Placing Our Solar System in Context:
[A 12 step program to learn to accept disk evolution]

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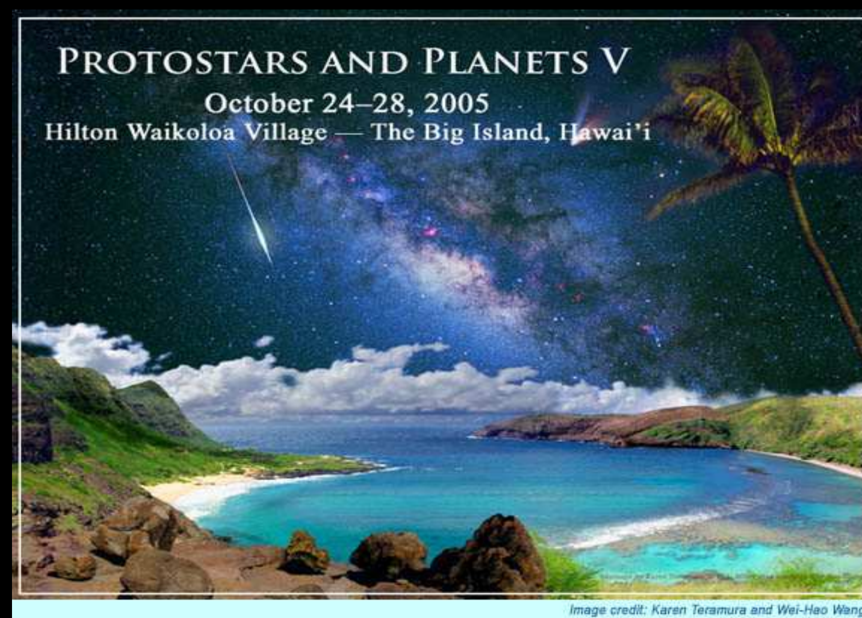


Planetary Disk Studies: The Protostars and Planets View

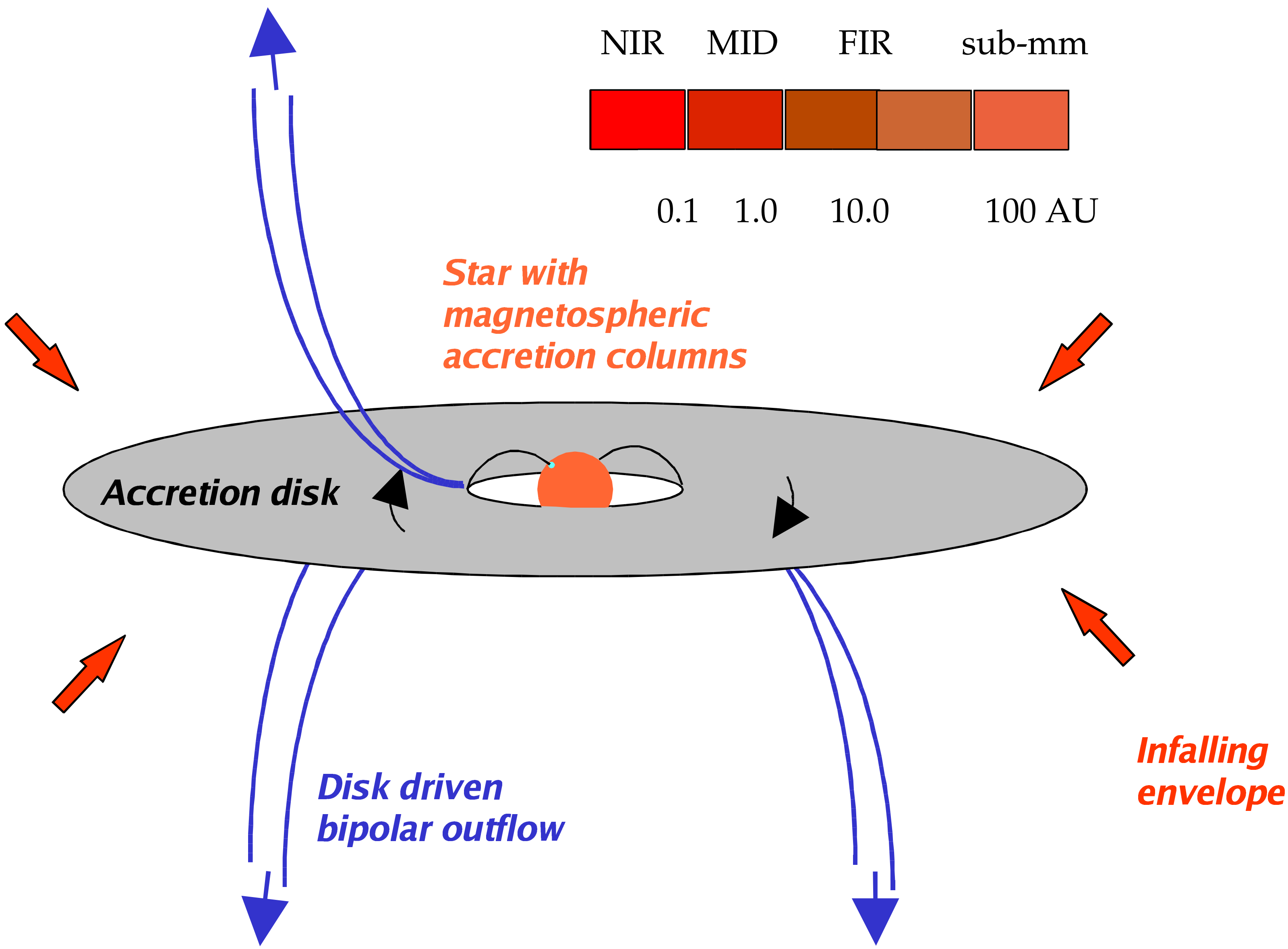
I. *Interpreting IR Observations of T Tauri Stars*, A.E. Rydgren (1978)

2. *Observ. Evidence for Disks Around Young Stars*, P.M. Harvey (1984)

3. *Main Sequence Stars with Circumstellar Solid Material: The Vega Phenomenon*, D.E. Backman and F. Paresce (1990).

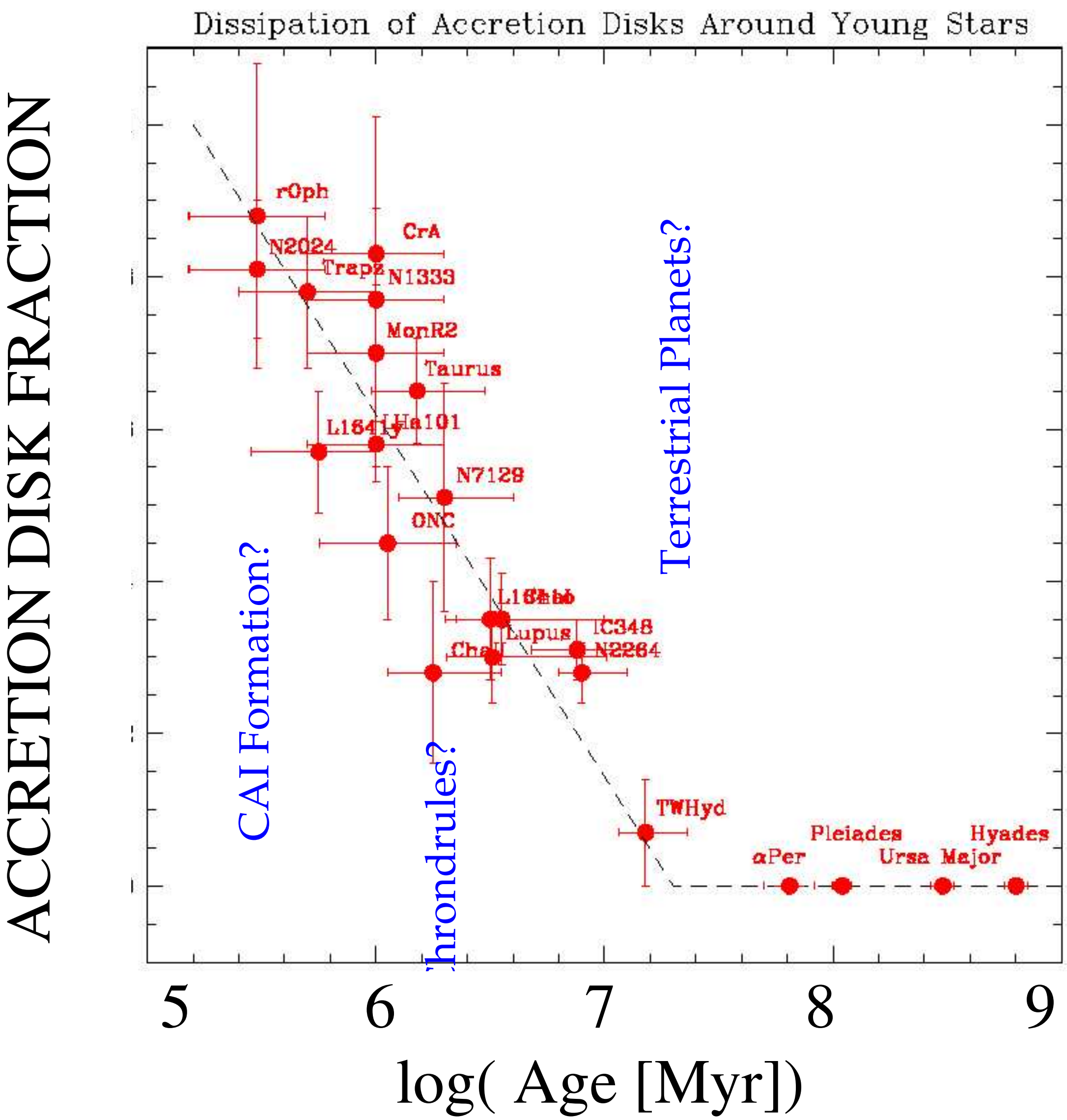
4. *Planetary Material around Main Sequence Stars*, A.-M. Lagrange, D.E. Backman, and P. Artymowicz (1998).

Step #1. Different Wavelengths Trace Different Radii.



Step #2. Inner Disks Dissipate 1-10 Myr.

