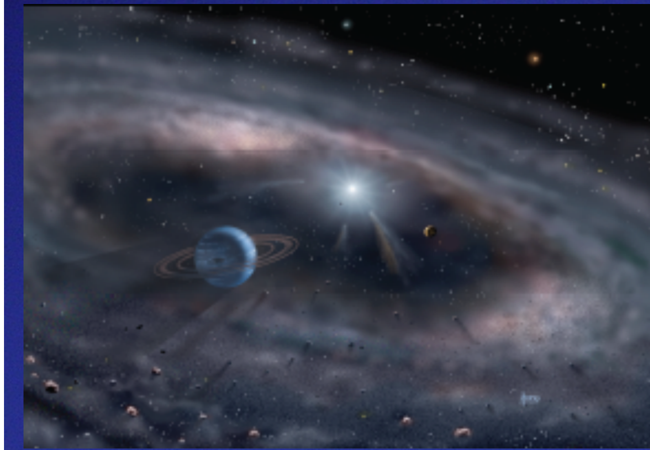
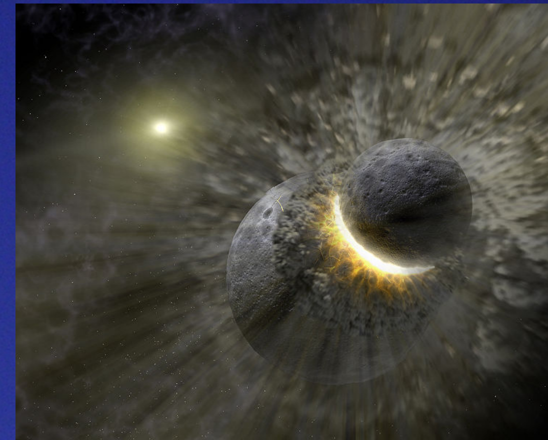




Exozodi dust emission measured with the nulling interferometers (KIN and LBTI)

Rafael Millan-Gabet

Sagan/Michelson Fellows Symposium

Nov 8-9 2012 - Caltech

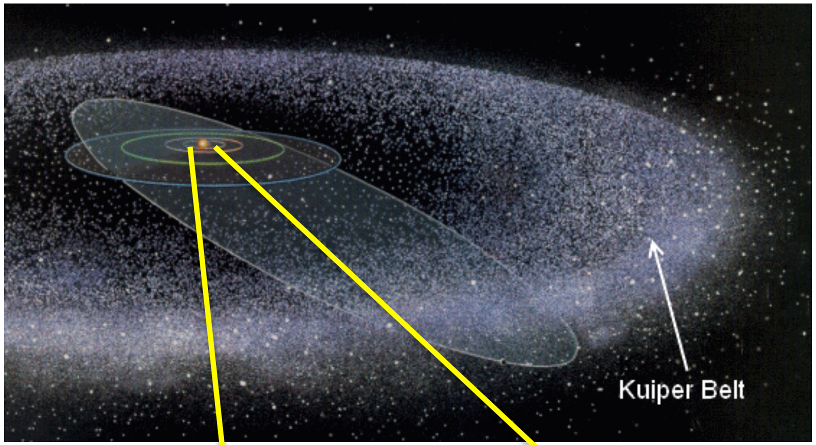
Exozodis

- **Debris disk: dust generated by collisions in asteroid and Kuiper belts and by comet outgassing. The inner component (<5AU) is called zodiacal cloud.**

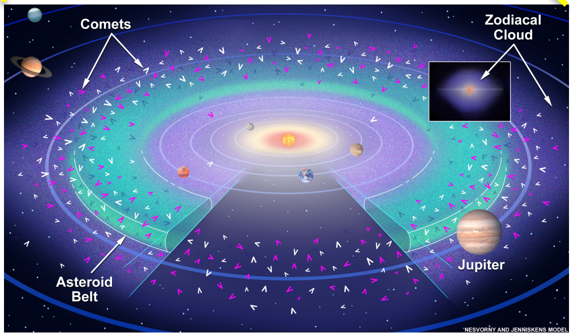
- **Extra-solar analogs are common, but due to observational limitations we know a lot more about outer, colder dust (exo-Kuipers) than about debris dust in the planet formation zone.**

