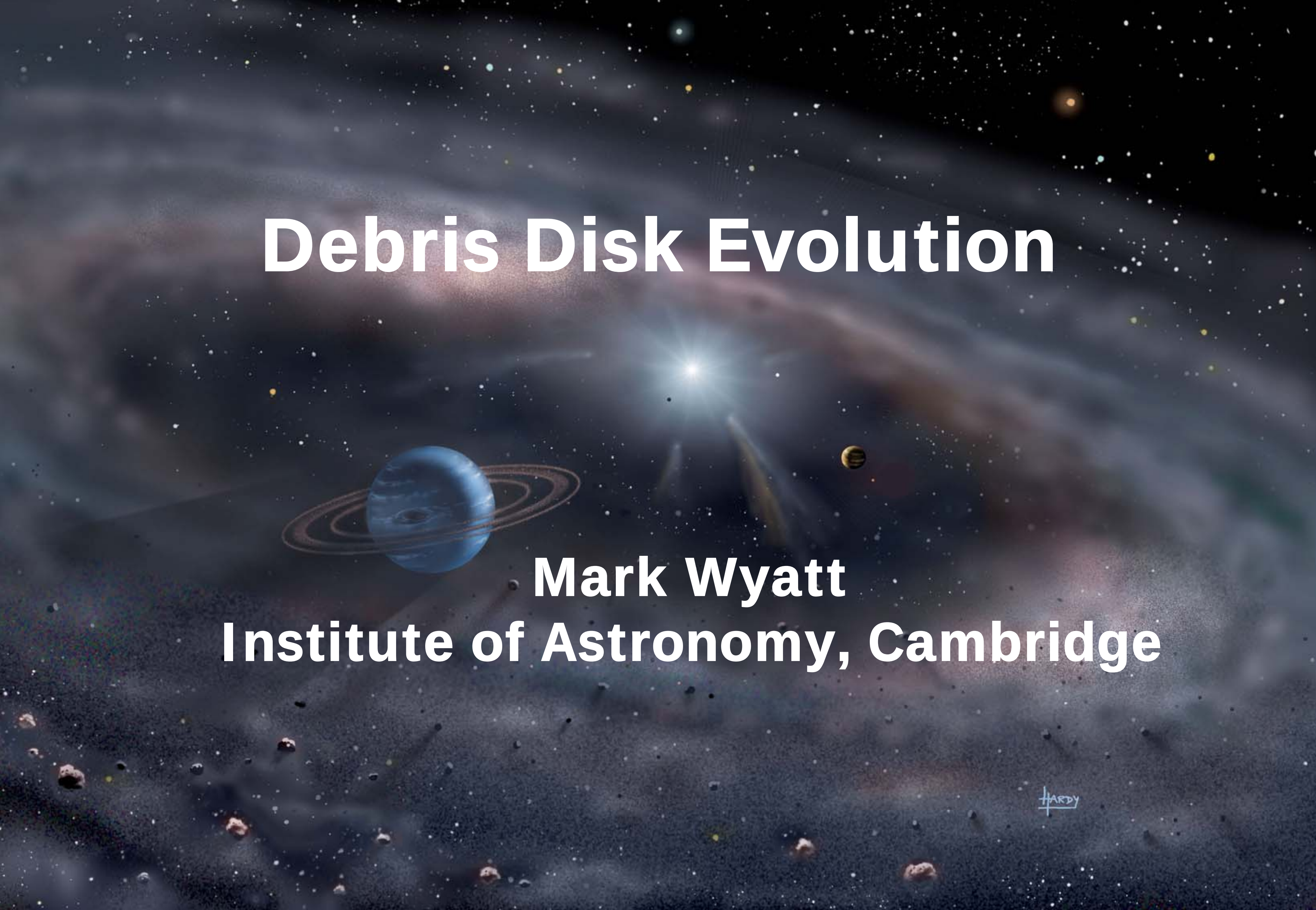

Debris Disk Evolution

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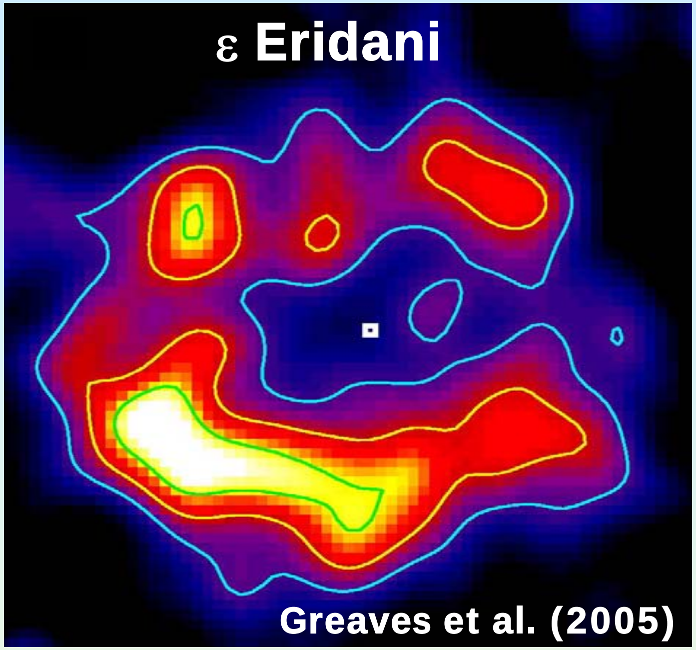
What are debris disks?

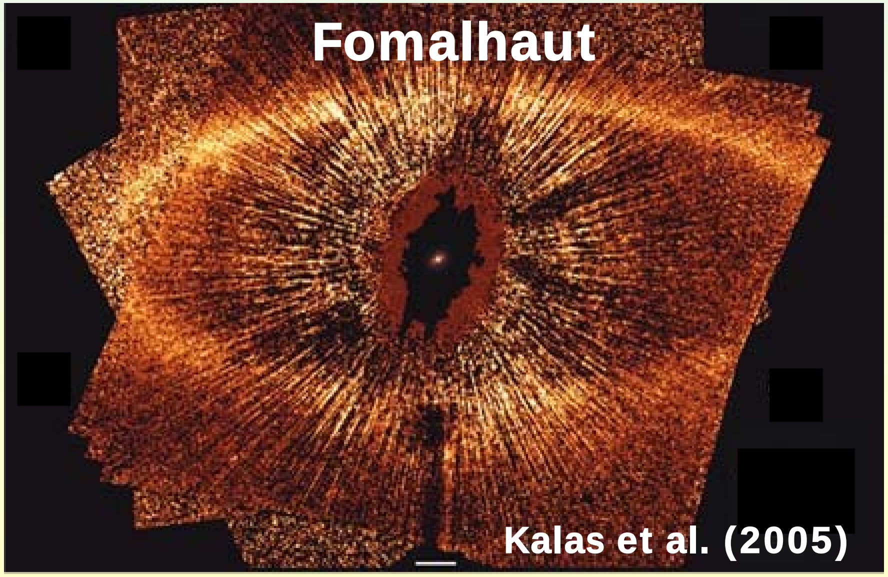
Planetesimals and dust found around ~15% of main sequence stars

