Signatures of Planets in 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?

Debris Disks Modeling:

- Density structure (if spatially resolved)
- Spectral Energy Distributions (if spatially unresolved)
- Predicted *Spizter* colors

Conclusions

Introduction

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

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

Dust Removal Time Scales: Poynting-Robertson drag ~ 10^5 yrs	$\ll$	Age of Star > 10^7 yrs

↓

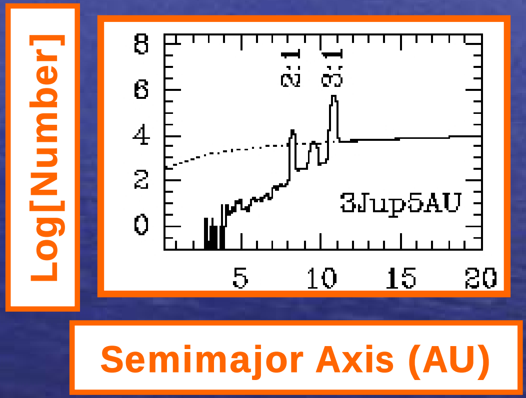
- Dust is **not primordial** but must be "continuously" replenished by a reservoir of undetected **planetesimals** (of unknown mass) producing dust by mutual collisions

Do debris disks harbor massive planets?

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

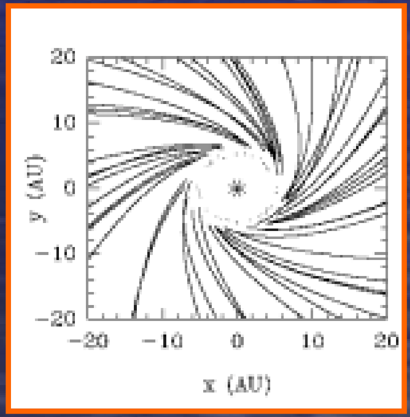
- As dust particles spiral inward (due to PR drag), they can get **trapped in Mean Motion Resonances** with the planets.
  I.e. massive planets shepherds the dust grains in the disks.

  ➡ **Radial and azimuthal structure**

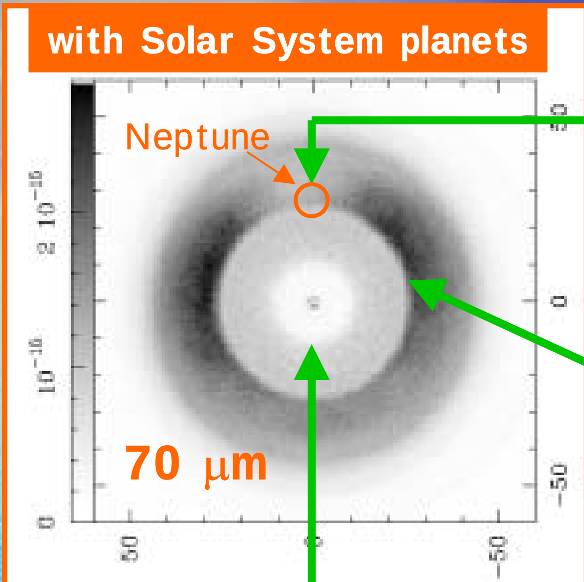


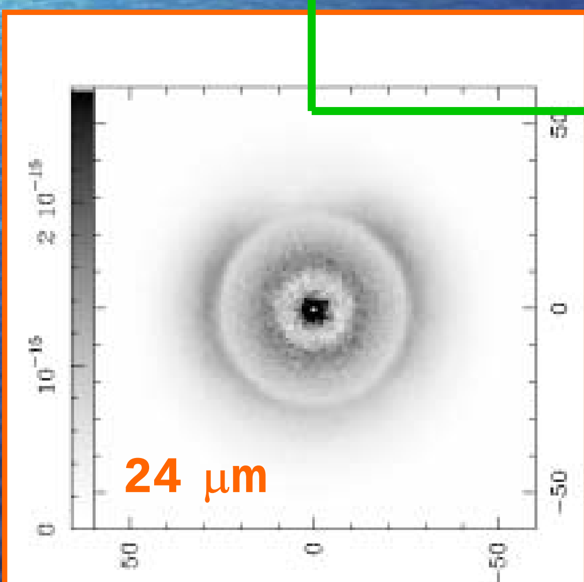
- Massive planets may scatter and **eject dust particles** out of a planetary system

  ➡ **Gaps**



Kuiper Belt Dust Disk Structure



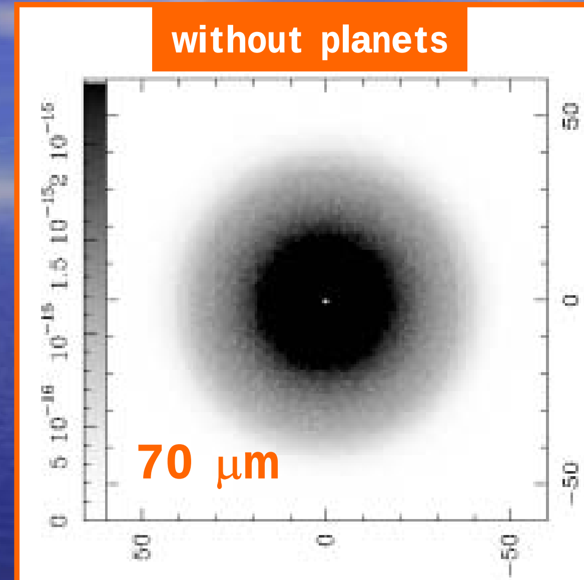


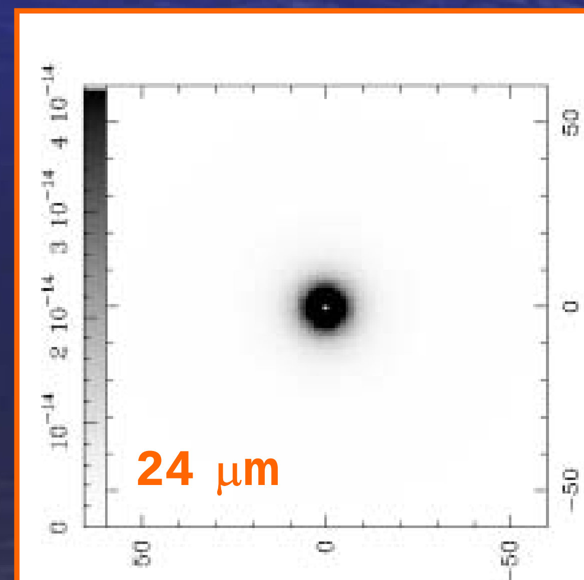
Effect 1

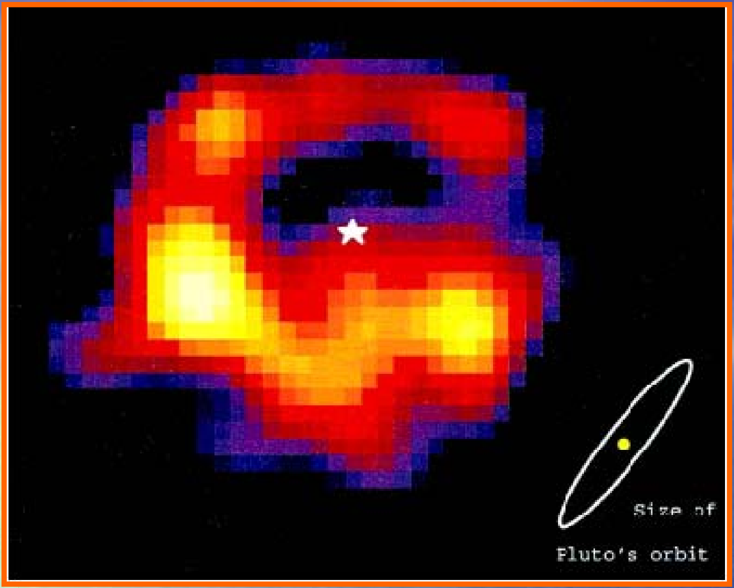
- minimum at Neptune's position (avoid resonant planet)
- ring-like structure along Neptune's orbit (MMRs)

Effect 2

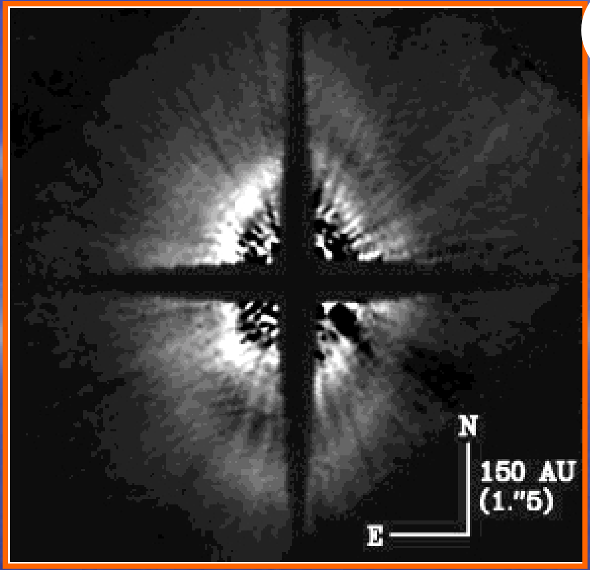
clearing of dust from inner 10 AU (due to gravitational scattering by Jupiter and Saturn)



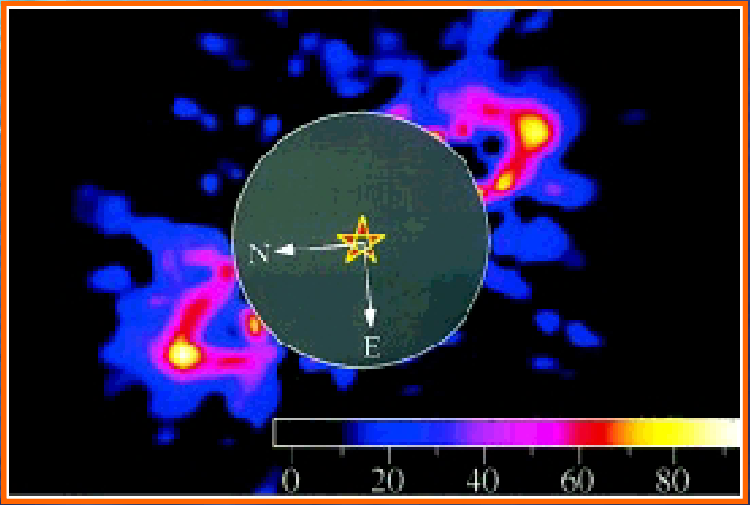




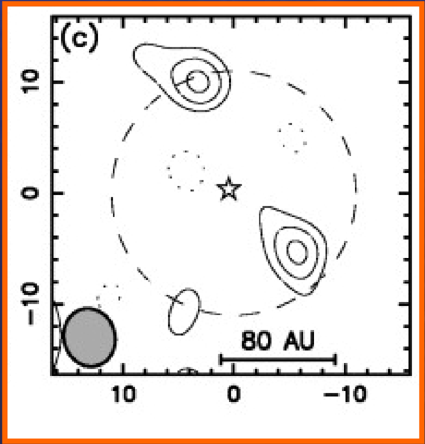
ε-Eri 850μm (emitted light) JCMT
(Greaves et al. 1998)



