ExoZodiacal Emission and Challenge and Opportunity for The Detection of ExoPlanets

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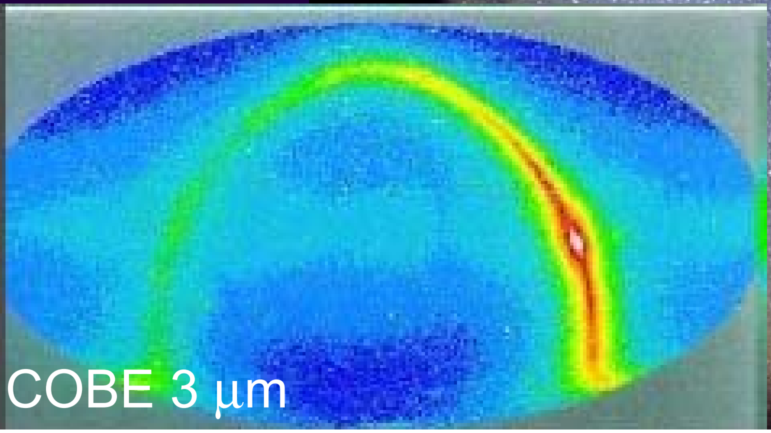
Friday, March 26, 2010

5 AU Workshop

With lots of help from A. Tanner (Georgia State), G. Bryden (JPL), S. Lawler (Wesleyan/UBC), R. Akeson (NExScI), D. Ciardi (NExScI), C. Lisse (JHU), Mark Wyatt (Cambridge)

Debris Disks and Formation of Planets

- Prediction of debris disks by Witteborn et al (Icarus 1982)
  - "Accretion models of planet formation and the early cratering history of the solar system suggest that planet formation is accompanied by a cloud of debris resulting from accumulation and fragmentation. A rough estimate of the infrared luminosities of debris clouds is presented for comparison with measured 10-micron luminosities of young stars. New measurements of 13 F, G, and K main-sequence stars of the Ursa Major Stream, which is thought to be about 270-million years old, place constraints on the amount of debris which could be present near these stars."
- IRAS discoveries followed in 1984 (Aumann, Gillett et al)
- Fractional luminosity, Ld/L*, a convenient metric
  - $1\text{-}10^{-2}$ for protostars & classical T Tauri stars
  - 10^{-3} to 10^{-4} for brightest, youngest (?) disks --- accessible to non-IR
  - $10^{-4}\text{-}10^{-5}$ for typical disks --- IRAS& ISO for early Sp Type→Spitzer
  - $10^{-6}\text{-}10^{-7}$ for weak disks like solar system


COBE 3 μm

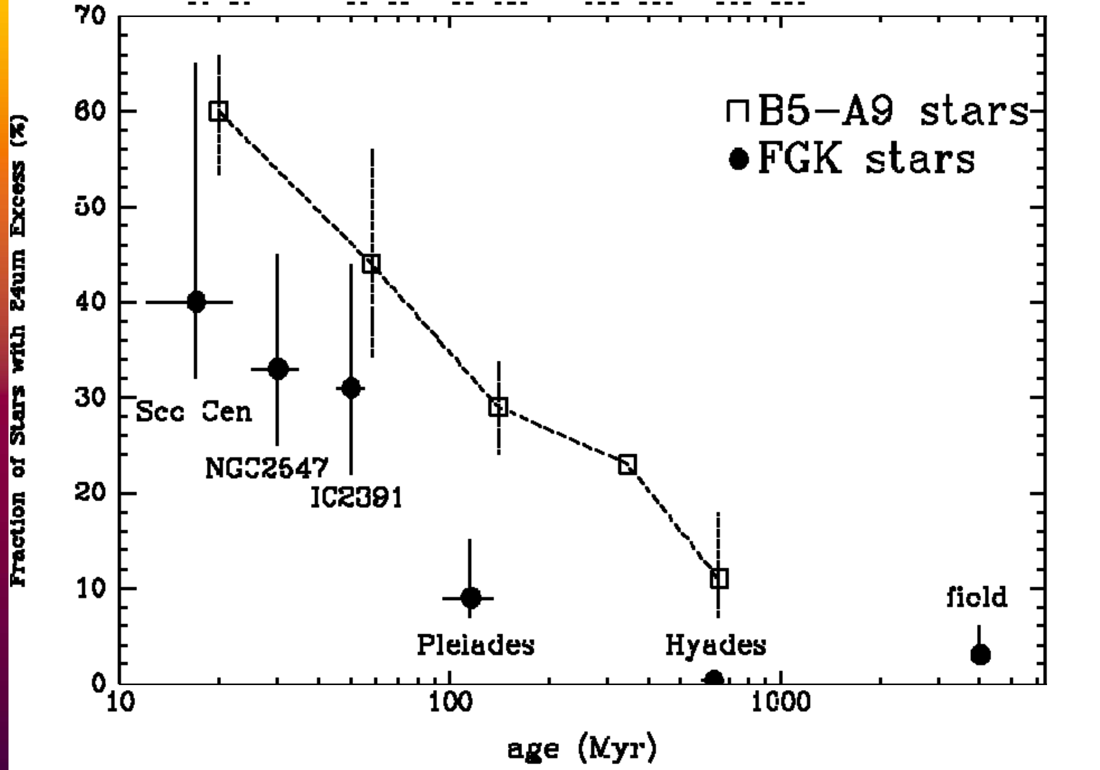

COBE 25 μm

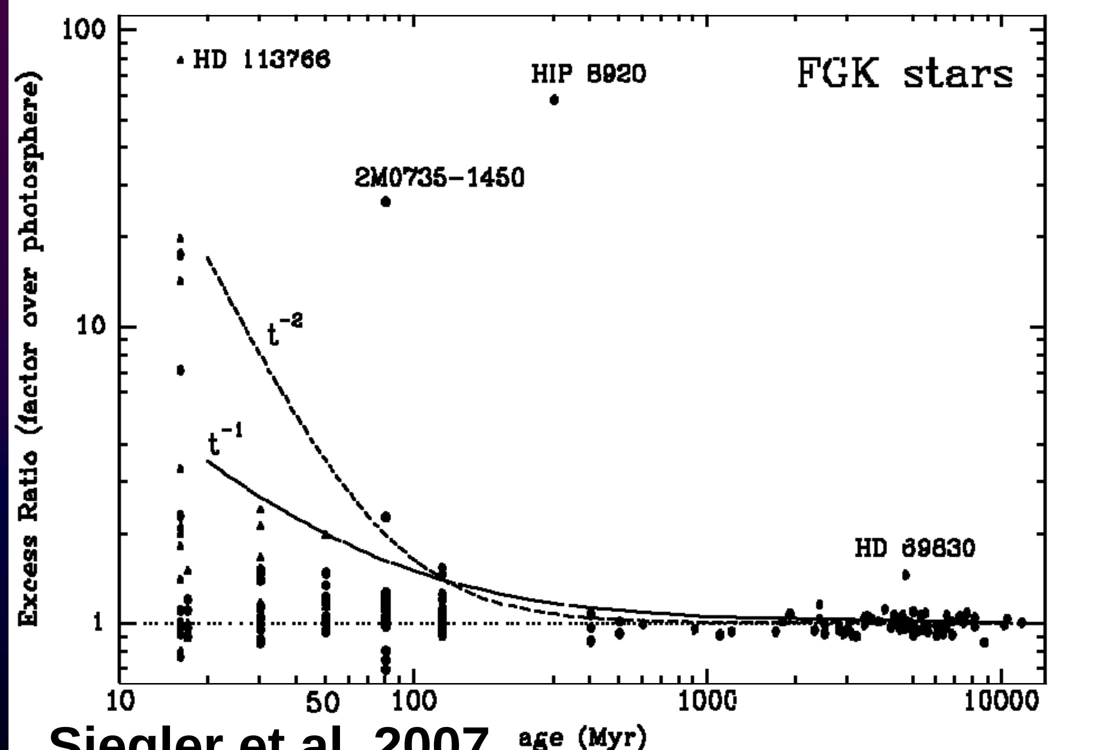
Points To Consider

- Evolution
- Census
- Where is the material?
- What is the material?
- What is the effect of planets
- What is the effect of EZ on planet detection
- What could we learn about EZ from our own LZ

Disk Fraction Declines with Age: Primordial→Debris

- Spitzer surveys of AFGK stars (Rieke 2004; Siegler 2007) confirm and extend ISO results
- Young, hot disks common, but rare beyond 100 Myr → formation of planetesimals and planets common evolutionary feature <100Myr
- Sporadic later outbursts due to collisions (Vega, HR 8799 Su 2004) with multiple grains sizes

