Planets, planetesimals and dust in HD 38529 and HD 128311

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Abstract

In the search for Solar system analogs, the study of planetary systems with multiple planets and dust emission is of critical importance. Only five of these systems have been identified so far: HD69830, HD10647, HD 82943, HD38529 and HD128311. Here we summarize the study of the later two. Spitzer/MIPS observations show spatially unresolved excess emission above the stellar photosphere at 70 μm with S/N = 4.7 (HD38529) and ~4 (HD128311). No dust excess is detected at shorter wavelengths. We discuss the distribution of the potential dust-producing planetesimals from the study of the dynamical perturbations of the two known planets, considering in particular the effect of secular resonances, and from the modeling of the spectral energy distributions. We find that the configuration might resemble that of the Jovian planets + Kuiper Belt in our Solar System.

Introduction

Debris disks are evidence of the presence of planetesimals

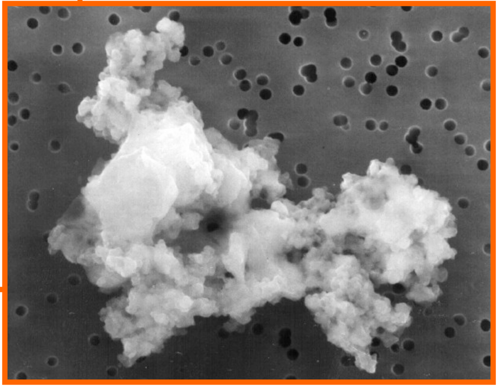
Dust Removal Time Scales < 10^4-10^6 yr

Poynting-Robertson: $t_{PR} = 710(\frac{b}{\mu m})(\frac{\rho}{g/cm^3})(\frac{R}{AU})^2(\frac{L_\odot}{L_*})\frac{1}{1+albedo}\, yr,$

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

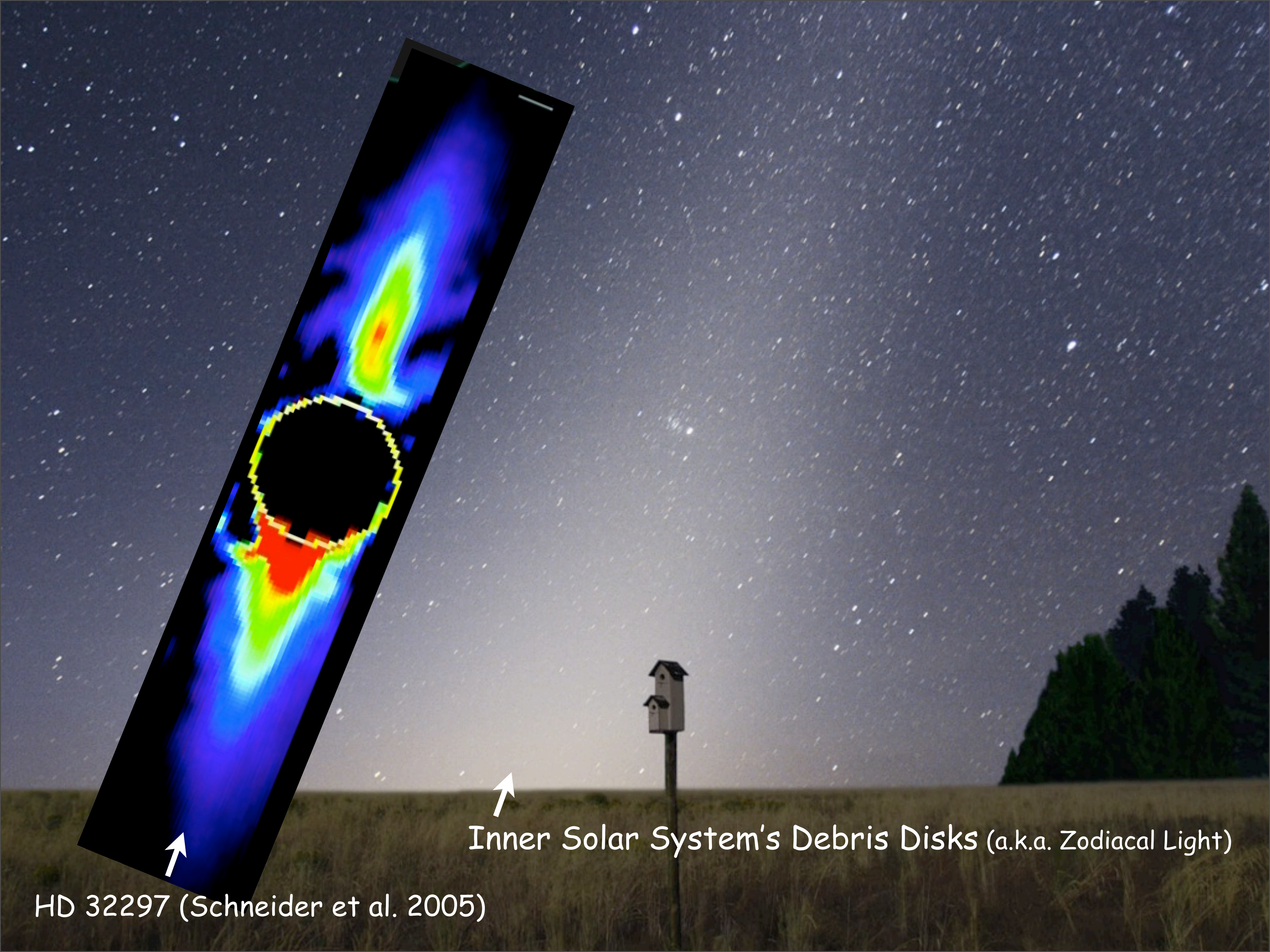
Radiation Pressure: $\frac{\tau_{blowout}}{yr} = 0.5\sqrt{\frac{(R/AU)^3}{(M_*/M_\odot)}}.$

<< Stellar age > 10^7 yrs



Dust is not primordial but is replenished by planetesimals (like asteroids, comets and KBOs). Indirect evidence that the first steps of planet formation have taken place.

Debris disks are planetary systems.


Inner Solar System's Debris Disks (a.k.a. Zodiacal Light)
HD 32297 (Schneider et al. 2005)

The study of stars with dust and planets can help us...

- Improve our understanding of the diversity of planetary systems, by studying where the dust and dust-producing planetesimals are located with respect to the planets.
  - ⇨ Help us place our Solar System into context.
- Understand the processes by which planets can affect the debris disk structure.
  - ⇨ The disk structure can help us identify long-period planets.

HD 38529

The star:

G8 III/IV, 3.5 Gyr, evolved

1.45 M_{sun}, 6.31 L_{sun}, 42 pc

T_{eff} = 5697 K, [Fe/H] = 0.445

The planets:

M sin(i)	a (AU)	e
0.8 M_{Jup}	0.13	0.25
12.2 M_{Jup}	3.74	0.35

The dust:

70 μm excess (SNR = 4.7)

Small 33 μm excess

No excess < 30 μm

Where are the dust-producing planetesimals located?