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



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



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

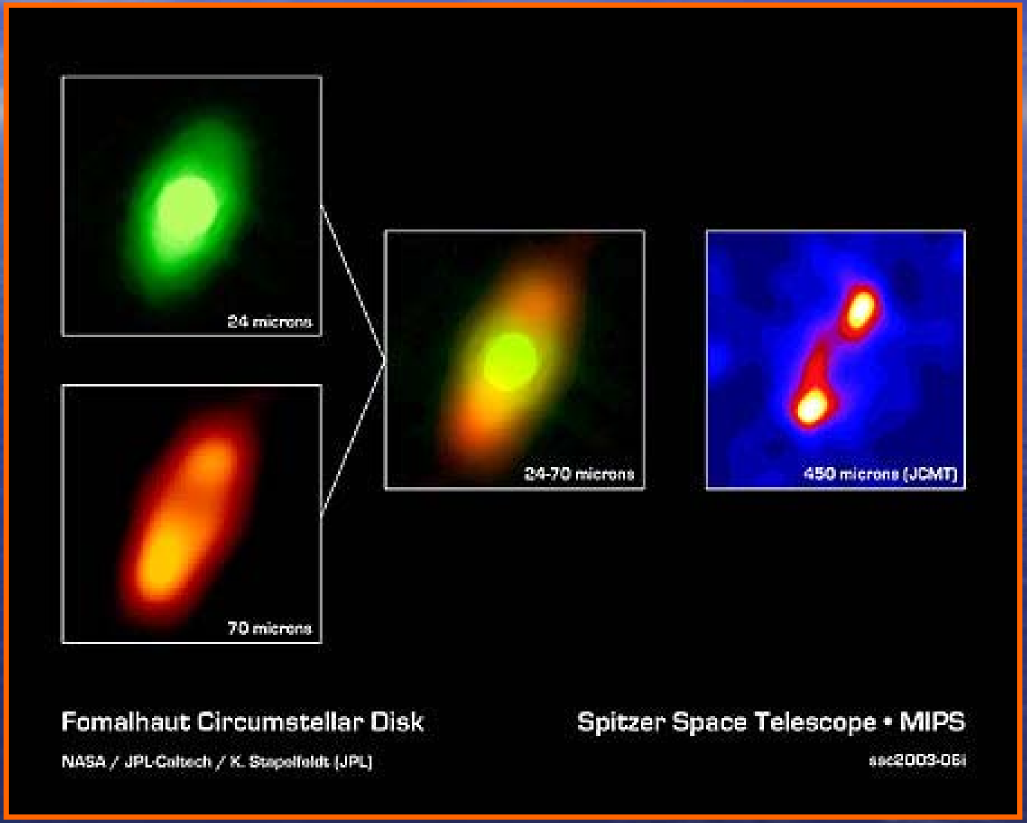
- Gaps and asymmetries observed in high-resolution observations suggest giant planets may be present.

- 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*?

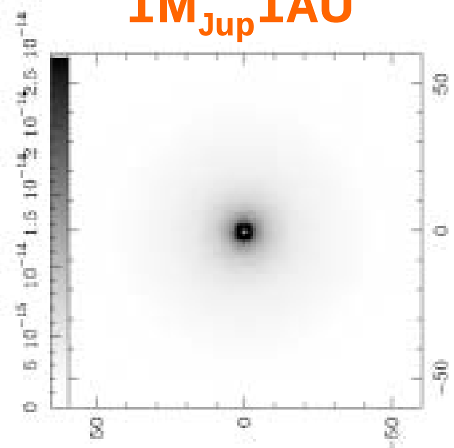
- Very few systems will be spatially resolved: ➡ in most cases we won't be able to look for planets by studying debris disk structure directly.
- But the structure carved by the planets can affect the shape of the Spectral Energy Distribution (SED) of the disk ➡



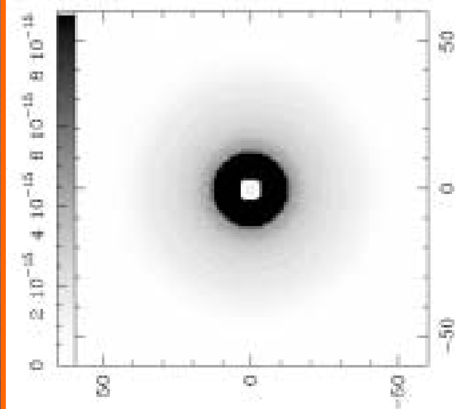
maybe we can study the debris disk structure indirectly (*FEPS*)

