Lasts Gasps from the Keck Interferometer: new exozodi results

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Exo-Zodi Dust

- The “inner” (few AU) component of a stellar system dust, generated by collisions between larger objects and by comets outgassing.
- x100s brighter than the Earth in IR and visible.

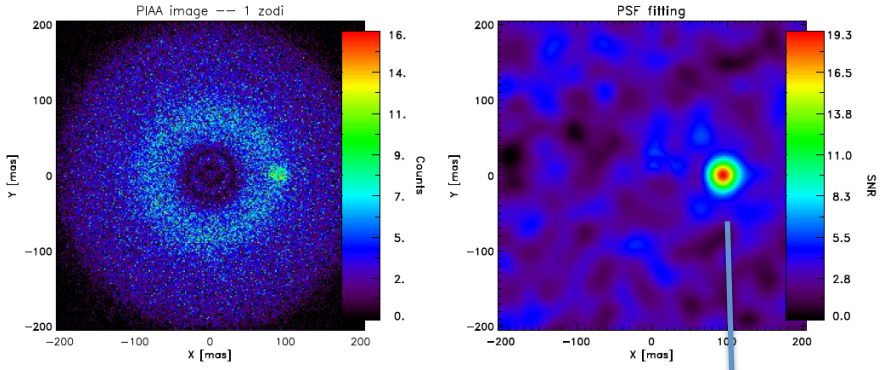
- Yet, current Solar System levels (both zodi and Kuiper belt) would be undetectable around other stars.

- We know very little about: the origin of the dust, or frequency/levels/structure of zodi around other stars.

Zodiacal light seen from Paranal (credit: ESO).

Why is NASA interested in exozodi?