The dust traces the planetesimals

Collisional lifetime:

$t_{coll} = P_{orb}/8\Sigma\sigma_{geo}$

$\Sigma\sigma_{geo} = L_{dust}/L_{star} = 10^{-5}(5600/T_{star})^3(F_{70,dust}/F_{70,star})$

$\Sigma\sigma_{geo}$: fractional surface area

L_{dust}/L_{star}: fractional excess luminosity

$t_{coll} = 2800(R/AU)^{3/2}$ yr

$t_{coll} \ll t_{P\text{-}R}^{fill}$

P-R lifetime:

$t_{P\text{-}R} = 4\pi b\rho c^2R^2/3L_{star}$

$= 710(b/\mu m)(\rho/gcm^{-3})(R/AU)^2(L_{sun}/L_{star})$

$\times\ 1/(1+albedo)$ yr

Time to drift x% or R under P-R drag:

$t_{P\text{-}R}^{fill} = (1-(1-x)2\ t_{P\text{-}R} = 20000(R/AU)^2$ yr

x = 10%	$L_{star} = 6.3\ L_{sun}$	
$\rho = 2.5\ gcm^{-3}$	b = 10 μm	albedo = 0.1

Dust grains may suffer many collisions and fragment before they migrate far from their parent bodies

The dust traces the parent planetesimals

Locating the dust assuming single T blackbody grains

From F_{70}/F_{33}

→ T_{dust} = 43 K, R_{dust} = 106 AU

From IRS (5-33 μm)

→ T_{dust} = 79 K, R_{dust} = 31 AU

⇨ Model SED as an extended disk

SED Disk Models

Green corresponds to models that would fit the SED

SED models are degenerate

Free parameters: R_{in}, M_{dust}

Fixed parameters:

R_{out} = 50, 100, 500 AU

Grain size and composition:

astronomical silicates

single grain size 10 μm

$n(b) \propto b^{-3.5}$ (2.2-10 μm)

Constant surface density

$\Sigma(r) \propto r^0$

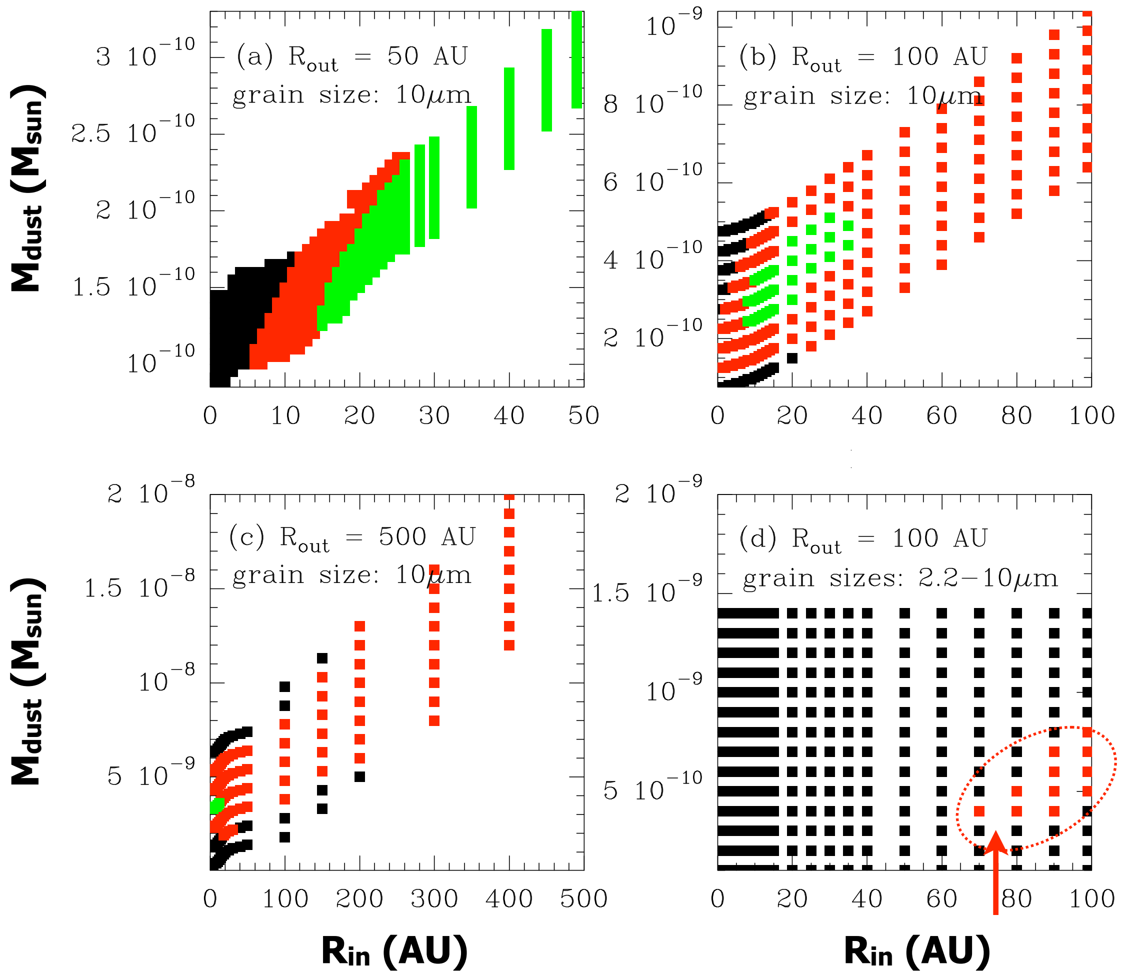
Each point represents a modeled SED;

goodness of the fit:

$P(\chi^2|\nu) < 0.683$

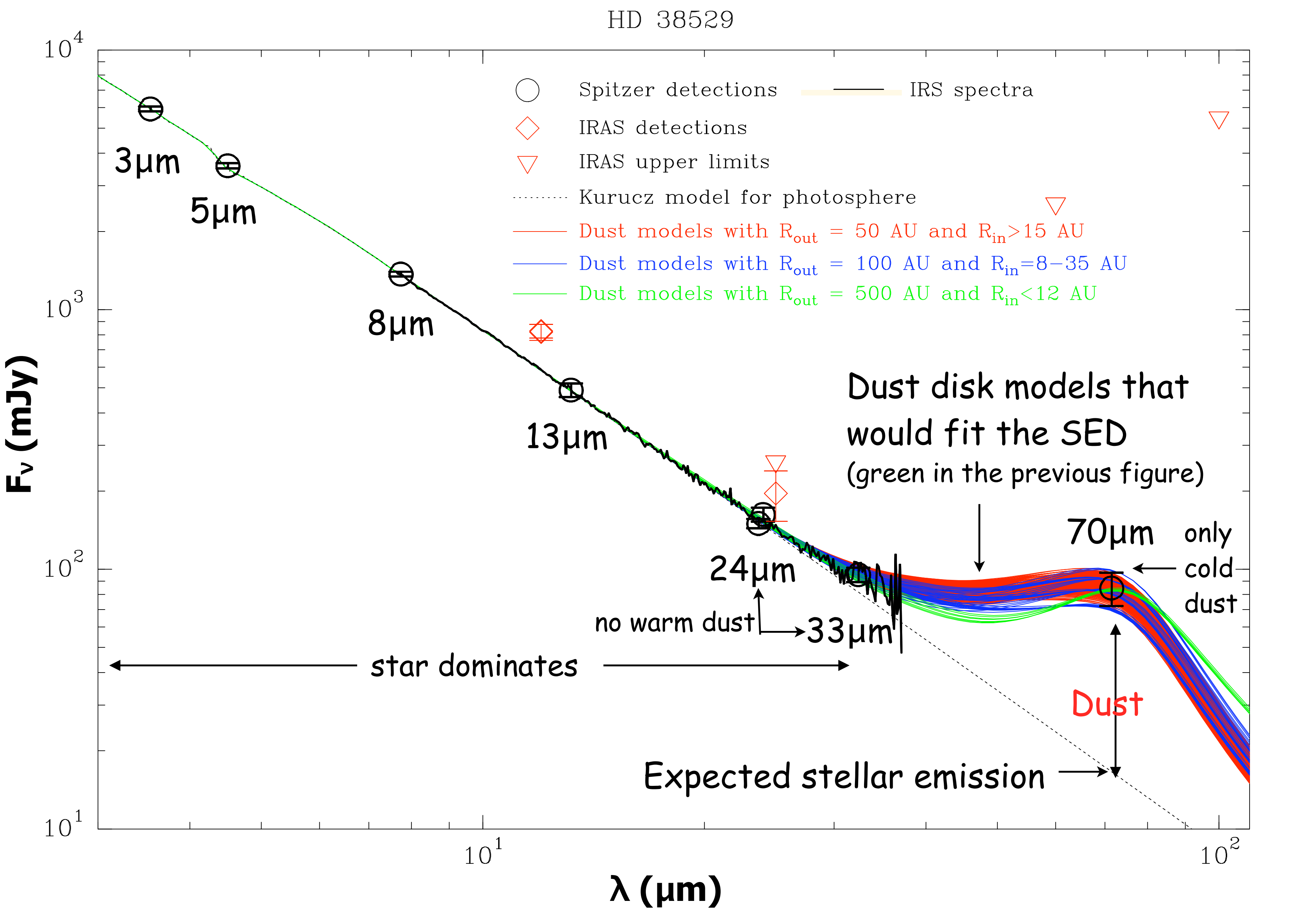
$P(\chi^2|\nu) > 0.683$ excluded to > 1-σ certainty

$P(\chi^2|\nu) > 0.997$ excluded to > 3-σ certainty



$P(\chi^2|\nu) > 0.988$

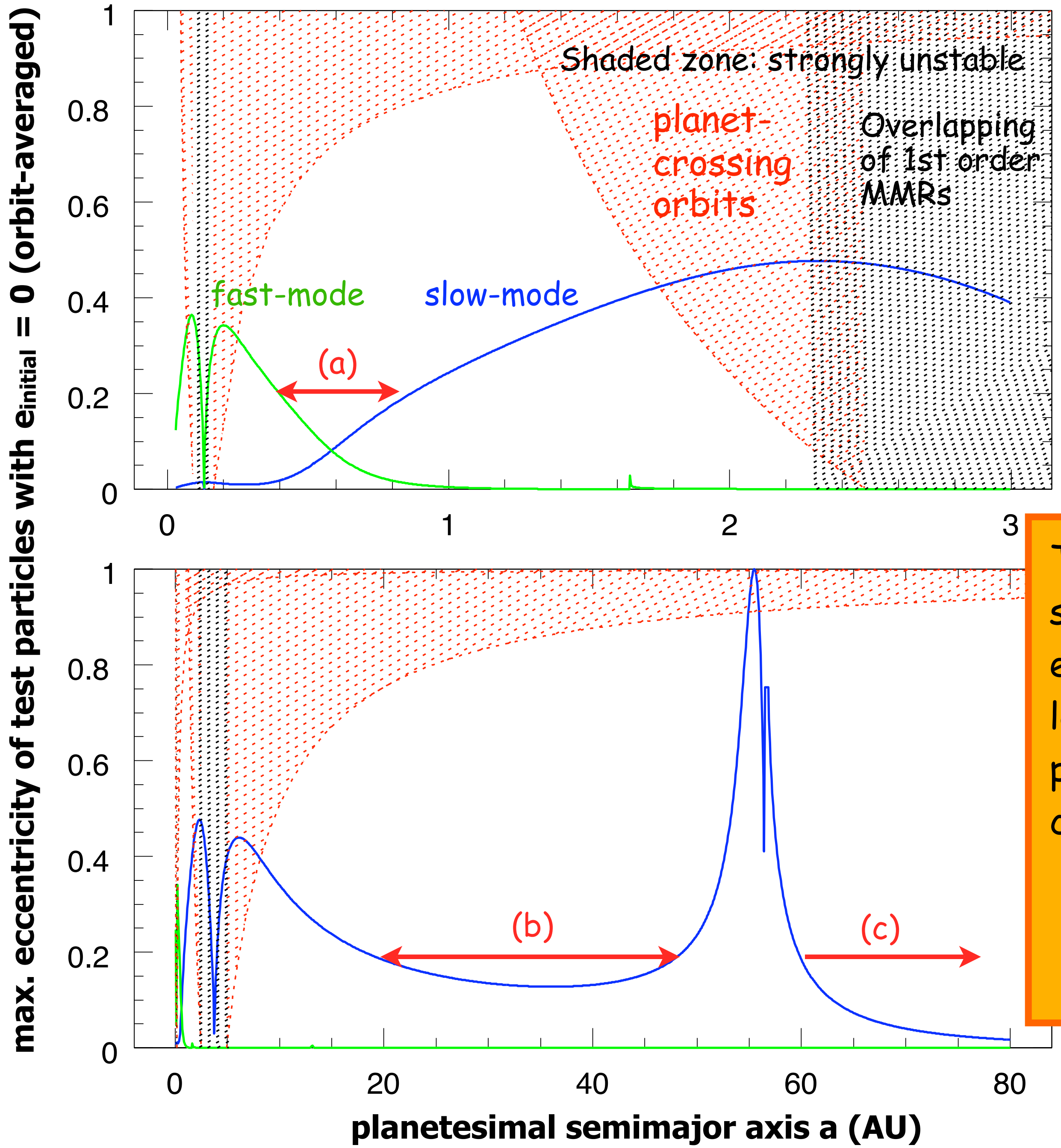
no small grains



HD 38529
Spitzer detections
IRS spectra
IRAS detections
IRAS upper limits
Kurucz model for photosphere
Dust models with R_{out} = 50 AU and R_{in}>15 AU
Dust models with R_{out} = 100 AU and R_{in}=8−35 AU
Dust models with R_{out} = 500 AU and R_{in}<12 AU
3μm
5μm
8μm
13μm
24μm
33μm
70μm
Dust disk models that would fit the SED
(green in the previous figure)
only cold dust
no warm dust
star dominates
Dust
Expected stellar emission
$F_ν$ (mJy)
λ (μm)
10^1
10^2
10^3
10^4

Use dynamical analysis to identify the regions where the planetesimals could be located

