The Rise of Debris Disks and The Formation of Terrestrial and Icy Planets

Thayne Currie (CfA)

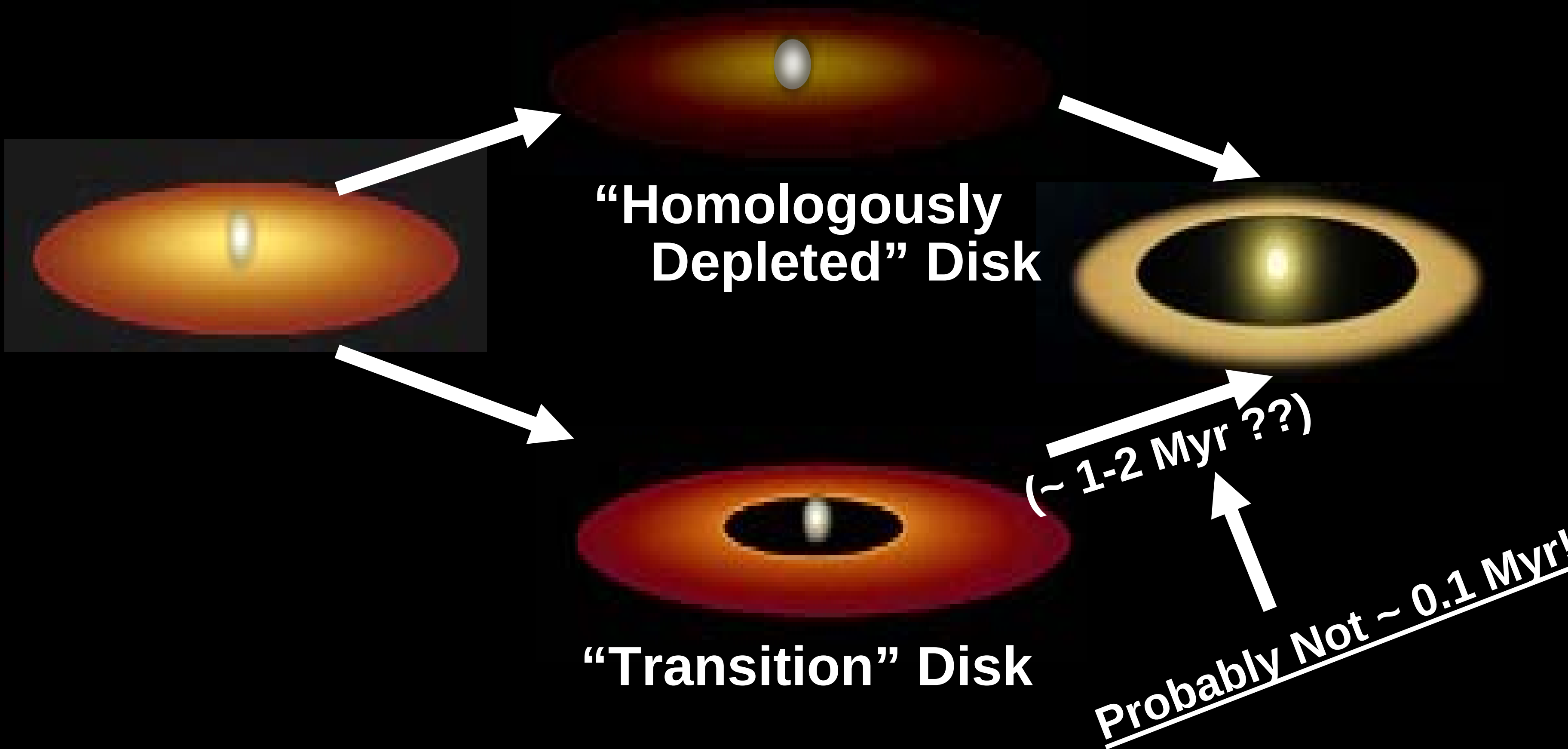
Collaborators: Scott Kenyon (CfA), Charles Lada (CfA), George Rieke (UA)
, Zoltan Balog (UA), Peter Plavchan (Caltech),
Jesus Hernandez (UM), Jonathan Irwin (CfA)

Outline

- When Do Debris Disks First Emerge?
- (T > 200 K) ***<u>Warm</u>*** Debris Disks/Terrestrial Planet Formation (individual, statistics)
- (T < 150 K) ***<u>Cold</u>*** Debris Disks/Icy Planet Formation (individual, statistics)
- Debris Disks and the Growth of Planetesimals to Protoplanets