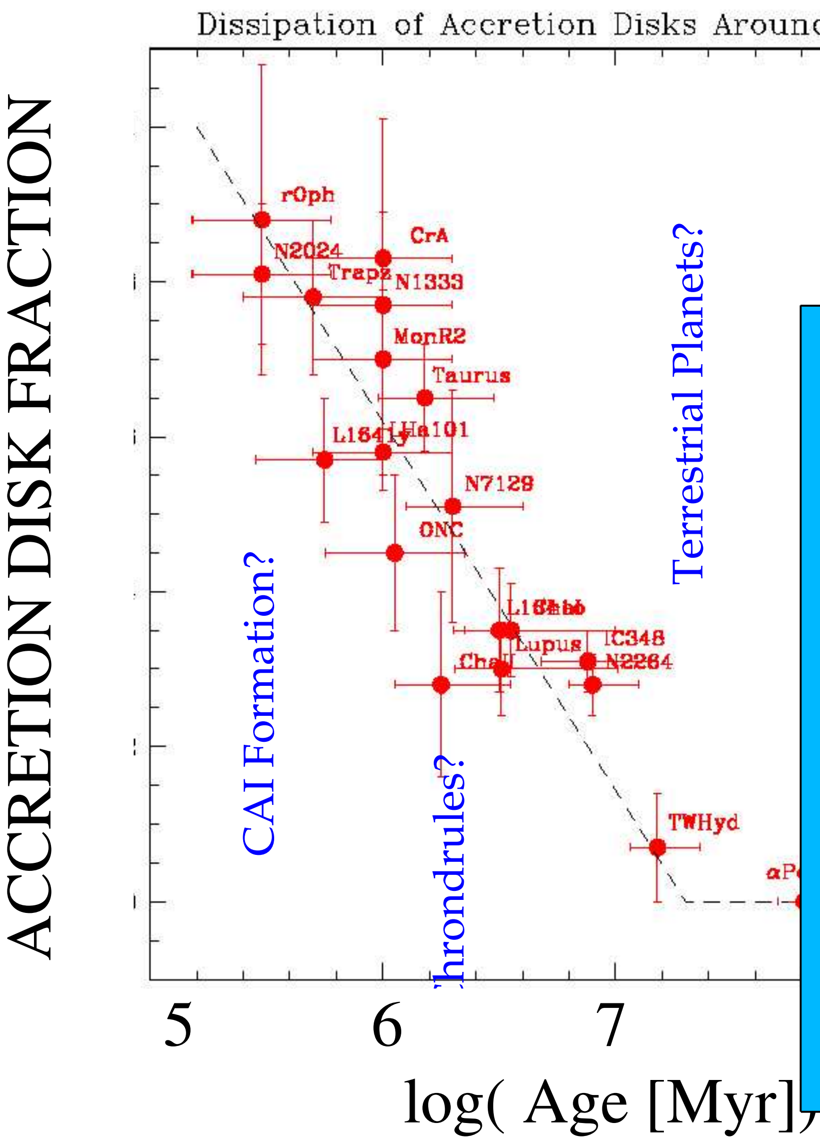
NIR



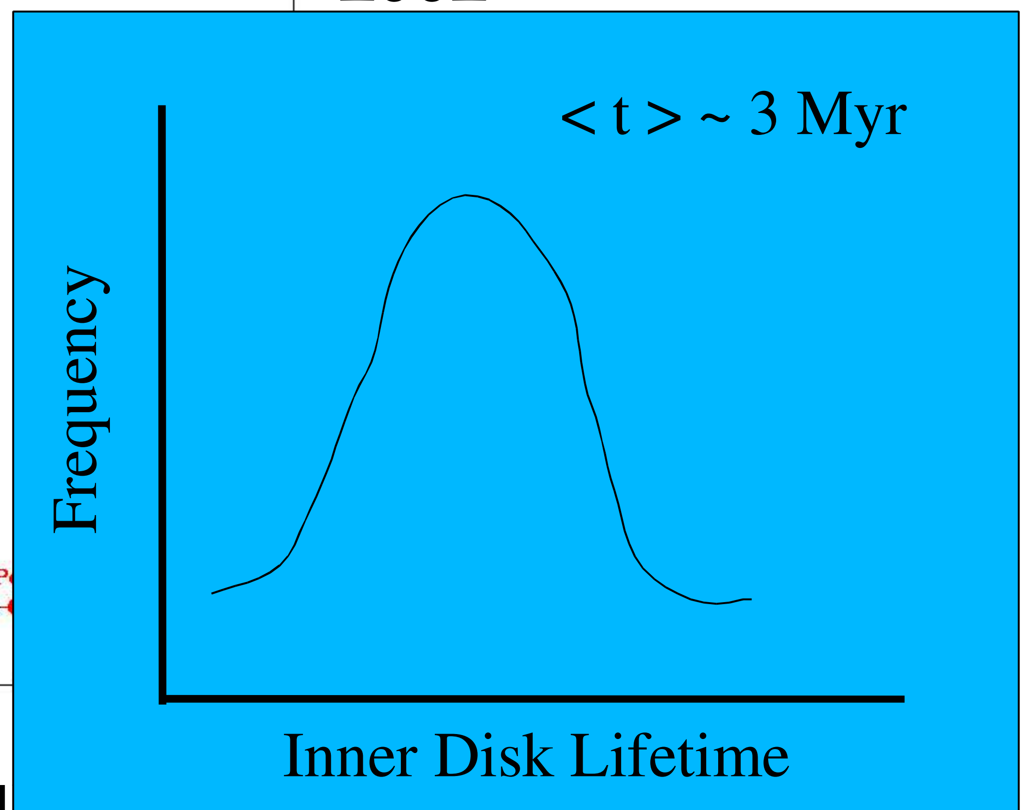
Haisch etal. 2001; see also Hillenbrand (2002).

...but there is a dispersion in inner disk lifetimes

NIR

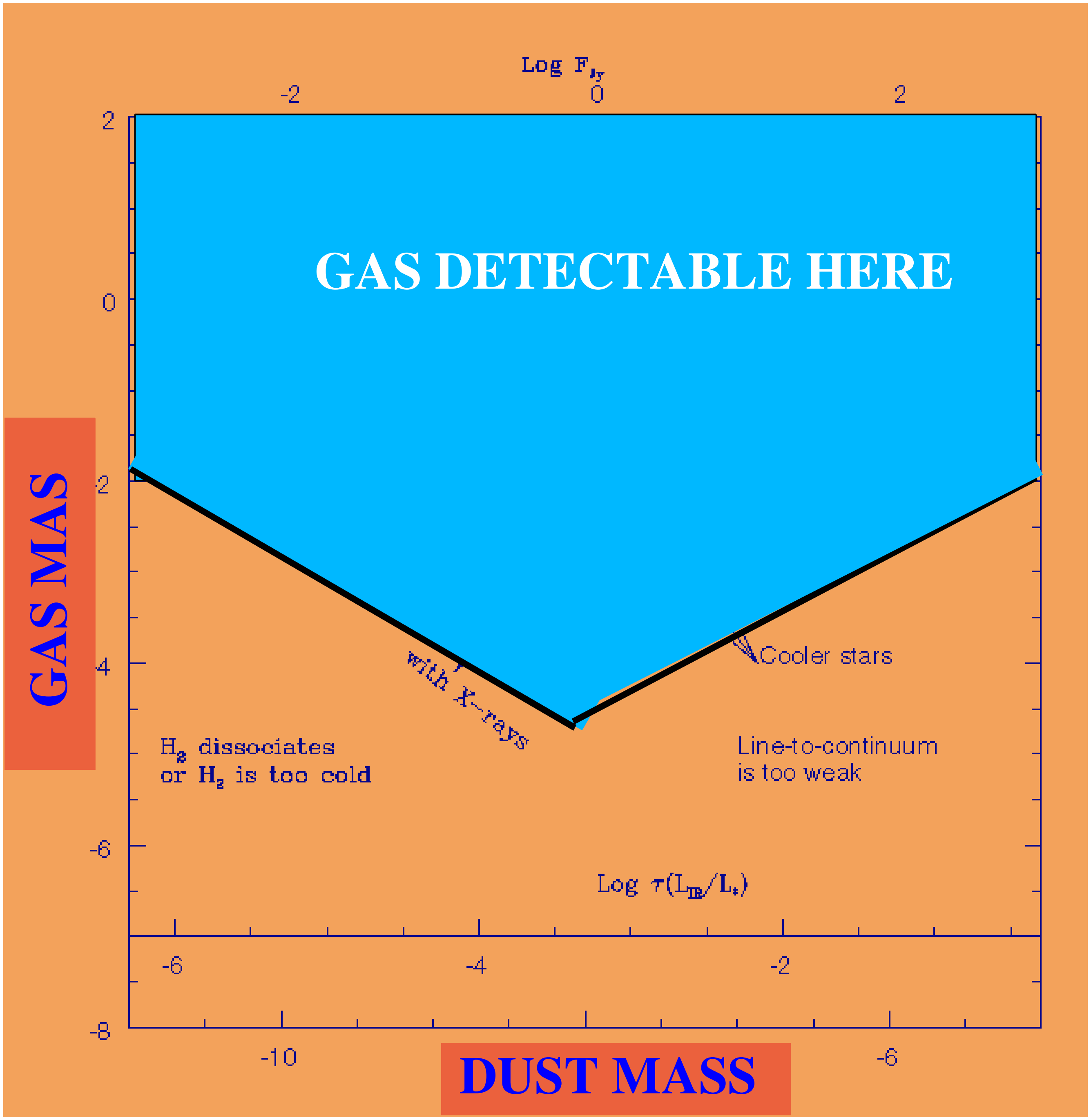


Haisch etal. 2001; see also Hillenbrand 2002



There is a difference between primordial and debris disks.

- Primordial Disks:
  - Opacity dominated by primordial grains.
- Debris Disks:
  - Opacity dominated by grains produced through collisions of planetesimals.
- How can you tell the difference?
  - Absence of gas (Gas/Dust < 0.1) argues for short dust lifetimes (blow-out/P-R drag).
  - Dust processing through mineralogy?



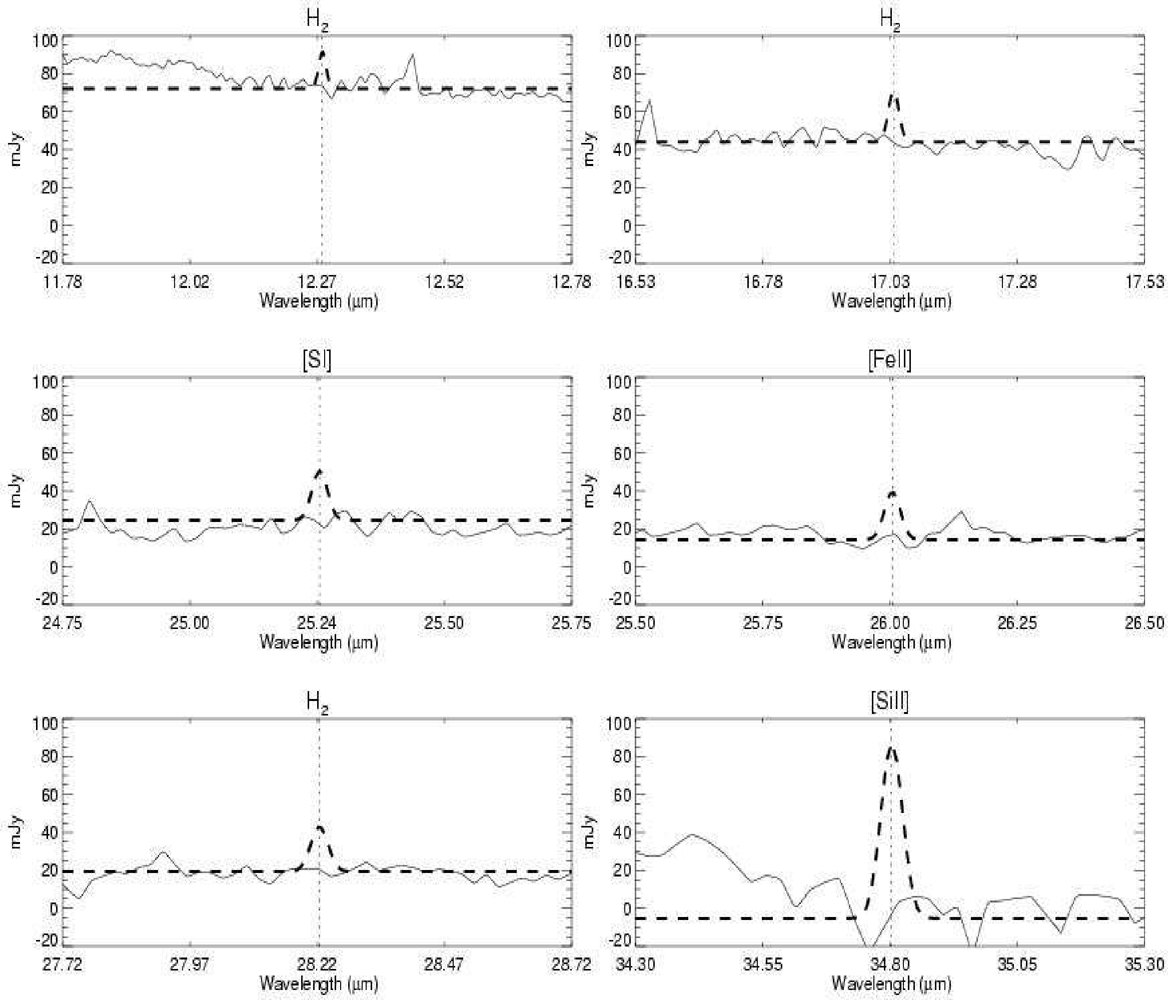
Detecting Cool Gas in Disks is *HARD!*

cf. Najita et al.
This meeting

Gorti & Hollenbach
ApJ (2004)

Step #3. Gas disk lifetimes appear to be < 10 Myr.

