Dust in disks

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MAD summer school
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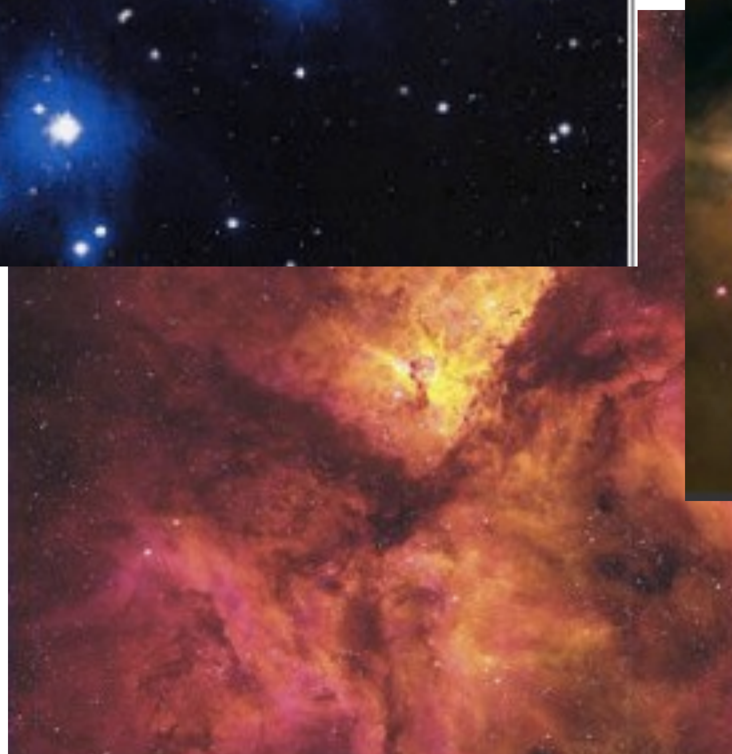
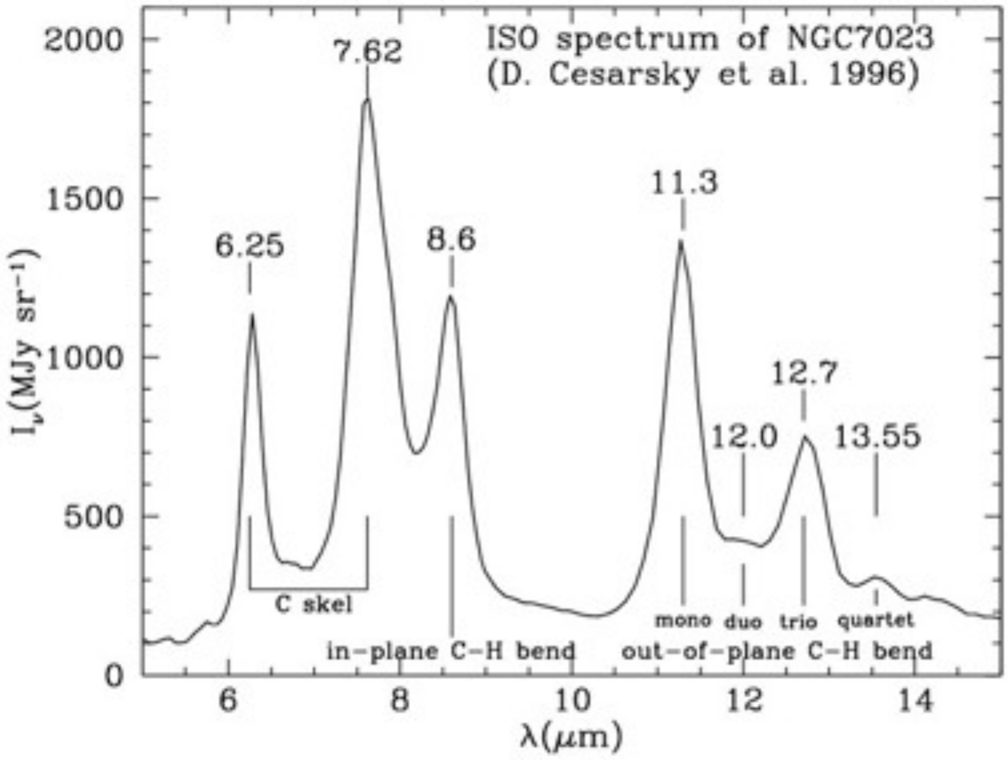
Part I
Dust in the ISM