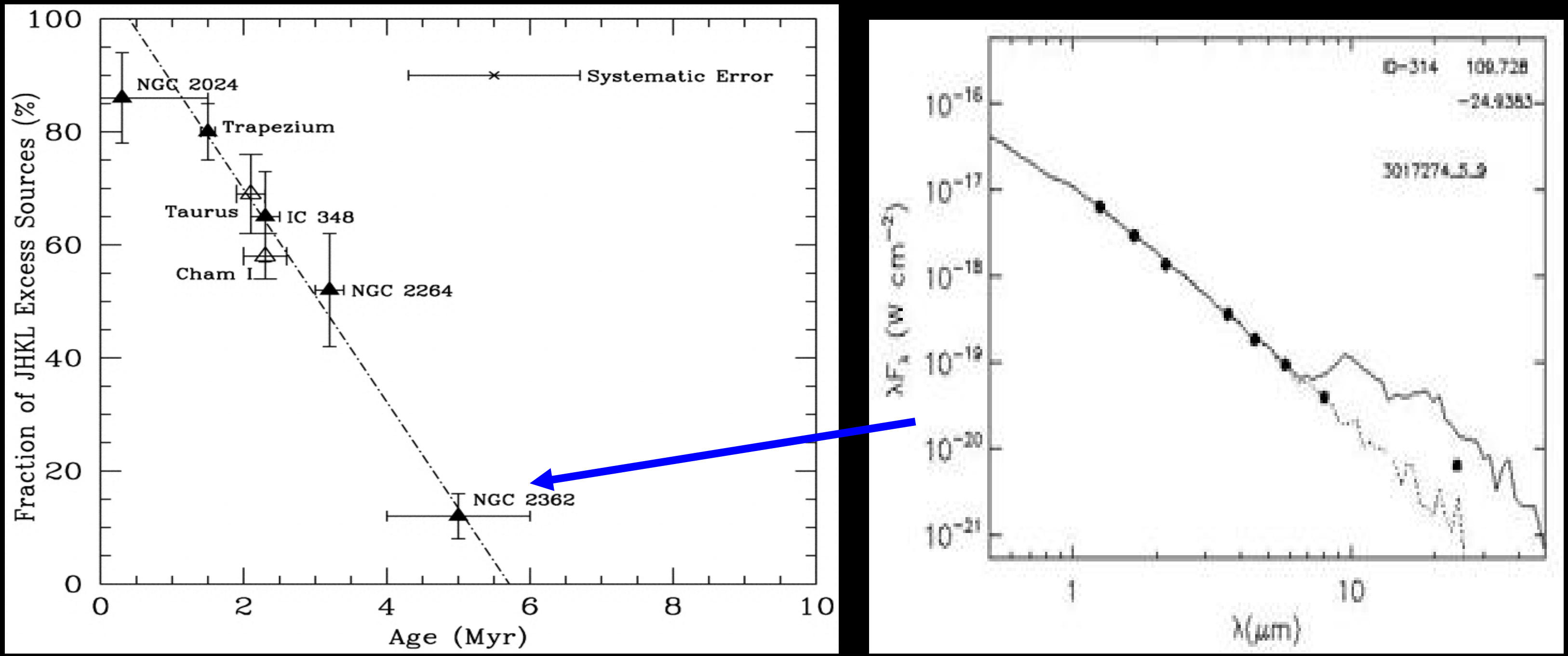
Circumstellar Disk Evolution

- **Primordial Disk**
- **'Evolved' Primordial Disk**
- **Debris Disk**



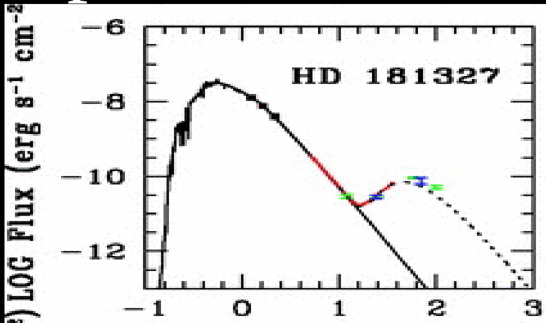
Currie & Lada et al. 2008, ApJ submitted

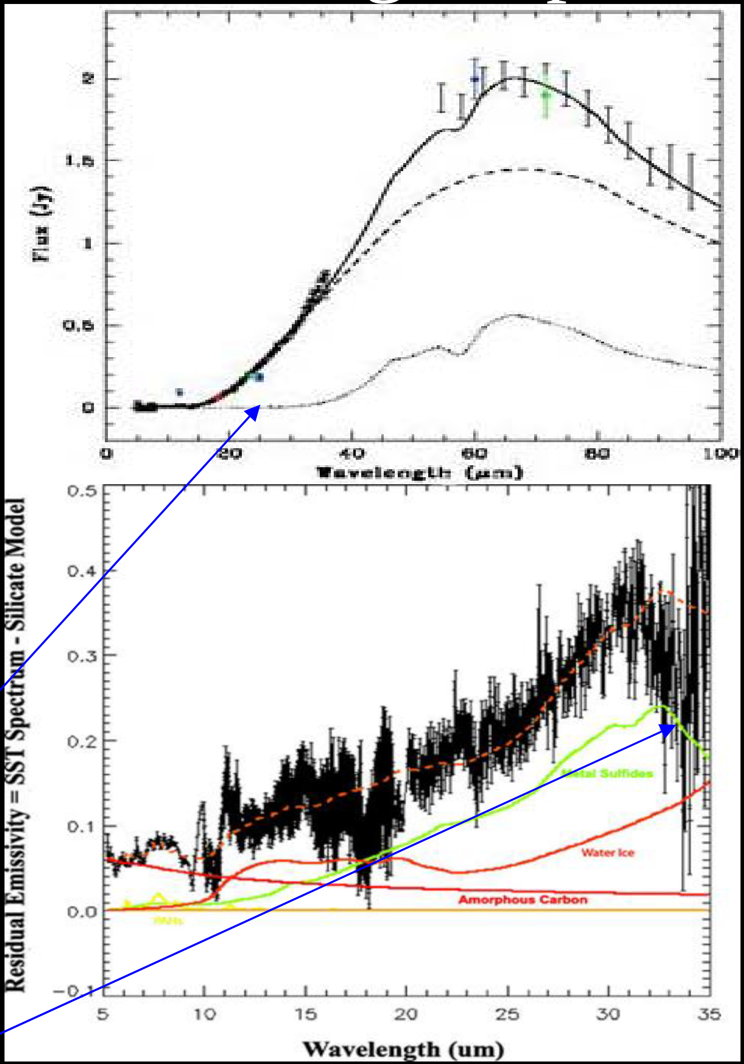
When do Debris Disks Emerge?



- Primordial Disk Timescale ~3—7 Myr
  (Haisch et al. 2001; Hernandez et al. 2007)
- 5 Myr-old stars in NGC 2362 with debris disks: Opt. Thin Emission, No Accretion; Replenishment → debris disk
- By 5 Myr, debris disks dominate disk population around > 1 Msun stars (Currie & Lada et al. 2008); 2--3 Myr? (Currie & Kenyon 2008)

