Debris Disk Evolution Around A Stars

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Sample Selection:

• About 160 main-sequence A type stars observed with the Multiband Imaging Photometer for Spitzer (MIPS) at 24 and/or 70 μm, which are part of MIPS GTO programs and calibration program.

• Ages range from 5-850 Myr from literature (cluster or moving group associations) or from the HRD and isochrones.

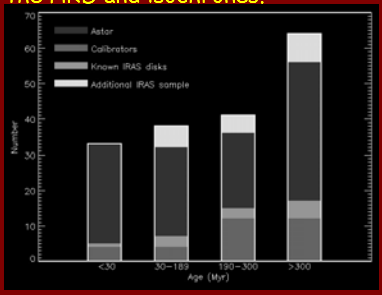

Figure 1 – Age distribution of the Sample, including Spitzer GTO programs: Astar, known IRAS disks (Dirty12 and Fab4), Calibration stars (mostly observed at 24 μm only). Additional nearby (old) 19 stars from the IRAS observations (consistent with photospheres) are included.

Excess Decay Time Scales

• The amount of excess emission at 24 μm shows a rapid decline with stellar age (~150 Myr/t, Rieke et al. 2005), and a large variety of excess amounts at any given age (Figure 4 below).

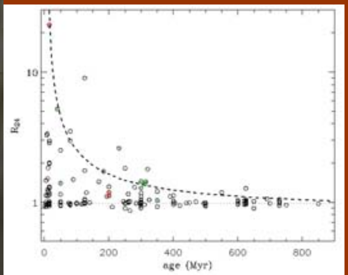

Figure 4 – 24 μm excess vs. age. A decay curve of t_0/t is indicated as the dashed line with t_0 ~ 150 Myr. β Pic, Fomalhaut and Vega are also shown as star-shaped symbols, the other known IRAS disks are also shown in plus signs.

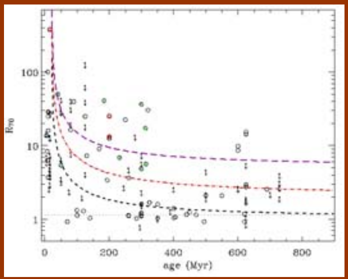

Figure 5 – 70 μm excess vs. age. Three decay curves of t_0/t are indicated as the dashed line for t_0~150 Myr (same as 24 μm), the dot-dashed line for t_0~400 Myr, and the long-dashed line for t_0~800 Myr.

• The trend at 70 μm also shows a large variety at any given age in Figure 5, but has a much longer decay time with t_0 ≥400 Myr, i.e., the 24 μm excesses decay more rapidly than those at 70 μm at the 99% confidence level.

[24]-[70] color Temperature Evolution

Group I: 36 stars have both 24 and 70 μm excesses.

Group II: 8 stars have only 70 μm excess.

GroupIII: 20 stars no excess above 3-σ level.

(maximum [24]-[70] color temperature is estimated for Goupr II and III assuming the excess flux at each wavelength is 3 times the measured flux)

• Majority of the disks have T~ 90 K (~100 AU from stars if blackbody radiators)

• Figure 6 shows the stellar age vs. observed color temperatures. Stars in Group I have T between ~60K and ~250K, while stars in Group II have T_{max} ≤ 100K.

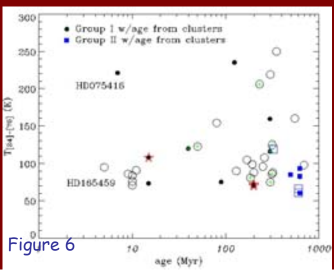

Figure 6

Excess Identifications and Statistics:

• Photospheric predictions used synthetic Kurucz model by fitting all available photometry (e.g., Johnson, Stromgen, Hipparcos Typco, and 2MASS photometry)

• The combination of photospheric predictions and MIPS photometry accuracy is ~3% and ~15% at the 1-σ level at 24 and 70 μm, respectively (Shown in figures 2,3).

