From observations of debris dust to properties of planetesimals

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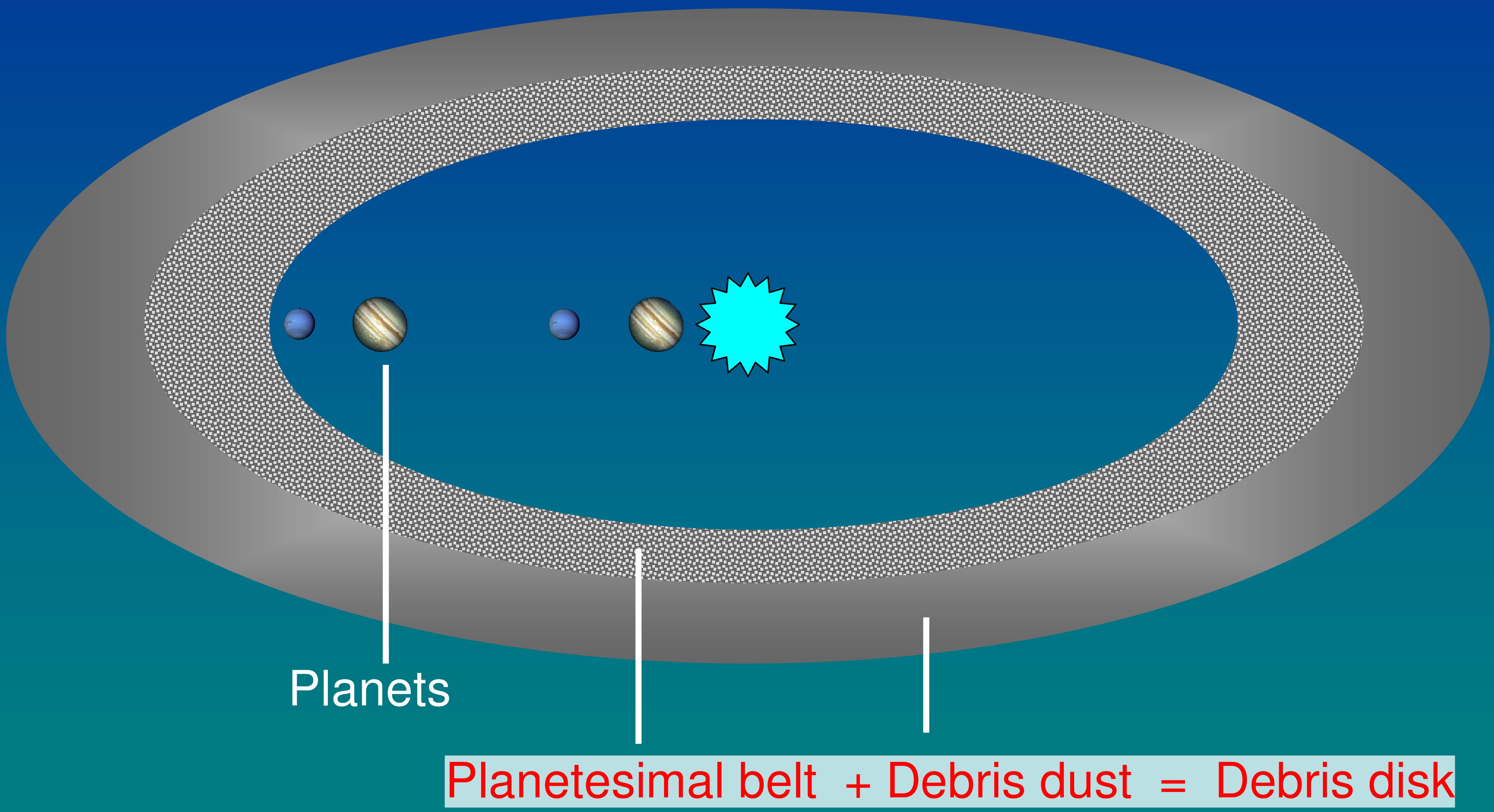
A planetary system and its debris disk



Outline

- **Approach**
- **Application to unresolved disks**
- **Application to resolved disks**
- **Summary**

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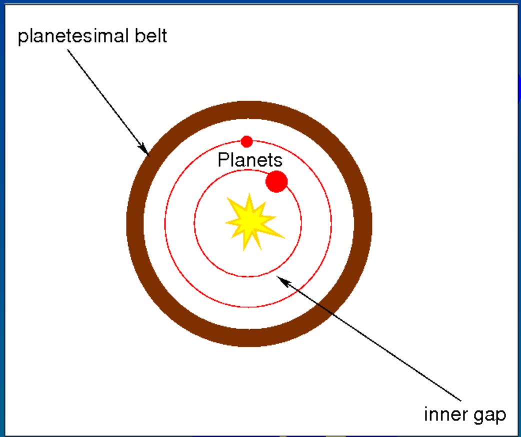
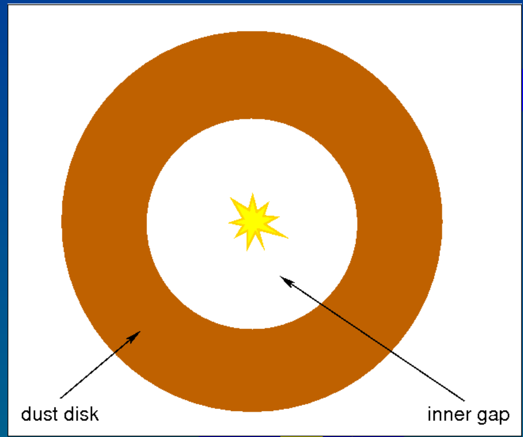
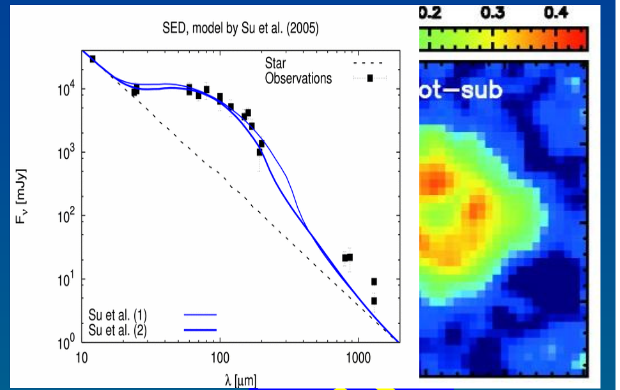
Idea of this work

Traditional approach

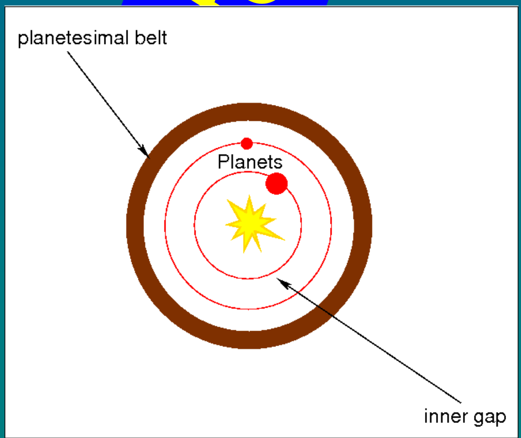


?