Spectra of Debris Disks: Constraining Properties

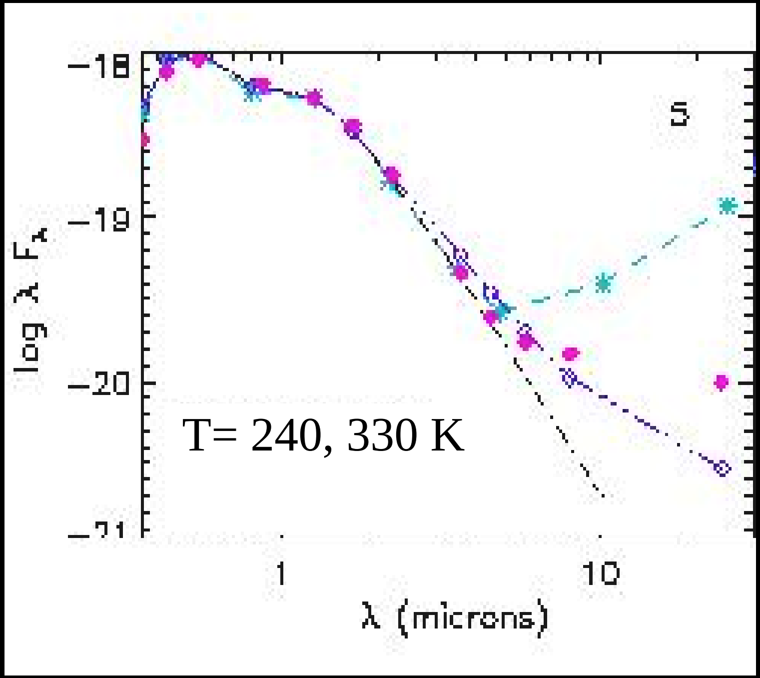


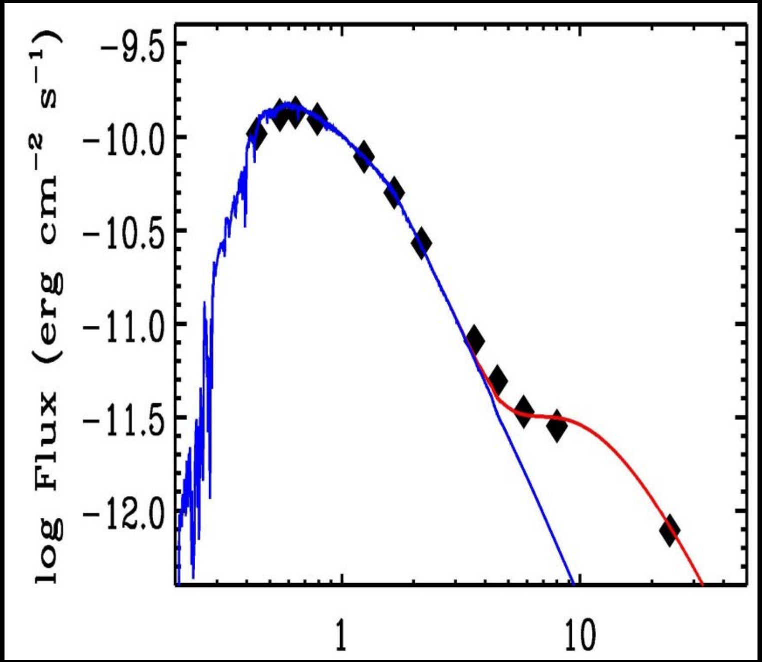


- HD 181327 (cold dust), ~86 AU, low albedo crystalline water → icy planet formation
- HD 113766A (warm dust), ~ 1.8 AU; metal sulfides, similar to S-type asteroids → terrestrial planet formation

Chen et al. 2006; Lisse et al. 2008; Chen, Fitzgerald & Smith 2008

Warm Debris Disks in Clusters

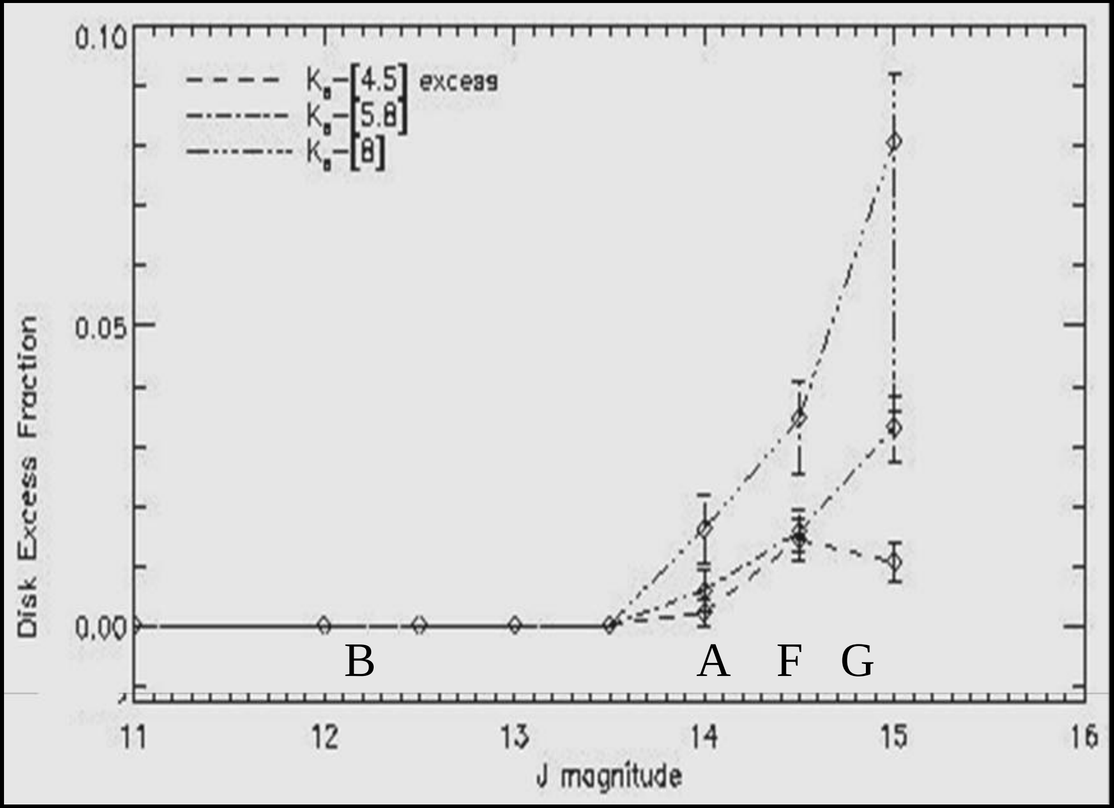




- Nearly all warm debris disks are 10—35 Myr old (exceptions: e.g. BD 20+307, Zuckerman et al. 2008)
- Only a few clusters have more than 1—2 (e.g. h and chi Persei, NGC 2547)
- Only h and chi Persei (and maybe Sco-Cen) massive enough for strong statistical study comparing frequencies for high to low-mass stars

