Are debris disks and planets correlated?

Amaya Moro-Martín
(Princeton University)

and the Spitzer FEPS Legacy Team:
Debris disks are evidence of planetesimal formation. Spitzer surveys indicate ~15-20% of solar-type stars harbor debris disks.

From extrapolation of RV surveys: 12% of stars harbor planets <20 AU.

In core accretion model, giant planet formation require planetesimals.

Are they correlated?

No evidence of correlation from Spitzer data.

Why?

Planets are efficient en clearing out planetesimals in Late Heavy Bombardment-type of events.

Or may be is telling us something about planet formation...

But need larger and deeper samples to improve statistics.

Planets are not required to produce debris dust.

Debris Disks

Planets
1. Introduction

Different wavelengths trace different dust temperatures and distances to the star.
Fomalhaut Debris Disk

24 μm
Spitzer/MIPS
Stapelfeldt et al. (2004)

70 μm
Spitzer/MIPS
Stapelfeldt et al. (2004)

450 μm
JCMT/SCUBA
Holland et al. (2003)
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Spitzer:
IRAC 3,4,5,8 μm
IRS 5-37 μm
MIPS 24,70,160 μm

Disk SED
(Moro-Martín, Wolf & Malhotra 2005)
Dust disk models

Expected stellar emission

Star dominates

no warm dust

Dust disk models

only cold dust

(Moro-Martin et al. 2007b)
Spitzer Debris Disks Surveys

**FEPS Legacy survey:** spectrophotometric obs. from 5 to 70 \( \mu \)m of 328 FGK stars (0.7--1.4\( M_{\text{sun}} \)) with ages >3 Myr.

**FGK GTO Survey:** 150 FGK stars observed with MIPS 24 \( \mu \)m and 70 \( \mu \)m and IRS 8-40 \( \mu \)m (older and closer than FEPS sample).

13\( \pm \)3% detection rate  \(\) (Bryden et al. 2006, Beichman et al. 2006, 2007)

Other surveys:

**MIPS GTO Binary Survey:** 69 A3-F8 binaries. Detection rates: 9\( \pm \)4% at 24 \( \mu \)m and 40\( \pm \)7% at 70\( \mu \)m (1/2 circumbinary and 1/3 circumstellar)

**MIPS GTO A-star Survey:** 160 A stars, 5-850 Myr. Detection rates: 32\( \pm \)5% at 24 \( \mu \)m and 33\( \pm \)5 at 70\( \mu \)m; higher than solar-type stars.

And surveys of young clusters.
Why are debris disks interesting?

**Dust Removal Time Scales** $< 10^4$-$10^6$ yr

- **Poynting-Robertson:** $t_{PR} = \frac{\mu m}{b} \left( \frac{\rho}{g/cm^3} \right) \left( \frac{R}{AU} \right)^2 \left( \frac{L_\odot}{L_*} \right) \frac{1}{1 + \text{albedo}} \text{ yr}$

- **Grain-grain collisions:** $t_{col} = 1.26 \times 10^4 \left( \frac{R}{AU} \right)^{3/2} \left( \frac{M_\odot}{M_*} \right)^{1/2} \left( \frac{10^{-5}}{L_{dust}/L_*} \right) \text{ yr}$

- **Radiation Pressure:** $\frac{\tau_{\text{blowout}}}{yr} = 0.5 \sqrt{\left( \frac{R/AU}{} \right)^3 \left( \frac{M_*/M_\odot}{} \right)}$

**Age of Star** $> 10^7$ yrs

Dust is not primordial, must be replenished by planetesimals

Debris disks are indirect evidence that the first steps of planet formation have taken place in other stars.

Debris disks harbor planetesimals... how about massive planets?
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High resolution observations show complex morphology that could result from gravitational perturbations by planets.
2. FEPS 70 μm DETECTIONS

Log $[ν F_ν (\text{erg s}^{-1} \text{ cm}^{-2})]$ Log $[λ (\mu \text{m})]$ (Hillenbrand et al. in preparation)
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~15% show excess at 70 μm but no 24 μm (i.e. cold dust disks)
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HD 38529 only FEPS star with planets and debris disks.

(Hillenbrand et al. in preparation)
### Only stars known to have debris disks and planets

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$^b$Wavelength at which the excess is detected, with the fractional luminosity of the excess in brackets. For stars with 70 $\mu$m excess, and assuming that the peak of the emission is at 70 $\mu$m ($T_{dust} = 52.7$ K), $L_{dust}/L_* \sim 10^{-5}(5600/T_*)^3(F_{70,dust}/F_{70,*})$, where $F_{70,dust}$ and $F_{70,*}$ are the dust excess and photospheric flux at 70 $\mu$m and $T_*$ is the stellar temperature (Bryden et al. 2006). For HD 69830, the fractional luminosity of the excess is calculated by integrating the excess and photospheric emission between 7 and 35 $\mu$m. References are: (1) Moro-Martín et al. (2007); (2) Beichman et al. (2005a); (3) Beichman et al. (2005b) and (4) Greaves et al. (1998, 2005).
Dust disk models

Star + Disk SED

Expected stellar emission

Star dominates

Dust only cold dust

no warm dust

3 μm

5 μm

8 μm

13 μm

24 μm

33 μm

70 μm

(Moro-Martin et al. 2007b)
Evidence for Extended Debris Disks

Discrepancies in color temperatures... imply dust over a range of radii

\[
\frac{F_{\text{excess} (33 \, \mu m)}}{F_{\text{excess} (70 \, \mu m)}} \times \frac{F_{\text{excess} (24 \, \mu m)}}{F_{\text{excess} (70 \, \mu m)}}
\]

\(T = 200 \, \text{K}\)

\(T = 100 \, \text{K}\)

\(T = 30 \, \text{K}\)

\(R_{\text{inner}} \) (minimum)

(Hillenbrand et al. in preparation)
Evidence for Extended Debris Disks

Discrepancies in color temperatures... imply dust over a range of radii

\[
\frac{F_{\text{excess}}(24 \ \mu m)}{F_{\text{excess}}(70 \ \mu m)} \times \begin{cases} T = 200 \ K \\ T = 100 \ K \\ T = 30 \ K \end{cases}
\]

Many with \( T = 50-100 \ K \)

(Between AB and KB in the Solar System)

\( R_{\text{inner}} \) (minimum)

(Hillenbrand et al. in preparation)
3. Are debris disks are planets correlated?