- **Zodiacal dust reflects planetary system formation history and current dynamical state.**
- **But, could be a major hindrance to the direct detection of exo-Earths (noise + confusion).**

Outer Solar System …



Inner Solar System …

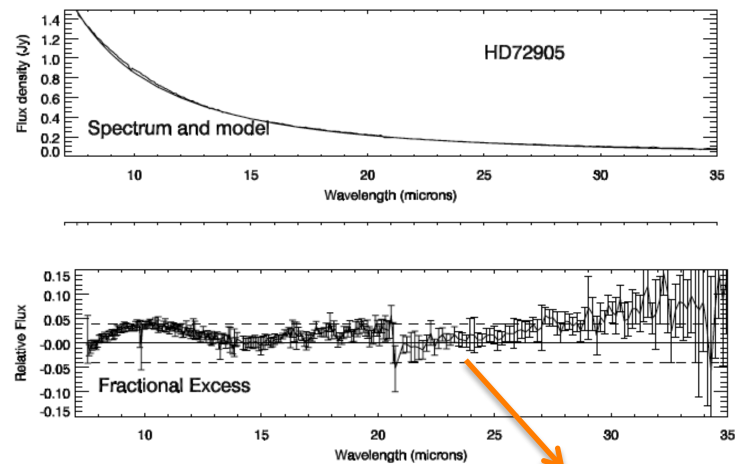


Zodi light seen from Paranal

Exozodis are difficult to detect

- **The dust emission is faint and close to the star.**
- **Unresolved photometry is the most common method.**
- **Even with infinite photometric accuracy, limited to ~1% best case relative photometry by ability to predict the stellar MIR flux (~300 zodi, 1σ).**

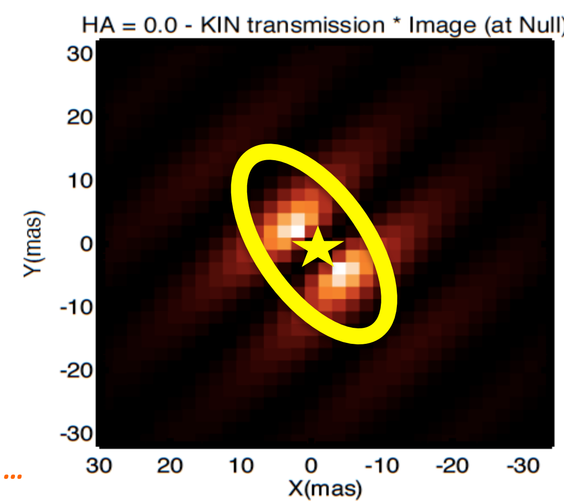
Spitzer/IRS – Beichman et al. 2006



2σ stellar model uncertainty

Interferometry helps

- **Spatially separate the signal from the star and the surrounding disk.**
- **2 main methods:**
  - **NIR high-accuracy visibility (CHARA/FLOUR, VLTI/PIONIER).**
  - **MIR Nulling (MMT/BLINC, KIN, LBTI).**
- **Free of modeling assumptions on the stellar spectrum.**



See refs. by: Ciardi, Absil, Di Folco, Defrere, Smith, Akeson, Liu, Stock, Stark, Millan-Gabet, Mennesson etc …