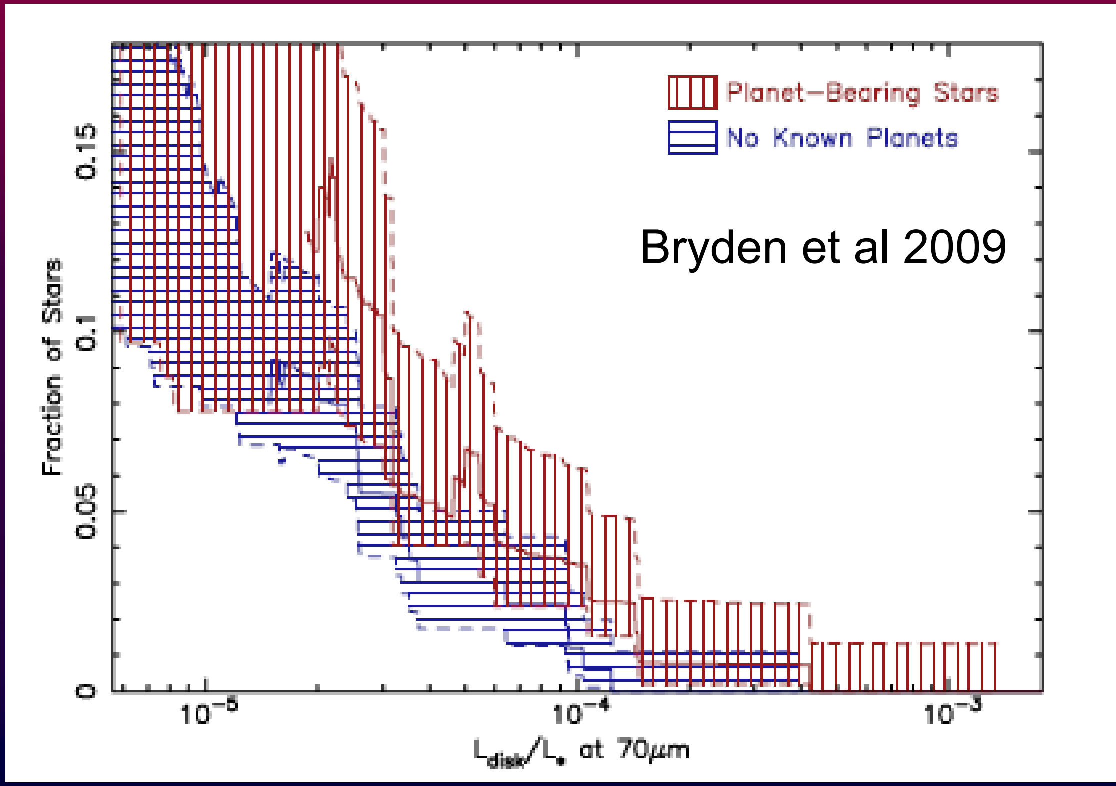




Siegler et al. 2007

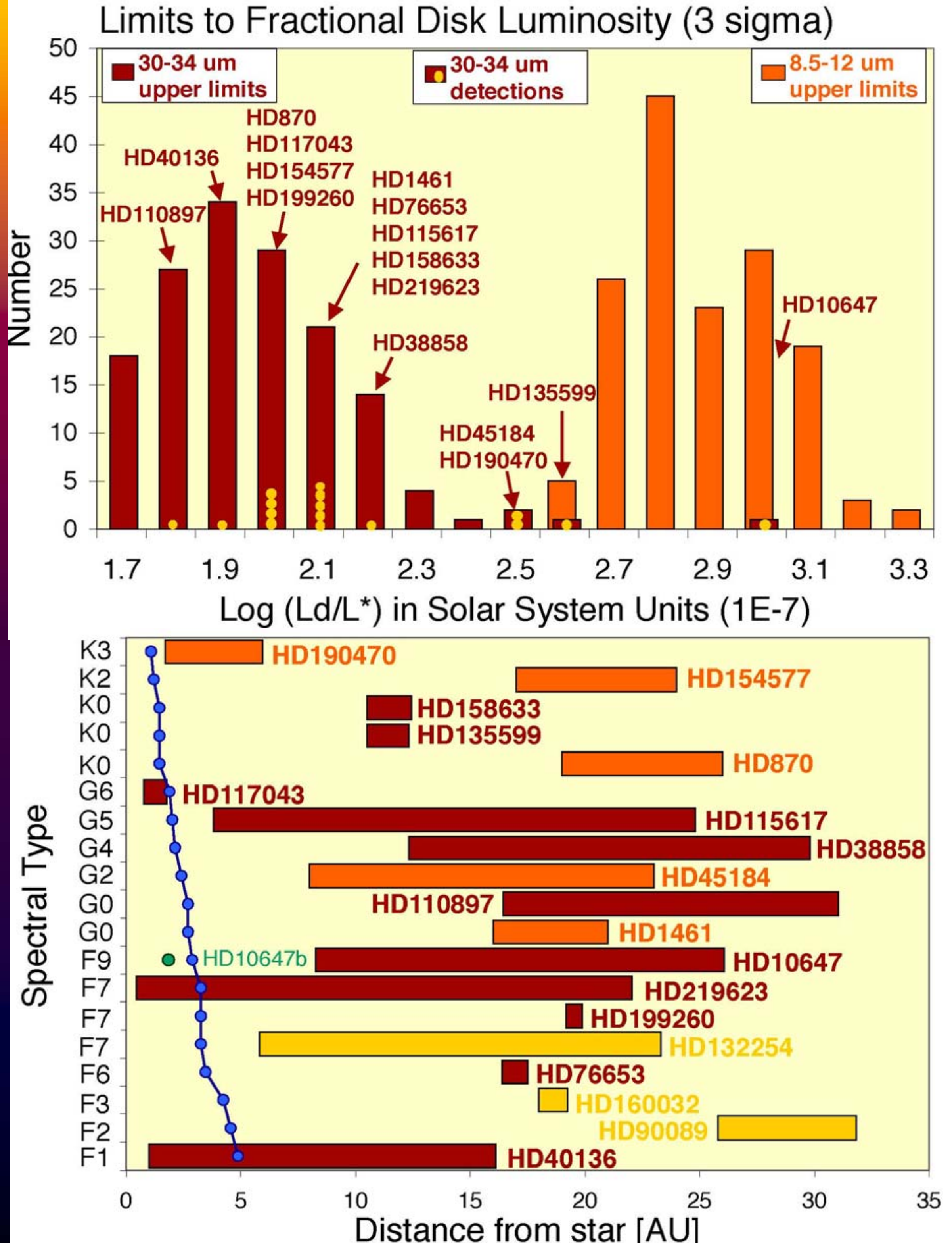
Spitzer Results On Kuiper Belts

- $L_d/L_* \sim 10^{-5} \sim 10^{-6}$ for cold Kuiper Belt dust (30-60 K, >10 AU; 70 μm) for roughly 14% of MATURE stars.
- No statistical difference between debris disk incidence for stars with or w/o planets
- Most systems consistent with large dust grains, relatively warm dust located just outside snowline

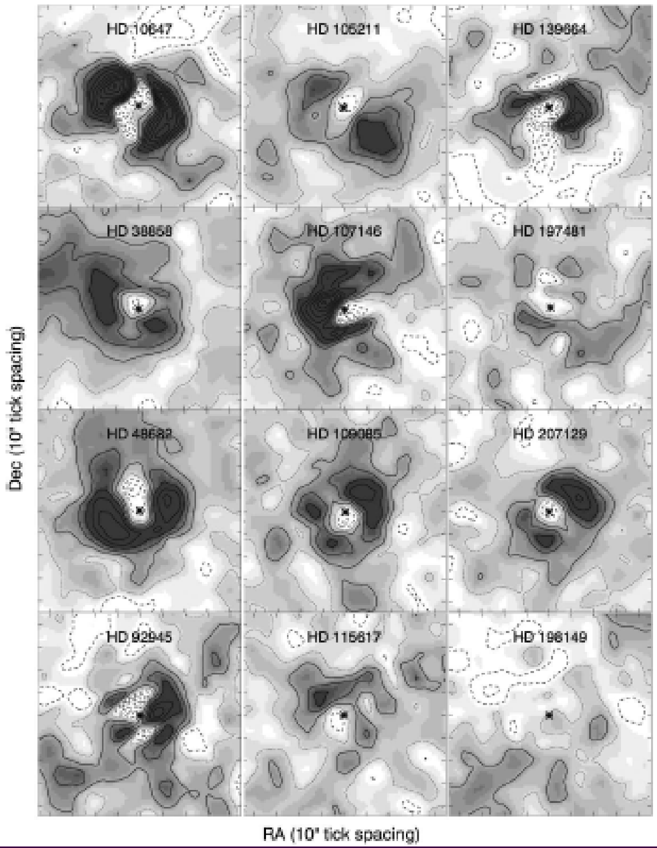


Spitzer Limits on Hot Dust

- Most Kuiper Belt systems show **WARM** dust (70-150 K) located outside ice-line ~100 Zodi
- **HOT** dust in Habitable Zone (10 μm) rare
  - ~1,000 zodi (3 σ) for 1-2% of mature stars
- Only 1-2 systems with strong HZ disk at Spitzer photometric levels

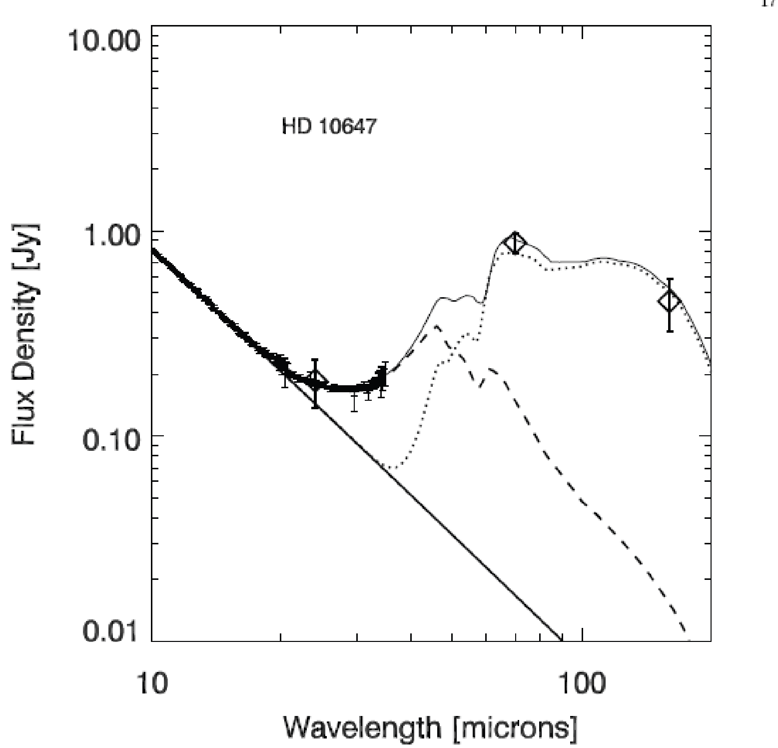


Lawler et al



Large Warm Disks

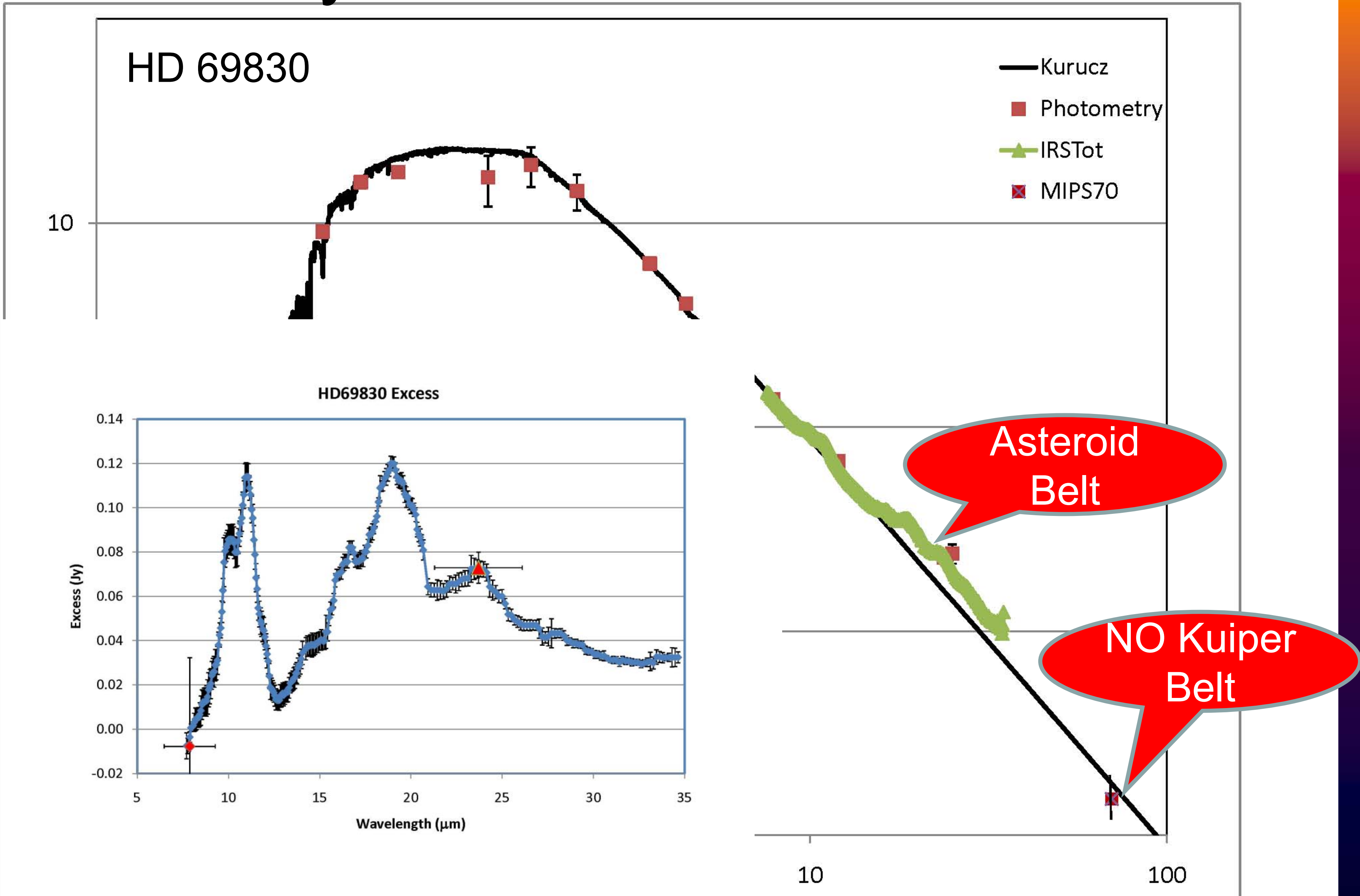
- 11 of 41 70 μm excess sources are extended (≥10″) → 30-100 AU (Bryden)
- HST confirms size and PA of many
- Herschel/SCUBA-2 will resolve dozens of objects
- Submm shows large, cold disks



