



Signatures of Planets in Circumstellar Debris Disks

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Outline

☀ Introduction:

- ☀ What is a debris disk?
- ☀ How its structure is created?
- ☀ What can it tell us about massive planets?

☀ What can we do with *Spitzer*:

...and what we cannot do: SEDs are degenerated

☀ We need *SAFIR*!

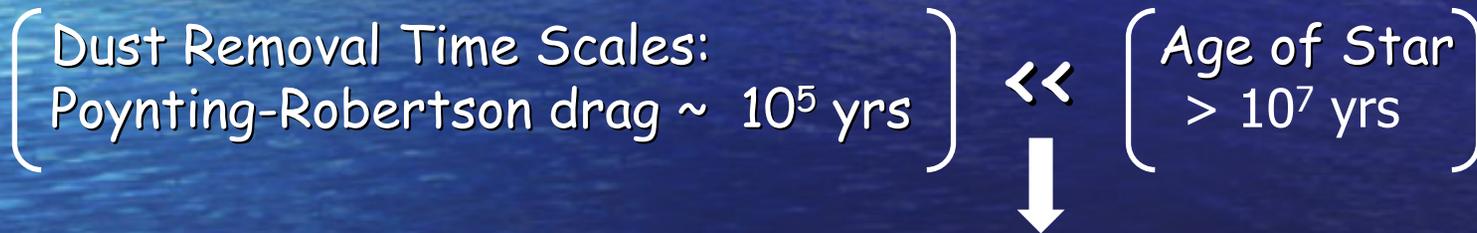
- ☀ We need **high resolution imaging**:
 - To interpret debris disk structure.
- ☀ We need **high sensitivity observations**:
 - To understand how debris disk are created (stochastic collisional events? or slow and constant grinding down of planetesimals?)
 - To study timescales and frequency of terrestrial planet formation.



Introduction

- ☀ Many (>15%) MS stars are surrounded by **debris disks**: cold far-IR emitting dust ($1-10M_{\oplus}$) that reprocesses star light and emits at longer λ 's.

- ☀ Debris disks are **indirect evidence of planetary formation**:



- ☀ Dust is **not primordial** but must be "continuously" (?) replenished by a reservoir of undetected **planetesimals** (of unknown mass) producing dust by mutual collisions

Do debris disks harbor massive planets?

☀ To induce frequent mutual collisions the planetesimals' orbits must be dynamically perturbed by massive planetary bodies.

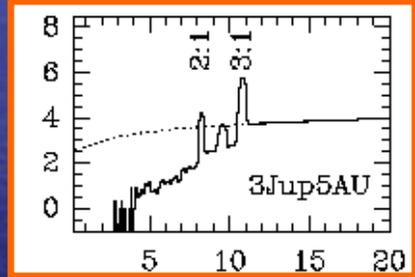
☀ As dust particles spiral inward (due to PR drag), they can get **trapped in Mean Motion Resonances** with the planets. I.e. massive planets shepherds the dust grains in the disks.

→ **Radial and azimuthal structure**

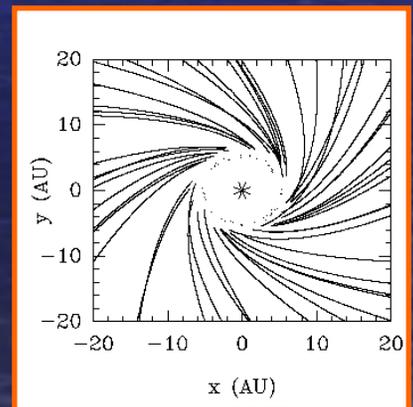
☀ Massive planets may scatter and **eject dust particles** out of a planetary system

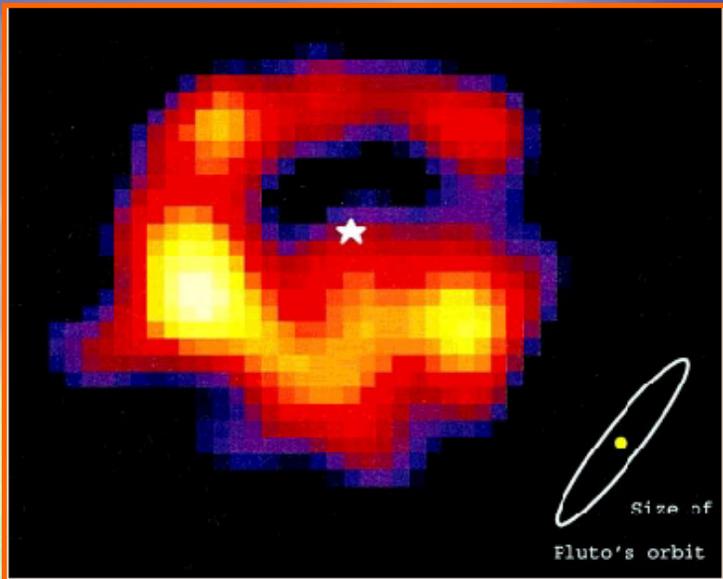
→ **Gaps**

Log[Number]

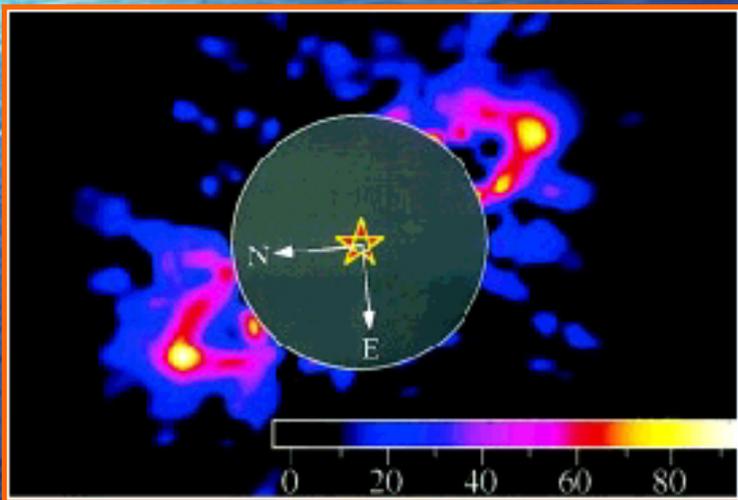


Semimajor Axis (AU)