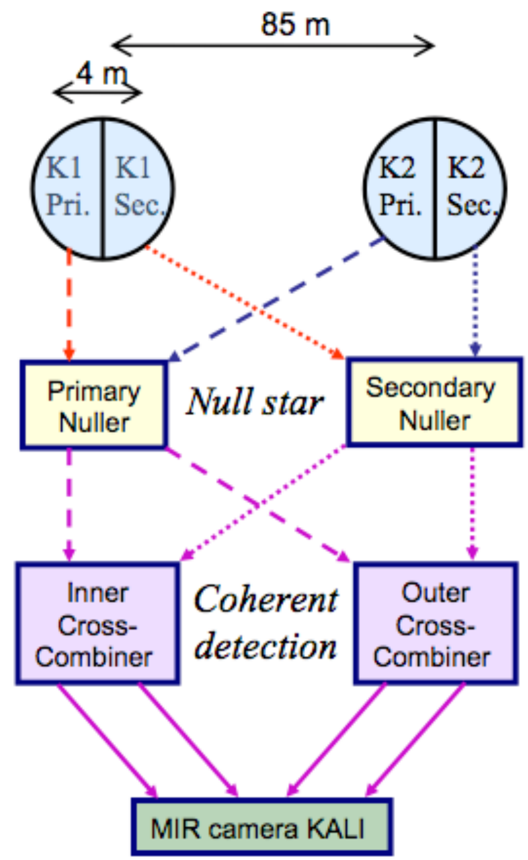
The Keck Interferometer Nuller

- Spectral band: 8 – 13 μm (R~25).
- Sensitivity: 1.5 Jy @ 10 μm
- Resolution (λ/2B) = 10 mas @ 8.5 μm
- FOV: 0.1 AU – 4 AU @ 10 pc ➔ sensitive to inner dust.
- Double-nuller architecture:
  - DC signal ➔ AC signal. Allows accurate visibility measurements in spite of large thermal background.

- σ(Leak) = 0.003 (typical) corresponds to σ(Vis) = 0.006 (0.6%, much better than standard MIR interferometry!
- Translates to σ(zodi) = 160.

Note: the unit "zodi" refers to a scaled zodiacal-twin disk (see discussion of units in Roberge et al 2012).

Instrument details: Colavita 2009. Theory: Serabyn 2012



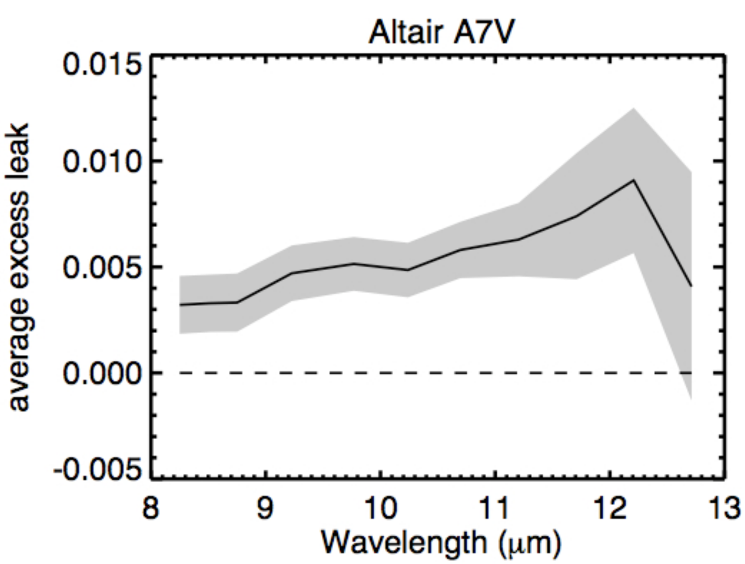
KIN exozodi surveys

- **Three NASA Key Science projects (2008-2009):**
  - **23 mostly FGK stars with no previously known dust (PI: Serabyn 2008-2009)**
  - **19 mostly early type stars with previously known cold dust (PIs: Hinz & Kuchner 2008-2009)**
- **One additional PI program (Mennesson 2010-2011):**
  - **6 mostly early type stars suspected to have very hot/ close-in dust (from the Absil et al. survey at CHARA).**