Currie et al. 2007, ApJL, 663, 105 Currie et al. 2008a, ApJ, 672, 558, Gorlova et al. 2007

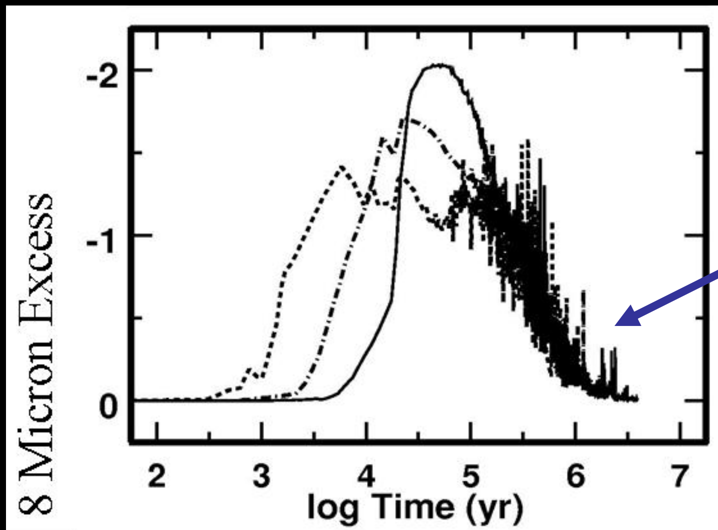
Statistics of Warm Debris Disks/Terrestrial Planet Formation

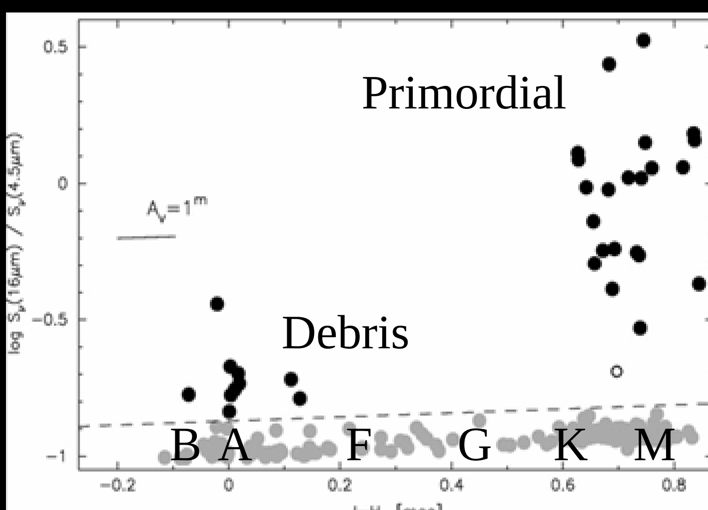


- Warm debris disk frequency is *spectral type/stellar mass dependent*
- TPF faster for high-mass stars than intermed. mass stars
- At least ~3--5% of intermed. mass stars form terrestrial planets

Currie et al. 2007a, ApJ, 659, 599; Currie et al. 2009a

Time History of Warm Debris Disks/Terrestrial Planet Formation



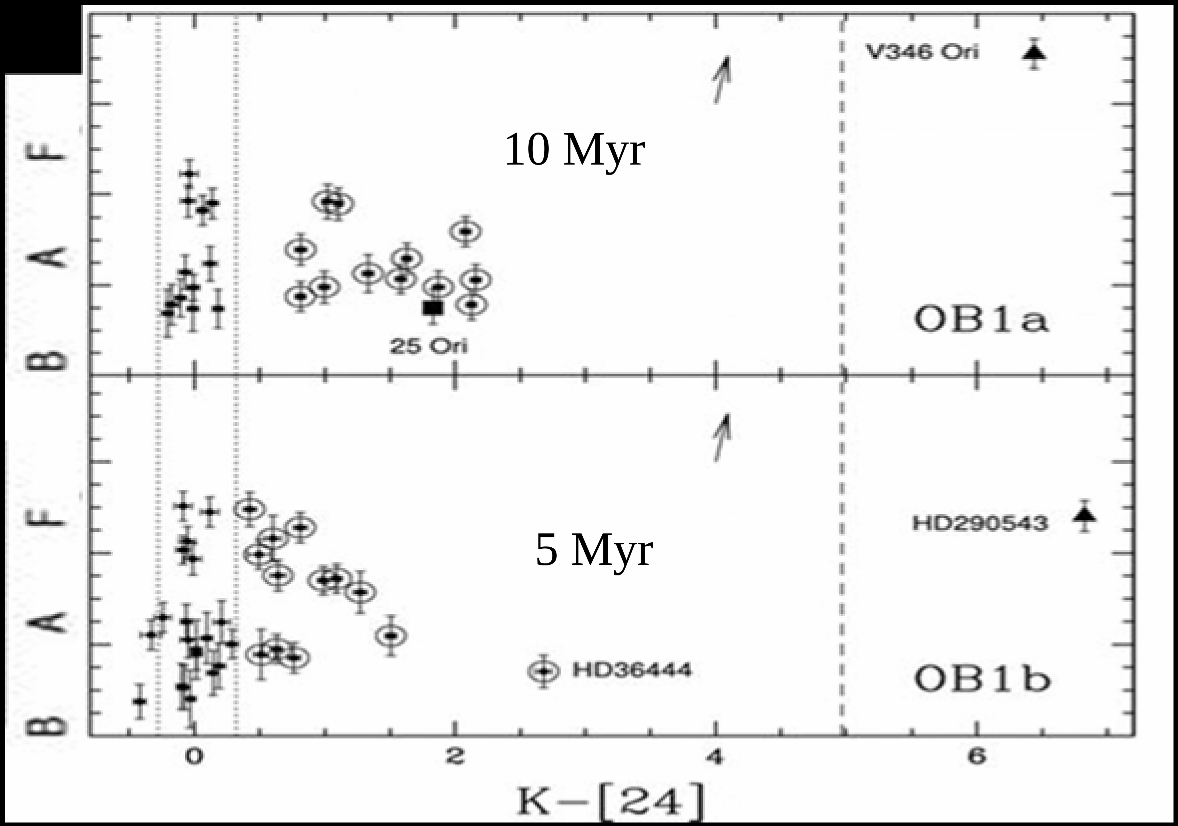


- Debris Disk/Terrestrial Planet Formation Models Predict Short Lifetime of Warm Debris Dust: Explains Low Frequency

