Scale Height Evolution of Debris Disks

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Abstract

We investigated the vertical thickness of five debris disk systems, and derived their inclination dispersions of dusts. Including the inclination dispersions of Kuiper Belt Objects in the solar system, the dust inclination dispersion seems to increase with age. This result shows that dusts' and planetesimals' orbits are supposed to be excited by planetesimals or planets.

1. Introduction

About Debris Disk

- More than 15 % of main sequence stars have excess in mid- to far-infrared, so called "Vega-type stars".
- Most of the gas have been dissipated.
- Debris disks consist of dusts produced by planetesimal impacts.
- About 40 debris disks have been spatially resolved in visible or infrared region (Fig. 1.1).
- Possibly have relationship with gravitational interaction between the disk and planets.

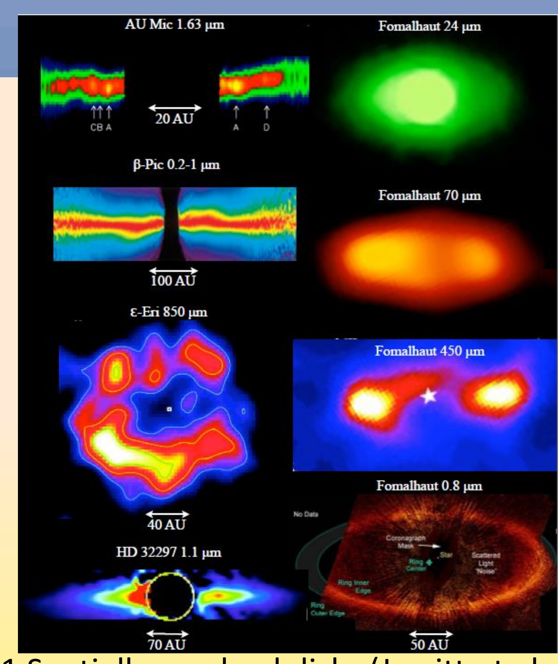


Fig. 1.1 Spatially resolved disks (Jewitt et al. 2009)

Morphological Evolution of Debris Disks

Disk Radius

Radial evolution informs collisional frequency.

Numerical Simulation

A wave of dust formation propagates outward.

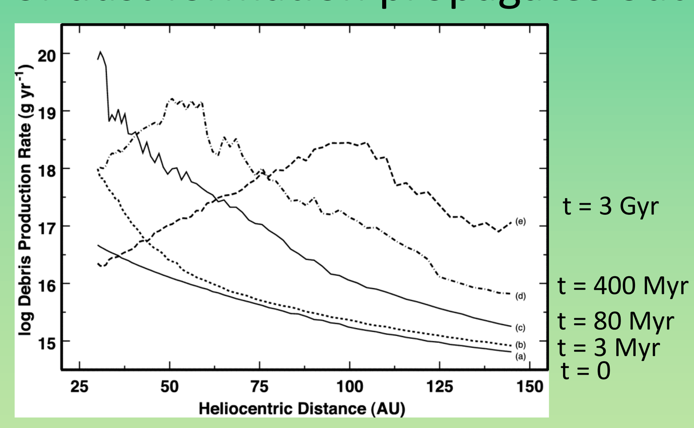
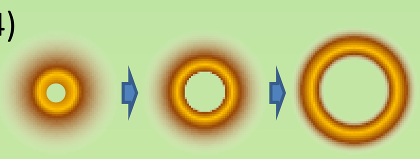


Fig. 1.2 Debris formation rate in each annulus at selected epoch (Kenyon & Bromley 2004)



Observations

Disk radius seems to increase with age.

