Are Debris Disks Self-Stirred?

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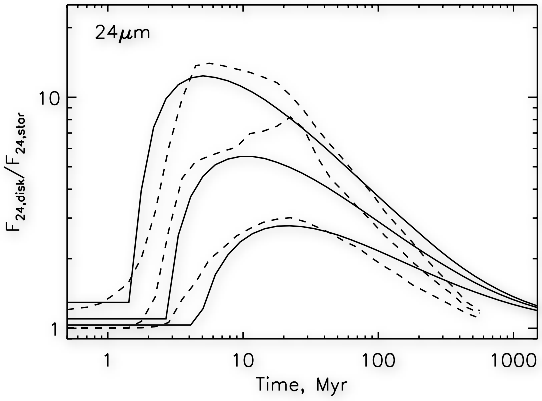
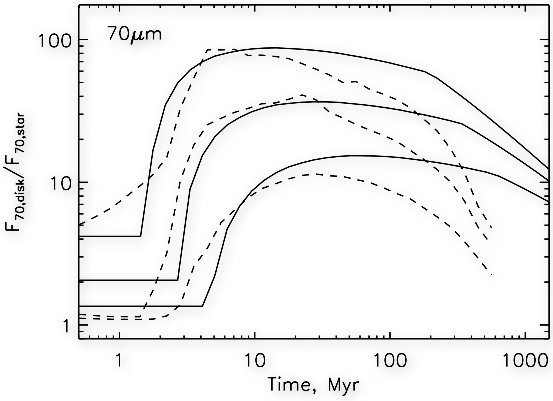
Debris disks are self-stirred when formation of Pluto-size objects stirs planetesimals to fragmentation velocities. The time taken for Pluto-formation in disks with an inner hole has motivated self-stirring as an explanation for the “rise and fall” of fractional 24μm excesses around A-stars. Here we use a simple model (Wyatt 2008) to illustrate how these disks evolve and assess the ability of self-stirring to reproduce the A-star observations. We find that A-star debris disks may be self-stirred, but that they are narrow belts, not extended like their parent protoplanetary disks.

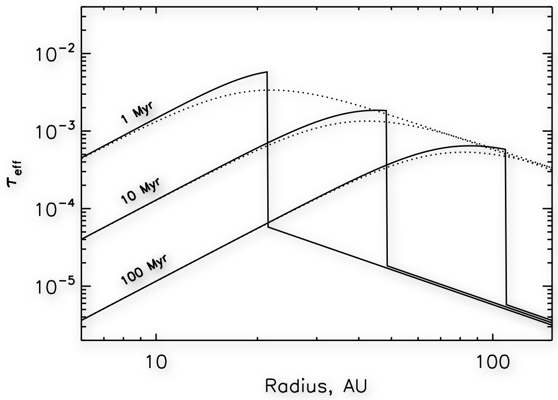


Our model *(solid lines)* reproduces the Kenyon & Bromley (KB) excess evolution *(dashed lines)* reasonably well. The main difference at 70μm is probably due to increased stirring as objects continue to grow in the KB model.



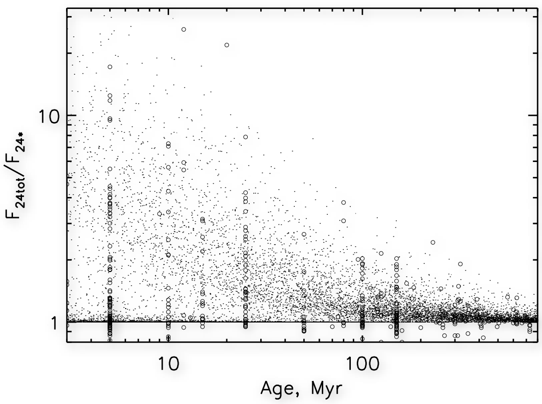
Narrow belts or extended disks?