Debris Disks Modeling: density structure and SEDs

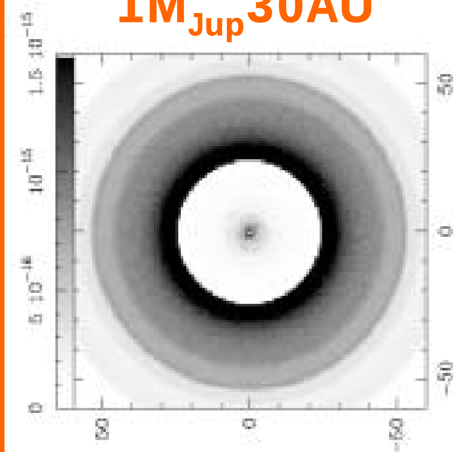
$1M_{Jup}1AU$



$1M_{Jup}5AU$

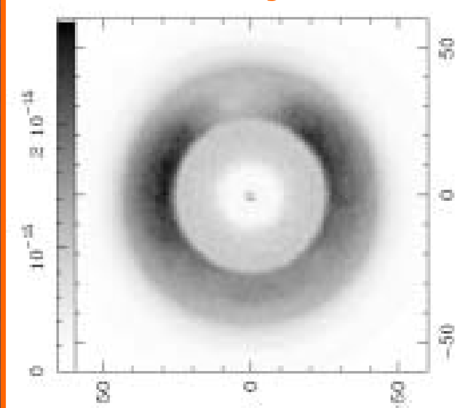


$1M_{Jup}30AU$

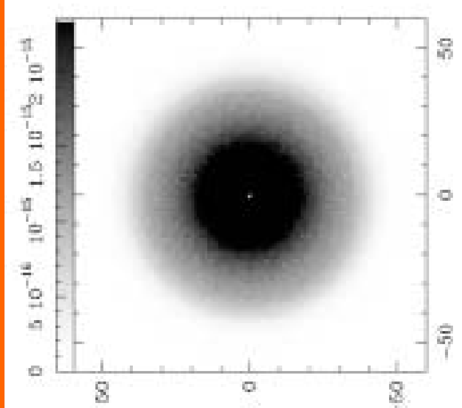


70 μm

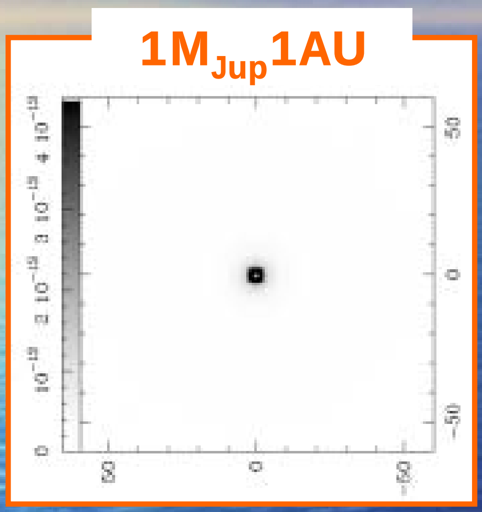
Solar System

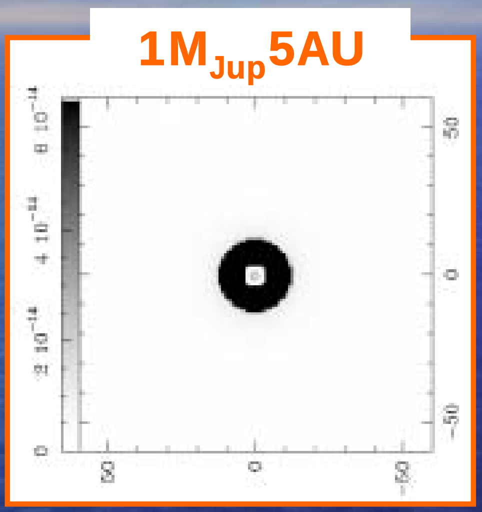


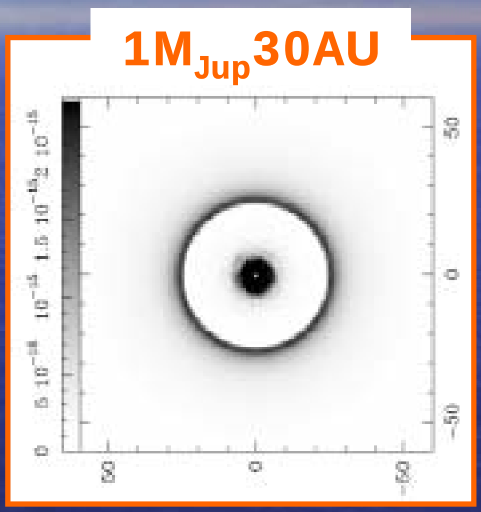
No planets



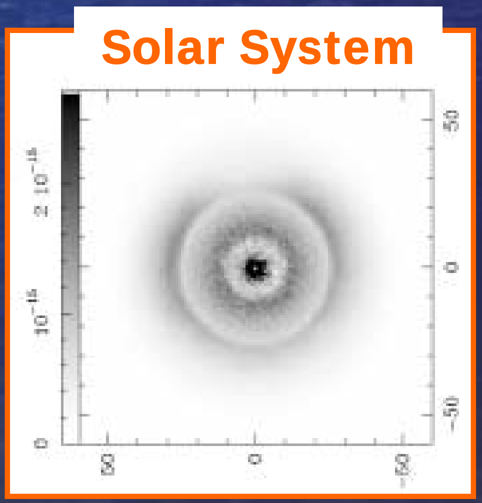
Output from dynamical simulations

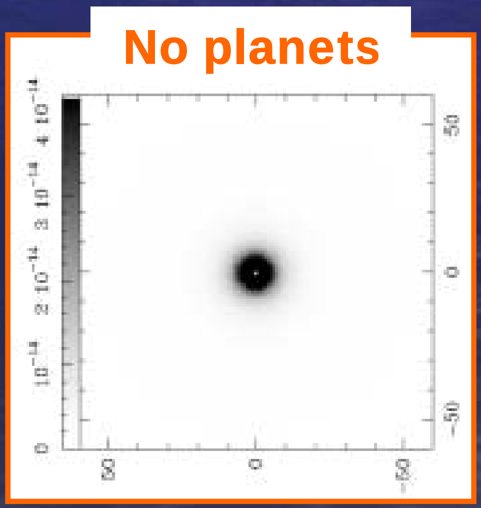






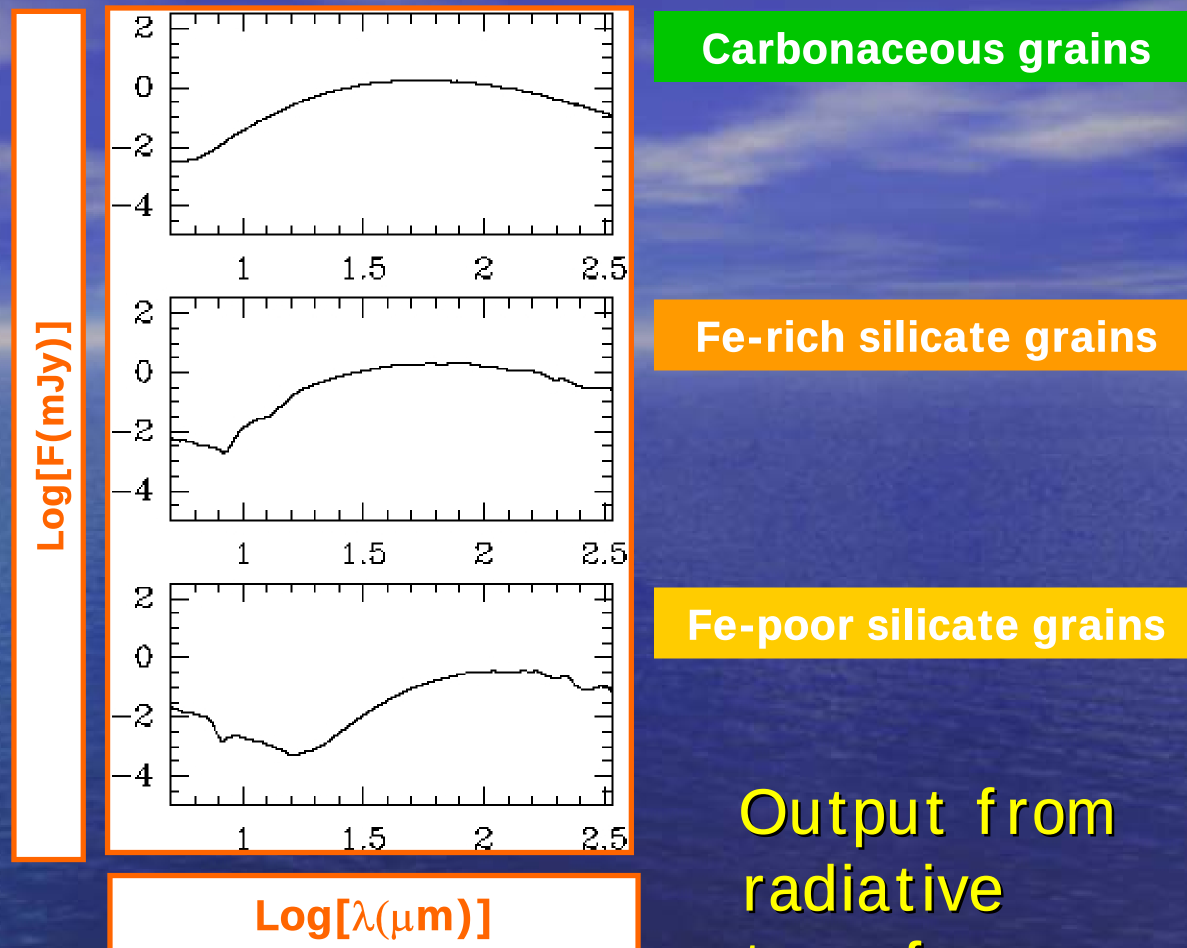
24 μm





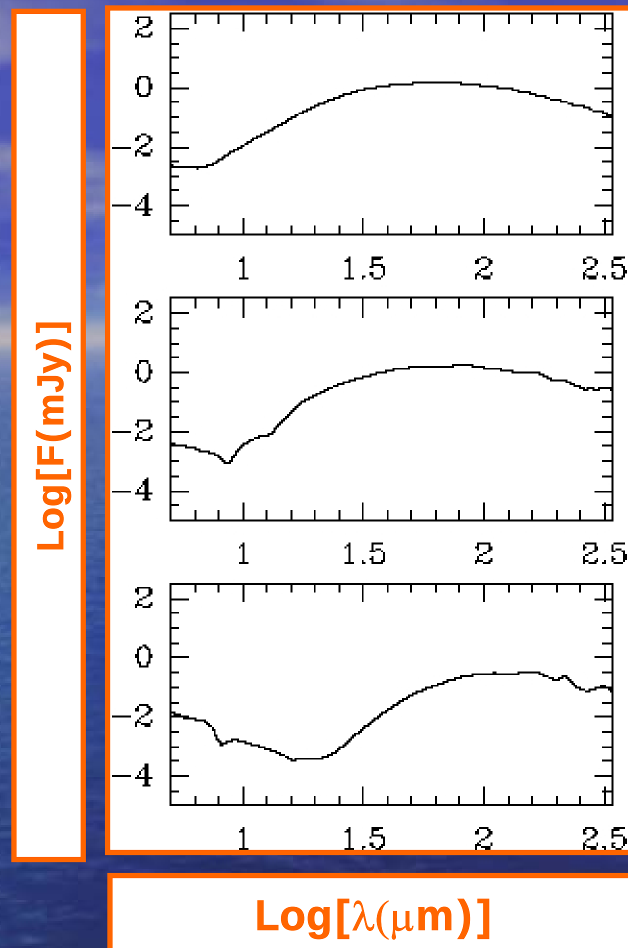
Output from dynamical simulations

1 M_{Jup} at 5 AU



Output from radiative transfer simulations

3 M_{Jup} at 5 AU