The planetesimals are confined to narrow(ish) belts, even if the dust distribution is broad

Forgetting detailed structure there are two main observables:

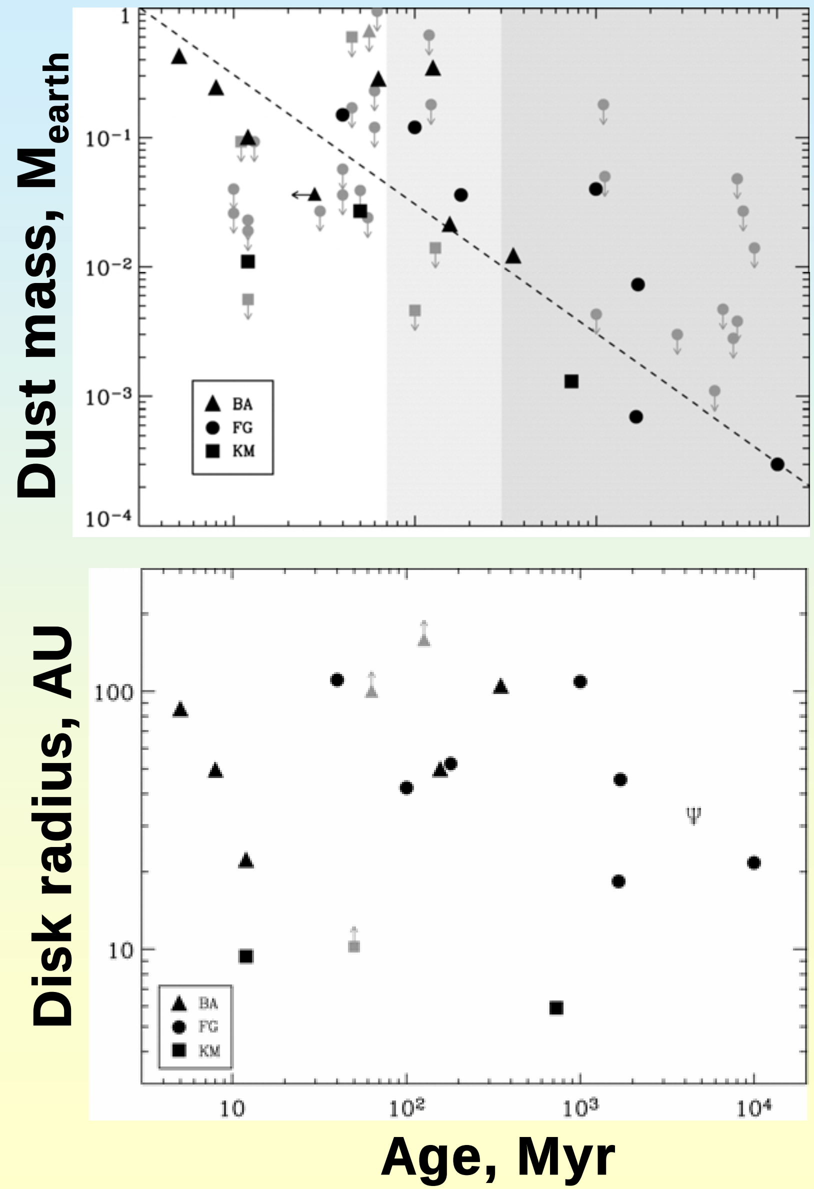
- Radius, **r**
- Mass, **M**, or luminosity, $\mathbf{f = L_{ir} / L_{*}}$





How do debris disks evolve?

Najita & Williams (2005)



Why do we care?

Debris disk evolution tells us about planetary system formation and evolution

How do we measure it?

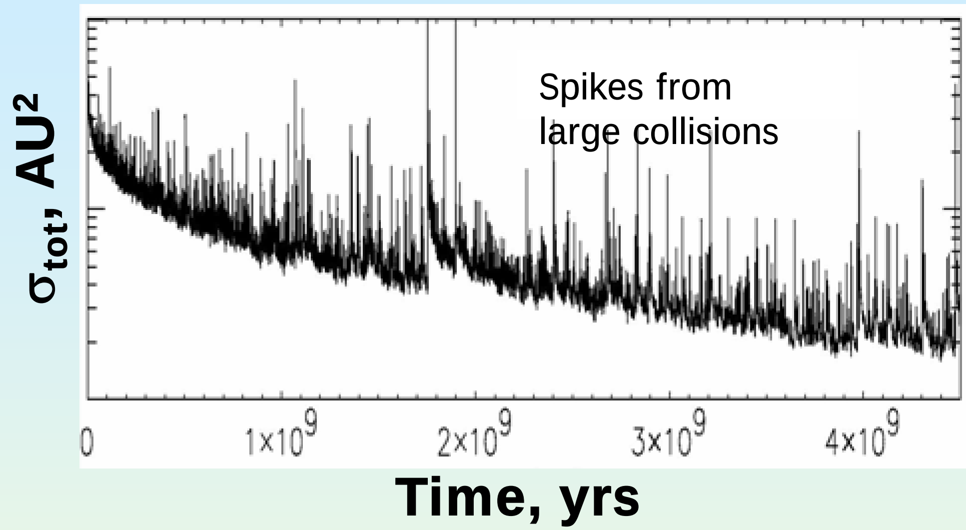
- Detailed structure of individual objects
- Observing thermal emission from dust of stars of different ages
    - Mass higher when younger
    - Range of radii at all ages