GAS



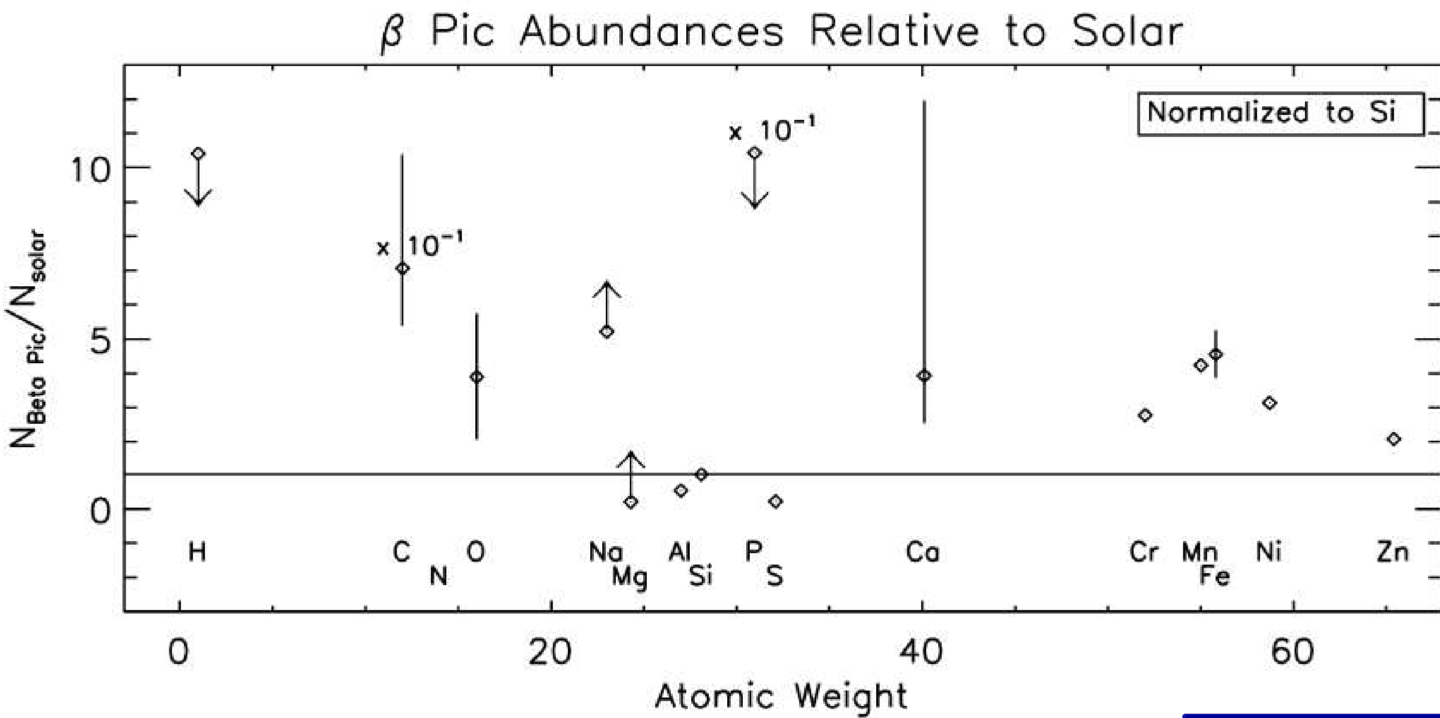
=> No gas rich disk (> 0.1 Mjup) detected.

=> 20 stars with ages 3-100 Myr

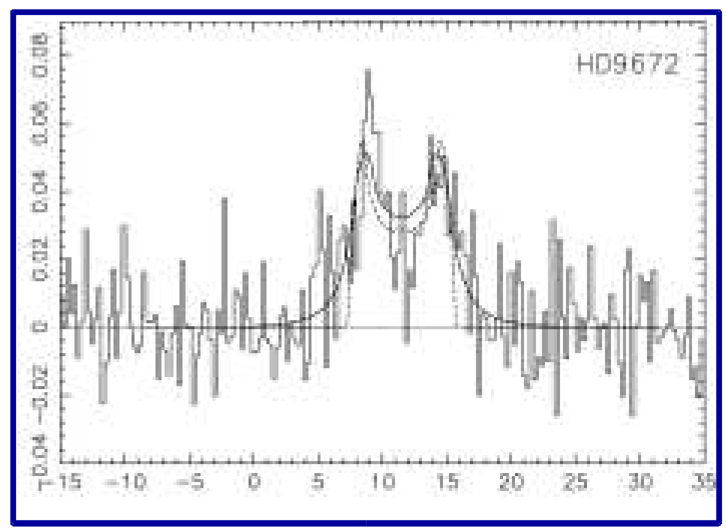
Hollenbach et al. (ApJ, 2005); Pascucci et al. This meeting

...but there are detections of gas in debris disks

GAS



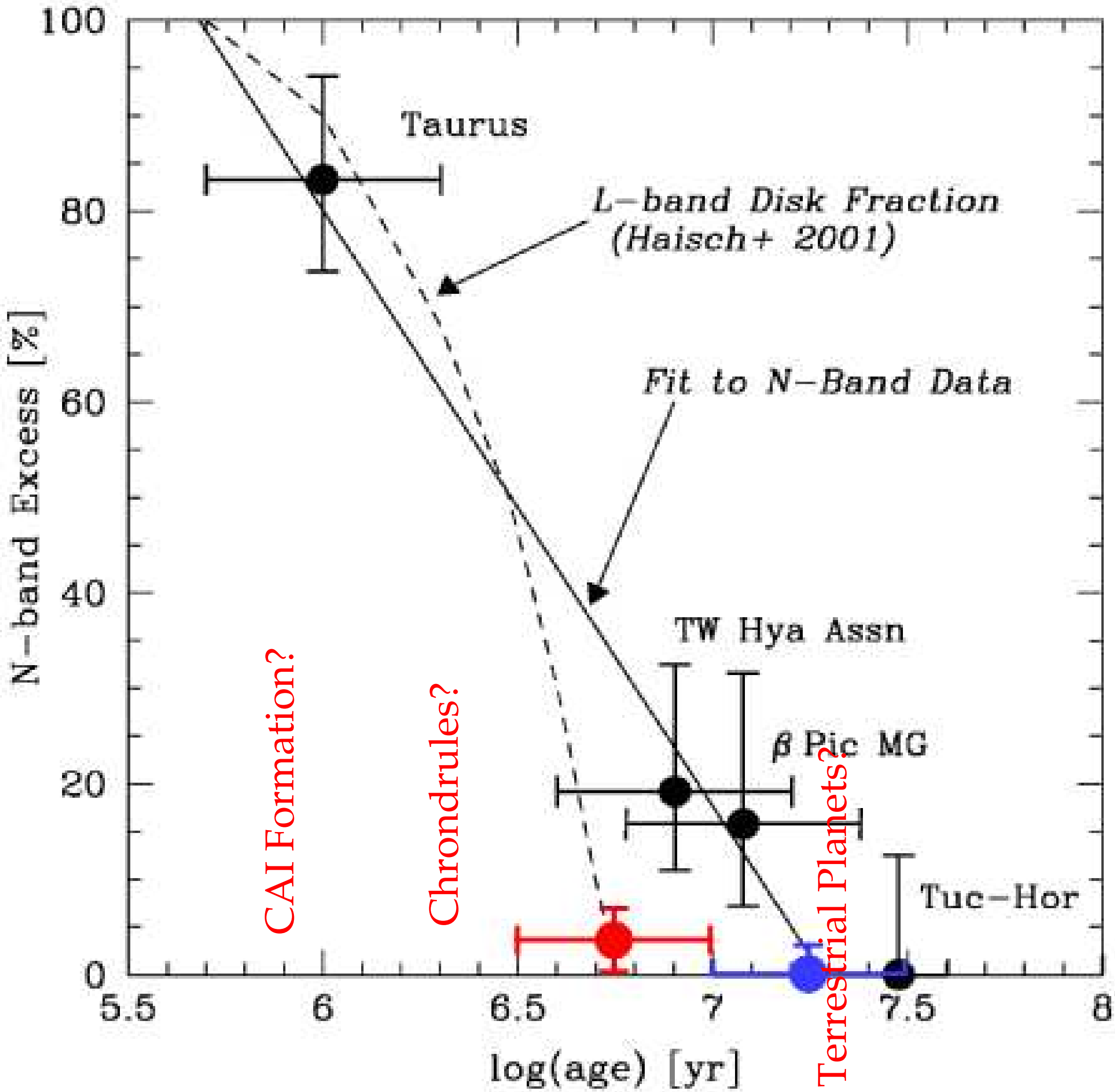
Roberge et al. (this meeting)
[Beta Pic, FUSE/HST/Visible]



Dent et al. (2005) [49 Cet, JCMT]

Step #4. Dust from 0.3-3 AU evolves on timescales comparable to the cessation of accretion

MIR



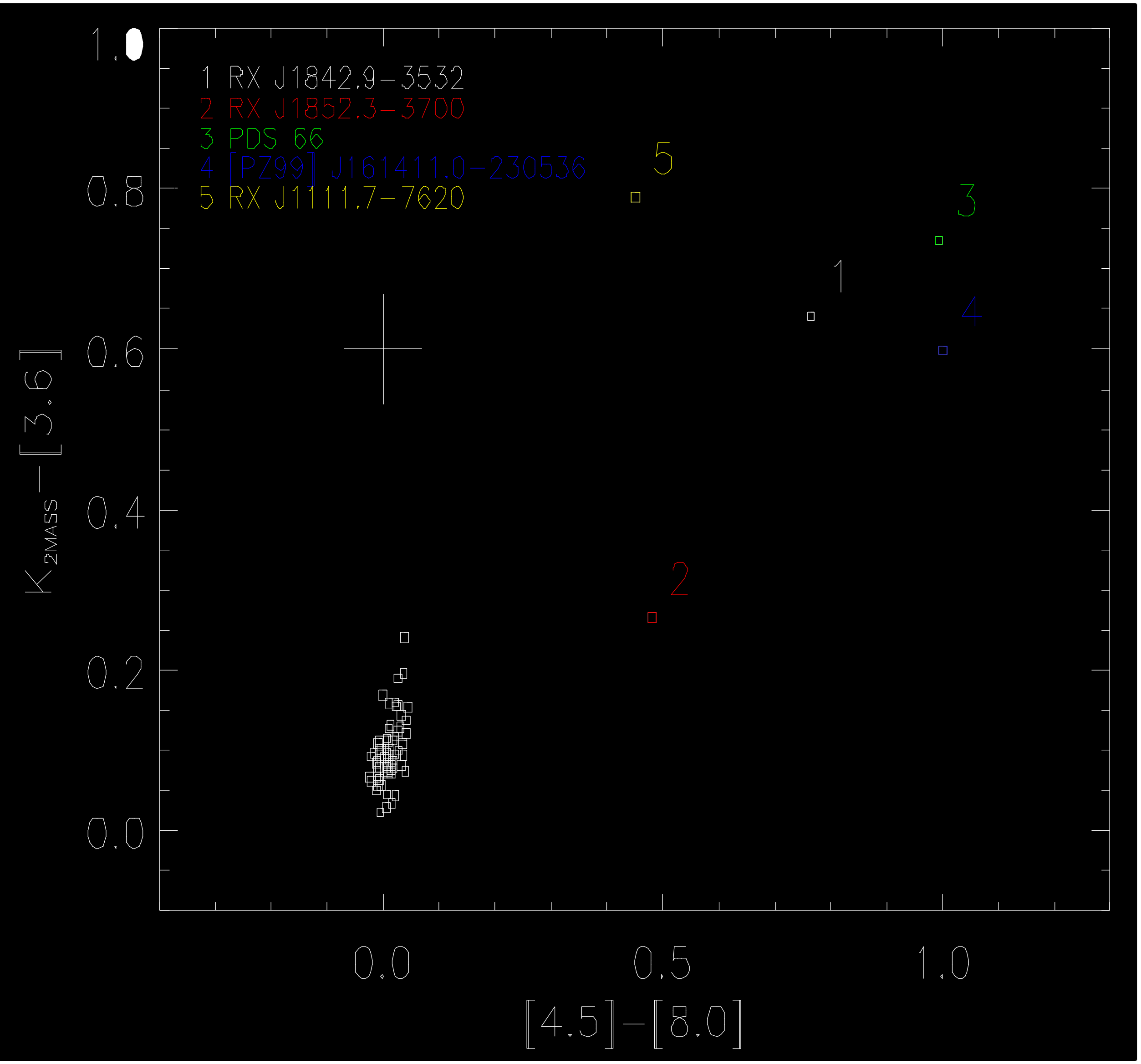
Silverstone et al. (ApJ, Submitted); See also Mamajek et al. 2004; Weinberger et al. 2004; Metchev et al. 2004.