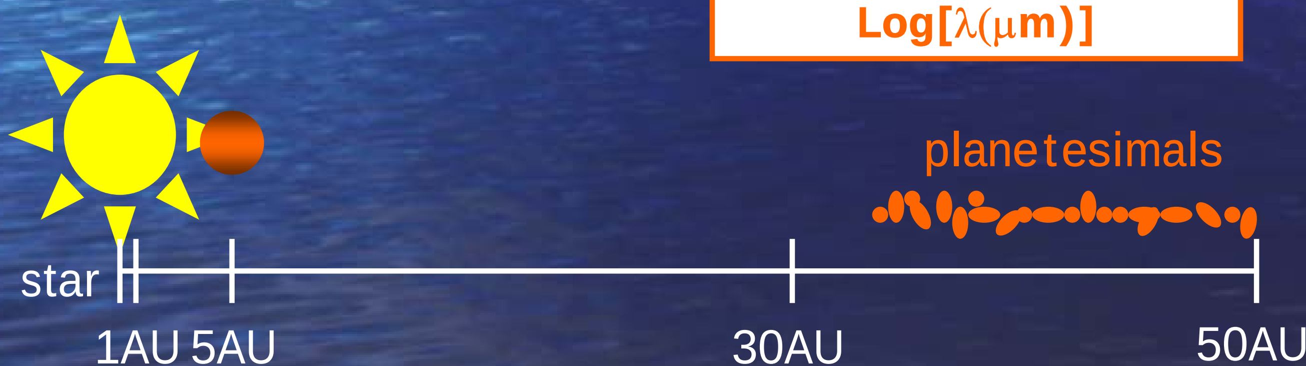


Carbonaceous grains

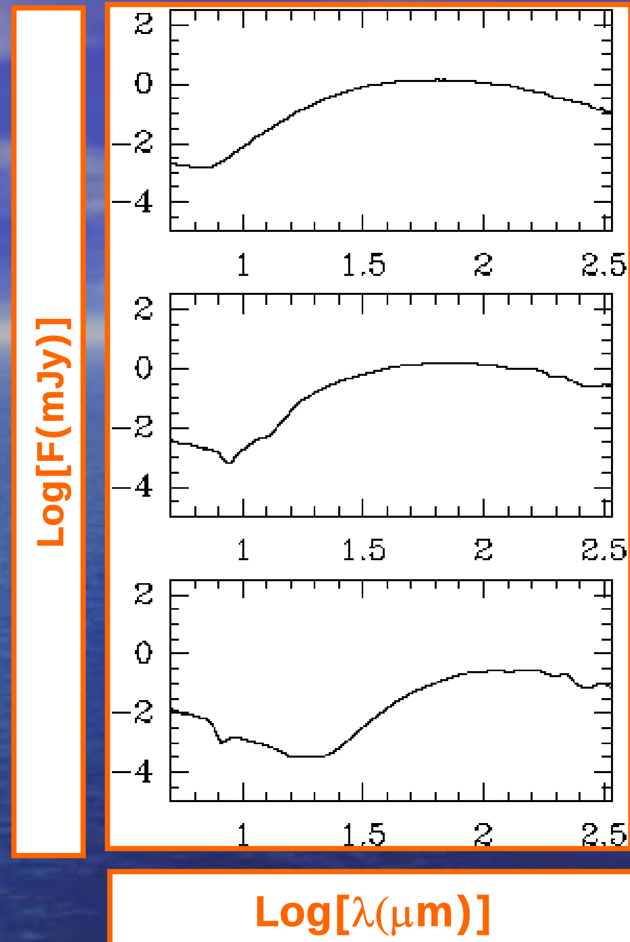
Fe-rich silicate grains

Fe-poor silicate grains

Output from radiative transfer simulations



$10M_{Jup}$ at 5 AU



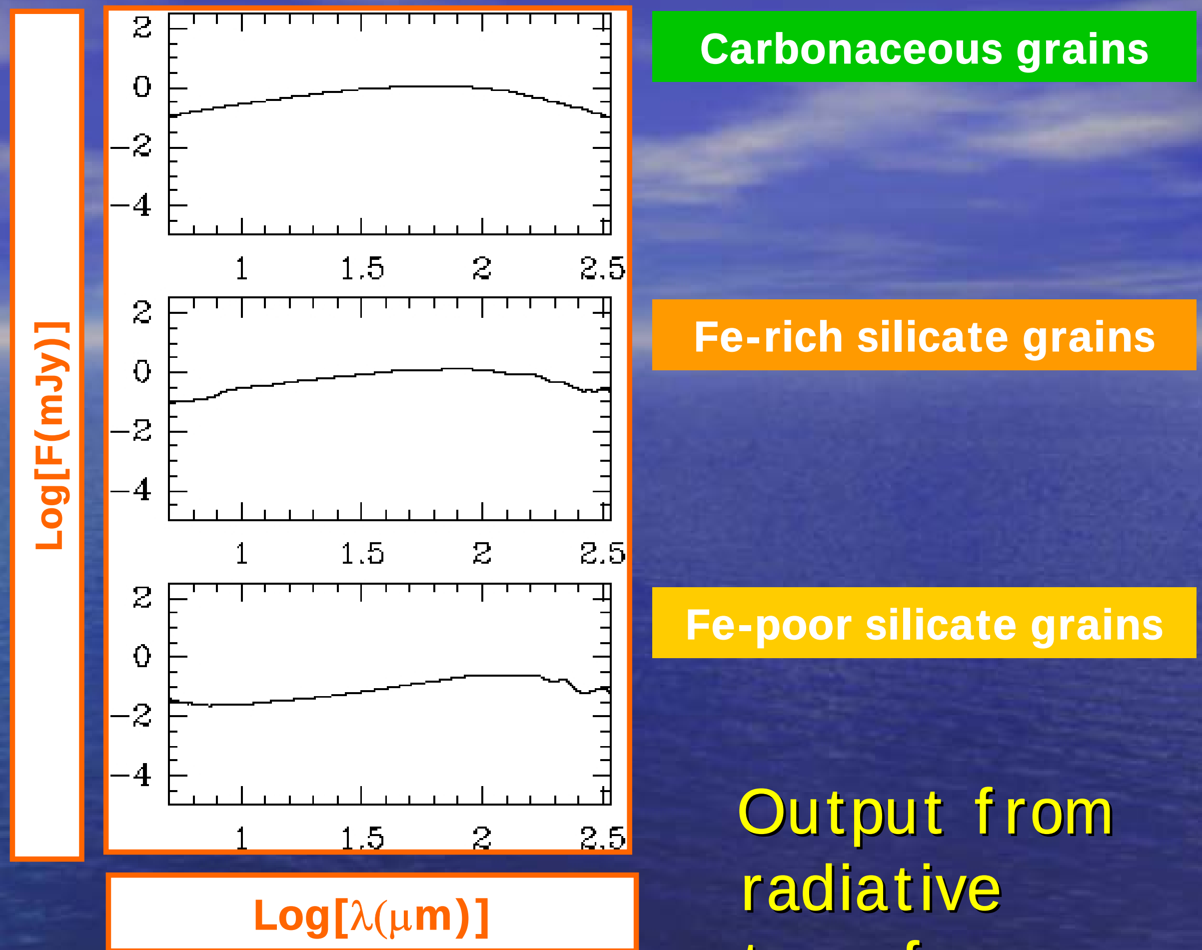
Carbonaceous grains

Fe-rich silicate grains

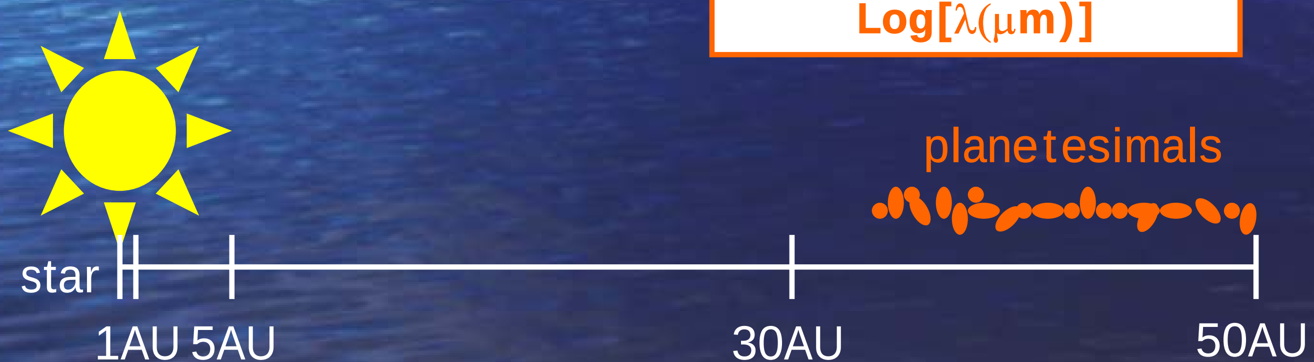
Fe-poor silicate grains

Output from radiative transfer simulations

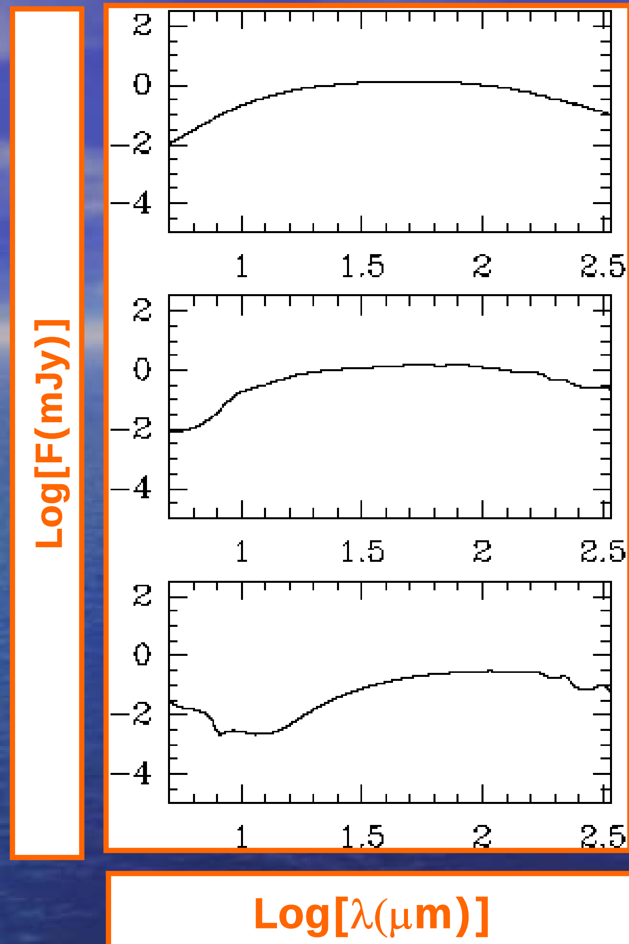
No planet



Output from radiative transfer simulations



3 M_{Jup} at 1 AU



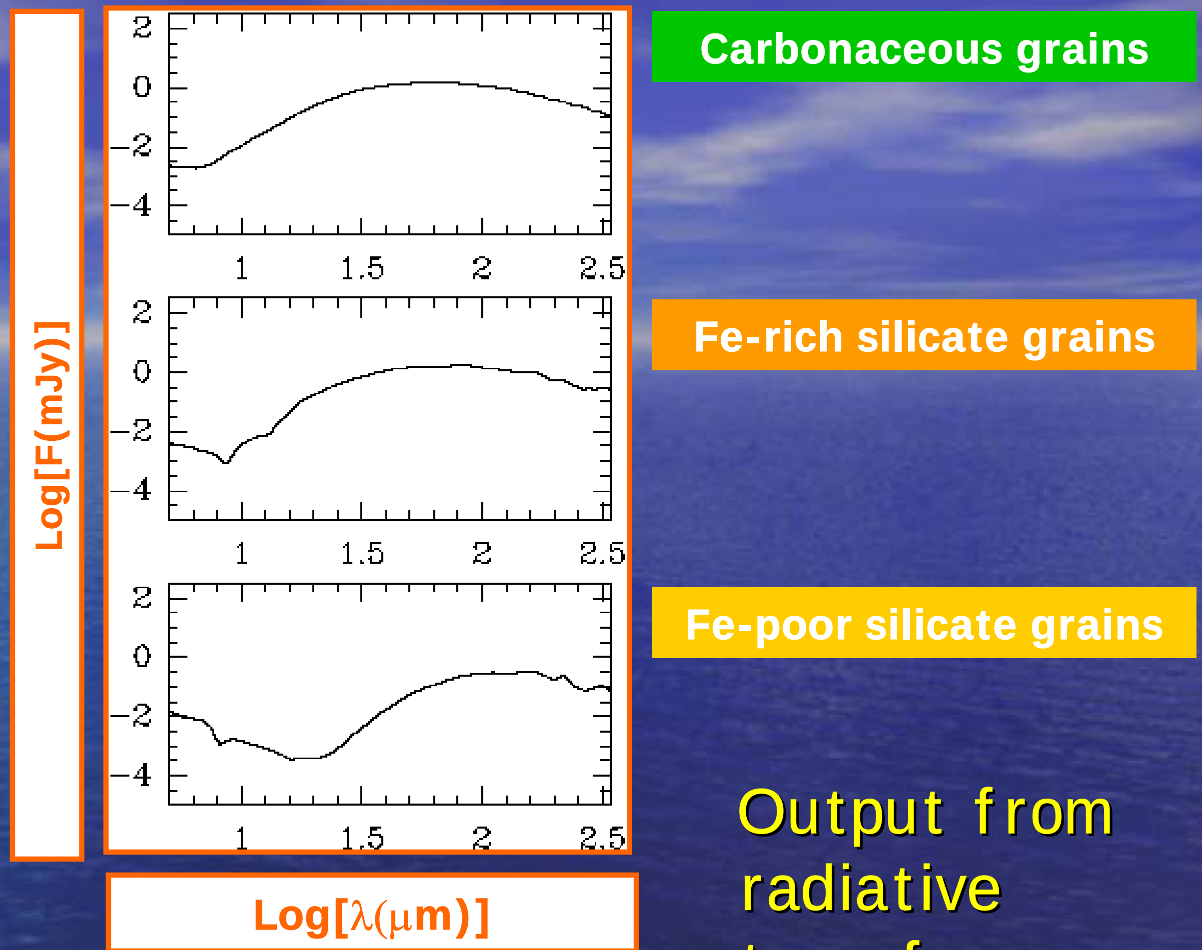
Carbonaceous grains

Fe-rich silicate grains

Fe-poor silicate grains

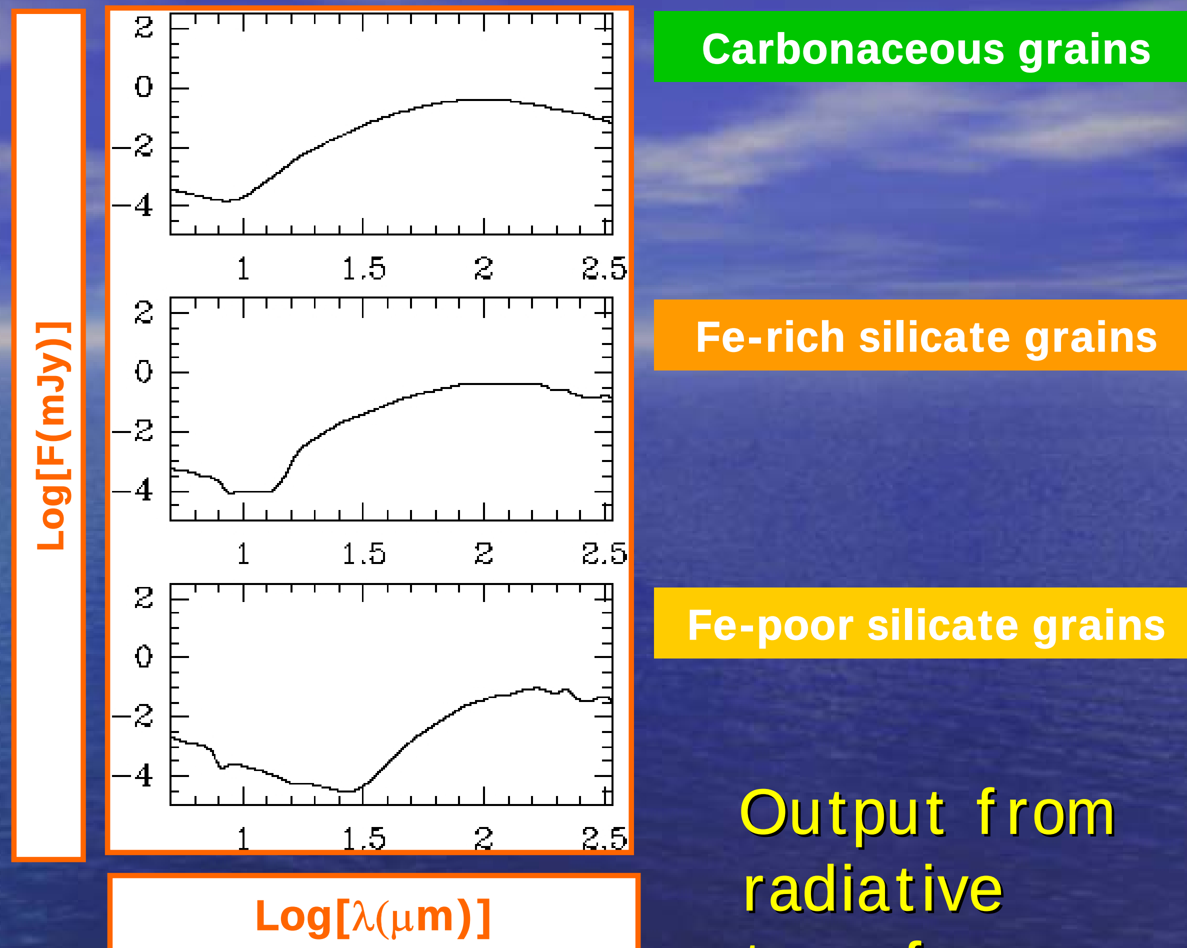
Output from radiative transfer simulations