Models for debris disk evolution

- Steady-state
  - (A) Classical steady-state
  - (B) Delayed stirring

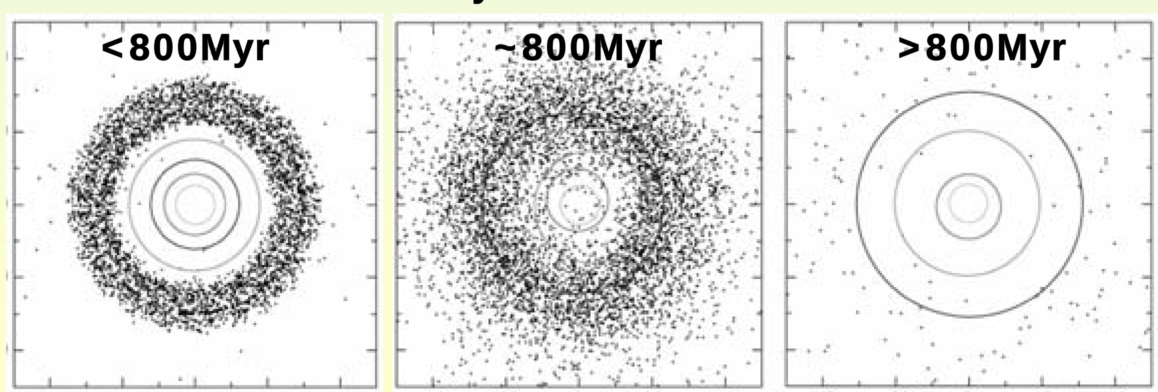
- Stochastic
  - (C) collisions
  - (D) dynamical instability
  - (E) supercomet
  - (F) passing star

Dust in inner solar system



Grogan et al. (2001); Dermott et al. (2003); Nesvorny et al. (2003); Farley et al. (2006)

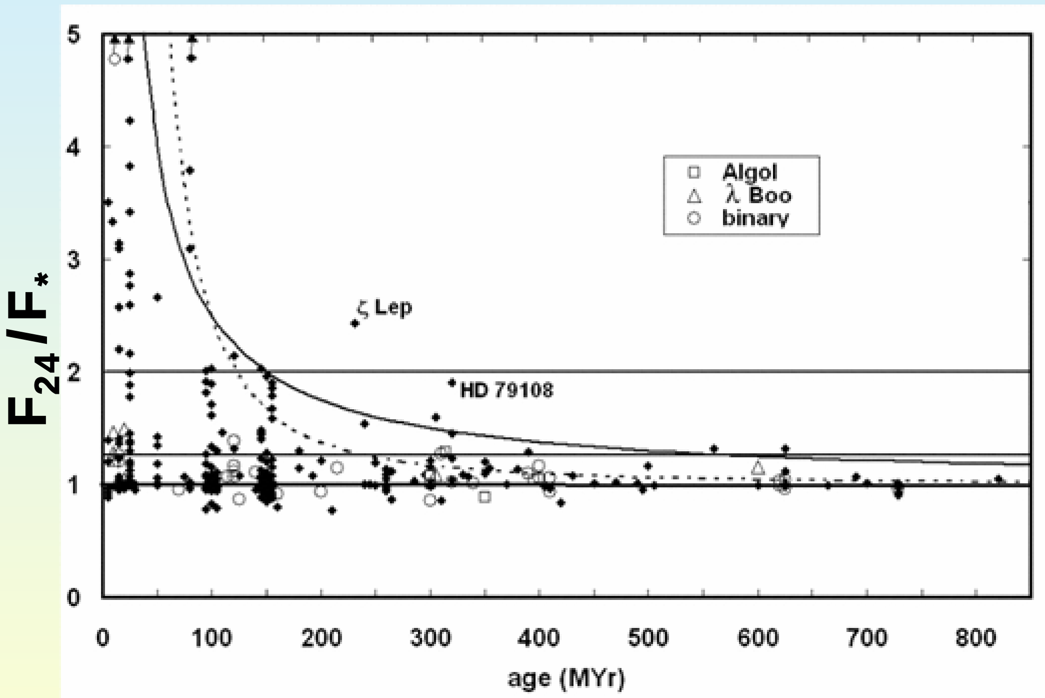
Late Heavy Bombardment Model

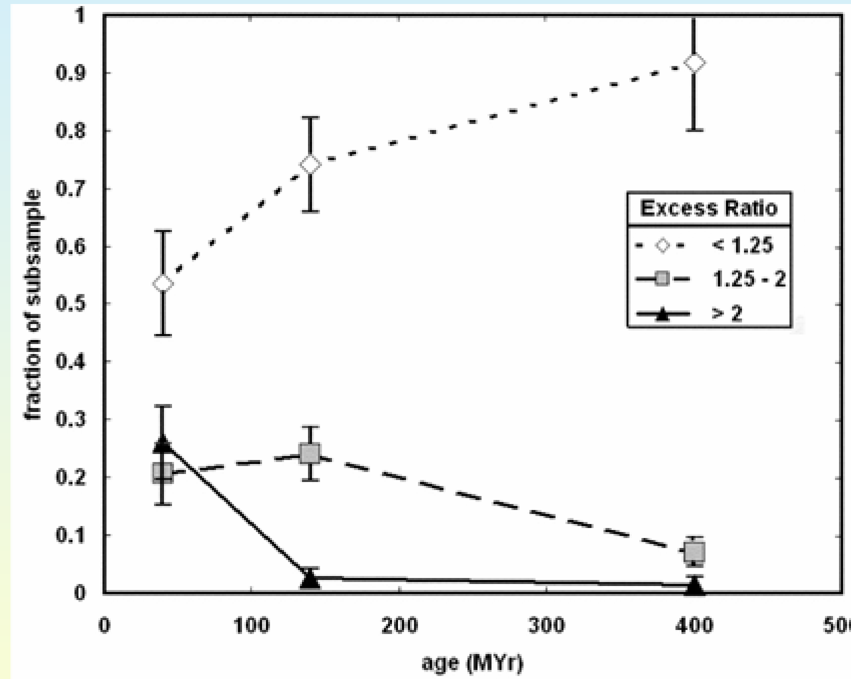


Gomes et al. (2005)

Constraints from statistics

Survey of 266 A stars for dust emission at 24μm (Rieke et al. 2005):





