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Planet Formation and Debris Disks

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Contents

- Planet formation results in debris disks:
- Planetary embryo formation.
- Impacts between embryos.

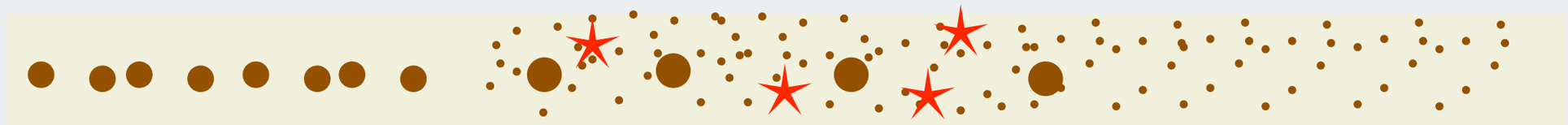
Standard Scenario

(e.g., Hayashi, Nakazawa, Nakagawa 1985)

$10^{5\text{-}6}$yr

Planetesimal

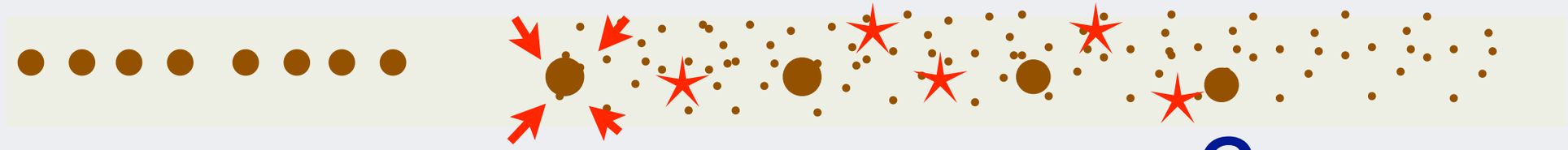
$10^{5\text{-}7}$yr



Protoplanet

Collisional Fragmentation

$10^{6\text{-}7}$yr



Gas accretion

$10^{7\text{-}9}$yr

Debris disk

10^{9}yr

Simulation

(Kobayashi et al. 2010,2011)

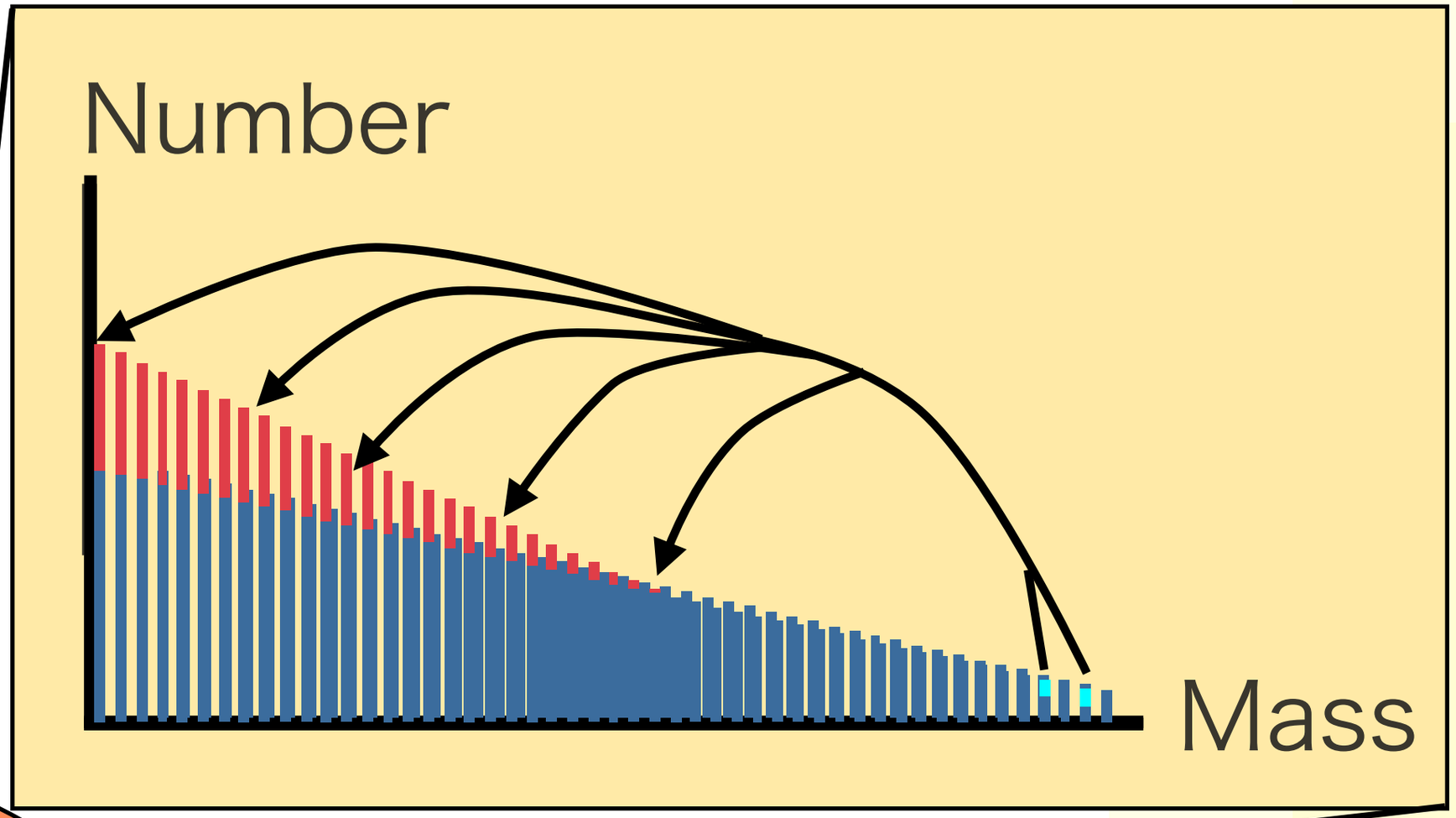
Mass evolution affects the relative velocities between bodies.

