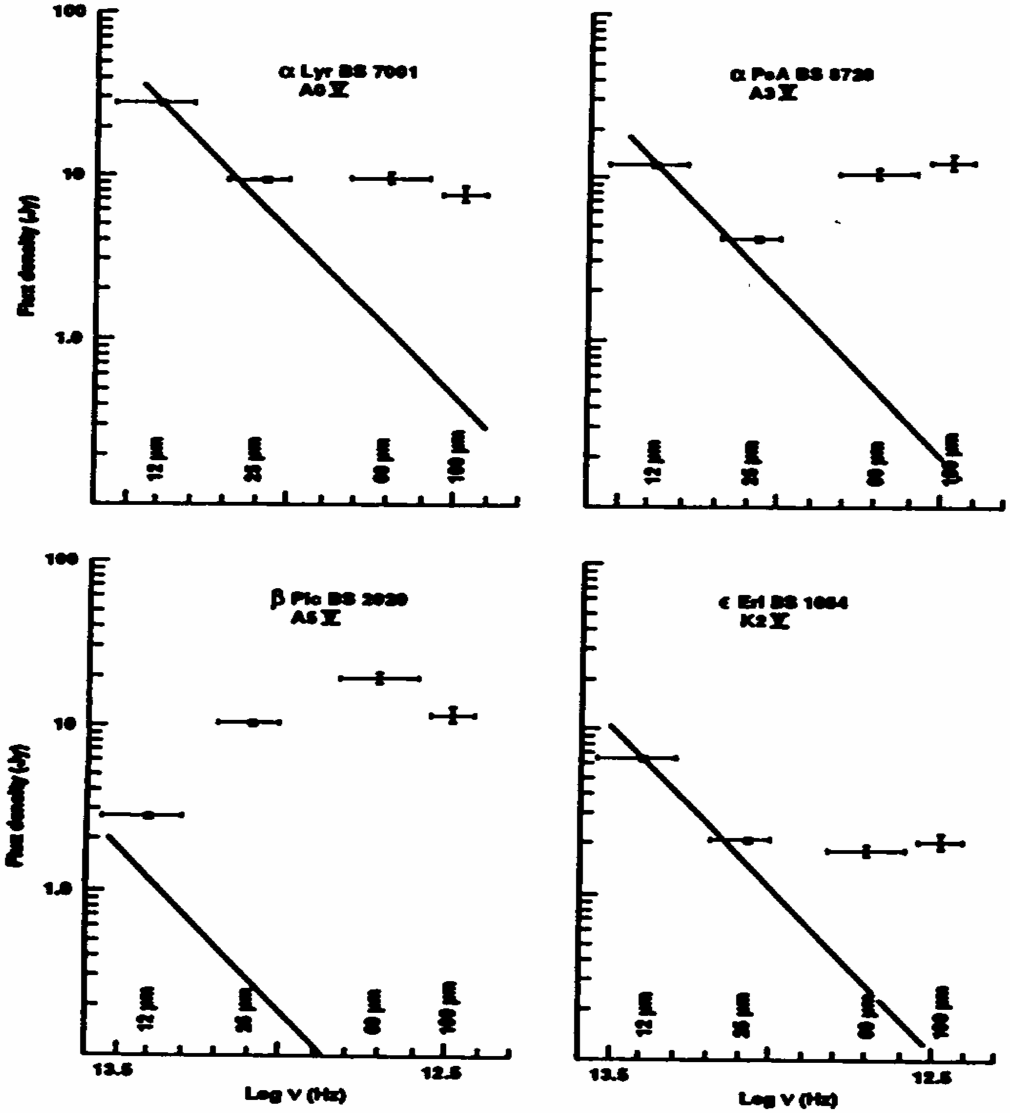
Spitzer Debris Disk Studies

Michael Werner, JPL

Outline:

- The "Fab 4" Resolved Disks
- FGK stars – with and without planets
- Disks around white dwarfs
- Spitzer Warm Mission