Radiation meets dust

Dust meets radiation ISM



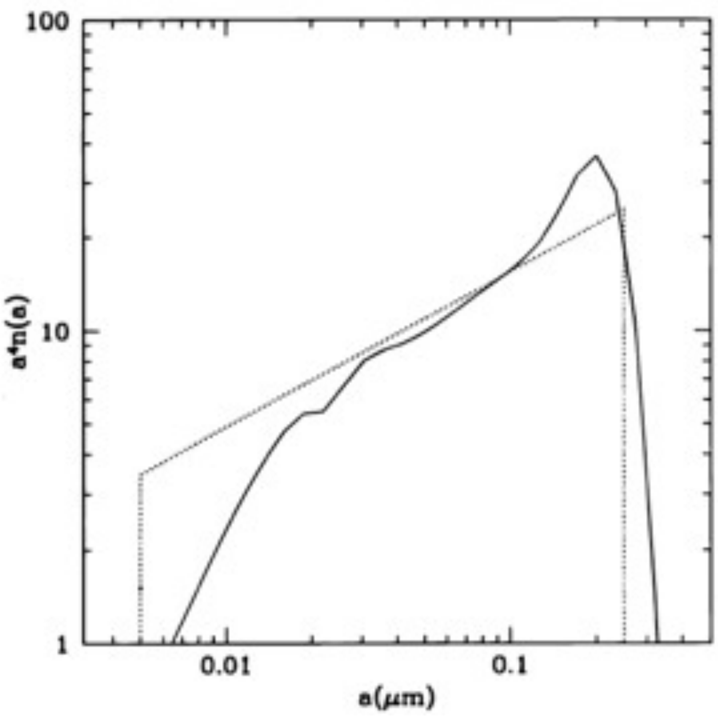
Dust in the ISM

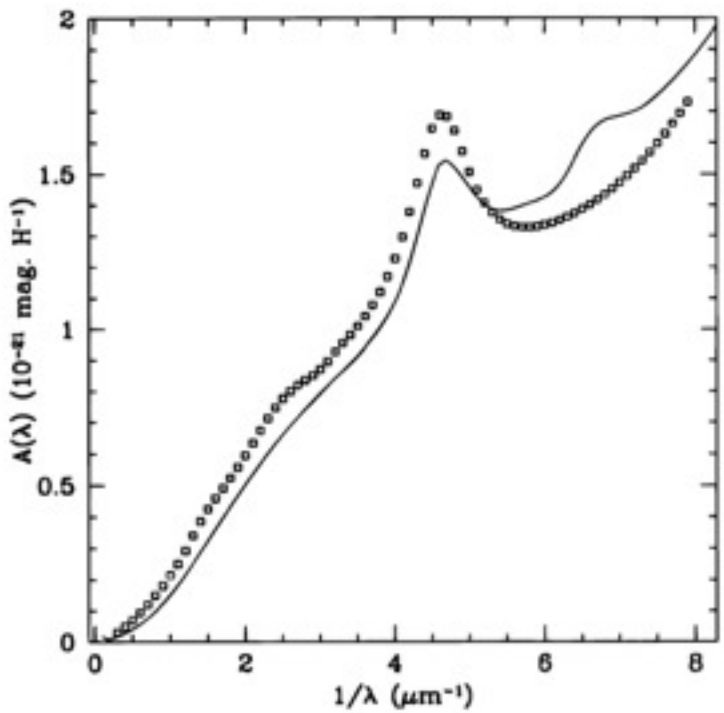


- polycyclic aromatic hydrocarbon (PAH) molecules

- similar evidence for silicates and graphite

Grain size distribution



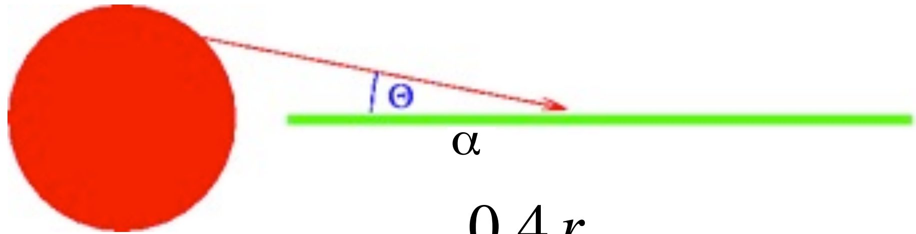


From ISM to disks

- Jeans instability
- Collapse