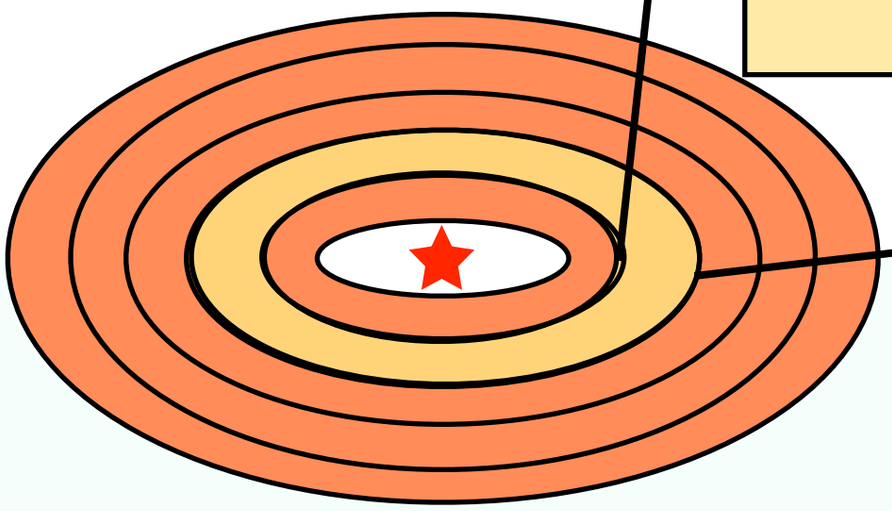
Follow the velocity and mass evolution.

Collisional velocity:

Low => coagulation.

High => destruction.





(e.g., Wetherill & Stewart; Inaba et al.; Weidenschilling et al.; Kenyon & Bromley)

