Debris Disks – from Spitzer to Herschel and Beyond

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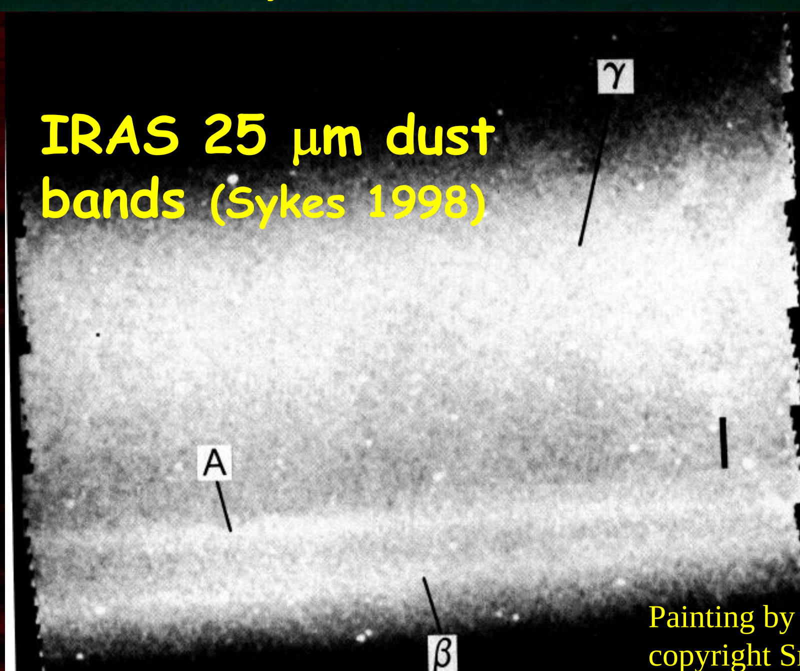
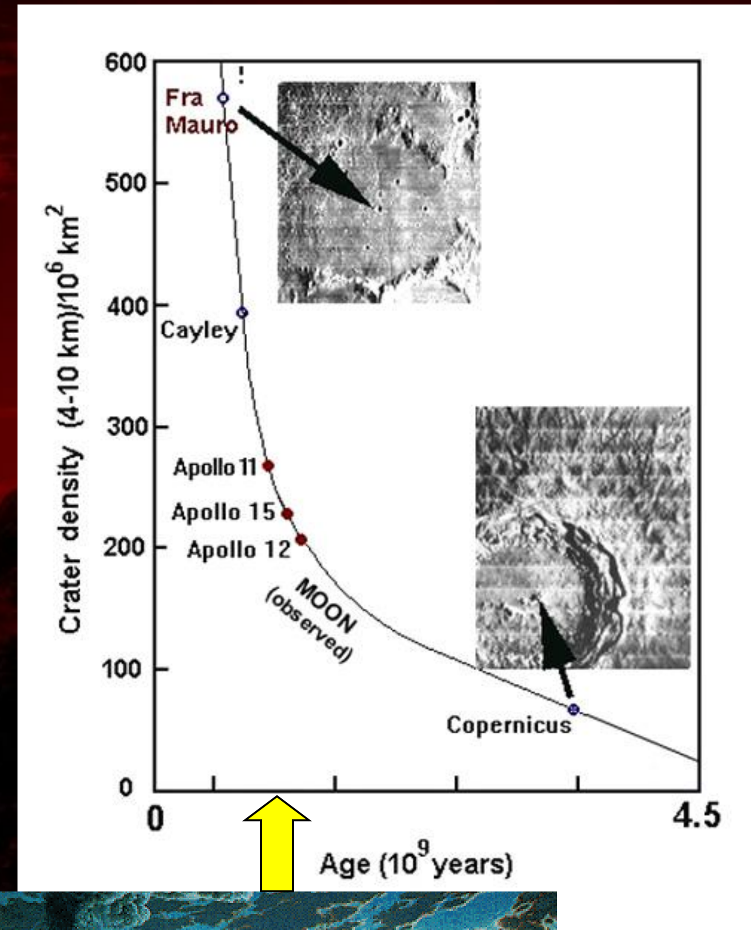
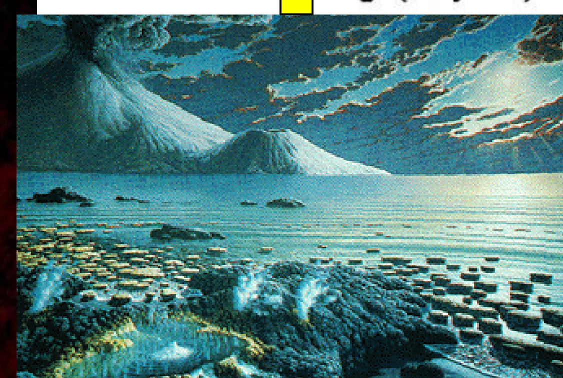
Our neighborhood debris disk

There was a huge amount of collisional activity and debris generation in the first few 100 Myr

Photo by Mark Johnston

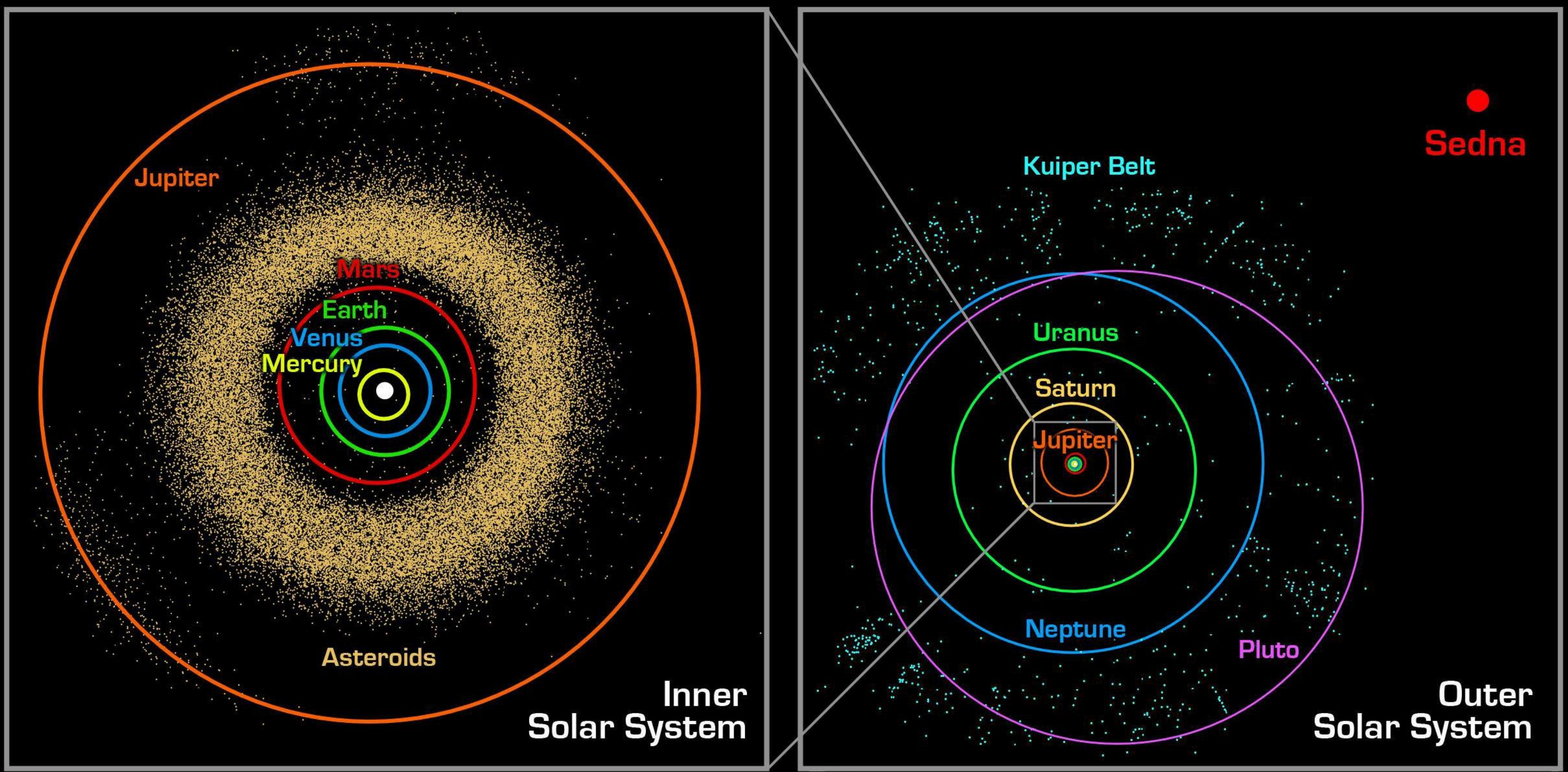






Painting by Peter Sawyer, copyright Smithsonian Institution

We actually have two of them, both maintained by collisions among planetesimal parent bodies. The asteroid parent bodies have relatively short dynamical time scales. The Kuiper Belt has a much longer dynamical time scale and is therefore evolving much more slowly. In both cases, the dust is lost fairly quickly and must be replenished.



What can we learn about planet system evolution from the debris disks around other stars?

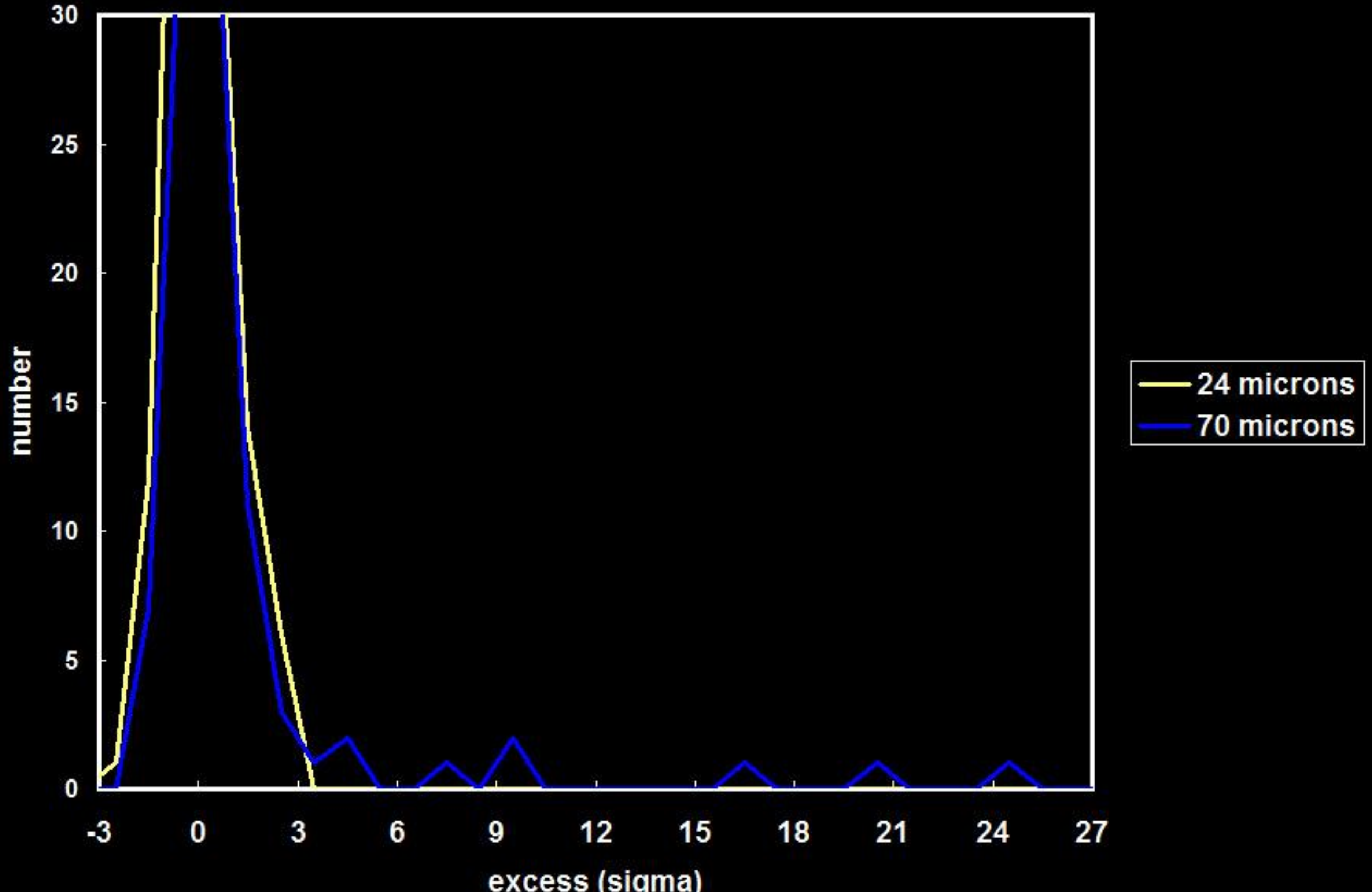
Spitzer has detected hundreds them through the infrared excess emission by warm dust.