- Large distance from star → small dust grains for T~30K, e.g. HD 10647 with outer ring of 0.25 um silicates or water ice (Tanner et al)
- Origin as fossil collisional event

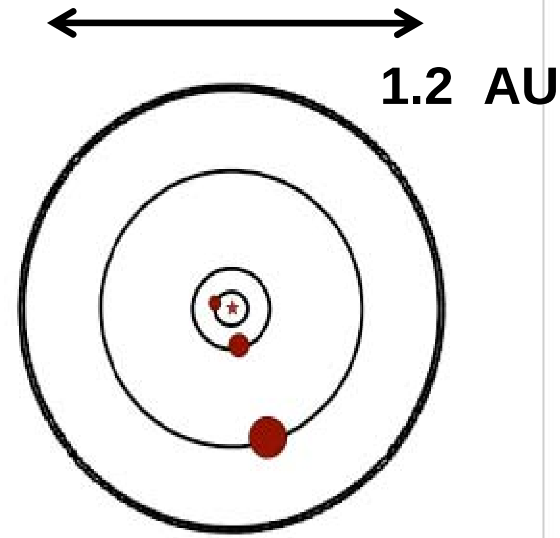
Star	R_i AU	R_o AU	T_{dust} K	L_d/L_* 10^{-5}	Dust Mass[a] 10^{-4} $M_\oplus$	Dust Composition[b]
HD 10647	6±0.5 97±10	150±150 140±50	70-40 33-27	21.1	3.43	blackbody silicate - 0.25 μm or water ice

Laboratory For Planet Disk Interactions

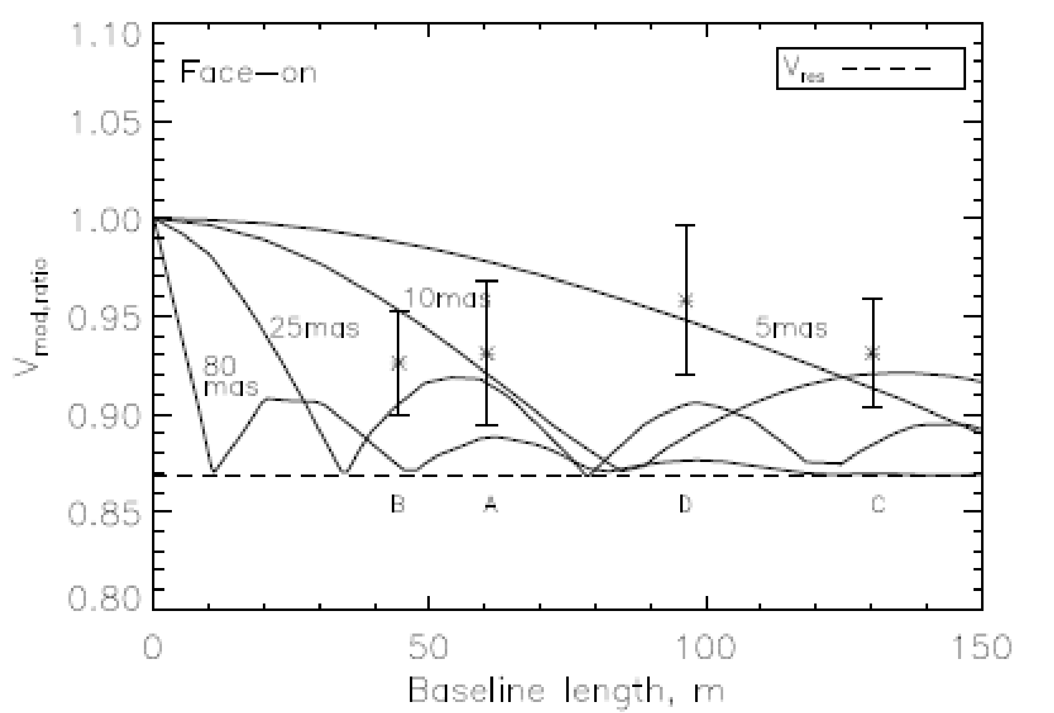


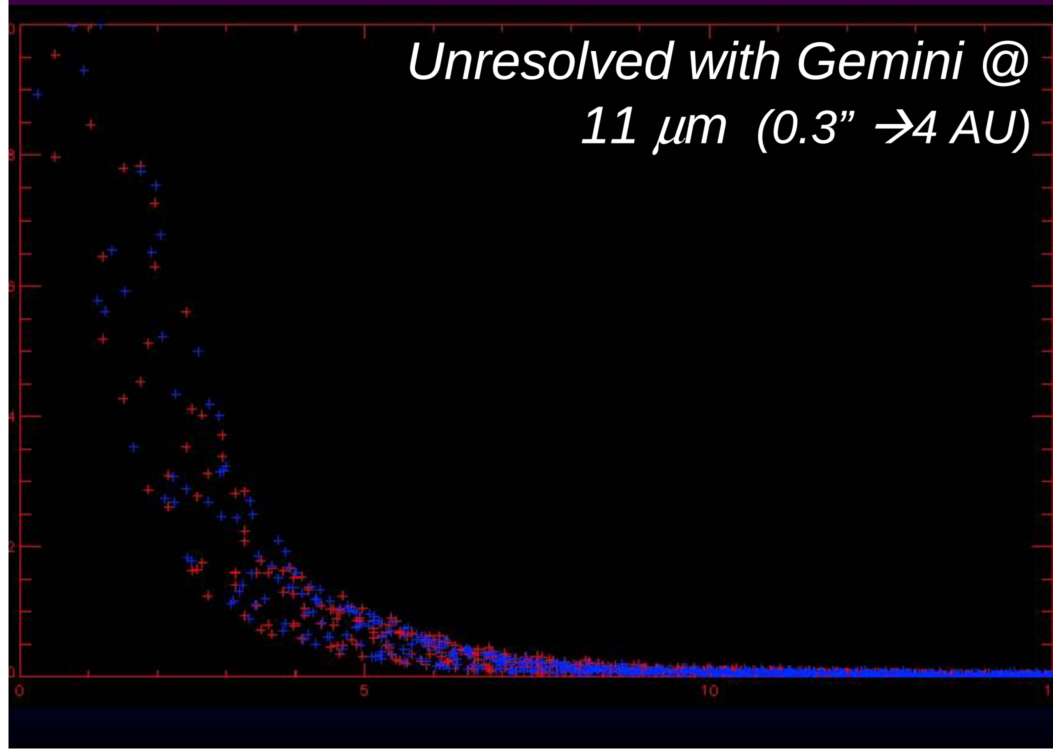
Disk Location and Extent

- SED→ material at 1 AU, 2:1 or 5:2 resonance outside most distant planet
  - VLTI/MIDI resolves emission, 0.25 -1 AU (Smith, Wyatt and Haniff 2009)
  - No Keck-Interferometer excess at 3 μm (Akeson)
- Debris from R~30 km C-type asteroid disrupted after perturbation by planet



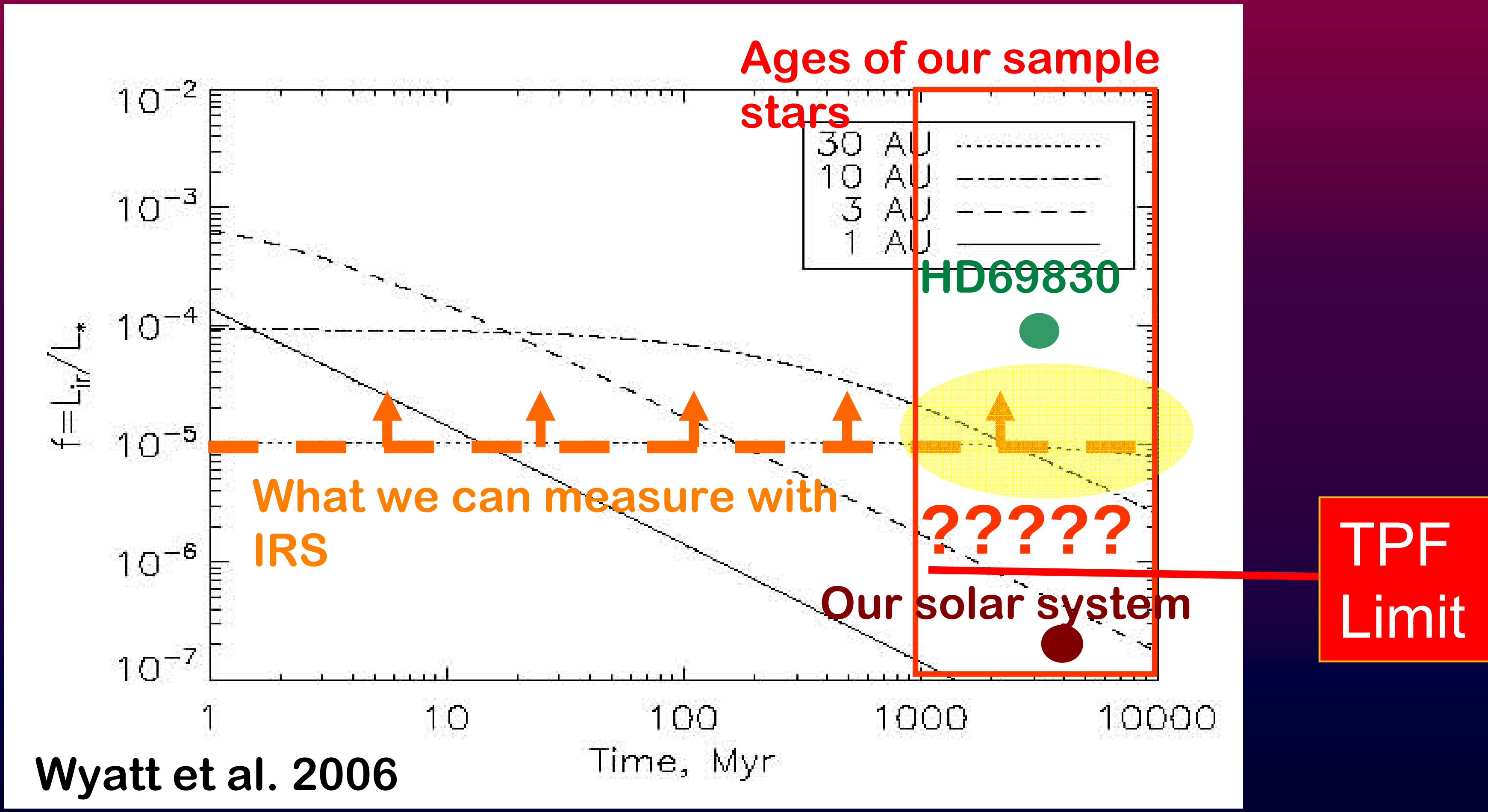
Lovis et al 2006





Evolution of Hot Dust Disks

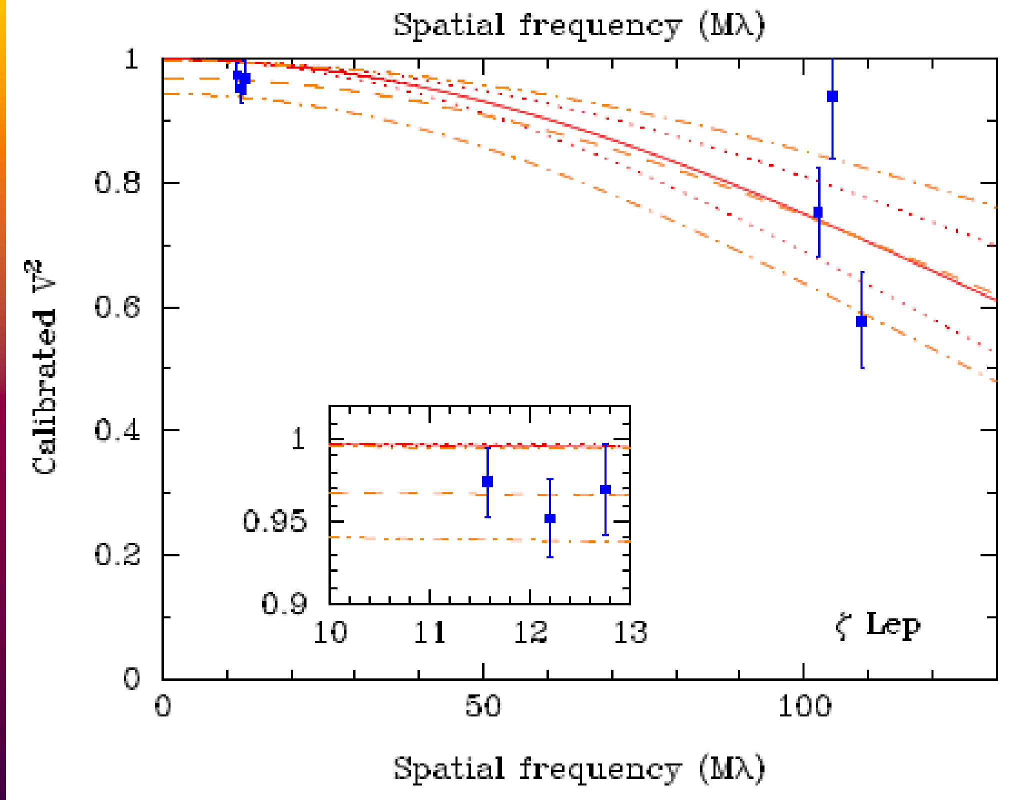
- Long term decline due to dissipation at few AU implies mature systems may be clean (few Zodi)
- Hot dust disk in mature stars may be LHB analogs