3-10 Myr old IRAC.

10-30 Myr old IRAC.

...and the transition time from thick to thin is << 1 Myr years.

MIR

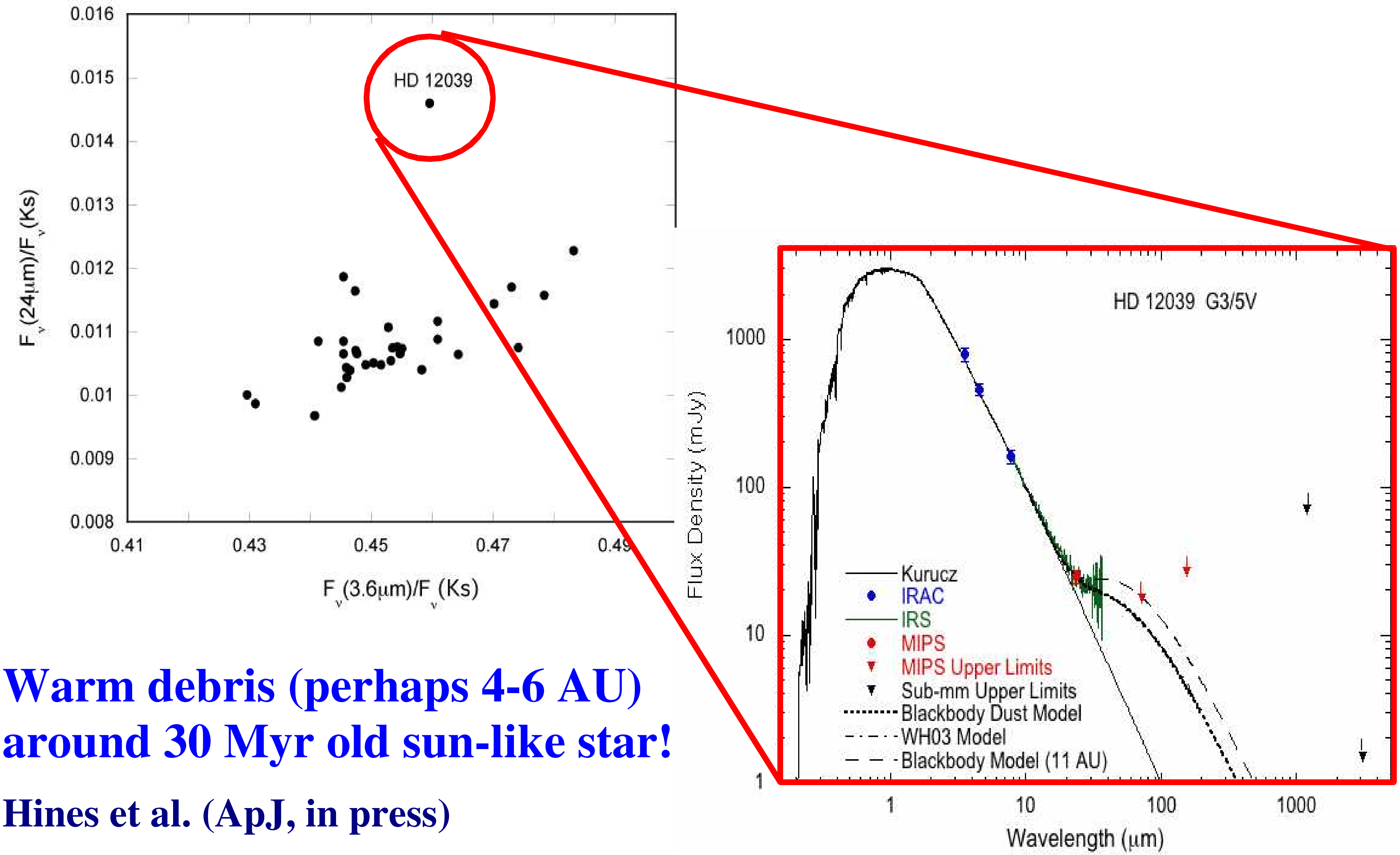


Silverstone et al. (ApJ, Submitted); See also Wolk and Walter, 1996; Kenyon and Hartmann, 1995; Prato and Simon, 1995; Skrutskie et al. 1990.

Out of a sample of > 70 stars 3-30 Myr old, 5 optically-thick disks, and no optically-thin disks.

Step #5. Warm Debris (> 100 K) surrounding Sun-like stars are rare (few %)

MIR

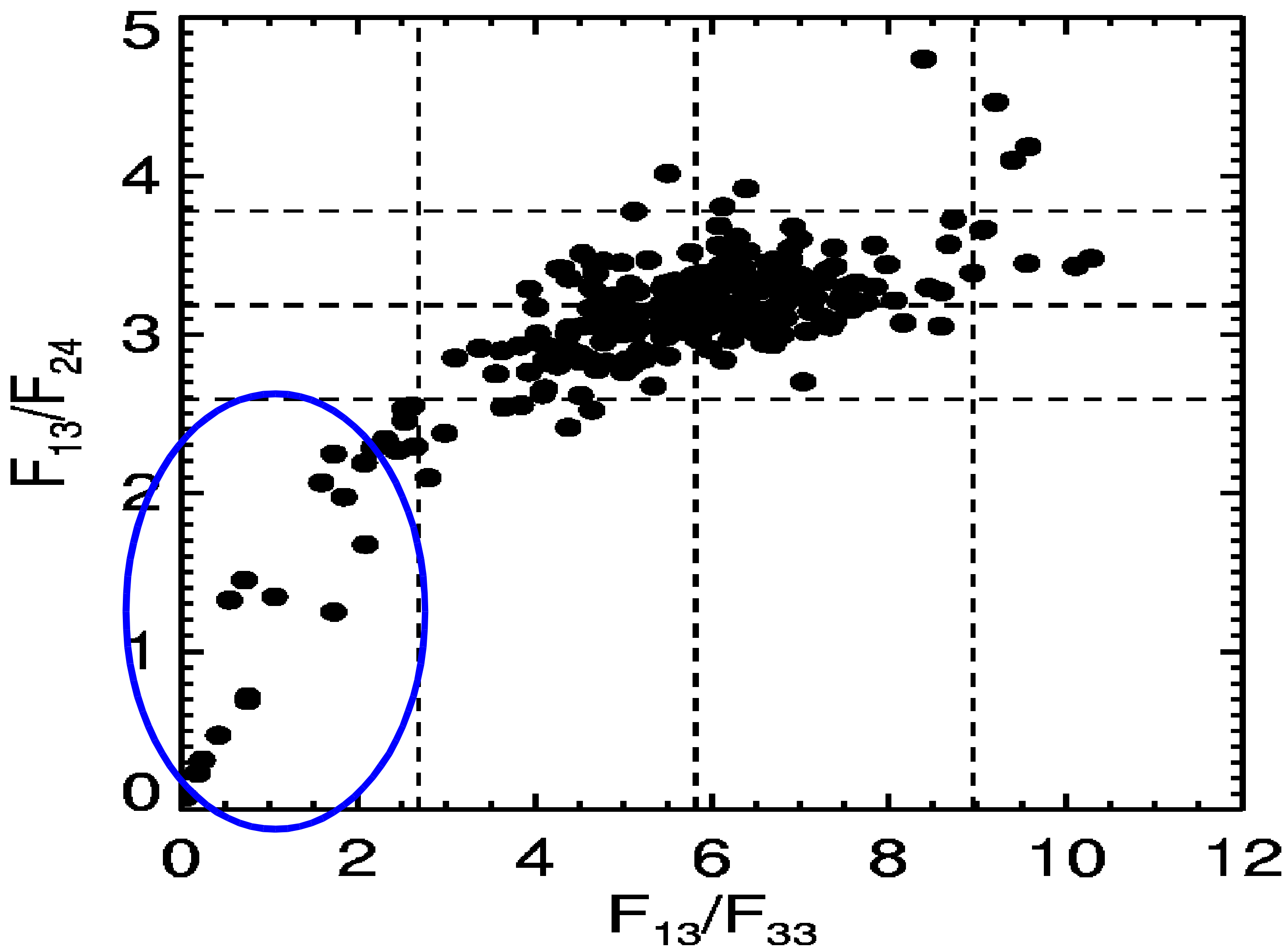


Warm debris (perhaps 4-6 AU) around 30 Myr old sun-like star!

Hines et al. (ApJ, in press)

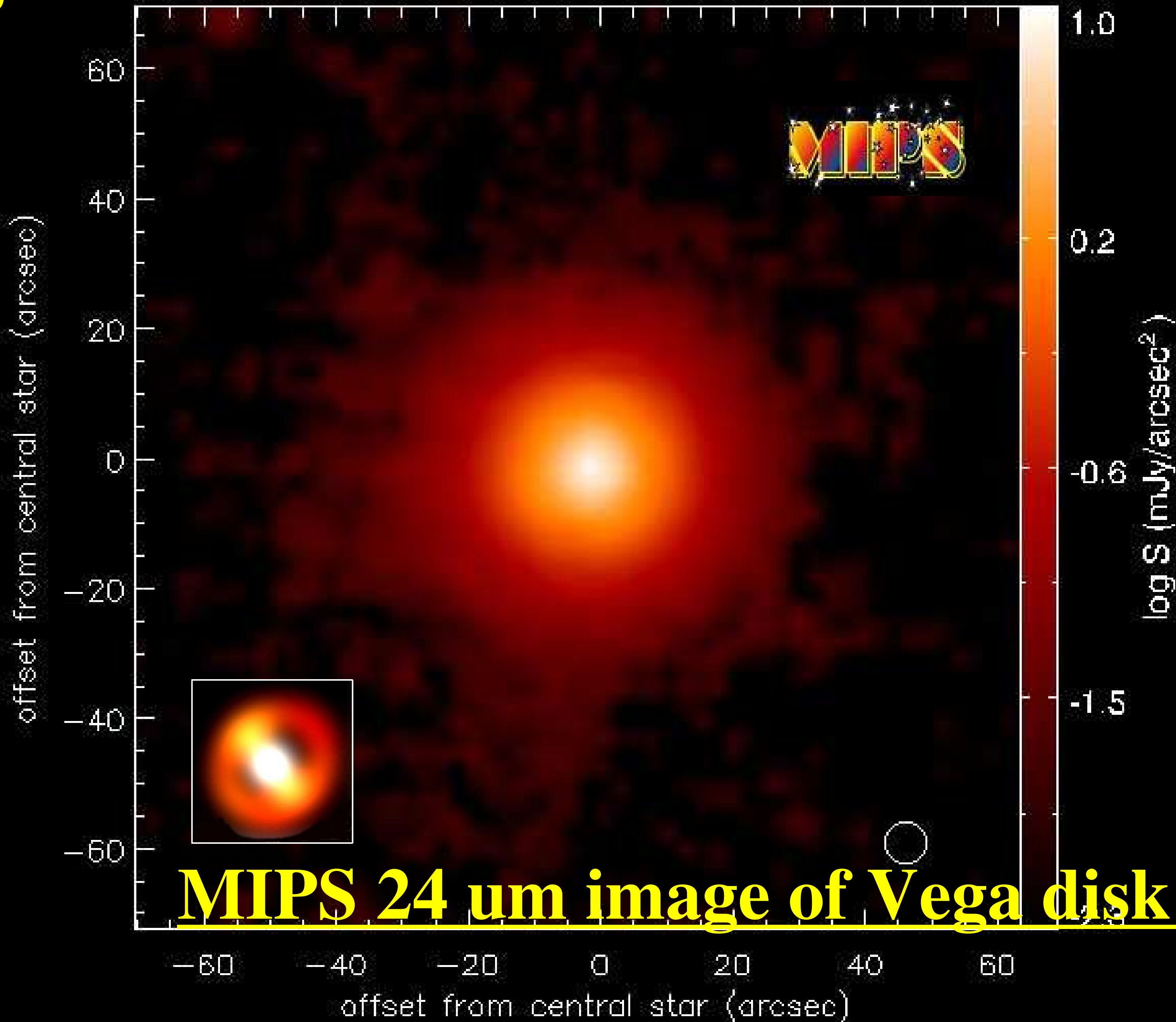
...but more common around stars < 100 Myr.