- Conservation of angular momentum
- Disks around forming stars
- initially gas/dust mass ratio and grain size distribution = ISM

Part II
Basics about (irradiated) disks

Irradiating a flat disk



$$\alpha \cong \frac{0.4\, r_*}{r}$$

Irradiation flux:

$$F_{\rm irr} = \alpha \frac{L_*}{4\pi r^2}$$

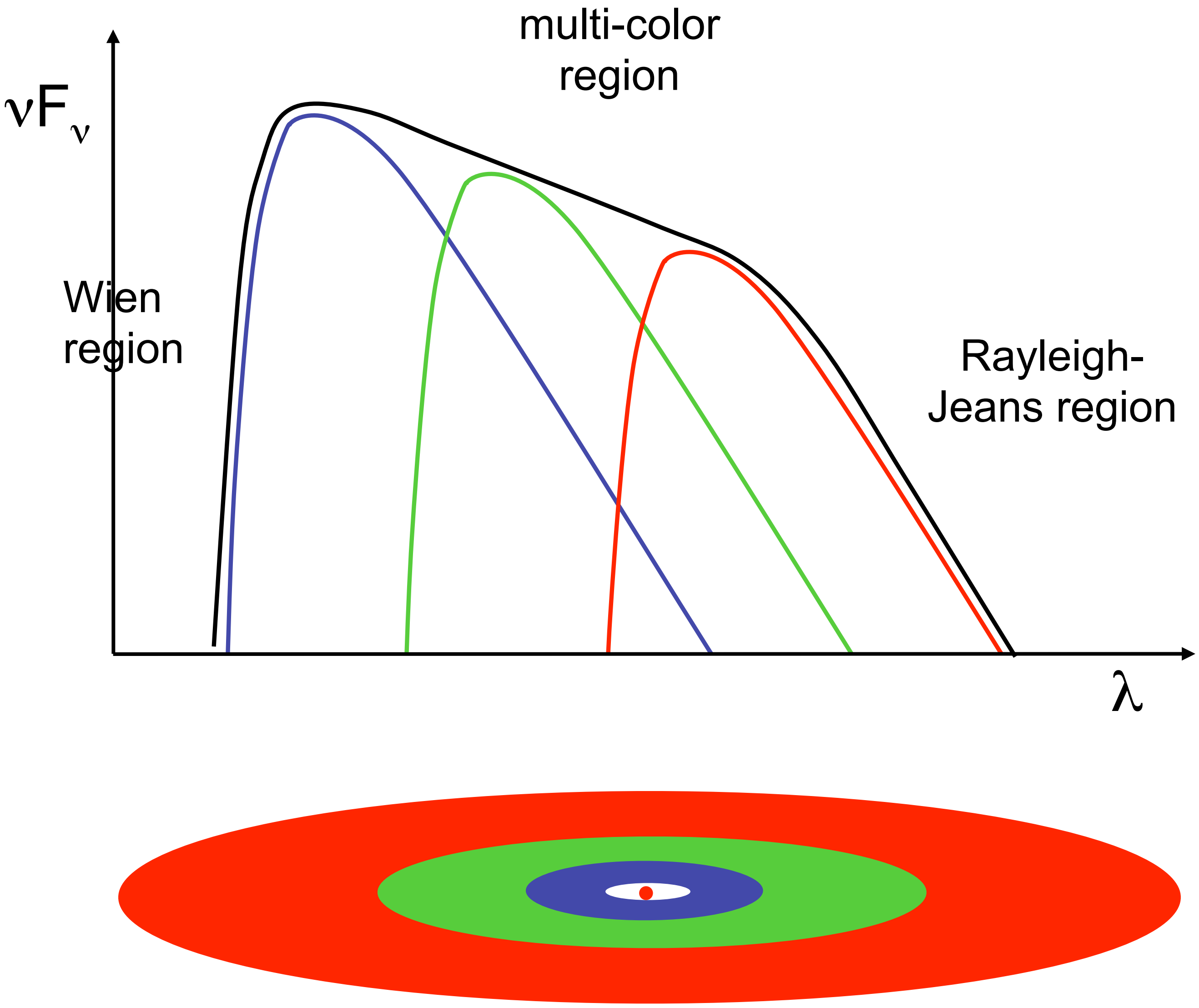
Cooling flux:

$$F_{\rm cool} = \sigma T^4$$

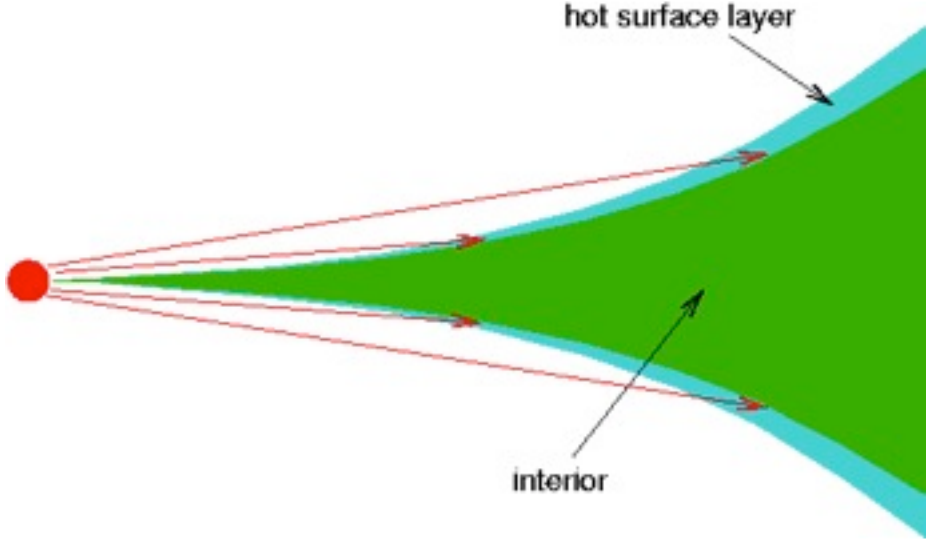
$$T = \left(\frac{0.4\, r_* L_*}{4\pi\sigma r^3} \right)^{1/4}$$

