How Extrasolar Planetesimals Show Up in Spitzer Data

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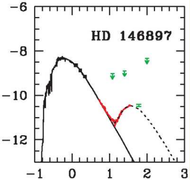
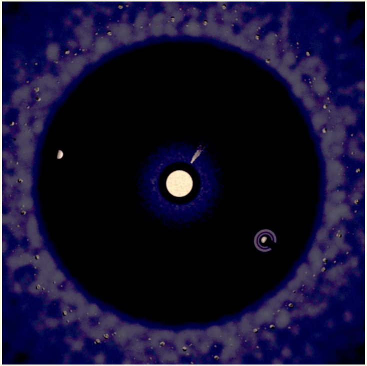
Outline

- Introduction
- Long-term debris disk evolution
- Comparison with *Spitzer* Statistics
- Individual systems
- Outlook and conclusions

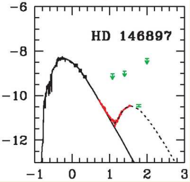
Introduction



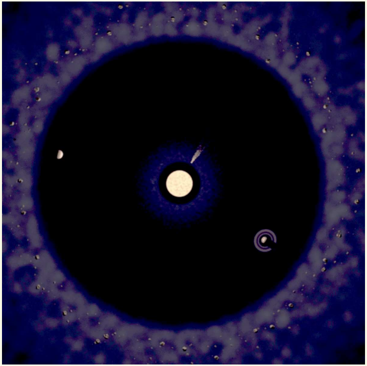
(*Chen* et al. 2006)



Dust distribution → Planetesimal distribution → Planet formation ⋯→ Star formation



(*Chen* et al. 2006)

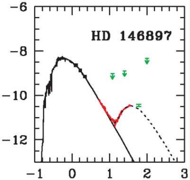


Direct problem?

Dust distribution ← Planetesimal distribution

Planet formation

Star formation



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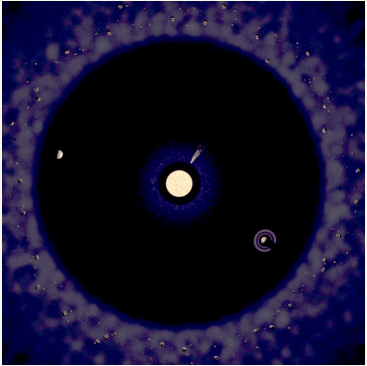
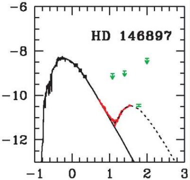


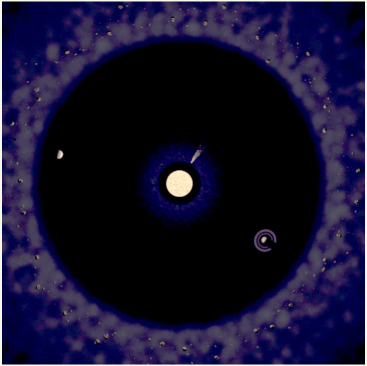
Inverse problem!

Dust distribution ← compute ← Planetesimal distribution ← Planet formation

Dust distribution → compute ↓



(*Chen* et al. 2006)



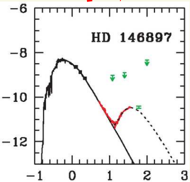
Inverse problem!

Dust distribution → infer → Planetesimal distribution

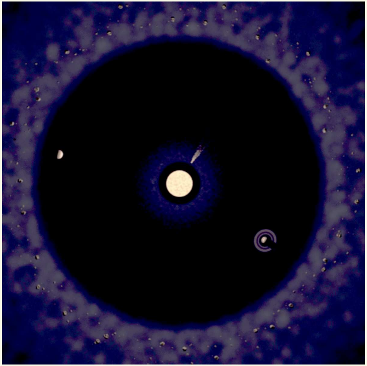
Planetesimal distribution → compute → Dust distribution