DEBRIS DISKS AND THE FORMATION OF PLANETS
A Symposium in Memory of Fred Gillett

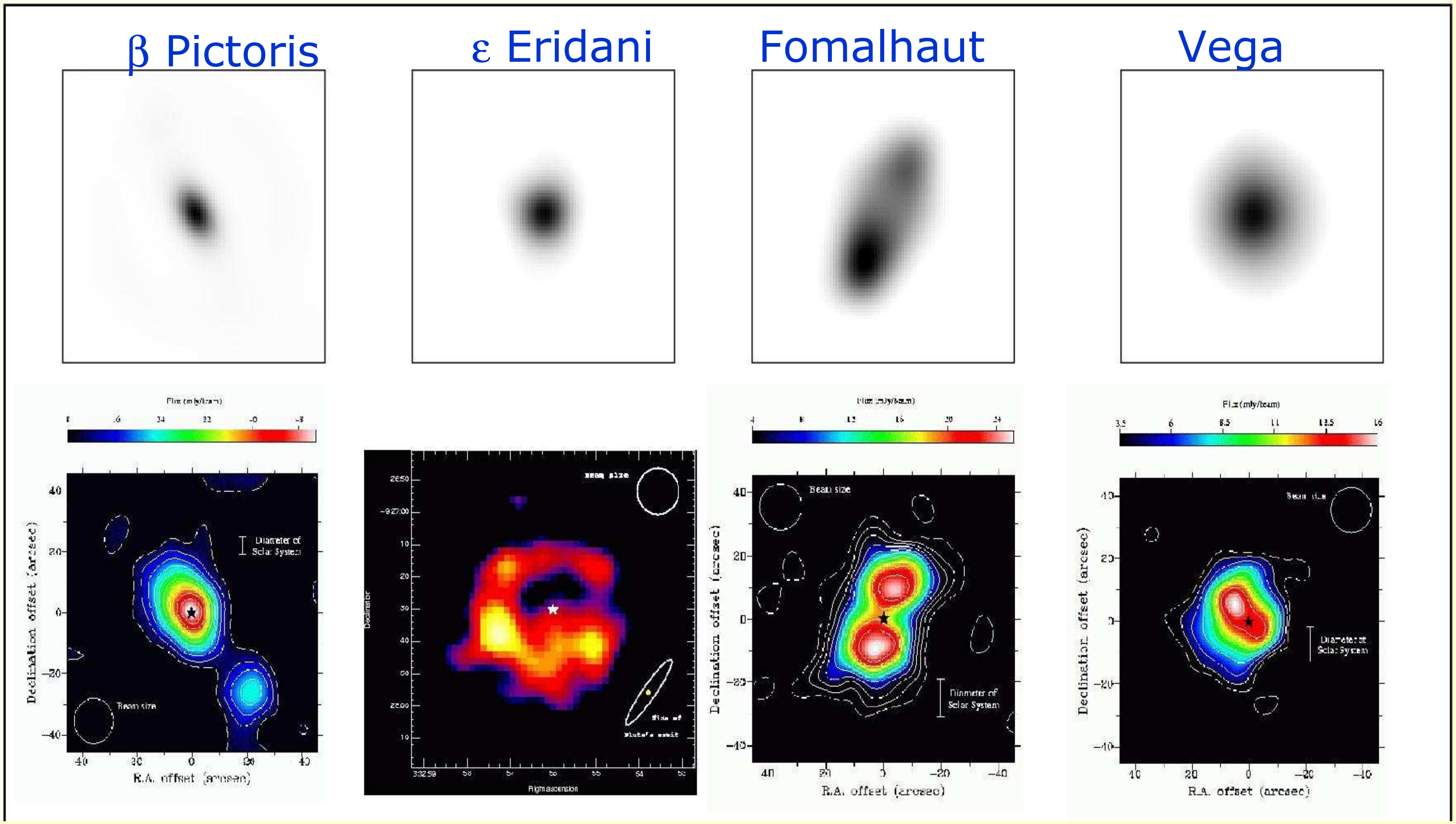


Edited by

Larry Caroff, L. Juleen Moon, Dana Backman and Elizabeth Praton

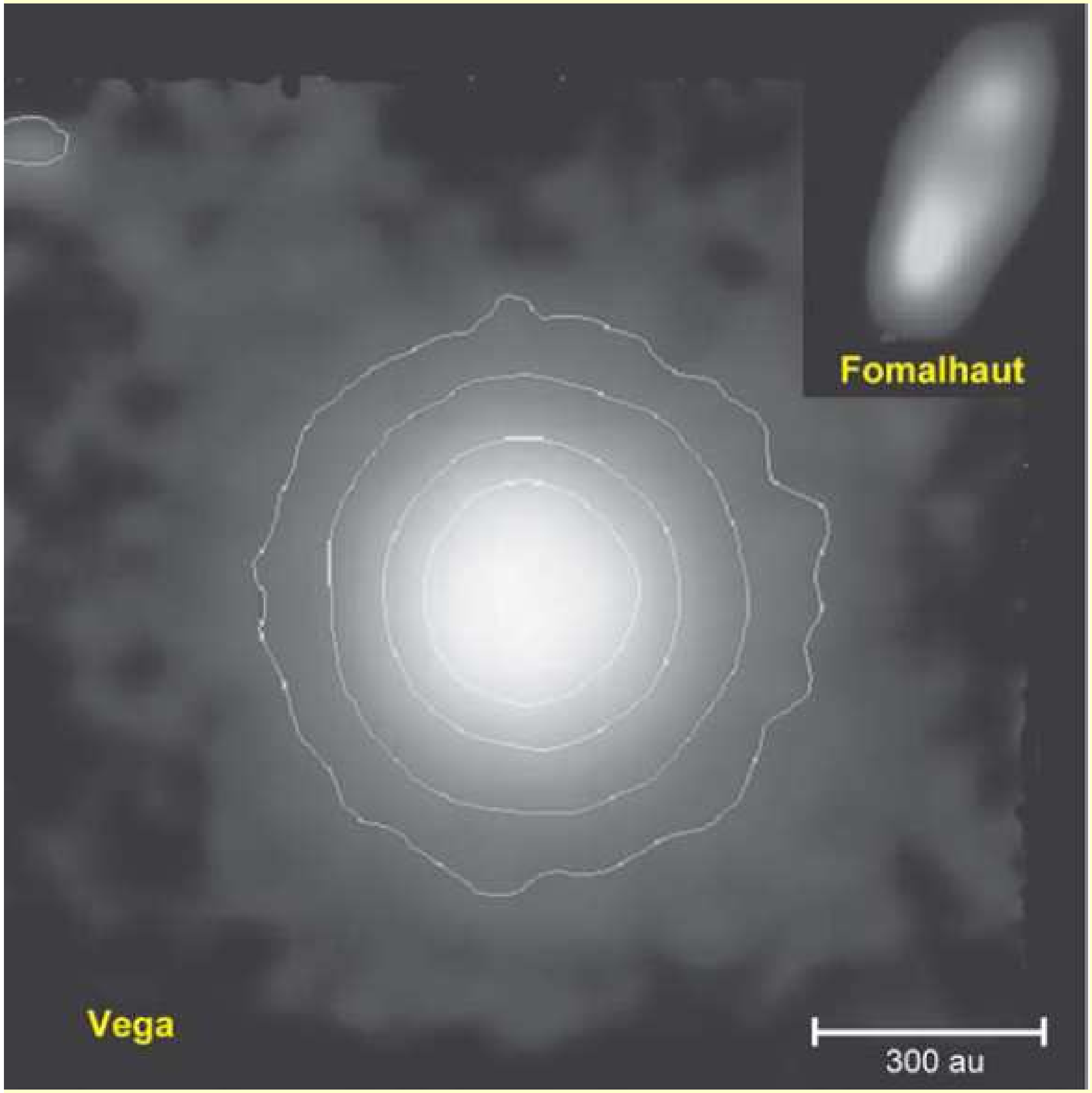
Before Spitzer… and SCUBA

The Fabulous Four Debris Disks: MIPS 70 µm vs. JCMT 850 µm



Debris disks vary from object to object and from wavelength to wavelength – one size definitely does not fit all!

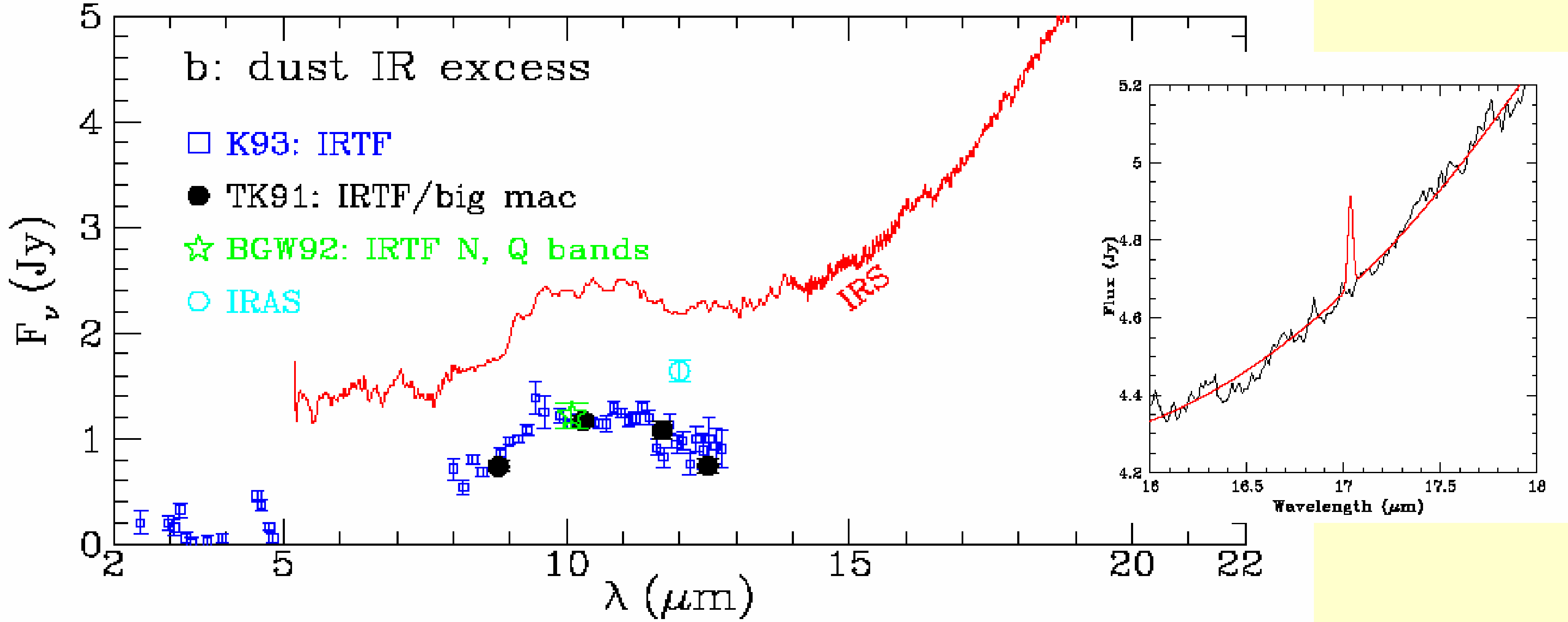
Spitzer 70um Images of Vega and Fomalhaut: Each Debris Disk is Unique



Fomalhaut: ~Edge-on annulus, well-imaged by CSO and HST. Disk is eccentric [not centered on star], suggesting presence of inner planet at r~50 au at least as massive as Neptune [Stapelfeldt et al].

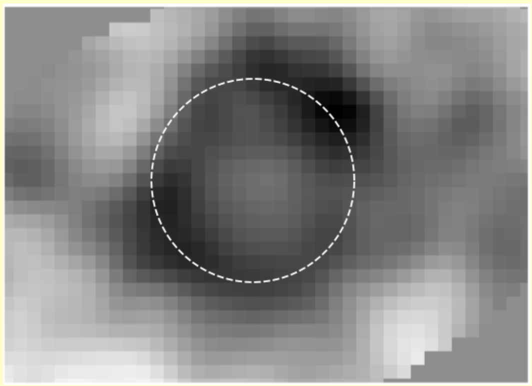
Vega: Flux seen by MIPS due to particles liberated by collisions in dense sub-mm ring and blown away by radiation pressure. Dust production rate suggests this is a transient phase [Su et al].