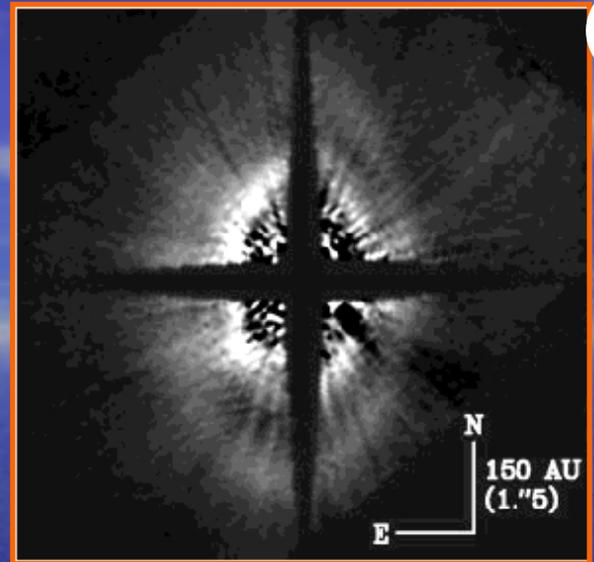




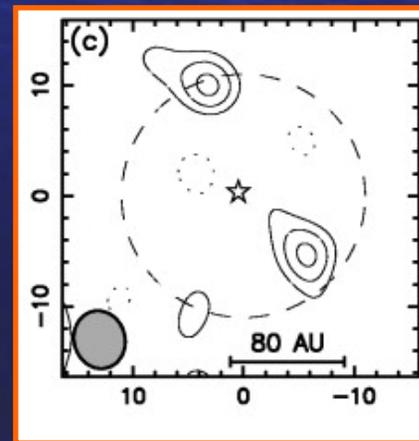
ε-Eri 850 μ m (emitted light) JCMT
(Greaves et al. 1998)



HR4796A 1.6 μ m (scattered light)
NICMOS (Schneider et al. 99)



H141569 1.1 μ m (scattered light) NICMOS
(Weinberger et al. 99)



Vega 1.3mm (emitted light)
PdB (Wilner et al. 2002)



☀ Gaps and asymmetries observed in high-resolution observations suggest giant planets may be present.



☀ Debris disk structure is sensitive to a wide range of semimajor axis (complementary to radial velocity and transit surveys).

We can learn about the diversity of planetary systems from the study of debris disks structure!

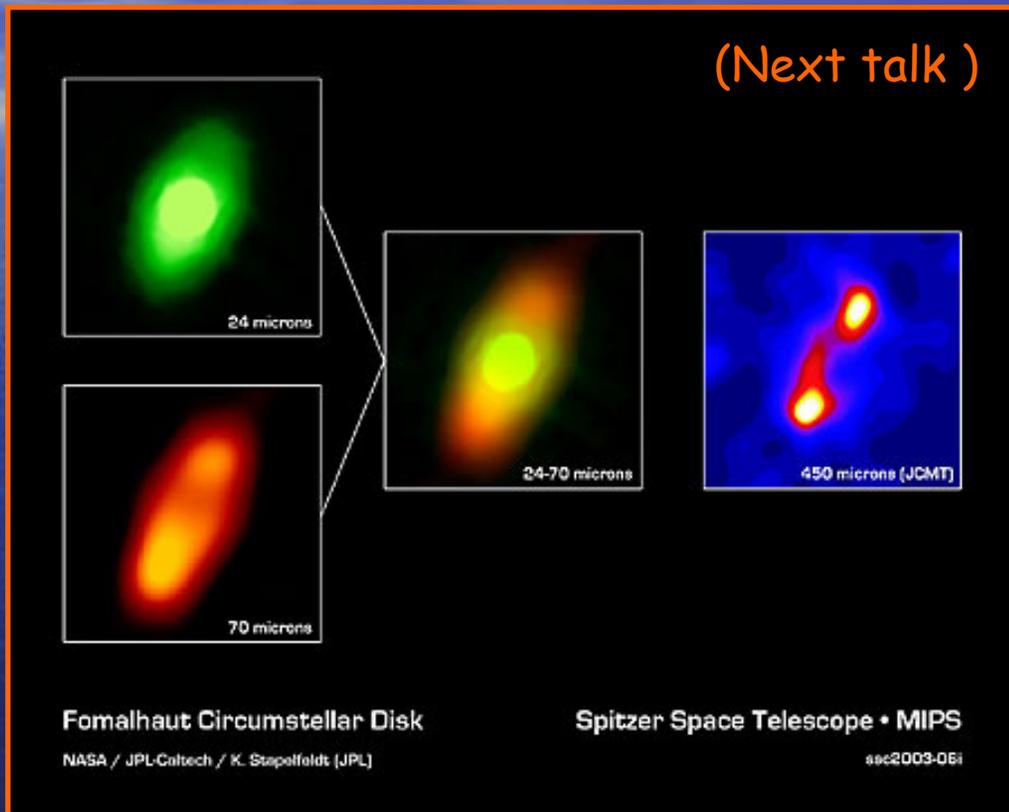
What can we do with *Spitzer*?



☀ Very few systems will be spatially resolved:
→ in most cases we won't be able to look for planets by studying debris disk structure directly.



☀ But the structure carved by the planets can affect the shape of the Spectral Energy Distribution (SED) of the disk →

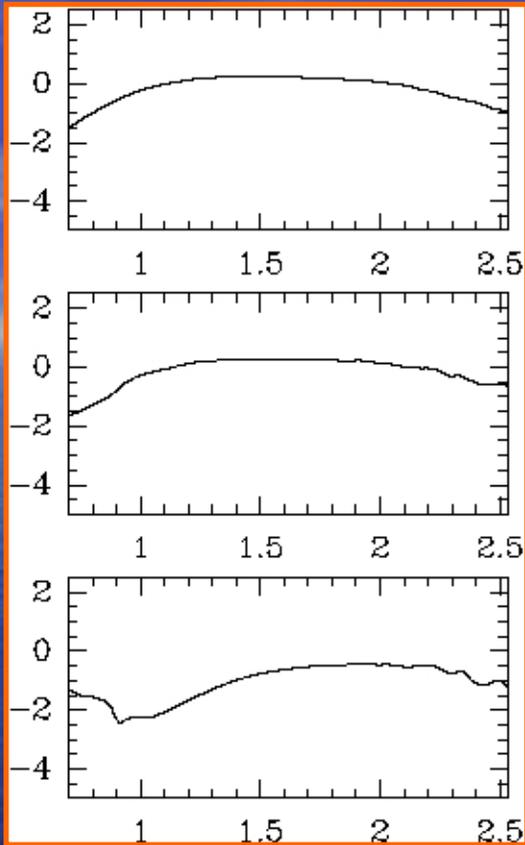


maybe we can study the debris disk structure indirectly (*FEPS*)

1 M_{Jup} at 1 AU



Log[F(mJy)]