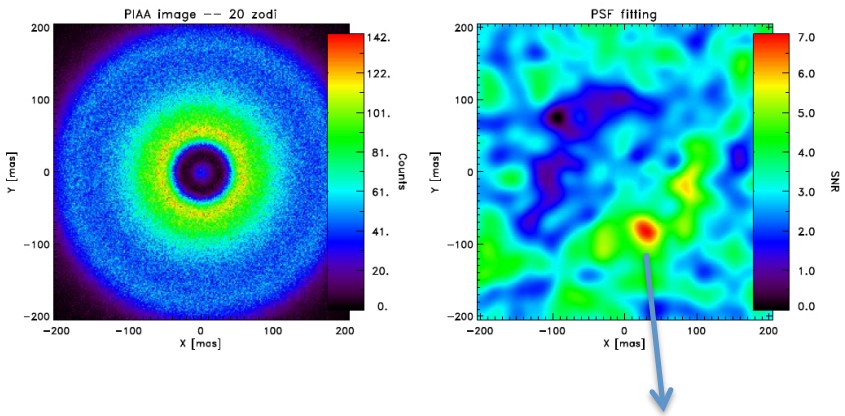
1 zodi



Defrere et al. 2012

Earth

20 zodi



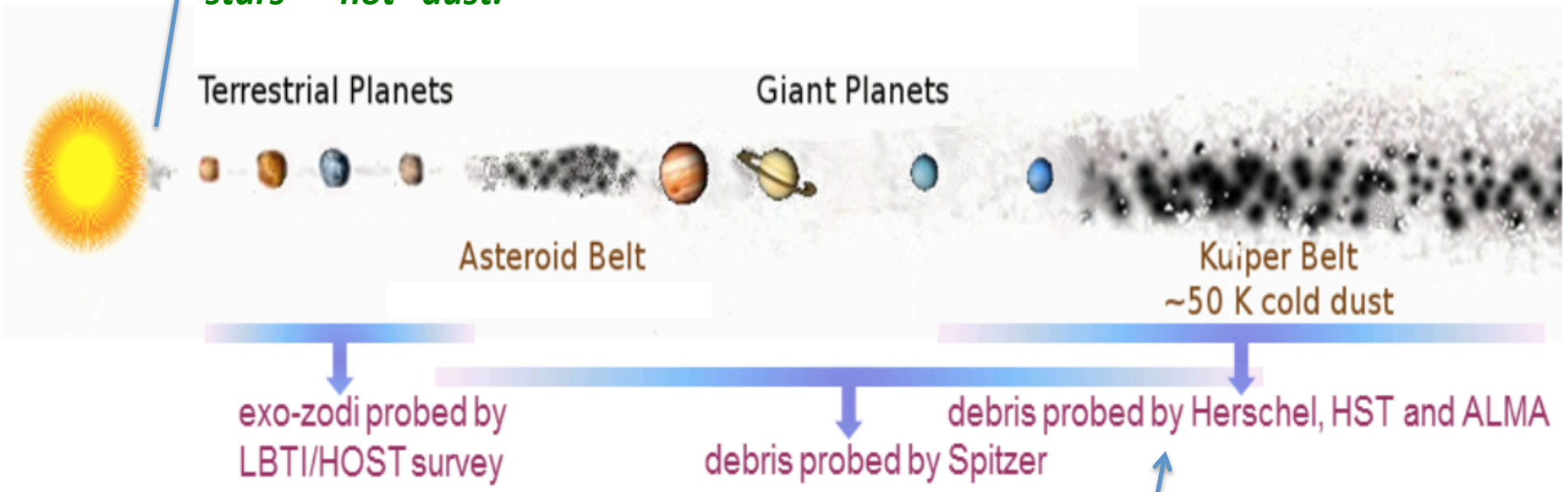
Earth-trailing clump!

KI - 1996 - 2012

LBTI - About to start science operations

Some context and definitions: “Hot, warm, cold”

There are also intriguing detections of NIR excess for many main sequence stars – “hot” dust.



KIN sensitive to “warm” dust located ~0.1-4 AU (at 10pc) producing MIR flux excess.

“Cold” dust producing FIR excess (or resolved in images).

Methodology

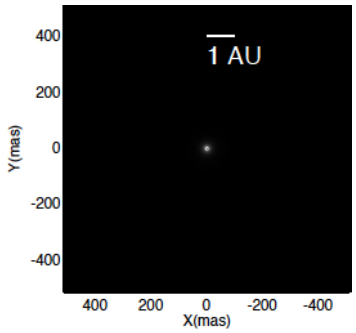
- **MIR 8-13 µm (R~25) long baseline nulling interferometry:**

STAR

EXOZODI CLOUD (much weaker)

DESTRUCTIVE INTERFERENCE

PARTIALLY TRANSMITTED EXOZODI CLOUD



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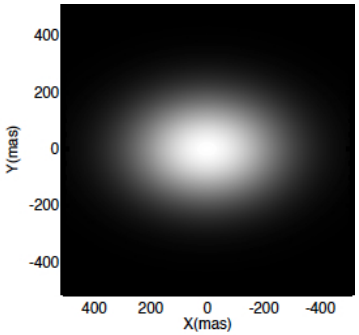

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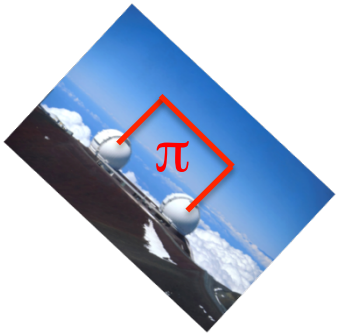