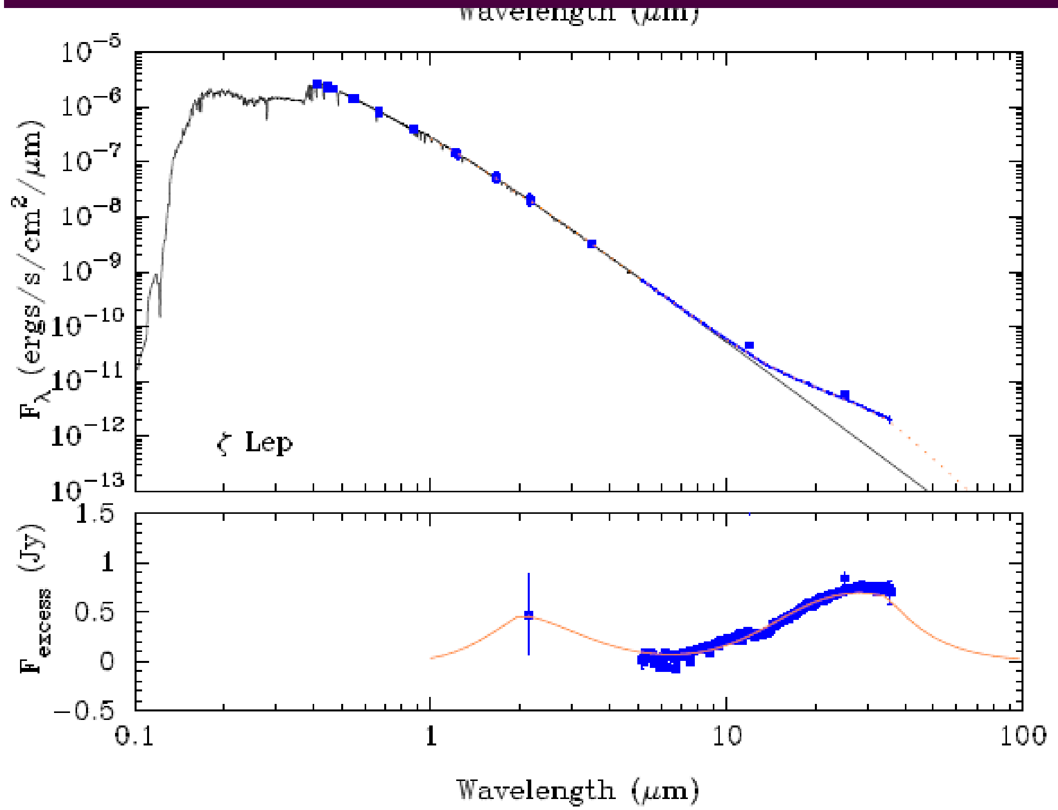
Very Hot Dust

Interferometers (PTI, CHARA) have identified hot dust at sublimation radius of A stars known EZ clouds

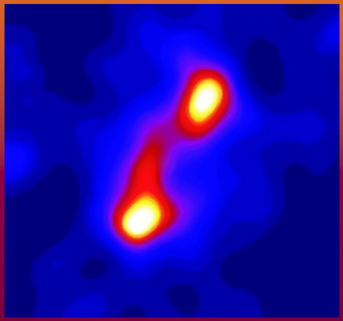
Inner ring: R=0.16 AU dR=0.05 AU,
Outer ring: R = 0.8 AU, dR = 13 AU
Ciardi et al, Akeson et al.



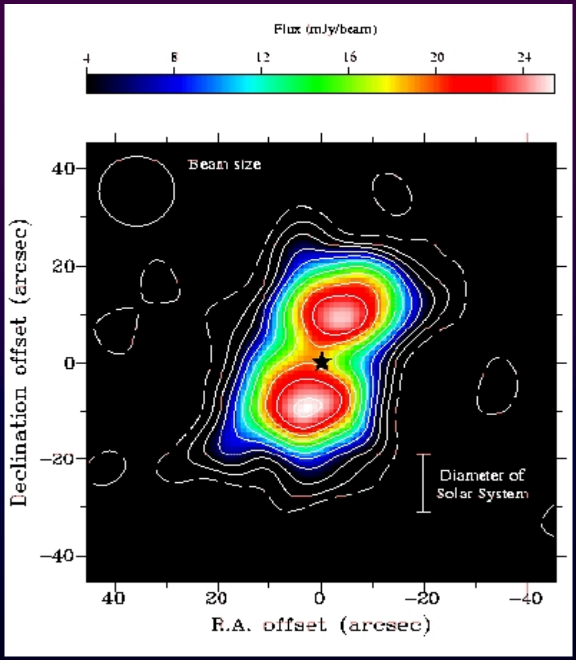
- 2 to 10 μm flux ratio requires small, hot, non-silicate grains
  - Grain size below nominal radiation blowout radius
  - Transient event
- Minimum mass from breakup of single 10 km radius body
- Collisions in planetesimal belt at < 1 AU

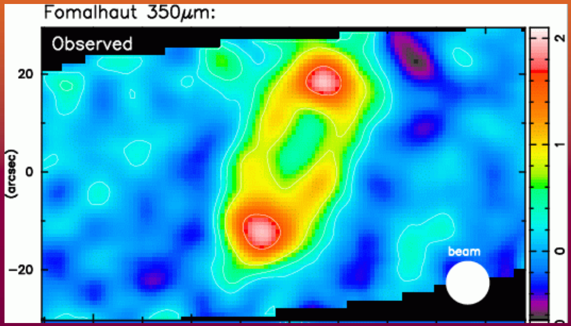


Fomalhaut’s Resolved Disk Hints at Planets



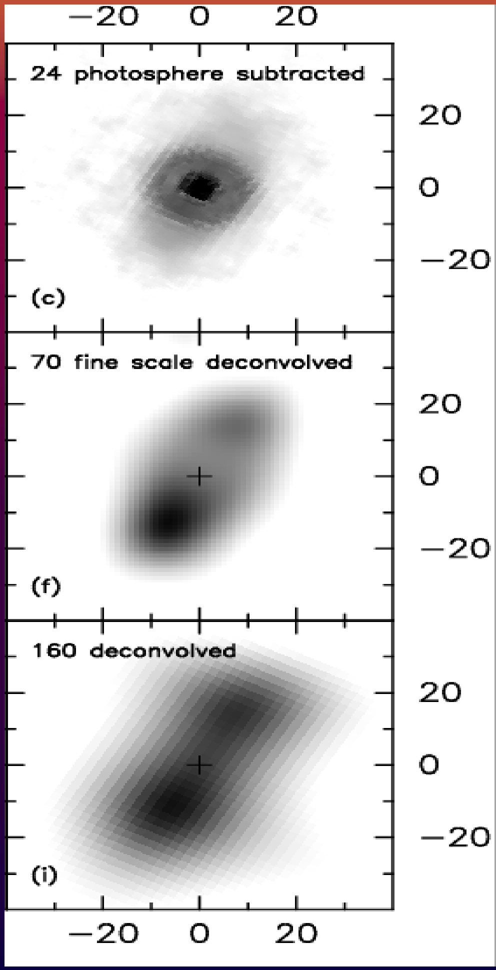
JCMT 450 µm
(Holland 1998, 2003
Wyatt 1999)
JCMT 850 µm





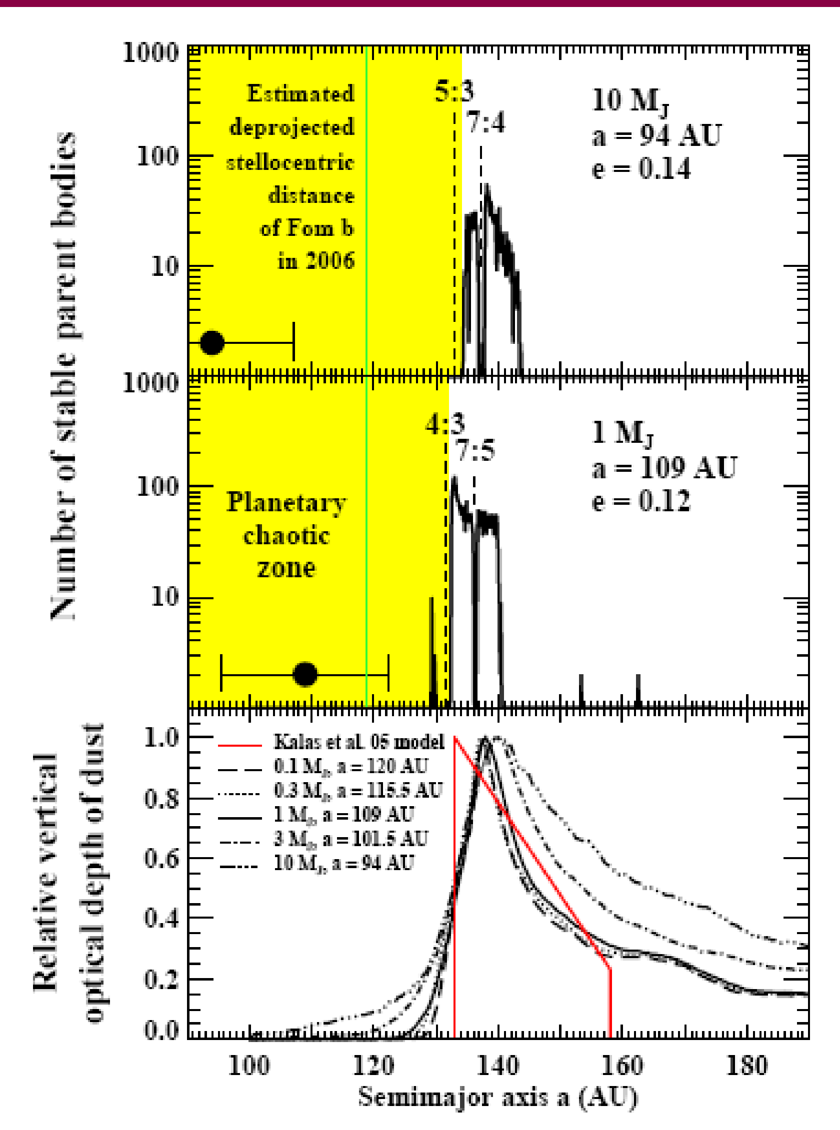
CSO 350 µm
(Marsh 2005)