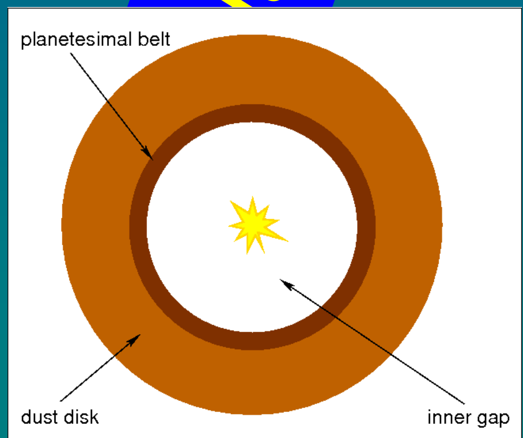




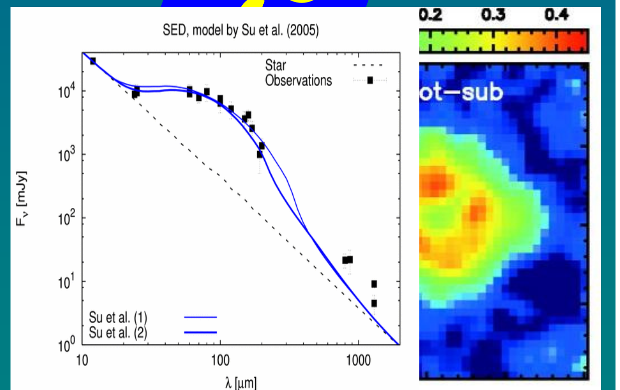
Our approach



Collisional model

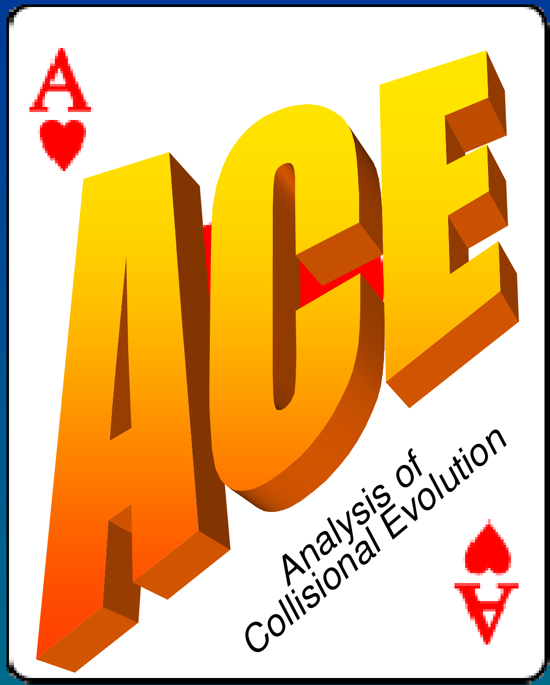


Thermal emission model



Krivov, Müller, Löhne, & Mutschke, ApJ ***687*** *(2008)*

Collisional model: ACE

Initial planetesimal belt →  → *Debris disk at subsequent time instants*

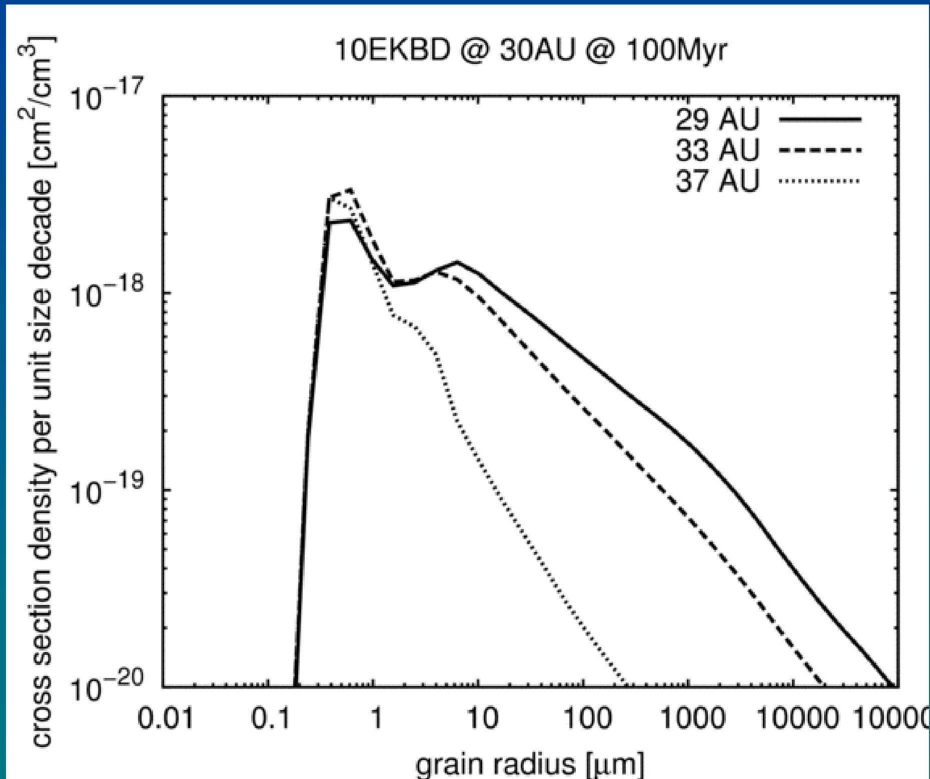
Features:

- statistical code in an (m,a,e)-mesh
- accurate photogravitational dynamics
- collisions (mergers, cratering, disruption)
- diffusion by P-R and stellar wind
- distributed parallel computing

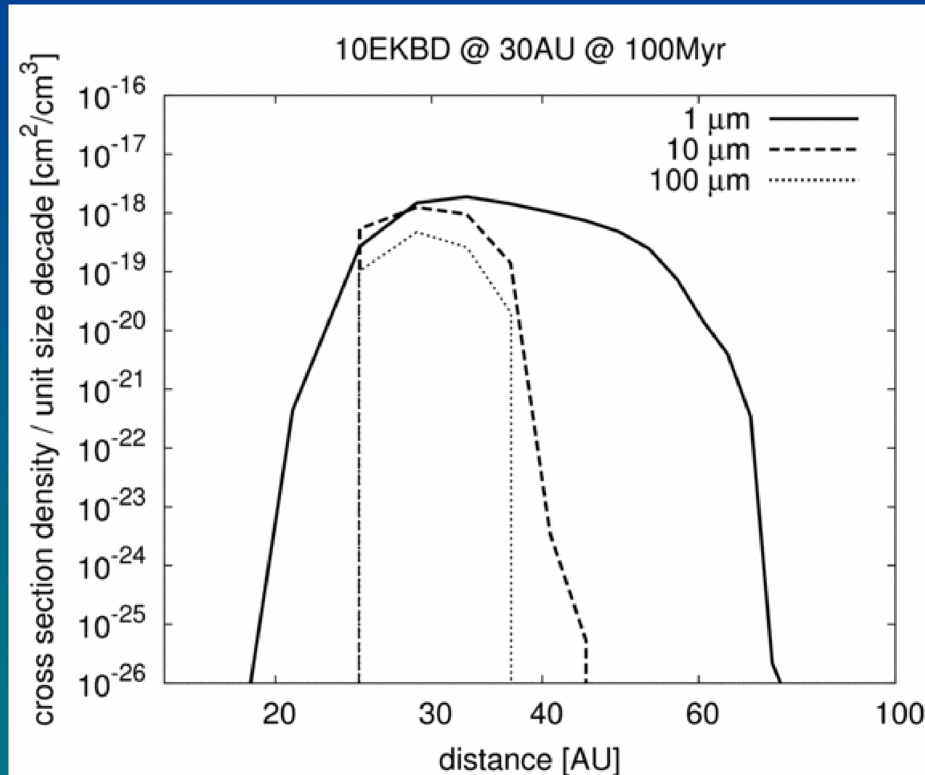
Authors: Krivov & Sremčević (2003-2004), Löhne (2005-2009)