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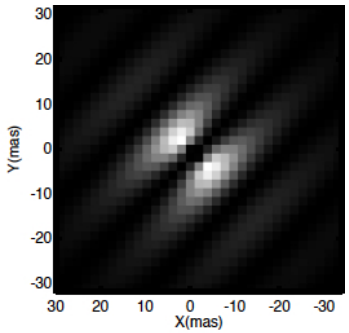
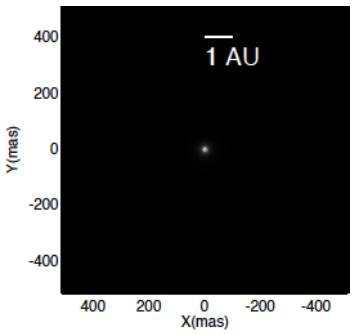


$$\frac{\Sigma}{\Sigma} = \text{“NULL DEPTH”}$$



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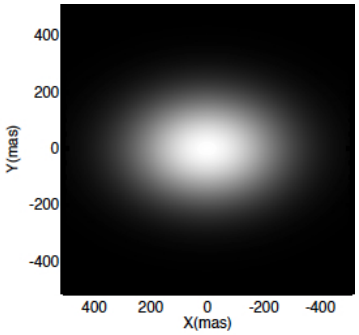

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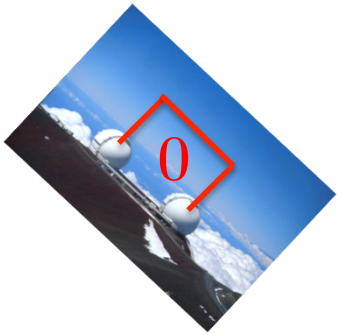

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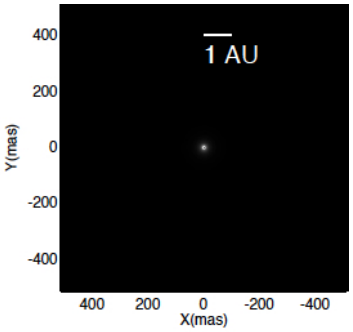

CONSTRUCTIVE INTERFERENCE

~ STAR

KIN Paper I

THE ASTROPHYSICAL JOURNAL, 734:67 (16pp), 2011 June 10 doi:10.1088/0004-637X/734/1/67
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EXOZODIACAL DUST LEVELS FOR NEARBY MAIN-SEQUENCE STARS: A SURVEY WITH THE KECK INTERFEROMETER NULLER

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- 25 MS stars – most selected to not be known to have circumstellar dust
  - 1 clear detection:
    - η Crv - (F2V) 1250 ± 260 zodi
  - 2 marginal detections:
    - γ Oph (A0V) 200 ± 80 zodi
    - α Aql (A7V) 600 ± 200 zodi
  - 22 (FGK) non-detections

- Based on the 23 stars not previously know to have dust:
  - Mean level for the class < 150 zodi (3σ)

Now, Paper II

THE ASTROPHYSICAL JOURNAL, 797:119 (28pp), 2014 December 20 doi:10.1088/0004-637X/797/2/119
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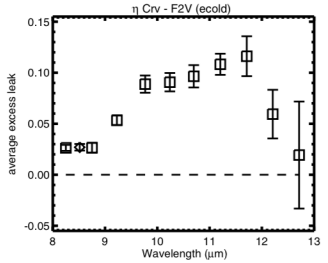
CONSTRAINING THE EXOZODIACAL LUMINOSITY FUNCTION OF MAIN-SEQUENCE STARS: COMPLETE RESULTS FROM THE KECK NULLER MID-INFRARED SURVEYS

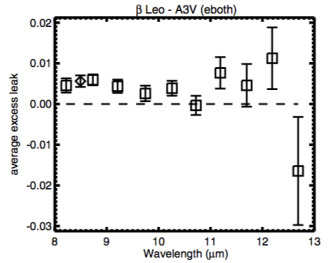
B. MENNESSON[1], R. MILLAN-GABET[2], E. SERABYN[1], M. M. COLAVITA[1], O. ABSIL[3], G. BRYDEN[1], M. WYATT[4], W. DANCHI[5], D. DEFRÈRE[6], O. DORÉ[1], P. HINZ[6], M. KUCHNER[5], S. RAGLAND[7], N. SCOTT[8], K. STAPELFELDT[5], W. TRAUB[1], AND J. WOILLEZ[9]