Is there evidence that debris disks are more prevalent in systems with close-in giant planets?

Similar frequency of debris disks in planet and control samples:

- Planet sample: 1/9 FEPS
- Control sample: 9/99 FEPS

1/11 GTO (Moro-Martin et al. 2007a)

HD 38529 (Bryden et al. 2006)
Survival Analysis:
The probability that the planet and control samples could have been drawn from the same parent distribution with respect to the 70\(\mu\)m excess is 60-90%.

We cannot rule out the hypothesis that the planet sample and the control sample have been drawn from the same population.

There is no sign of a correlation between the presence of planets and the presence of debris disks.
4. Implications

1. Debris disks are not more prevalent in systems with giant close-in planets.

Debris may be produced by a process that does not involve massive planets. This is supported by:
- Collisional cascade models (Kenyon & Bromley 2005).
- The lack of correlation between high metallicity and debris disks (Greaves et al. 2006).
- The correlation between high metallicity and massive close-in planets (Fischer & Valenti 2005).

The conditions required to produce debris may be more commonly met than those required to produce close in massive planets.
Frequency of giant planets (<20 AU): ~12% (extrapolating from RV surveys; Marcy et al. 2005).

Debris disks at the Solar System level may be common.

They look similar but the sensitivities are very different

The luminosity of the Solar System dust is consistent with being 0.1-10 x that of an average solar-type star (extrapolating from Spitzer observations; Bryden et al. 2006).

Debris disks at the Solar System level may be common.
2. On the low incidence rate of debris disks in systems with planets (10%):

- Most massive planets form in systems that were rich in planetesimals (in core-accretion model).
- But systems with massive planets do not preferentially show debris disks (e.g. the Solar System).

Maybe massive planets are efficient in grinding away or cleaning up planetesimals, as e.g. during the Late Heavy Bombardment in the early Solar System.
Key to understand the history of the Solar System

Late Heavy Bombardment (3.85 Gyr ago; impact objects from main AB due to orbital migration of giant planets.

No planets
Dust produced from colliding planetesimals (1-10km), excited by 1000 km planetesimals

Large depletion of the asteroid and Kuiper Belts
Dust production increased during short period of time, steeply decreasing afterwards.

Other peaks related to asteroidal collisions like the creation of the asteroidal families few Myr ago

Excess Ratio (over photosphere - at 24 \mu m)

Age (Myr)

Dust production rate

Time

Planets

collisions: 1/t

PR: 1/t^2

(Siegler et al. 2006)
Debris disks are evidence of planetesimal formation. Spitzer surveys indicate ~15-20% of solar-type stars harbor debris disks.

From extrapolation of RV surveys: 12% of stars harbor planets <20 AU.

In core accretion model, giant planet formation require planetesimals. No evidence of correlation from Spitzer data.

In a Debris Disks and Planets, are they correlated? Why? Or may be is telling us something about planet formation... But need larger and deeper samples to improve statistics.

Planets are not required to produce debris dust. Planets are efficient en clearing out planetesimals in Late Heavy Bombardment-type of events.
IN THE NEAR FUTURE...

HERSCHEL

ALMA
Other Spitzer Debris Disks Surveys

FGK GTO Survey: 150 FGK stars observed with MIPS 24 μm and 70 μm and IRS 8-40 μm (older and closer than FEPS sample).
(Bryden et al. 2006, Beichman et al. 2006, 2007)
- 12/88 show 70 μm excess: **13±3% detection rate**
- 1/88 show 24 μm excess and no 70 μm excess
- Most stars with 70 μm excess, have IRS spectral rising at red end (~33 μm).

Other surveys:
MIPS GTO Binary Survey: 69 A3-F8 binaries. Detection rates: 9±4% at 24 μm and 40±7% at 70μm (1/2 circumbinary and 1/3 circumstellar)
MIPS GTO A-star Survey: 160 A stars, 5-850 Myr. Detection rates: 32±5% at 24 μm and 33±5 at 70μm; higher than solar-type stars.
Also surveys of young clusters.
3. Are debris disks are planets correlated?

Goal: Compare a sample of planet bearing stars to a control sample. Is there evidence that debris disks are more prevalent in systems with close-in giant planets?

Samples: Drawn from FEPS

Planet sample: 9 stars known from radial velocity surveys to have massive planets. Control sample: 99 stars (without regard to the presence of planets), and with...
- similar distances (26-62pc) and IR background levels as planet sample (to reach similar sensitivity).
- older than 300 Myr (exclude bias due to disk evolution)
**Variables:** Narrow distribution of F24/F8 compared to a wide distribution of F70/F24.

- Flux at 24\(\mu\)m is mainly photospheric
- Best indicator of the presence of a disks is the 70 \(\mu\)m excess

Similar frequency of debris disks in planet and control samples:

- Planet sample: 1/9 FEPS, 1/11 GTO (Bryden et al. 2006)
- Control sample: 9/99 FEPS, 7/69 GTO (Bryden et al. 2006)
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