Embryo Formation & Debris Disks

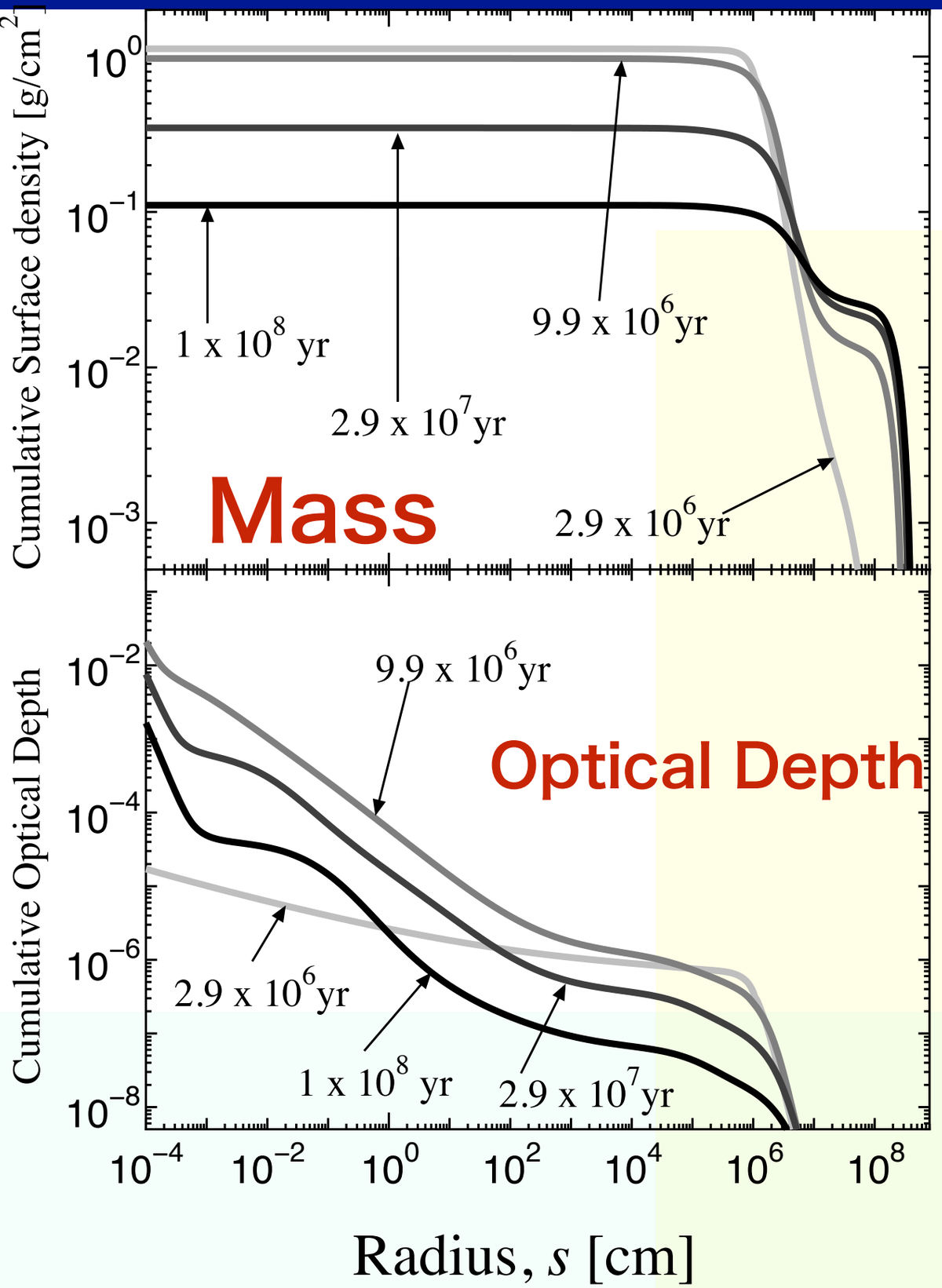
Collisional Evolution

After gas dissipation

- Starting from 10km radius planetesimals at 10AU in the MMSN, planetary accretion produces embryos.