Planet formation → Planetesimal distribution

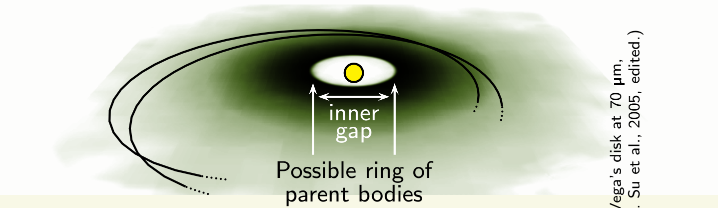
Dust distribution ↔ infer / compute

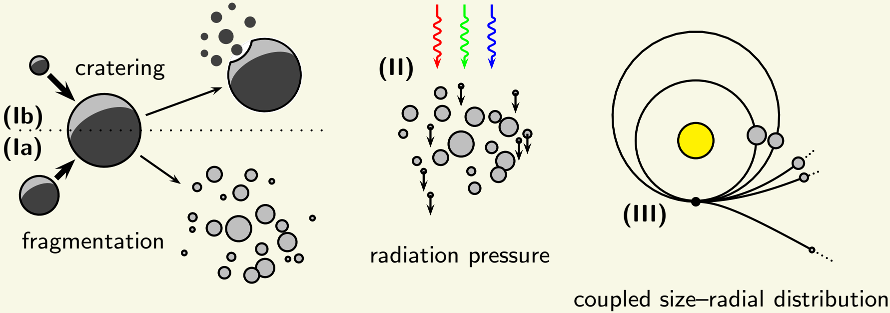


(*Chen* et al. 2006)

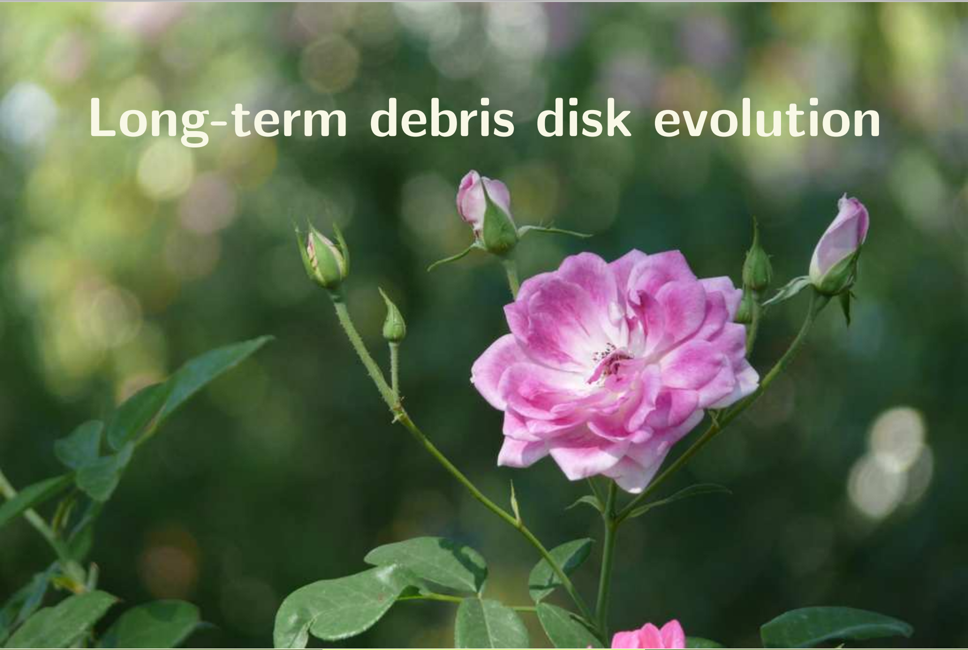


Inverse problem!


inner
gap
Possible ring of
parent bodies
(Vega's disk at 70 μm,
K. Su et al., 2005, edited.)