Results: dust distributions

Distance-dependent size distribution



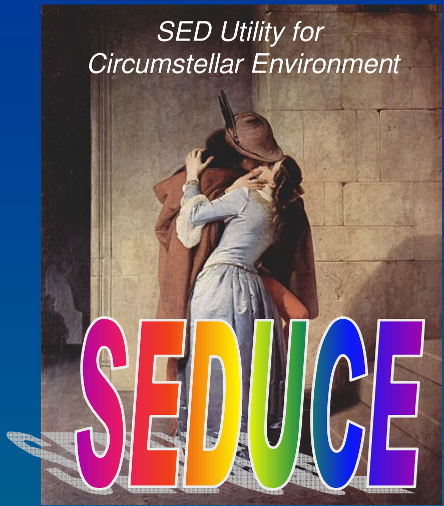
Size-dependent radial distribution



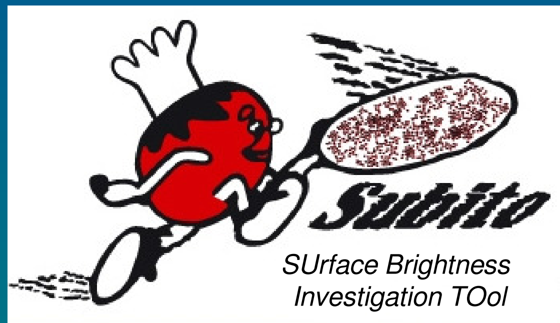
cf. Krivov, Löhne, & Sremčević, AAp ***455*** *(2006)*
Thébault & Augereau, AAp ***472*** *(2007)*
Löhne, PhD thesis (2008)

Thermal emission model: SEDUCE & SUBITO

Size and spatial distribution of dust, its optical properties



→ *SED*

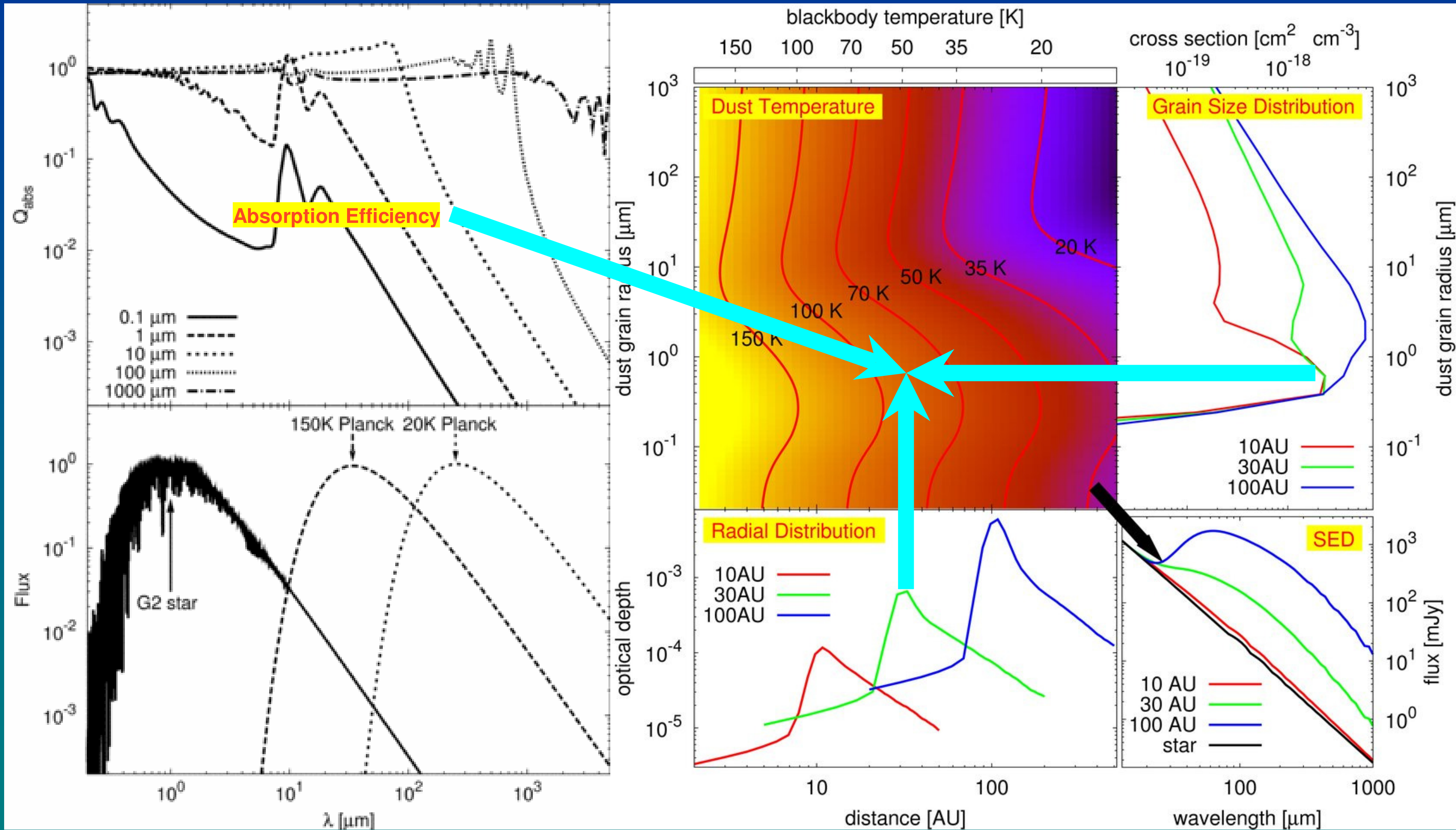


→ *radial brightness profile*

Features:
- NextGen stellar photosphere models
- Mie calculations for arbitrary (n,k)
- Thermal emission (no scattered light)

Author: Müller (2007-2009)