- Stellar-Mass Dependent Primordial Disk Transition Explains Trend in Frequency

Kenyon and Bromley 2004;
Carpenter et al. 2006

Cold Debris Disks in Clusters (BAF stars)

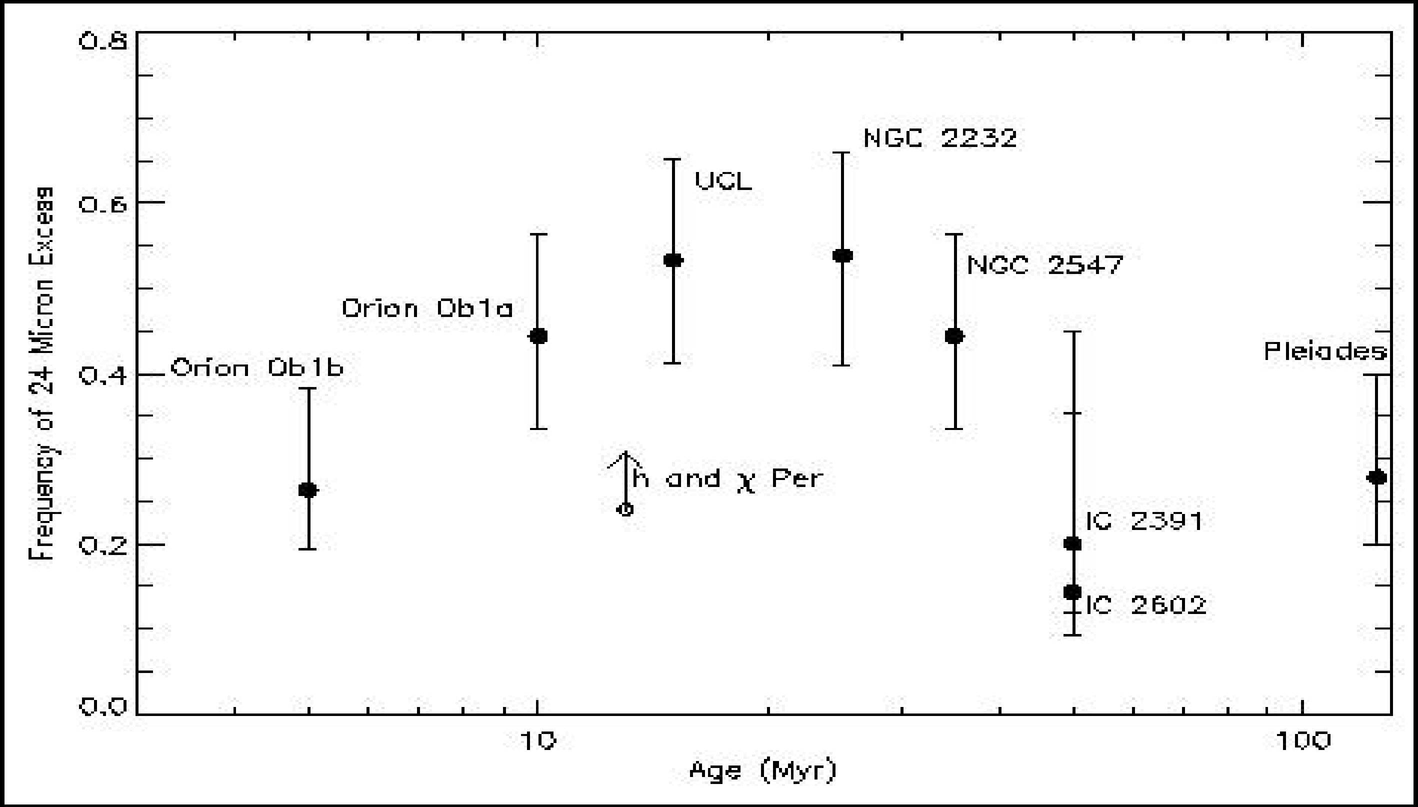


Orion Ob1 (5, 10 Myr) – Hernandez et al. 2006

- Much higher frequency than warm debris disks
- Compare luminosity and frequency vs. time