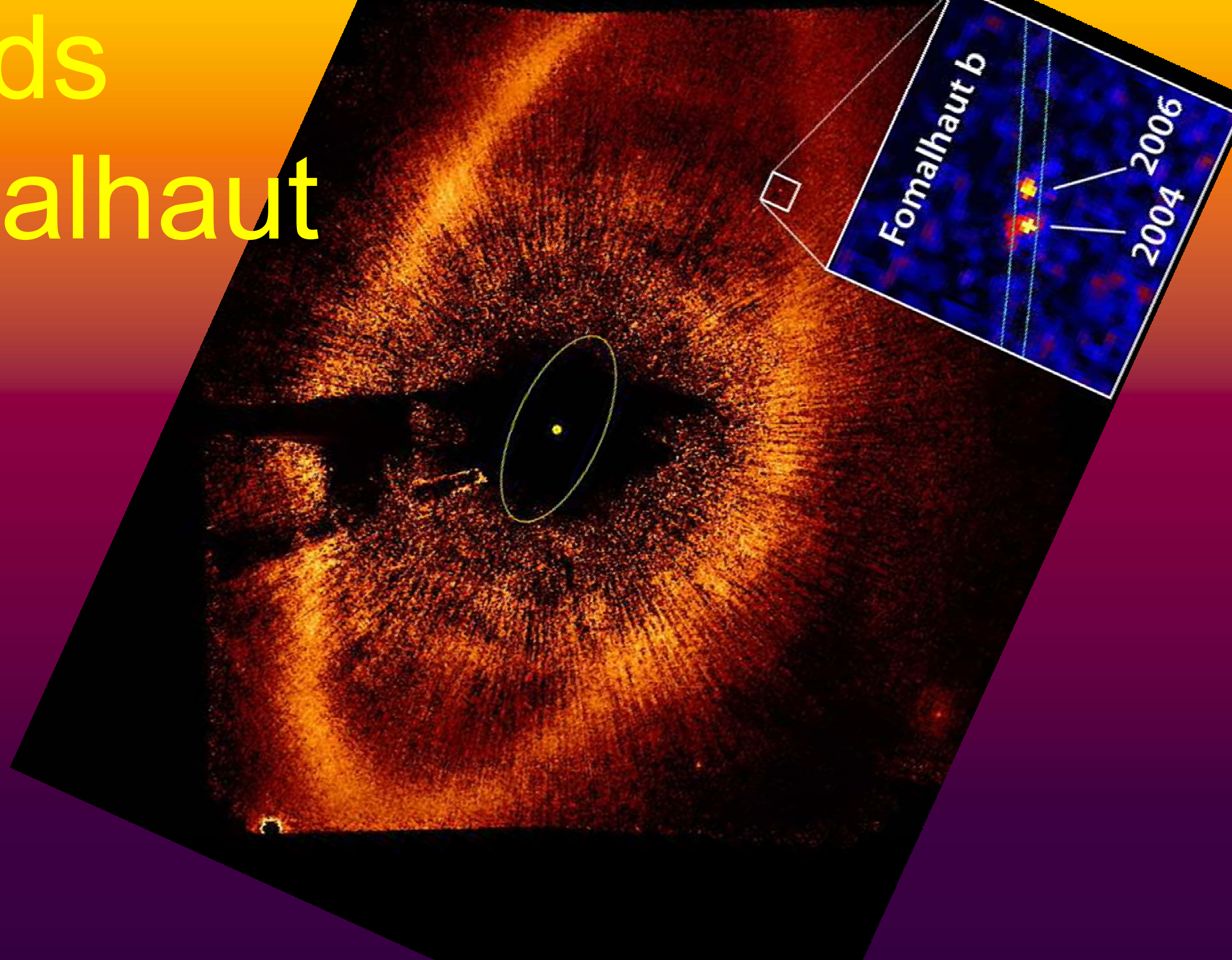
(Stapelfeldt 2004)



- A3V star at 7.7 pc; 200 Myr
- Submillimeter suggest disk perturbed by planet (e=0.07)
- MIPS resolves SE ansa into a ring with azimuthal variations from warmer dust at periastron
- CSO 350 µm ring displaced from star by 8 AU
  - Excess of material at apocenter due to slow orbital motion
  - Perturber: 86 AU orbit and e=0.07
  - M>> MEarth

HST/Keck Finds Cause of Fomalhaut Disk Offset

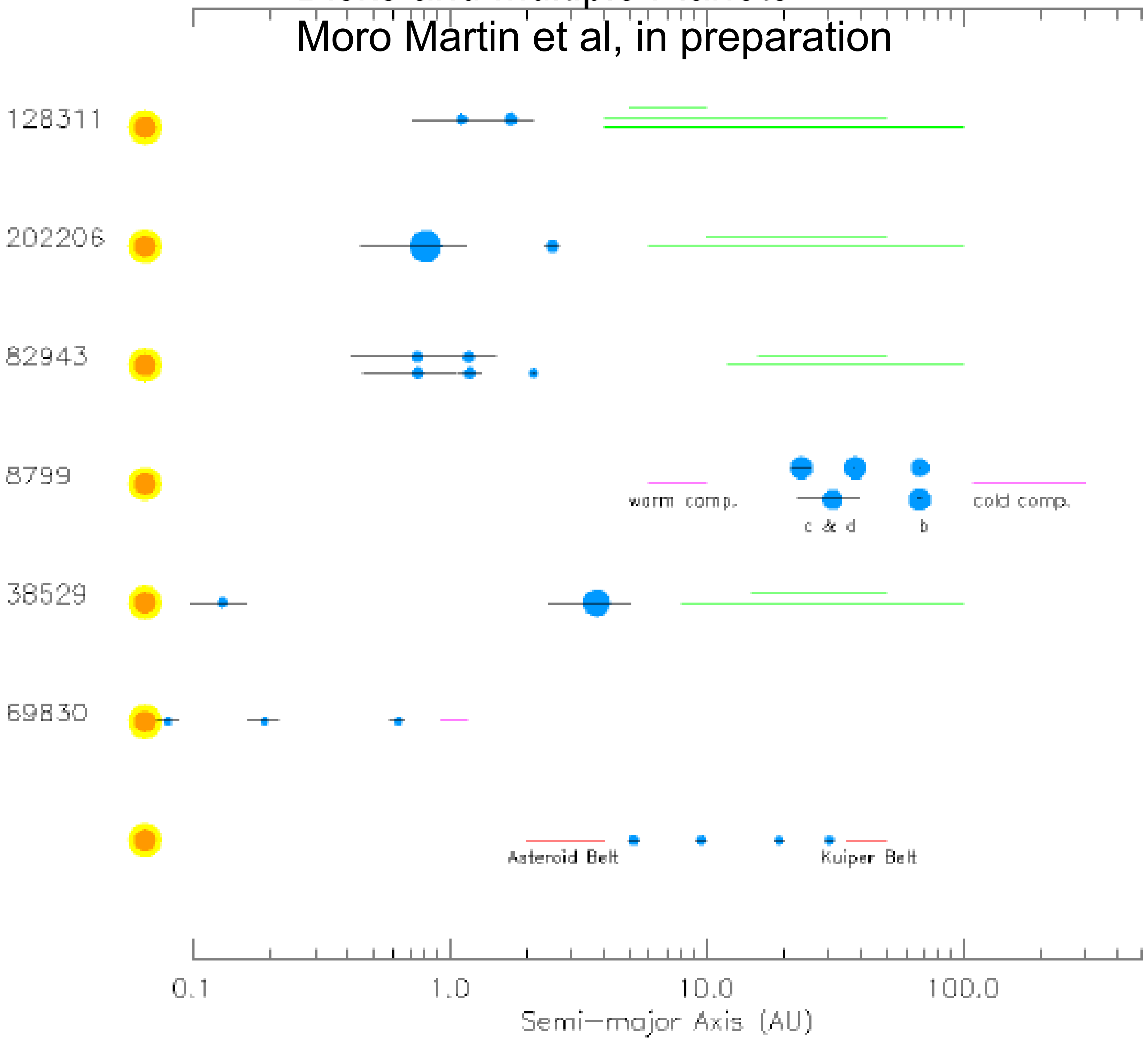




- Kalas et al (2009) directly detect Fomalhaut-b at 115 AU, e$\simeq$0.13
- Common Proper Motion and orbital motion (1.4 AU in 1.7 yr)➔P=872 yr
- Quasi-dynamical mass: M$\leq$ 3 MJup to avoid disrupting/spreading disk

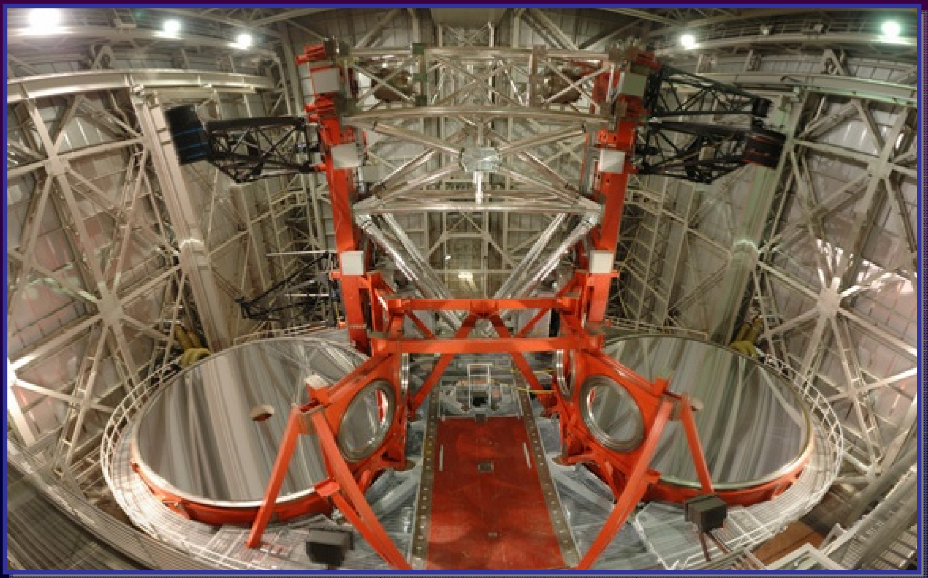
Disks and Multiple Planets

Moro Martin et al, in preparation

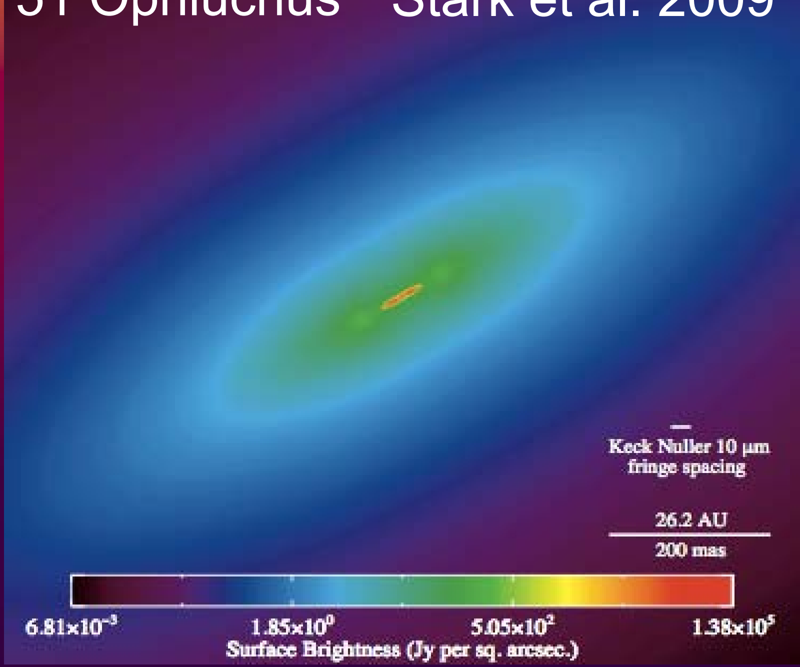


Next Steps in EZ Research

- Spitzer (even JWST) limited by photometric accuracy
- Interferometers null star signal to reveal disk: 10 mas resolution with Keck → 0.1-1 AU
- Keck ExoZodi survey of nearby stars
  - Hinz, Kuchner, Serabyn