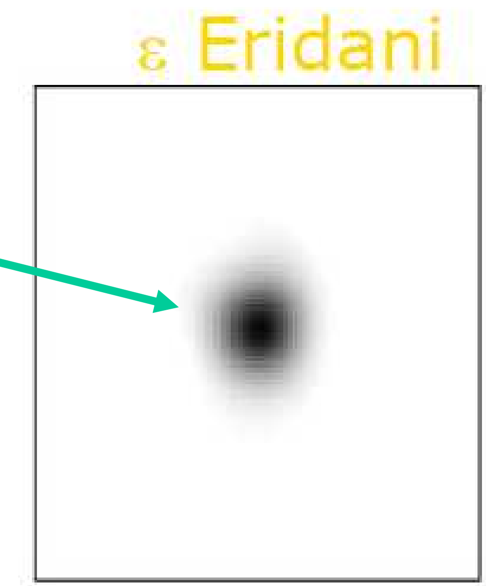
Beta Pic Spectral Results – Chen, Li et al (ApJ, in Press; astro-ph 0705.3023)

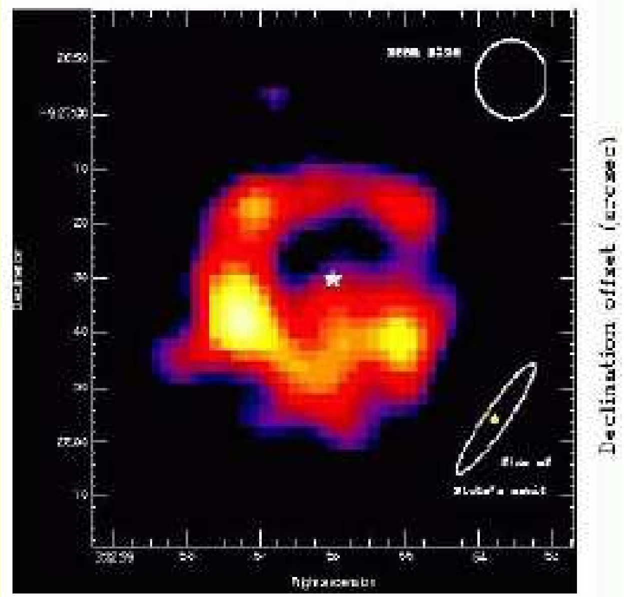


Spectrum covers central 11x22 arcsec
Crystalline silicate emission seen at 10, 28 and 35um
Data including photometry to 850um well fit by model using fluffy cometary [amorphous silicate] and olivine grains
We do not confirm ISO report of 17um H2 emission – less than 17 Earth masses of 100K gas. Gas dissipates very quickly.

Eps Eri – CSO 350um Image
Similar to Scuba Image
– Spitzer 70um Differs

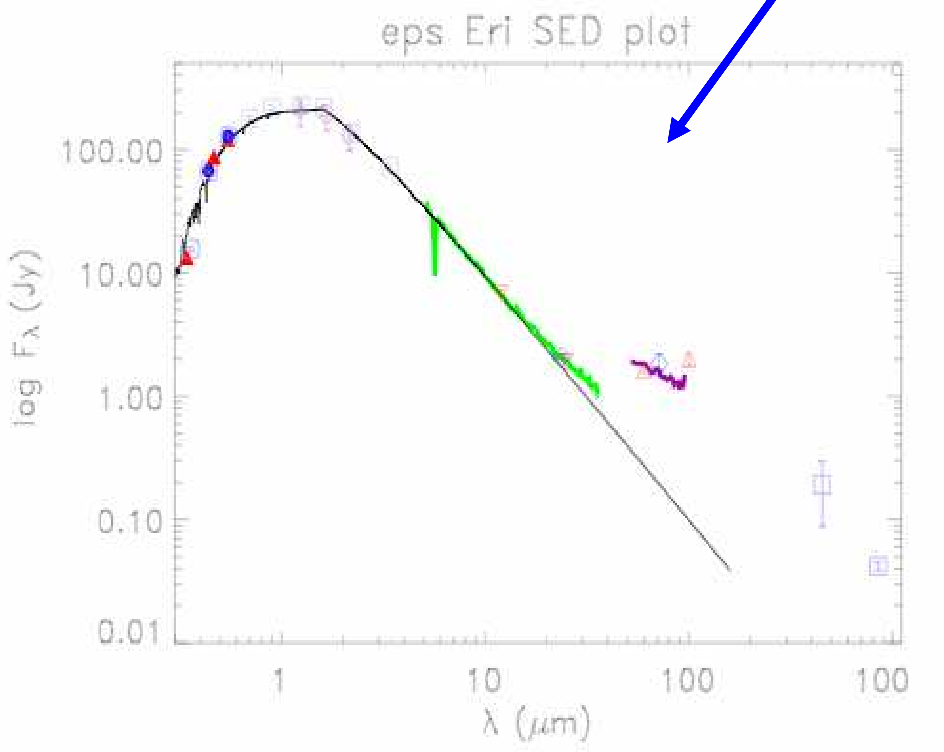




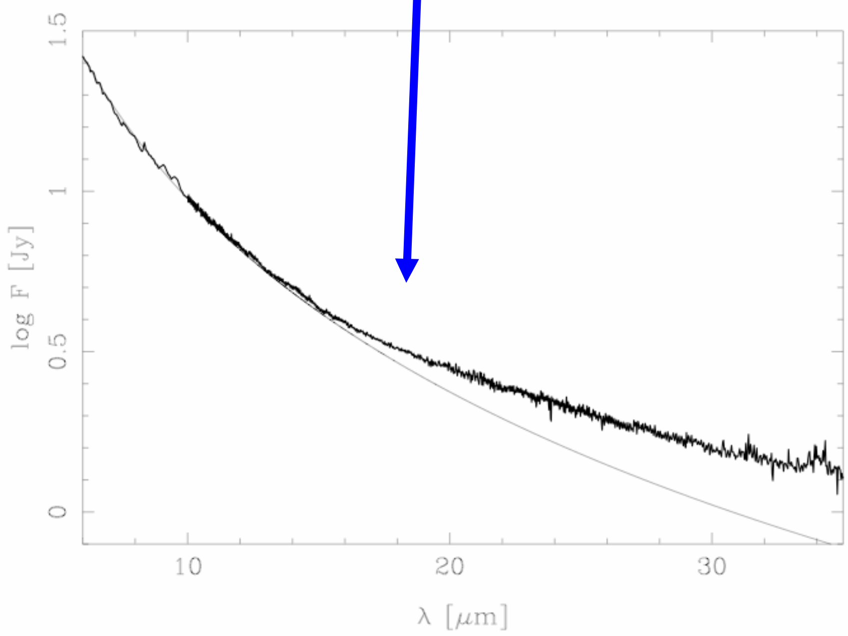


Eps Eri results from Dana Backman, David Wilner, et al. [in prep]. At 24um source is unresolved