Results: dust temperatures



Krivov, Müller, Löhne, & Mutschke, ApJ ***687*** *(2008)*

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Input and output

known (fixed)
poorly known (fixed)
unknown (free)

Model parameters

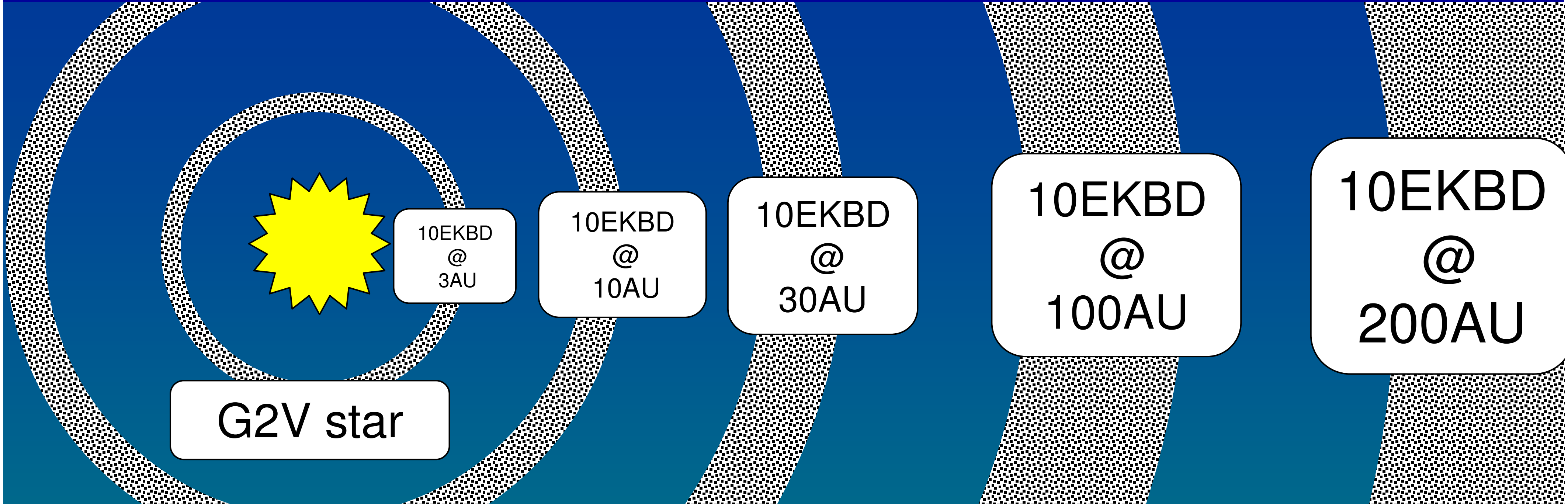
Star:	stellar mass	M_*
	stellar luminosity	L_*
	stellar age	t_*
Planetesimal belt:	initial mass	M_0
	location	r
	width	dr
	excitation	$\langle e \rangle, \langle i \rangle$
All solids:	bulk density	
	mechanical properties	
	optical properties	
Collisions:	critical fragmentation energy	
	fragments' size distribution	
	cratering efficiency	

→

Observables

SED

Reference disks



Disk identifier	Belt location [AU]	Initial disk mass [$M_\oplus$]	a range [AU]	r range [AU]
10EKBD @ 3AU	3	0.001	0.3 – 30	0.5 – 20
10EKBD @ 10AU	10	0.03	1 – 100	2 – 50
10EKBD @ 30AU	30	1	3 – 300	5 – 200
10EKBD @ 100AU	100	30	10 – 1000	20 – 500
10EKBD @ 200AU	200	200	20 – 2000	30 – 1000