51 Ophiuchus   Stark et al. 2009



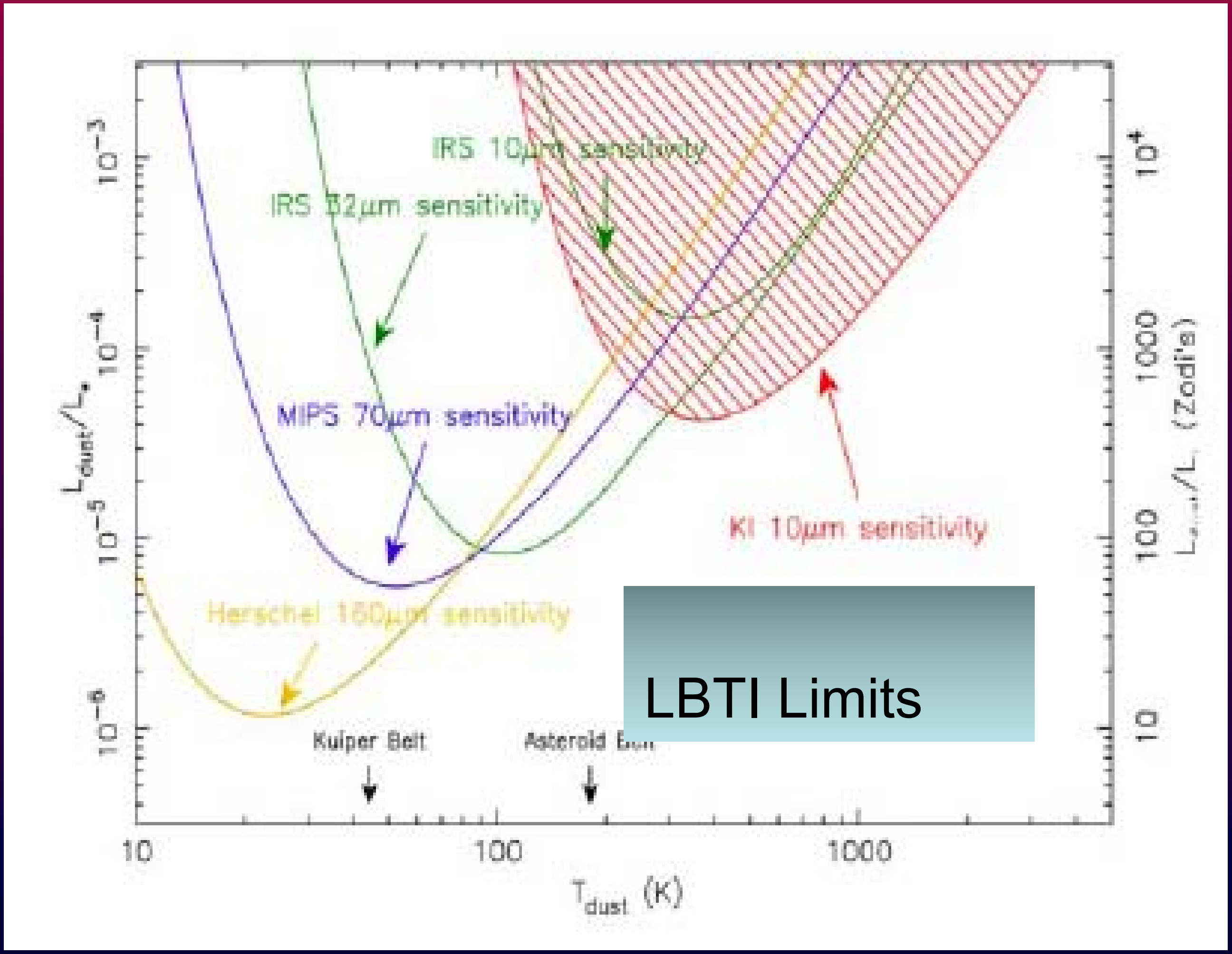
Fit Spitzer, Keck-I, MIDI with 2 dust clouds:

1) inner ring of large grains ("birth ring")
2) small particles (maybe β meteoroids)

LBTI will reach ~10 zodi (5-10x KI)

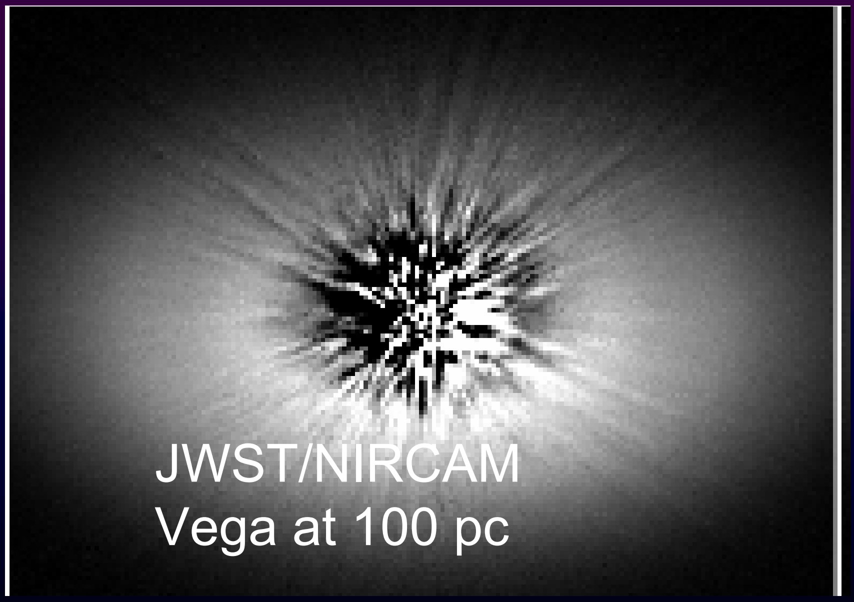
Ground-based Zodi Survey Prospects

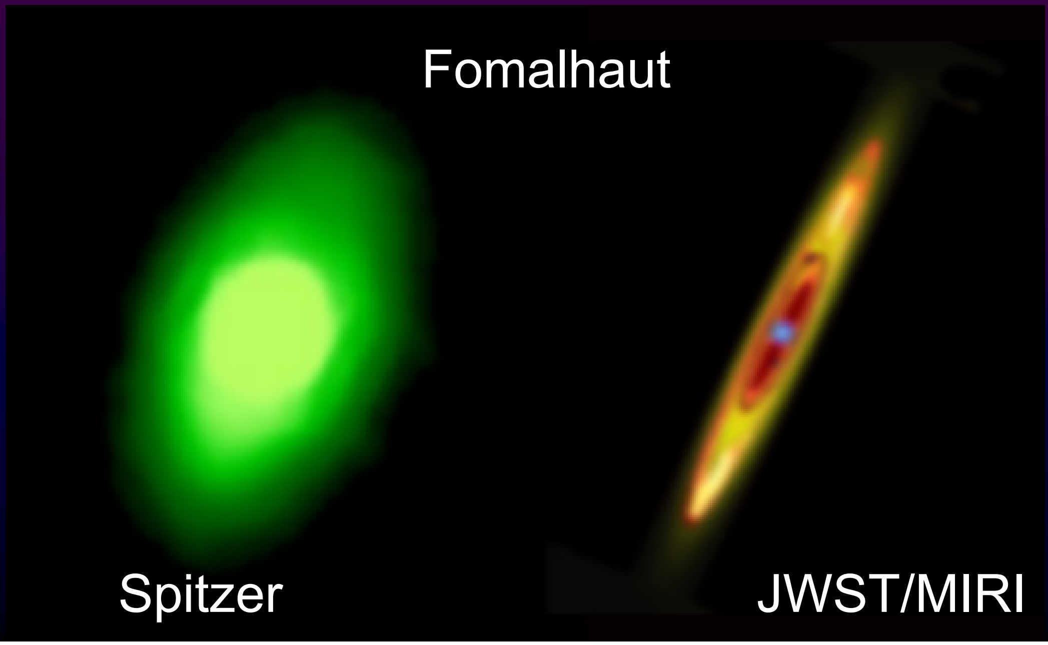
- Space-based (Spitzer, JWST) cannot get below 1000 Zodi at 10 μm
- Ground based observations at few hundred Zodi, 3-4x Spitzer
- LBTI will go below 100 SS, perhaps as low as 10 SS, approaching TPF limit
- Modest extrapolation with theory may satisfy concerns



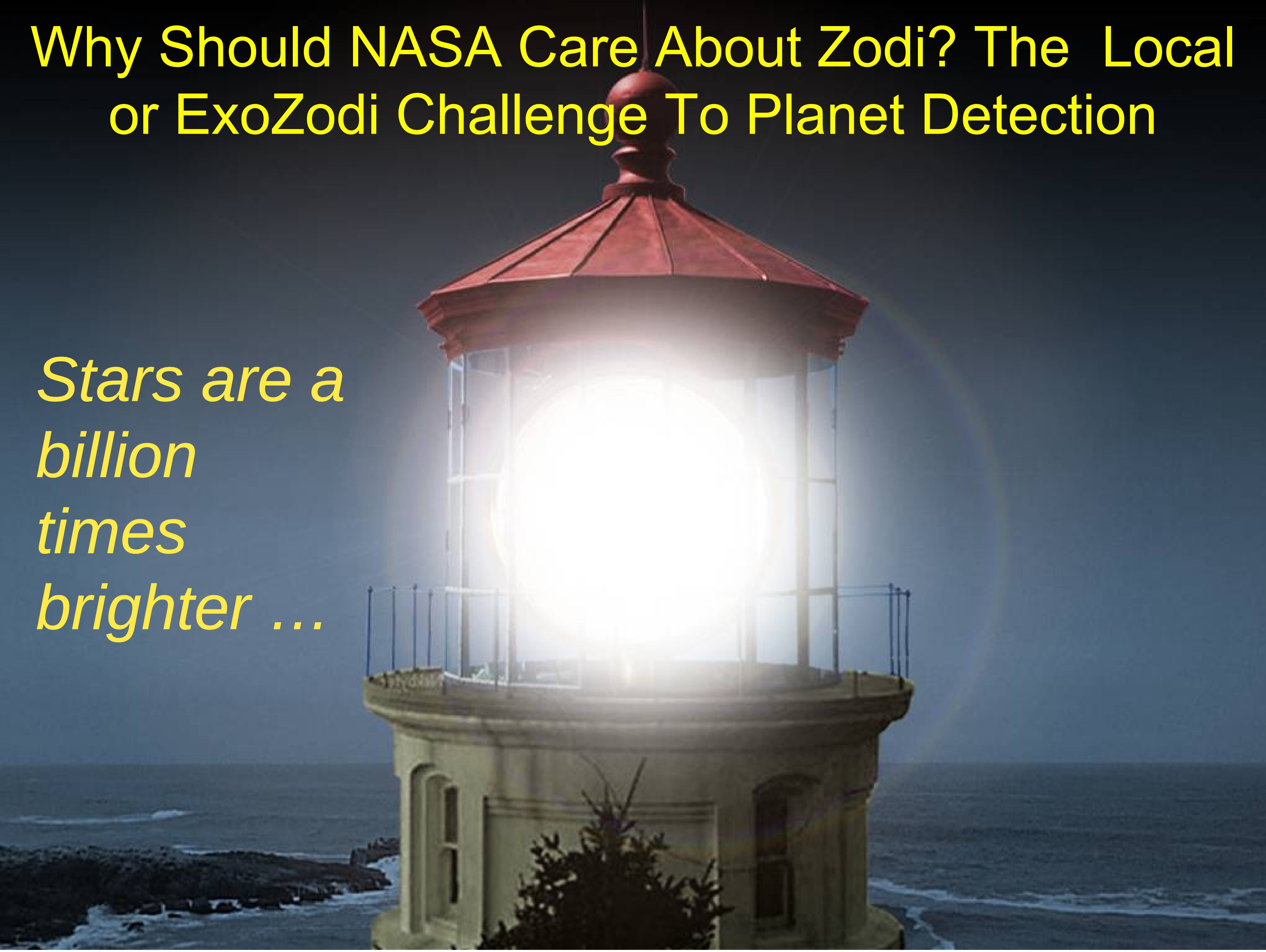
Future Capabilities

- Herschel/SCUBA-2 will map dozens of resolved systems, probing cold dust (160 um) 3-10x more sensitive/resolution than Spitzer
- JWST/MIRI and NIRCAM will give resolved, spectroscopic maps of brightest, biggest disks allowing detailed study of structure, including composition gradients