Frequency of Cold Debris Disks for B/A stars

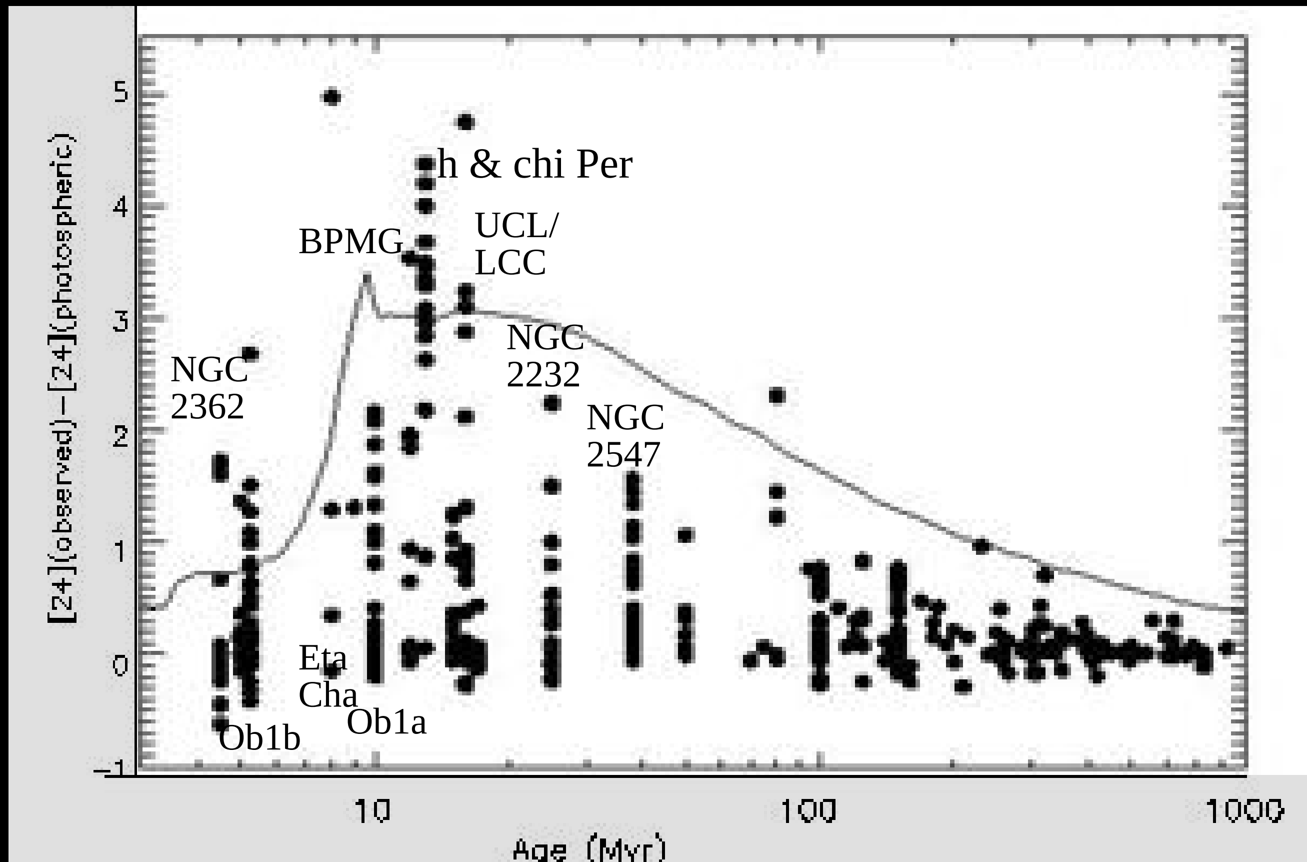
Currie, Plavchan, and Kenyon, 2008, ApJ in press



- Multiple clusters have f([24] exc) > 45-50%, Tdust < 200K
- f(icy planets) > 50%
- Frequencies for solar and subsolar-mass stars different

(see Carpenter talk; Forbrich and Plavchan posters; Carpenter et al. 2008; Hillenbrand et al. 2008)

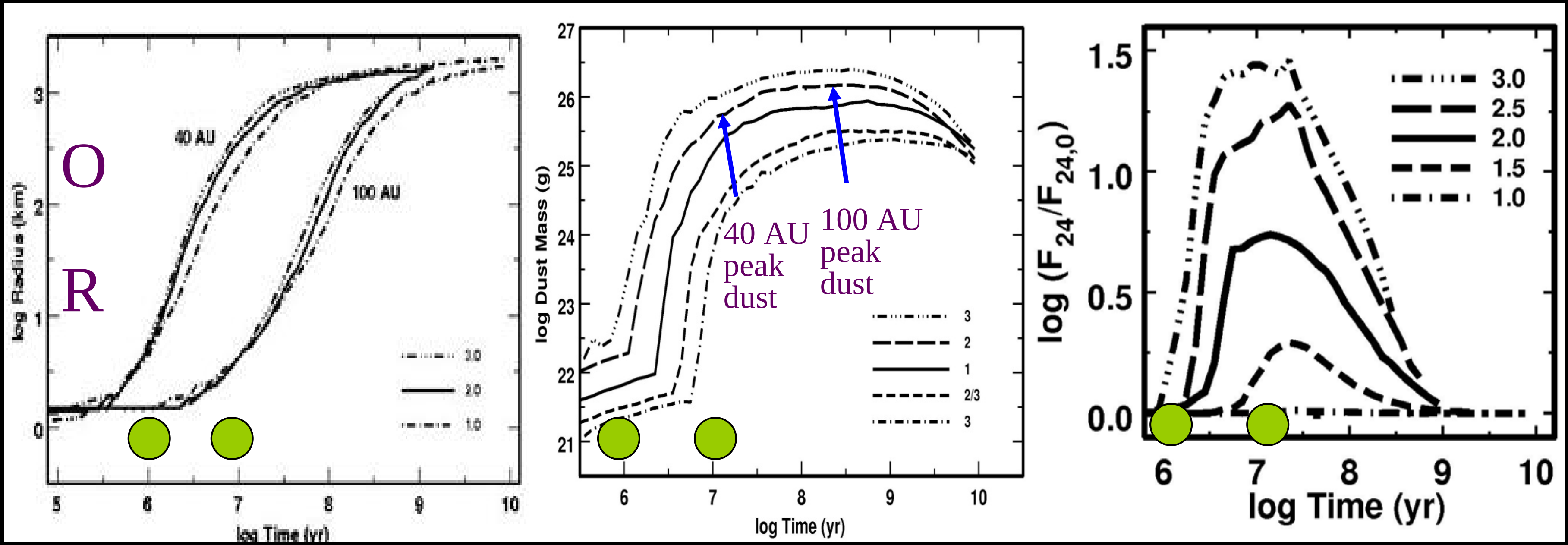
Evolution of Debris Emission from Planet Formation (BAF stars, October 22, 2008)



- Rise in emission from 5-10 Myr
- Peak in emission from ~ 10-20 Myr
- decline in emission from ~ 30-1000 Myr

Currie et al. 2008, ApJ, 672, 558; Currie & Lada et al. 2008; Currie et al. 2009a in prep.

Connection between Debris Disk Evolution and Growth of Protoplanets



Kenyon & Bromley (2008), ApJS in press

- Runaway-to-Oligarchic Growth Transition Explains Observed Trends (~100km to 1000km)
- Timing and amplitude of peak emission depend on star & disk masses

Future Work

- *Spitzer Cycle 4 & 5, new observations of massive clusters: h and chi Persei, NGC 1960, NGC 6871, Upper Sco*

  h and chi Persei (>>10,000 members, M > 0.8 Msun; opt. phot: 47,000; near-IR phot: 60,000; opt. spec: 11,000) <u>Expected yield: ~500—1,000 terrestrial planet forming systems</u> !!!