Scaling rules

$$F(M_o, r, t)$$

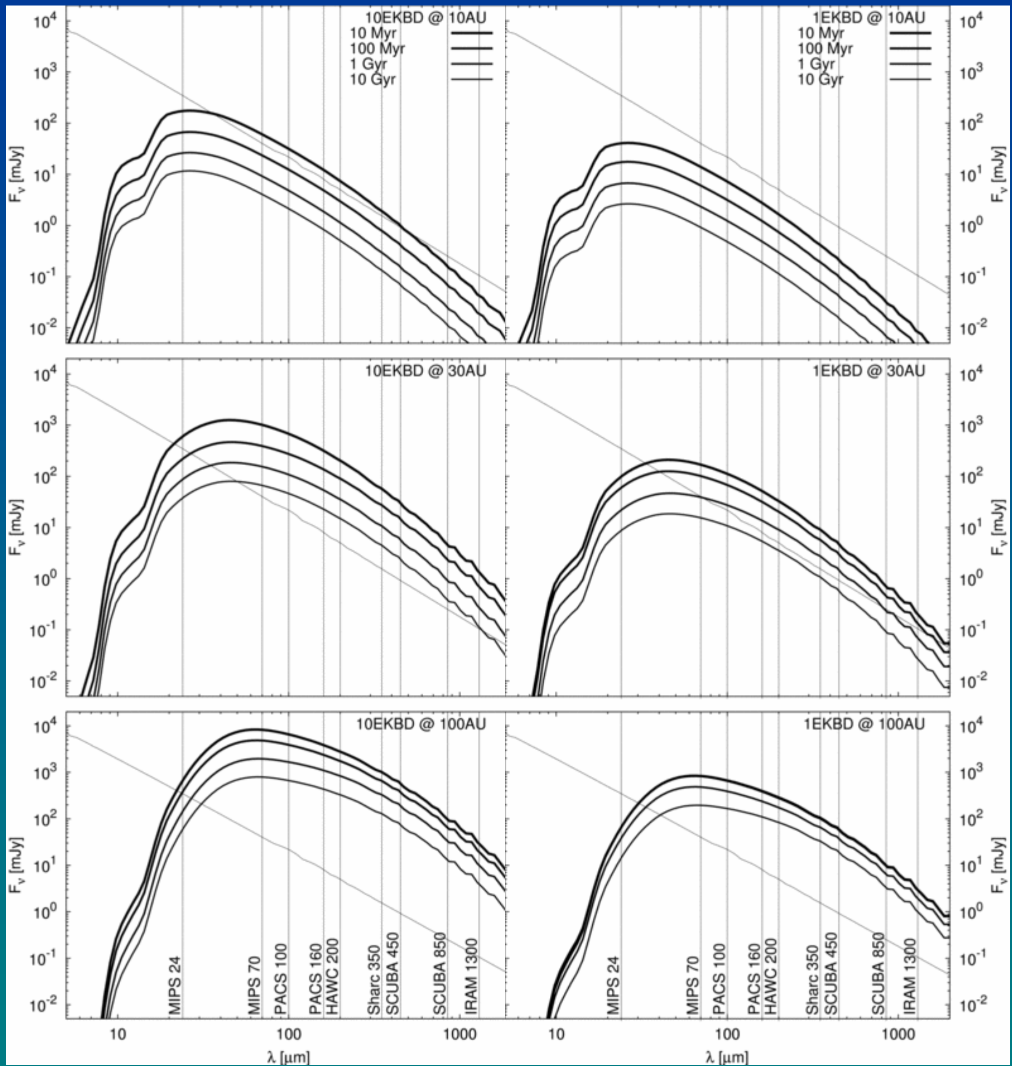
$$F(xM_o, r, t) = x\, F(M_o, r, xt)$$

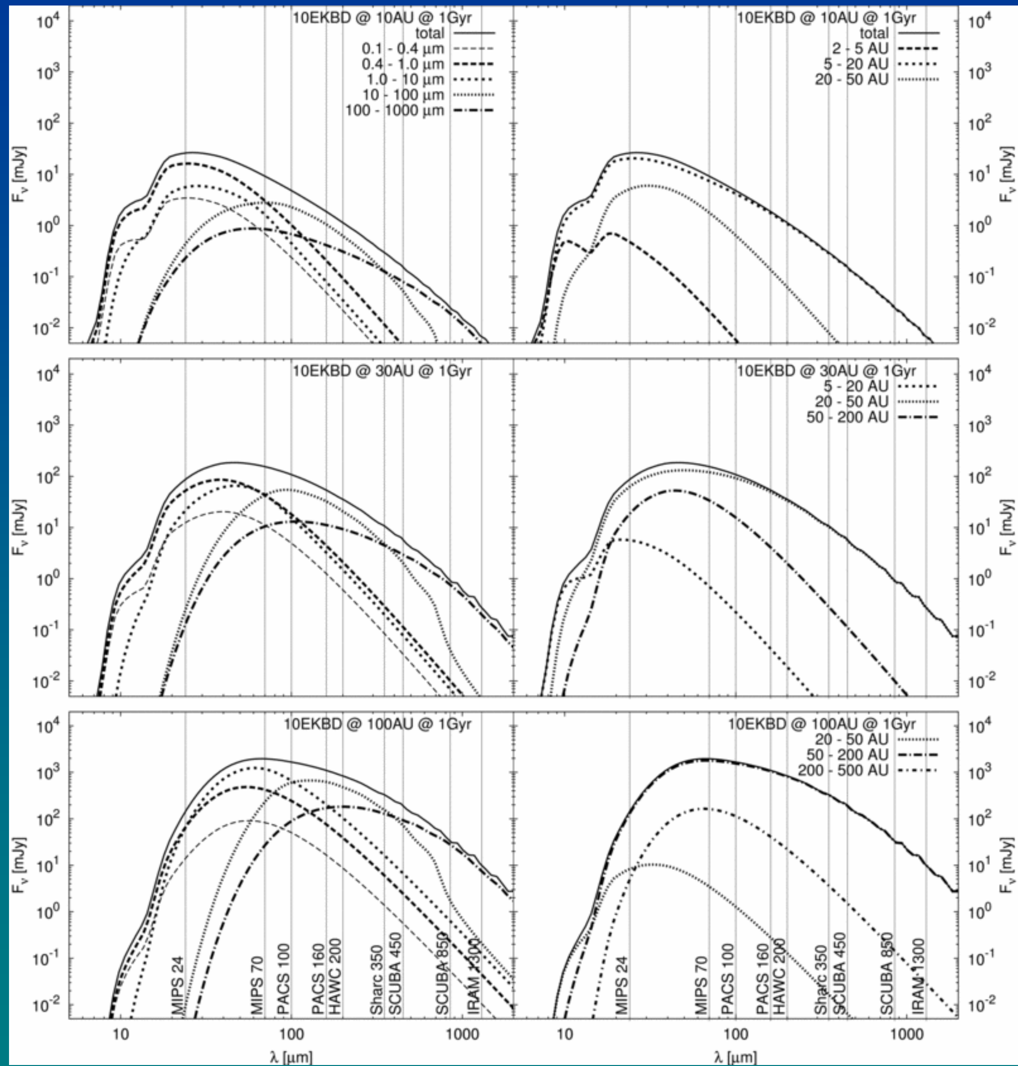
Löhne, Krivov, & Rodmann, ApJ **673** *(2008)*

↓

$$F(M_o, r, t)$$

Results: SEDs for reference disks





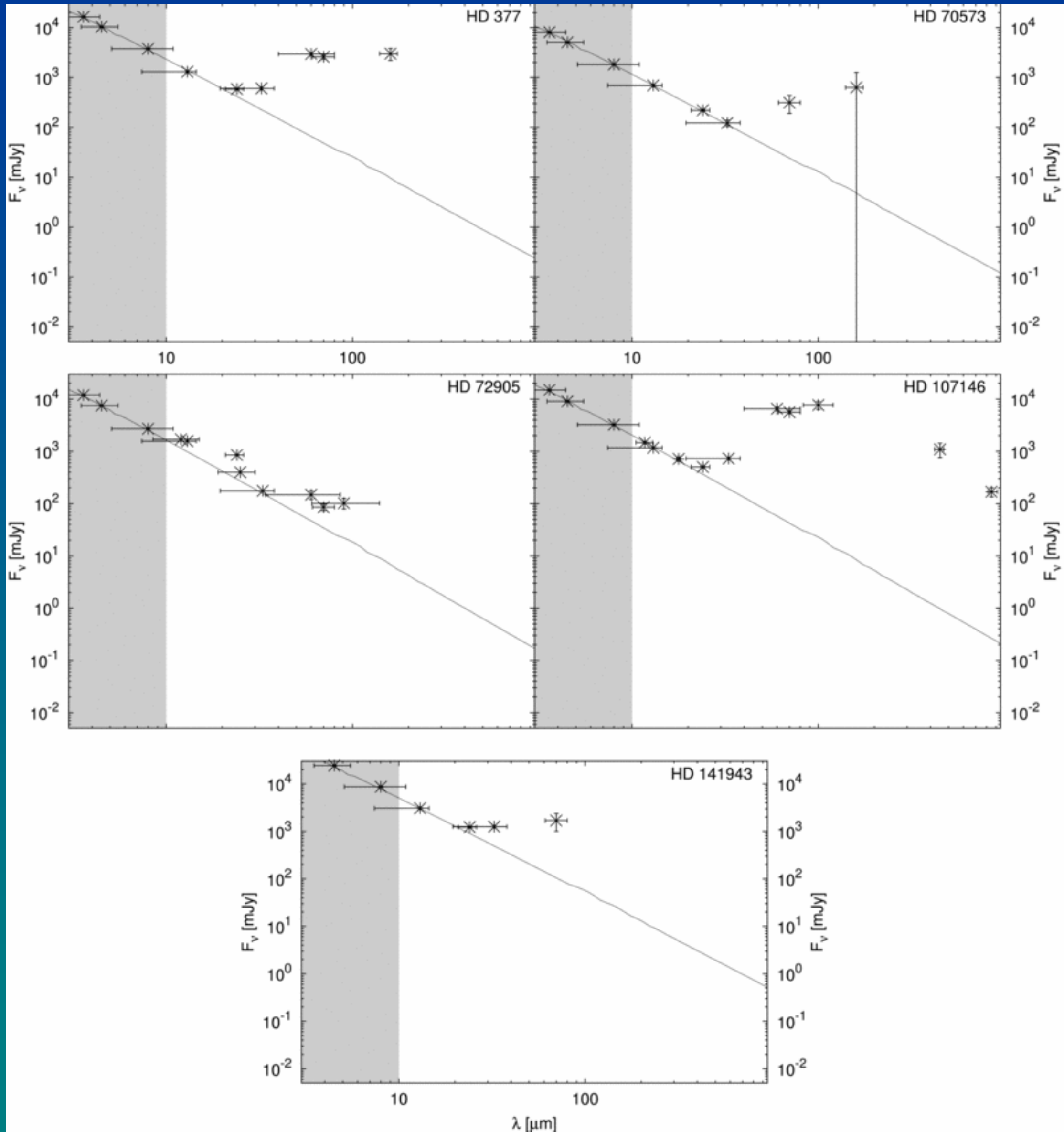
Krivov, Müller, Löhne, & Mutschke, ApJ **687** *(2008)*