How does debris disk activity decay? Do we see evidence for different dynamical time scales as between the asteroid and Kuiper belts? Does the asteroidal activity die away in 100 Myr?

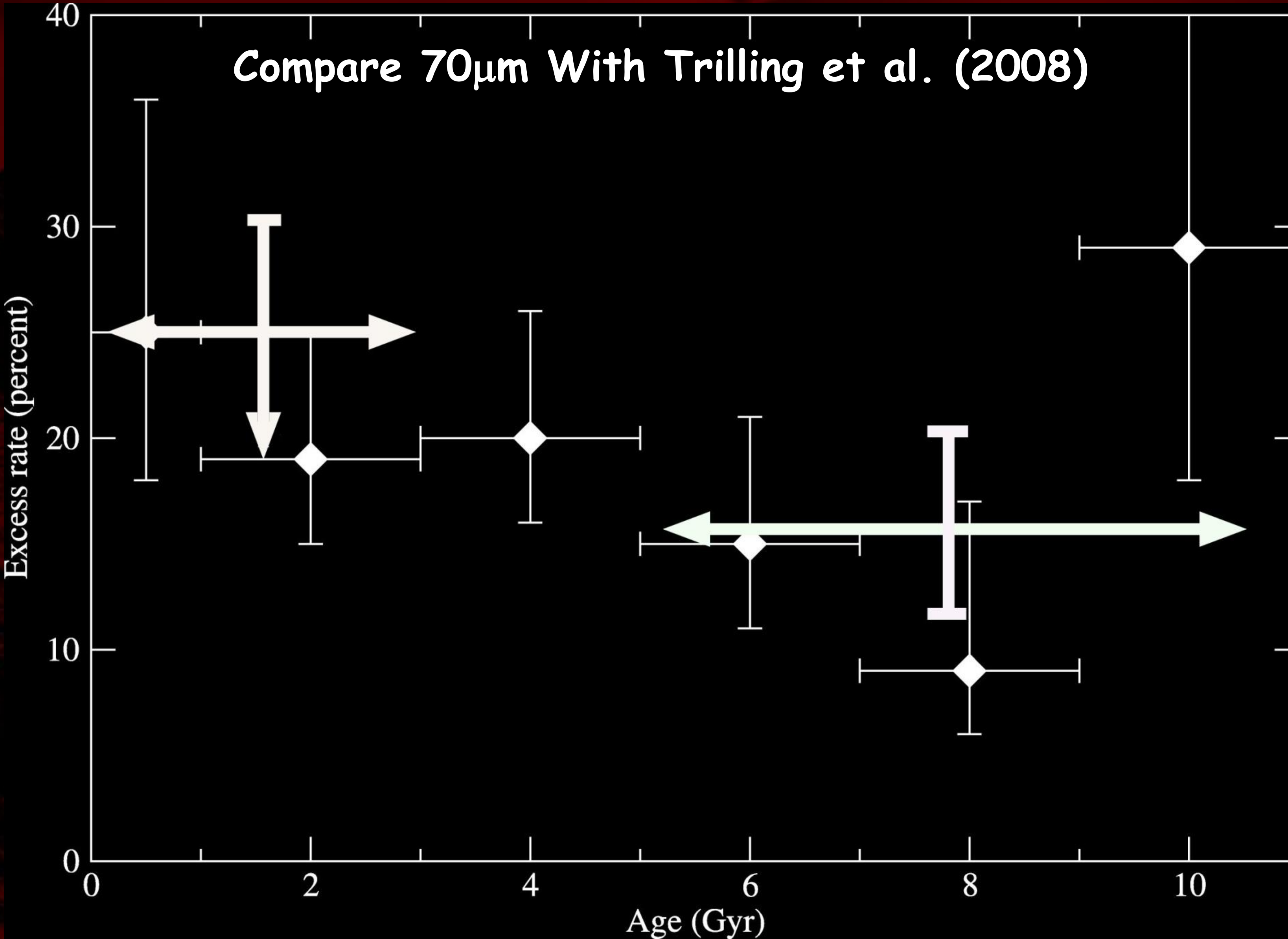
How Debris Disk Excesses Behave With Age

- A small contamination by young stars can bias the results toward more excesses
- Identifying old stars (mid-F to early K)
  - Validate chromospheric activity ages on HR diagram
  - Select stars from full sample above 5 Gyr isochrone
  - Purge sample of stars < 5 Gyr by chromospheric activity
- Final sample is 122 stars
- Excess properties:
  - No 24μm excesses above 10% of photosphere
  - $\geq$ 16% have excesses at 70μm
  - Identical to samples dominated by younger stars
    - 16.4%, Trilling et al. (2008)

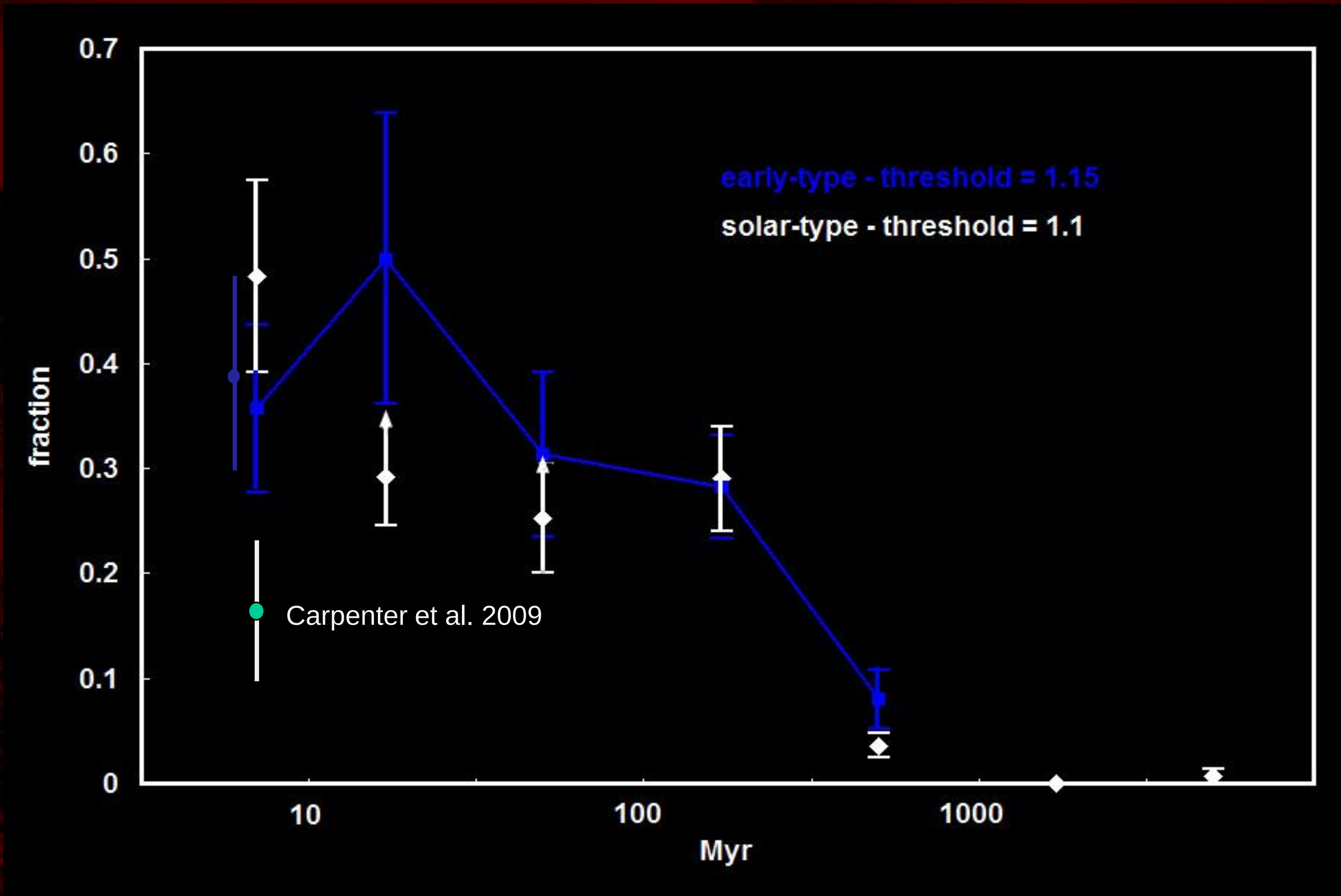
Excess Incidence for Stars > 5 Gyr Old



Number of 70μm Excesses Hardly Decays with Stellar Age

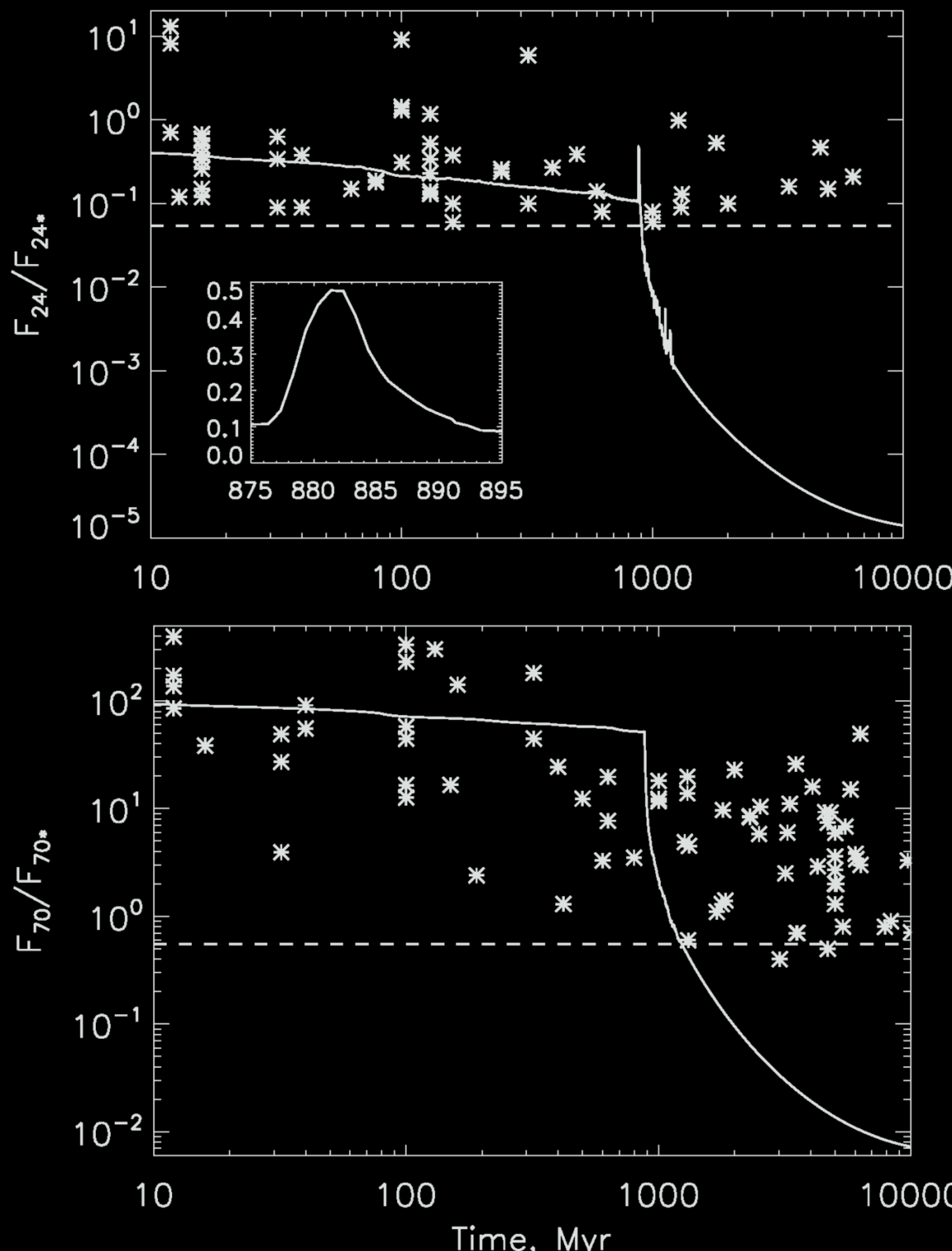


Number of 24μm Excess Stars Decays Dramatically
High-weight point at 120MYr from Pleiades (Sierchio et al. in prep.)