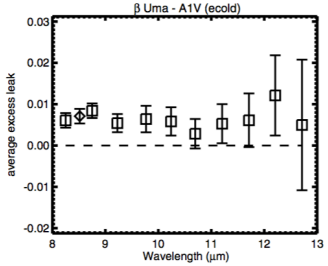
- **Added new classes of stars:**
  1. **known to have outer cold dust belts (16 stars).**
  2. **known to have NIR excess, presumably from hot dust very close to the star (11 stars).**
  - ***The sample in this paper includes ALL exozodi targets ever observed by the KIN.***
- **Complete re-calibration (turned out not to make much difference …).**
- **NEW: Analyzed the complete spectral coverage (R~25) 8-13 µm.**

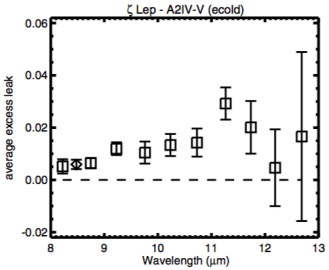
Basic results

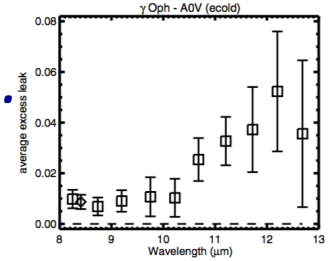
	11	13	9	7	
	A	F	G	K/M	Total
Stars with Cold or Hot Excess	4/11	1/4	0/3	0/2	5/20
Stars with Cold Excess	4/7	1/4	0/3	0/2	5/16
Stars with Cold Excess only	3/4	1/2	0/2	0/1	4/9
Stars with Hot Excess	1/7	0/2	0/1	0/1	1/11
Stars with Hot Excess only	0/4	none	none	none	0/4
Stars with No Known Excess	none	0/9	0/6	0/5	0/20
Overall Sample	4/11	1/13	0/9	0/7	5/40