3 M_{Jup} at 5 AU

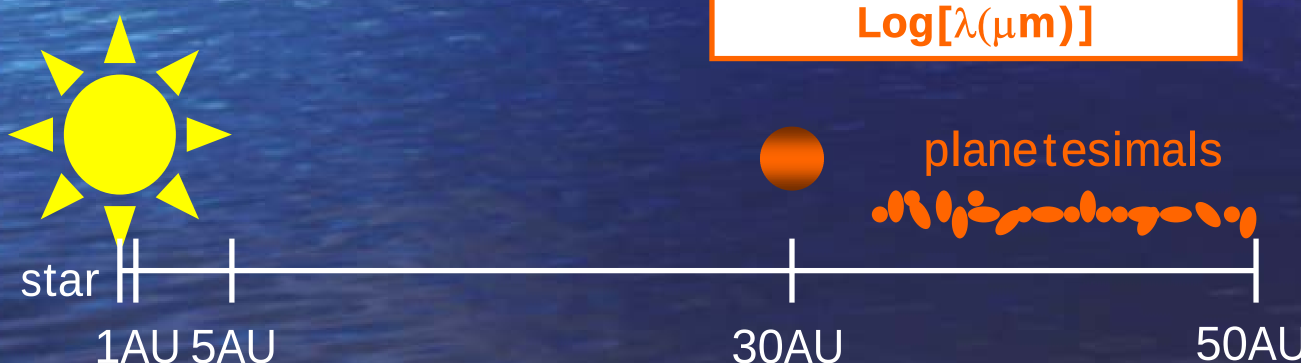


Output from radiative transfer simulations

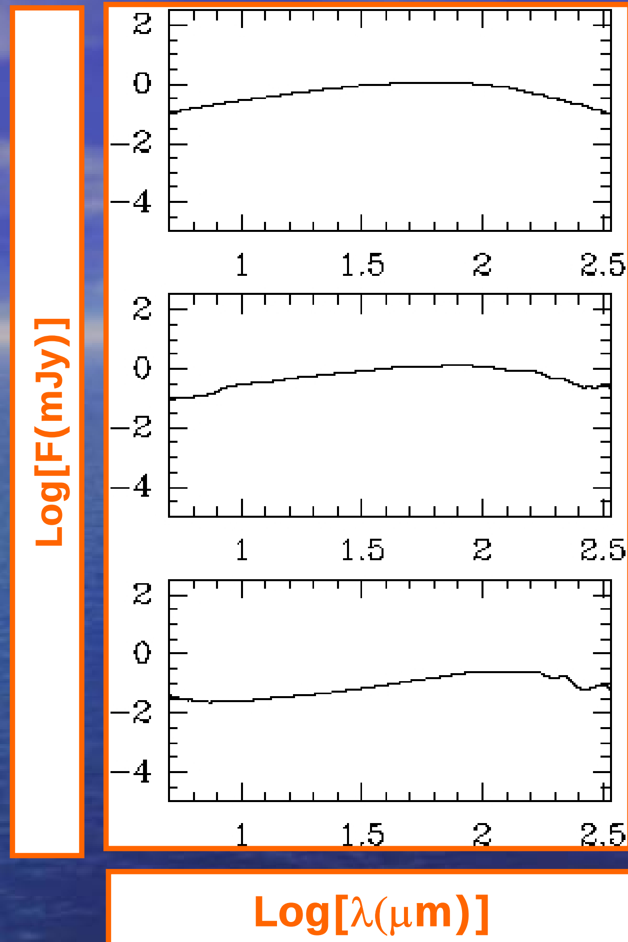
3 M_{Jup} at 30AU



Output from radiative transfer simulations



No planet



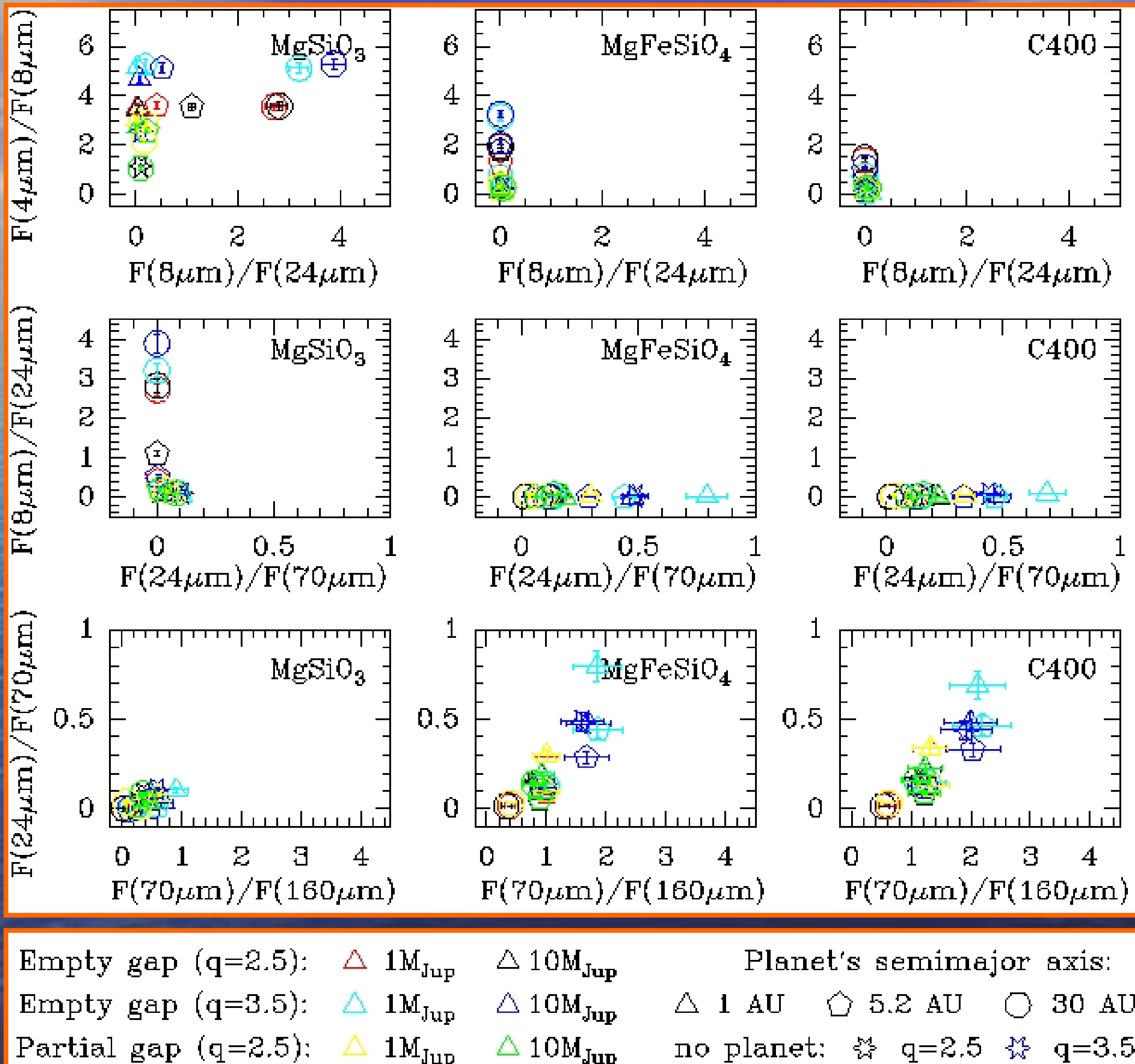
Carbonaceous grains

Fe-rich silicate grains

Fe-poor silicate grains

Output from radiative transfer simulations

Predicted *Spizter* Broadband Colors



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.

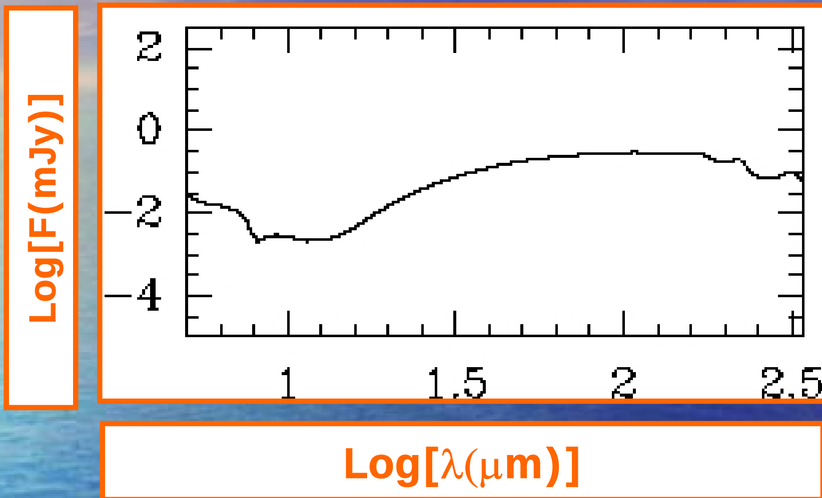
- It is difficult to diagnose the mass of the planet

- It may be possible to diagnose the location of the planet and the absence/presence of planets

but...