MIR



Bouwman et al. (in preparation); Beichman et al. (2005);
Song et al. (2005), Chen et al. (2005); cf. Kenyon & Bromley (2004)

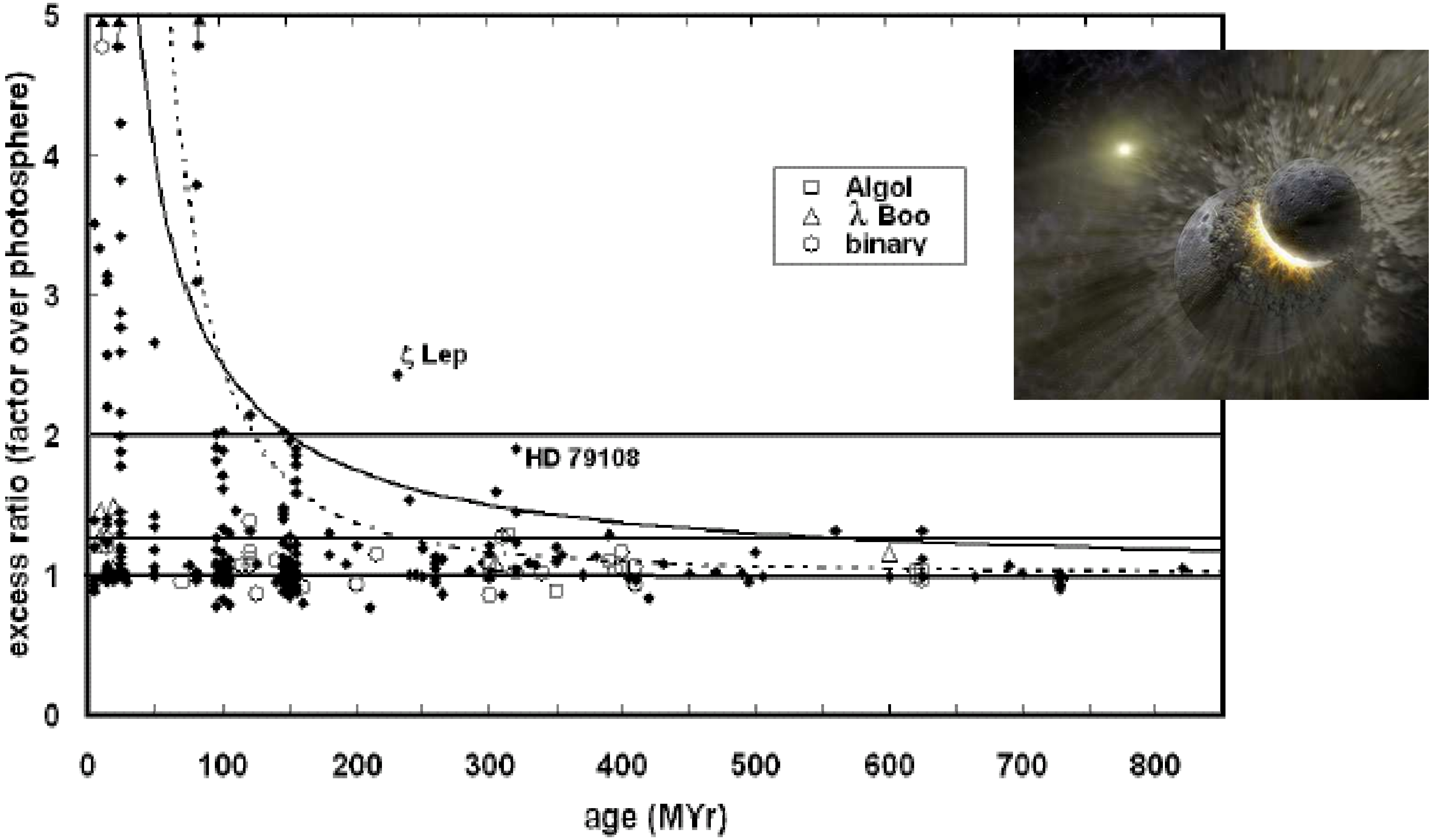
Step #6. In some cases can infer that unusual objects are common but short-lived



MIPS 24 um image of Vega disk

...or could be rare but extreme.

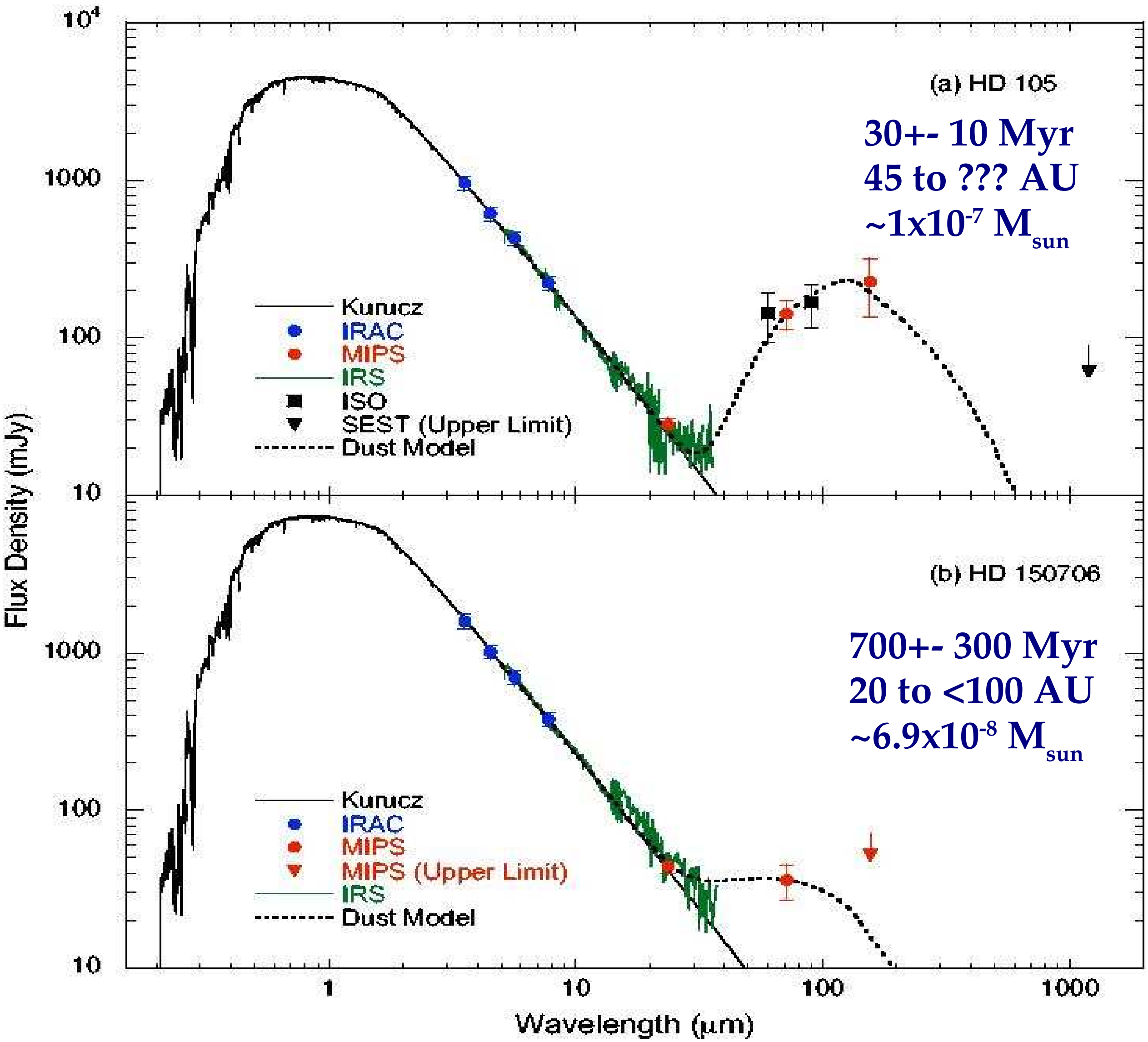
MIR



Rieke et al. (ApJ, 2005); See also Su et al. (this meeting).

Step #7. Cool Debris Disks (< 100 K) are Common (10-20 %) around Sun-like Stars.