Application to selected debris disks

- Stars : G2V

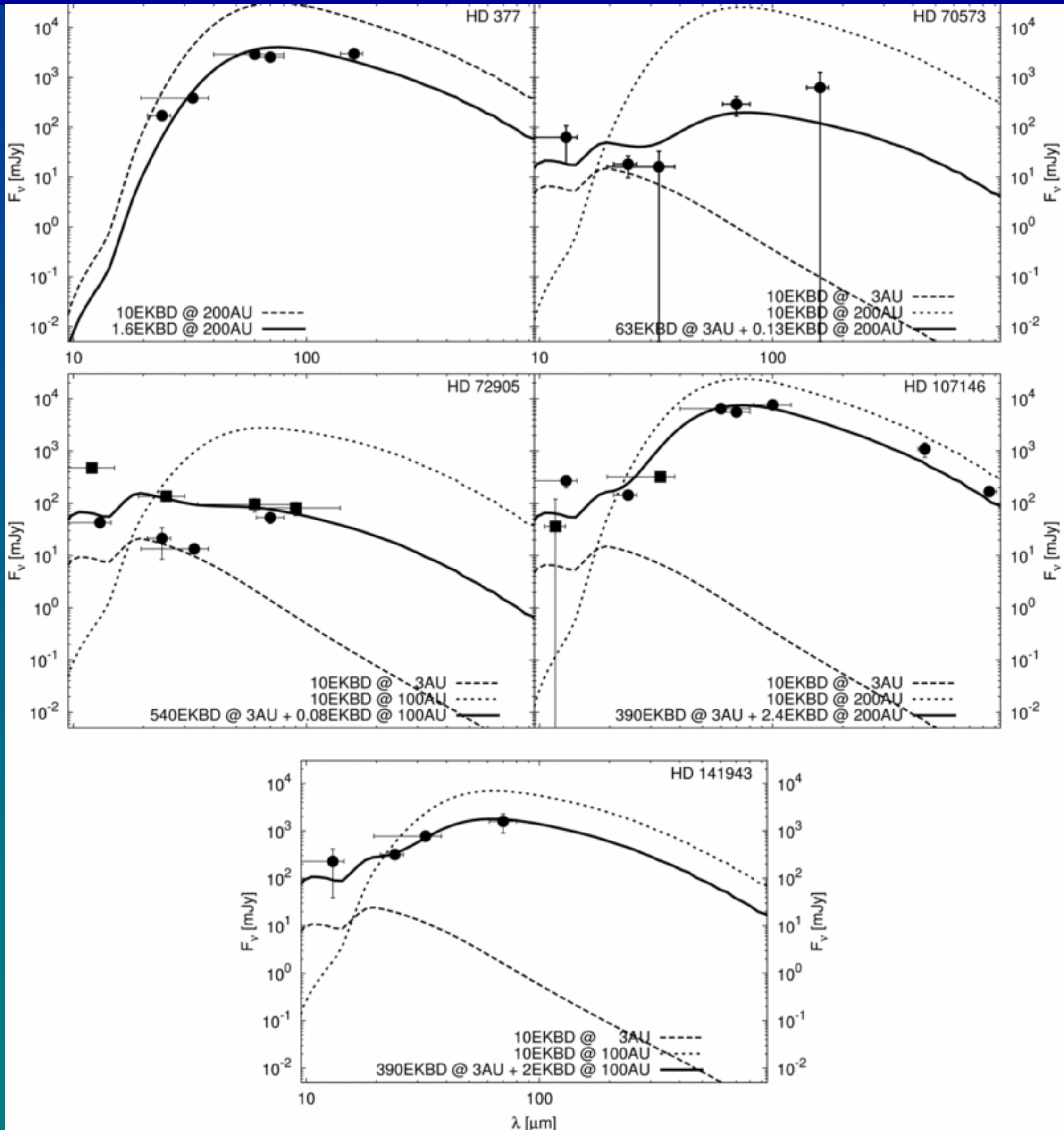
Star	$T_{\rm eff}$ [K]	$\log L_*/L_\odot$	D [pc]	age [Myr]
HD 377	5852 $^{a)}$	0.09 $^{a)}$	40 $^{a)}$	32 $^{a)}$
HD 70573	5841 $^{a)}$	-0.23 $^{a)}$	46 $^{a)}$	100 $^{a)}$
HD 72905[1]	5831 $^{a)}$	-0.04 $^{a)}$	13.85 $^{d)}$	420 $^{d)}$
HD 107146	5859 $^{a)}$	0.04 $^{a)}$	29 $^{a)}$	100^{+100}_{-20} $^{c)}$
HD 141943	5805 $^{a)}$	0.43 $^{a)}$	67 $^{a)}$	32 $^{a)}$