Eps Eri - Composite SED with Kurucz photosphere

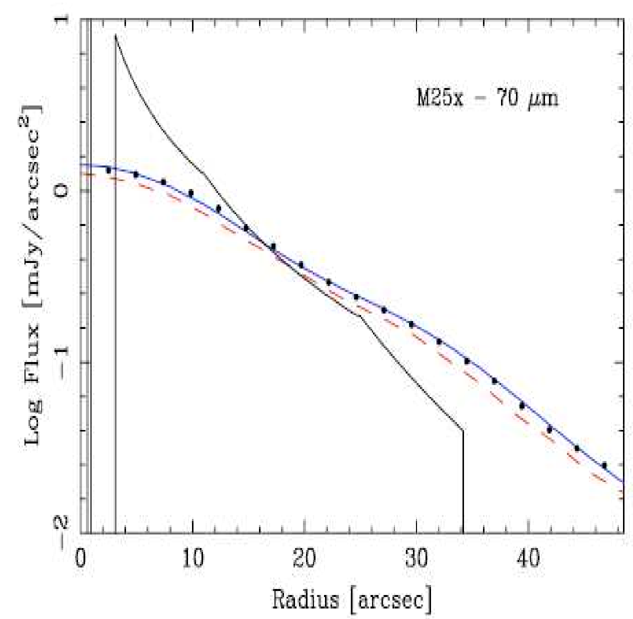


Excess from 10 to 20um requires hot dust very near star



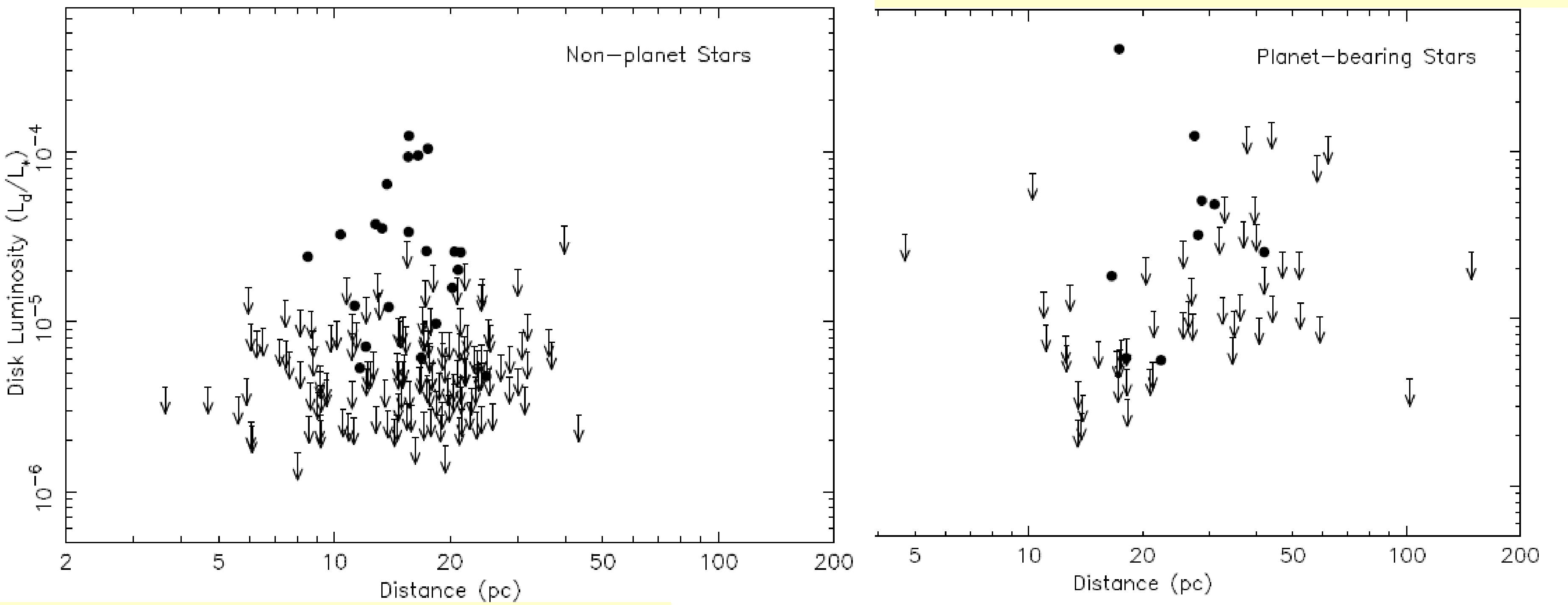
Implications – Backman et al, in prep

- Source region of mixed icy + silicate grains in sub-mm ring, r = 35 - 80 AU -- Kuiper Belt analog. ~0.03 Earth masses
- Total mass of 10 km-diameter parent bodies needed for collisional equilibrium ~ 10 M(earth)
- Grains drift inward by P-R drag; a planet with mass ~ 0.1 Mjup at 35 AU acts as filter to large, slow grains
- ~ 6x10-4 Earth masses of smaller particles extend inward to ~10 AU
- Warm inner belt at 2-3 AU contains ~10-7 M(earth)
- Candidate r.v. planet supposedly at r ~ 3.4 AU associated with inner warm belt, BUT planet eccentricity cannot be 0.7 as suggested by Benedict et al.



Lesson learned: Images are much more constraining on the models than is the SED alone. Any imaging possible from ALMA, even at long wavelengths, will be very valuable!

Debris Disks Around Planet and Non-Planet Bearing Stars



Results taken from paper by Bryden et al. Although results may look superficially similar, there are interesting impications because stars with planets are relatively rare and hence more distant

70um Detection Statistics – Are Debris Disks Associated with Planets?

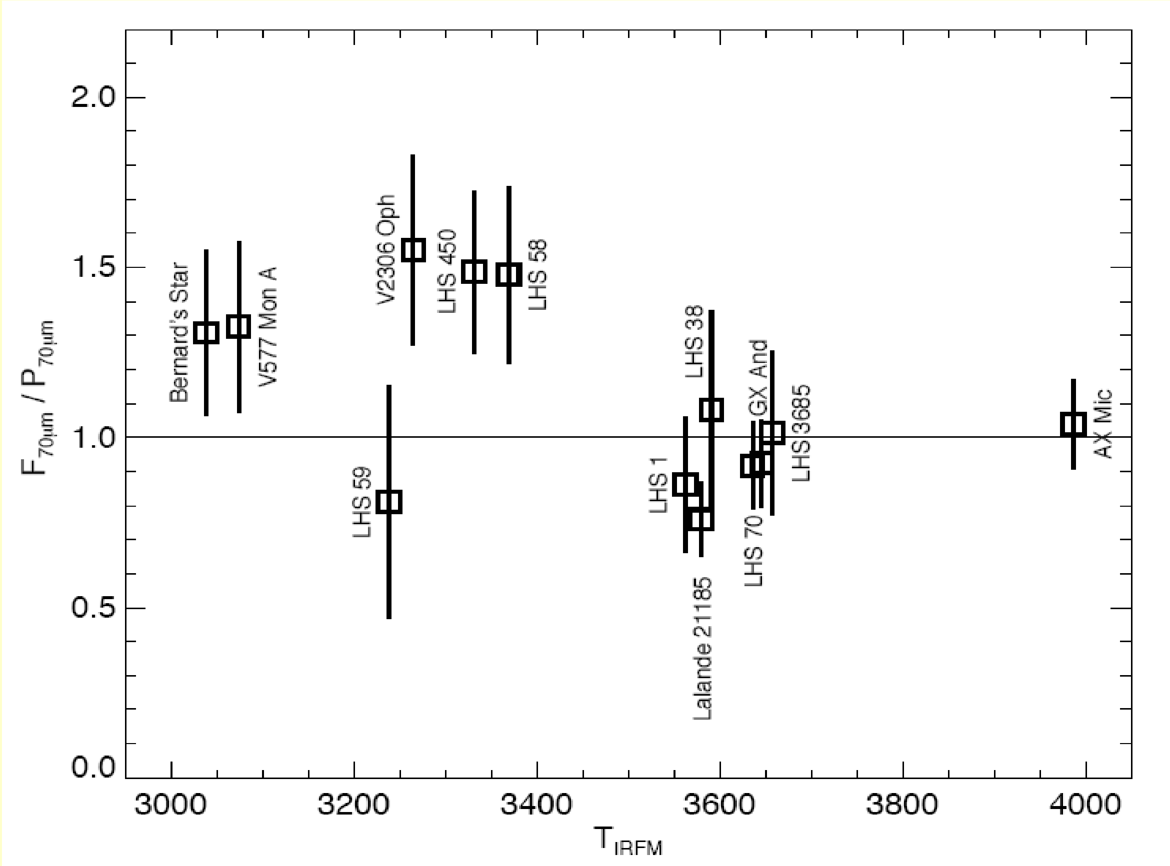
Table 2. Summary of Detection Statistics at 70 μm

	Stars without known planets	Stars with known planets[a]
Detection of any significant IR excess	22/163 (13 ± 3%)	10/58 (17 ± 5%)
Detection of strong excess ($L_{dust}/L_\star > 5 \times 10^{-5}$)	5/163 (3 ± 1%)	5/52 (10 ± 4%)
Probability that planet/non-planet distributions are the same	13%	

[a]For consistency, only solar-type stars (F5-K5) are considered

Based on over 200 stars with L[dust]/L* as low as 1e-5. Suggested explanations for increased dust around planet-bearing stars include denser disks, creation of Kuiper Belt by planetary migration, and resonant excitation of planitesimals similar to effects responsible for Late Heavy Bombardment (Geoff Bryden, Chas Beichman et al, in press).