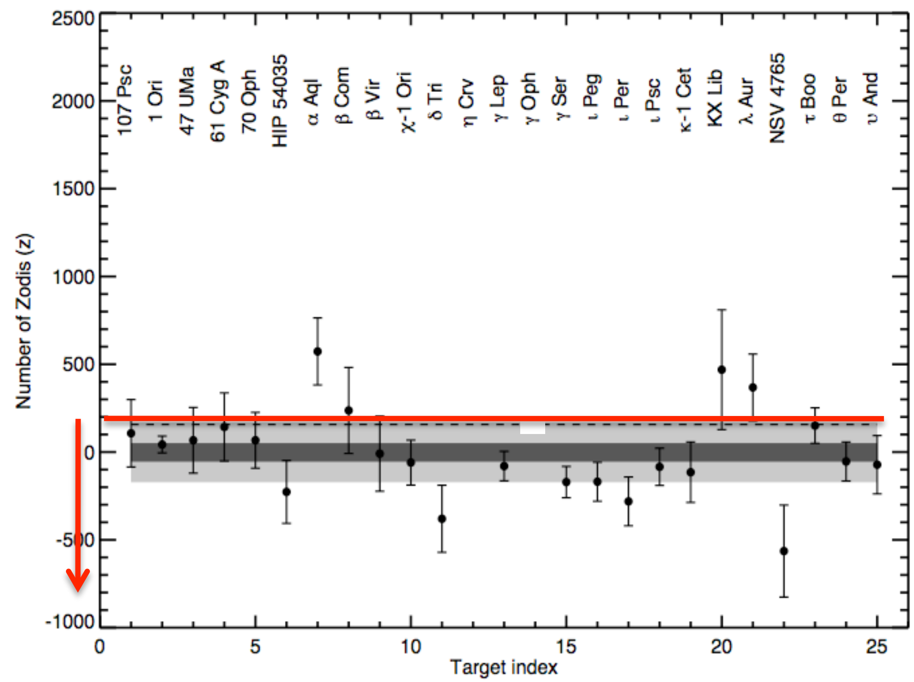
Analysis of stars with a priori no dust

(Millan-Gabet, Serabyn, Mennesson et al. 2011)

- **23 FGK stars.**
- **Only one shows dust at marginal detection level (Altair – but later, NIR excess also detected by CHARA).**
- **Mean 3σ upper limit = 570 zodi.**
- **Population analysis: 3σ upper limit for the class = 150 zodi.**



600 +/- 200 solar zodi



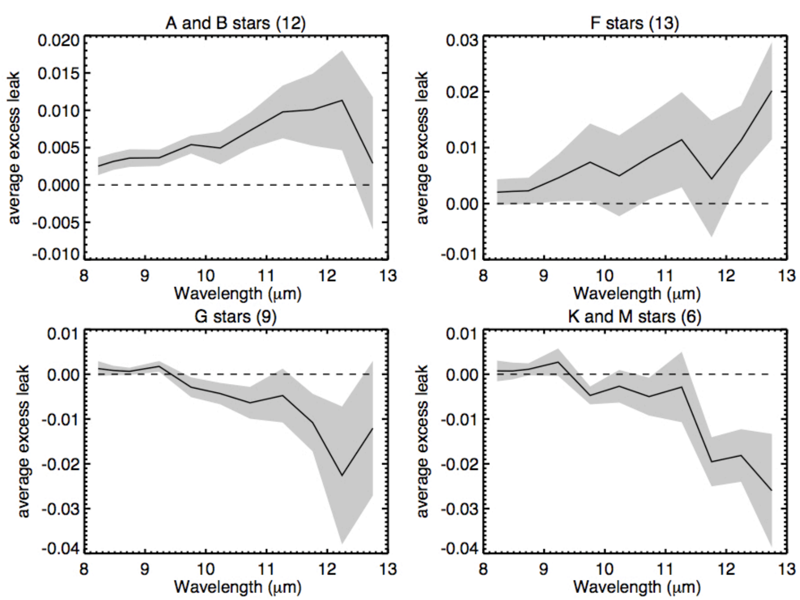
150 zodi 3σ upper limit for the *class*

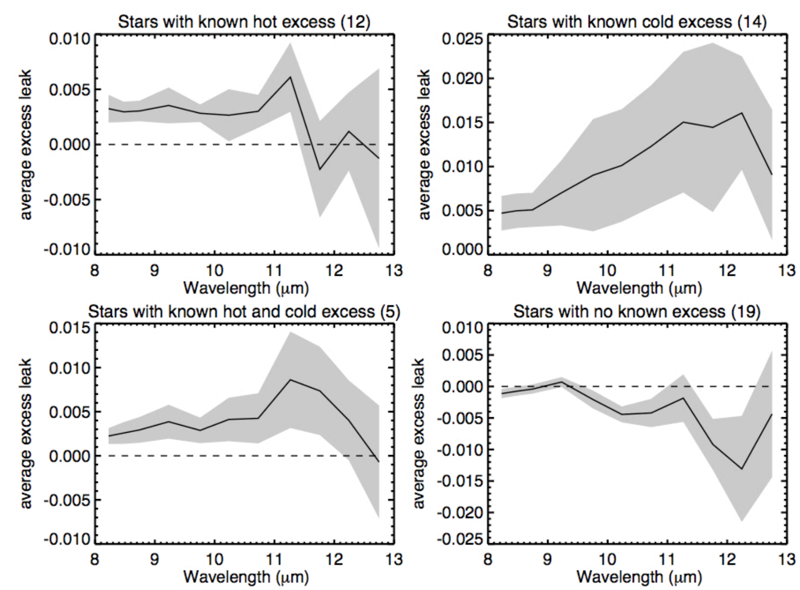
Analysis of stars with previously known dust