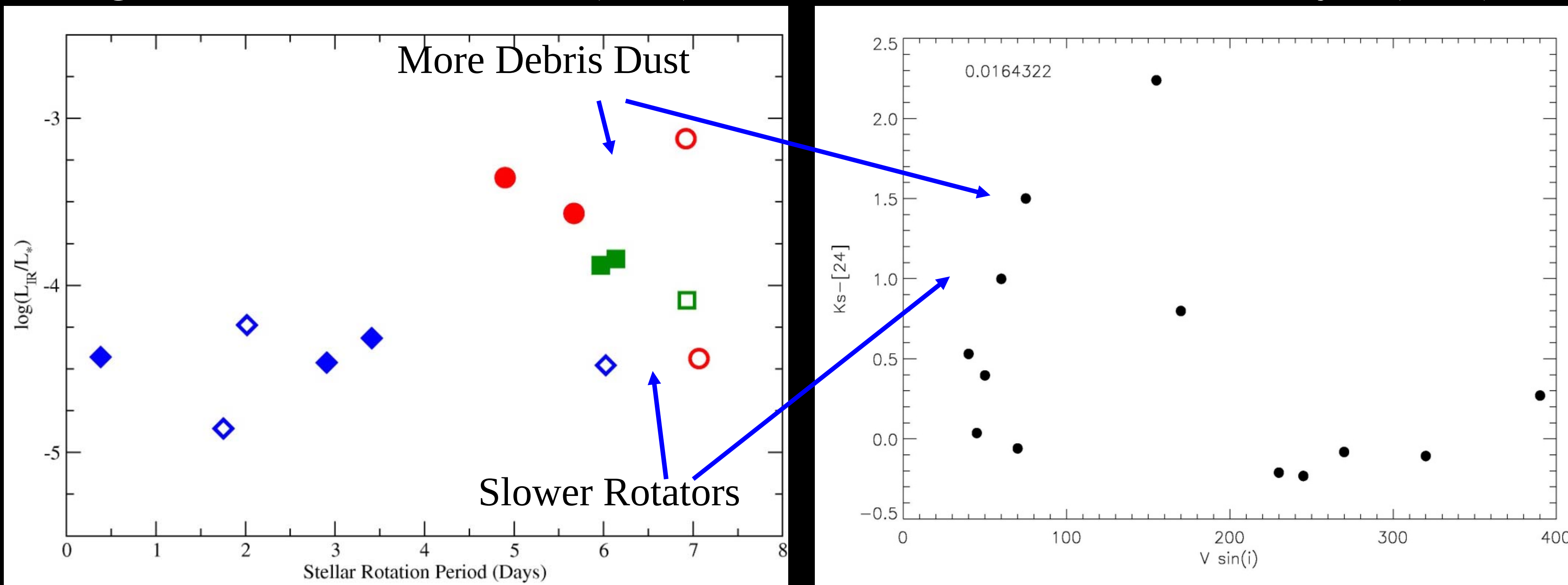
- *JWST (MIRI) – Investigate chemical composition of *all* terrestrial & icy planet-forming systems; Spatially resolve nearby systems*

- *→ Constrain Planet formation; characterize terrestrial and icy planets*

Currie et al. 2009abcd; Carpenter et al. 2009; Dahm & Carpenter 2009

A Connection Between Primordial Disk Properties and Debris Disk Properties?

Young GKM stars; Plavchan et al. (2008) B/A Stars; Currie, Plavchan, and Kenyon (2008)



- Massive Primordial Disks Evolve into Massive Debris Disks?

See also Rebull et al. (2008)