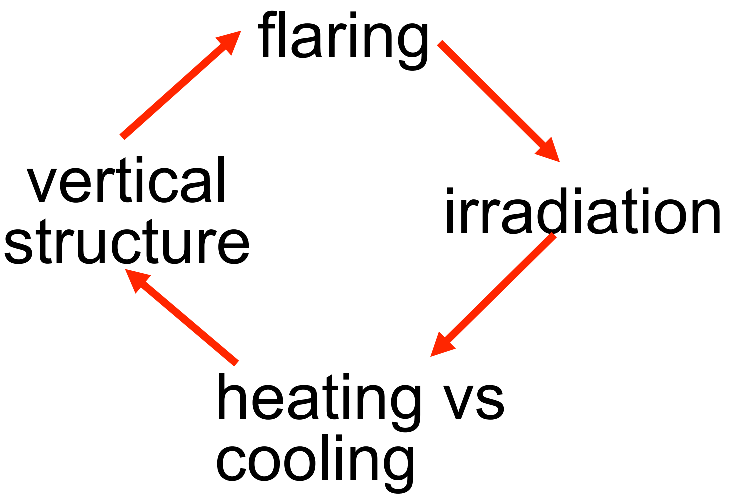
$$\boxed{T \propto r^{-3/4}}$$

Multi-color blackbody disk SED