(hot and/or cold, *Mennesson, Millan-Gabet et al. work in progress*)

- **14 single stars with previously known cold (far IR) excess:**
  - **4 detected by KIN: Fomalhaut, ζ Lep, γ Oph and η CrV.**

    (+ 5 more marginal detections)
- **12 single stars with known hot (NIR) excess (CHARA/FLUOR):**
  - **stars with only hot excess, do not tend to show KIN excess - 3 of 8 and with only very weak excess.**
- **Complete sample: 40 single stars, look for trends with:**
  - **Spectral type: more KIN detections for A stars. disk difference or age effect?**
  - **Presence of cold/hot dust: hot dust appears to have physically different origin.**
- **Produce "top-10" list of cleanest stars (<100 zodi), as input to the next survey.**



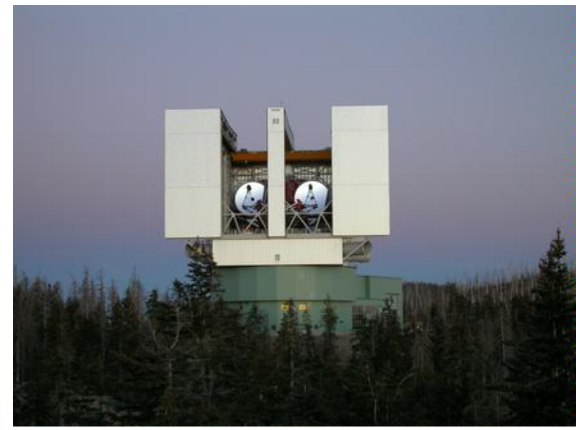


Conclusions so far

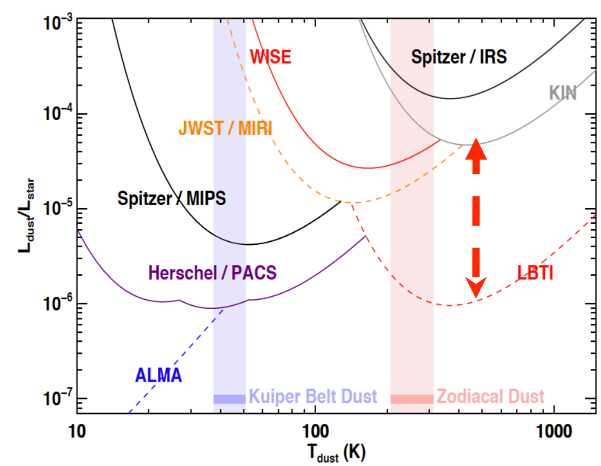
- **We are learning very interesting things with NIR and MIR interferometry.**
- **The sensitivity of current exozodi finders, 300-1000 zodi 3σ, is not adequate to assess whether exozodis in the 10–100 zodi range (problematic for direct exo-Earth detection & characterization missions from space) are common or not.**
- **Need dedicated effort with x10 or more improvement.**

The Large Binocular Telescope Interferometer (LBTI)

- **PI: Phil Hinz, U. Arizona.**
- **NASA-funded instrument for the LBT:**
  - **8-13 μm / 3-5 μm.**
  - **Nulling, Fizeau and aperture masking interferometry.**
- **Currently in commissioning.**
- **Expected ultimate nulling performance: noise equivalent 10 zodi (3σ).**