FIR

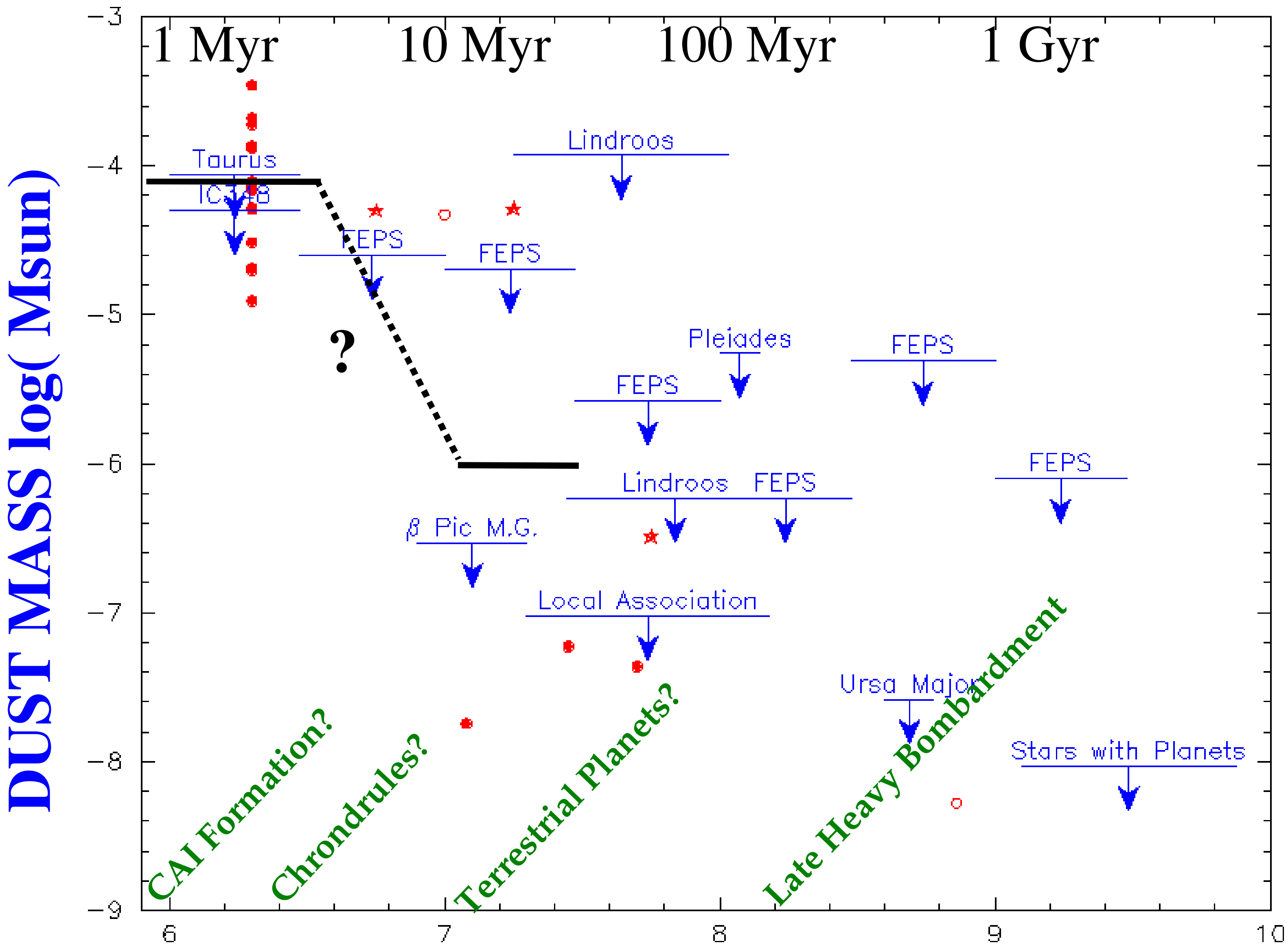


The Vega phenomenon

Decin et al. (2000), Meyer et al. (2004), Kim et al. (2005), Bryden et al. (2005), Hillenbrand et al. 2006.

Sub-mm Photometry: Dust Mass over Time

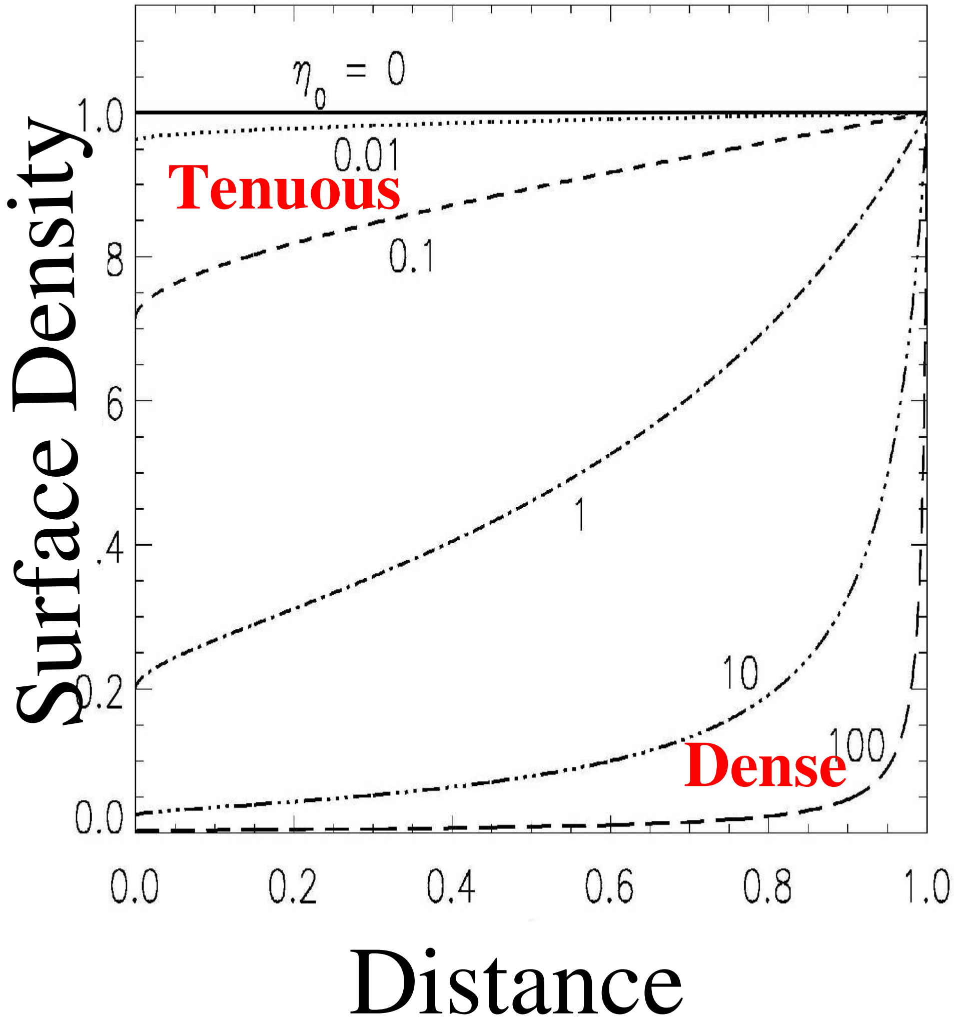
SMM



Carpenter et al. (2004); Greaves et al. 2004.

Step #8. Cold debris disks with inner holes are not strong evidence for giant planets

- Collisionally maintained holes decay as t^{-1} (Decin and Dominik, 2004; Wyatt, 2005).
- Detected disks are not P-R Drag dominated.
- Extremely low density disks maintain constant dust production rate (e.g. Solar system asteroid belt).



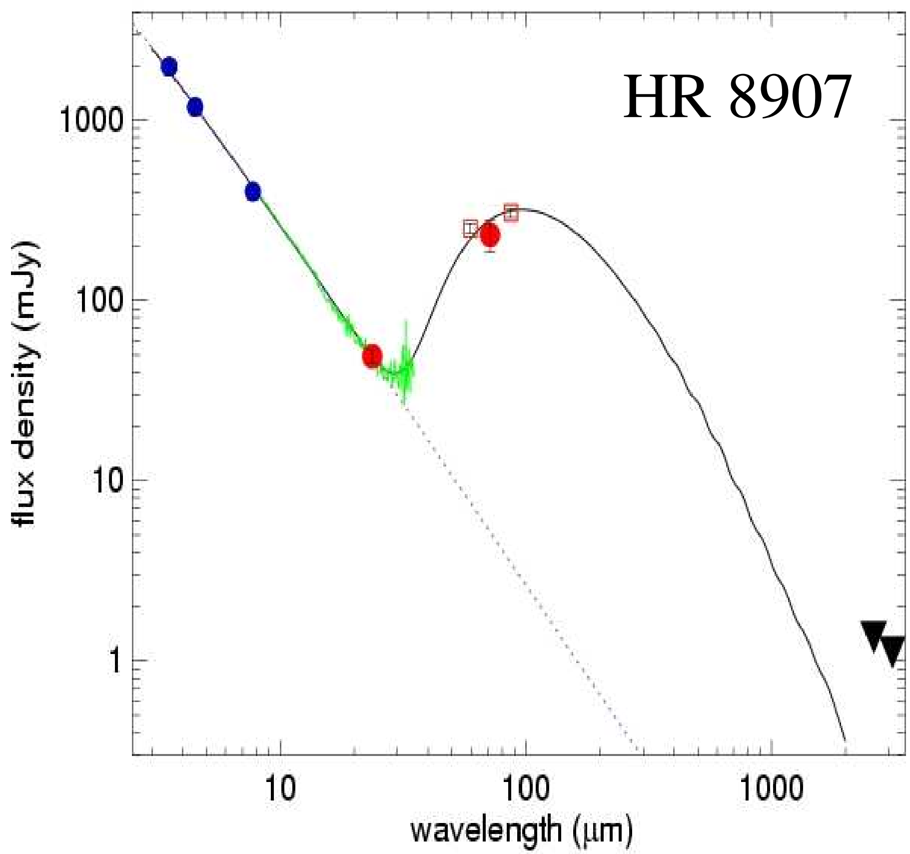
FIR

...but they ARE evidence for

- Dynamically hot outer planetesimal belts.

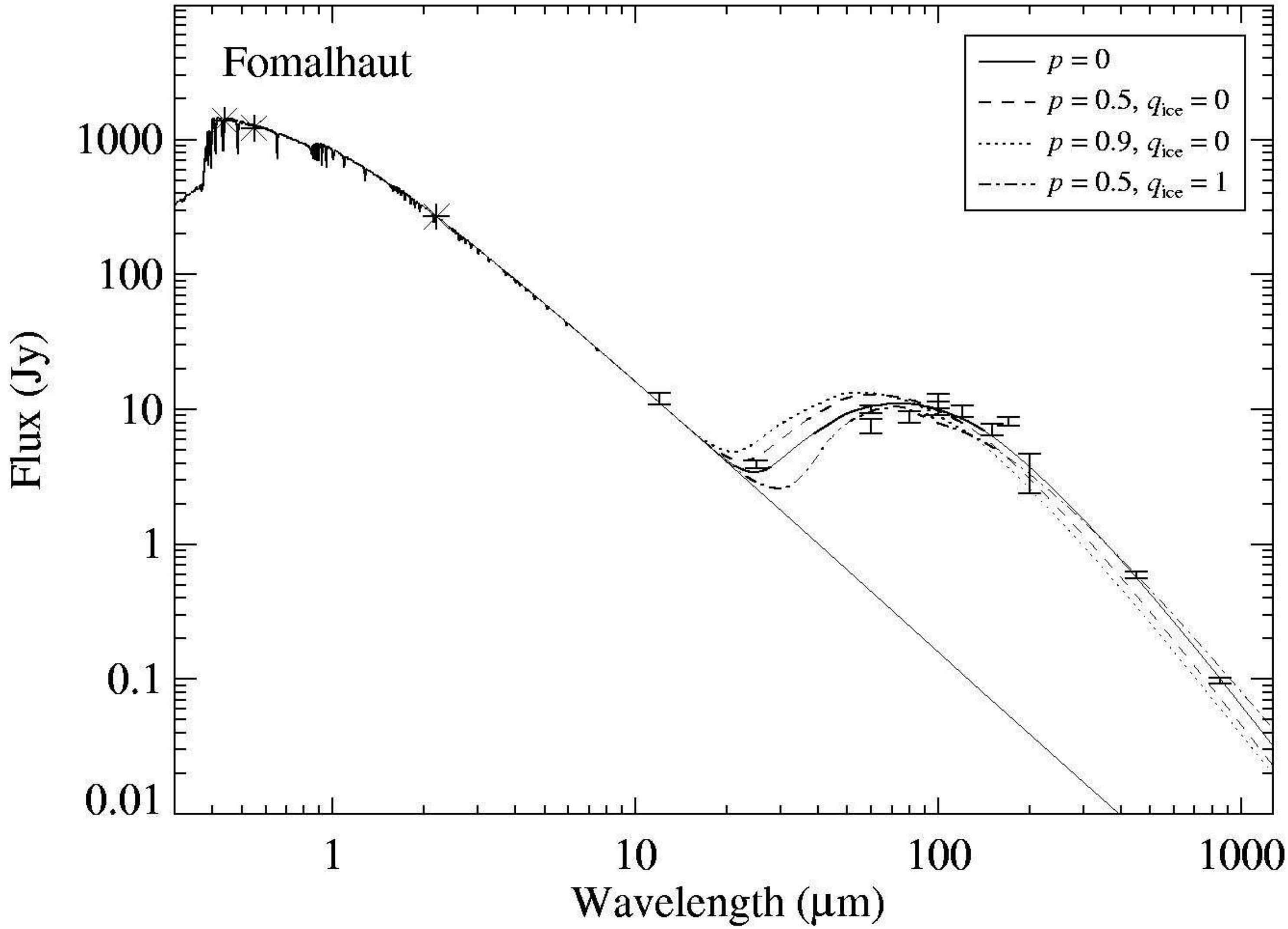
- Lack of interior planetesimal belts.