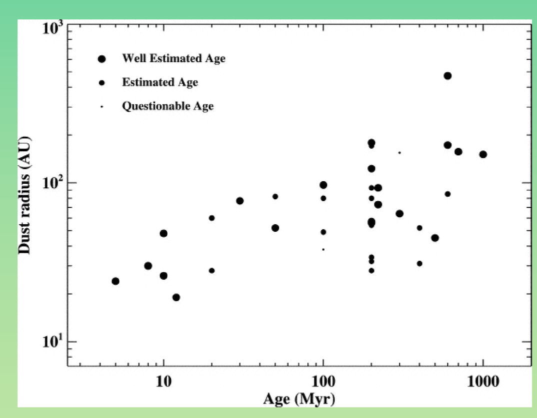


Fig. 1.3 Disk radius against stellar age (Rhee et al. 2007)

Disk Thickness

Vertical evolution informs collisional speed.

$$v_{rel}^2 = \left(\frac{5}{4} < e >^2 + < i >^2\right) v_{Kep}^2$$ (Wetherill & Stewart 1993)

$$< e > \sim 2 < i >$$

$$\rightarrow v_{rel}^2 = 6 < i >^2 v_{Kep}^2$$

Theoretical prediction

Inclination dispersion $< i(t) >$ increases with time.

$$< i(t) > \approx \left(\sqrt{\frac{4G}{\pi}} \frac{\ln \Lambda m \Sigma r^{\frac{1}{2}} t}{M_*^{\frac{3}{2}}}\right)^{\frac{1}{4}} \propto M_*^{-\frac{3}{8}} t^{\frac{1}{4}}$$ (Quillen et al. 2007)

Observations

Unclear !!

2. Method

Aim: To Confirm Evolution of Disk Thickness by Observations

Approach:

1. **Deriving the disk aspect ratio (Scaleheight/Radius) from previous studies**
2. **Estimating each $< i >$ with each aspect ratio, and then plot them against stellar age.**

Name	Sp. Type	Reference
β Pic	A6	Ahmic et al. 2009
AU Mic	M1	Quillen et al. 2007
HD 32297	A5	Currie et al. 2012
Fomalhaut	A4	Kalas et al. 2005
HD 15115	F2	Sai et al. 2014 (submitted)

Table. 2.1 The list of debris disk systems whose scaleheights were measured.

Only HD 15115, we fitted the disk model with the resolved disk image using Subaru/IRCS data.

Observing condition

- Date : 2011/11/11
- Filter : H band (1.6 μm)
- Observing mode : ADI
- FWHM : 0.1" (4.5 AU)
- Parallactic rotation angle: 17.3°
- Total exposure time: 30.7 min

Model fitting

We use an "inclined annulus disk model" to probe the disk geometry.

$$\rho_{r,h} \propto \left(\frac{r}{R_{in}}\right)^{-q} exp\left(-\frac{h^2}{2\left(\sigma_h \frac{r}{R_{in}}\right)^2}\right)$$

$$F(r,h) = A \cdot \frac{1}{d^2} \cdot \rho_{r,h} \cdot \frac{1-g^2}{(1+g^2-2g\cos\alpha)^{\frac{3}{2}}}$$

q: Radial density slope
g: Henyey-Greenstein parameter
α: Scattering angle
A: Scaling factor

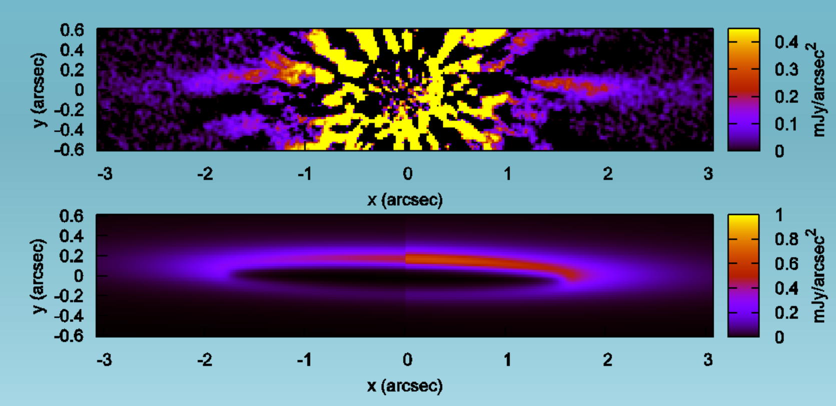


Fig. 2.1 The reduced image of HD 15115 disk (top) and the model disk (bottom). The star position is (x,y)=(0,0).