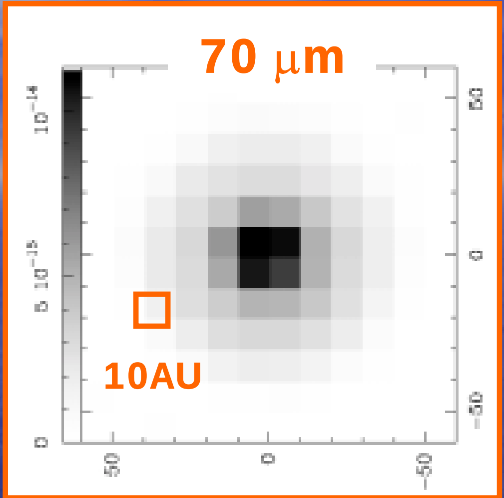
3 M_{Jup} at 1 AU

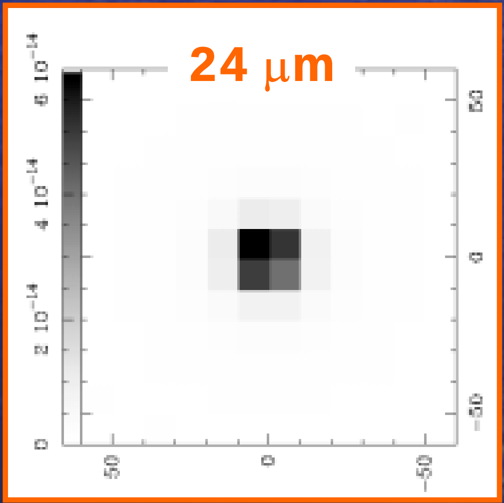
There are degeneracies that can only be solved with high-resolution observations...



Fe-poor silicate grains

1" at 10 pc



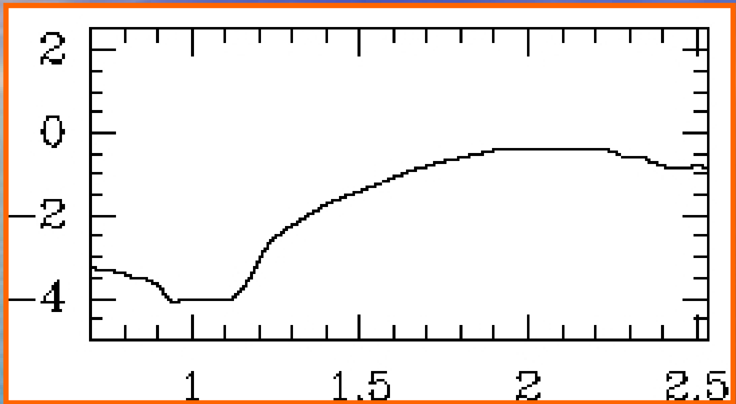


3 M_{Jup} at 30AU

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

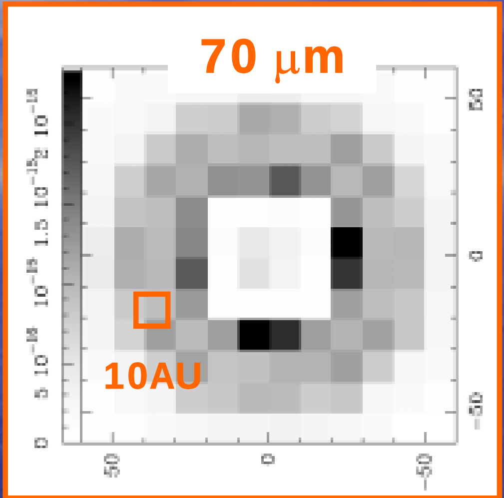
1" at 10 pc

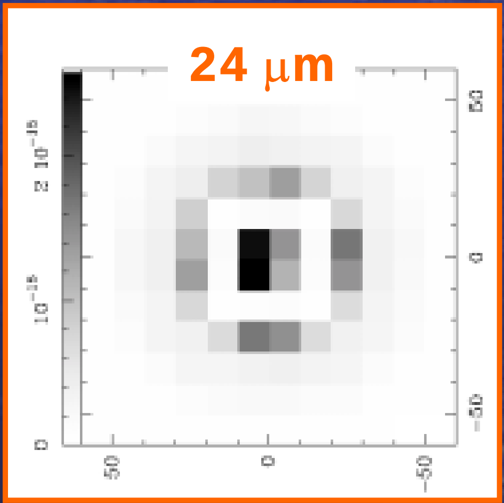
Log[F(mJy)]

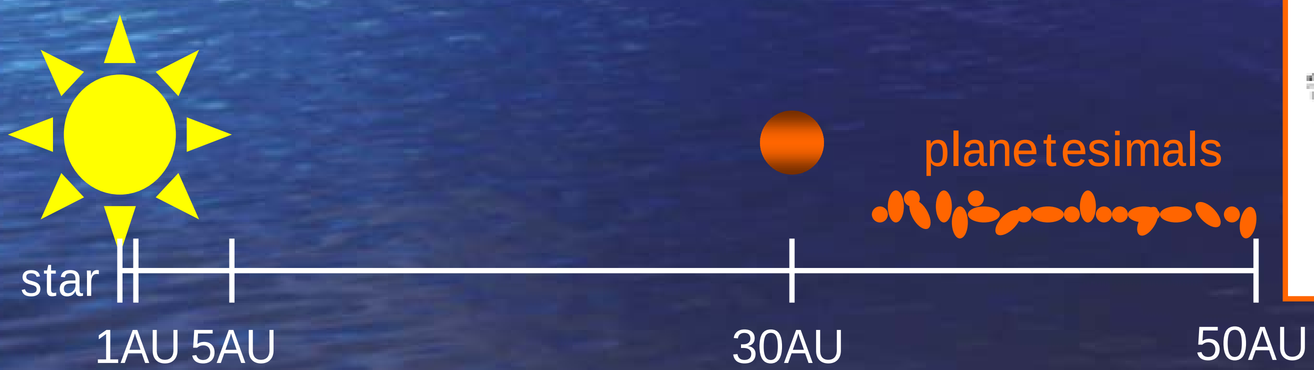


Log[λ(μm)]

Fe-rich silicate grains







Conclusions

- Debris disks structure is sensitive to long period planets ➡ learn about diversity of planetary systems.

- Dust disk structure:
  - Depletion of dust inside the planet's orbit (grav. scattering)
  - Enhanced dust density (trapping of particles in MMRs).

- SED:
  - significant decrease of the near/mid-IR flux due to the clearing of dust inside the planet's orbit.
  - difficult to diagnose the mass of the planet
  - possible to diagnose the location of the planet
  - there are degeneracies that can only be solved with high-resolution observations...

Why do we need dynamical simulations?

- Dynamical models are necessary for all systems studied (1-10$\mathbf{M}_{\mathbf{Jup}}$ at 1-30 AU), because:

  -At 1AU is important to estimate the enhancement of particles at the MMRs with the planet.

  -At 5 and 30 AU is important to determine accurately how many particles drift inward.

- Our dynamical models (with 100 particles) are sufficient to study systems with planets at 1AU, but are not sufficient for planets at 5 and 30 AU

For details about the modeling:

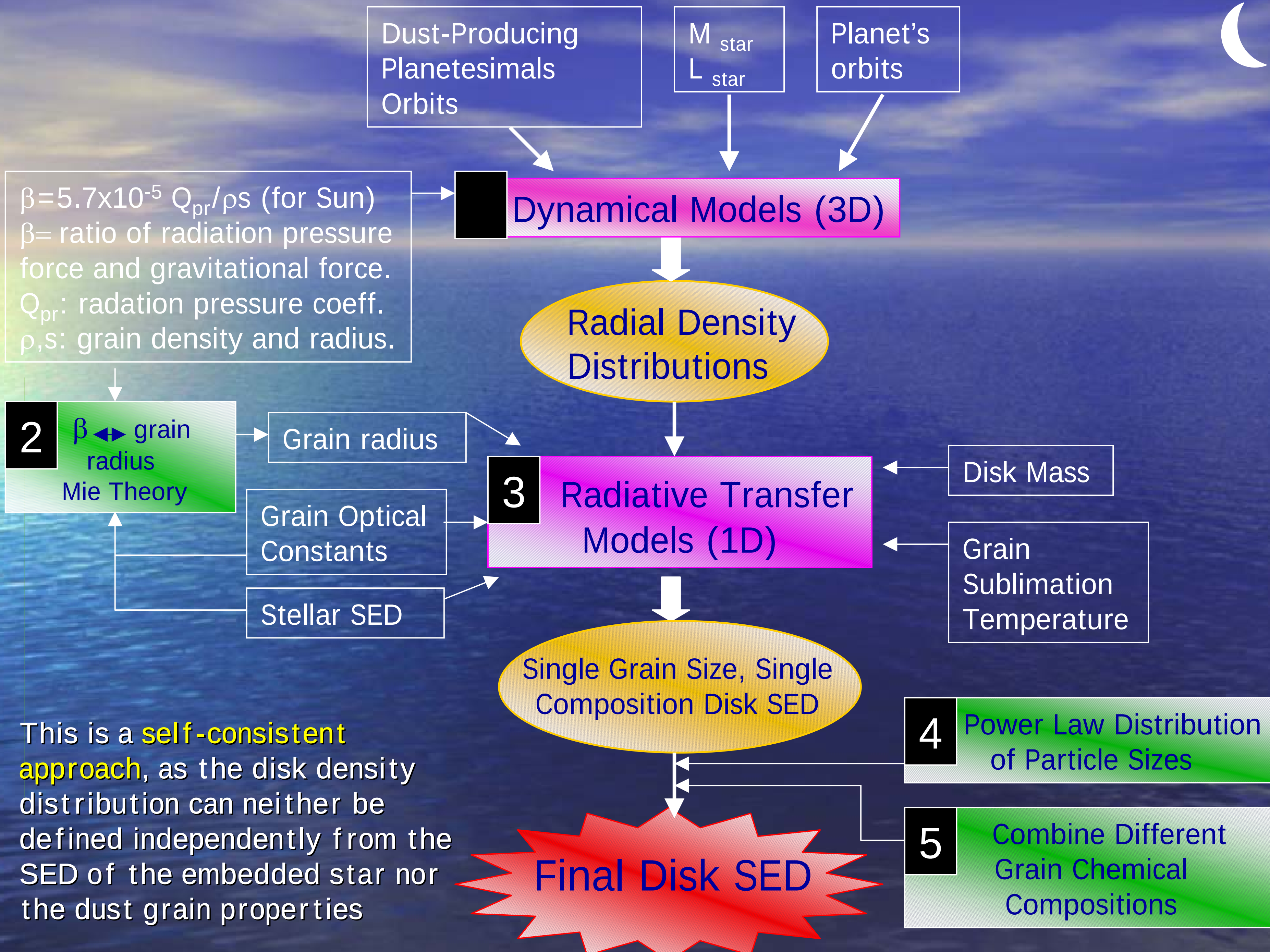
- "Study of the Dynamics of Dust from the Kuiper Belt: Spatial Distribution and Spectral Energy Distribution", Moro-Martin & Malhotra, 2002, AJ, 124, 2305