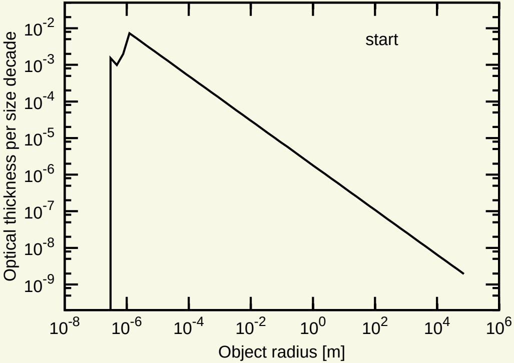

cratering
(Ib)
(Ia)
fragmentation
(II)
radiation pressure
(III)
coupled size–radial distribution

Long-term debris disk evolution

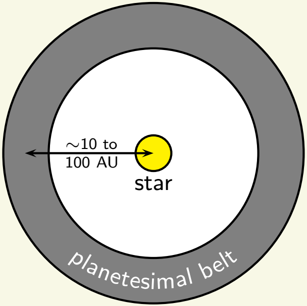


Long-term debris disk evolution

Size distribution



Initial radial distribution



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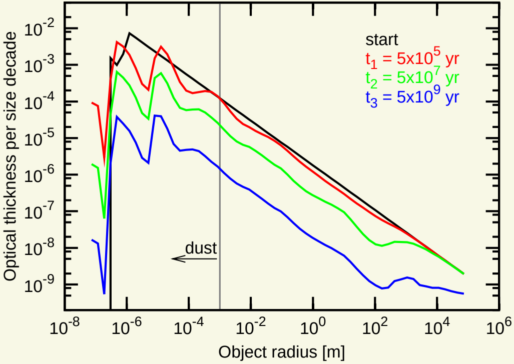
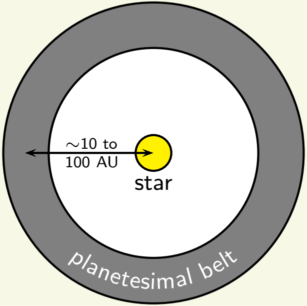


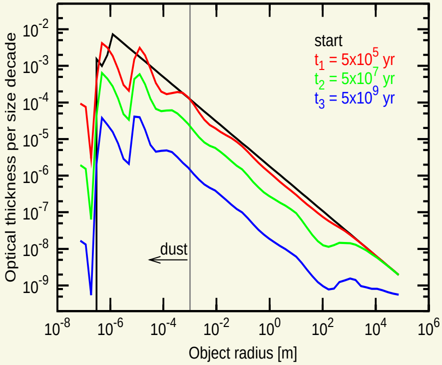
Initial radial distribution



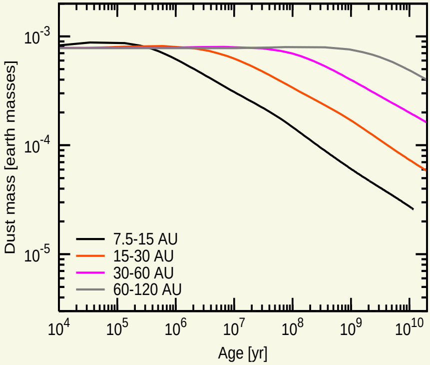
Campo-Bagatín et al., *Plan. Space Sc.*, **42** (1994), S. 1079–1092
Thébault, Augereau, *Astron. & Astroph.*, **472** (2007), S. 469–485
Krivov, Löhne, Sremčević, *Astron. & Astroph.*, **455** (2006), S. 509–519
Thébault et al., *Astron. & Astroph.*, **408** (2003), S. 775–788
Löhne, Krivov, Rodmann, *ApJ*, **673** (2008), 1123