3. Results & Discussion

- The dust inclination dispersion seems to increase with age.
  → Consistent with the disk thickening prediction.
- β Pic has the thickest disk, possibly due to heavily scattering by β Pic b.
- HD 15115, whose disk is thinnest, probably has a problem with the reduced image.
  ✓ The poor parallactic rotation angle caused large self-subtraction within ~1"

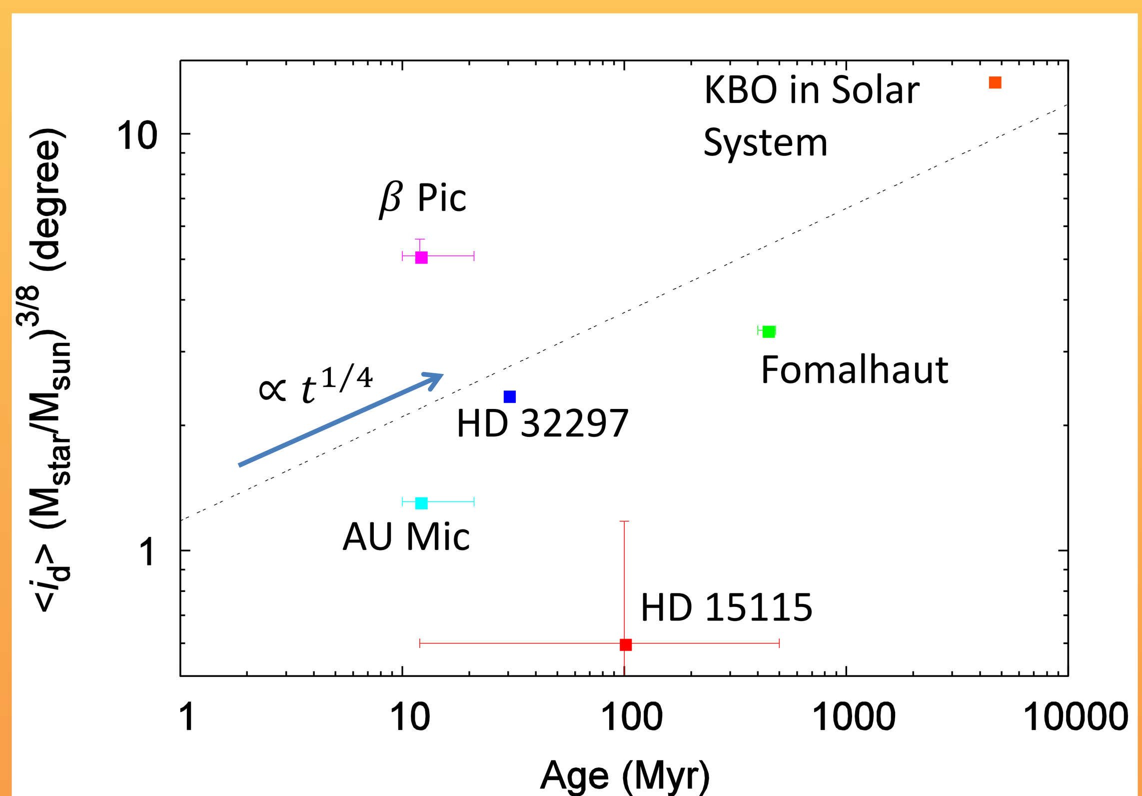


Fig. 3.1 Dust inclination dispersion against stellar age. Every $< i >$ are multiplied by $\left(\frac{M_*}{M_\odot}\right)^{3/8}$ to calibrate the factor of stellar mass. The dash line represents the slope of $t^{1/4}$.

4. Summary

- We investigated the dust inclination dispersions of five debris disk systems.
- Except for HD 15115, the dust inclination dispersion seems to increase with age.
  → The dusts and planetesimals are supposed to be excited by planetesimals or planets.
- We need more resolved disk samples to confirm the evolution of disk thickness.
  ✓ Using archive data
  ✓ Proposing observations with large telescopes

Acknowledgment

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