Dynamical Analysis: Analytical



Effect of secular perturbations on particles on circular orbits

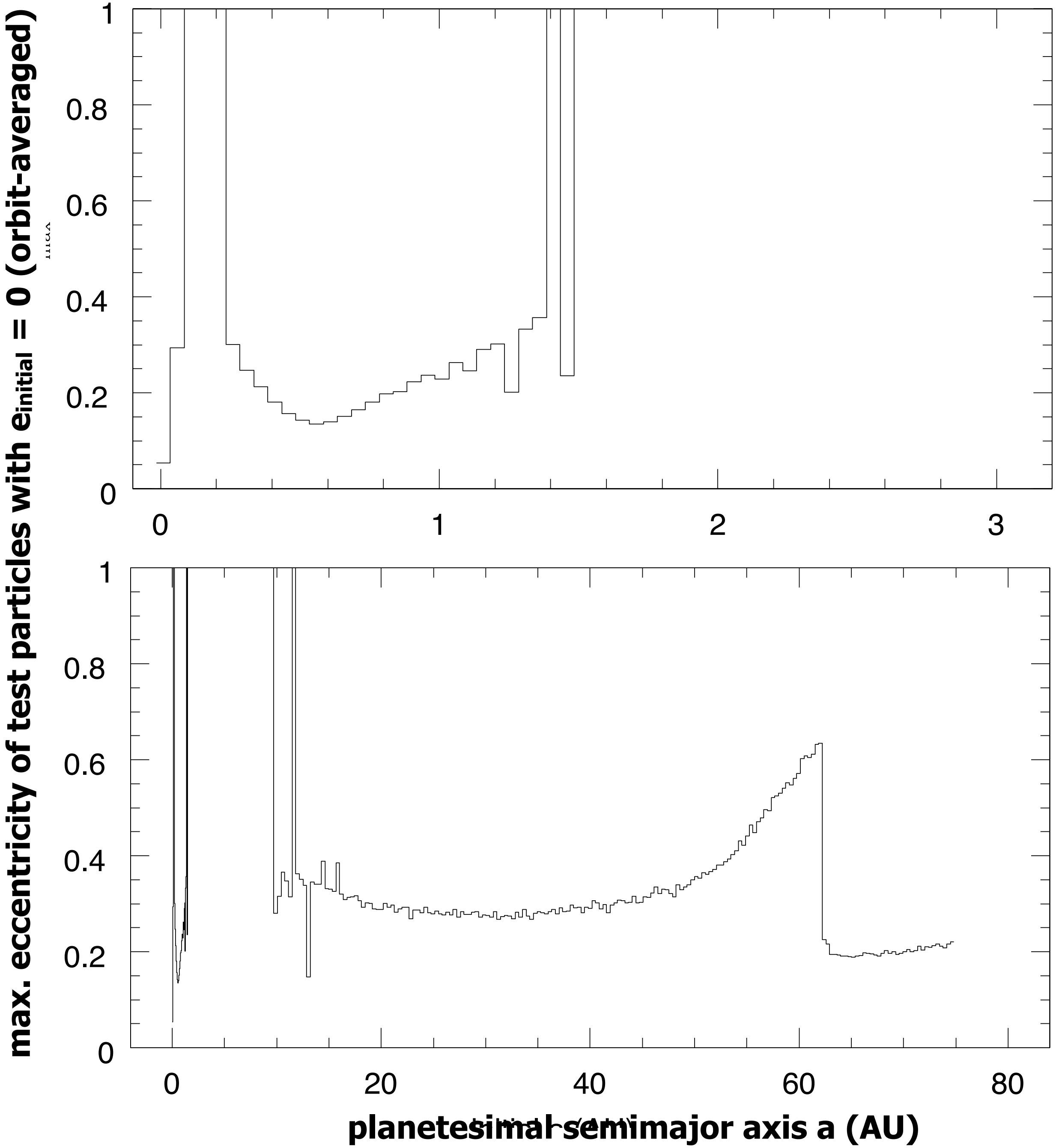
Three regions of small eccentricity excitation where long-lived planetesimals could survive:

(a) 0.4-0.8 AU

(b) 20-50 AU

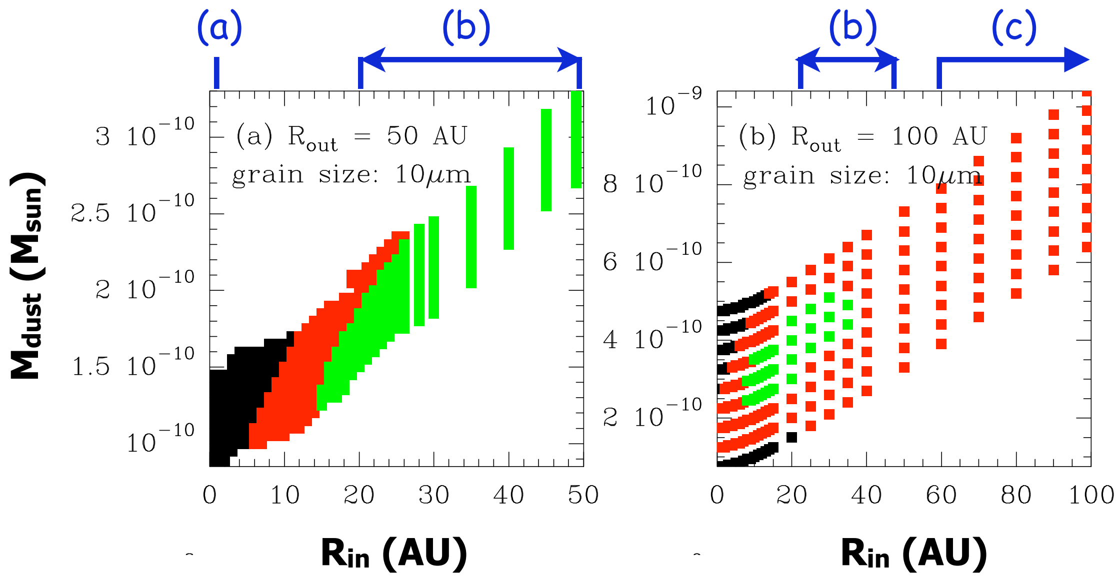
(c) > 60 AU

Dynamical Analysis: Numerical



Secular and non-secular perturbations of particles on circular orbits

(from simulations of 300 test particles using a symplectic integrator integrated during 200 Myr).