Summary

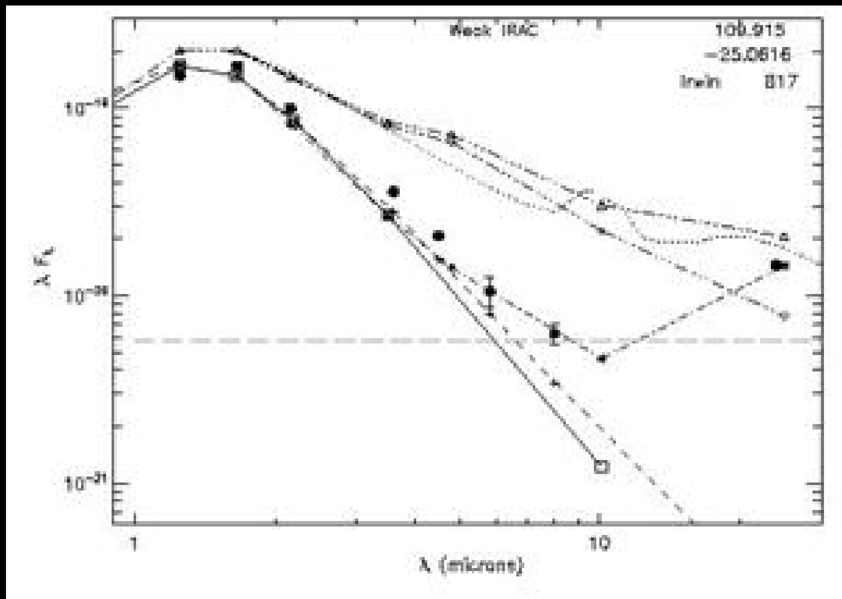
- *Debris Disks Emerge Between*

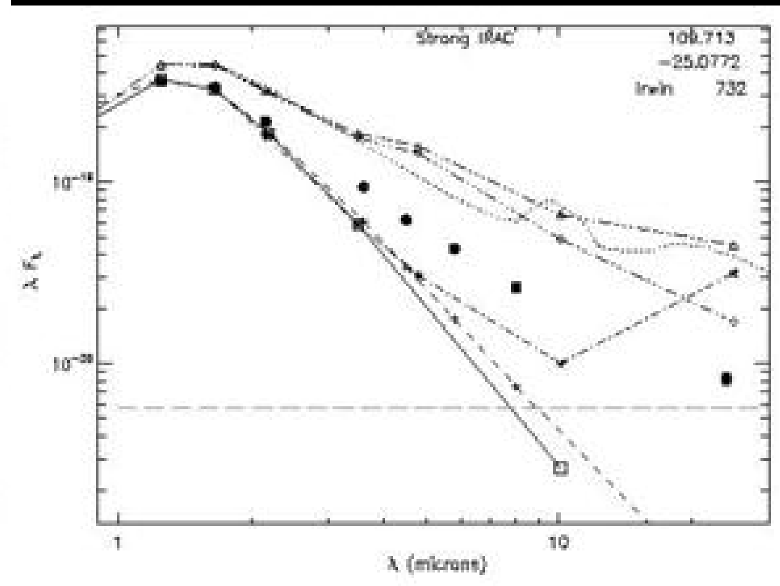
  3 Myr and 10 Myr
- *Warm Debris Disks: rare; Terrestrial Planet Formation; TPF finishes fastest for*

  higher mass stars
- *Cold Debris Disks: common: Icy Planet Formation; Icy Planets also common*
- *Debris Emission from Icy Planet Formation peaks at ~10—20 Myr for BAF stars; due to planetesimal → planet growth*

Supplementary Information

NGC 2362 Disk Population for < 1.2 Msun Stars





- **“Transition” Disk (~28 %)**
- **“Homologously Depleted” Disk (~56 %)**

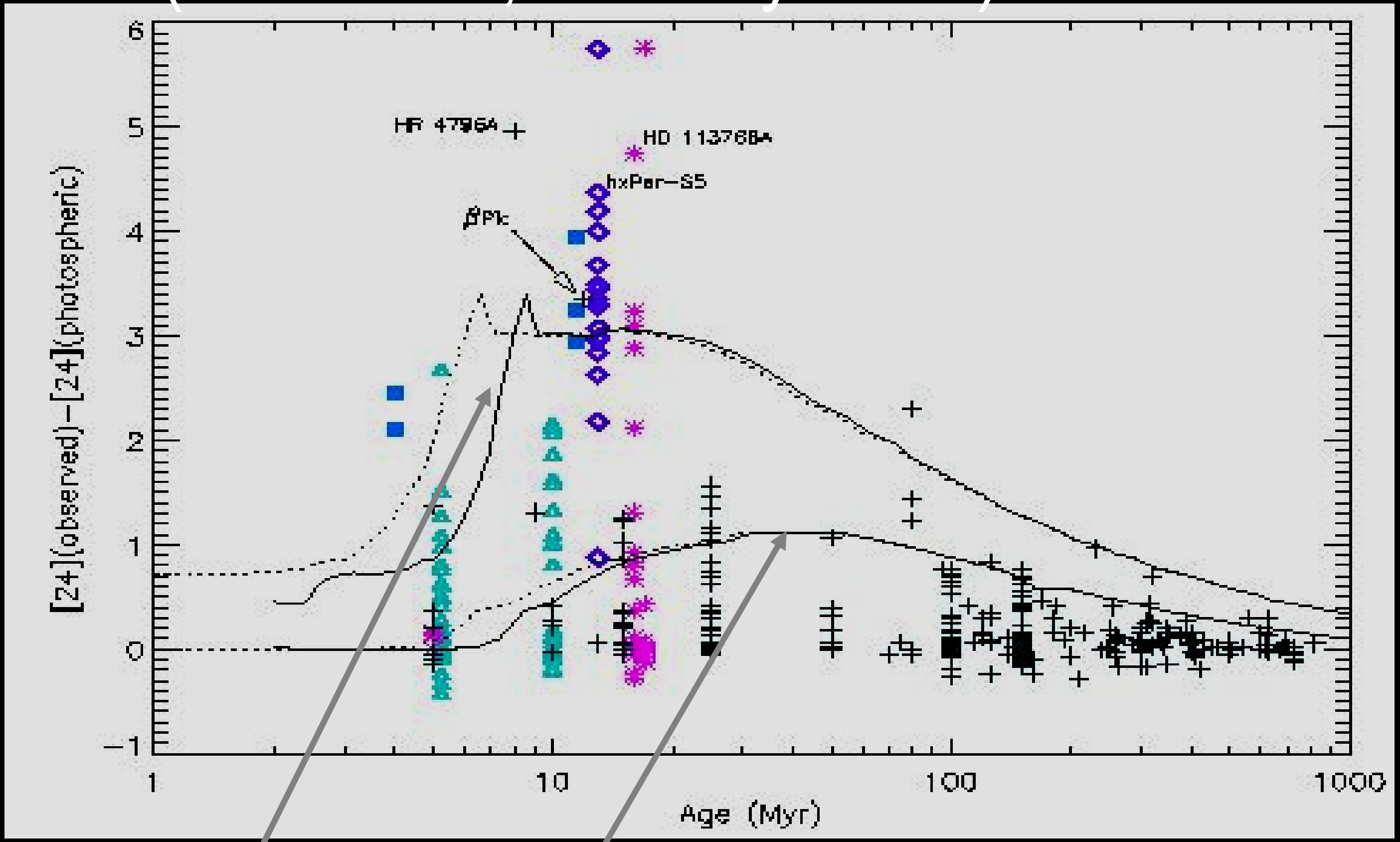
N(TD)/N(PD) ~ 2.5!; N(TD+HDD)/N(PD) ~ 8 !!!

Implies long (~ 1—2 Myr?) transition timescale; not 0.01—0.1 Myr

UV photoevaporation ruled out?; gas giant planet formation and MRI-induced accretion viable alternatives (e.g. Rice et al. 2003; Chiang and Murray-Clay 2007)

Short timescale from Taurus data due to young age + binaries (e.g. Ireland & Kraus 2008)

Evolution of Debris Emission from Planet Formation (BAF stars, January 2008)



- High-mass debris disk (Kenyon and Bromley (2008)
- Low-mass debris disk
- Observed Peak at 10—20 Myr

Currie et al. 2008, ApJ, 672, 558