- "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

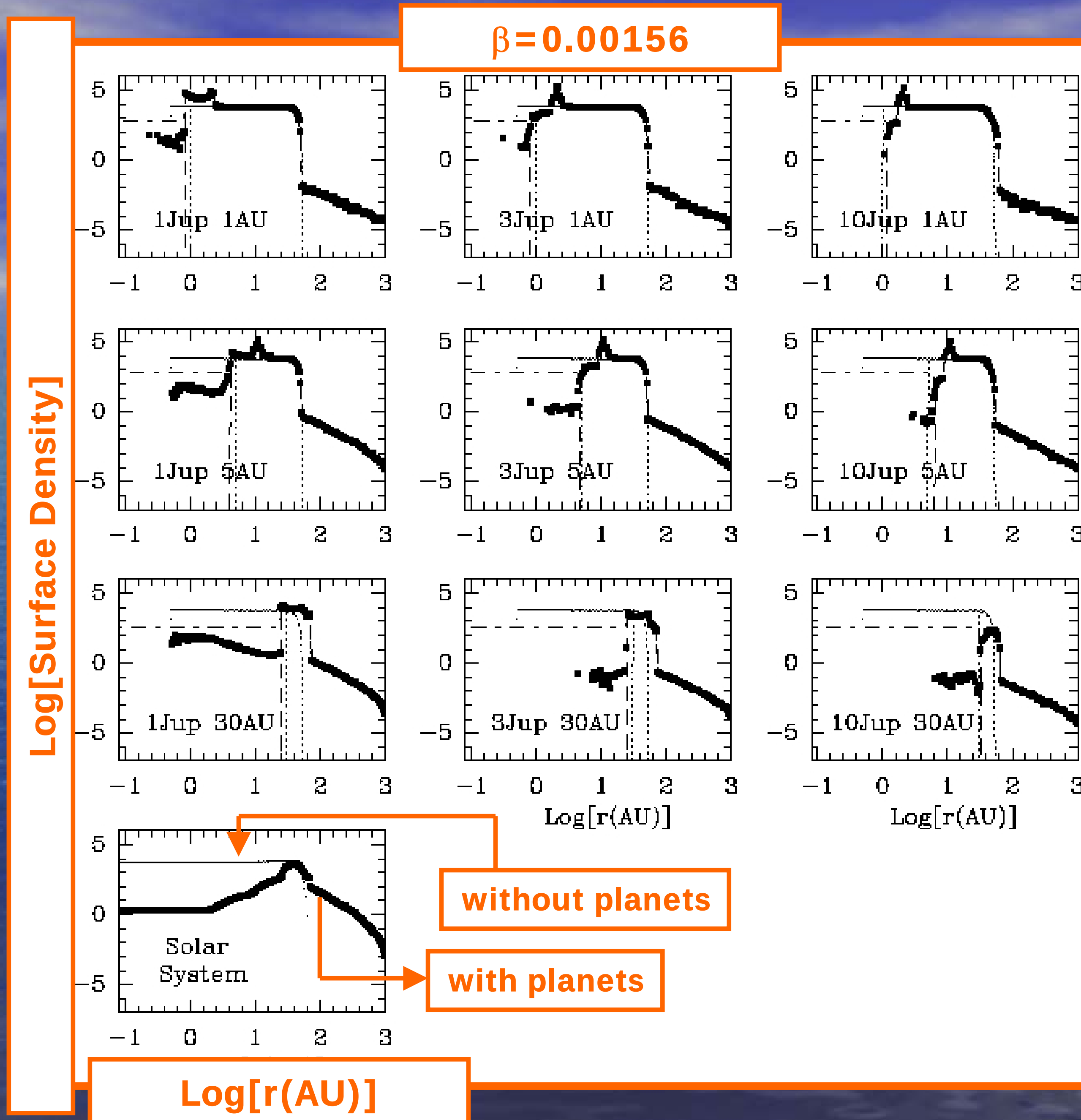
- "Model Spectral Energy Distributions of Circumstellar Debris Disks. II. Outer Belt of Planetesimals with Inner Giant Planets", Moro-Martin, Wolf & Malhotra, 2004, submitted to ApJ

Pre-prints at:
http://www.lpl.arizona.edu/people/faculty/malhotra2.html

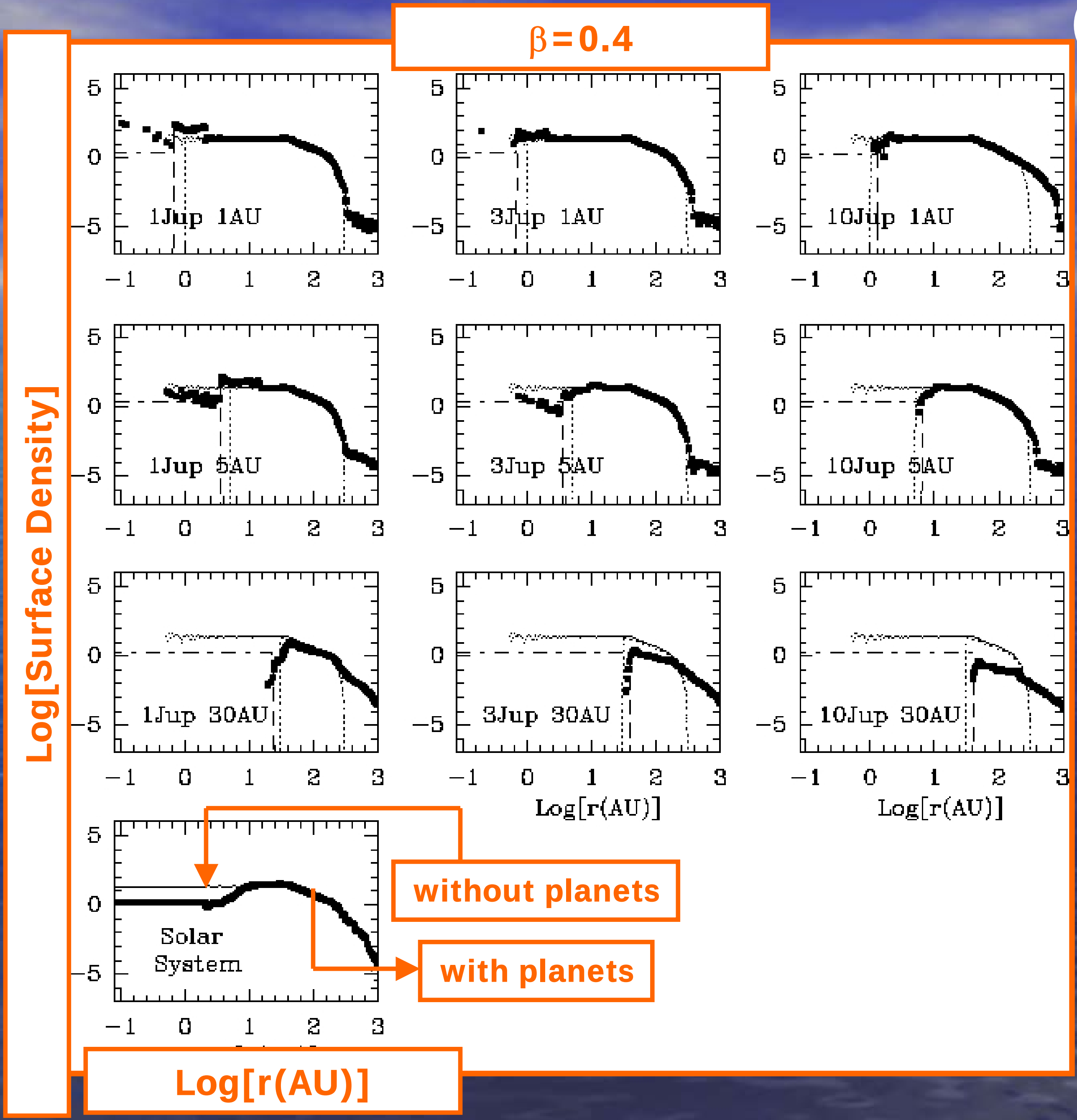


This is a self-consistent approach, as the disk density distribution can neither be defined independently from the SED of the embedded star nor the dust grain properties