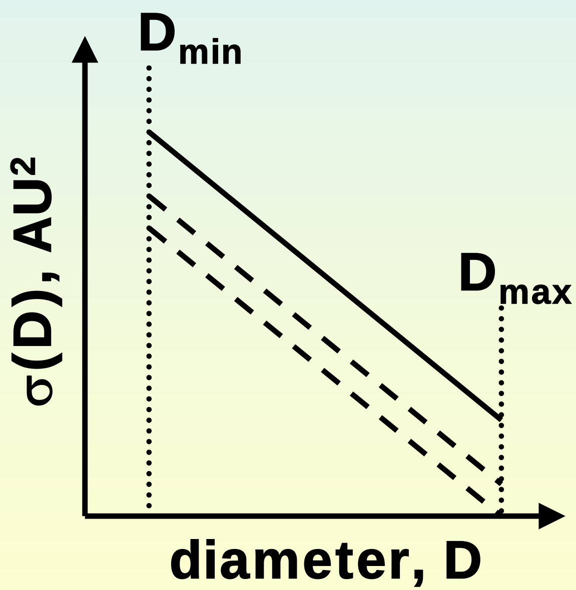
Conclusions:

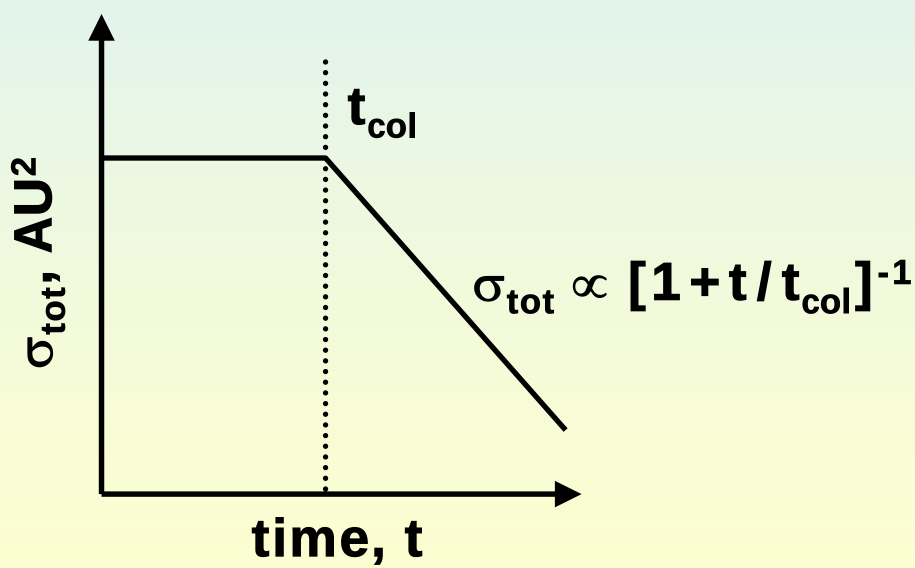
- fall off in upper envelope ~150Myr/t
- large excess declines rapidly, but intermediate excess peaks at 150Myr
- large range of dust masses at any given age implies stochastic evolution?

Steady-state planetesimal belt evolution

The size distribution in a collisional cascade is to first order described by a power law

Dust luminosity falls off as largest objects (**D_{max}**) are depleted in collisions on a timescale **t_{col}** which depends on planetesimal strength (**Q_D***) and eccentricity (**e**)