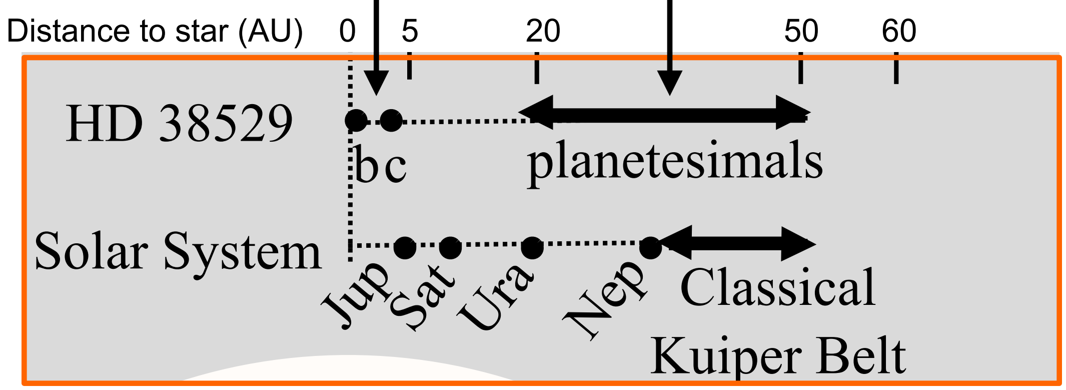


(a)
(b)
(b)
(c)
(a) R_out = 50 AU
grain size: 10μm
(b) R_out = 100 AU
grain size: 10μm
Mdust (Msun)
Rin (AU)
Rin (AU)

Most likely configuration

Warm dust upper limit in dynamically stable zone (0.25-0.75 AU):
< 8×10^{-10} M_{lunar} of 10 μm grains

Estimate of cold dust (20-50 AU):
$1\text{-}5 \times 10^{-10}$ M_{sun} of 10 μm grains (about 10xKB dust mass)



Could the dust production rate be sustained for the age of the system?

At 20-30 AU, e_{max} = 0.25-0.3 → collisional velocities ~ $0.3v_{circ}$ = 2.8 km/s
Following Wyatt et al. (2007), the maximum fractional luminosity of the excess that could originate from a planetesimal belt of a given age that is evolving in quasi-steady state is $f_{max} = 2.26 \cdot 10^{-6}$ ($f_{obs} = 3.6 \cdot 10^{-5}$)
⇨ Timescale over which f_{obs} could be maintained = $t_{age} \cdot f_{max}/f_{obs}$ = 220 Myr

A possible scenario could be that the stable region beyond 60 AU supplies some planetesimals that drift into the 20--50 AU region by non-gravitational effects. However, there are two orders of magnitude uncertainty in the estimate of f_{max}, so we cannot reject a scenario in which the dust observed is the result of the steady grinding down of planetesimals.

HD 128311

The star:

K0, 0.6-6 Gyr

0.84 M_{sun}, 0.24 L_{sun}, 16.57 pc

T_{eff} = 4965 K

The planets:

M sin(i)	a (AU)	e
2.19 M_{Jup}	1.1	0.25
3.22 M_{Jup}	1.76	0.17

The dust:

70 μm excess (SNR ~ 4)

No excess < 33 μm

SED Disk Models

Free parameters: R_{in}, M_{dust}

Fixed parameters:

R_{out} = 50, 100, 500 AU

Grain size and composition:

astronomical silicates

single grain size 10 μm

$n(b) \propto b^{-3.5}$ (2.2-10 μm)

Constant surface density

$\Sigma(r) \propto r^0$

Each point represents
a modeled SED;
goodness of the fit:

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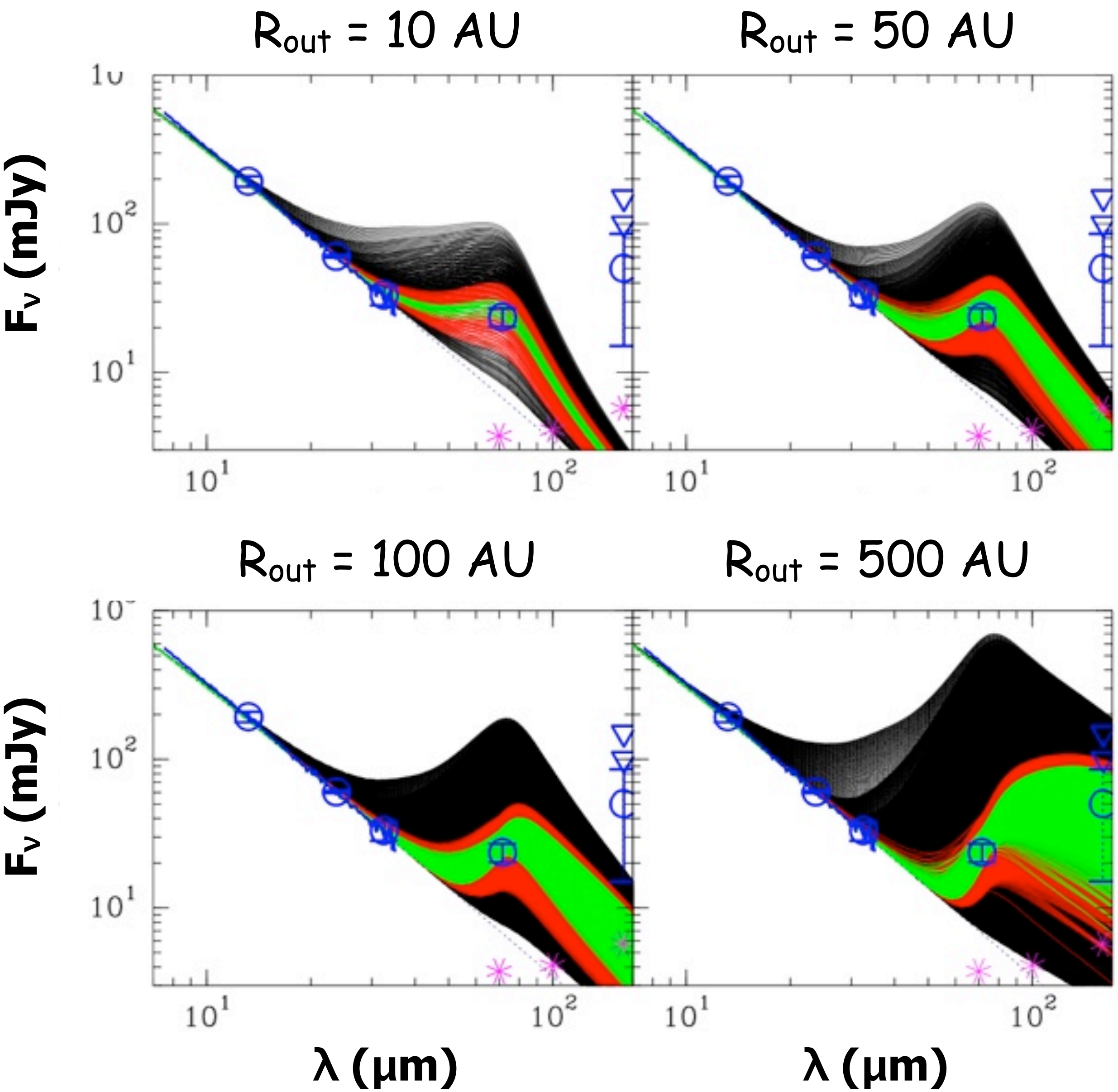
Observed vs. modeled SED