70um Photometry of M-Stars [Gautier et al]

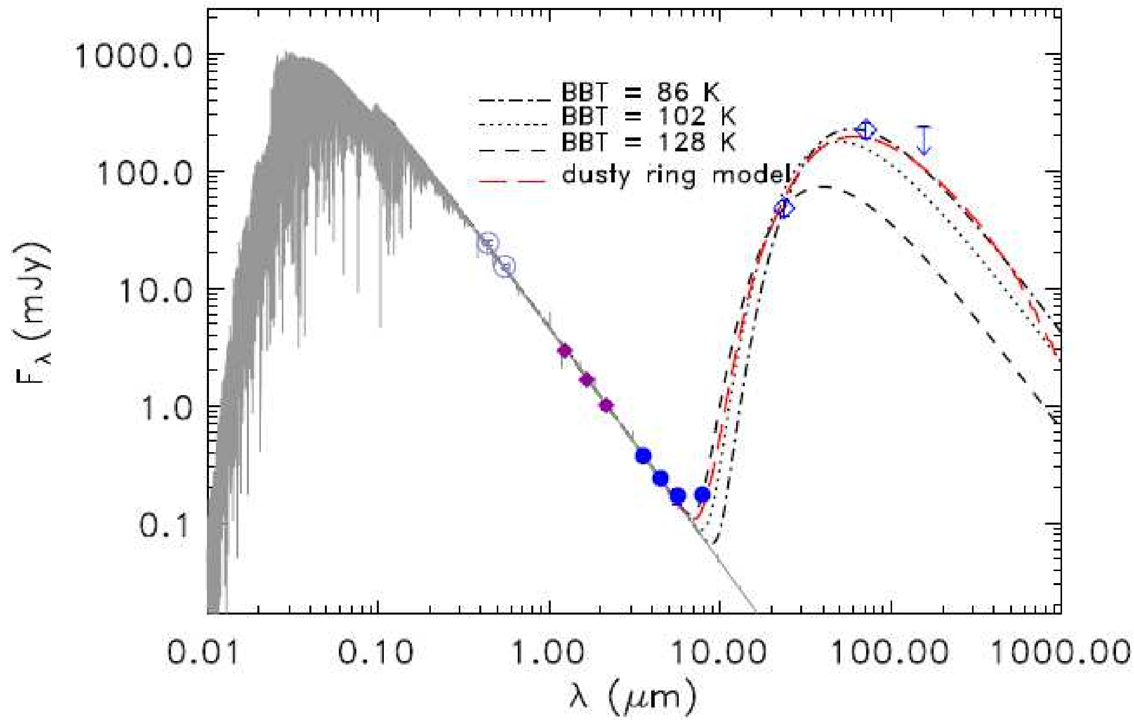


No definite excess around field M dwarfs at 24 [N=62] or 70um [see above]. Limits just allow average fractional luminosity to be about the same as for FGK stars, but implied dust masses are much lower. In fact, no excess yet reported for any field star later than ~K3.

Post Main Sequence Disks – What happens to solar system as star evolves?

The central star of the Helix Nebula, a hot, luminous White Dwarf, shows an infrared excess attributable to a planetary debris disk

The Debris Disk in the Helix Nebula
Su et al, 2007



Helix central star shows debris-disk like SED with Ld/L* ~ 2e-4 and estimated size and mass of 75au and 0.11 M[earth]. Looks like a proper debris disk to me. Has a Kuiper Belt survived the post main-sequence evolutionary throes?

White Dwarf Disks (Jura et al)

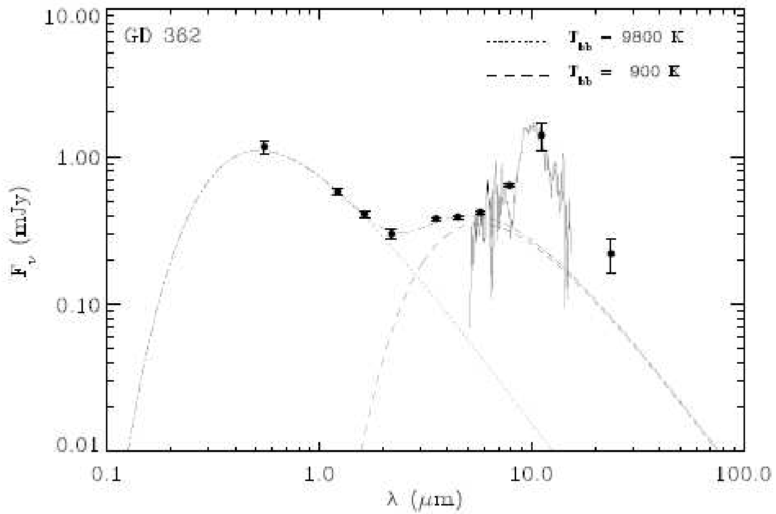
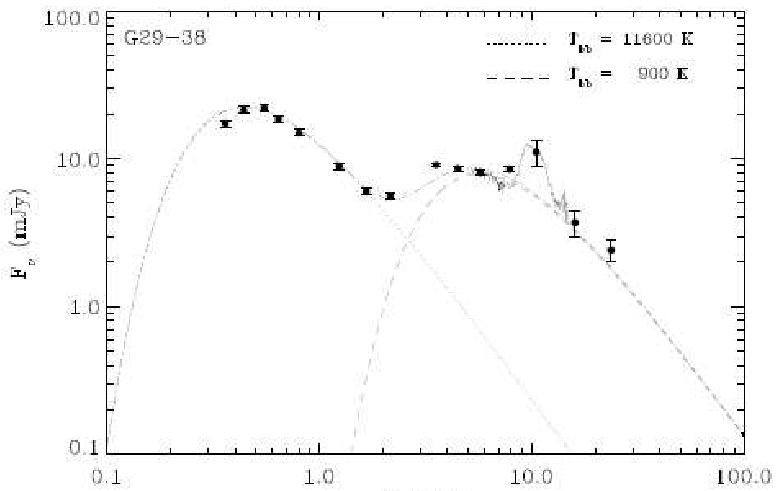
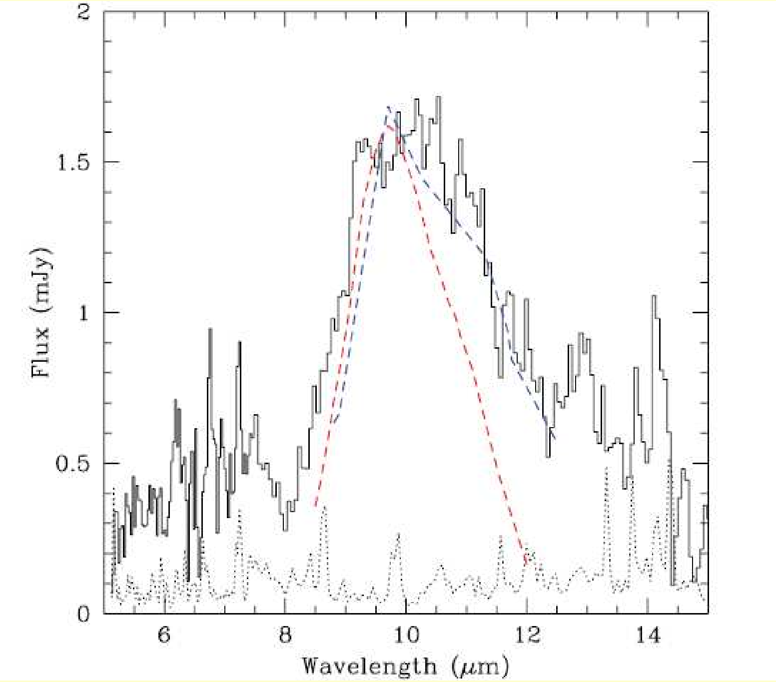


Figure 1. Spectral energy distribution of GD 362. Shown are data from all three *Spitzer* instruments.





IR excess seen around ~15% of white dwarfs with metal rich atmospheres – tidal destruction of an asteroid?

Spitzer Warm Mission*

Warm mission [starting mid 2009] includes:

- IRAC Bands 1&2 with current sensitivity
- Robust program of research using archive from cryo mission and from warm mission
- Five year duration plus one year of final processing