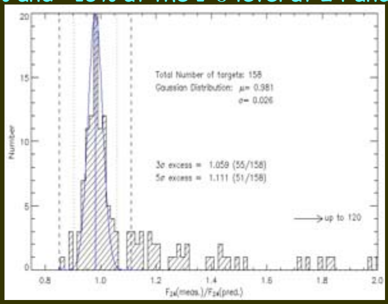

Figure 2— Distribution of the 24 μm fluxes relative to the expected photospheric values (R_{24}). A Gaussian distribution with a dispersion of 0.026 is shown for comparison. Boundaries for ±3σ (dotted lines) and ±5σ (dashed lines) are marked.

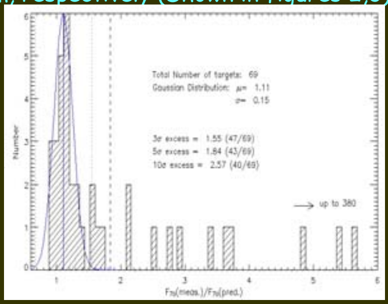

Figure 3— Distribution of the 70 μm fluxes relative to the expected photospheric values (R_{70}). A Gaussian distribution with a dispersion of 0.15 is shown for comparison. Boundaries for ±3σ (dotted lines) and ±5σ (dashed lines) are marked.

• 3-σ excess criteria: R_{24} >1.06 at 24 μm and R_{70} > 1.55 at 70 μm

• 24 μm excess rate is: 34±5% out of 155 stars.

• 70 μm excess rate is: 33±5% (lower limits: out of 134 stars assuming that all the non-detected stars do not have 70 μm excesses), up to 67±10% (upper limits: out of 66 detected stars) .

• Infrared excess rate around A-type stars is 38±5% (out of 157 stars), much higher than what was found in field (old) FGK stars (12±4%, Bryden et al. 2006) and nearby (old) M stars (~0%, Gautier et al. 2006, in prep.).

Fractional Dust Luminosity (f_d) Evolution

• The majority of the stars have f_d~ 5x10^{-5}; stars in Group II have lower f_d than stars in Group I.

• Figure 7 (right) shows a histogram of f_d with two age groups (age ≥ or < 300 Myr), and suggests that older stars tend to have lower f_d.

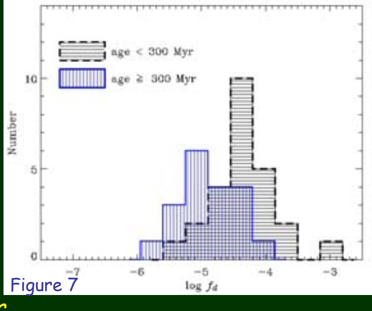

Figure 7

• The evolution of f_d vs. stellar age (shown below in Figure 8) suggests that

1.) the data are consistent with a general 1/t relation in the f_d vs. age diagram but with at least two orders of magnitude variation in f_d,

2.) an upper envelope of 1/t, with no stars older than 100 Myr having f_d >1x10^{-3}; i.e. collisions followed by radiation pressure blowing out small grains are the dominant process to remove grains in these systems,

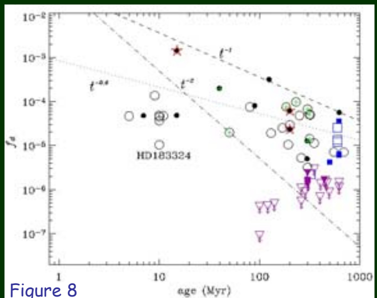

Figure 8

3.) all the only-70 μm excess stars are old and have colder dust temperatures (combining Figure 6),

4.) Stars have no detectable excess (Group III, upside down triangles with downward arrows) have f_d as low as ~ 10^{-7}, showing our ability to detect the amount of dust in our current Solar System around these A-type stars.

The decreases of observed $T_{[24]-[70]}$ and f_d suggest that the debris disk clearing is an inside-out process.