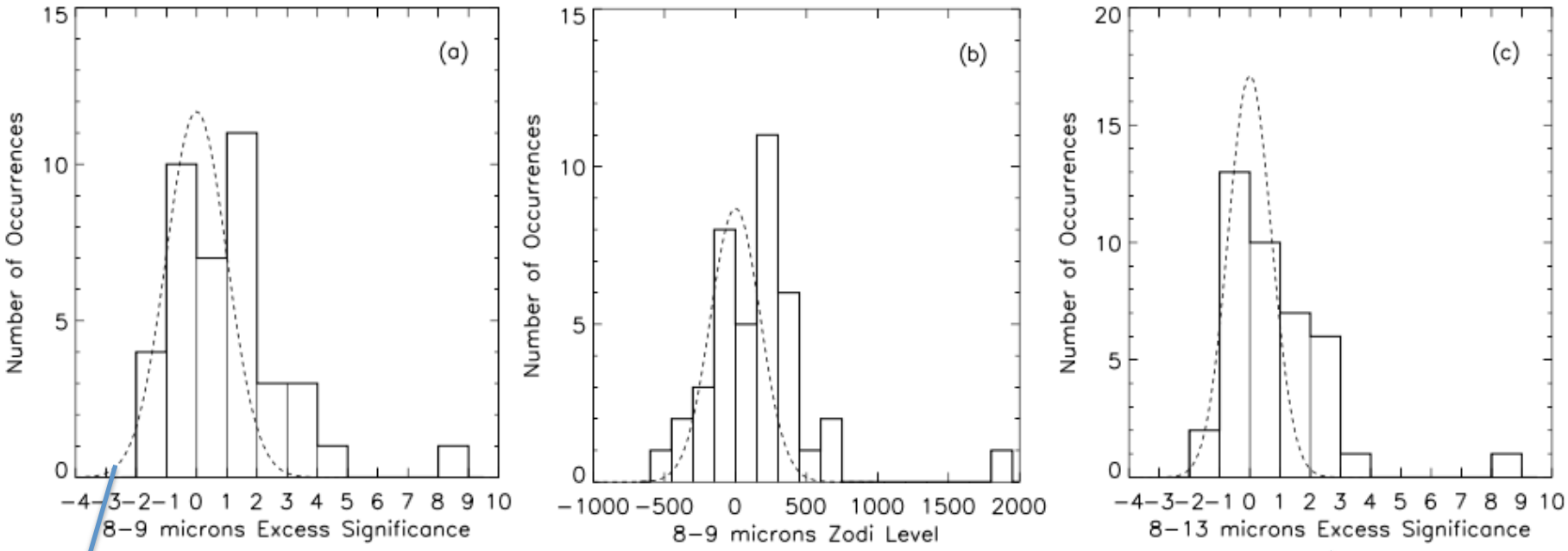






- 5 stars show a resolved 8-9 μm excess > 3σ:
  - η Crv, β Leo, β UMa, ζ Lep and γ Oph.
- All excess stars have types earlier than F2. *This is not new.*
- All excess stars also have FIR excess (cold dust). *This would be new…*
- None of the NIR-only excess stars (hot-dust only) have MIR excess.

But wait a minute …



Estimate of the instrument noise

No matter how you look at it, there seem to be many more MIR (~10-15) excess stars at the 1-3σ level, lurking just below the KIN detection limit …

Detailed (more sensitive) Statistical Analysis MLE & Blind Deconvolution

	Median Zodi Levels			
Distribution Type	Group 1 FGK Stars with No Known Excess	Group 2 Stars with Cold or Hot Excess	Group 2a Stars with Cold Excess	Group 2b FGK Stars with Cold Excess
Uniform	7 [0–56]	177 [137–234]	190 [145–259]	207 [110–375]
Truncated Gaussian	20	190	227	160
Lognormal	12 [0–60]	190 [142–242]	230 [178–280]	160 [60–296]
From blind deconvolution	18	240	250	220

- Under a variety of reasonable assumptions (shape of underlying zodi luminosity function) stars with cold dust have statistically higher exo-zodi levels.
- This is true even after removing the A stars from the sample!
- The most likely distributions also show that the exo-zodi level for stars with cold dust seems to cluster at the few 100 zodis level, just below the KIN detection threshold.

- Median exo-zodi brightness of solar type stars with no FIR excess is < 60 zodi with a 95% confidence (for a log normal distribution). These are the tighter limits to date.

Discussion

- **Need observations of a larger sample and better sensitivity, but the warm dust – cold dust correlation suggest an origin for the HZ dust in the outer regions of the system.**
- **Furthermore, the clustering of MIR excesses around a similar value, support the theory that the HZ dust arises from balance of P-R drag & collisions of dust from parent cold belts (Wyatt 2005, Kennedy 2015).**

- **None of the hot dust-only stars are KIN detections.**
- **Unclear whether or not NIR excesses correlate with the presence of detectable cold dust (Absil 2013, Ertel 2015). Also not sufficiently explored theoretically whether trapping mechanisms can explain the detection of inner hot dust, for systems with undetectable cold dust.**

Conclusions

- **Best limits to date on exo-zodi levels for nearby MS stars.**

- **Established observational cold-warm dust link. Constrains theories for the origin of HZ dust.**
- **Stars with outer cold dust are probably bad targets for exo-Earth imaging mission.**

- **Provided useful lists as input to next instrument with better sensitivity (LBTI):**
  - **List of "clean" targets as prime exo-Earth imaging candidates.**
  - **List of interesting candidate detections to be confirmed and studied in detail (e.g. Fomalhaut, Vega, Altair).**