Long-term debris disk evolution

Size distribution

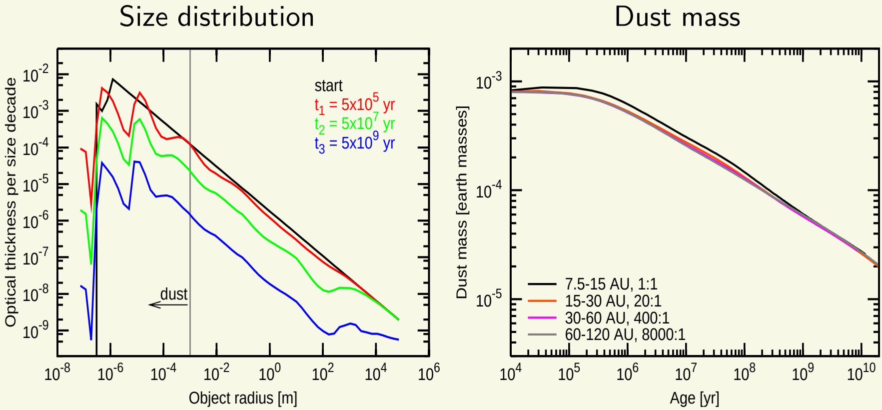


Dust mass



Löhne, Krivov, Rodmann, *ApJ*, **673** (2008), 1123

Long-term debris disk evolution



LÖHNE, KRIVOV, RODMANN, *ApJ*, **673** (2008), 1123

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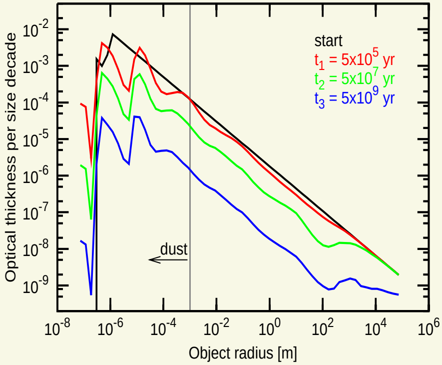

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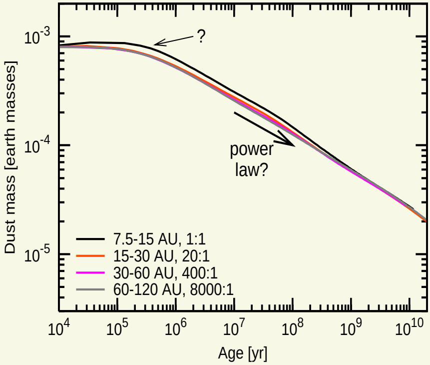
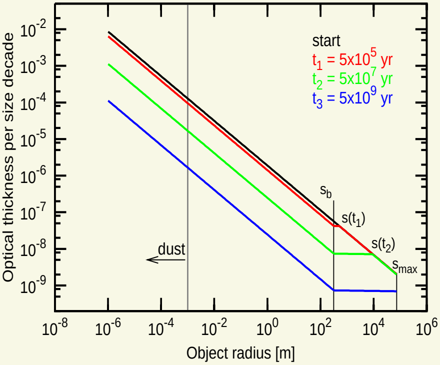


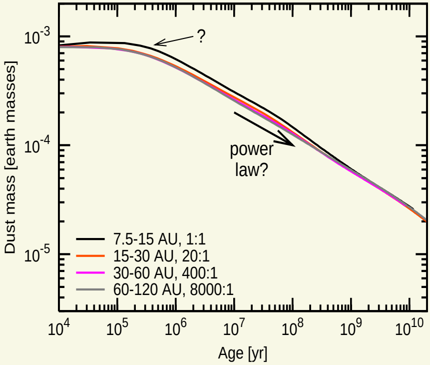
Löhne, Krivov, Rodmann, *ApJ*, **673** (2008), 1123

Long-term debris disk evolution

Size distribution



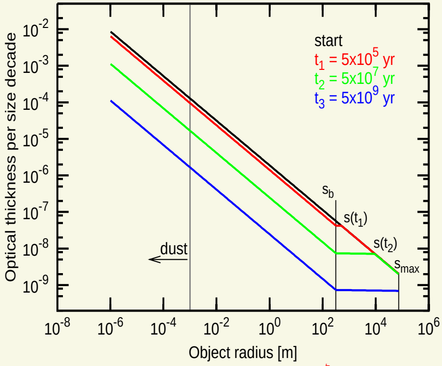
Dust mass



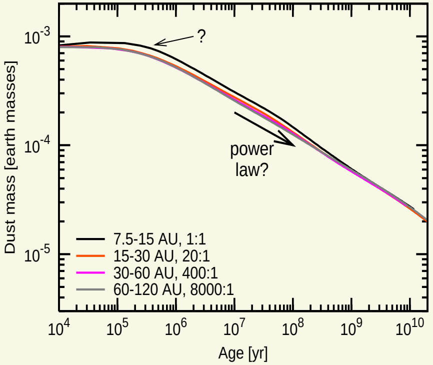
Löhne, Krivov, Rodmann, *ApJ*, **673** (2008), 1123