Booth et al. (2009): Modeled effect of the Nice model of the Late Heavy Bombardment on the 24 and 70μm excesses of the Solar System

However, with better ages, we know that their "old" points at 24μm are incorrect, but at 70μm the picture is more or less accurate.



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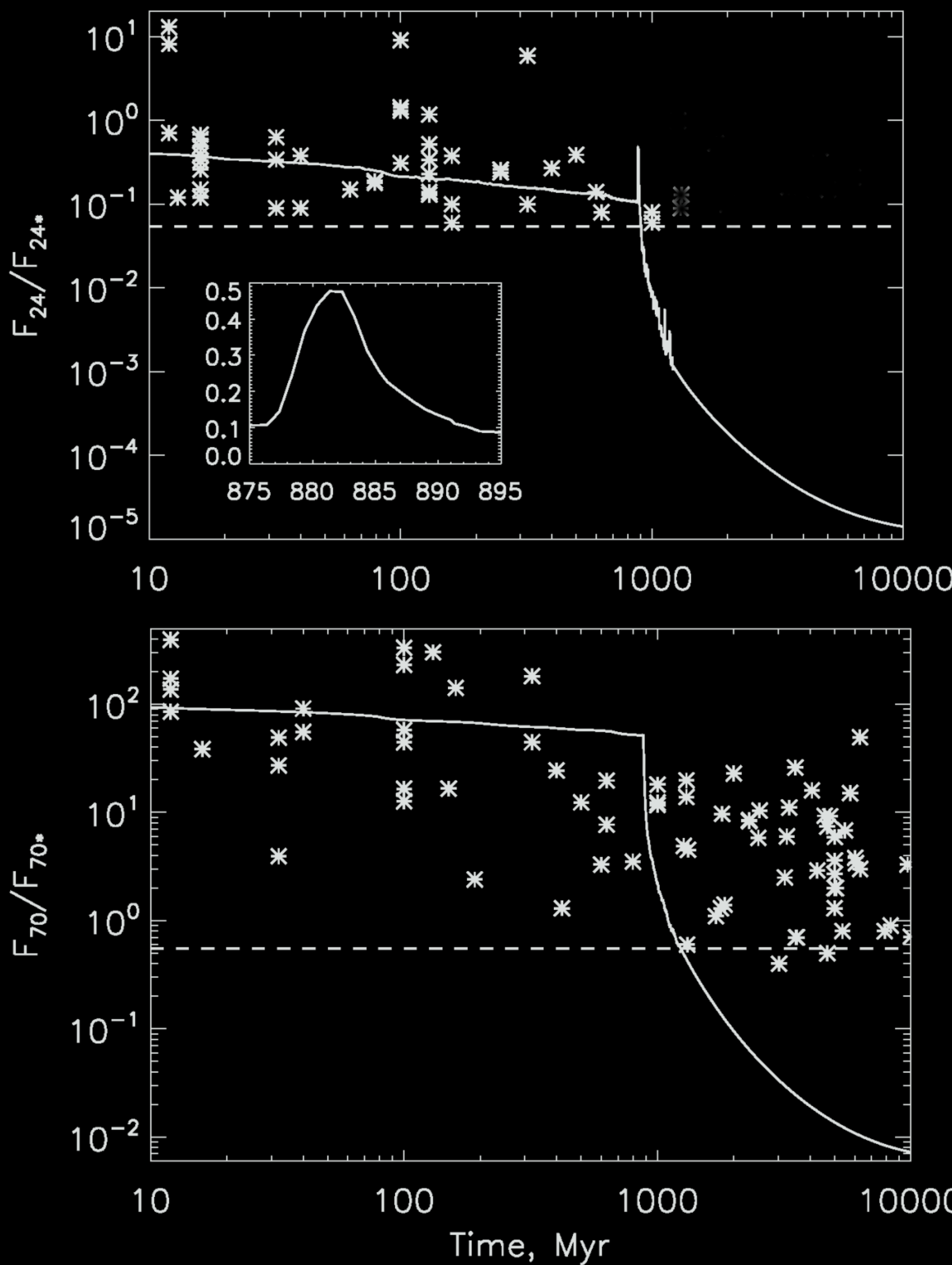
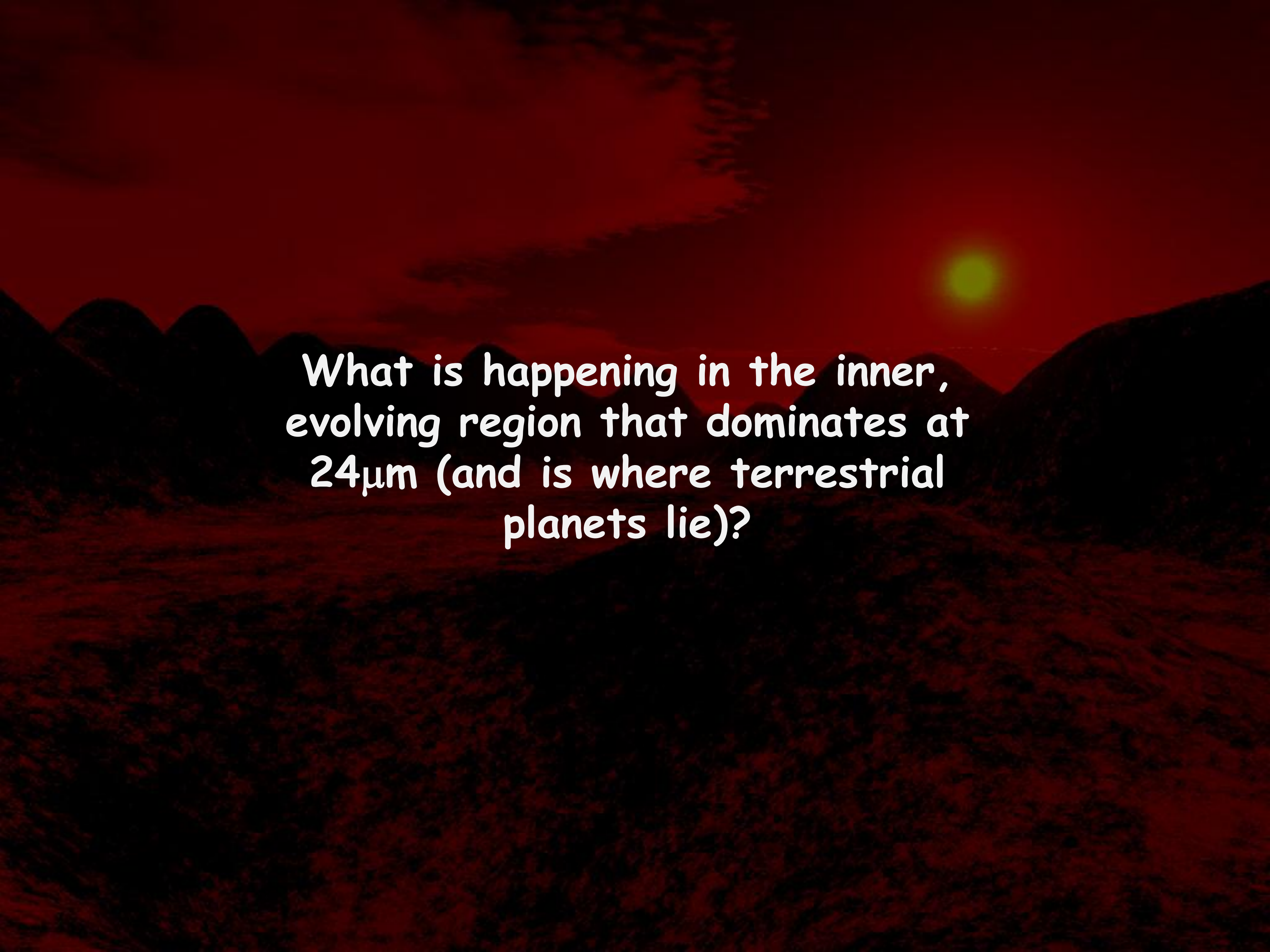
However, with better ages, we know that their "old" points at 24μm are incorrect, but at 70μm the picture is more or less accurate.

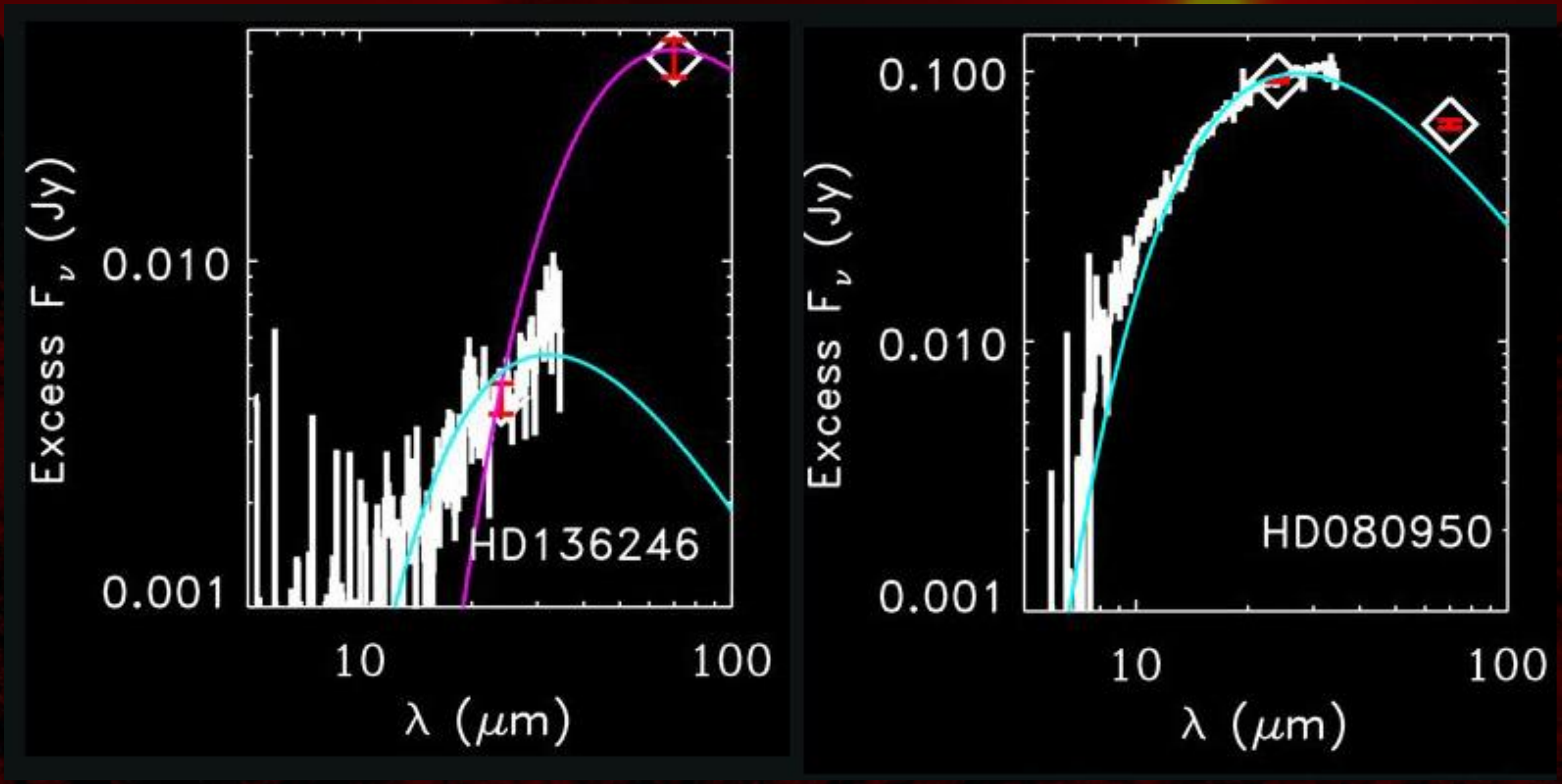
So either the Nice model is not quite right, or LHBs are rare. Herschel will test these possibilities further.