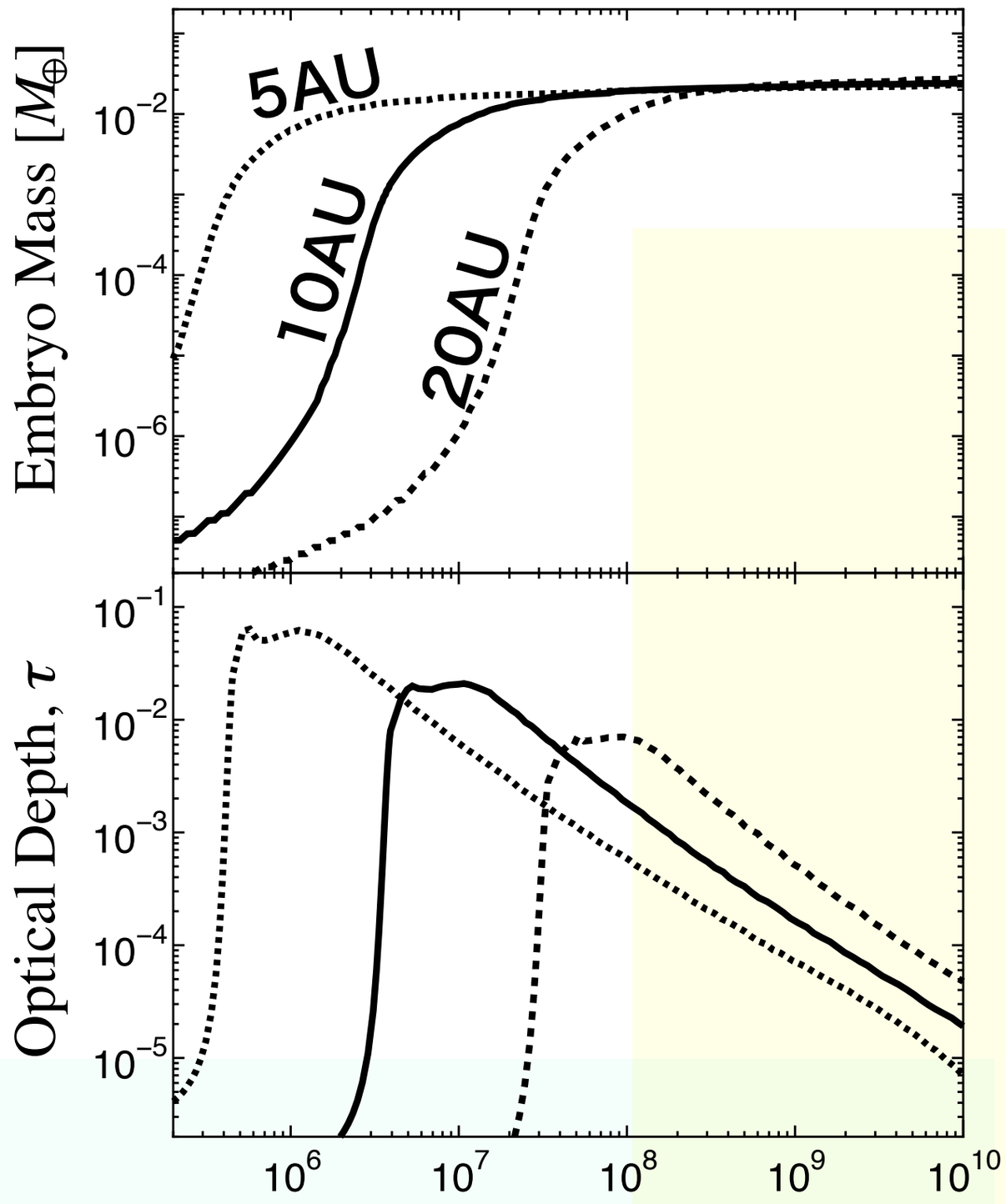
- Once embryos becomes larger than ~1000km in radius, collisional fragmentation of planetesimals enlarges the optical depth.

(Kobayashi & Löhne 2014)



Embryo Formation & Optical Depth

- Embryo growth propagates from an inner to an outer disk.
- The optical depth rises by embryo formation and then gradually decreases.
- The bright ring moves from the inside out.



(Kobayashi & Löhne 2014)