Long-term debris disk evolution

Size distribution



Dust mass

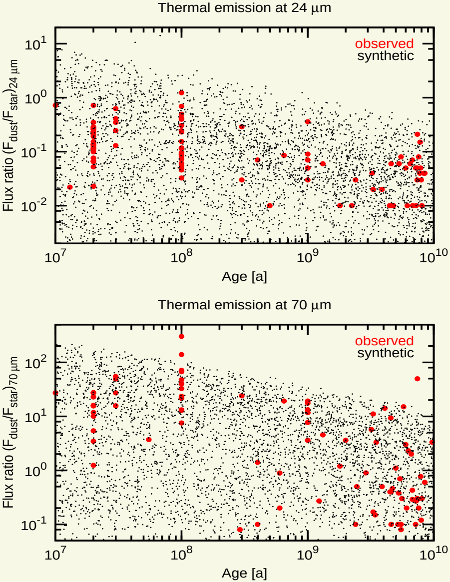


$$\text{dust mass} \propto \frac{1}{1+t/T_{\max}} \left(\frac{t}{T_b}\right)^{\xi}, \text{ where } \xi = \frac{q_g - q_p}{q_p - 5/3 + (q_p - 1) b_g} \approx -0.4$$

O'Brien, Greenberg, *Icarus*, **178** (2005), 179
Wyatt et al., *ApJ*, **658** (2008), 569
Löhne, Krivov, Rodmann, *ApJ*, **673** (2008), 1123

q_p: slope of the planetesimals' size distrib. set during growth phase
(See also: Poster #117 by A. Shannon)

Comparison with *Spitzer* statistics



- Flux calculation based on modified blackbody.
- Synthetic population within reasonable bounds ($M < 50\ M_\oplus$, $20 < R < 130\ AU$) covers range of observational data.

BEICHMAN et al., *ApJ*, 622 (2005), 1160;
BEICHMAN et al., *ApJ*, 652 (2006), 1674;
BRYDEN et al., *ApJ*, 636 (2006), 1098;
CHEN et al., *ApJ*, 623 (2005), 493;
CHEN et al., *ApJ*, 634 (2005), 1372;
HILLENBRAND et al., *ApJ*, 677 (2008), 630;
MEYER et al., *PASP*, 118 (2006), 1690;
TRILLING et al., *ApJ*, 674 (2008), 1086

- Onset of collisional cascade is not modelled here: work in progress.

WYATT et al., *ApJ*, 598 (2003), 1321;
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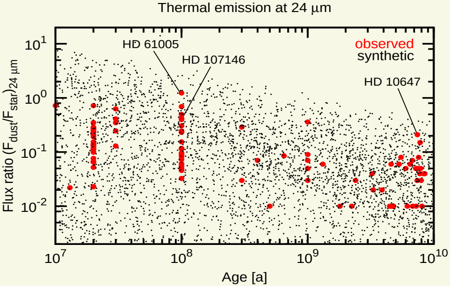
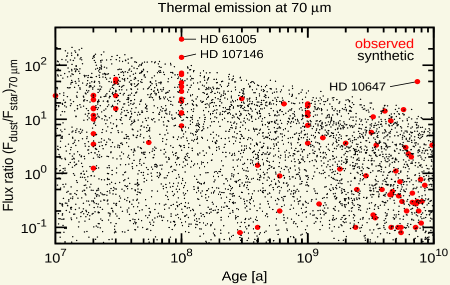
KENYON, BROMLEY, *ApJ*, in press

LÖHNE, KRIVOV, RODMANN, *ApJ*, **673** (2008), 1123





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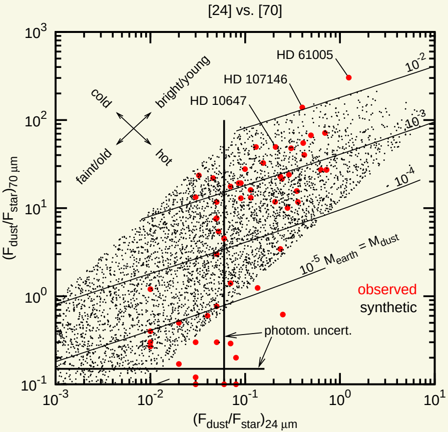