Radial Density Distributions



Radial Density Distributions

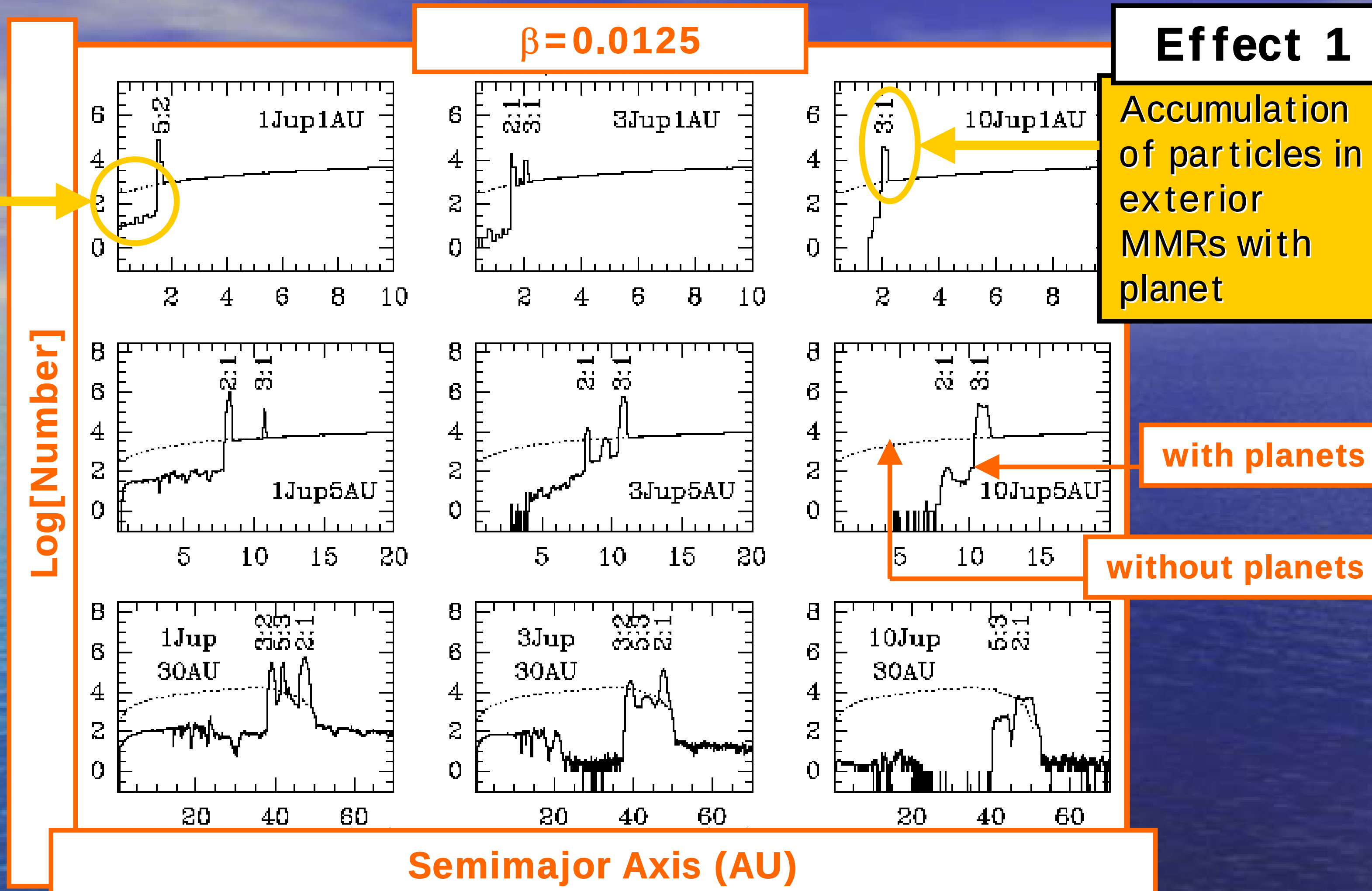


Effect 2

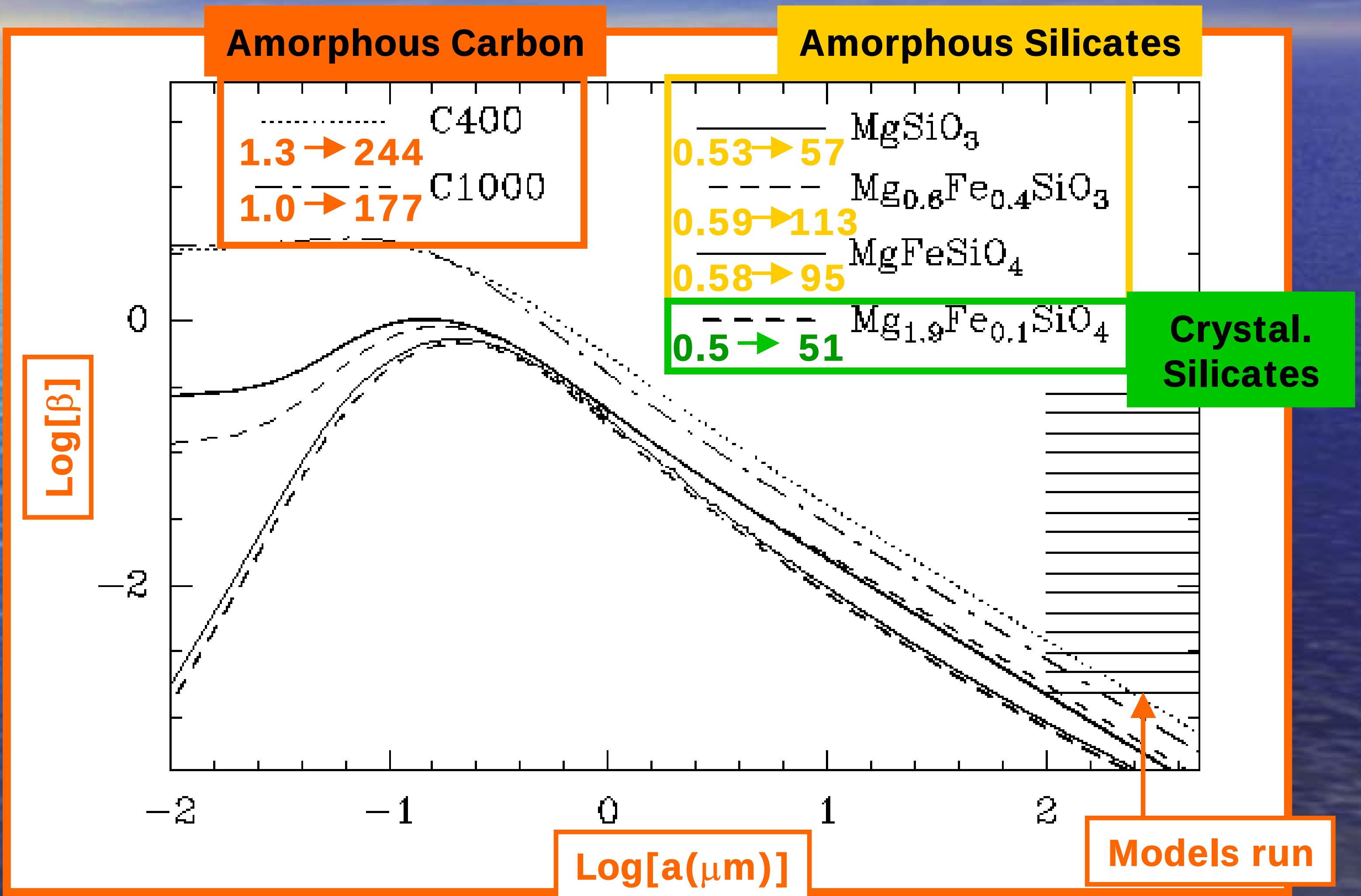
Clearing inside the planet's orbit

Effect 1

Accumulation of particles in exterior MMRs with planet



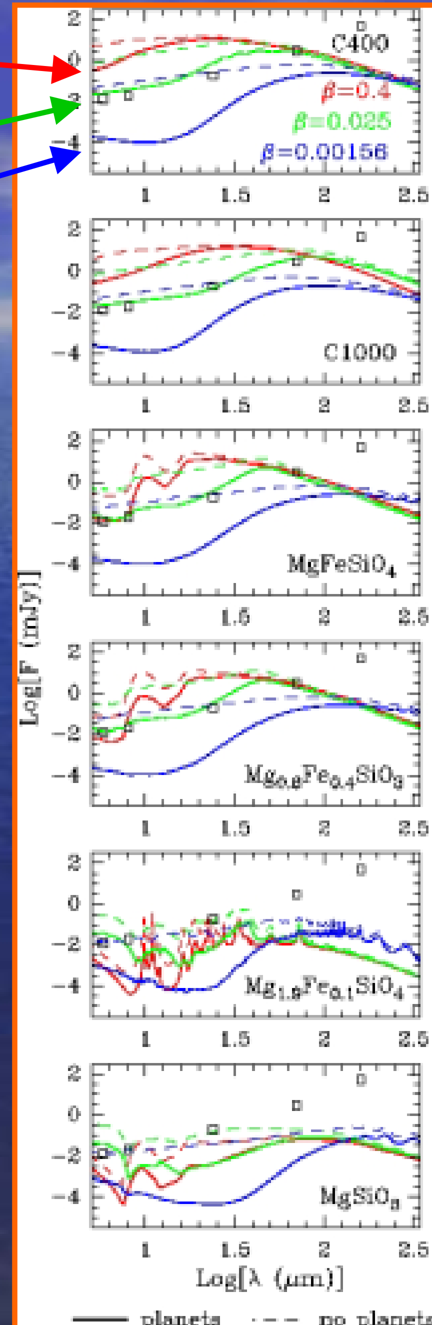
2 β↔Grain Radius Relation



Small grains

Intermediate grains

Large grains



C400

C1000

$MgFeSiO_4$

$Mg_{0.6}Fe_{0.4}SiO_3$

$Mg_{1.9}Fe_{0.1}SiO_4$

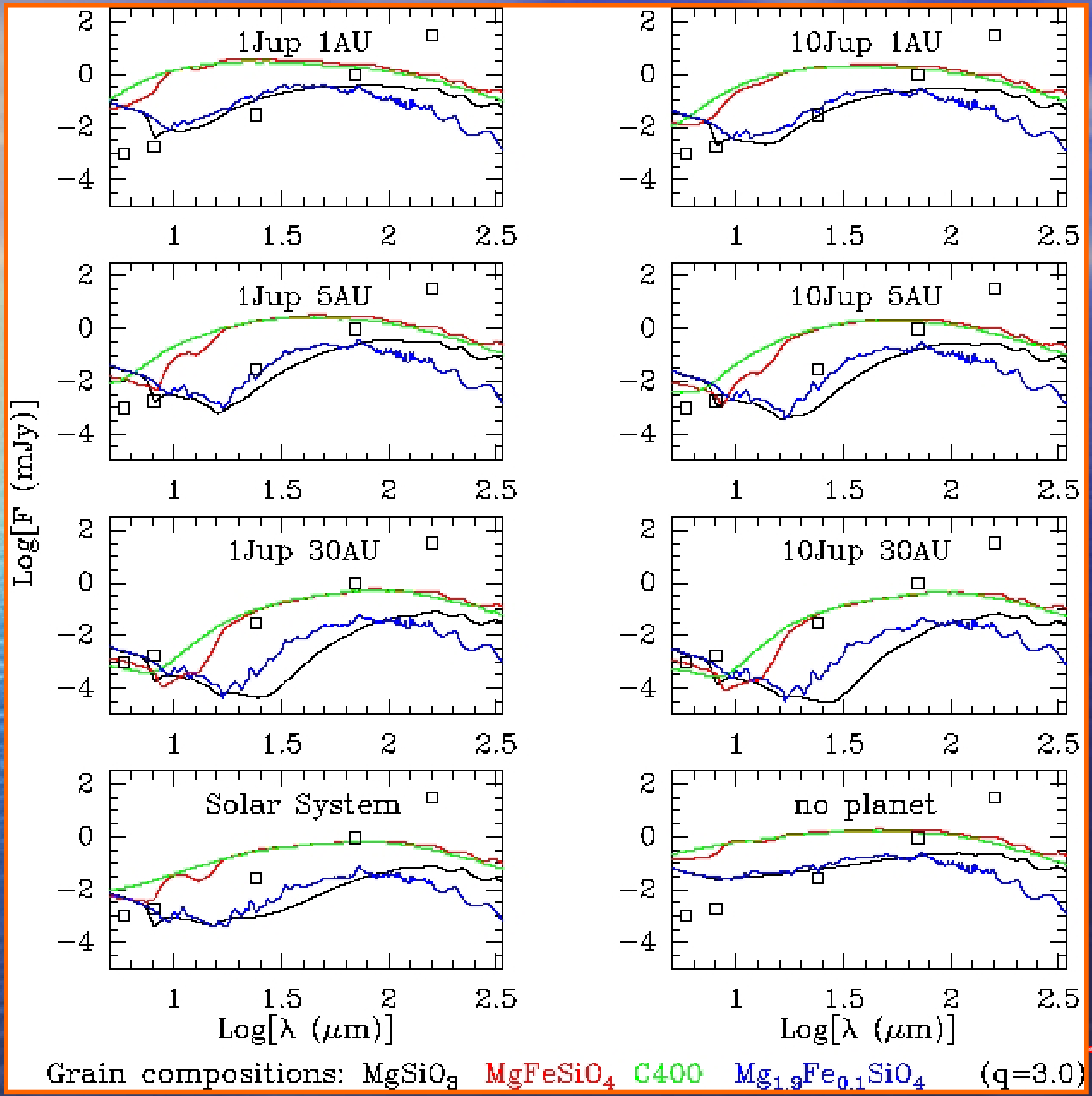
$MgSiO_3$

Single Grain Size, Single Composition Disk SED

List of planetary systems with distinct *Spitzer* colors

Composition	$4\mu m/8\mu m$	$8\mu m/13\mu m$	$8\mu m/24\mu m$
$MgSiO_3$	1,5,30AU—no pl	1Jup1AU—1Jup10AU[a]	30AU—no pl
		1Jup1AU—1Jup5AU[a]	1,5AU—30AU
		1AU—30AU	
		5AU—nopl	
$Mg_{0.6}Fe_{0.4}SiO_3$	1AU—5AU[a]	1,5AU,no pl—30AU[a]	
	1AU—30AU		
	5AU—no pl[a]		
	30AU—no pl		
	1Jup5—10Jup5[b]		
$MgFeSiO_4$	1AU—30AU[b]		
$Mg_{1.9}Fe_{0.1}SiO_4$[a]		1AU—5,30AU[a]	
		5,30AU—no pl[a]	

Composition	$13\mu m/24\mu m$	$24\mu m/70\mu m$
$MgSiO_3$	1,5AU—30AU	1Jup1—1Jup30[b]
	30AU—no pl	
$MgFeSiO_4$		1Jup1—1Jup30[b]



Final Disk SED