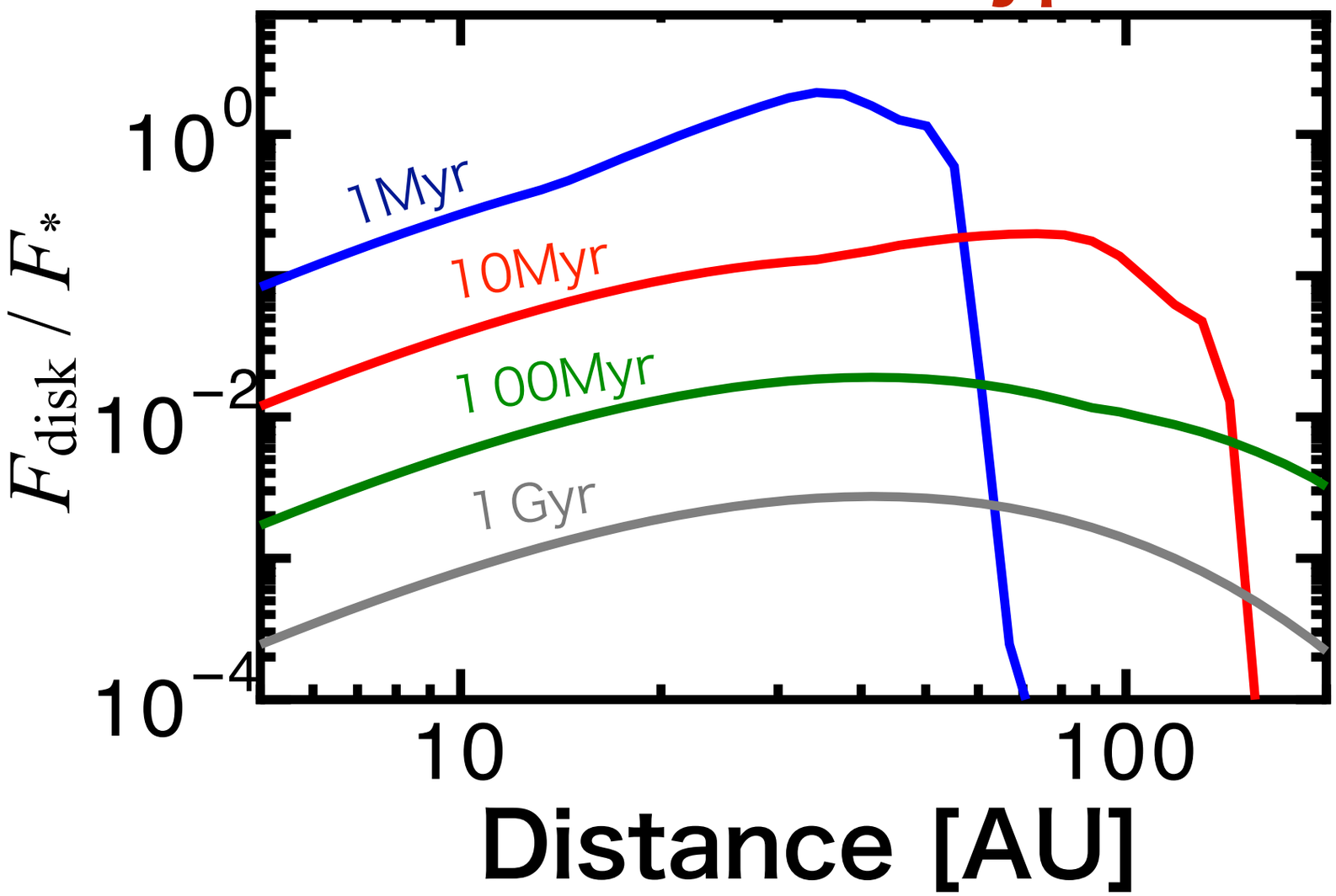
Distribution & Evolution

(e.g., Kenyon & Bromley 2004; 2008; Kennedy & Wyatt 2010)