- Clues to the physical state of the remnant disk (e.g. Najita & Williams, 2005).

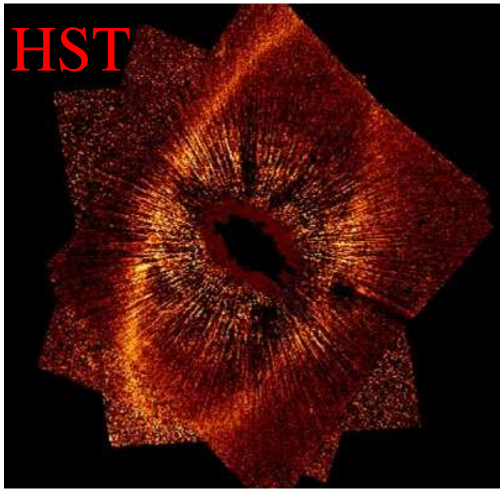


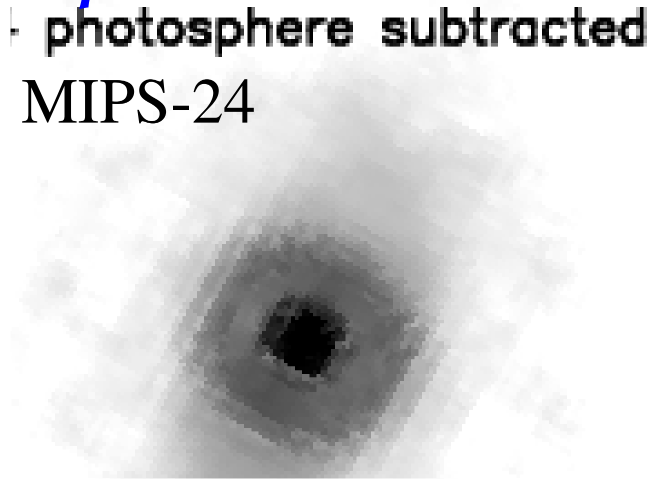
Kim et al. This meeting; Hillenbrand et al. (2006)

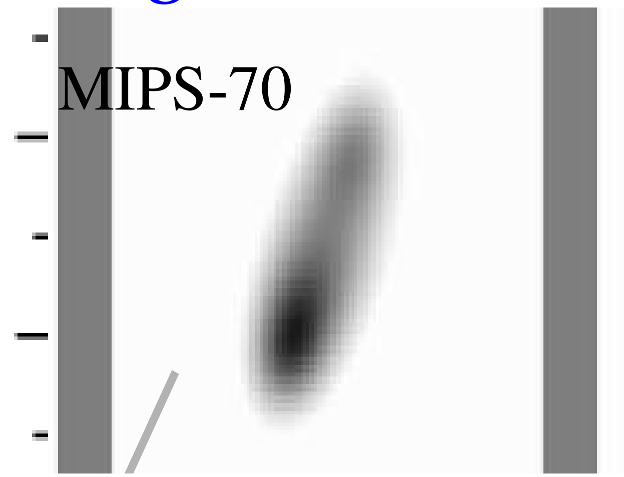
Step #9. Spectral energy distribution models are degenerate.

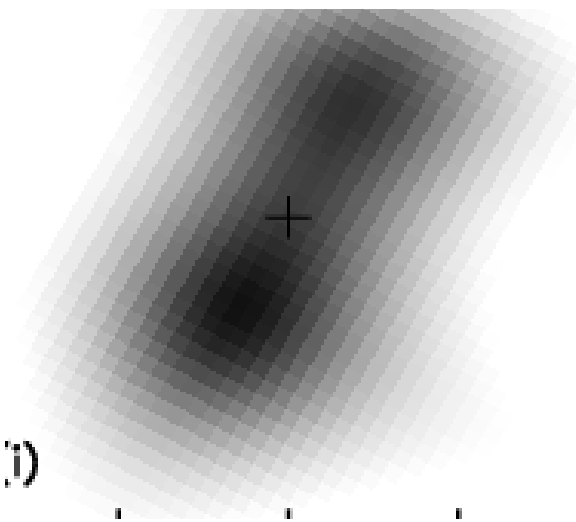


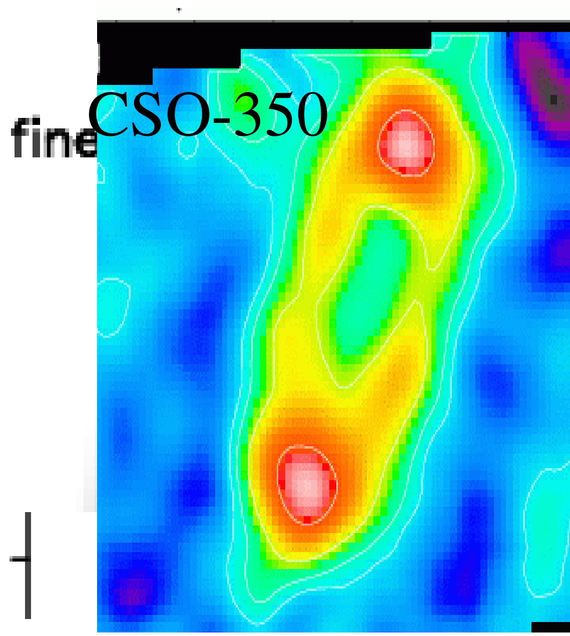
...but images & spectra break those degeneracies.