Workshop in early June discussed scientific opportunities

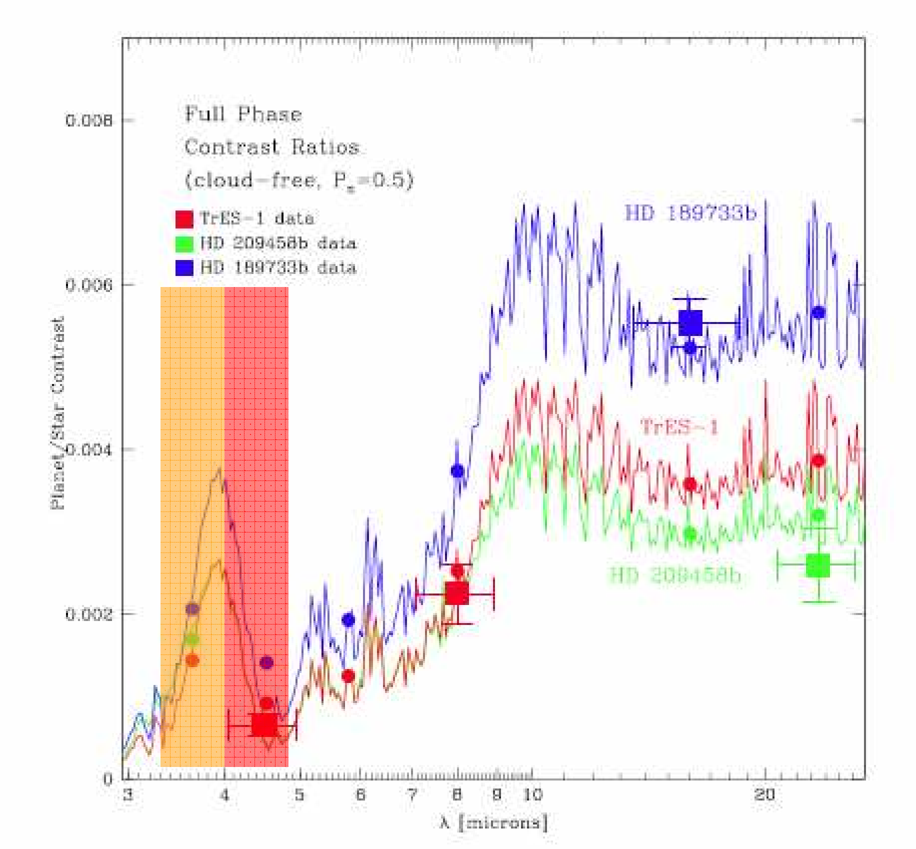
Purpose of Workshop: Help to articulate science case for warm Spitzer mission as input to Senior Review in Spring 2008

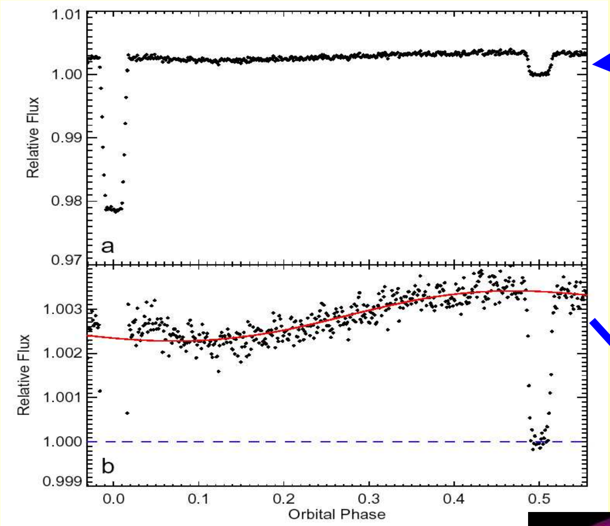
Animated discussion showed lots of enthusiasm for scientific potential of warm mission

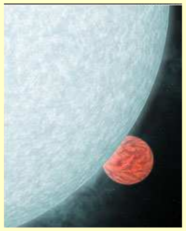
Consensus assessment: *Warm mission offers unique opportunity for in depth exploration of key scientific questions while also enabling study of emerging scientific problems and supporting other NASA missions*

*[http://ssc.spitzer.caltech.edu/mtgs/warm/]

Transiting Exoplanets

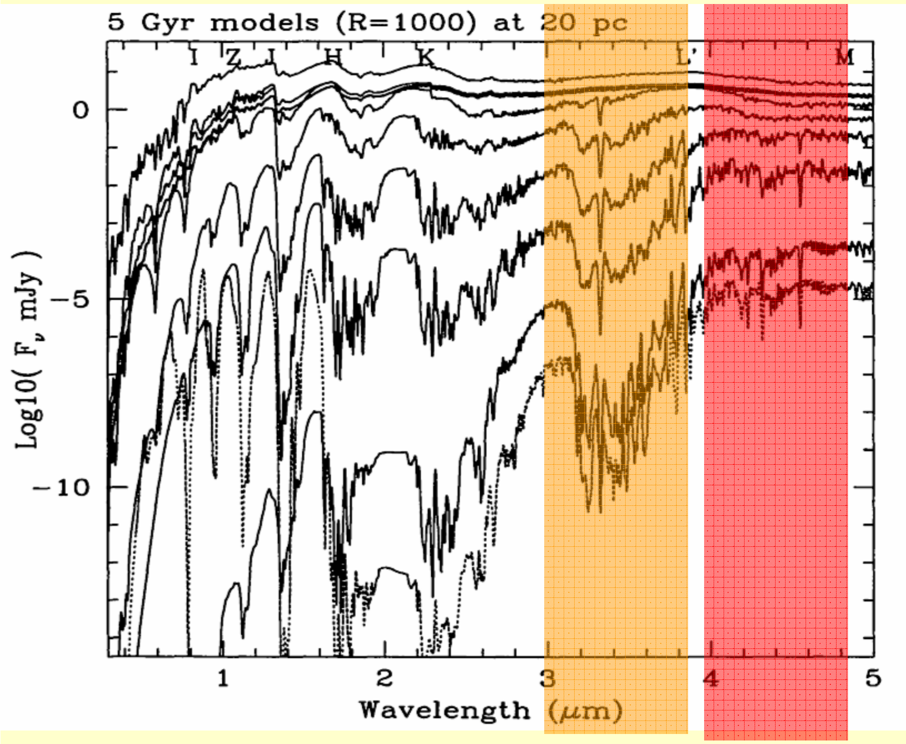


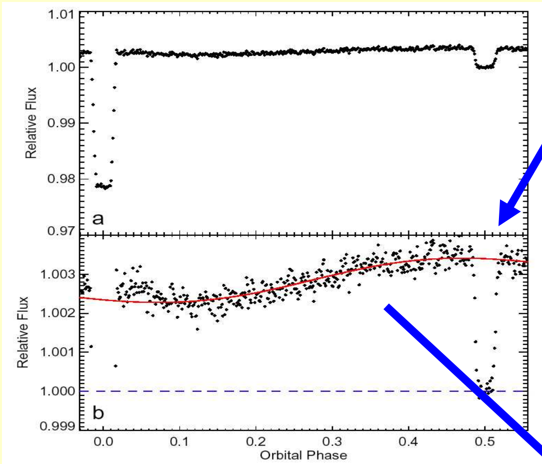




Warm Spitzer's capabilities for studying exoplanets (L) are shown by Spitzer measurement of temperature distribution on exoplanet (R). Monitoring each of ~100 transiting giant exoplanets over ~50 hrs [5000 hours total] will vastly increase understanding of exoplanet atmospheres while also searching for transits of resonantly coupled terrestrial planets.