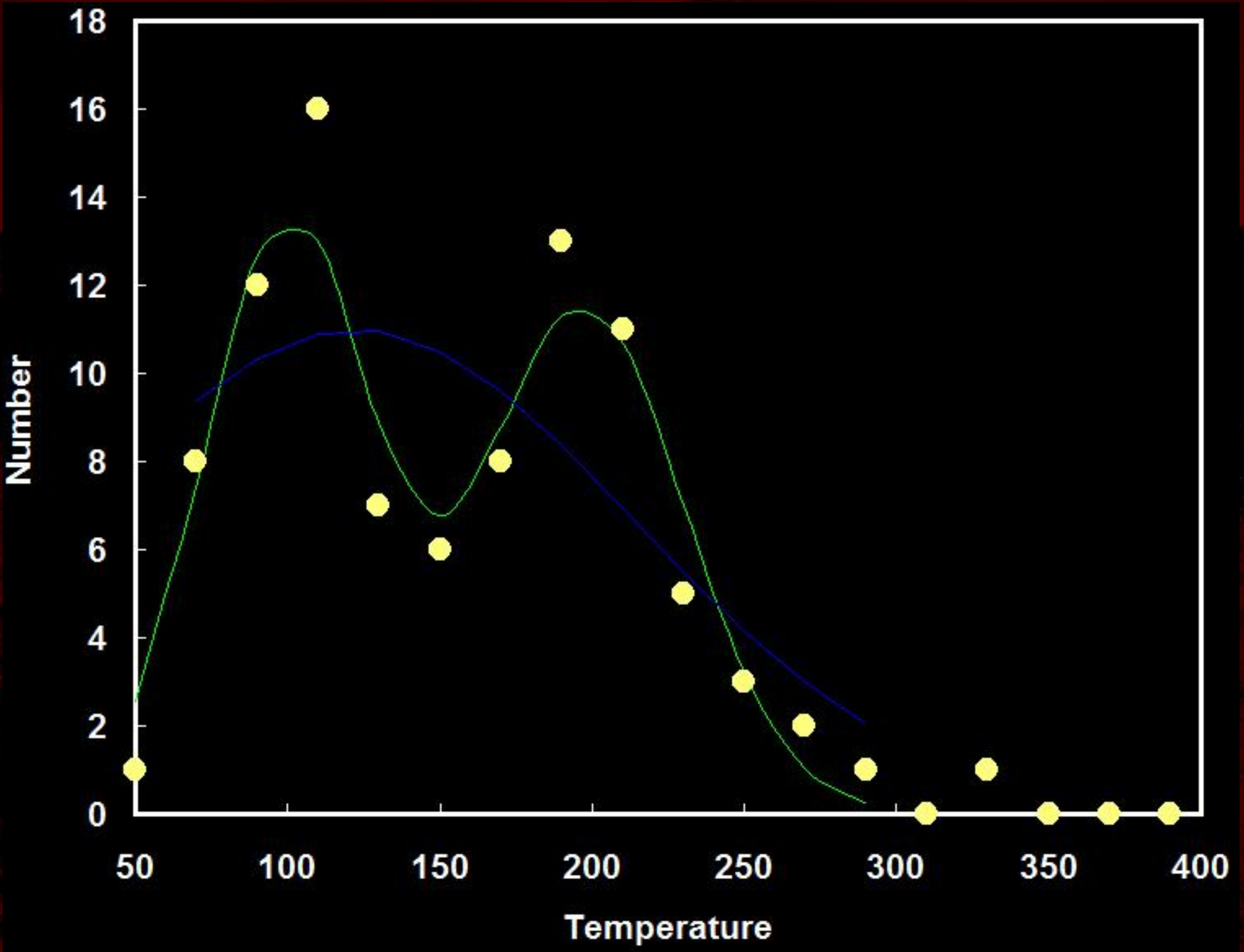


What is happening in the inner, evolving region that dominates at 24μm (and is where terrestrial planets lie)?

A-star excesses show a range of temperatures
(from Morales et al. 2009)



The temperature distribution is broad and hints at being bimodal



Solar-Type stars are characterized by cold excesses

But is this because they are on average older?
(Morales et al. in prep.)

- Morales et al., in prep: sample of 103 sources:
  - Spectral type K4 thru F5
  - MIPS 24 μm photometry
  - Estimated Ages up to 1 Gyr
  - Have IRS Lo-Res data
- 20 have MIPS 24 μm excess
- 24 μm excess confirmed by IRS in all but one

➔ the sample consist of 19 sources, w/ MIPS 24 μm excess

  - spectral type K0 thru F5
  - Ages 40-900 Myr

Warm systems are remarkably similar in temperature, A stars vs. solar-type stars (assuming blackbody grains)

w/ 70 μm detections

- Solar Type (9)
  - Median T_{dust_in} ≈ 188 K (Median R_{in} ≈ 2.5 AU)
  - Median T_{dust_out} ≈ 54 K (Median R_{out} ≈ 20 AU)
- A type stars (27)
  - Median T_{dust_in} ≈ 199 K (Median R_{in} ≈ 9.7 AU)
  - Median T_{dust_out} ≈ 58 K (Median R_{out} ≈ 114 AU)

No 70 μm detections

- Solar Type (10)
  - Median T_{dust} ≈ 178 K (Median R_{dust} ≈ 3.0 AU)
- A type stars (23)
  - Median T_{dust} ≈ 204 K (Median R_{dust} ≈ 12 AU)

Are the similarities telling us more about grain transport and destruction than disk underlying structure?

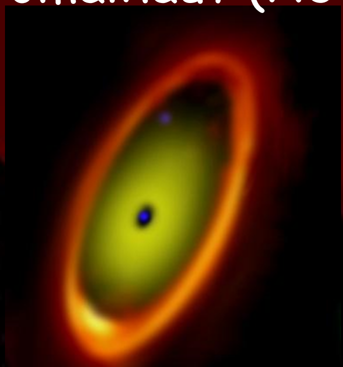
Resolved Disks and SEDs

- Inner and outer zones
- Disks and Planets
- Outflows and weakly bound grains
- General behavior patterns

Inner vs. Outer Zones in Debris Disks

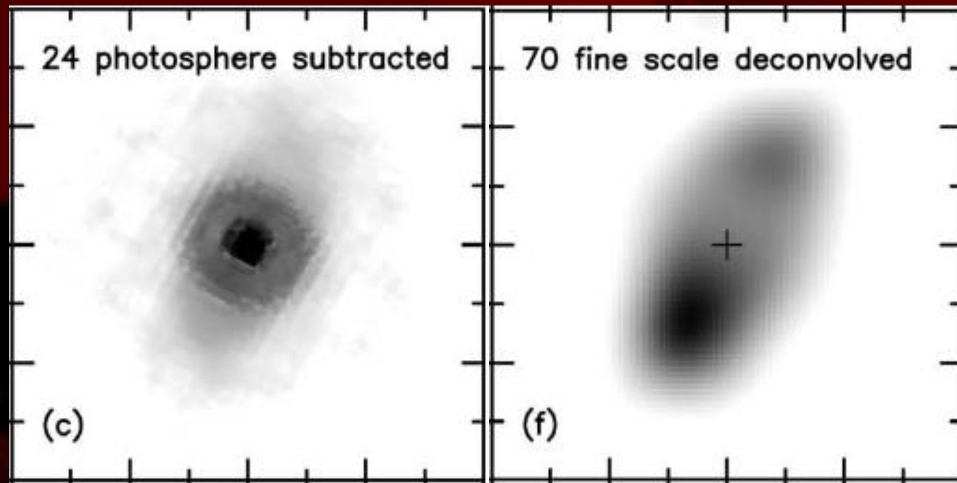
Illustration | MIPS 24 μm (PSF-subtracted) | MIPS 70 μm | SCUBA 850 μm

Fomalhaut (A3V)

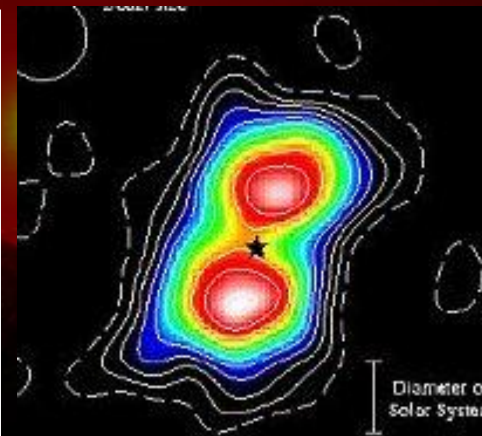


JWST view

7.8 pc

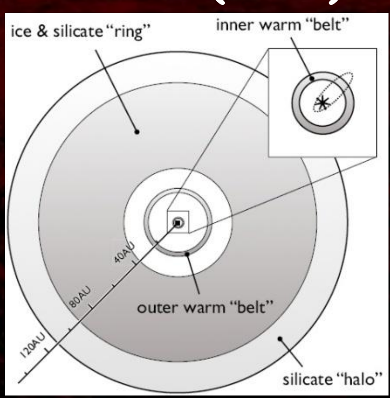


Stapelfeldt et al. 2004

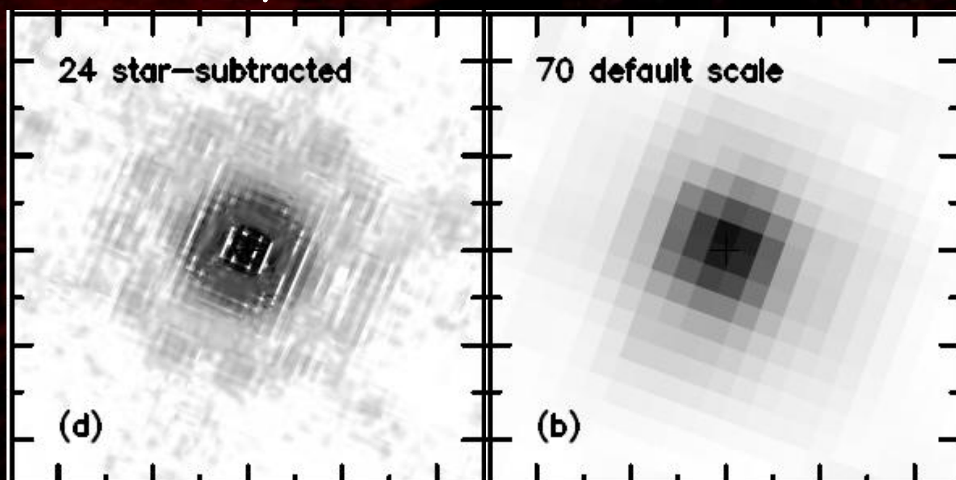


Holland et al. 1998

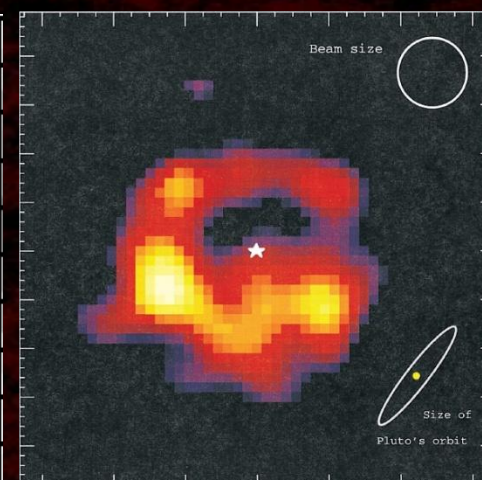
ε Eridani (K2V)