This simple model provides a reasonable description of more detailed models

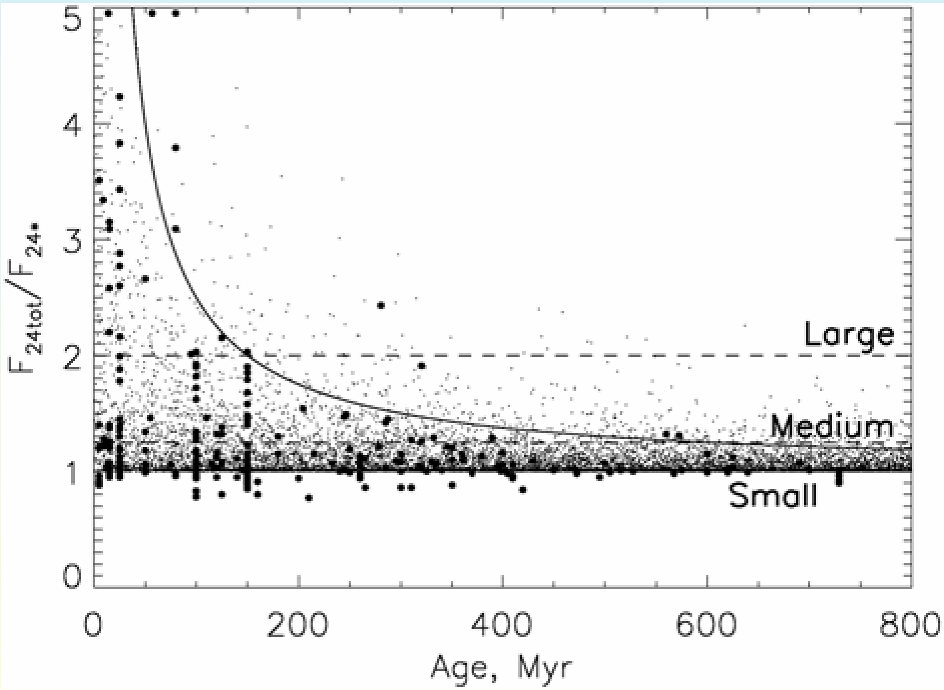
Model for debris disk populations

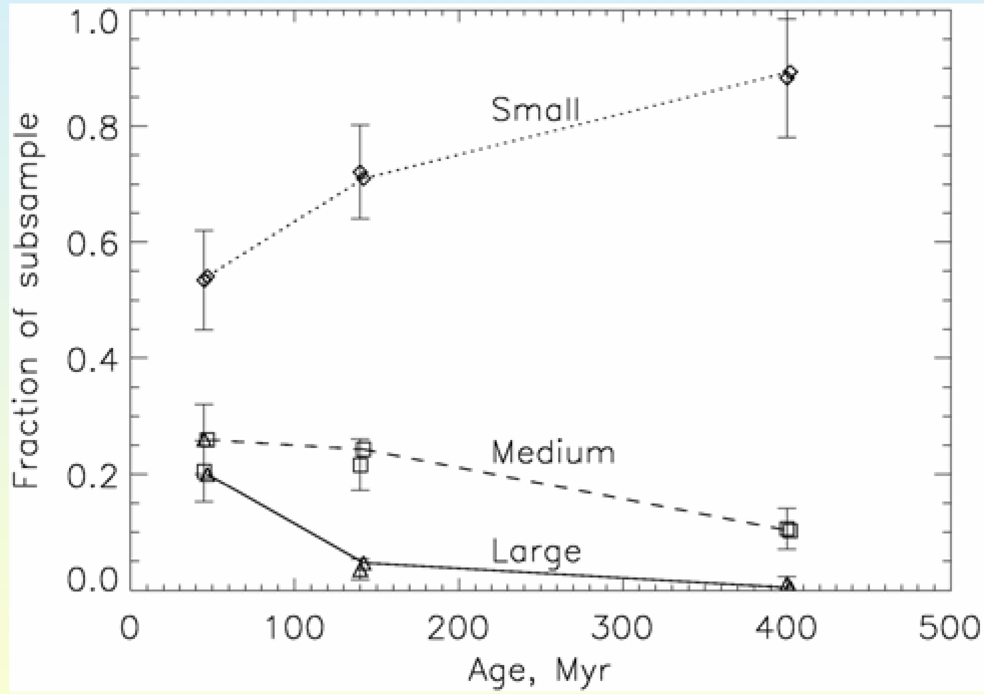
Model population of 10,000 A stars for which:

- Random spectral types A9-B8, and ages 0-800Myr
- All have a planetesimal belt, all of which have the same
    - largest planetesimal size, D_{max}
    - planetesimal strength, Q_D^*
    - eccentricity, e
- Initial mass of belts taken from the distribution observed in protoplanetary disks (Andrews & Williams 2005)
- Radius distribution, $n(r) \propto r^{\gamma}$, fitted to observations

Steady-state evolution explains 24μm stats

This model accurately reproduces the fraction of stars in different age bins with small, medium and large 24 μm excesses



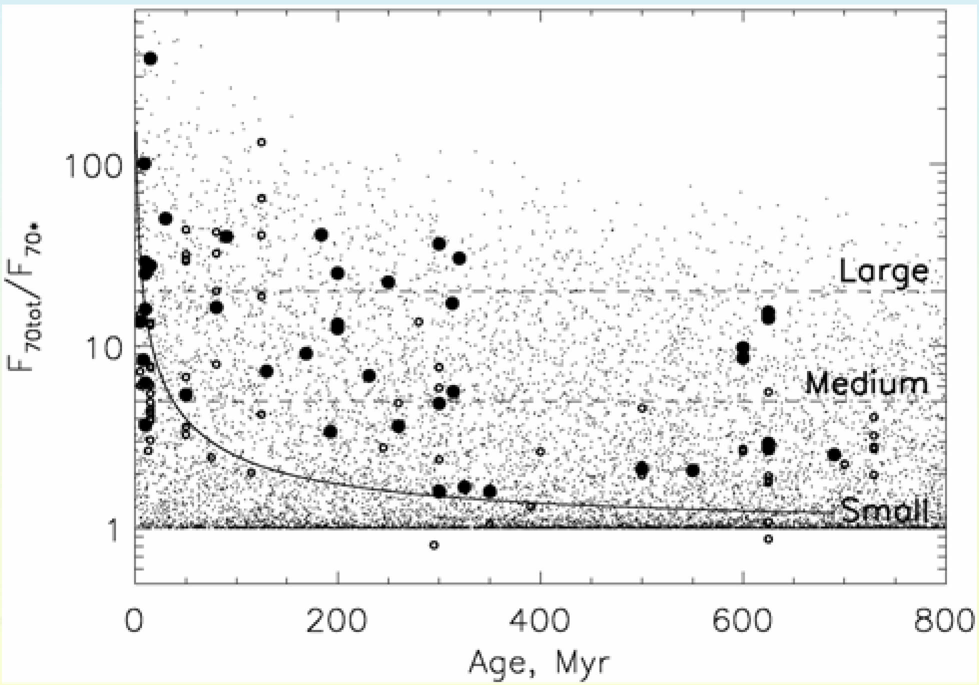


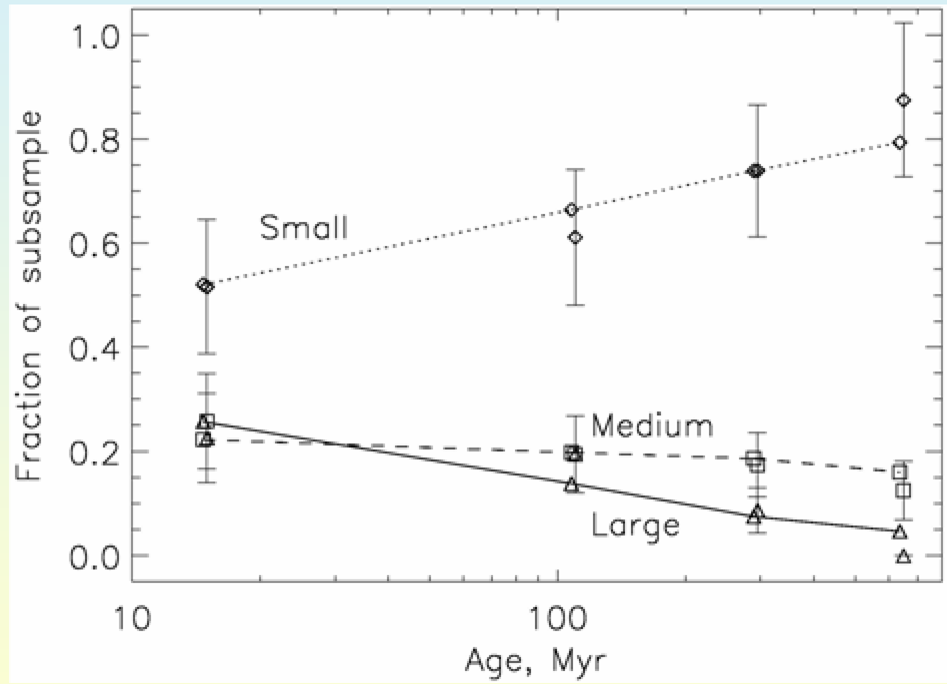
Wyatt et al. (2007a)

24μm statistics can be explained by steady-state evolution, and there is no need to invoke stochastic evolution

It also explains 70μm statistics

Survey of ~160 A stars for 70μm dust emission found different results to 24μm, notably a longer decay time and higher excess ratio (Su et al. 2006):