Why Should NASA Care About Zodi? The Local or ExoZodi Challenge To Planet Detection

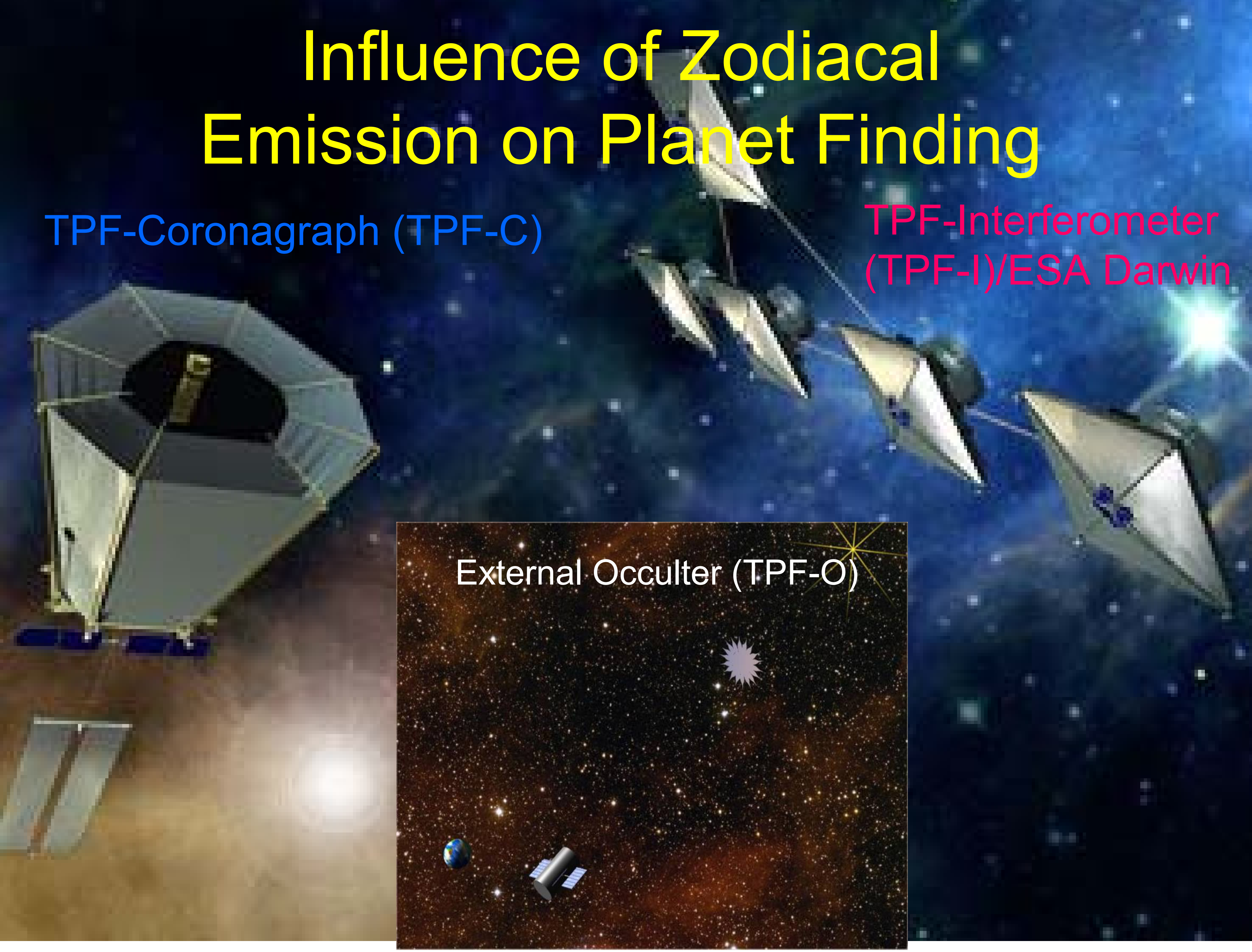


Stars are a billion times brighter …


…than the planet
…hidden
in the glare.

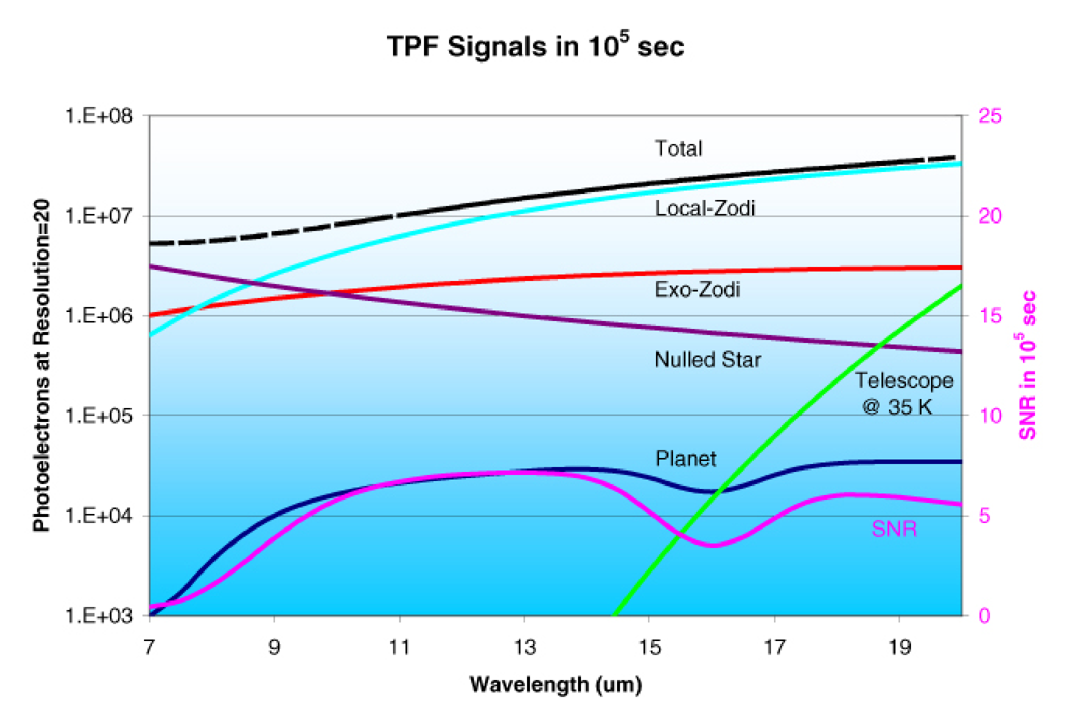

Like this firefly.
Hidden in the
Exo Zodi Fog

Influence of Zodiacal Emission on Planet Finding



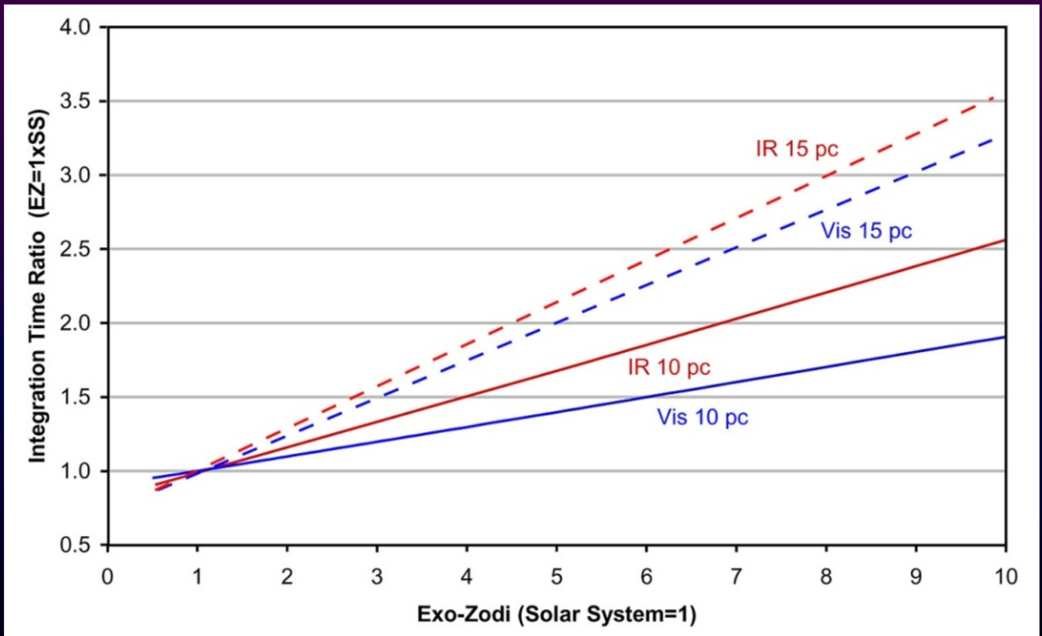
Zodi Problem for Earth-Detection

- Local zodiacal important noise source---put observatory at 5 AU (Leger et al)

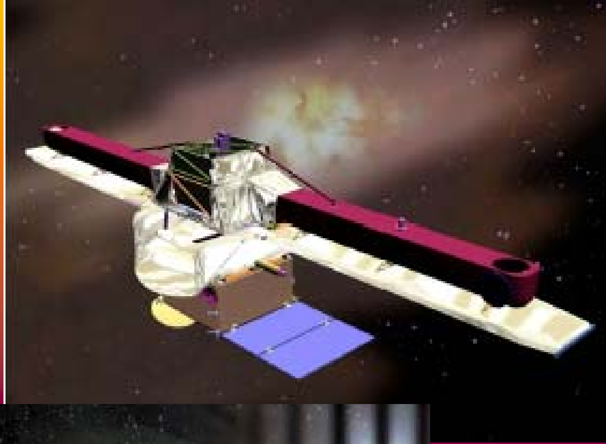


- Photon noise from EZ can overwhelm planet
- Total EZ ~300 x planet Solar System Zodiacal cloud