Roberge et al. ExoPAG report 2012

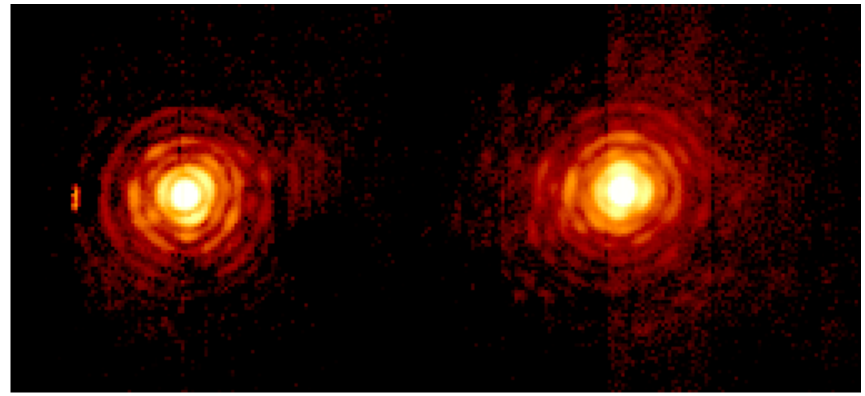


Exozodi key science survey:

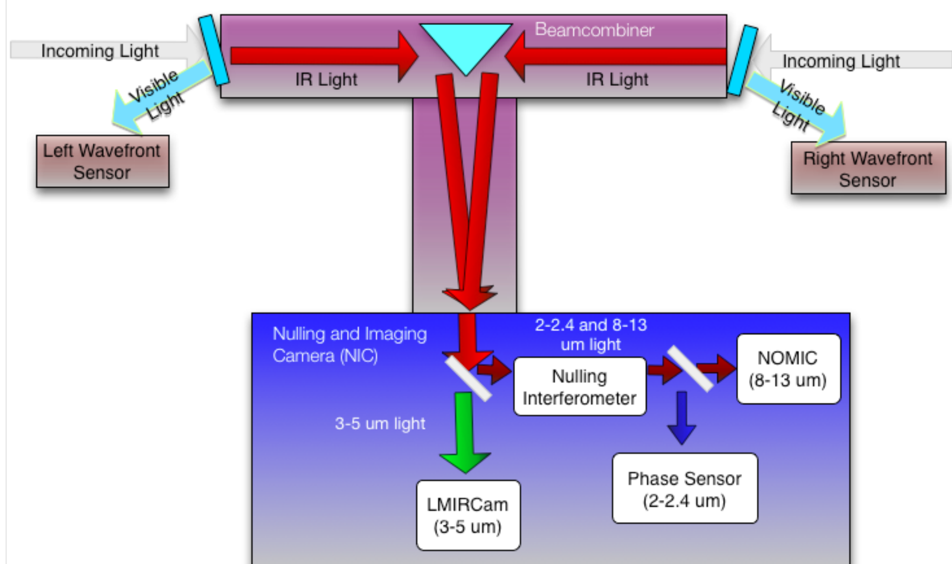
- **50-100 nearby Sun-like stars.**
- **Competitively selected science team.**
- **Reconnaissance of specific exo-Earth detection targets + statistical constraints on the exozodi "luminosity function".**

LBTI main features

- **Sensitivity: two 8.4 m telescopes.**
- **Resolution: Bmax = 22.7 m.**
- **Leverages secondary deformable mirror to achieve diffraction limited wavefronts.**
- **Relatively simple beam train + cooled optics beam combiner, allows high sensitivity in the MIR.**

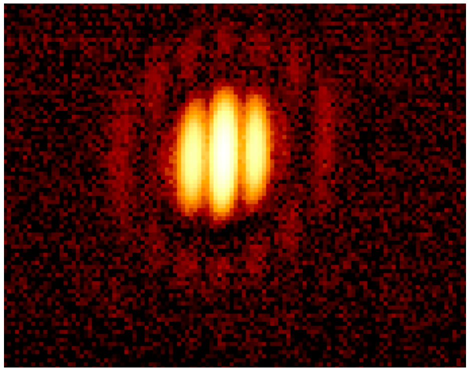


LBTI Block Diagram



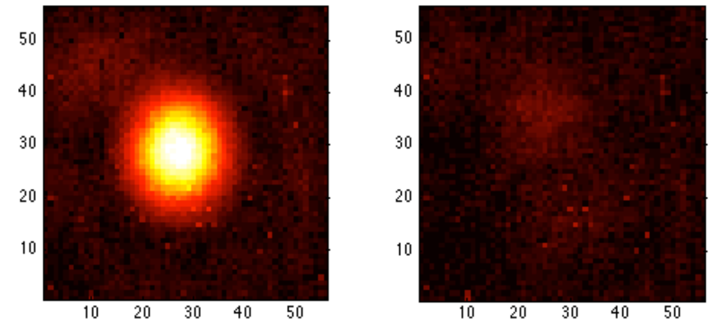
Status

10 µm Fizeau fringes.