Key Science Area #2: Exoplanets





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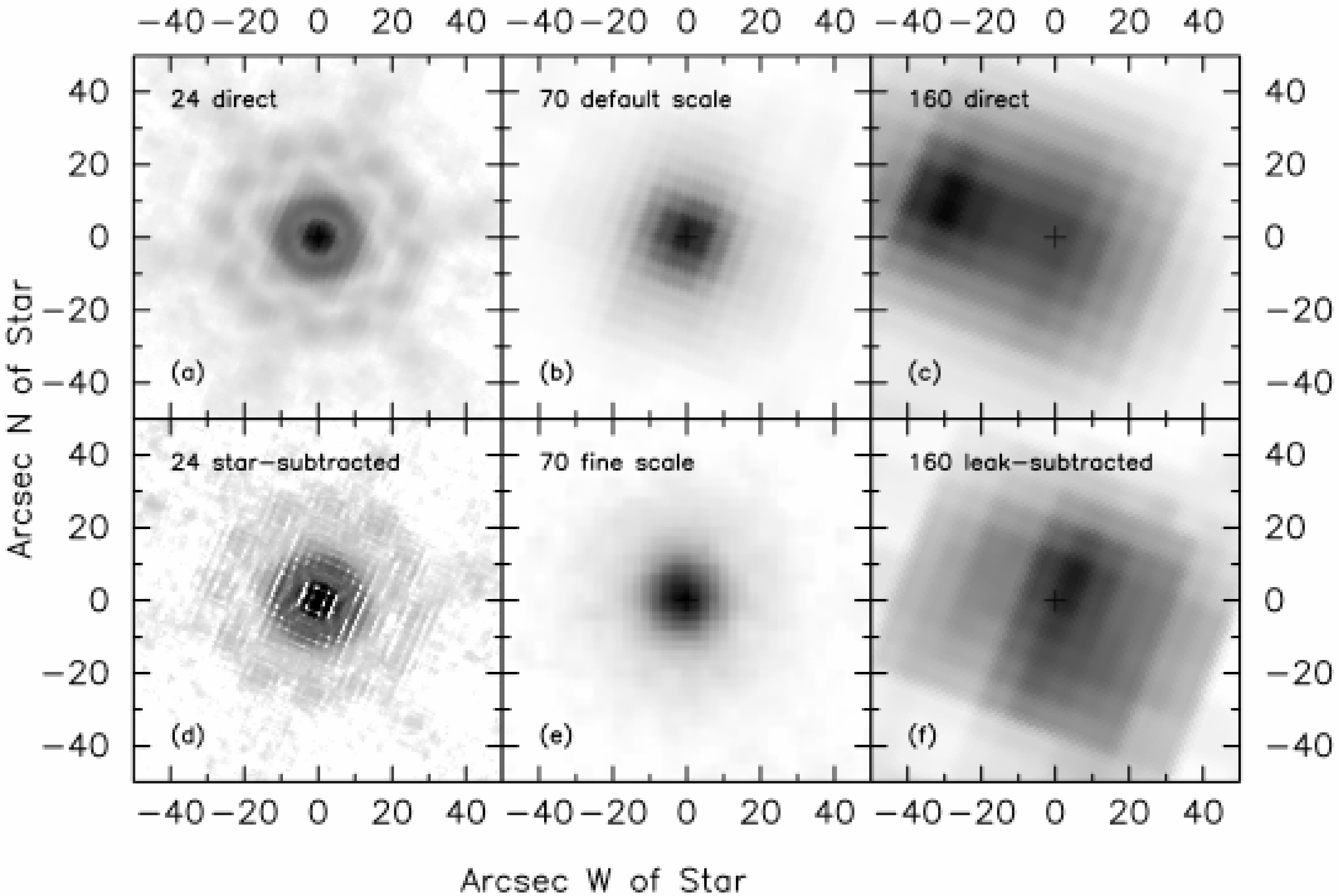
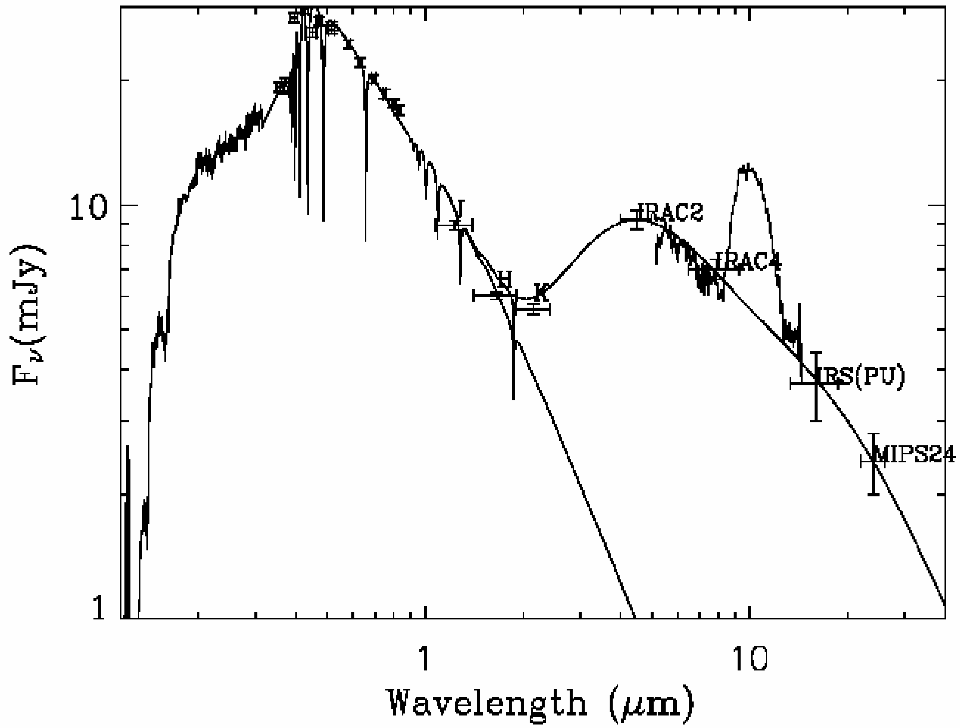
Eps Eri – Spitzer MIPS Images @ 24, 70, and 160um



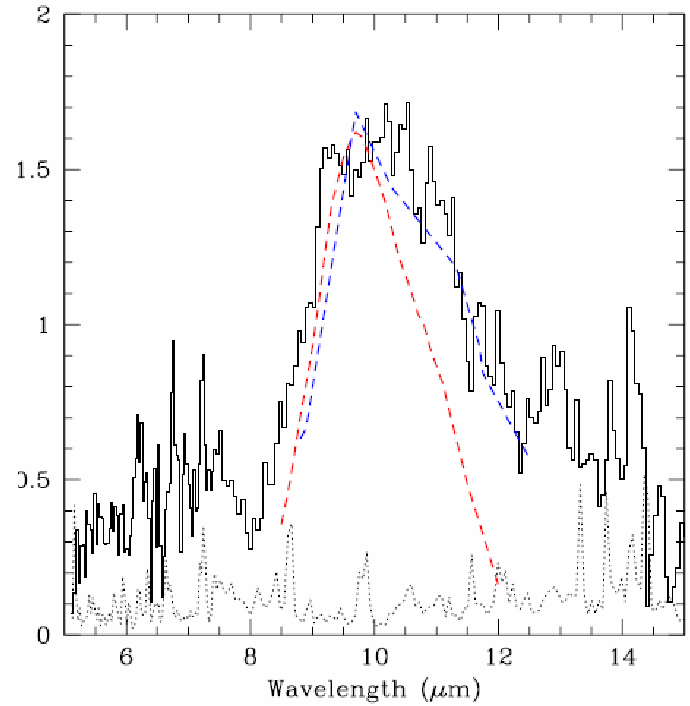
70um image shows bright central core plus diffuse halo. Central void seen in submm not seen at 70 or 160um

One possible model (NOT unique)

- **Previously known sub-mm Ring, r = 35 - 80 AU**
  - *Detected in 350-850 μm images (~ invisible in far-IR)*
  - *Large icy grains, typical radius = 300 μm*
  - *Total mass ~ 3 x 10^{-2} Mearth*
- **Broad far-IR Disk, r = 10 - 110 AU**
  - *Detected in 70, 160 μm images (~ invisible in sub-mm)*
  - *Material at sub-mm ring position, plus inner "skirt"*
  - *Medium-size SiO grains, typical radius = 15 μm*
  - *Total mass ~ 6 x 10^{-4} Mearth*
- **Warm inner Belt, r = 2 - 3 AU**
  - *Detected in IRS spectrum*
  - *SiO grains, typical radius = 3 μm*
  - *Total mass ~ 1 x 10^{-7} Mearth*



F_ν(mJy)
10
1
1
10
Wavelength (μm)
J
H
K
IRAC2
IRAC4
IRS(PU)
MIPS24



2
1.5
1
0.5
0
6
8
10
12
14
Wavelength (μm)

Modelling the Eps Eri SED

- Match over-all system SED from 10-850 μm, including “plateau” at 20-30 μm
- Match observed 70, 160, 350 μm radial profiles (and lack of resolution at 24 μm)
- Need high sub-mm emissivity but low far-IR emissivity in “ring” component seen at 350 μm and 850um.
- Need high far-IR emissivity but low sub-mm emissivity in component extending from inside ring across ring, seen at 70 and 160 μm

Lesson learned: Images are much more constraining on the models than is the SED alone. Any imaging possible from ALMA, even at long wavelengths, will be very valuable!