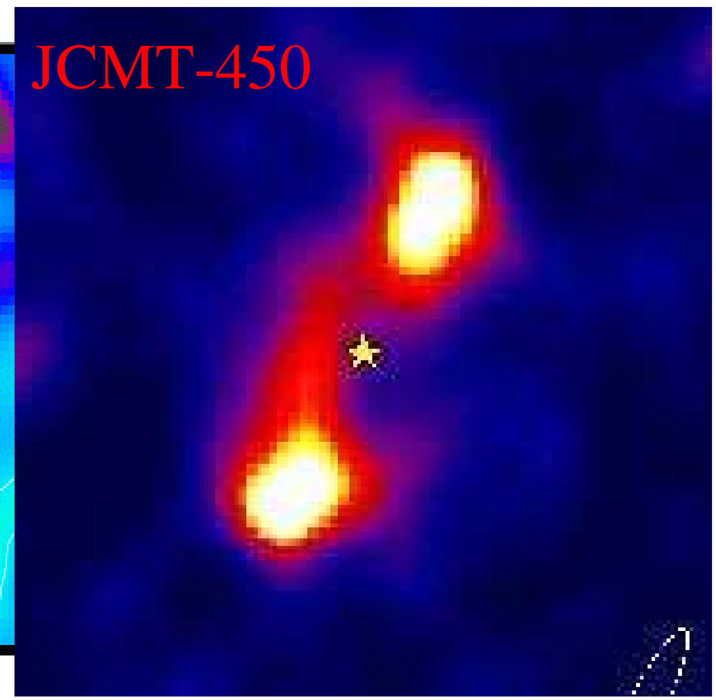






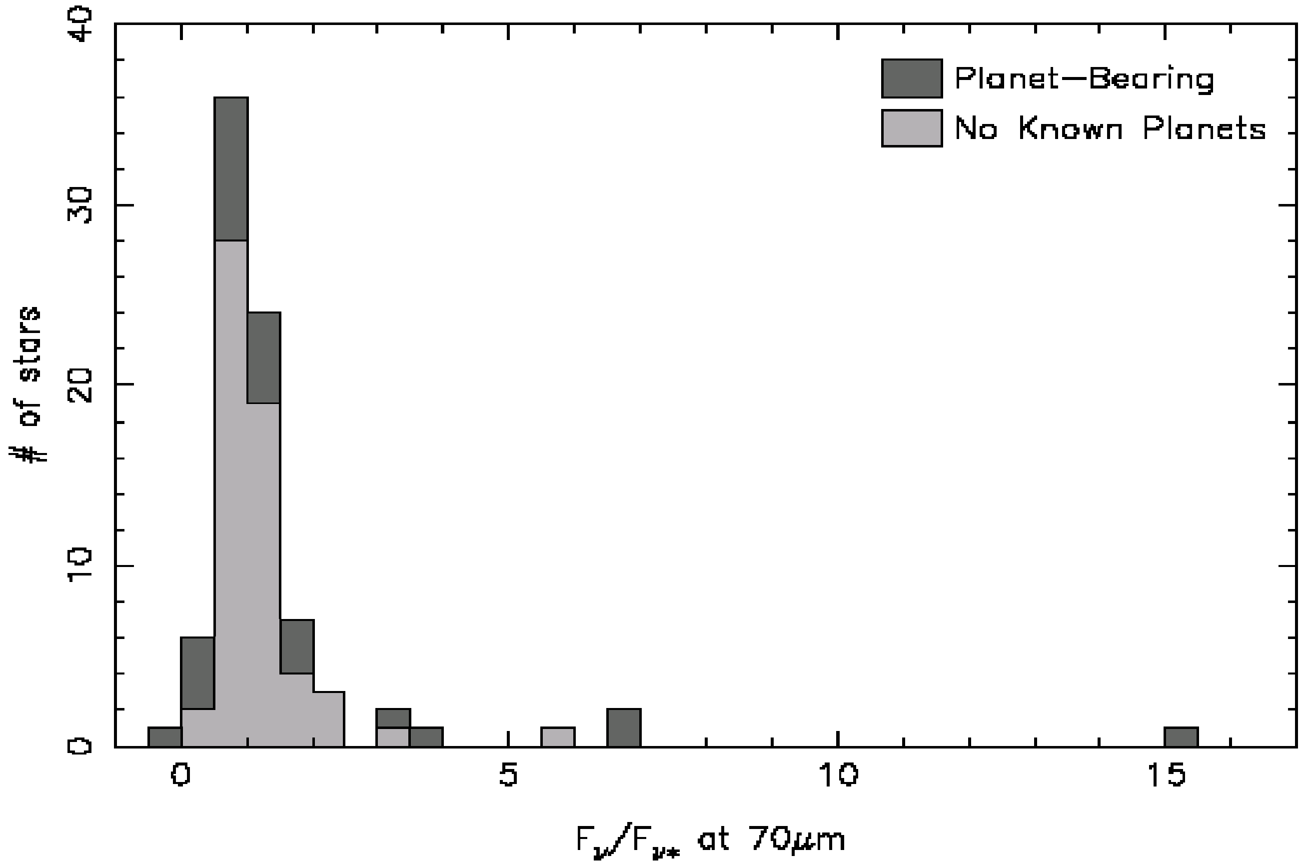






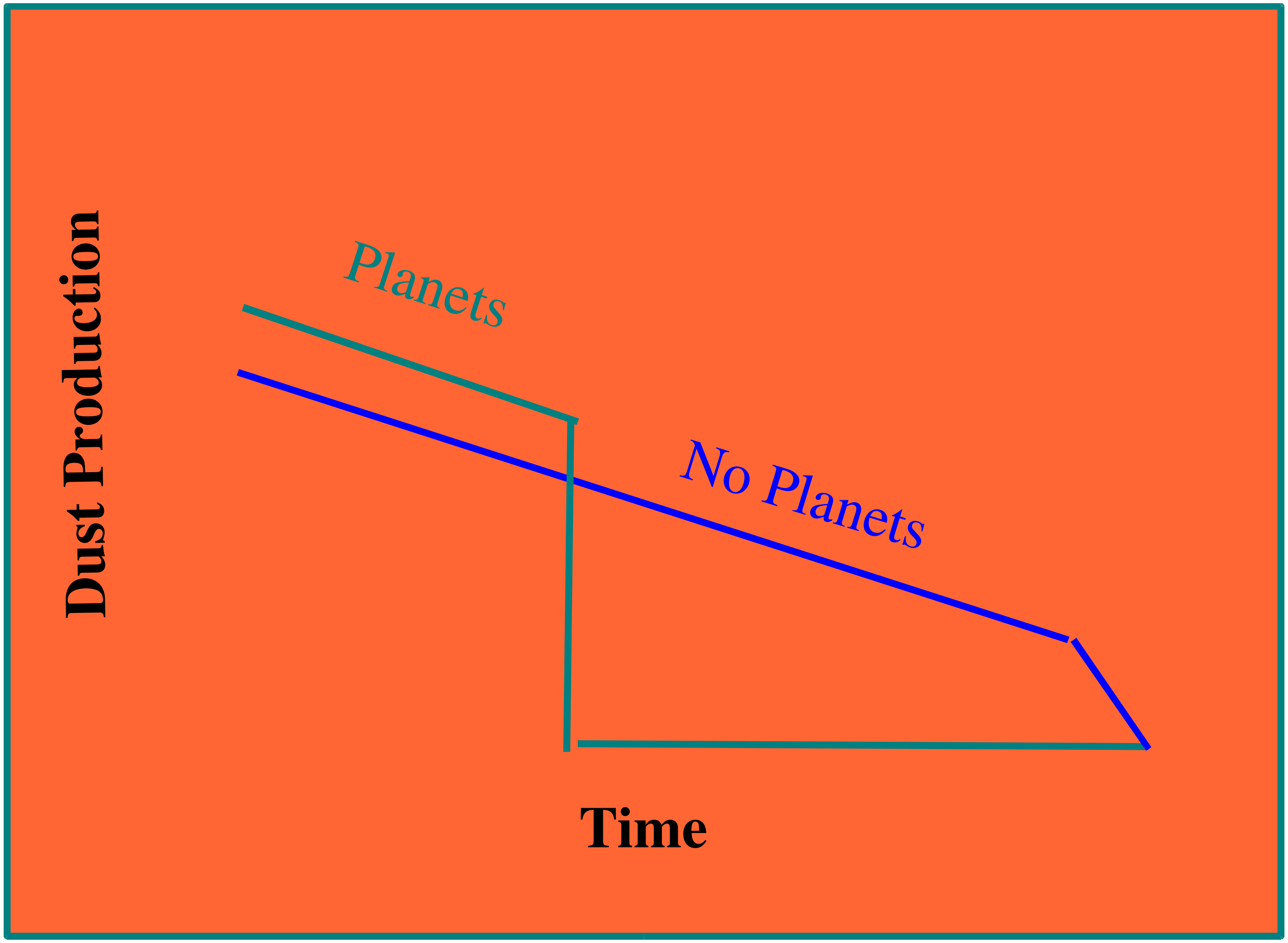
FIR

Do Stars with Inner Planets (< 5 AU) Also Have Kuiper Disks?

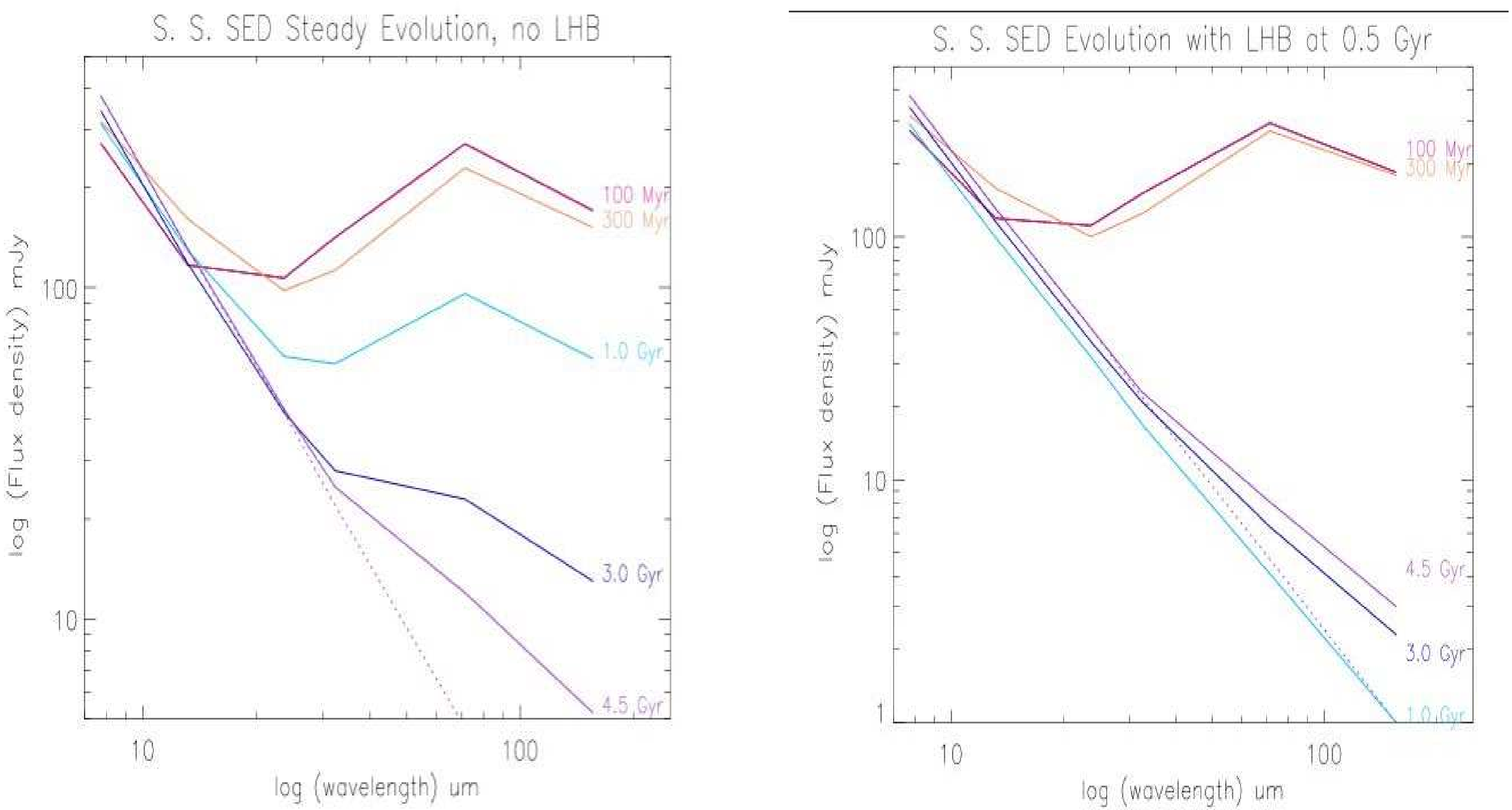


Beichman et al. (2005)

Step #10. The connection between dust emission and presence/absence of planets is not clear.

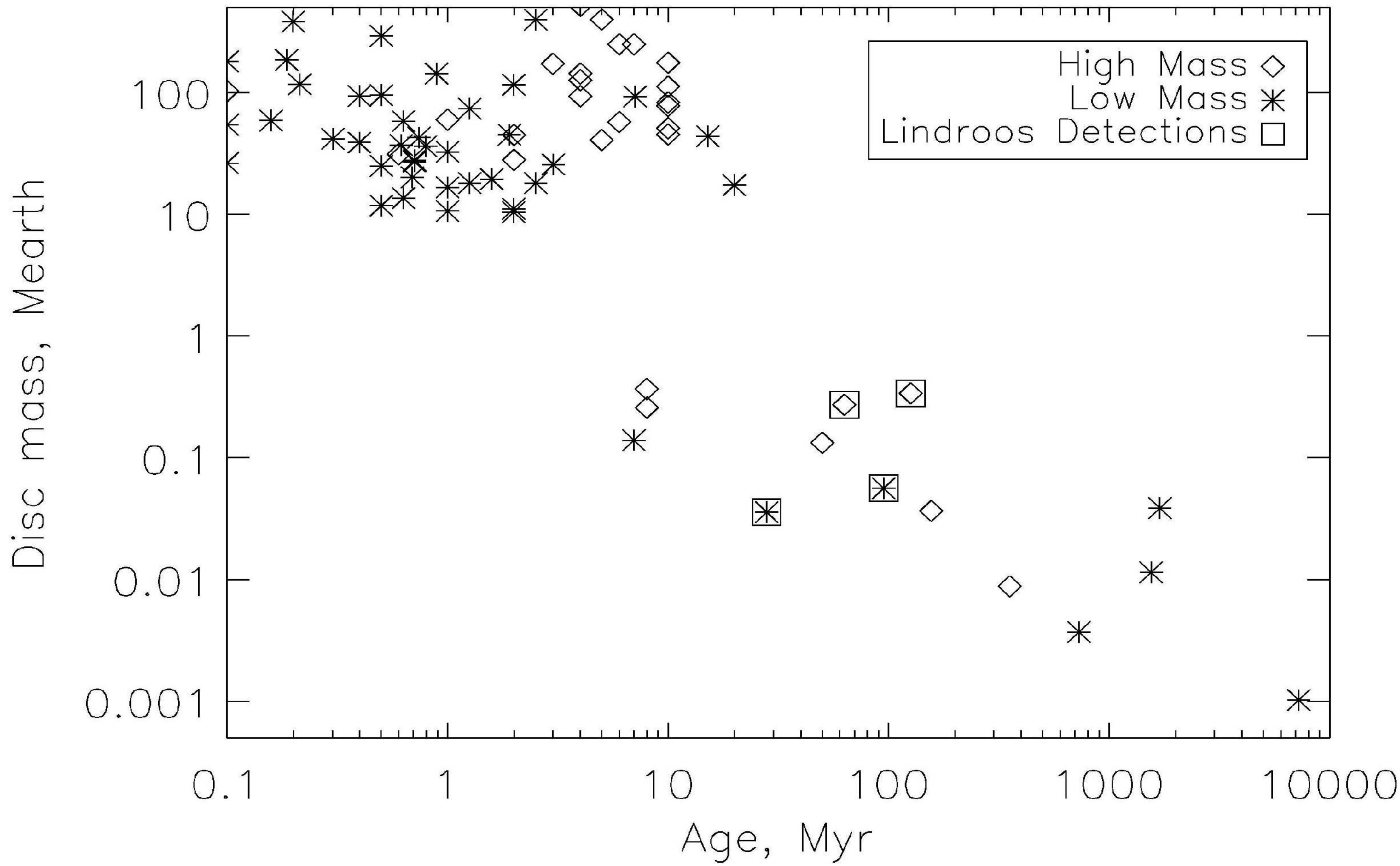


Step #11. Dynamical evolution is key to the history of our solar system dust disk.



Backman et al. (2005); Gomes et al. (2005); Strom et al. (2005)
Morbidelli et al. This meeting; See however Kenyon & Bromley (2004).

Step #12. Comparison of disk evolution between A stars, G stars, and M stars (Binaries?) consistent (so far).



Wyatt and Greaves (2003); cf. Natta et al. (2000); Rieke et al. (2005);
See however Plavchan et al. (2005); Stansberry et al. (this meeting)

Executive Summary Part I:

1. Results from disk surveys depend on wavelength of observation.
2. Accretion disks dissipate in 1-10 Myr.
3. Gas dissipation timescale is < 10 Myr.
4. Transition timescale 0.3-3 AU is << 1 Myr.
5. Warm debris disks are unusual.
6. Unusual objects can be transient or rare.

Executive Summary Part II:

7. Cool debris disks are common.
8. Inner holes not clear evidence for planets.
9. Images required for robust disk models.
10. Effect of planets on disk evolution unclear.
11. Dynamical history of SS important.
12. Disks might evolve independent of star mass or wide companions?

First Disk Imaged with the LBT!

Students please ask me about LAPLACE 2006 Astrobiology Winter School!