Carbonaceous grains

Fe-rich silicate grains

Fe-poor silicate grains

Log[λ(μm)]



star

1AU 5AU

30AU

50AU

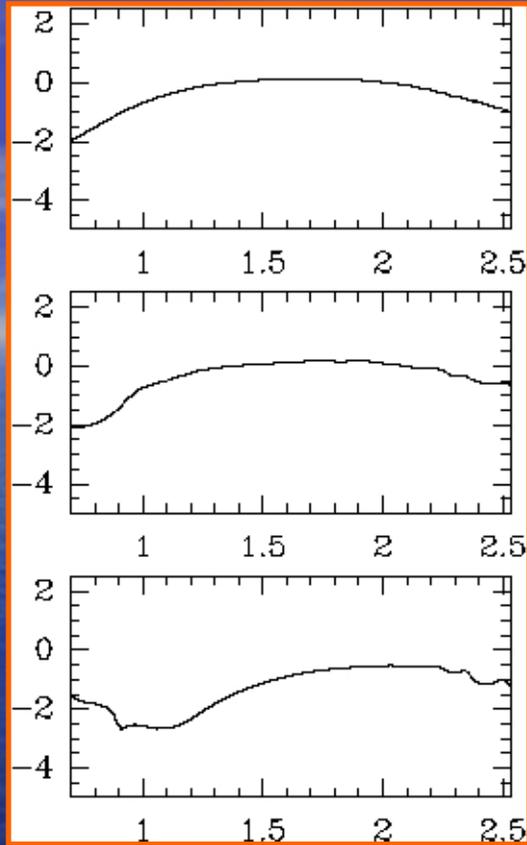
planetesimals



3 M_{Jup} at 1 AU



Log[F(mJy)]



Carbonaceous grains

Fe-rich silicate grains

Fe-poor silicate grains

Log[λ(μm)]



star

1AU 5AU

30AU

50AU

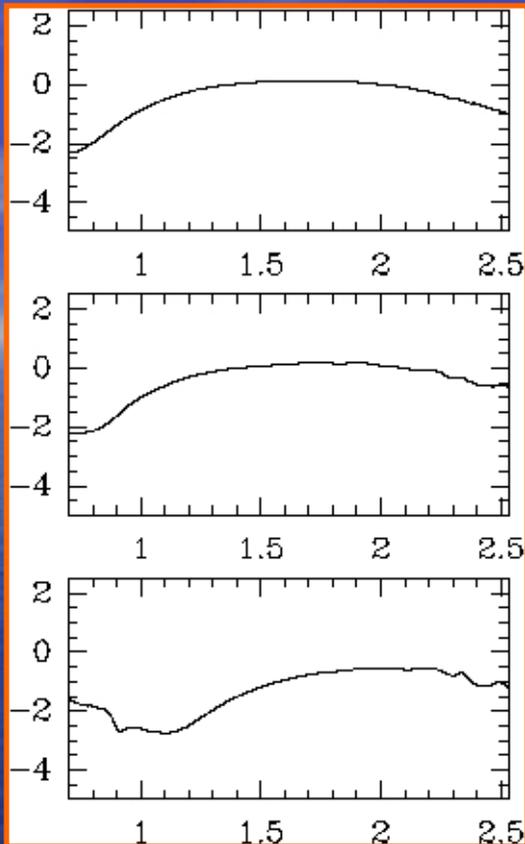
planetesimals



10M_{Jup} at 1 AU



Log[F(mJy)]



Carbonaceous grains

Fe-rich silicate grains

Fe-poor silicate grains

Log[λ(μm)]



star

1AU 5AU

30AU

50AU

planetesimals



No planet



star

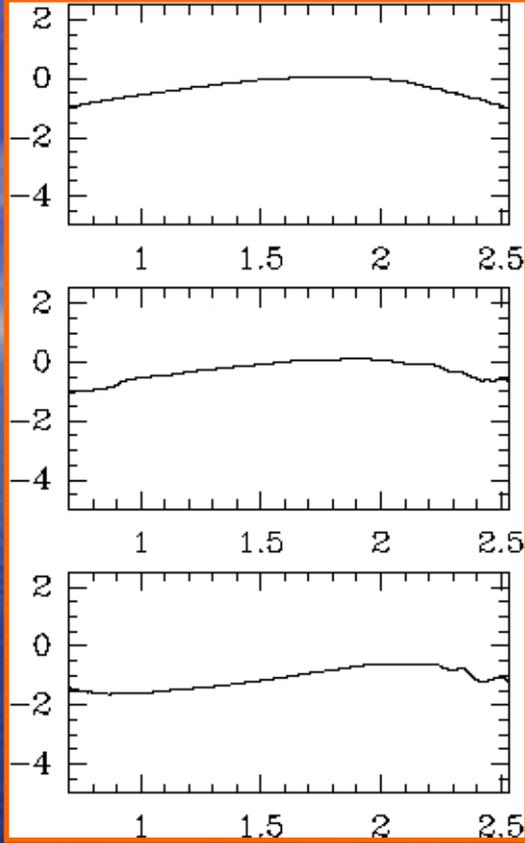
1AU 5AU

30AU

50AU

Log[$\lambda(\mu\text{m})$]

Log[F(mJy)]



Carbonaceous grains

Fe-rich silicate grains

Fe-poor silicate grains

planetesimals

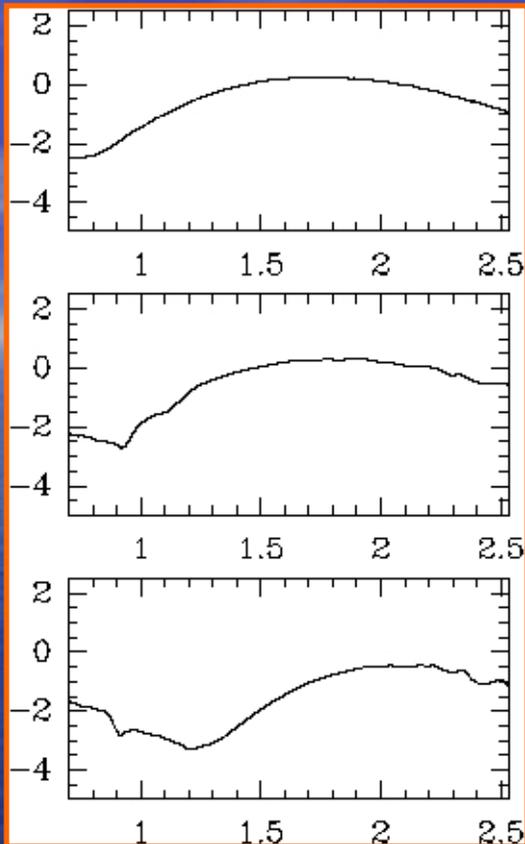




1 M_{Jup} at 5 AU



Log[F(mJy)]



Carbonaceous grains

Fe-rich silicate grains

Fe-poor silicate grains

Log[λ(μm)]



star
1AU 5AU

30AU

50AU

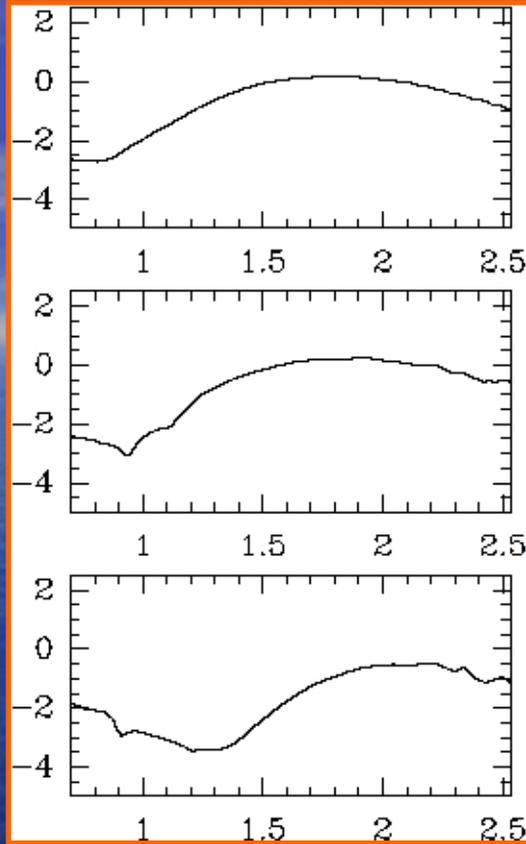
planetesimals



3 M_{Jup} at 5 AU



Log[F(mJy)]