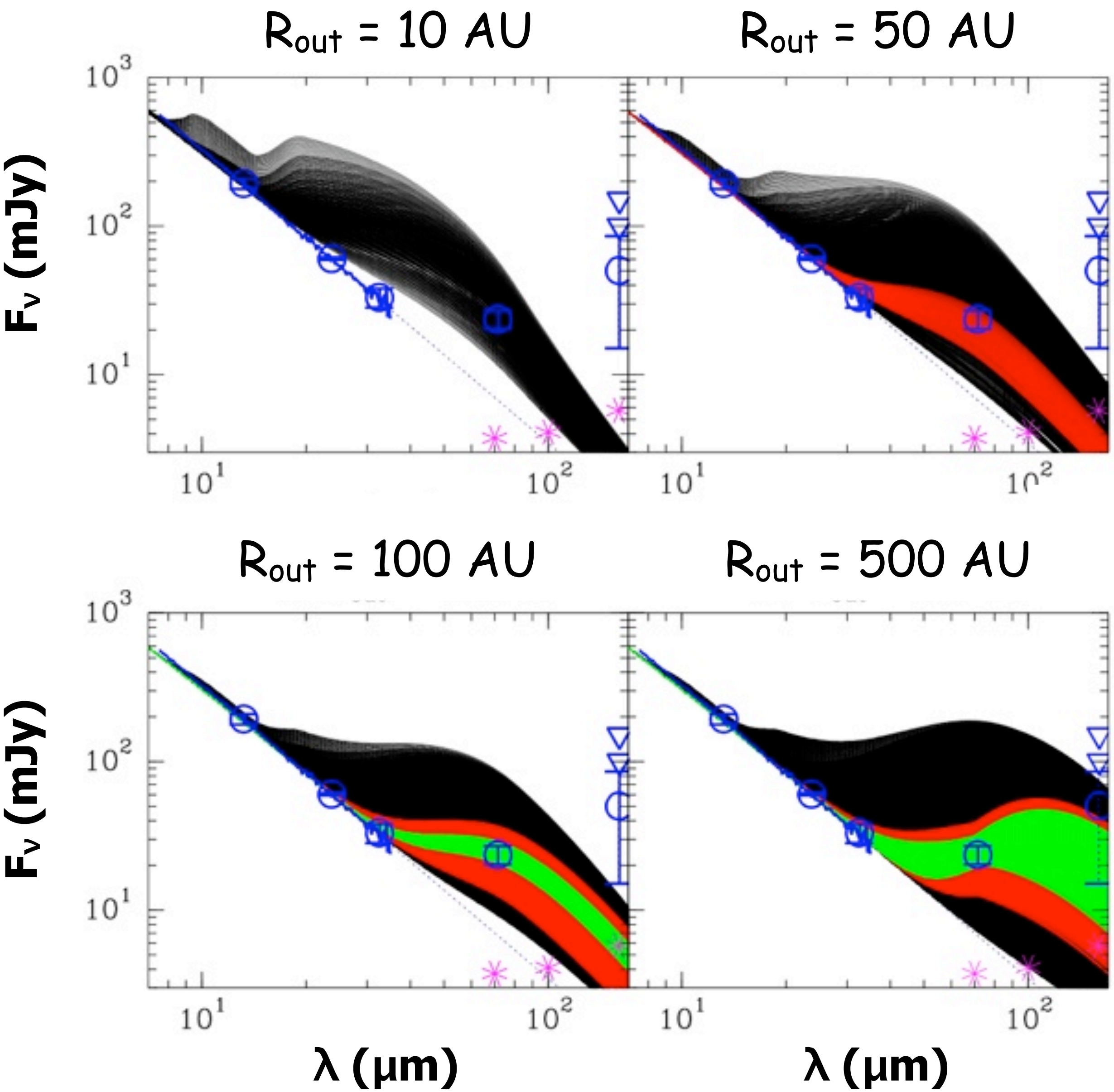
Single grain size: 10 μm



Spitzer observations

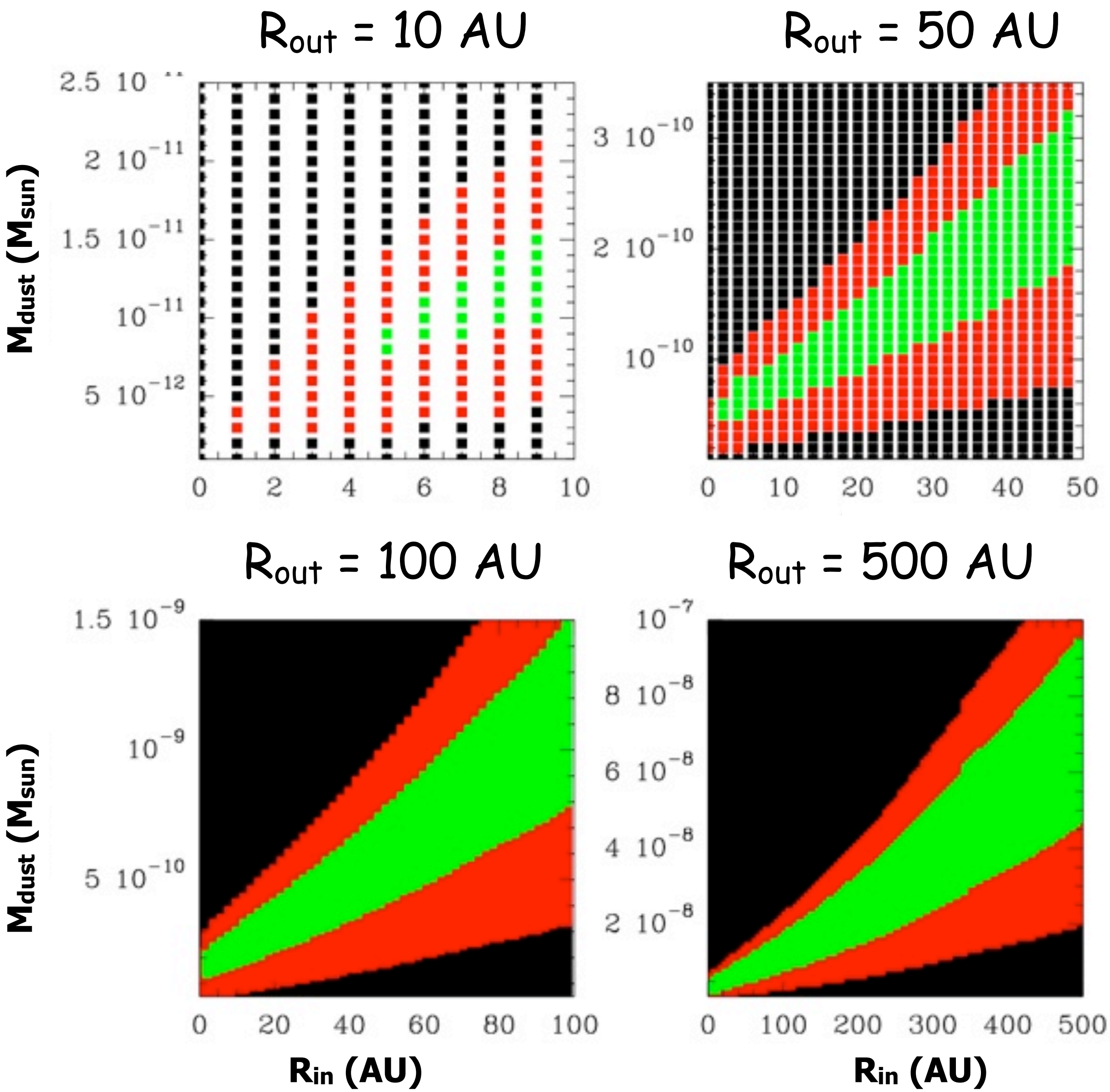
- ○ Detected flux with 1-σ errorbar
- ▽ 160 μm upper limit
- * Herschel/PACS 5-σ, 1 hour sensitivity