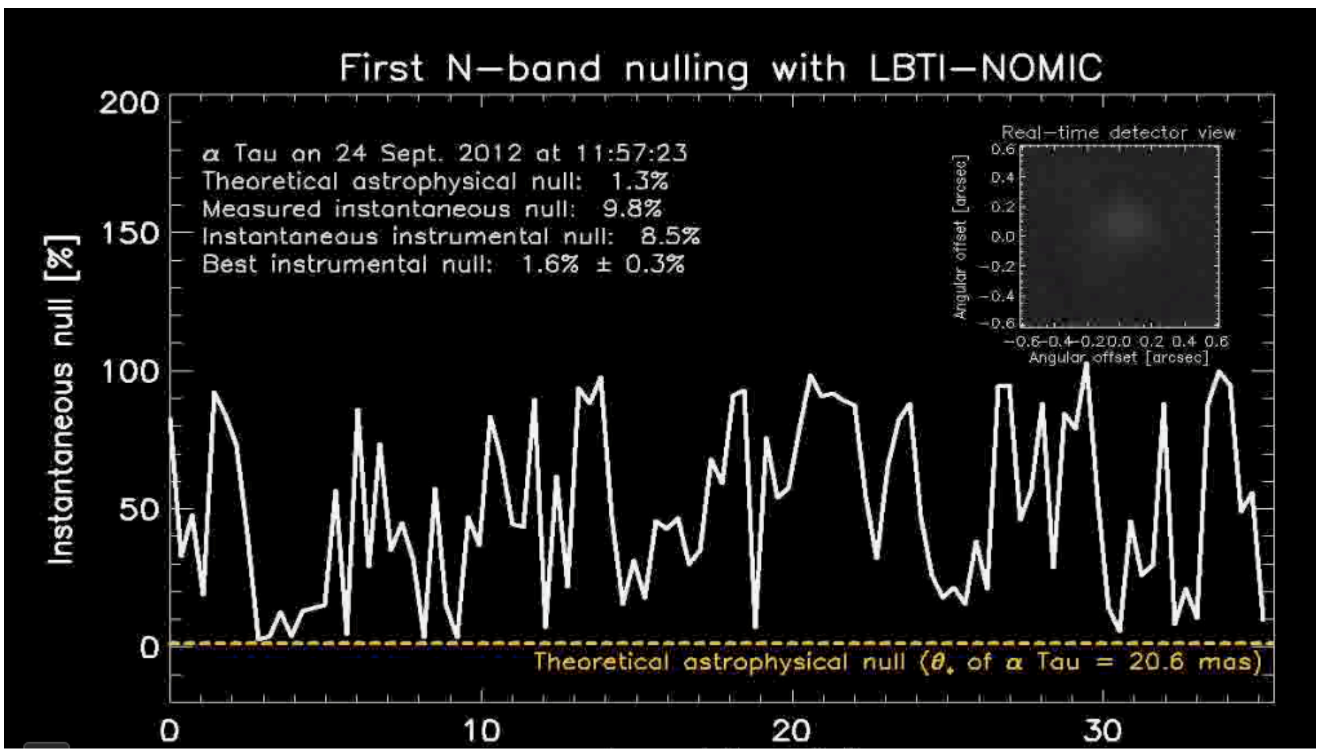


Best 6/100
Constructive Images

Best 6/100
Destructive Images



Open-loop (seeing limited) nulling (Sep 2012).