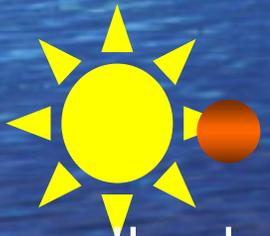


Carbonaceous grains

Fe-rich silicate grains

Fe-poor silicate grains

Log[λ(μm)]



star

1AU 5AU

30AU

50AU

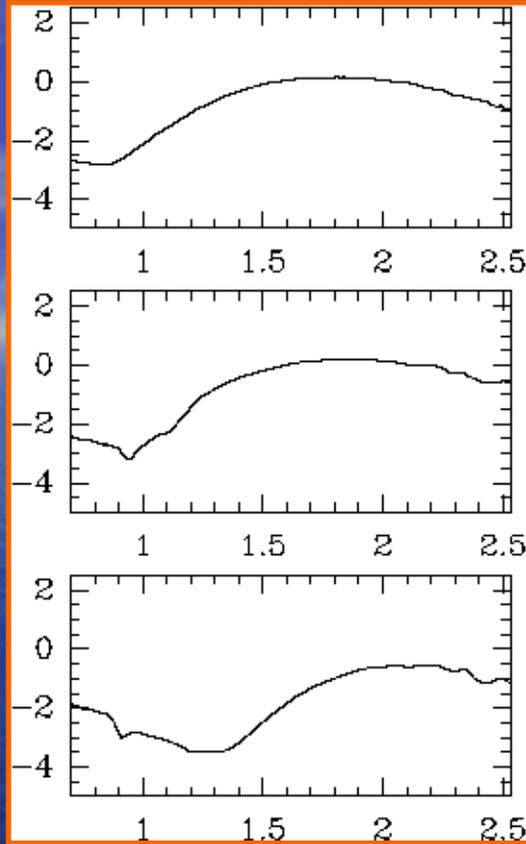
planetesimals



$10M_{\text{Jup}}$ at 5 AU



Log[F(mJy)]

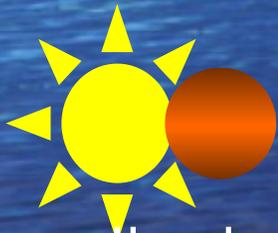


Carbonaceous grains

Fe-rich silicate grains

Fe-poor silicate grains

Log[λ(μm)]



star

1AU 5AU

30AU

50AU

planetesimals



No planet



star

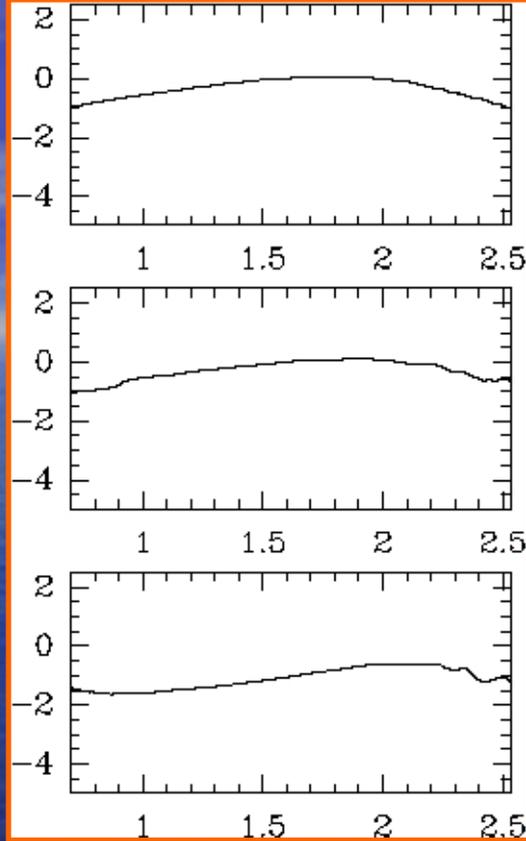
1AU 5AU

30AU

50AU

Log[$\lambda(\mu\text{m})$]

Log[F(mJy)]



Carbonaceous grains

Fe-rich silicate grains

Fe-poor silicate grains

planetesimals

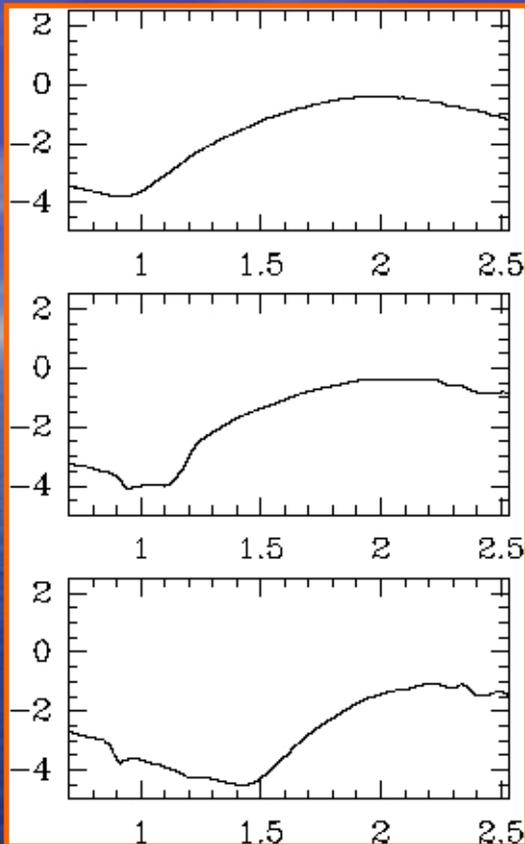




1 M_{Jup} at 30AU



Log[F(mJy)]