- Dust data: from various surveys with IRAS, ISO, Spitzer, Keck II, JCMT



Krivov, Müller, Löhne, & Mutschke, ApJ ***687*** *(2008)*

Comparison of observed SEDs to modeled SEDs



$$F\,(M_o\,,\,r,\,t_*)$$

Belt mass, from SED's height

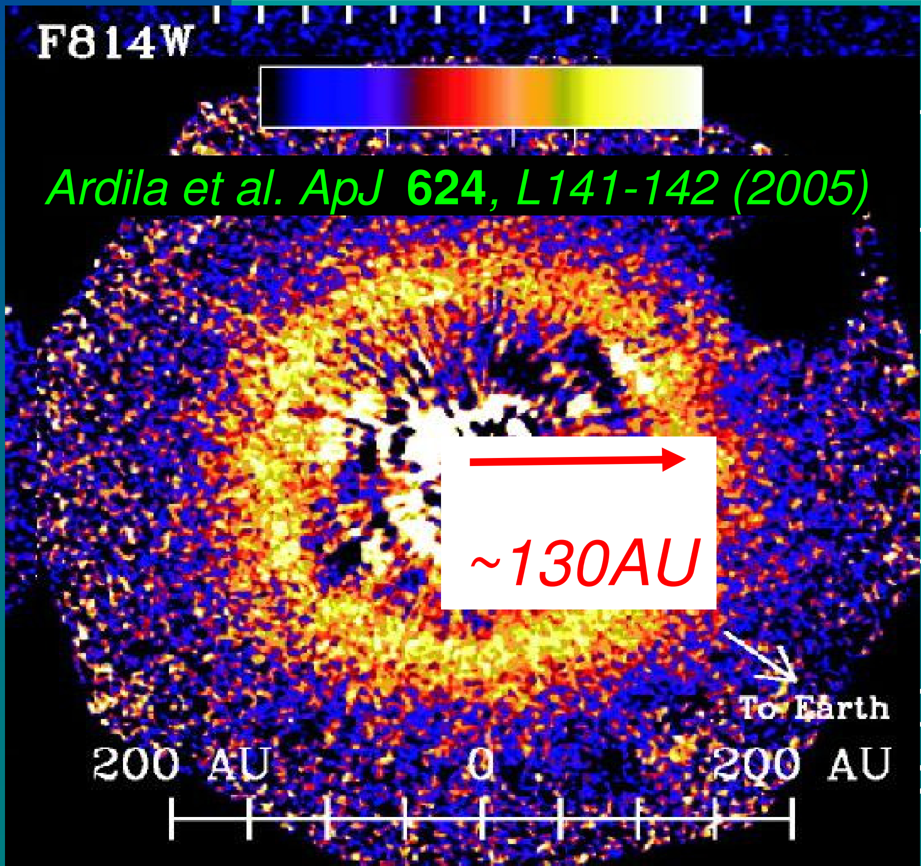
Belt location, from SED's peak wavelength

Age, assumed known

Krivov, Müller, Löhne, & Mutschke, ApJ ***687*** *(2008)*

Derived masses and locations of (outer) planetesimal belts

System [HD]	Belt mass [M_{earth}]	Belt location [AU]	Dust mass [M_{earth}]
		~200	3.1×10^{-2}
		~200	2.0×10^{-3}
		~100	2.1×10^{-4}
		~200	4.8×10^{-2}
		~100	5.5×10^{-3}



).2-50 earth masses) Kuiper belt analogs
)end on assumed dust properties

Krivov, Müller, Löhne, & Mutschke, ApJ **687** *(2008)*

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	mechanical properties	
	optical properties	
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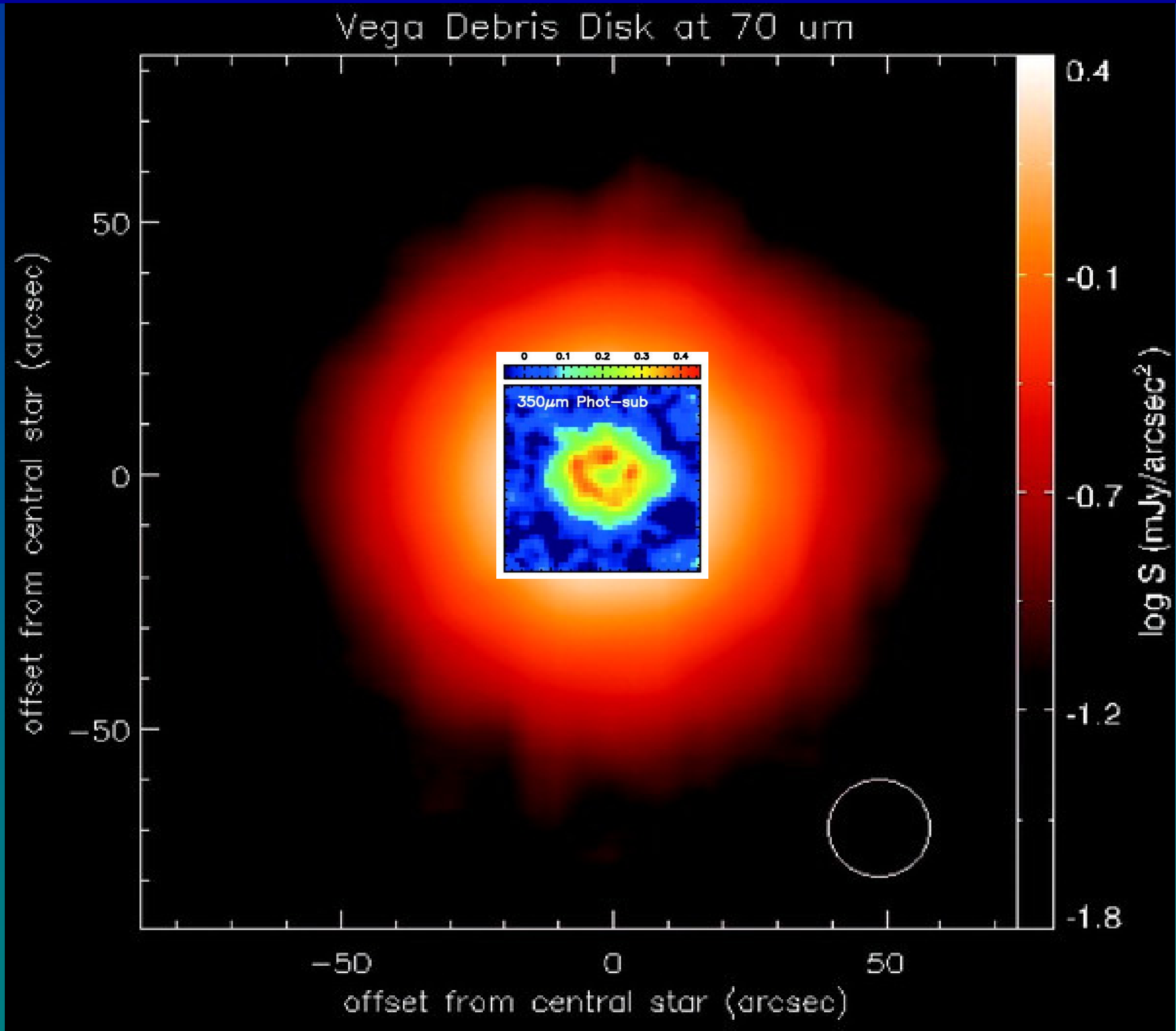
	cratering efficiency	