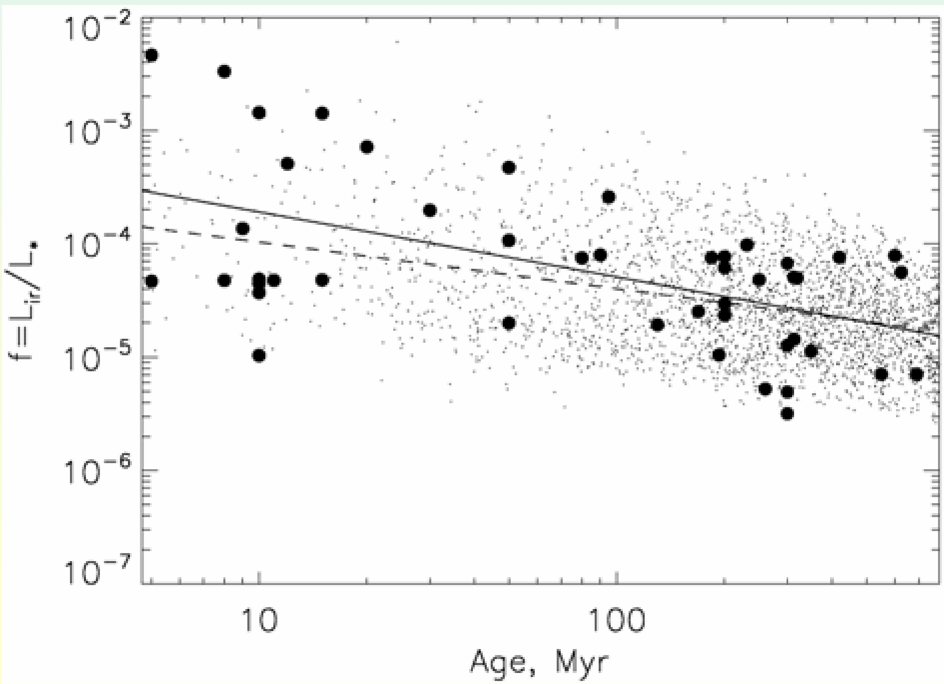


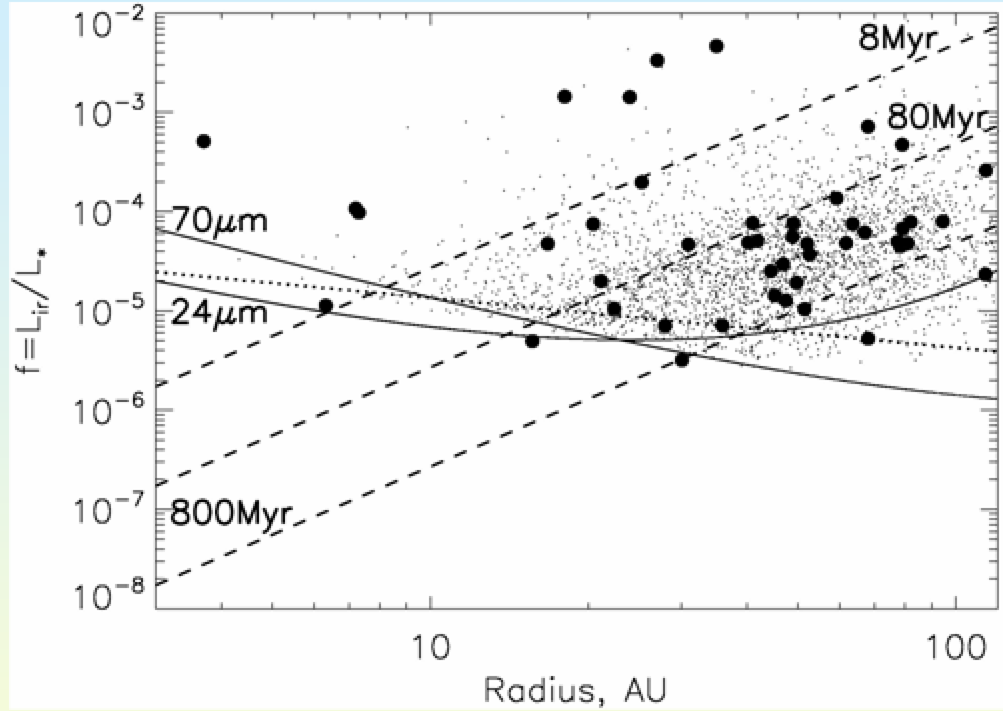
Wyatt et al. (2007a)

70μm statistics are reproduced by the same steady-state evolution model

As well as the trends seen in survey data

For example, the evolution of luminosities of disks detectable at 24 and 70 μm shows two orders of magnitude spread at each age, and a fall-off in the mean $\propto t^{-0.46\pm0.14}$

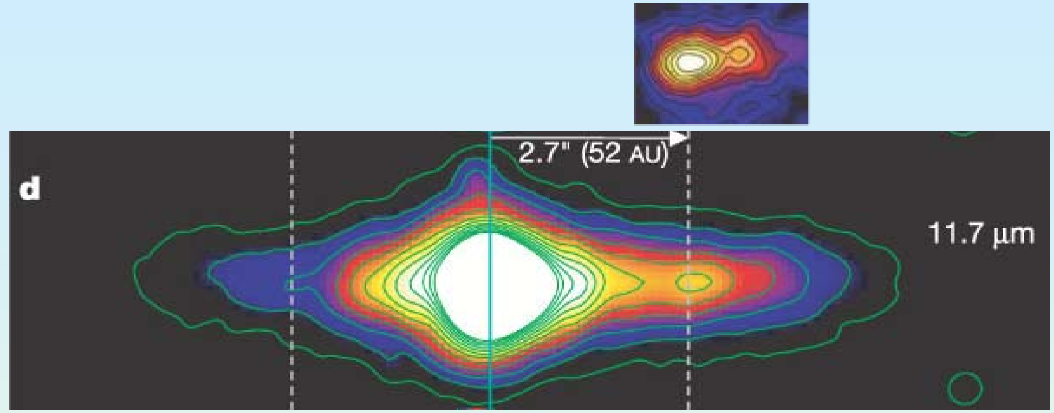




Noting that detectability is a strong function of planetesimal belt radius (must lie above f_{det} and below f_{max}), more unusual trends are also explained, such as that disks detected at 24μm but not 70μm are all <400Myr

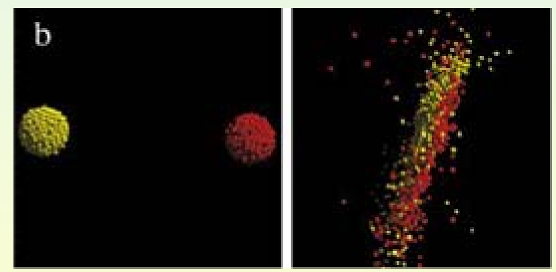
Caveats (1): β Pictoris and Vega

• Mid-IR images of 10-20Myr β Pic show a clump of dust at 52 AU which in in the process of radiation pressure blow-out on 100 year timescale (Telesco et al. 2005)



• Images (24-70μm) of Vega also show apparently short-lived dust (Su et al. 2005)

Problem: what produced these transient grains?
Solution: recent collision?