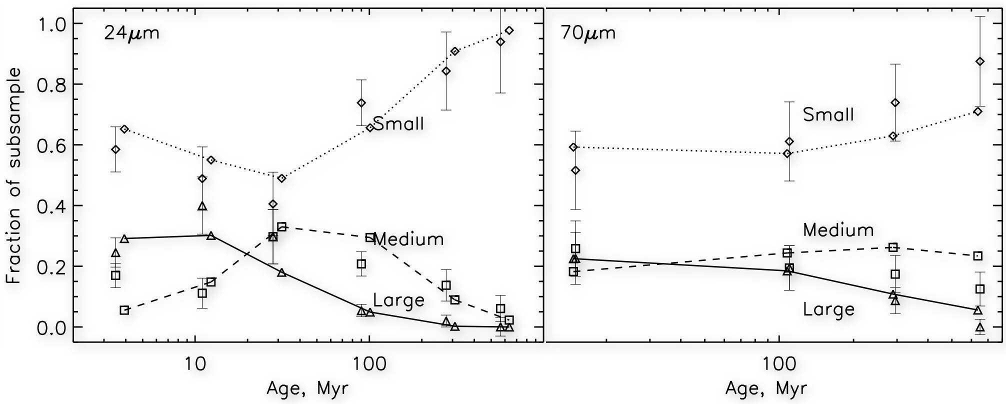
We are unable to fit the observations using disks with fixed inner and/or outer radii because the 70μm excess evolves too slowly *(above right)* and predicts too many (~40%) medium excess disks at late times compared to observations. This result is independent of the trends at early times. Therefore narrow belts describe the observations better. A possible explanation is that inner regions are cleared by planets, and the outer extent is set by where planetesimals can form.



Self-stirred *(solid lines)* **and pre-stirred disks** *(dotted lines)*. The disk is depleted faster closer to the star so τ_{eff} increases with radius. Where the disk age is less than the collision time the primordial surface density remains.

The best fit model excesses over time *(dots, symbols joined by lines)* has narrow belts at r±dr with dr=r/2 and r distributed between 15-120AU ($N[r] \propto r^{-0.8}$). This model reproduces A-star observations binned by time and into small, medium, and large excesses *(filled circles, symbols with errors)*.





Conclusions

- We can reproduce the A-star statistics and trends with a self-stirred population model of belts.
- A-star observations imply that debris disks are belts because extended disks evolve too slowly at large radii. Planet formation processes provide a possible explanation.

Supplementary information

Observations are the Rieke et al (2005) and Su et al (2007) samples of A-stars, with additional stars from σ Ori (Hernandez et al 2007), λ Ori (Hernandez et al 2009), Orion OB1a/b (Hernandez et al 2006), Upper Sco (Carpenter et al 2009), ϒ Velorum (Hernandez et al 2008), β Pic Moving Group (Rebull et al 2008), NGC 2362 (Currie et al 2008), and IC 2391 (Siegler et al 2007). To compare radius distributions we use the 46 star subsample of disks detected at 24 and 70µm used by Wyatt et al (2007b). HR 4796A (HD 109573) lies above the plot of 24µm excess vs. time with $F_{24,disk} / F_\star \sim 100$.

A KS-test shows that the apparent "rise and fall" of 24µm excesses is only 1-2σ significant (at times <50Myr), and we therefore attempt to reproduce the trends as well as obtain a good formal fit.

The model is that developed by Wyatt et al (2007a,b) with the inclusion of delayed stirring and multiple annuli. Self-stirring is included here by an empirical fit to the Kenyon & Bromley (2008) excess evolution, though the stirring time is similar to the expected growth timescale

$$t_{grow} \propto P/\sigma \propto r^3 / \Sigma_0 .$$

Carpenter et al 2009 have suggested stars moving towards the main-sequence can cause some of the increase in 24µm excesses. As stars reach the main-sequence their luminosities decrease, and therefore the grain blowout size increases, thus causing the excess (for fixed planetesimal belt mass) to increase. For A-stars they show that this effect is strongest in the first 10Myr.

References

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