Carbonaceous grains

Fe-rich silicate grains

Fe-poor silicate grains

Log[λ(μm)]



star

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50AU



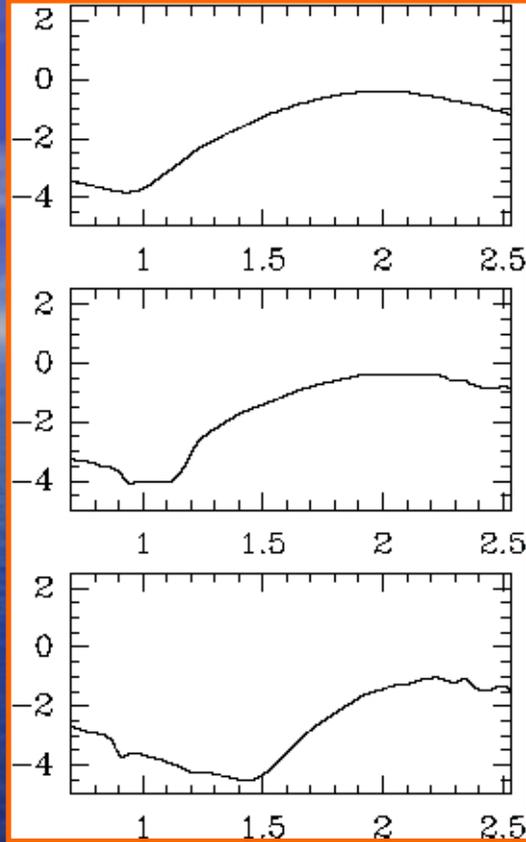
planetesimals



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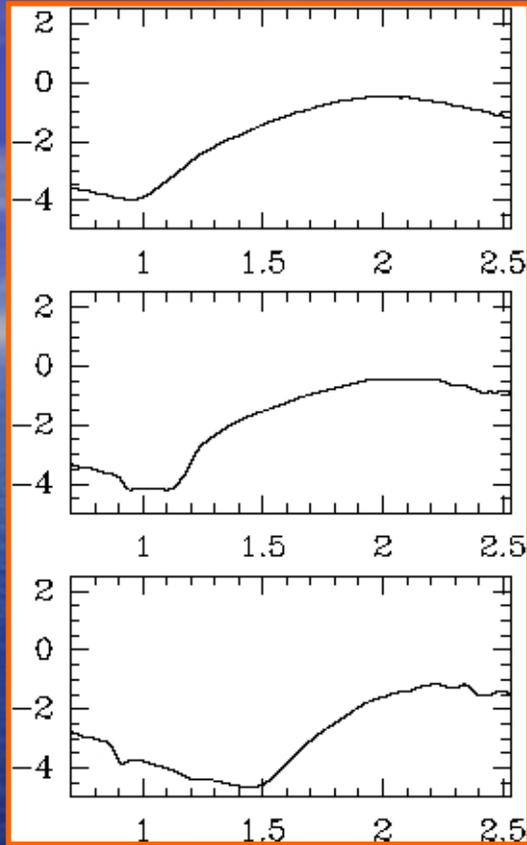
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50AU

$10M_{\text{Jup}}$ at 30AU



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Log[λ(μm)]



star

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planetesimals



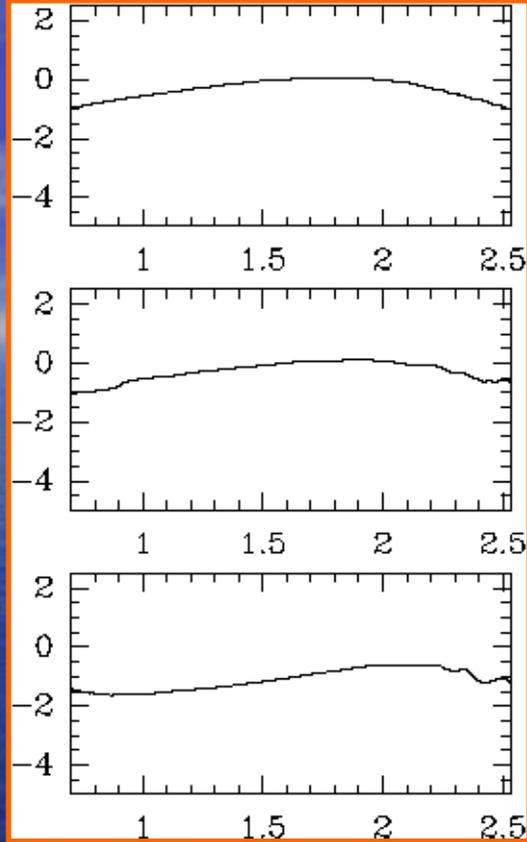
30AU

50AU

No planet



Log[F(mJy)]



Carbonaceous grains

Fe-rich silicate grains

Fe-poor silicate grains

Log[λ(μm)]



star

1AU 5AU

30AU

50AU

planetesimals

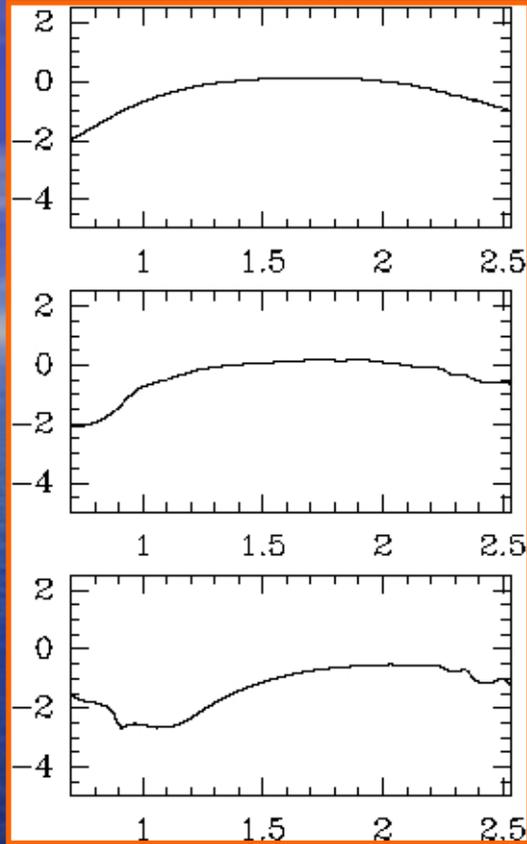




3 M_{Jup} at 1 AU



Log[F(mJy)]



Carbonaceous grains

Fe-rich silicate grains

Fe-poor silicate grains

Log[λ(μm)]



star

1AU 5AU

30AU

50AU

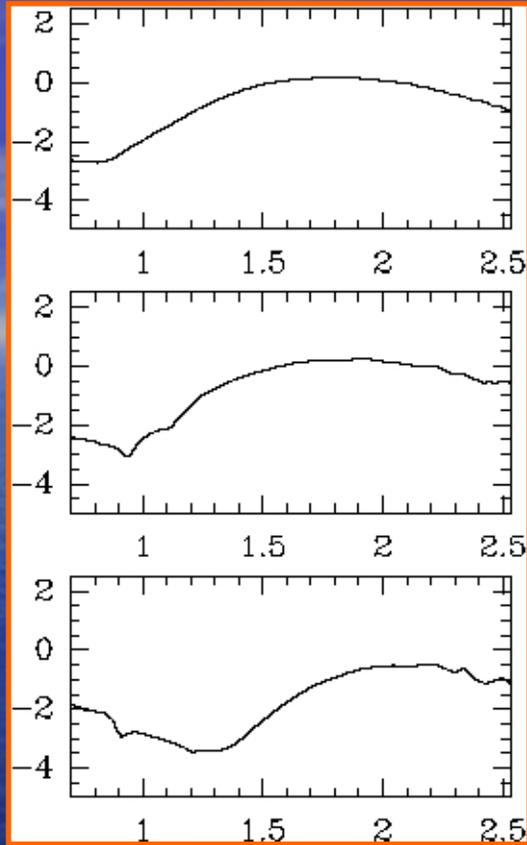
planetesimals



3 M_{Jup} at 5 AU



Log[F(mJy)]