Observables

SED

Brightness profiles in different colors

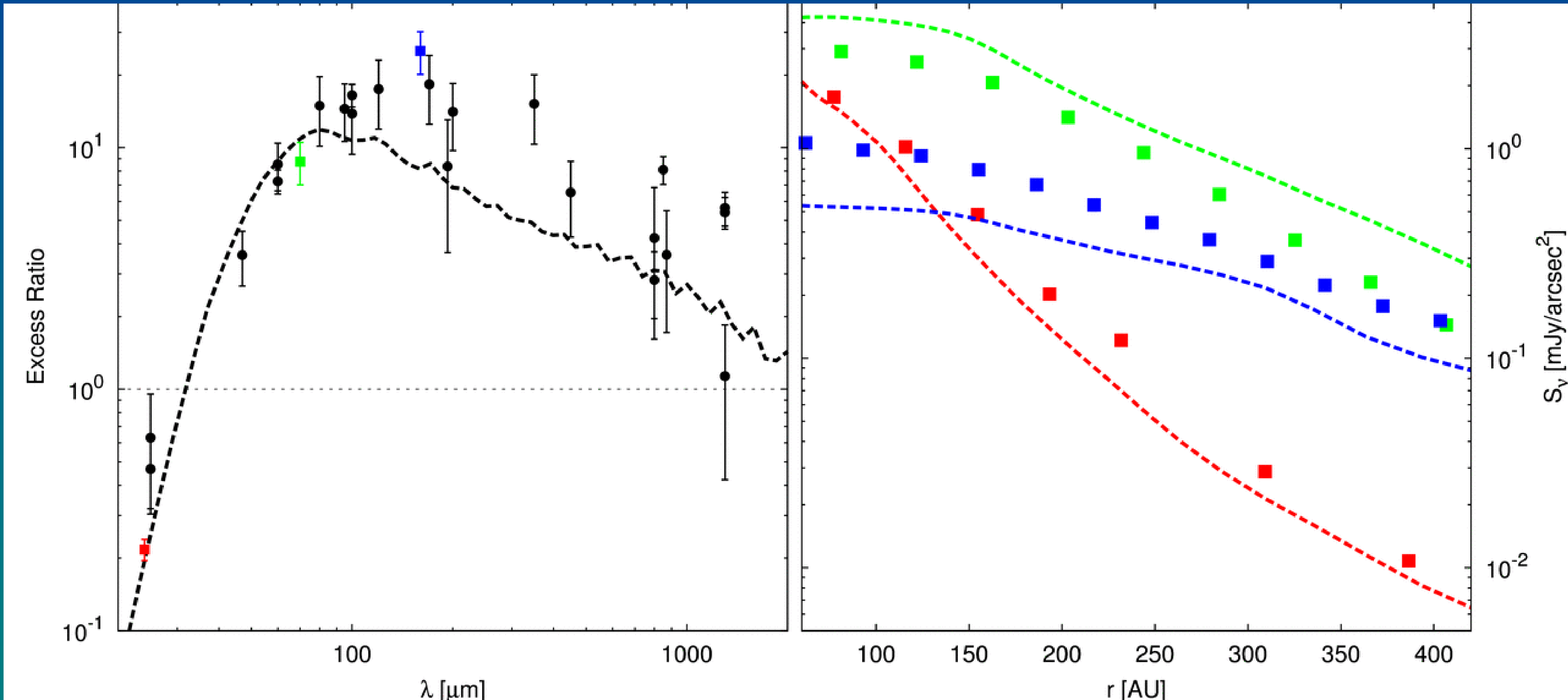
Application to the Vega disk



Su et al., ApJ (2005); Marsh et al., ApJ (2006)

The first-guess model

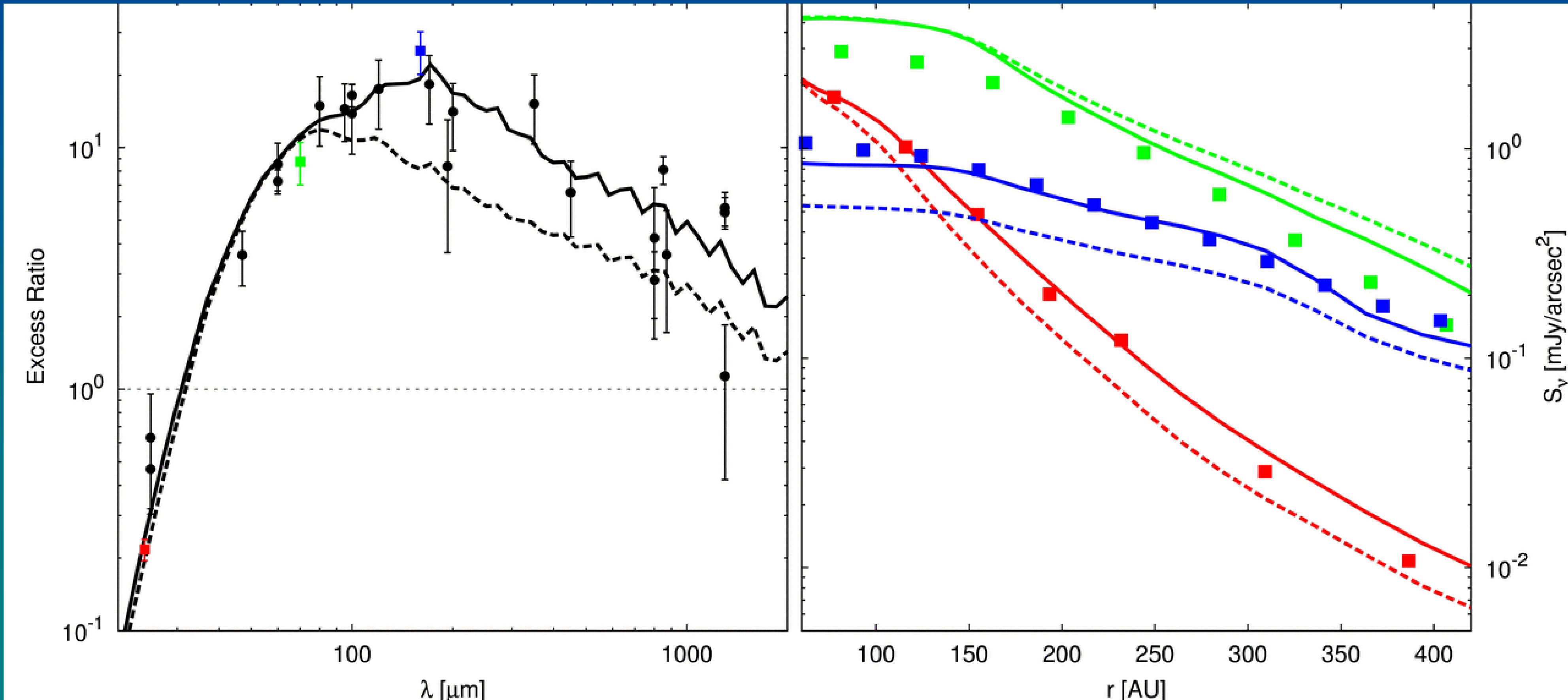
Star: L_*=37L_{sun} Belt: 70-100AU, <e>=0.1 Material: astrosil
Collisonal outcome model: nominal



Müller, Löhne, & Krivov, in prep.

The best model

Star: $L_* = 25 L_{sun}$ Belt: 70-100AU, <e>=0.1 Material: astrosil
Collisonal outcome model: flat size distribution of fragments



Müller, Löhne, & Krivov, in prep.

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Summary

- We suggest a constructive way of using debris disk observations to constrain planetesimal properties
- Unresolved cases: application to five G2V excess stars revealed large (100-200AU) and massive (0.2-50 earth masses) Kuiper belt analogs
- Resolved cases: application to the Vega disk showed it to be compatible to a steady-state collisional evolution scenario, contrary to previous claims

Herschel
Open Time Key Program
“DUNES”
(DUst around NEarby Stars)