3.2 pc

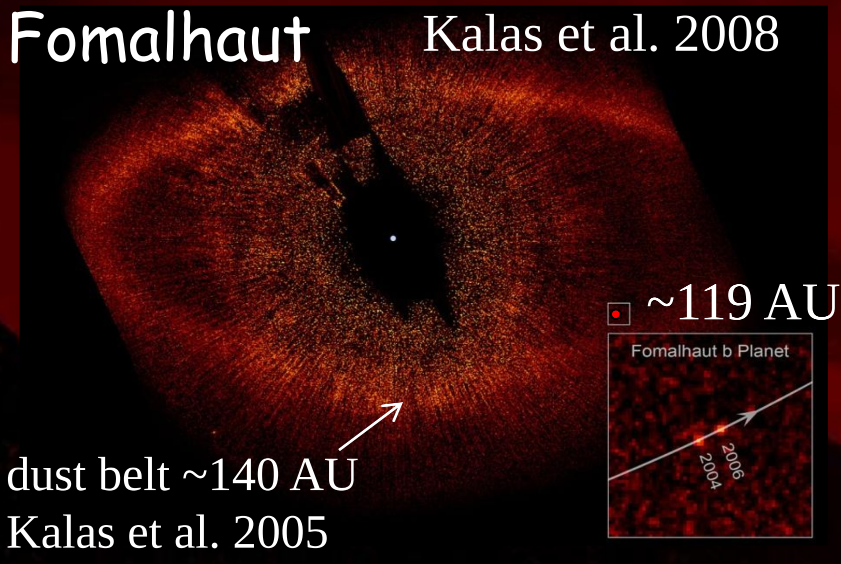


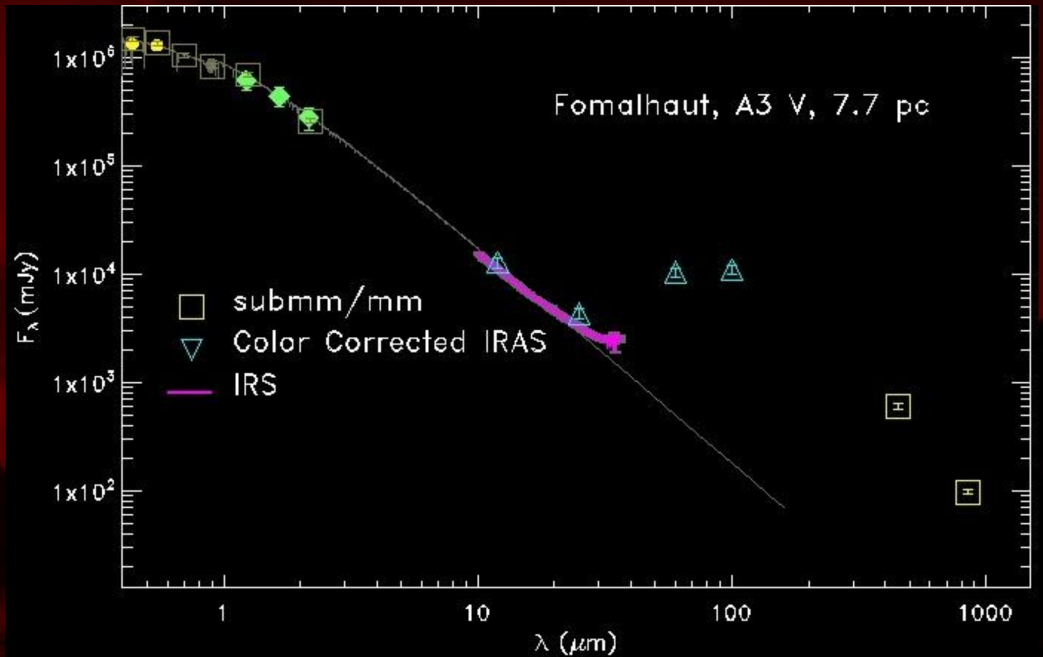
Backman et al. 2009

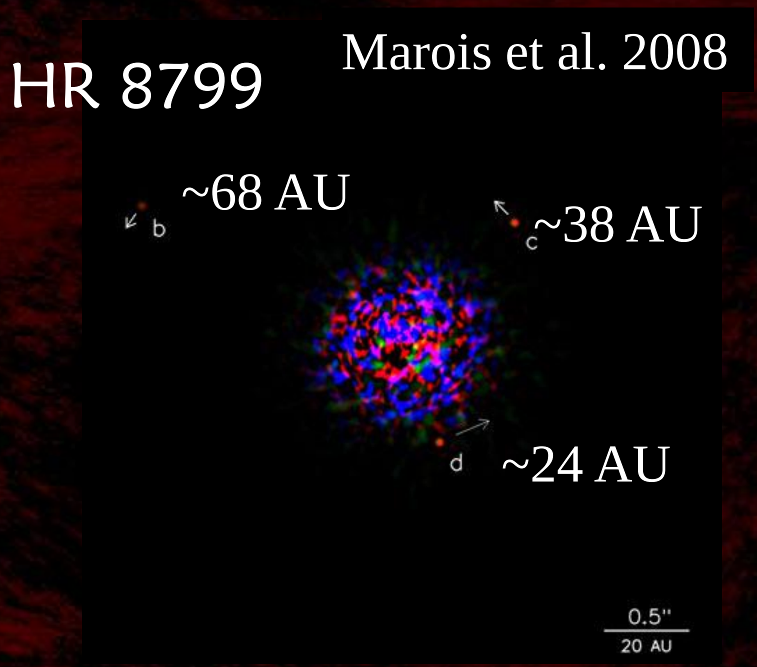


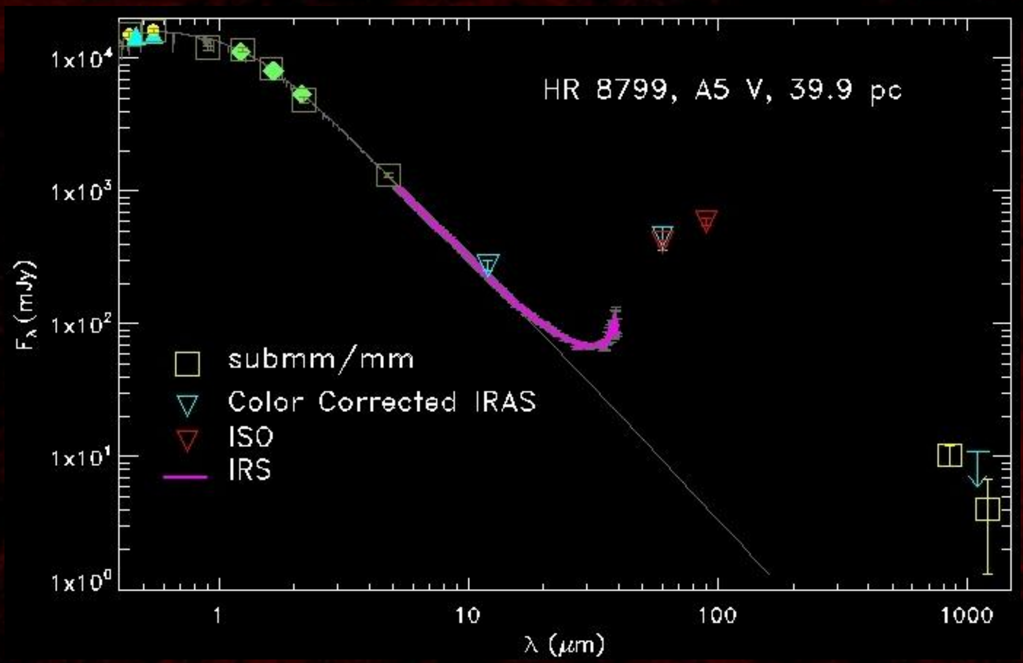
Greaves et al. 1998

Stars + Planets by direct imaging + Debris Disks





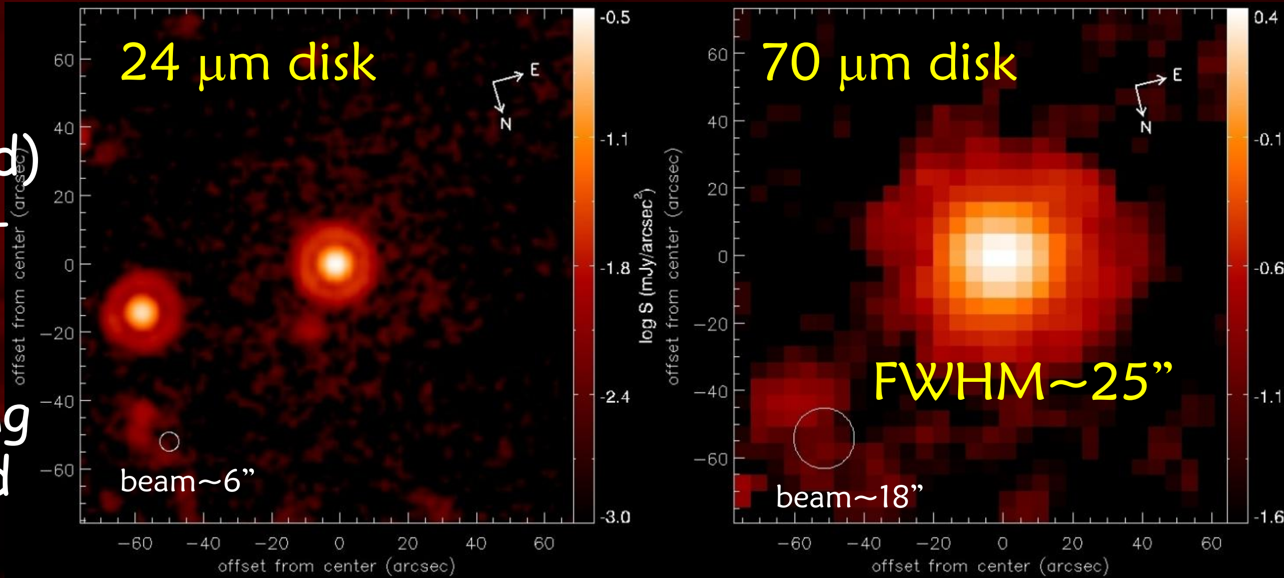




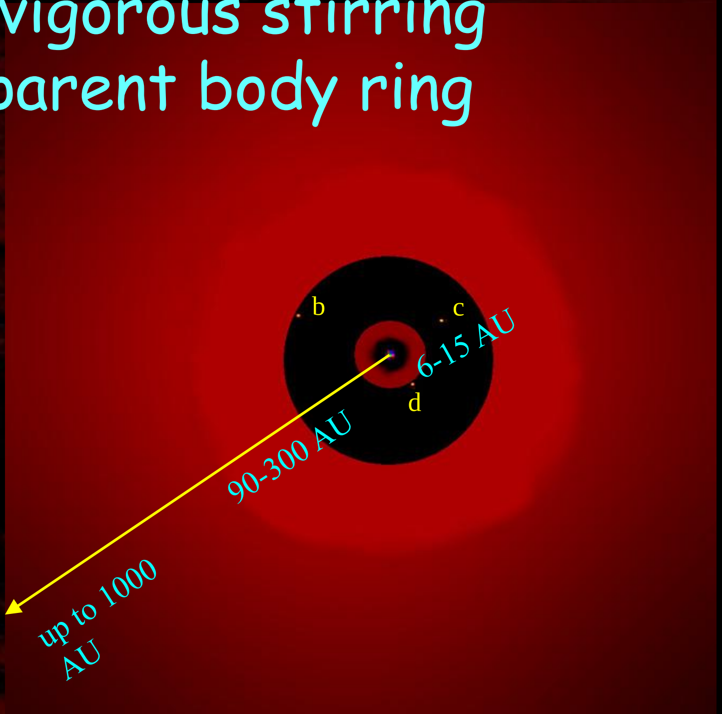
Outflows and Weakly Bound Grains: HR 8799

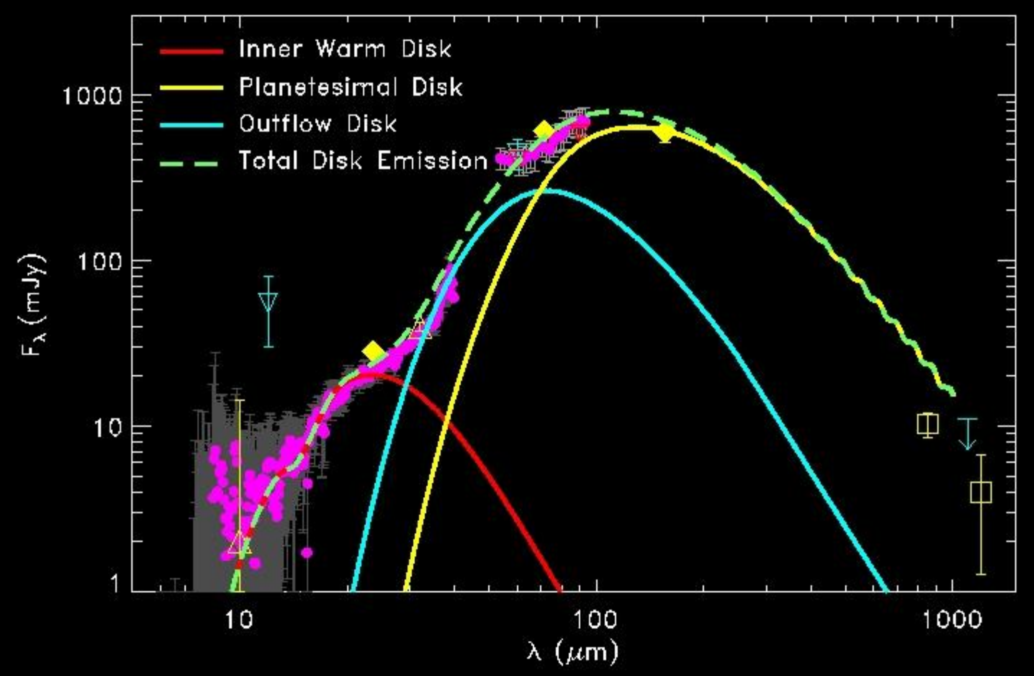
Three Component Disk:
- inner warm (asteroid-like) belt (inside planet d)
- outer cold (Kuiper-belt-like) planetesimal disk (outside planet b)
- extended halo extending up to 1000 AU, composed of fine dust grains