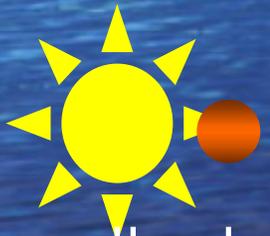


Carbonaceous grains

Fe-rich silicate grains

Fe-poor silicate grains

Log[λ(μm)]



star

1AU 5AU

30AU

50AU

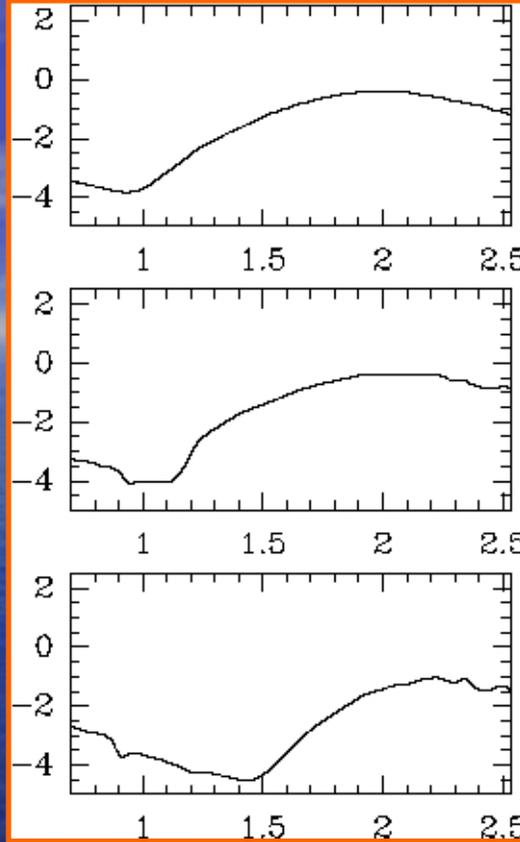
planetesimals



3 M_{Jup} at 30AU



Log[F(mJy)]



Carbonaceous grains

Fe-rich silicate grains

Fe-poor silicate grains

Log[λ(μm)]



star

1AU 5AU



planetesimals



30AU

50AU

No planet



star

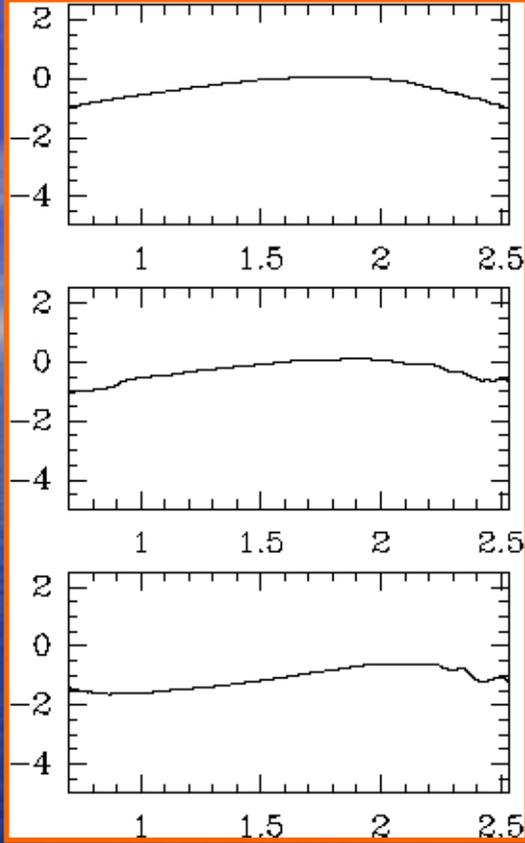
1AU 5AU

30AU

50AU

Log[$\lambda(\mu\text{m})$]

Log[F(mJy)]



Carbonaceous grains

Fe-rich silicate grains

Fe-poor silicate grains

planetesimals



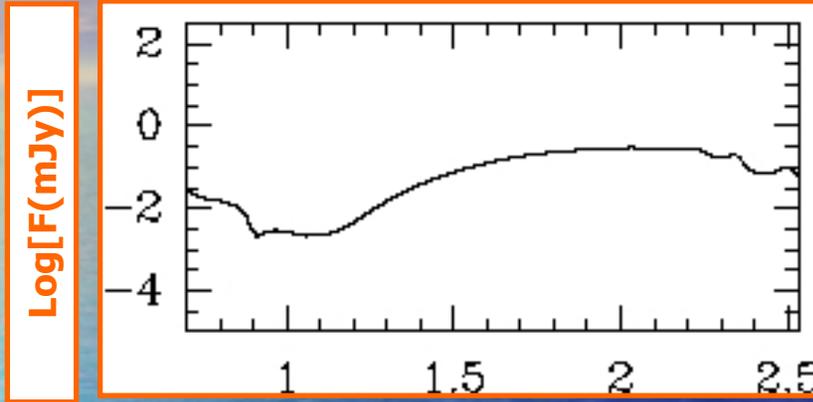
What can we learn from the SEDs?

- ☀ The SED of a dust disk generated by an outer belt of planetesimals with inner planets is fundamentally different from that of the disk without planets.
- ☀ Significant decrease of the near/mid-IR flux due to the clearing of dust inside the planet's orbit.
- ☀ It is difficult to diagnose the mass of the planet
- ☀ It may be possible to diagnose the location of the planet and the absence/presence of planets

but...

3 M_{Jup} at 1 AU

There are **degeneracies** that can only be solved with high-resolution observations...

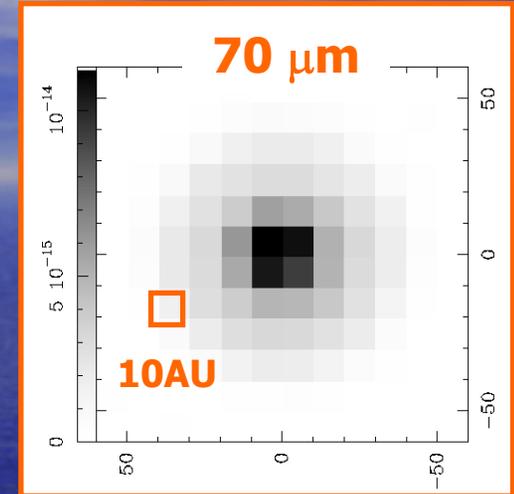


Log[F(mJy)]

Log[λ(μm)]