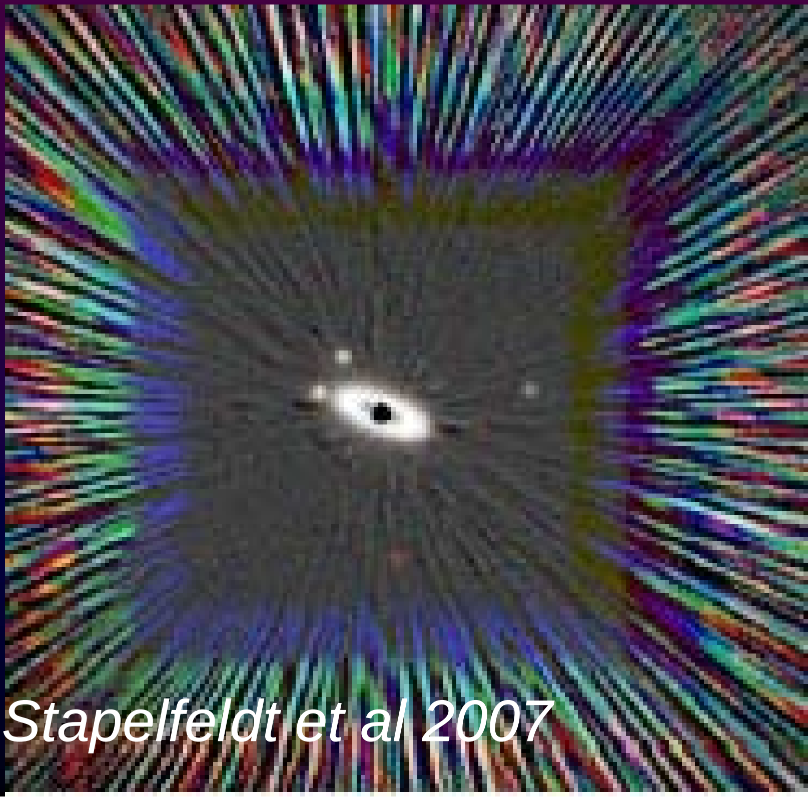
- EZ signal within single pixel (~λ/D) significant for >10 zodi for either visible or IR



The Next³ Step: A Dedicated Space Mission



- 5-10 μm interferometry from space can reach 1 zodi
  - Pegase separated s/c interferometer
  - FKSI interferometer on a stick being (Danchi et al)
- Visible coronagraphy (Trauger, Stapelfeldt)
  - High contrast imaging with ~2 m telescope at 1-5 zodi as well as imaging nearby Jupiters



Stapelfeldt et al 2007

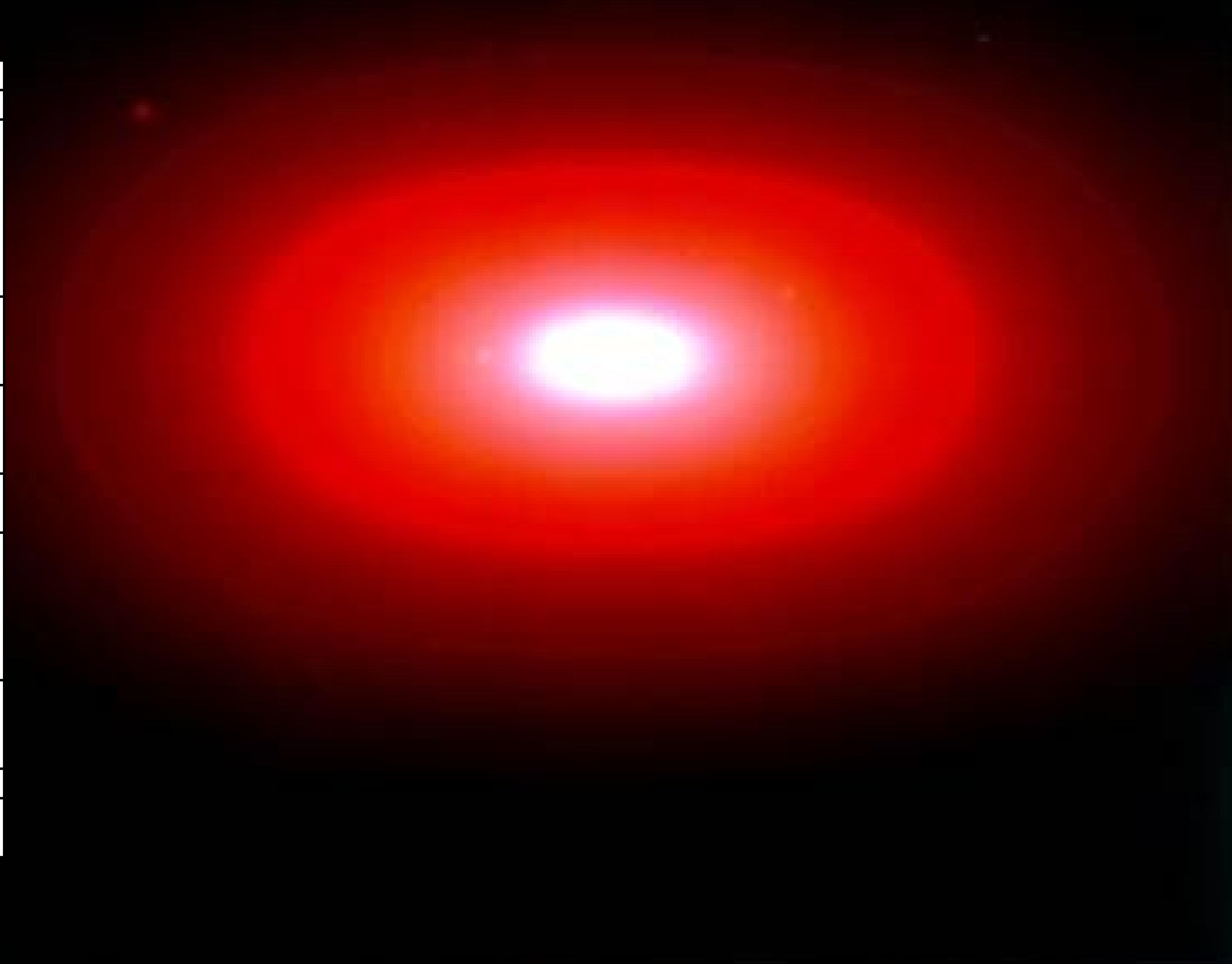
What Could We Learn About ExoZodi From Local Zodi

- Proposed mission in 1996---good idea then, still compelling now
- Know more about EZ than LZ, particularly beyond 1-3 AU
  - Steepness of drop-off at asteroid belt→ origin of material
  - Physical properties of dust from in situ measurements and spectroscopy
- Site Survey for future observatories

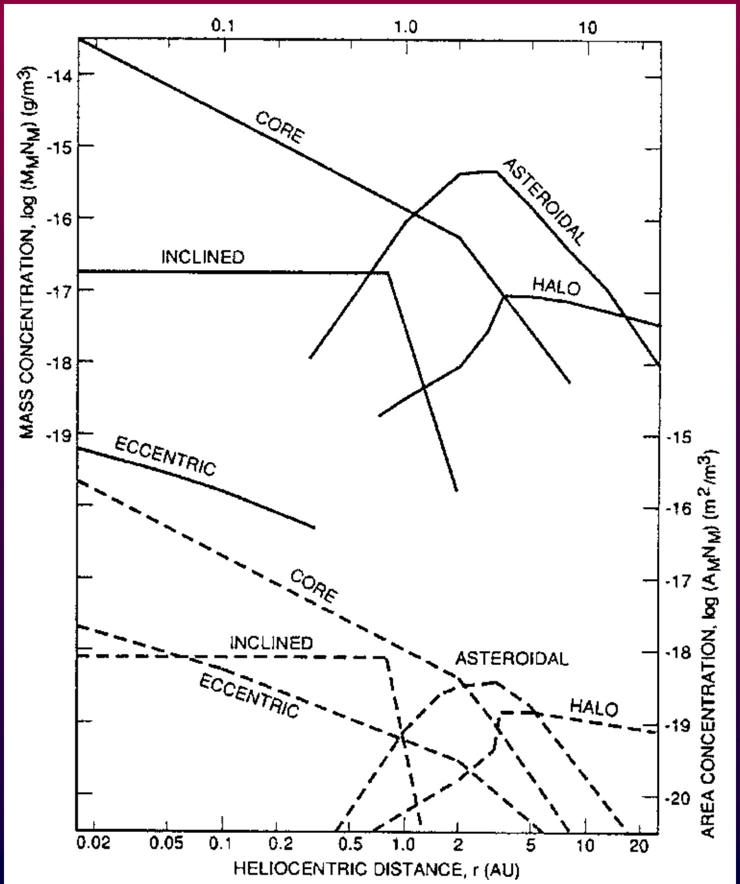
A Proposal for a Discovery Class Mission:
The Local Zodiacal Mapper (LZM)
Submitted 11 December, 1996

Table 4. Science Team Roles

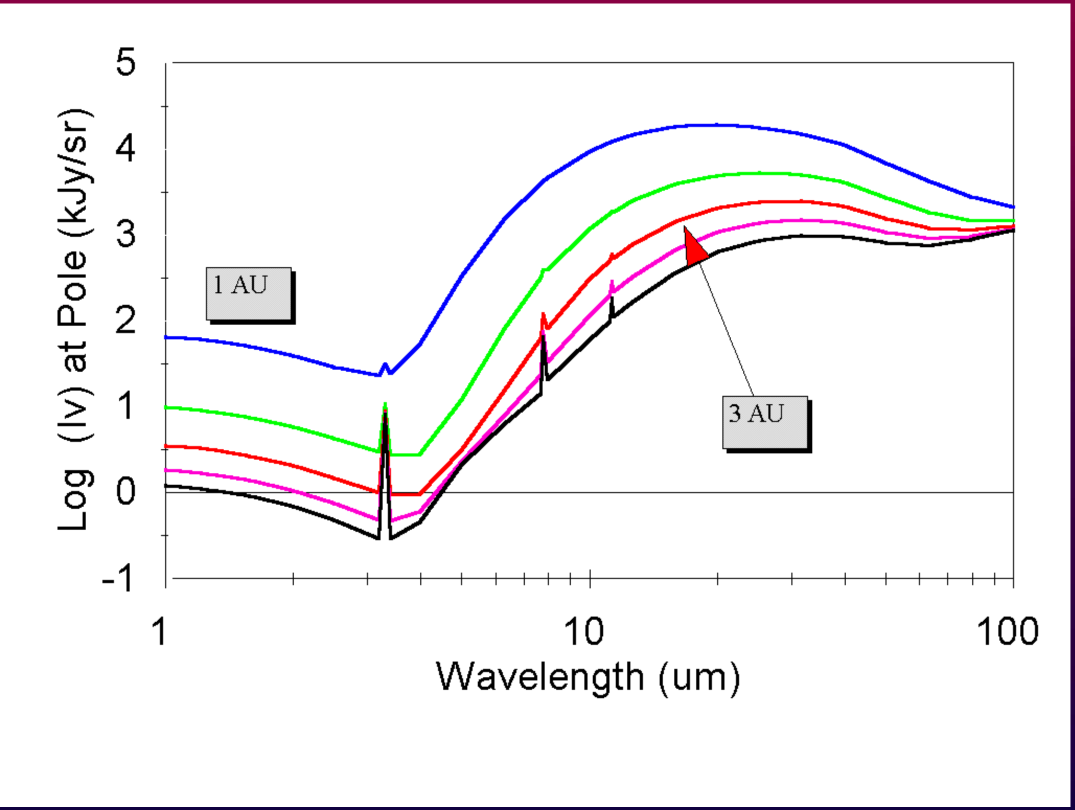
Role	**Team Member**
Solar System structures, Zodiacal cloud modeling, Relation to exo-zodi clouds	Backman Beichman Dermott Leger Reach Sykes
CIRB Theory and Analysis	Mather Phinney Wright
Cirrus	Boulanger Cutri Helou
Science Operations	Cutri Van Buren
Instrument	Beichman Gautier Herter Mather Moseley
Data Processing	Beichman Helou Van Buren
	Wright
Outreach and Education	Backman Sykes



In Situ Studies of the Local Zodi



The mass and surface area estimated for different constituents of the solar system as a function of heliocentric distance. LZM would make direct measurements of the scattered and re-radiated emission from these objects and constrain their properties (Divine 1993).



A model based on IRAS and COBE data obtained at 1 AU (Reach et al. 1996) is used to predict the sky brightness at other distances from the Sun. Curves go from 1 to 5 AU from top to bottom and include zodiacal and cirrus emission. Cirrus features are seen at 3.3, 7.7 and 11 μm.

LZM Characteristics