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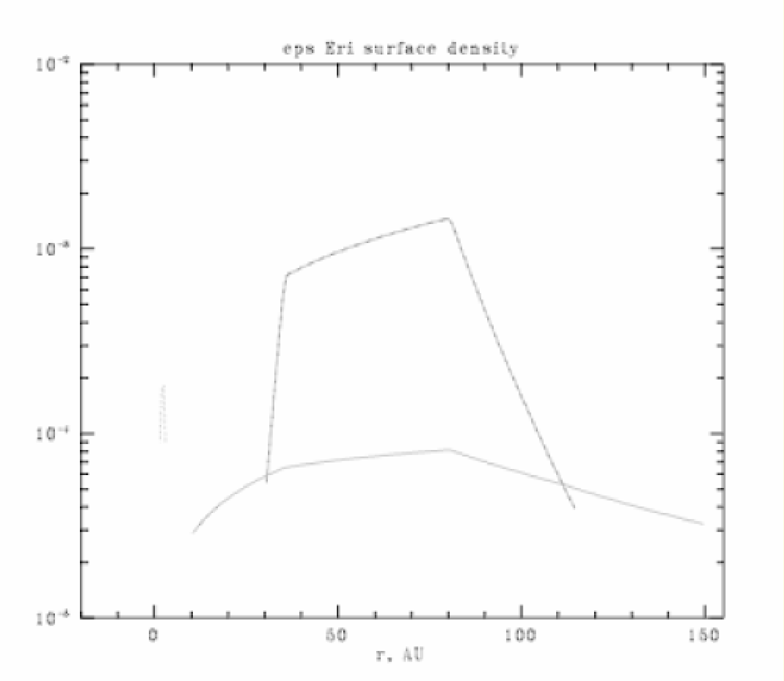
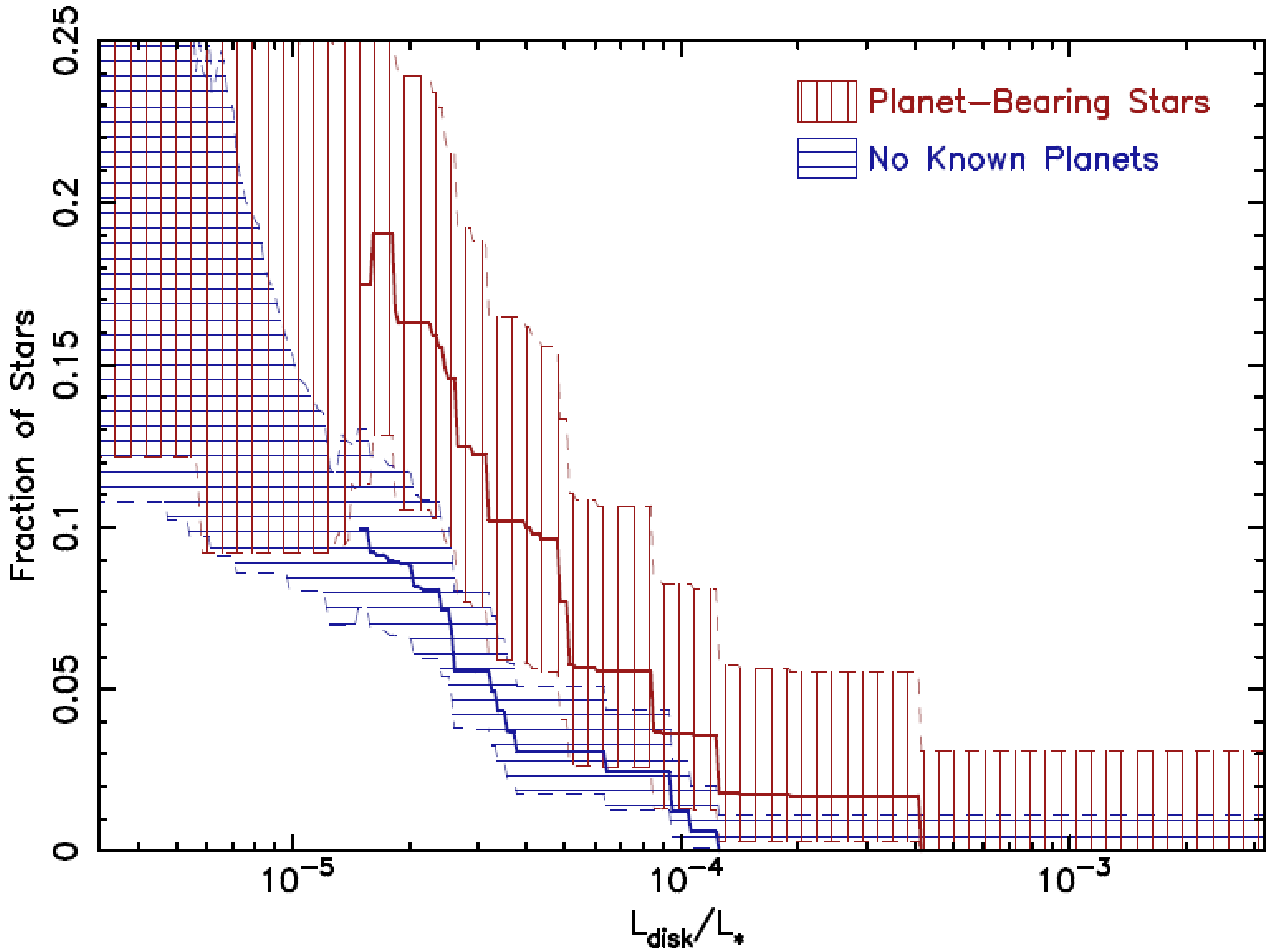
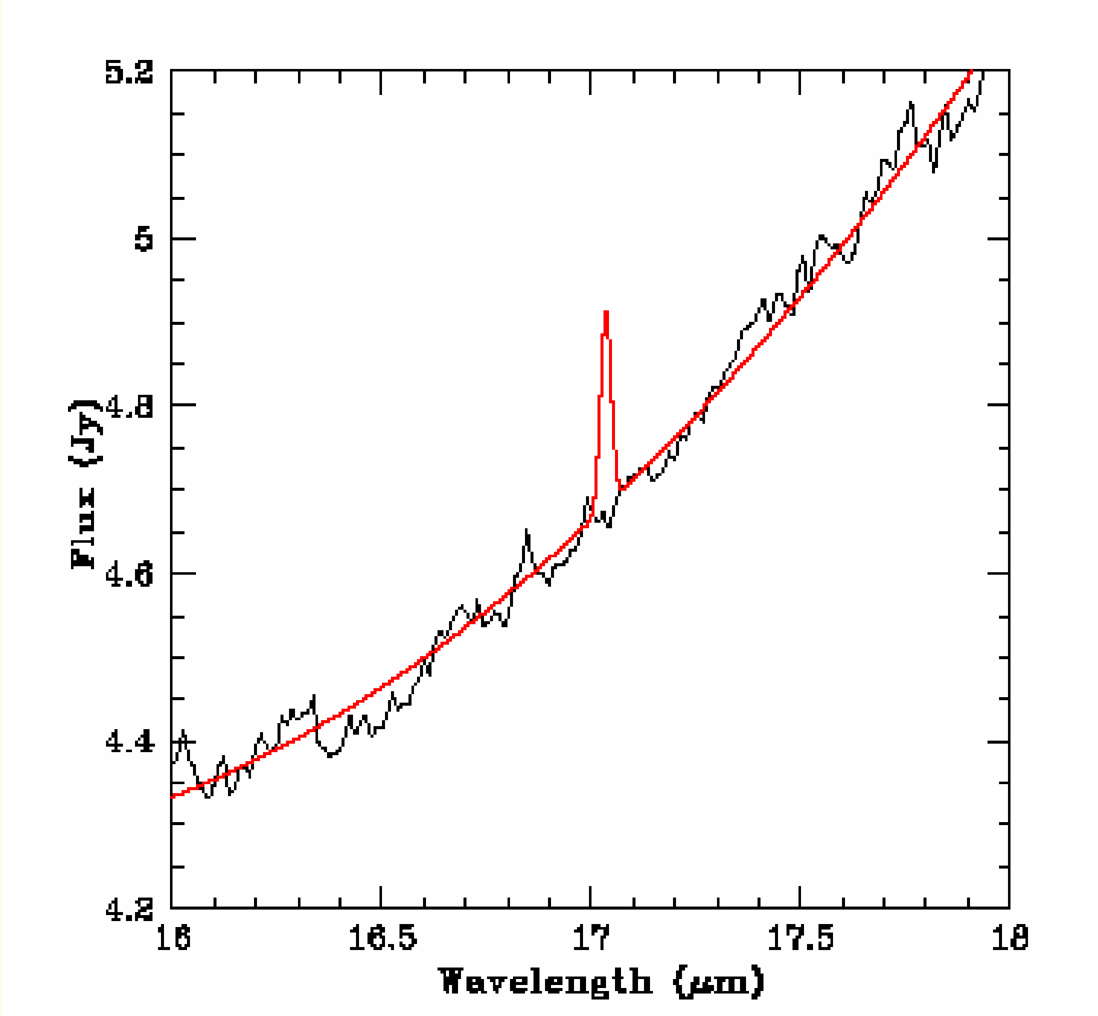


Planet-Bearing Stars appear dustier than those without presently known planets



mww



Spitzer data on Beta Pic fail to confirm H2 detection reported from ISO. Less than 17 Mearth if T=100K. Beta Pic does show atomic lines. Chen et al suggest NaI produced by photon-simulated desorption from dust.