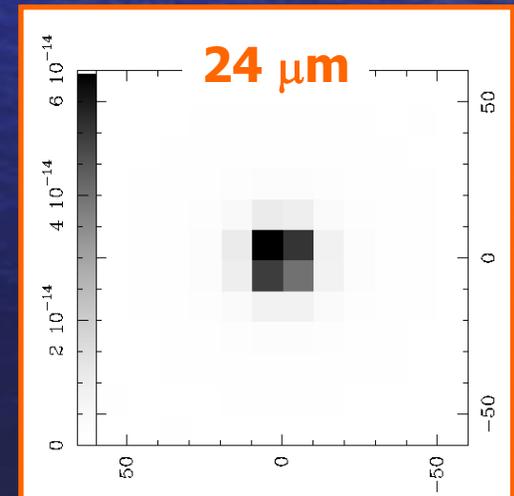
Fe-poor silicate grains

1" at 10 pc



70 μm

10AU



24 μm



star

1AU 5AU

planetesimals

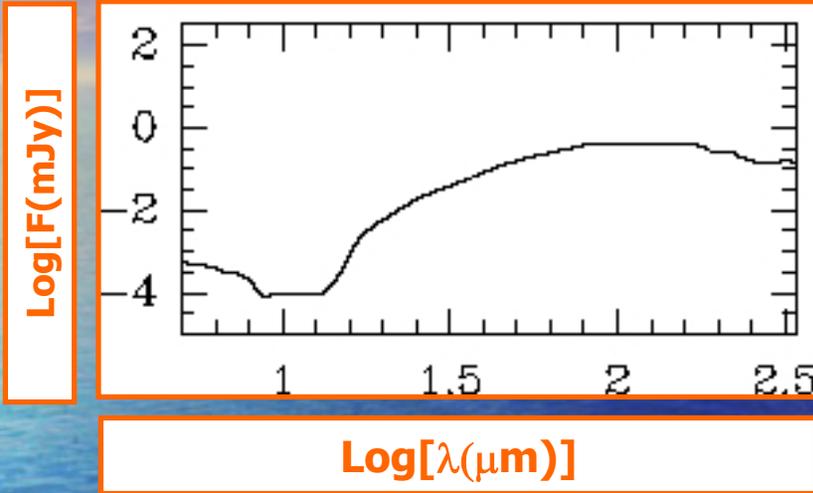


30AU

50AU

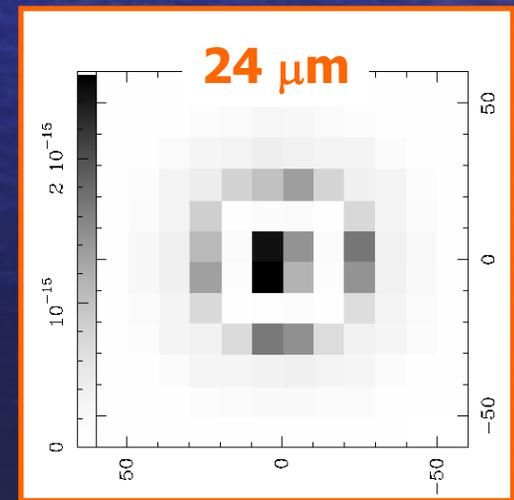
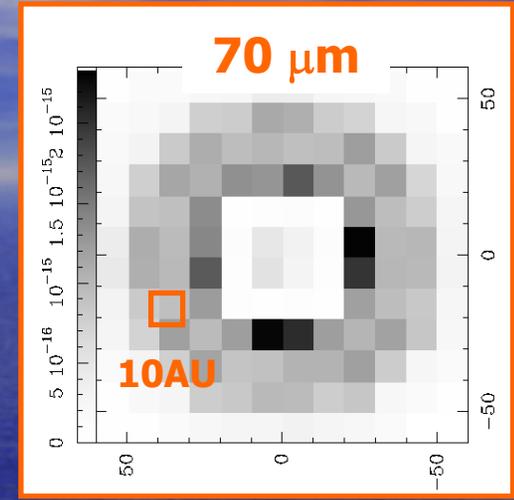
3 M_{Jup} at 30AU

There are **degeneracies** that can only be solved with high-resolution observations...



Fe-rich silicate grains

1" at 10 pc



star

1AU 5AU



planetesimals

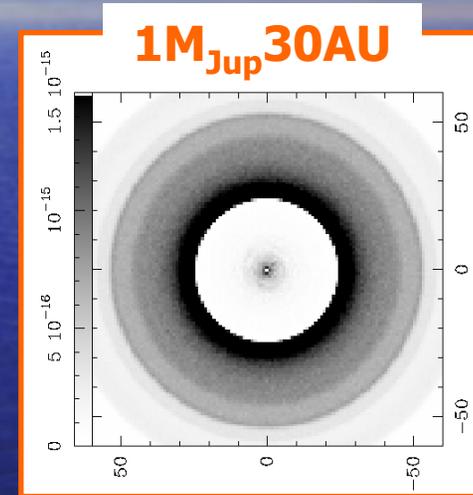
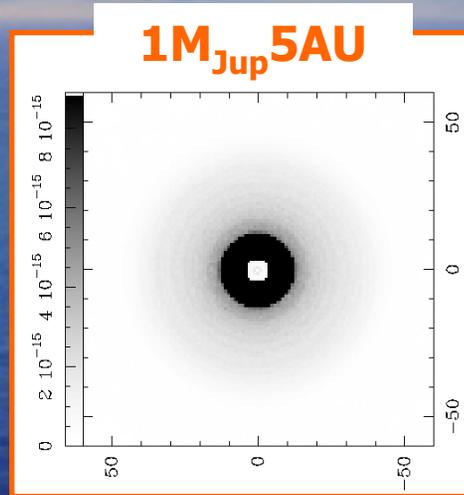
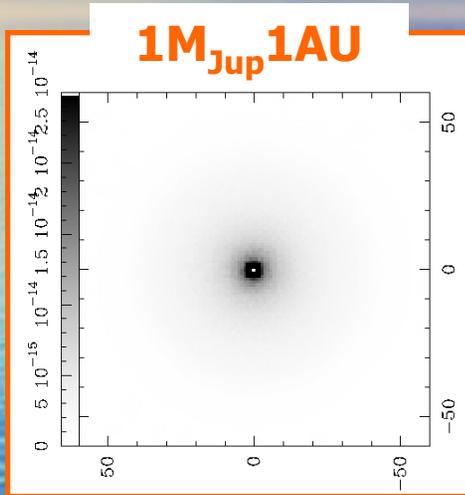
30AU

50AU

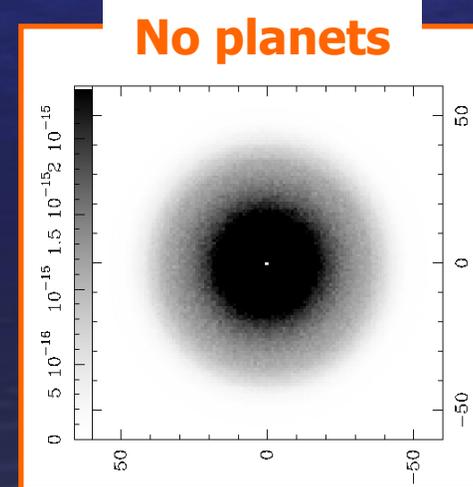
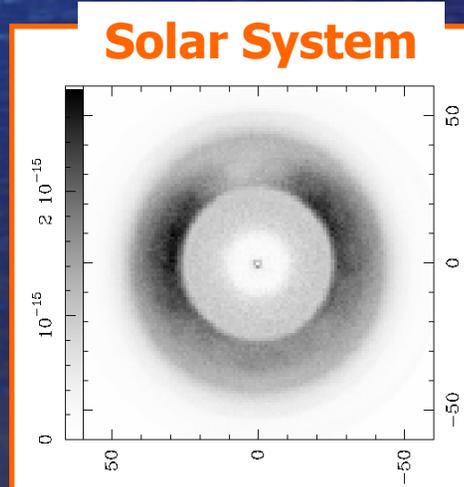
We need *SAFIR*!



