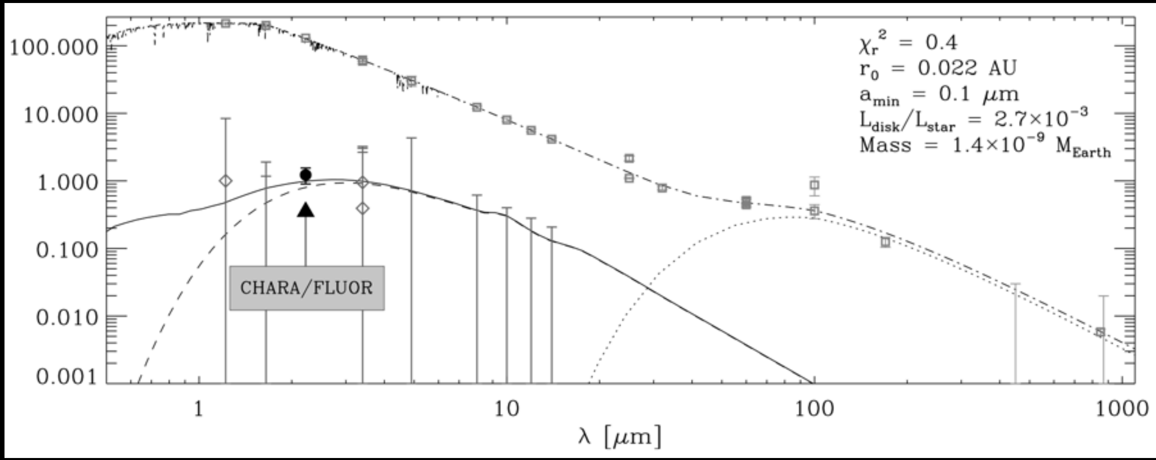
Kuiper belt
30 – 55 AU

Habitable zone
0.8 – 1.8 AU
(Kasting et al. 2009)

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

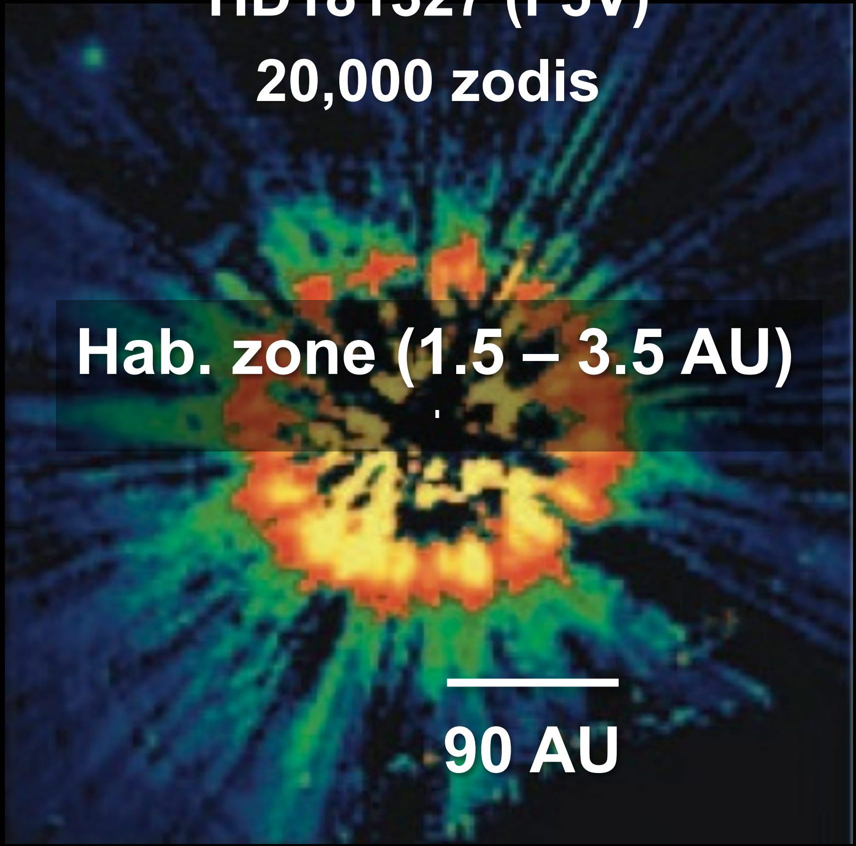
Tau Cet (di Folco et al. 2007)



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

HST / NICMOS image



Schneider et al. (2006)