→ vigorous stirring of parent body ring



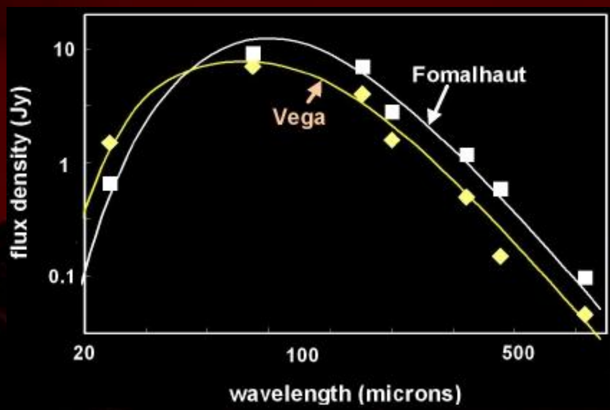
Su et al. 2009

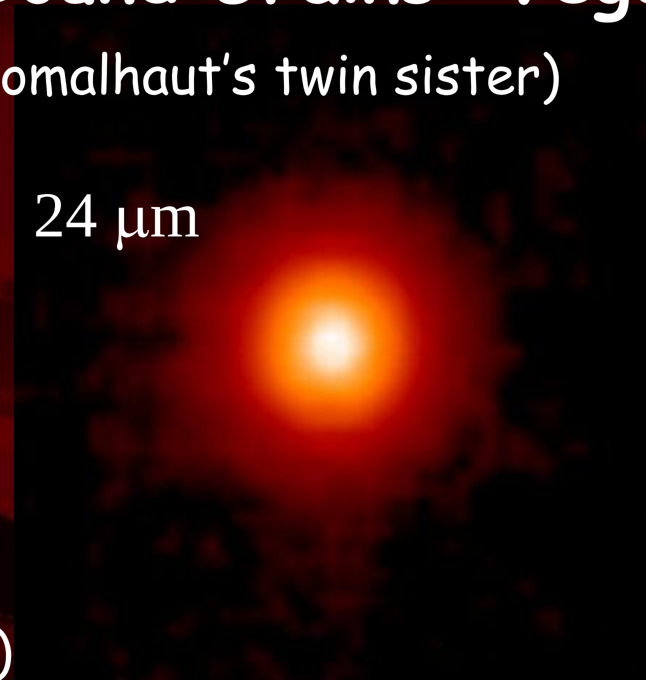




Outflows and Weakly Bound Grains: Vega

Vega, A0V, 7.7 pc, ~200 Myr (Fomalhaut's twin sister)

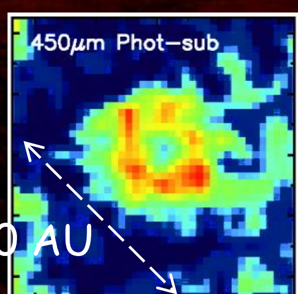




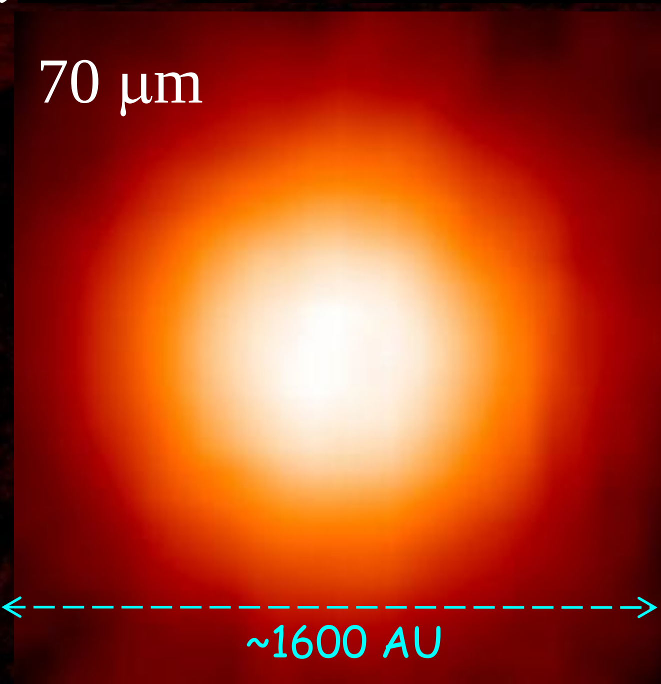
Su et al. 2005

(all images are to the same scale)

face-on ring-like disk



450 μm (Marsh et al. 2006)

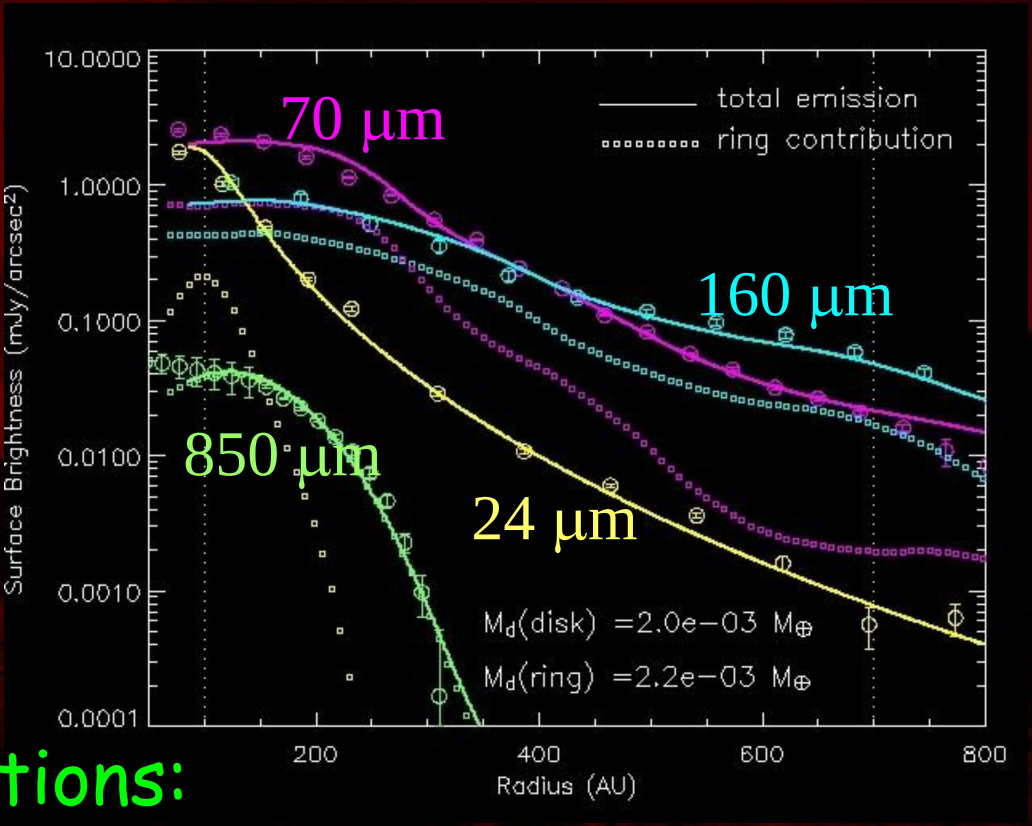


IR emission extends far outside the ring-like disk seen at sub-millimeters

Also see Holland et al. 1998,
and Wilner et al. 2002

Outflows and Weakly Bound Grains: Vega

illustration



Different Grain Populations:

- large parent bodies confined in a birth ring
- small grains driven outward by radiation pressure forming an extended disk

→ recent transient collisional events

Su et al. 2005

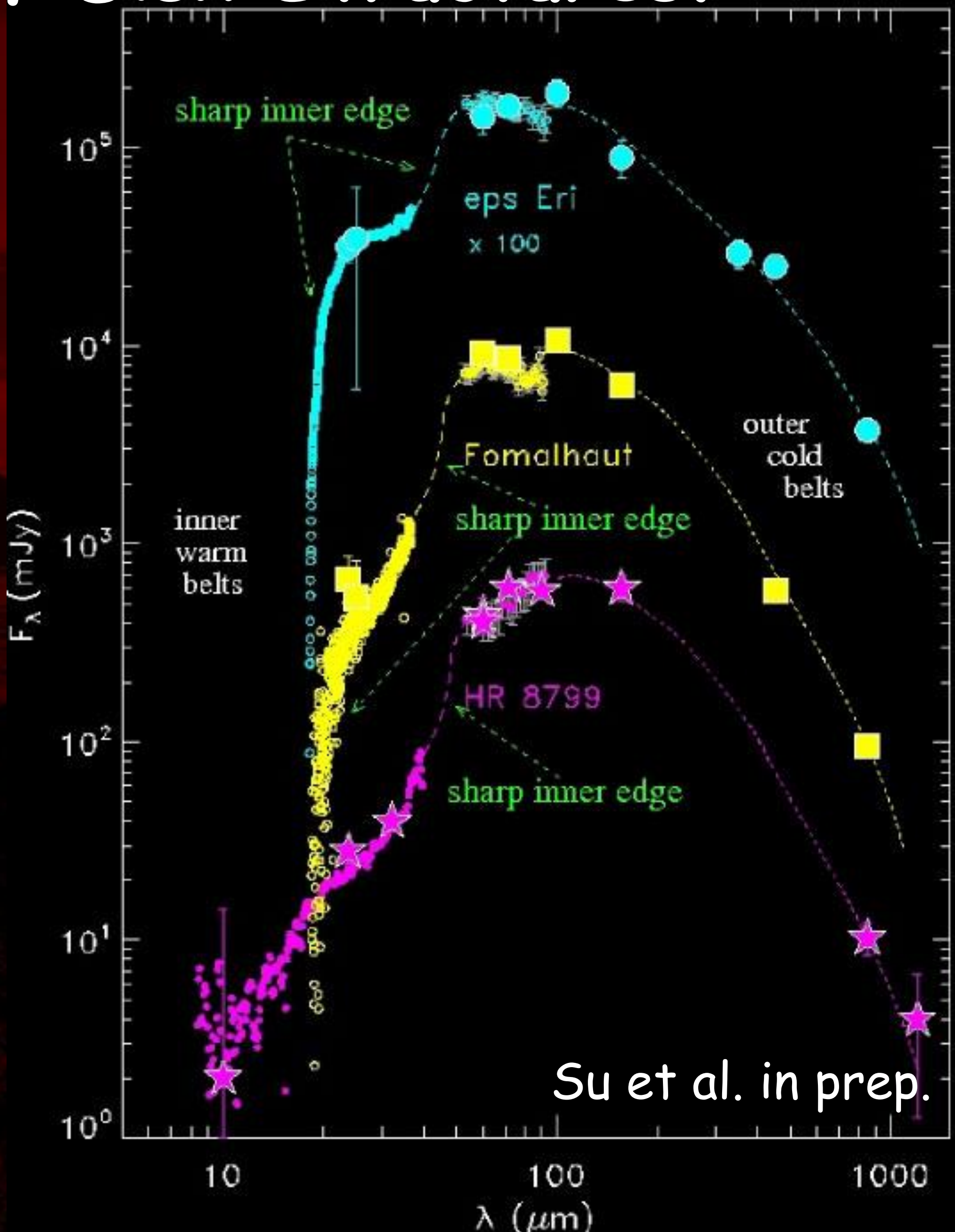
A General Pattern of Disk Structures?