backup

Discussion: Comparison with Spitzer/IRS

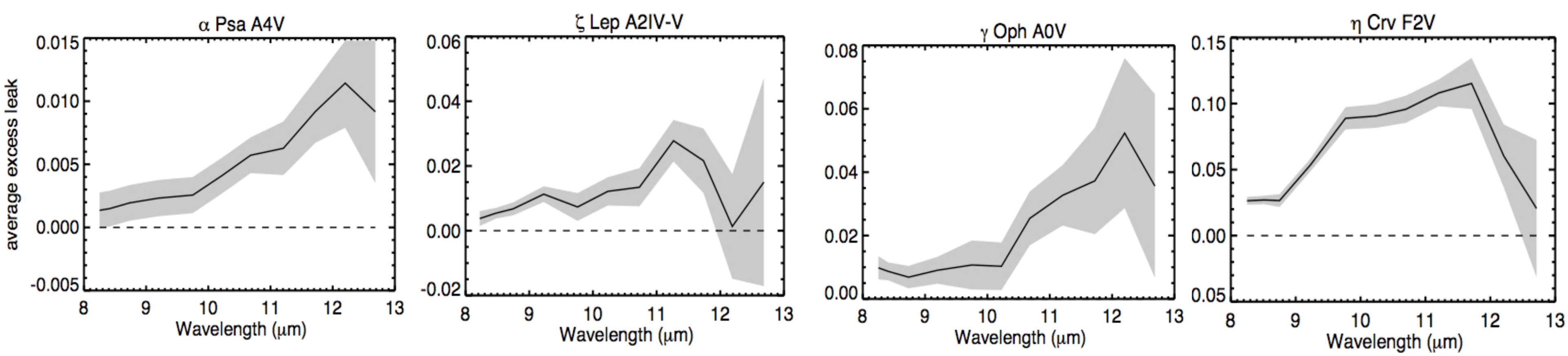
- **Different modelling aproaches, can the results in terms of nzodis be compared? ➔ put Spitzer/IRS & KIN results on equal footing.**
- **Spitzer/IRS measures: Fdust/Fstar.**
- **KIN measures L ~ f * Fdust/Fstar; f is the fraction of light allowed to pass through the instantaneous fringe pattern at null.**
- **f tends to be ~ 0.4.**
- **One can derive from the KIN Leak an equivalent Spitzer/IRS measurement:**
  - **Fdust/Fstar = L/f ~ 2.5 * L**
  - **Error in this quantity: σ(Fdust/Fstar) = f * σ(L) ~ 2.5 * σ(L).**
  - **Typical σ(L) = 0.003 ➔ σ(Fdust/Fstar) = 0.0075.**
  - **Compare with Spitzer/IRS errors (0.01 best case).**
  - **Not a HUGE difference. Expected improvement factor depends on precise errors in each case (range ~ 30% to x2).**
- **Do it exactly for the 8 stars in common between KIN & IRS surveys …**

Name	IRS (Lawler 2009)				KIN			
	Fdust/F*	3σ max Fdust/F*	3σ max Ldust/L* X10^-5	3σ max Nzodis	Fdust/F*	3σ max Fdust/F*	3σ max Ldust/L* X10^-5	3 σmax Nzodis
47 Uma	-0.02+-0.012	0.036	11	**1000**	-0.003+-0.015	0.044	13	**1337**
bet Com	0.014+-0.010	0.044	8	**800**	0.013+-0.009	0.039	11	**1089**
gam Lep	0.001+-0.01	0.031	8	**800**	-0.004+-0.008	0.024	6	**599**
iot Psc	-0.007+-0.014	0.042	10	**1000**	-0.0003+-0.009	0.027	7	**675**
kx Lib	0.002+-0.010	0.032	16	**1600**	0.010+-0.008	0.035	19	**1951**
tau Boo	0.011+-0.014	0.052	10	**1000**	0.008+-0.008	0.032	8	**773**
the Per	0.003+-0.01	0.033	8	**800**	0.006+-0.008	0.032	8	**802**
ups And	-0.003+-0.010	0.030	10	**1000**	-0.004+-0.008	0.023	6	**613**

$$Ldust/L^* = 3.5x10^{-3} \times \left(\frac{T^*}{5600K}\right) \times \frac{Fdust}{F^*}$$

Here 1-zodi is Ldust/L* = 10^-7

- The different modelling approaches do in fact give similar results.
- KIN/Spitzer-IRS limits not hugely different. On a star by star basis, which provides tighter limits just depends on the errors in the basic measurement.
- **Note**: IRS errors do not include a possible systematic in the stellar flux, to which KIN is immune.


α Psa A4V
ζ Lep A2IV-V
γ Oph A0V
η Crv F2V
average excess leak
Wavelength (μm)
Wavelength (μm)
Wavelength (μm)
Wavelength (μm)