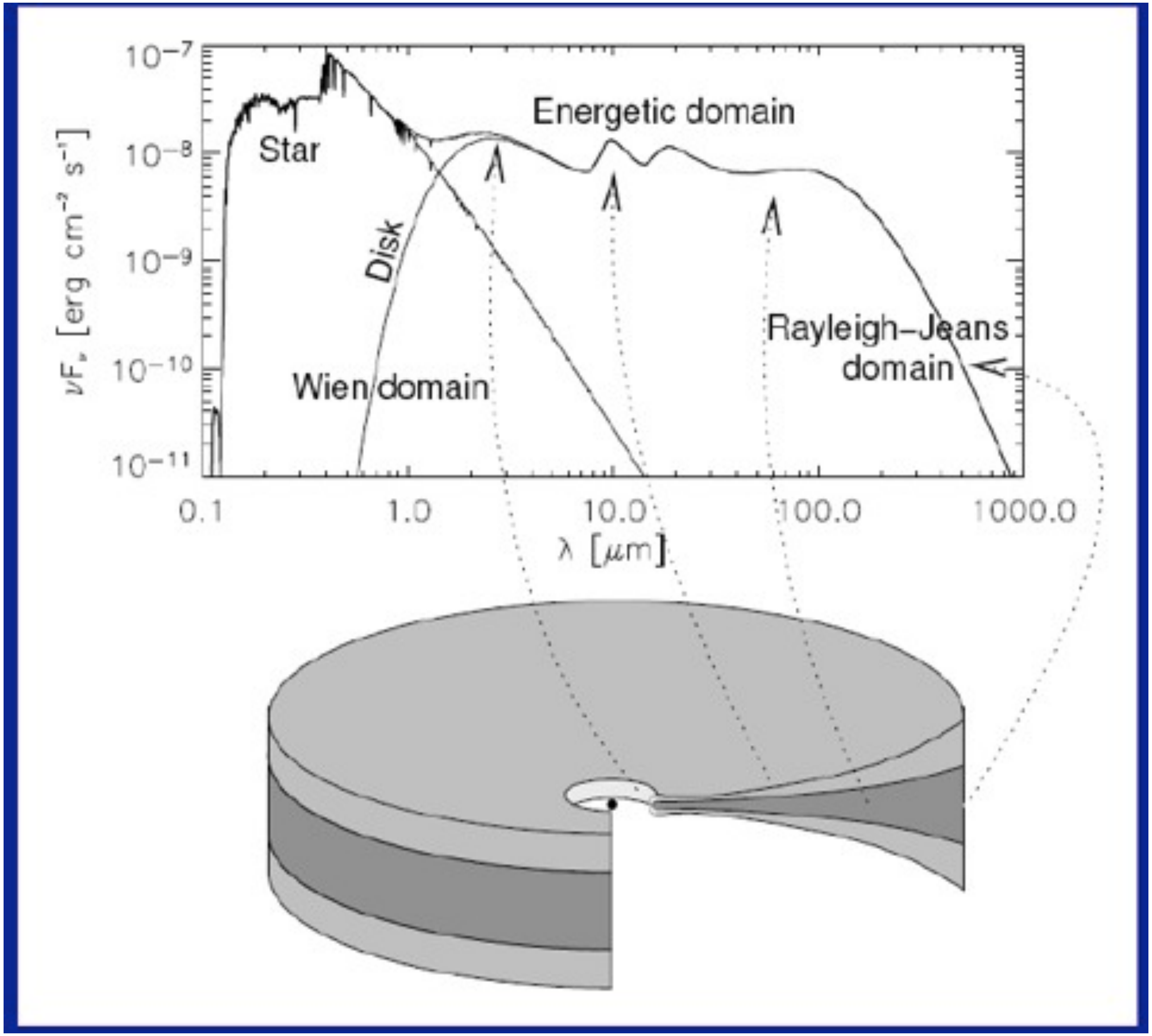


Flared disks





Understanding SEDs



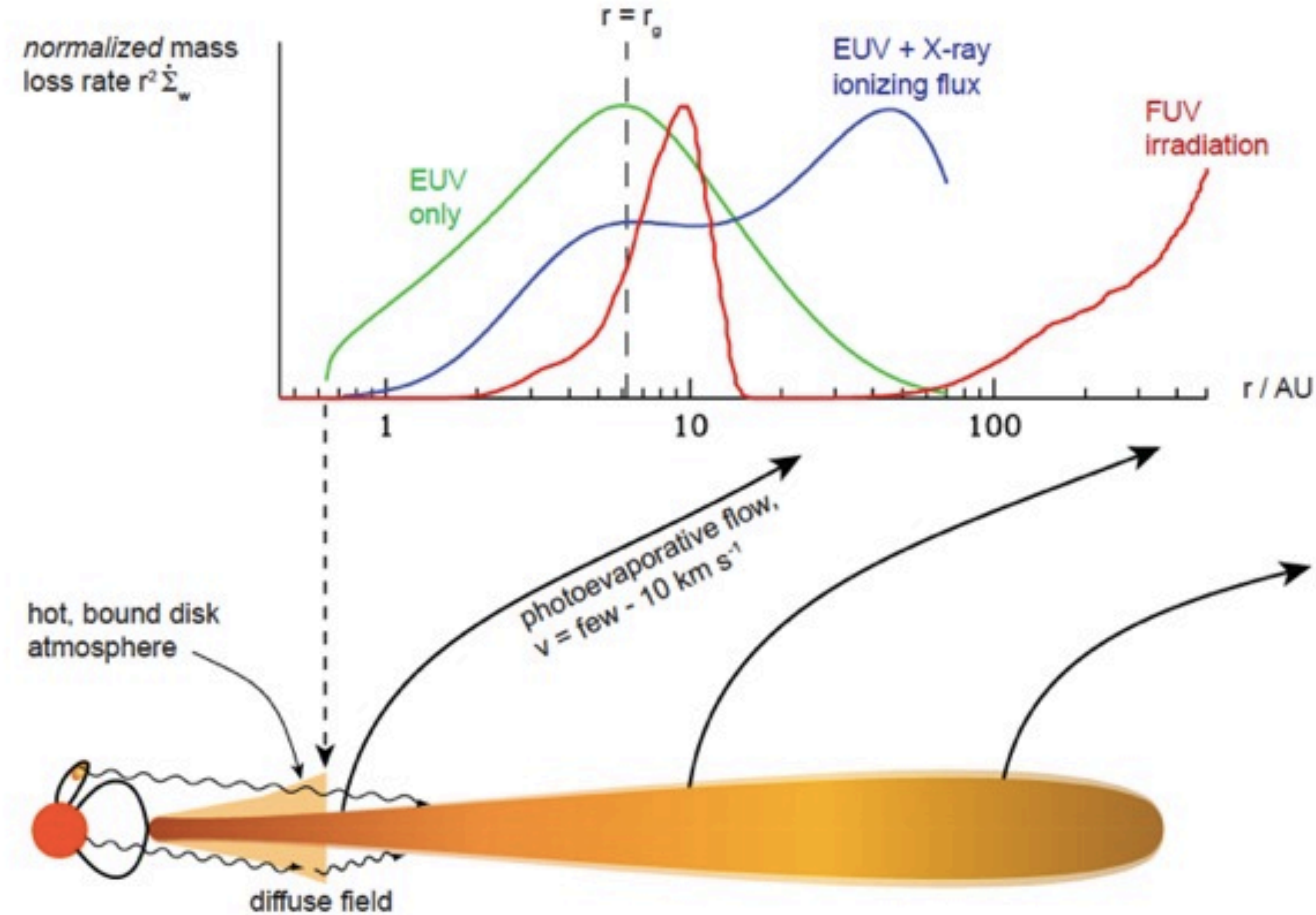
BUT: disks evolve!!