Various Zones:

- Outer planetesimal belt/disk T_d~60K, evolves very slowly
- Halo extending beyond the cold planetesimal disk (found around luminous stars)
- Warm ring/belt T_d~150–230 K, evolves faster

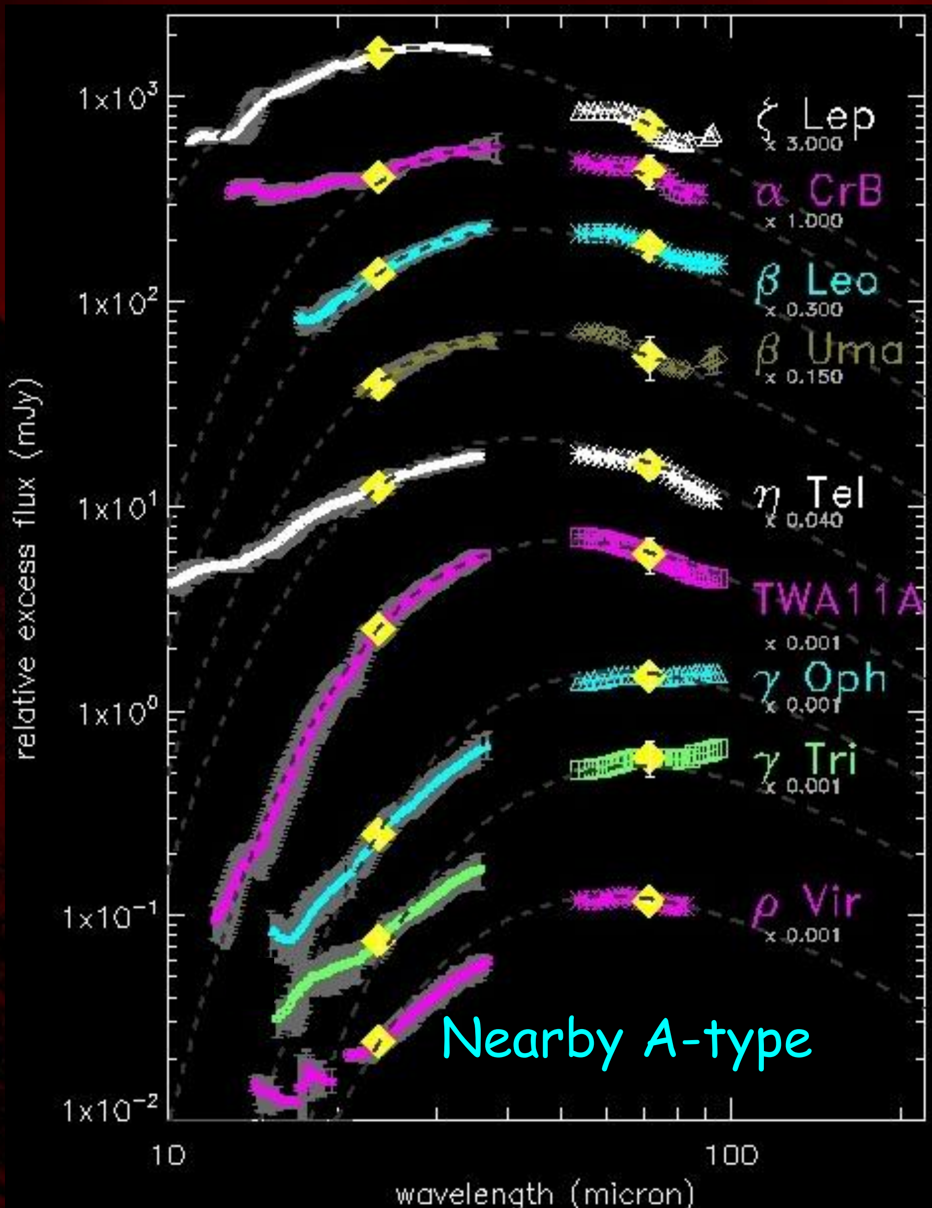
Detailed Excess SEDs:

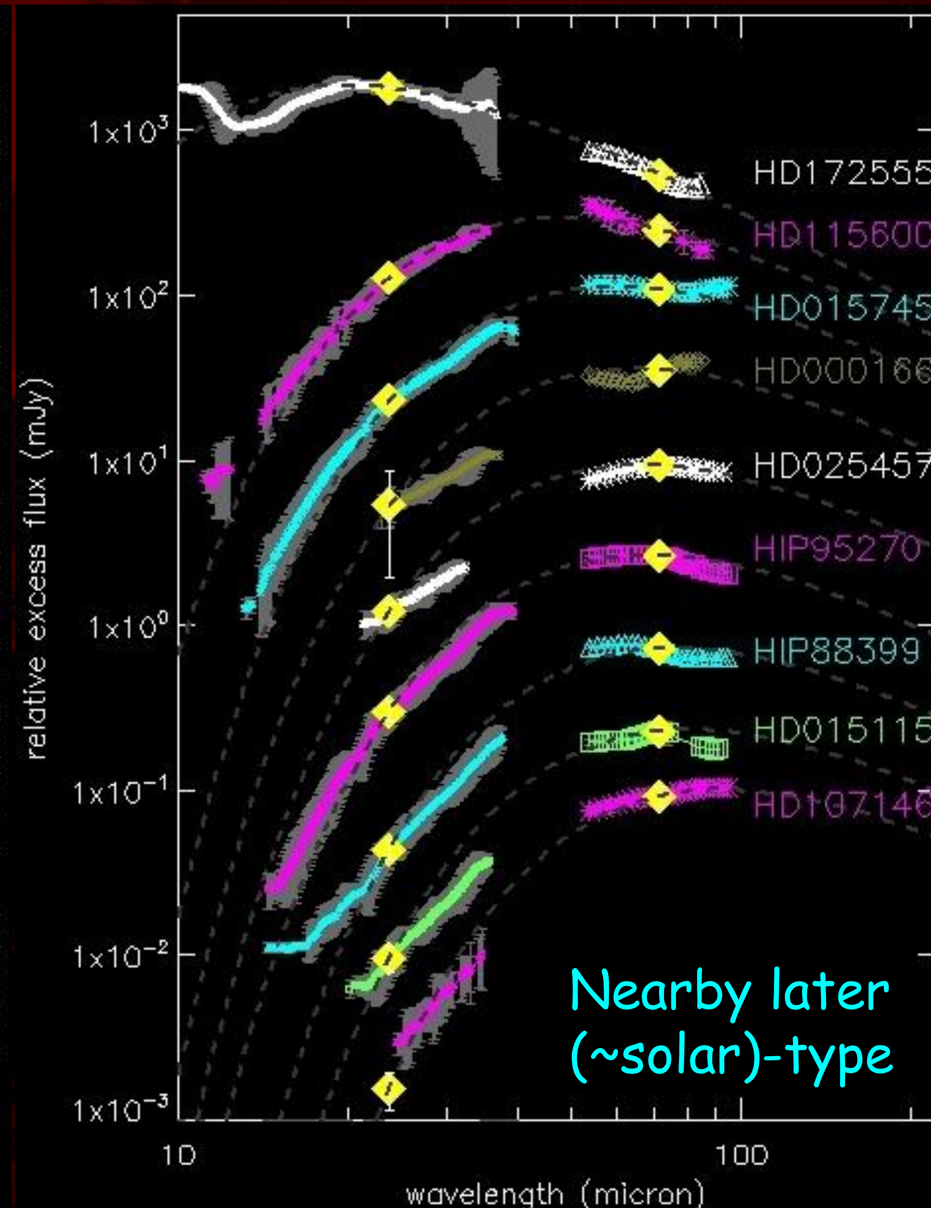
- Sharp SED cutoffs appear to be associated with inner disk edges maintained by planets
- Do these similarities reveal a generality in planet system architectures?



Su et al. in prep.

Sharp-Edge Features – Common? or Rare?

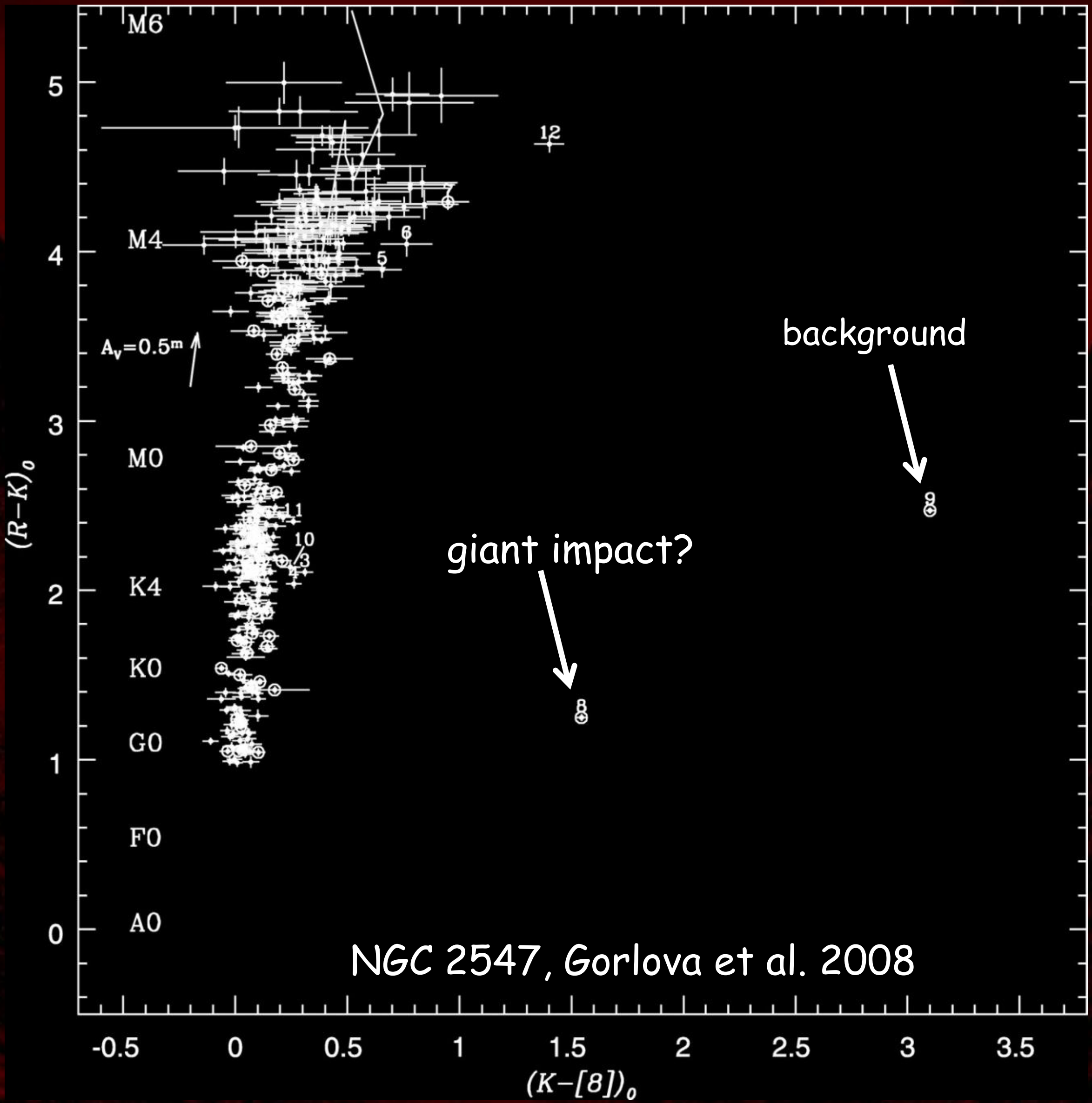




Su et al. in prep.

The Frequency of Late Giant Impacts
20 – 120 Myr
(such an impact produced our moon)

Extreme Inner Disks in Young Debris Systems.