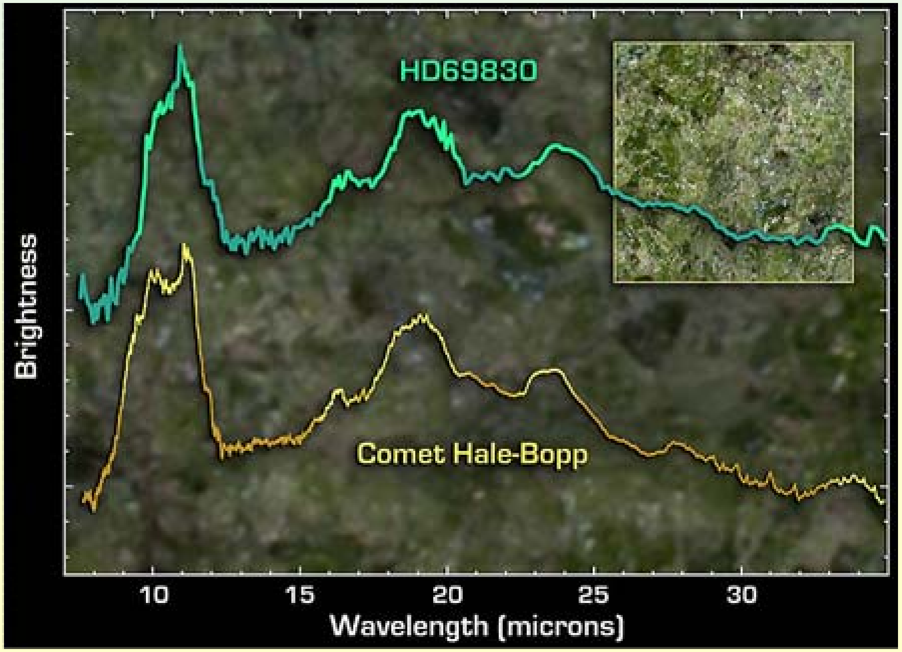


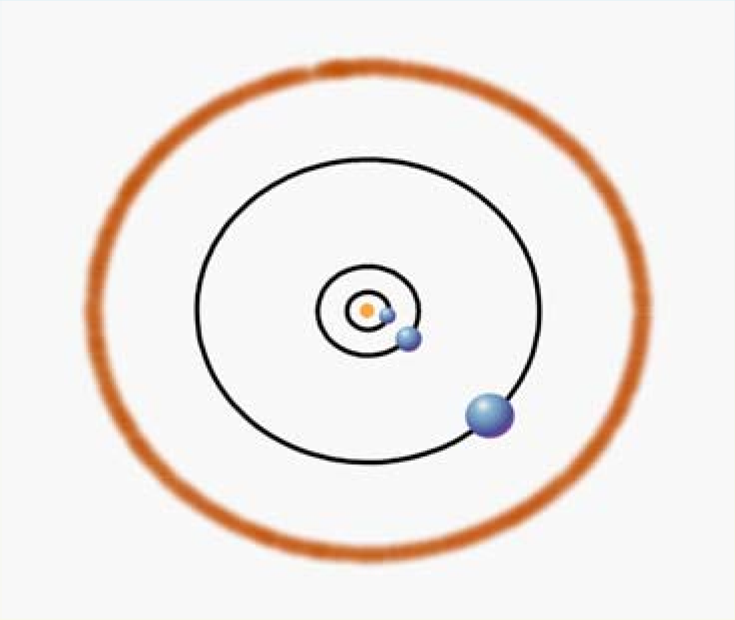
Problem: need MASSIVE collision (>100km objects) to produce observable dust signature and such collisions are infrequent (Wyatt & Dent 2002)
Solution: **(i)** dust is not lost
(ii) collisions really are frequent

Caveats (2): Hot dust around sun-like stars

Just 7 sun-like stars (2%) have hot dust emitting at 25μm (e.g., Bryden et al. 2006)

One of the stars is 2Gyr old K0V star HD69830 whose mid-IR spectrum is similar to Hale-Bopp indicating dust at ~1AU (Beichman et al. 2005)





Recently found to have 3 Neptune mass planets orbiting at 0.08, 0.16 and 0.63 AU on nearly circular orbits (Lovis et al. 2006)