☀ We need **high resolution imaging** to interpret debris disk structure in terms of planetary architectures.

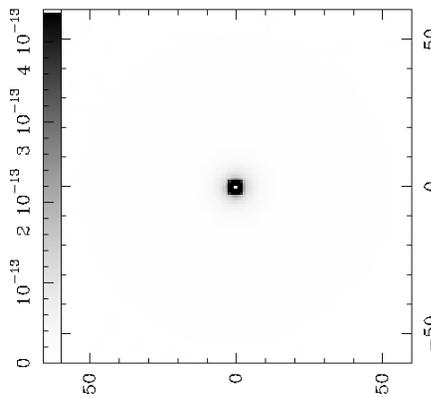


70 μm

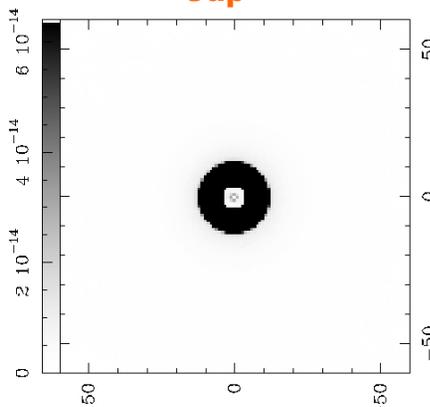




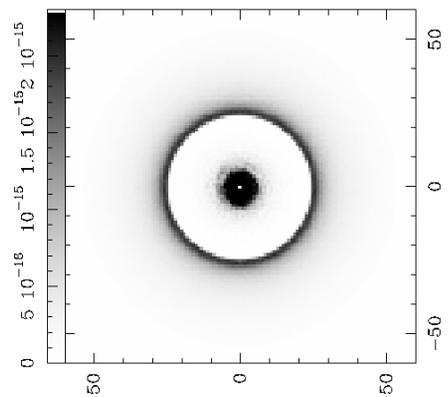
1M_{Jup} 1AU



1M_{Jup} 5AU

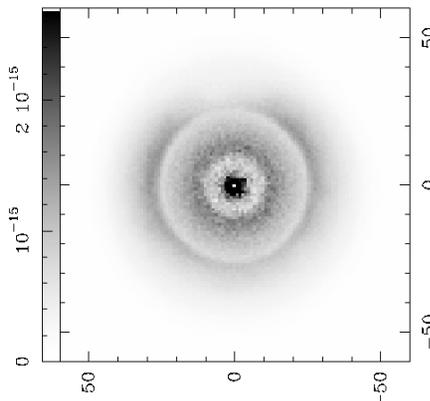


1M_{Jup} 30AU

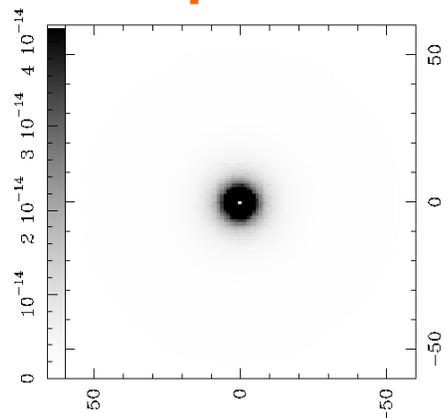


24 μm

Solar System



No planets





And ALMA alone is not enough because...

- ☀ **Warm dust** (i.e. "zodiacal light") produced by asteroid-like bodies in terrestrial planet region may be **invisible** for ALMA (low τ ; too diffused)
- ☀ **Vega** observations with *Spitzer* (next talk) show that **mm** and **far-IR** observations are **very different** from each other, and both need to be considered in the interpretation of this systems.





We need **high sensitivity** to understand the physical processes giving rise to debris disks, whether...

Steady production of dust during long periods of time ("standard scenario").

or...

Stochastic collisional events [new *Spitzer* results; and observations of debris disks around old stars (few Gyrs)].

The high sensitivity of *SAFIR* will allow us to make deeper surveys of stellar clusters of known age, to study the **number of stars with recent collisional events as a function of time.**

Questions *SAFIR* will answer....



☀ Is the "late bombardment" epoch in the early Solar System common among other stars? Is its intensity below or above average?

→ Consequences for the survival of Life in the terrestrial planets in the habitable zone.



☀ Terrestrial planet formation should produce a clear IR signal. High sensitivity surveys will allow us to:

☀ Study **timescales** for terrestrial planet formation.

☀ Estimate whether they are **common or rare**.

☀ Observation at different λ 's will allow us to tell where the action is taking place.

Conclusions

- ☀ Massive planets create structure in debris disks.
High resolution observations are fundamental for its interpretation in terms of planetary architectures:

- ☀ **SEDs are degenerated**
 - ➔ *Spitzer* is not enough.
- ☀ mm and far-IR give complementary information
 - ➔ *ALMA* alone is not enough.
- ☀ Debris disk structure is sensitive to **long period planets**
 - ➔ Radial velocity and transit surveys are not enough



☀ **High sensitivity observations** are needed to study:

- ☀ Whether dust is produced in stochastic collisional events, or in a slow grinding down of planetesimals.
- ☀ Timescales of **terrestrial planet formation**.
Are terrestrial planets common or rare?
Are other planetary systems more hostile to Life?



We need SAFIR!



For details about the modeling:

- ☀️ "Study of the Dynamics of Dust from the Kuiper Belt: Spatial Distribution and Spectral Energy Distribution",
Moro-Martin & Malhotra, 2002, AJ, 124, 2305
- ☀️ "Dynamical models of KB Dust in the Inner and Outer Solar System",
Moro-Martin & Malhotra, 2003, AJ, 125, 2255
- ☀️ "Dust outflows from planetary systems",
Moro-Martin & Malhotra, 2004, submitted to ApJ
- ☀️ "Model Spectral Energy Distributions of Circumstellar Debris Disks. II. Outer Belt of Planetesimals with Inner Giant Planets",
Moro-Martin, Wolf & Malhotra, 2004, submitted to ApJ

Pre-prints at:

<http://www.lpl.arizona.edu/people/faculty/malhotra2.html>