Grain size distribution: 0.17-10 μm



SED parameter space

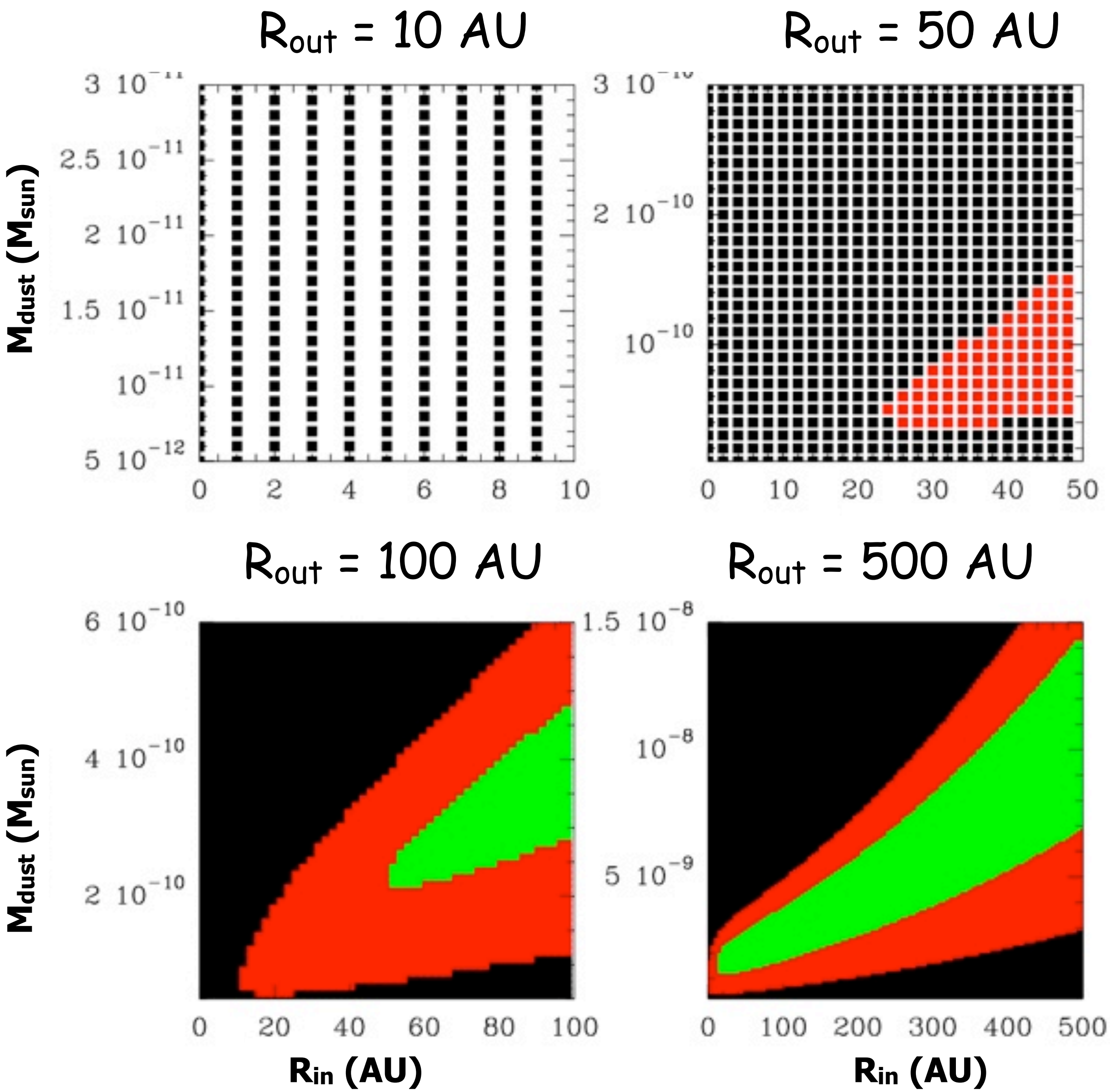
Single grain size 10 μm



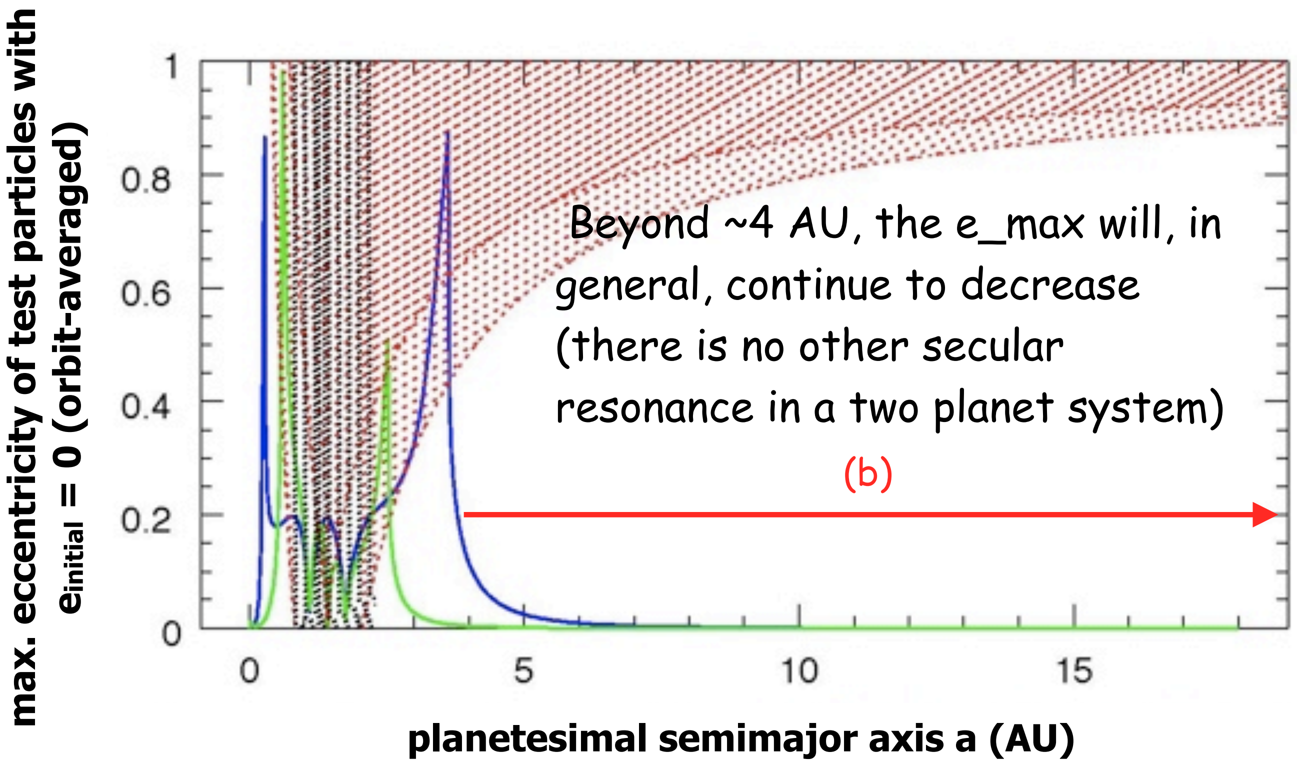
Green corresponds to models that would fit the SED