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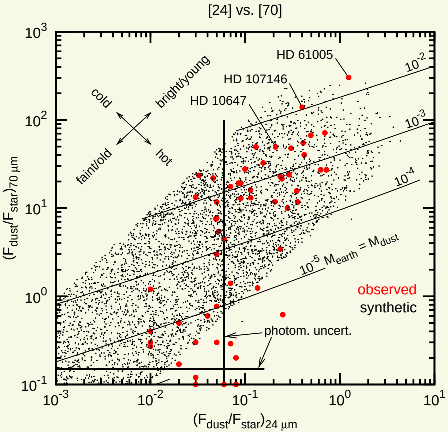
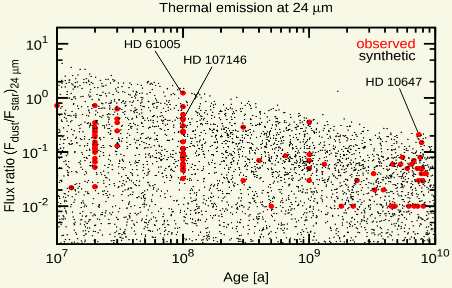
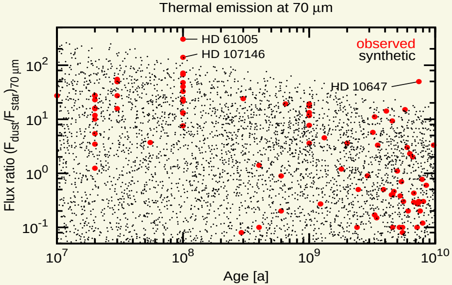
LÖHNE, KRIVOV, RODMANN, *ApJ*, **673** (2008), 1123

Comparison with *Spitzer* statistics
G-type stars







- Example for possible refinement: disk mass range made disk size-dependent ($M_{max} \propto R$)

Individual systems

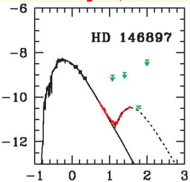
Dust distribution

Planetesimal distribution

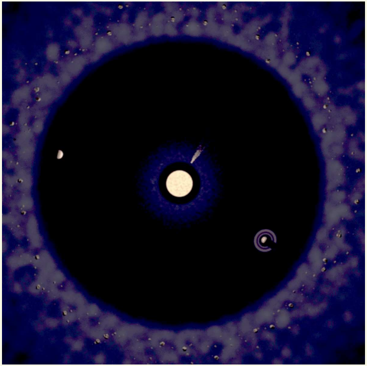
ACE

SEDUCE

Planet formation

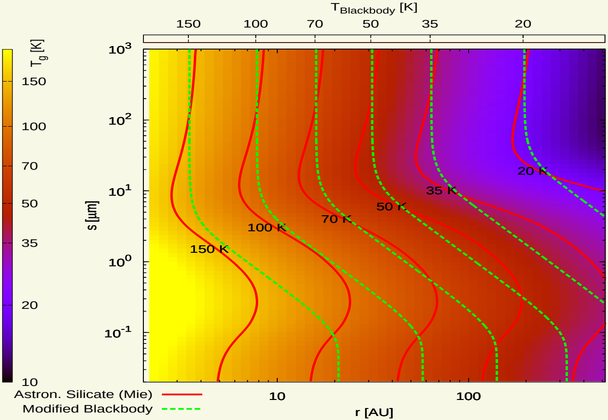


(Chen et al. 2006)



Mie-based calculation of thermal emission

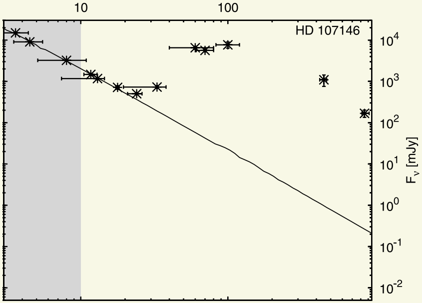
Temperature distribution for astron. silicate around G2V:



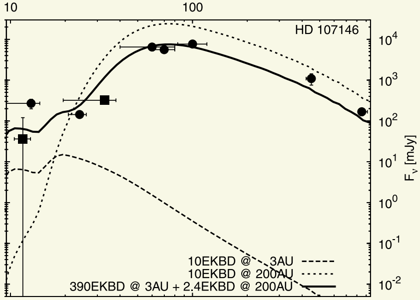
KRIVOV, MÜLLER, LÖHNE, MUTSCHKE, *ApJ*, **687** (2008), 608

HD 107146

Flux



Excess

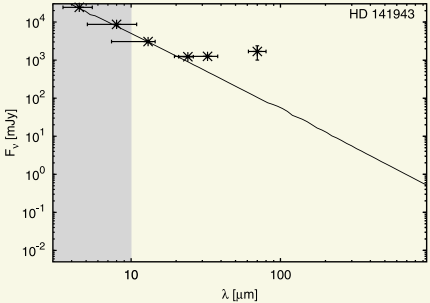


	Radius [AU]	Mass total [$M_\oplus$]	Mass dust [$M_\oplus$]
inner disk:	3	2×10^{-2}	5×10^{-7}
outer disk:	200	50	5×10^{-2}

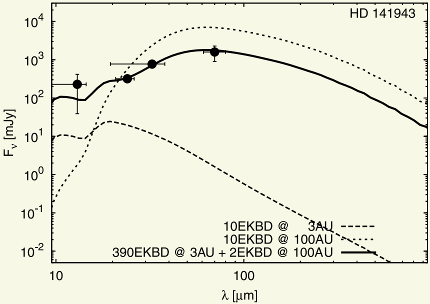
Krivov, Müller, Löhne, Mutschke, *ApJ*, **687** (2008), 608

HD 141943

Flux

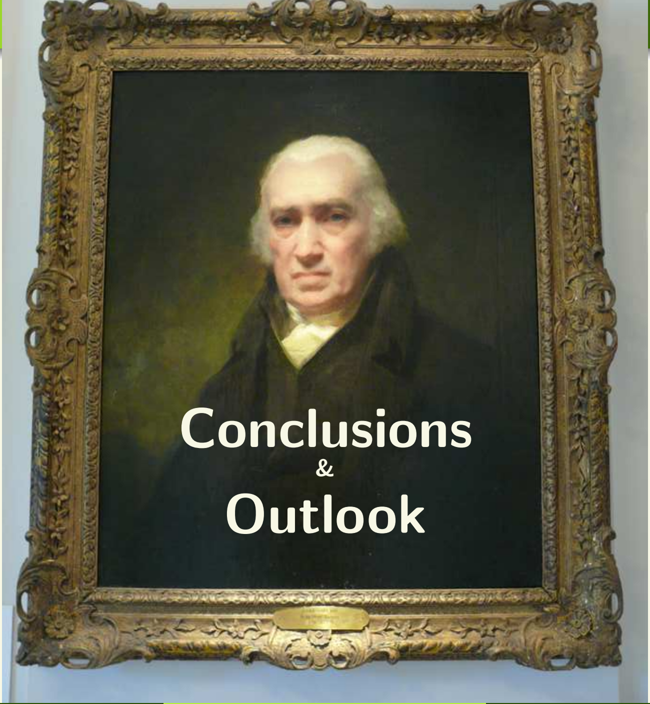


Excess



	Radius [AU]	Mass total [$M_\oplus$]	Mass dust [$M_\oplus$]
inner disk:	3	3×10^{-2}	8×10^{-7}
outer disk:	100	6	6×10^{-3}

Krivov, Müller, Löhne, Mutschke,
ApJ, **687** (2008), 608



J. Watt

Conclusions and Outlook

- Size and radial distribution are coupled;
  dust mass and total mass evolve differently.
- Primordial planetesimal distribution
  constrained by IR excess statistics.
- Belt masses and sizes are more realistically inferred from improved dynamical/collisional and thermal emission models.
- Typical planetesimal belts:
  a few to a few ten earth masses at
  a few ten to more than a hundred AU.
- To be done: model onset of collisional cascade,
  consider stochastic events,
  explore influence of optical dust properties

Thank you for your attention!