gas-free disk

A-type star

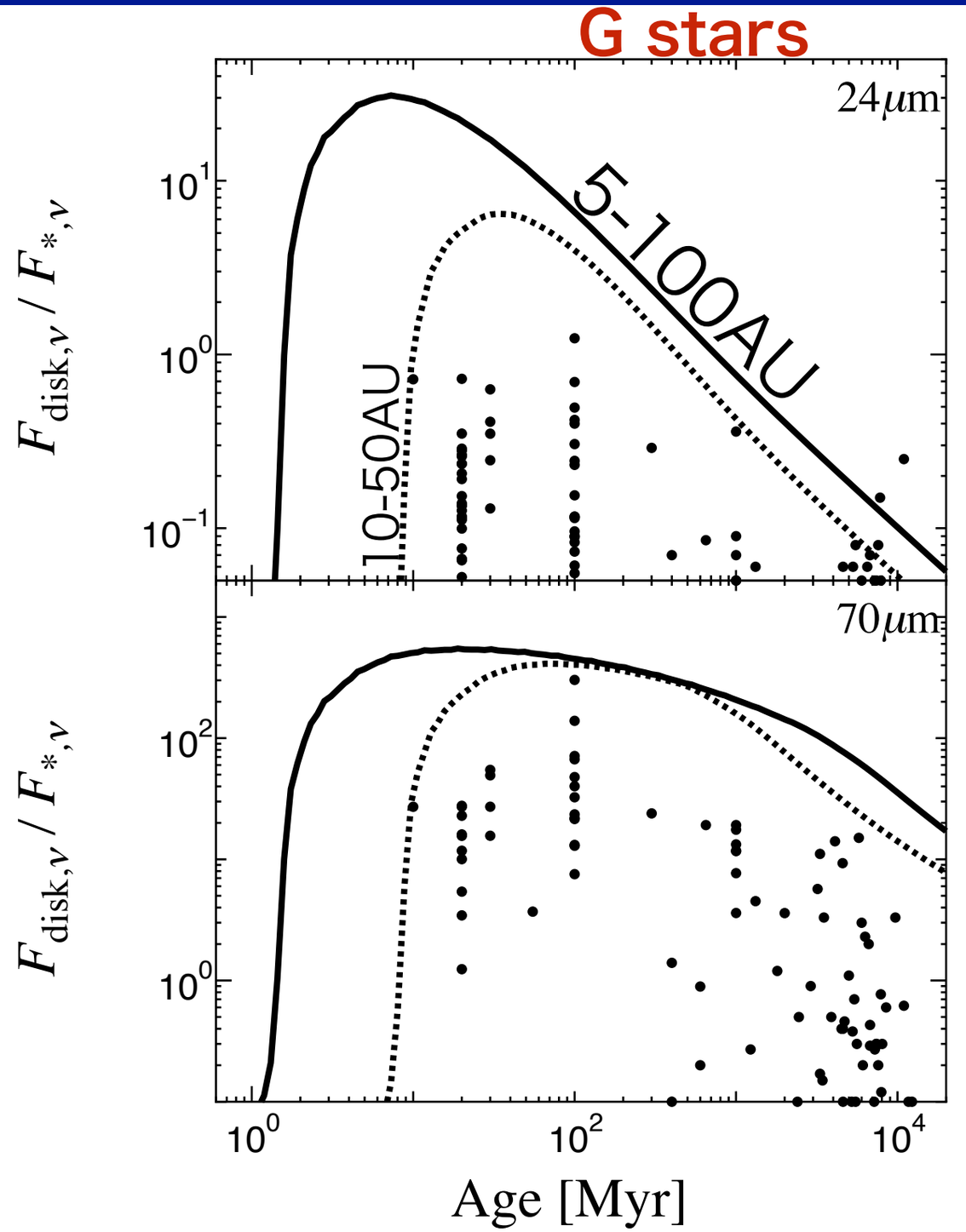
@20 μm



- Planet formation propagates inside out.
- Disk fluxes increase at planet formation.

Disk Flux Evolution

- When planet formation starts at the inner edge, the fluxes increase.
- The flux at 24um decreases, because the growth front reaches the cold disk (> 20-30AU).
- After planet formation finishes at the outer edge, the flux at 70um diminishes.