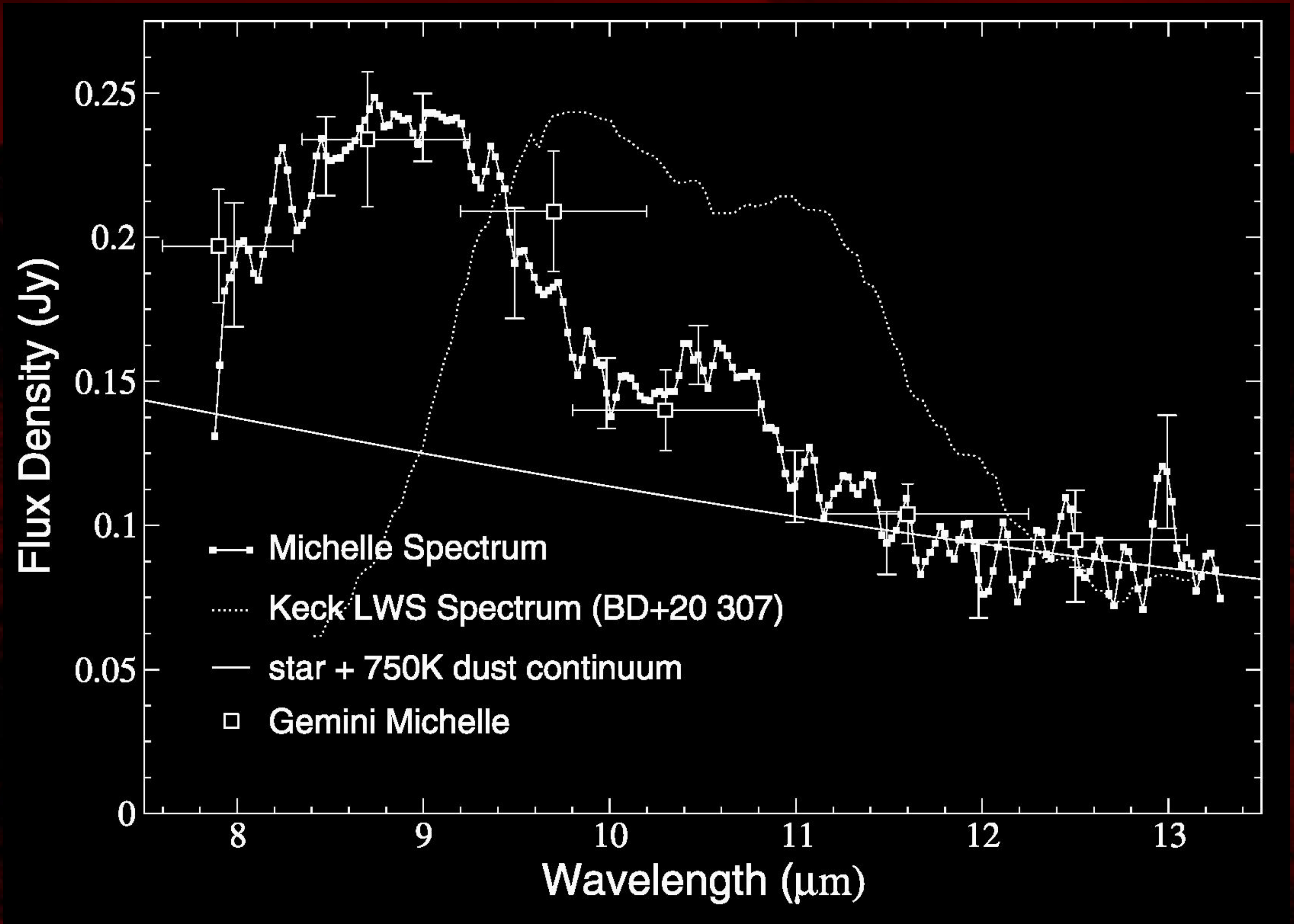


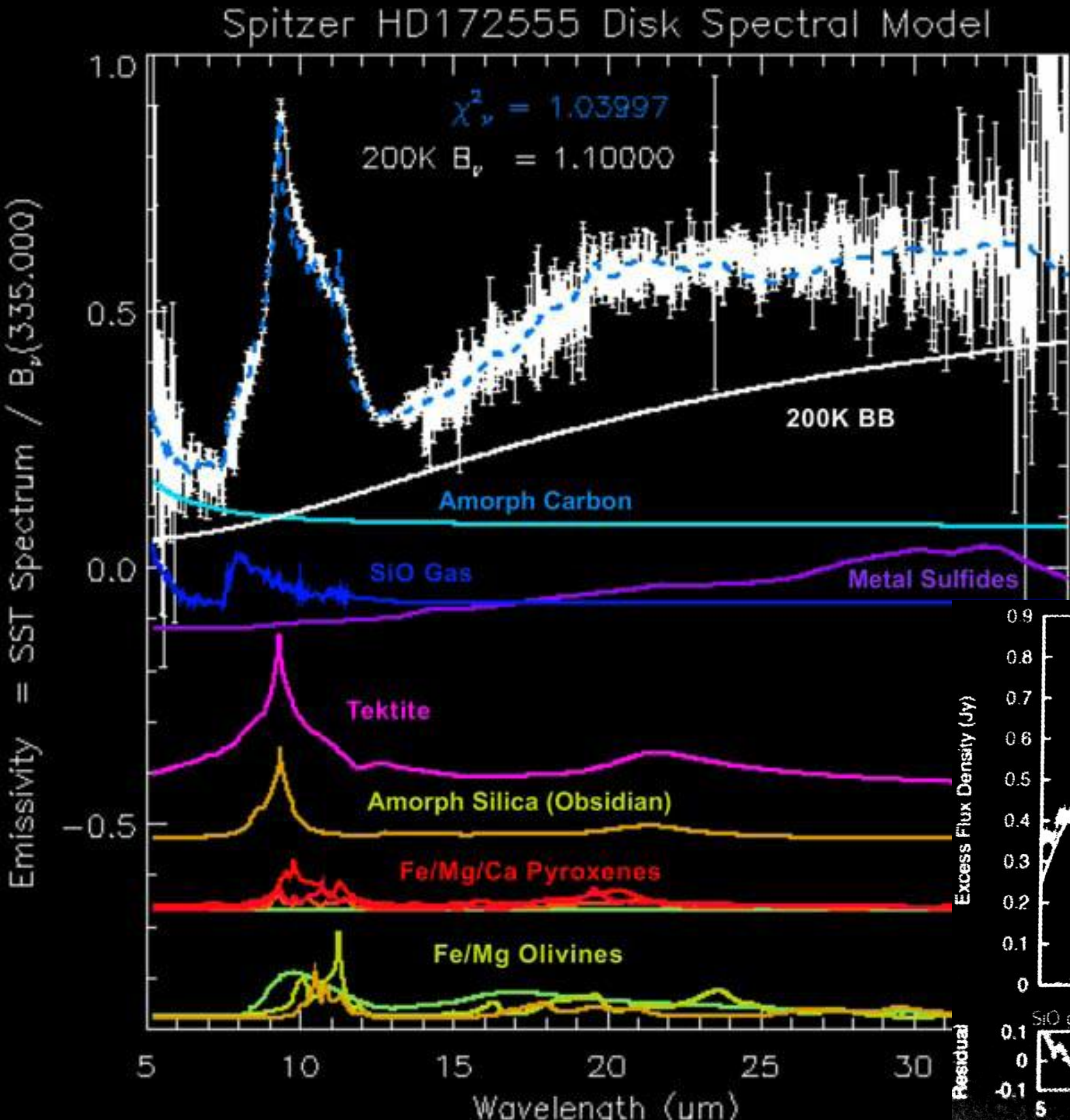
1 – 2% of solar type stars in the 20-120Myr age range have very large excesses.

That is, 3 - 4 examples in > 300 stars between 20 and 120 Myr old.

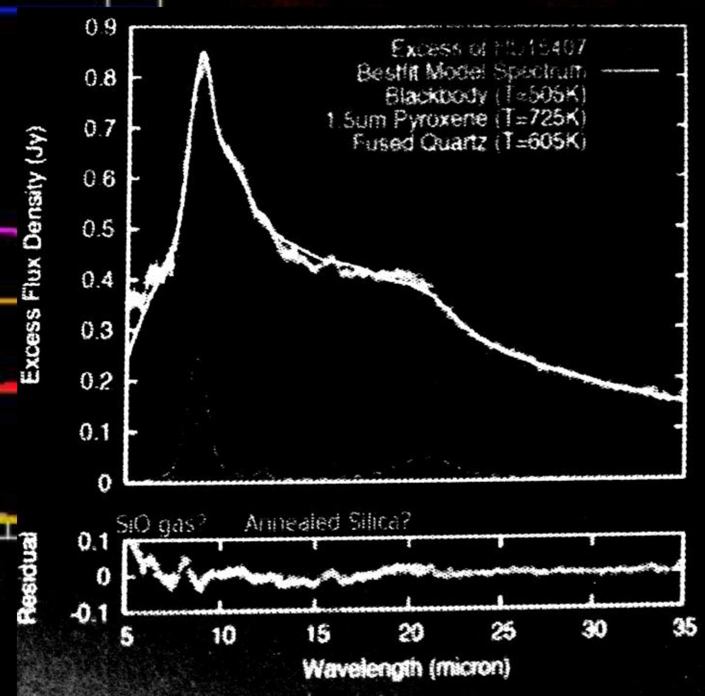
Must be rare events, or short-lived ones.

One candidate, HD 23514, shows a spectral feature at ~ 9μm, indicative of condensation of silicon oxides from vapor and thus of a major planetesimal collision. (Rhee et al. 2008)





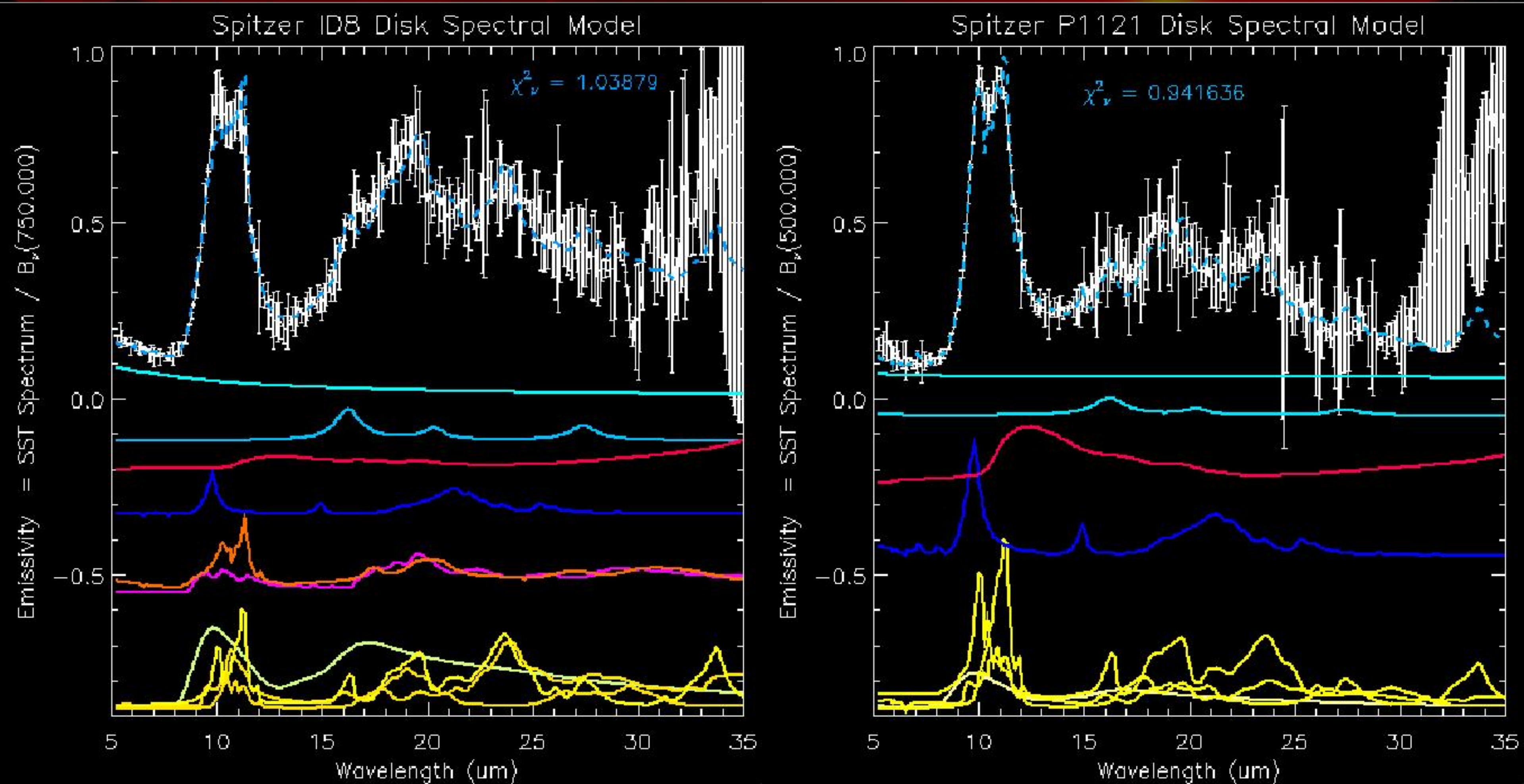
The signature of condensation from silicon oxide vapor is also found in HD 172555 (Lisse et al. 2009).
See also Fujiwara on HD 15407



Two others show very finely divided crystalline silicates (e.g., olivines) at high temperature -- ~ 600K (Gorlova et al., in prep; fits by C. Lisse, private communication). The masses and compositions indicate that the parent bodies were asteroid-like, ~ 260 km diameter, & within ~ 1 AU of the stars.

~ 35 Myr 680-780K T_{max}

~ 100 Myr 420-520K T_{max}



Summary

- Decay of debris disk activity
  - Slow evolution of excesses at 70μm
  - Rapid drop in 24μm excess incidence between 120 & 600Myr, for both A-type and solar-type stars
  - But few Late Heavy Bombardments (at least Nice-style)

- A look at the dynamically active region
  - Broad range of inner disk temperatures, similarity of average properties between A-type and solar-type stars

- Resolved disks and spectral energy distributions
  - Disks and Planets
  - Outflows and weakly bound grains
  - Can we recognize a general behavior pattern?

- The frequency of late giant impacts
  - Incidence of current giant impacts between 20 & 120 Myr is 1 – 2%
  - Some cases show presence of dust condensed from SiO vapor