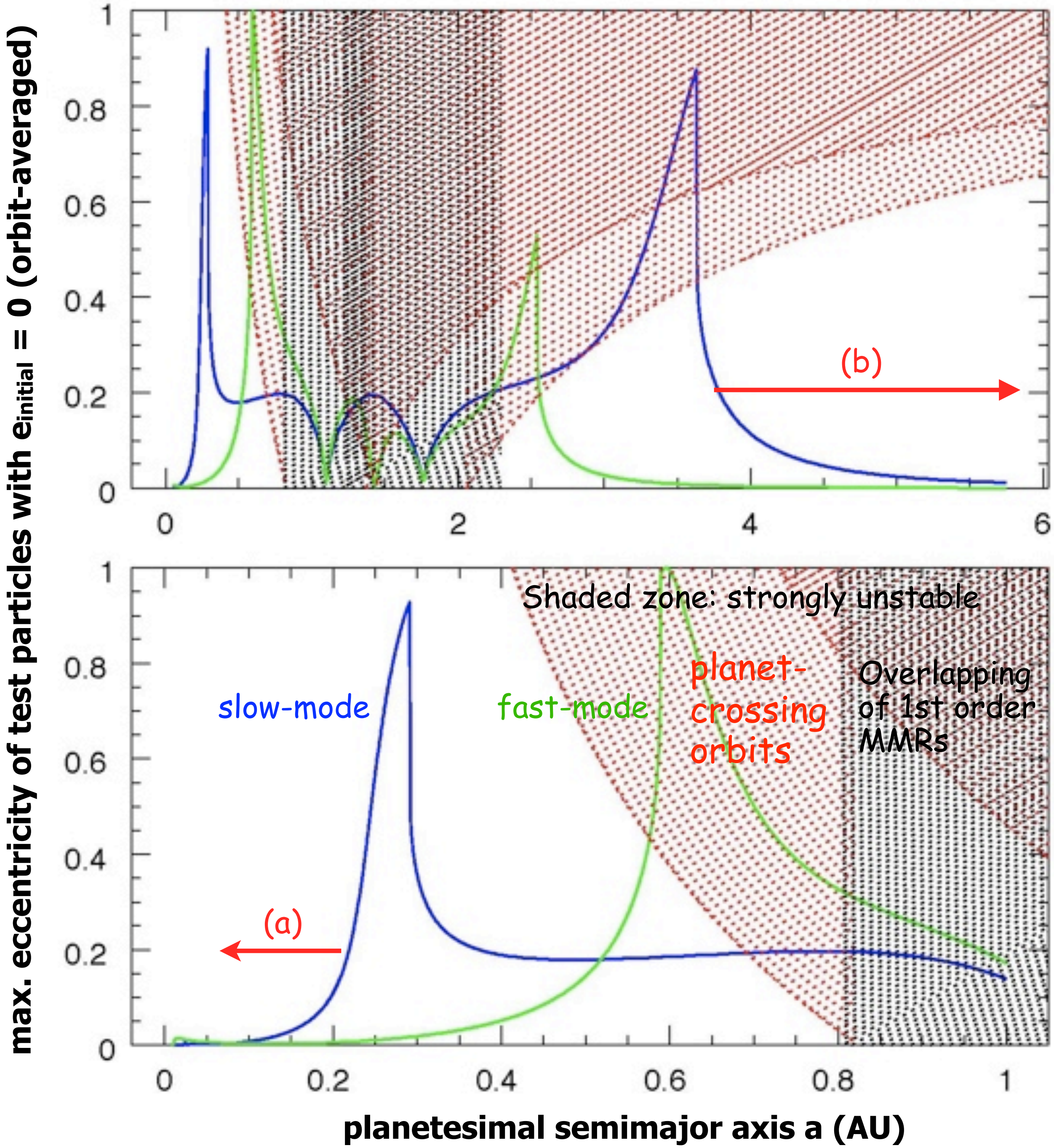
SED models are degenerate

Grain size distribution: 0.17-10 μm



Effect of secular perturbations on particles on circular orbits





Two regions of small eccentricity excitation where long-lived planetesimals could survive:

(a) <0.2 AU

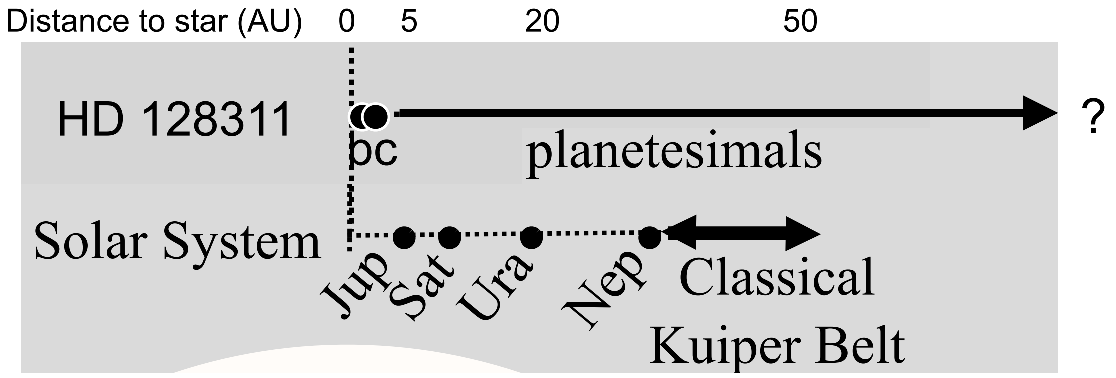
(b) > 4 AU

Most likely configuration

- The dynamics sets a boundary of 4 AU for the inner edge of the source of cold dust.

- This is in agreement with the allowed parameter space from the SED modeling (where an inner depleted region is inferred to account for the lack of emission < 30 μm)

- In this case, no other secular resonance exists that could set a constraint on the outer edge of the planetesimal disk.



...unless there is a third planet. Suppose that there is a planet > 4 AU (the plethora of RV solutions in the literature indicates that this may not be an unreasonable possibility); then a more distant boundary could be constrained for the "cold dust".

Conclusions

- Debris disks are evidence of the presence of planetesimals. Debris disks are planetary systems.

- The debris disks observed with Spitzer are sufficiently massive to be dominated by collisions, i.e. the dust particles don't travel far from their parent bodies before the are destroyed by collisions. The dust traces the parent planetesimals.

- The SED analysis can set some constraints on the dust (and parent planetesimals) location, but the SEDs are degenerate.

Conclusions

- Massive planets affect the dust production rate and the debris disk structure via MMR, secular resonances and gravitational scattering.

- In systems with multiple planets, the dynamical analysis, and in particular the analysis of the secular resonances, can in some cases break the SED degeneracy by identifying the stability niches where long-lived dust-producing planetesimals could survive.

- These studies shed light on the diversity of planetary systems (planets+planetesimals), helping us understand our Solar System into a broader context.