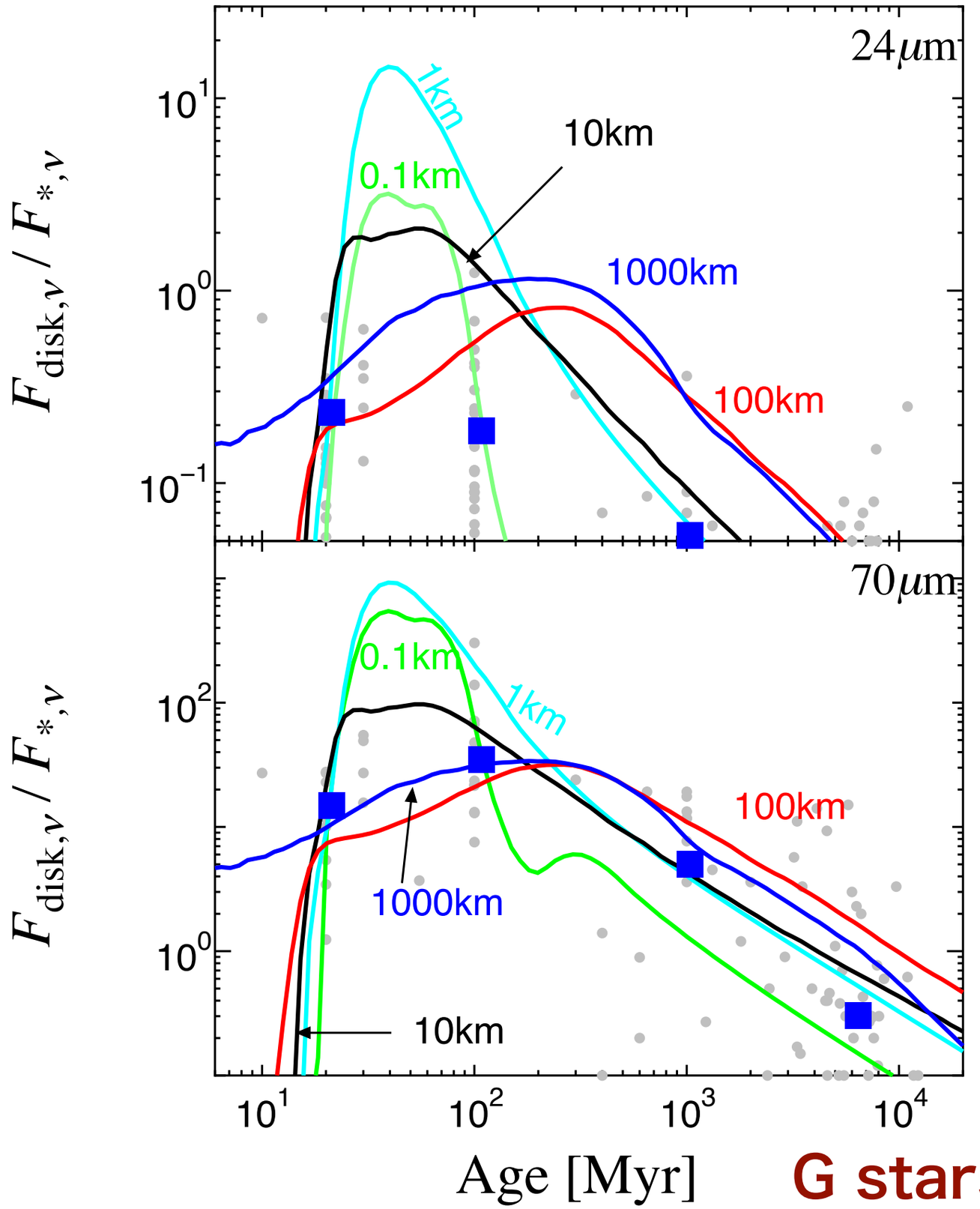
Smooth disks cannot explain Spitzer observation.

(Kobayashi & Löhne 2014)

Embryo Formation & Disks

- Comparison with Spitzer Space Telescope observation.
- Planet formation can explain somewhat observations if planetesimal disks are 20-30AU

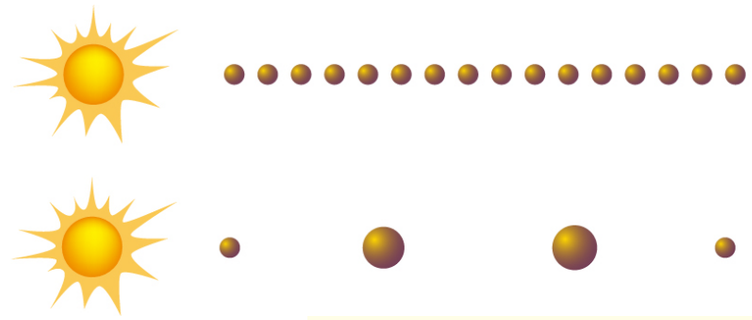
(Kobayashi & Löhne 2014).



Giant Impacts & Debris Disks

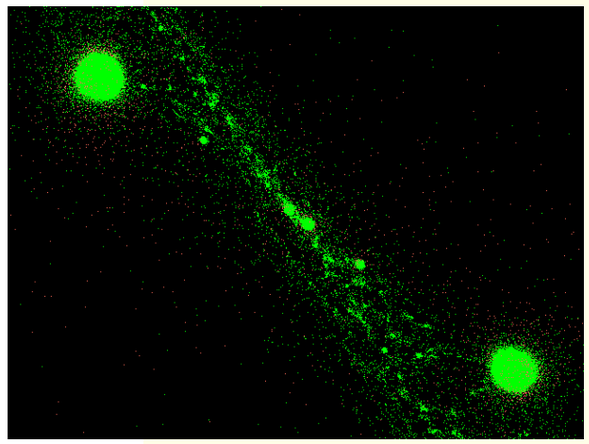
Model

- Orbital Integration
  (Kokubo & Genda 2010)



  - 16 isolation-mass protoplanets
    (total mass: 2.3 Mearth)