New Techniques & Coronagraphs

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

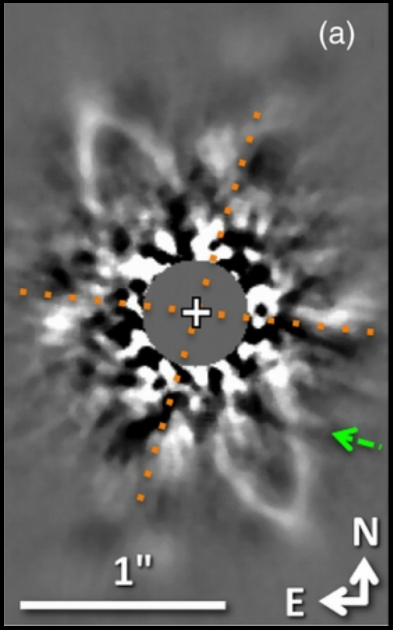
Table 2: High-contrast imaging of dust scattered light: instrument performance

Facility / Instrument	Operation Dates	Contrast [a] at 1″	Faintest Disk Imaged ID	($L_{dust}/L_{\star}$)	(zodis)	Refs.
HST/STIS	1997 – 2004, 2009 –	3×10^{-3}	HD202628	1×10^{-4}	1000	1, 2
HST/NICMOS	1997 – 1999, 2002 – 2008	10^{-5}	HD181327	2×10^{-3}	20000	3, 4
HST/ACS	2002 – 2007	10^{-5}	Fomalhaut	8×10^{-5}	800	5, 6
Subaru/HiCIAO	2010 –	$10^{-4.8}$ [b]	HR4796	5×10^{-3}	50000	7, 8
Gemini S/GPI	2012 –	$\sim 10^{-6 \text{ to } -7}$ [b]	...	...	...	9
JWST/NIRCam	2018 – 23	$\sim 10^{-5}$ [b]	...	...	...	10

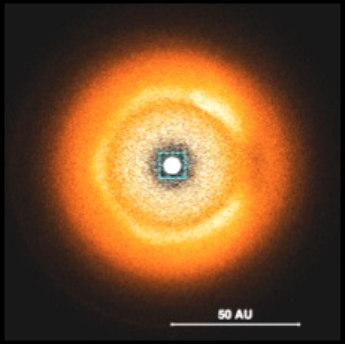
[a] Relative to peak of unobscured PSF, with reference PSF subtracted.
[b] Assuming a point-source. Will be worse for extended sources like disks.

References: [1] STIS Instrument Handbook, v10.0; [2] Krist et al., in prep.; [3] Schneider & Hines (2007); [4] Schneider et al. (2006); [5] ACS Instrument Handbook, v10.0; [6] Kalas et al. (2005); [7] Suzuki et al. (2010); [8] Thalmann et al. (2011); [9] GPI web page; [10] Krist et al. (2007).

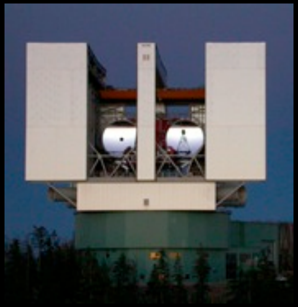
HR4796 w/ HiCIAO (Thalmann et al. 2011)



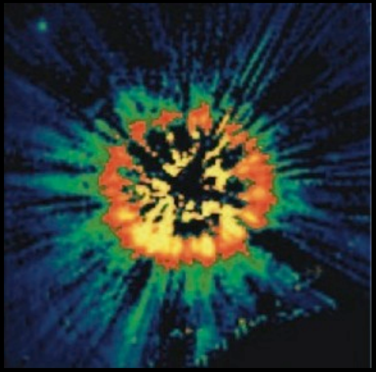
Summary



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



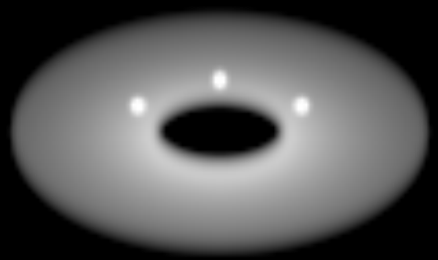
- Only facility sensitive enough to approach Solar System zodiacal dust level in habitable zones of nearby stars = LBTI



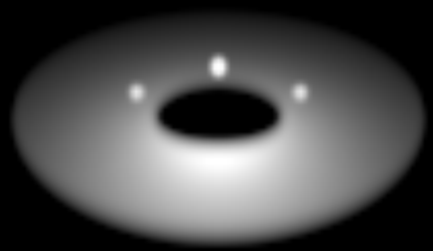
- High-contrast scattered light imaging of disks
  - Far less sensitive than unresolved thermal emission
  - Provides unique information on dust structures at large radii

Distinguishing Planets from Exozodi Clumps Using Modulation of Illumination Phase

Isotropic dust scattering



Somewhat forward dust scattering



Assumed 1 zodi dust distributed in 0.7 − 2.5 AU region, planet at 1 AU, 8m telescope, target at 7 pc, inclination = 30° from edge-on. Simulation by Karl Stapelfeldt.