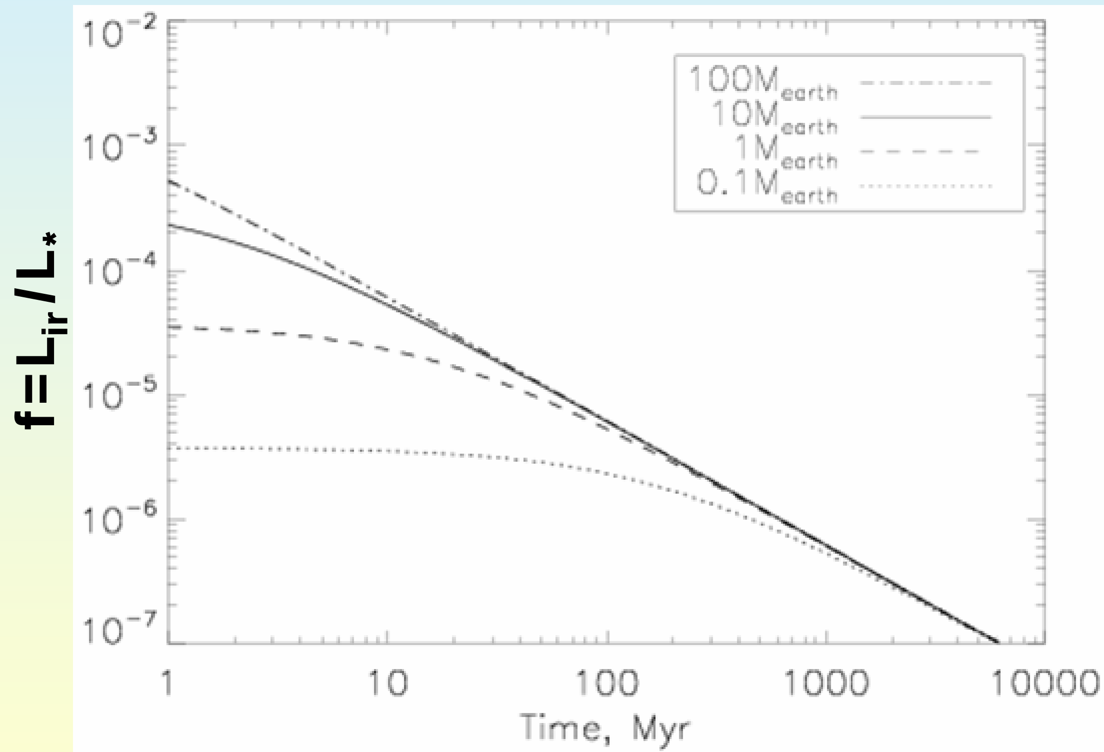
Are these massive asteroid belts?

No: this dust cannot be produced in a planetesimal belt coincident with the dust, rather it must be **transient** (Wyatt et al. 2007b)

Why: there is a maximum luminosity (and mass) that a belt can have:

$$f_{max} = 0.16 \times 10^{-3} \, r^{7/3} \, t_{age}^{-1}$$

4/7 hot dust sources exceed this by >1000

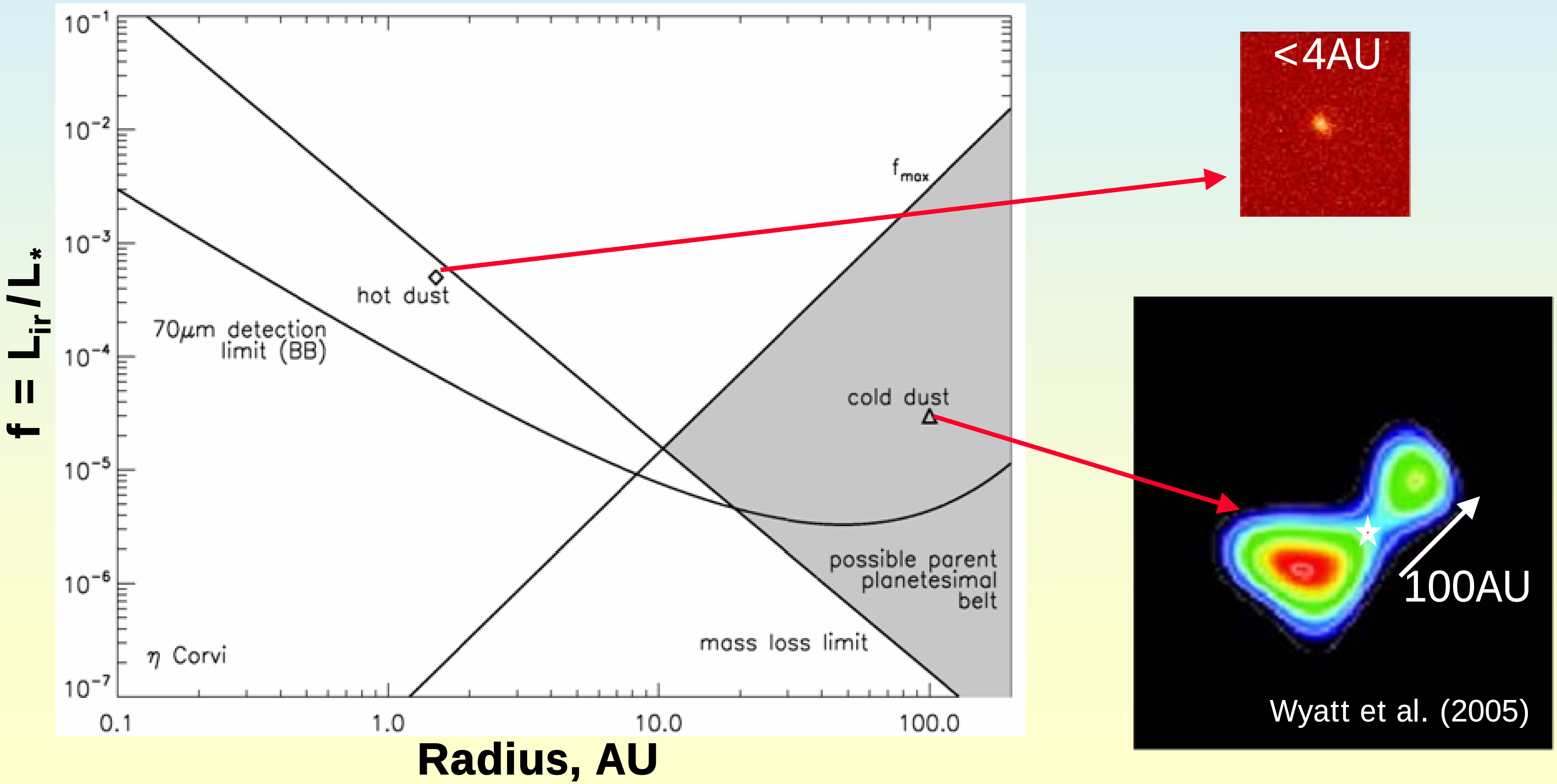


What are they then:

- recent collision **very unlikely**
- in situ planetesimal belt **no**
- scattered in from more distant planetesimal belt **possibly**

Kuiper belt of η Corvi

For 2/4 of the hot transient dust sources, including η Corvi, an outer planetesimal belt is known to exist which could be feeding the hot dust



Conclusions

- **Steady-state**

  (A) Classical steady-state — True for the majority of debris disks

  (B) Delayed stirring — Stirring must come from somewhere, perhaps for largest disks

- **Stochastic**

  (C) collisions — Would explain the small grains seen in some systems, but infrequent?

  (D) dynamical instability
  (E) supercomet — Planetary perturbations could move long-lived planetesimals to inner regions

  (F) passing star — Infrequent