- Giant Impacts

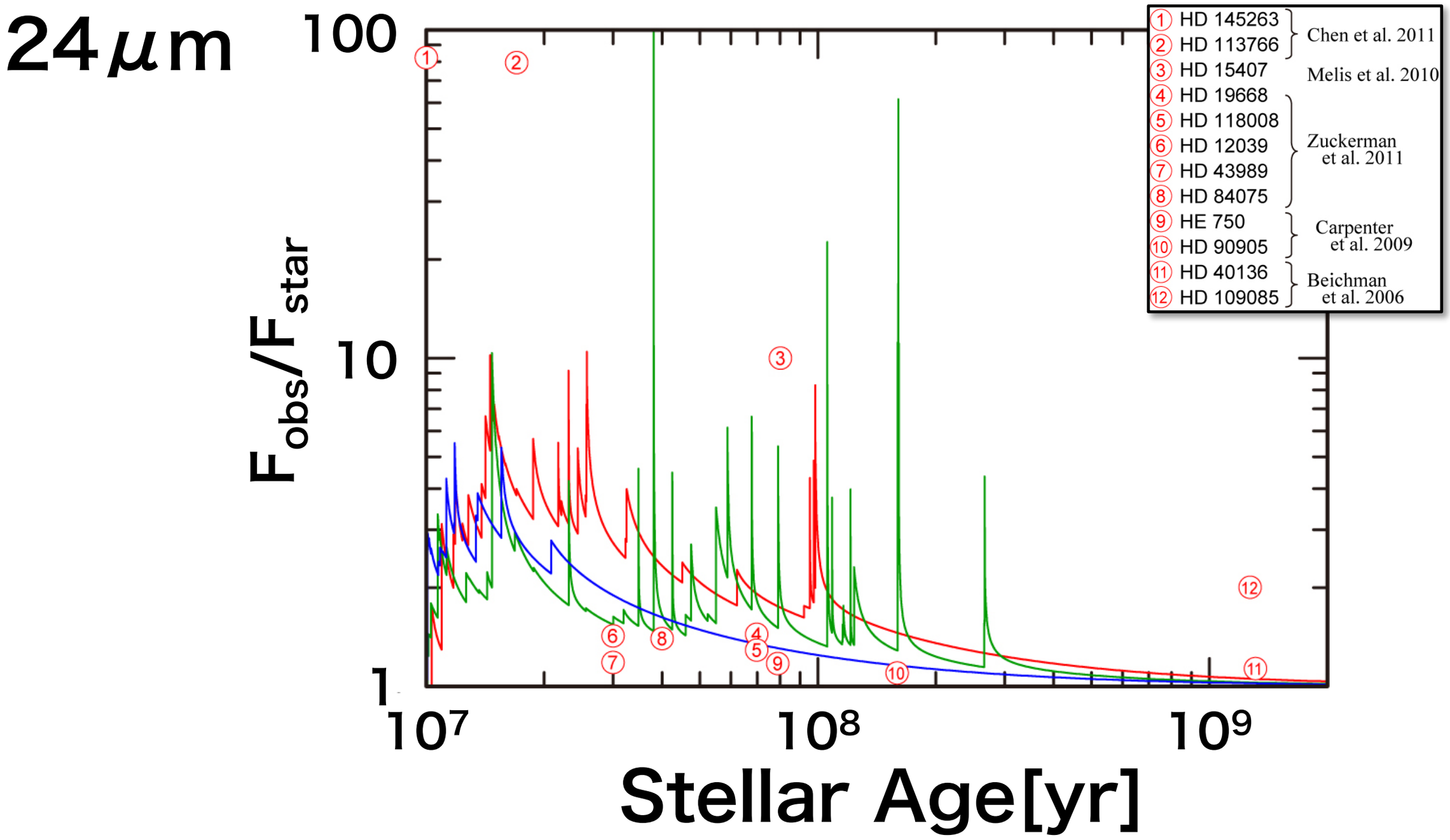


  - SPH simulation
    with 100K particles (Genda et al. 2012)

- Evolution of dust

  - Collisional cascade
    (Kobayashi & Tanaka 2010)

Disks by Giant Impacts



(Genda, Kobayashi, & Kokubo, submitted to ApJ)

Summery

- Planet formation produces debris disks:
  - Planetary embryo formation from planetesimals may explain cold disks.
  - Collisions between embryos, giant impacts, may form warm debris disks.

- For young (10-100 Myr) solar system, planet formation produces warm debris disks caused by giant impacts and cold disks by embryo formation.
- However, resulting debris disks strongly depend on the total mass of initial planetesimal disks.