- accretion – disk mass is reduced
- gas/dust mass ratio?
- photoevaporation becomes more important
- grains may grow
- grains settle in the midplane

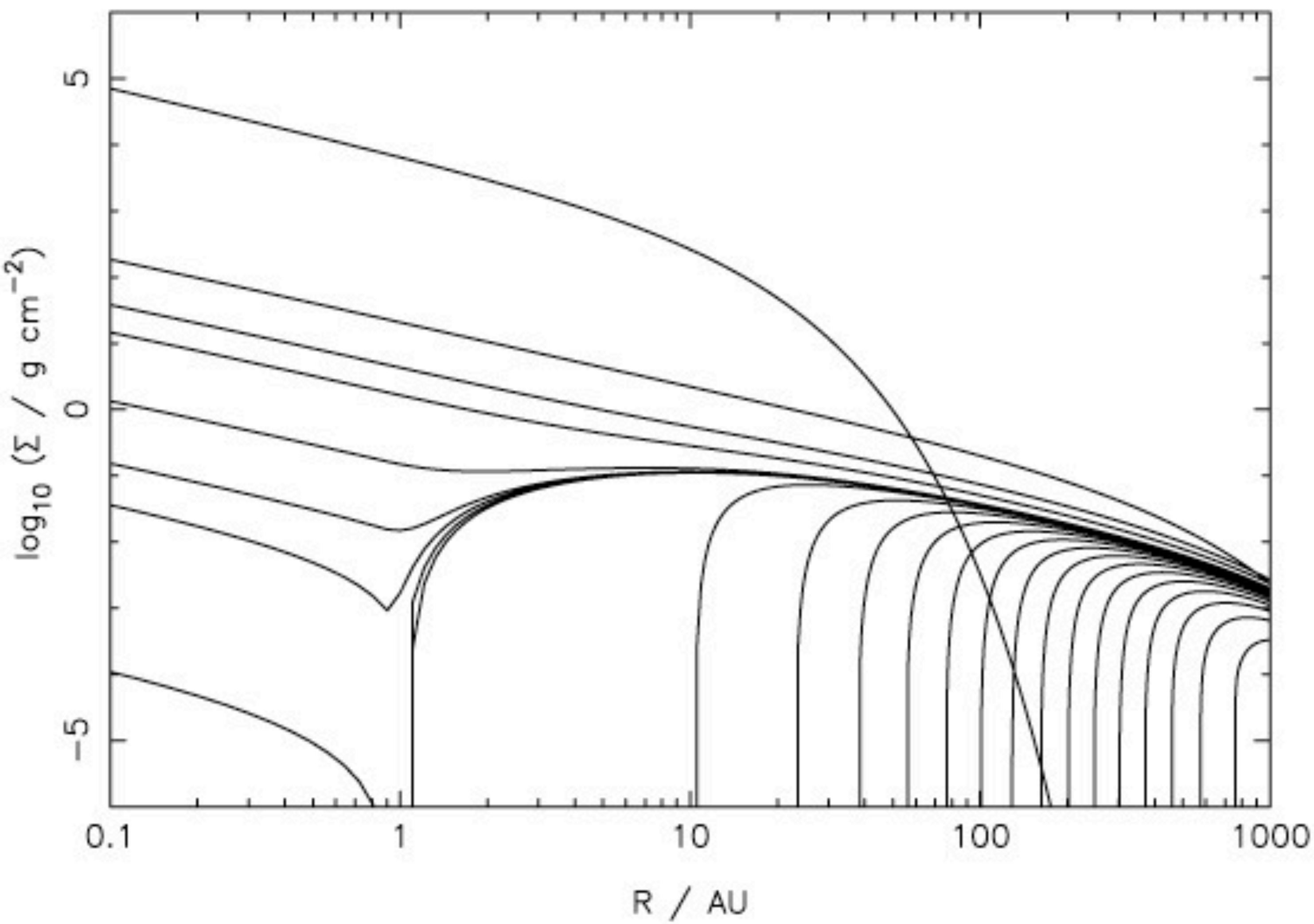
Accretion: viscous evolution

- thin disk
- alpha viscosity/MRI
- vertical structure decouples from radial evolution
- viscous time scale a few million years
- mass and accretion rate should decrease smoothly

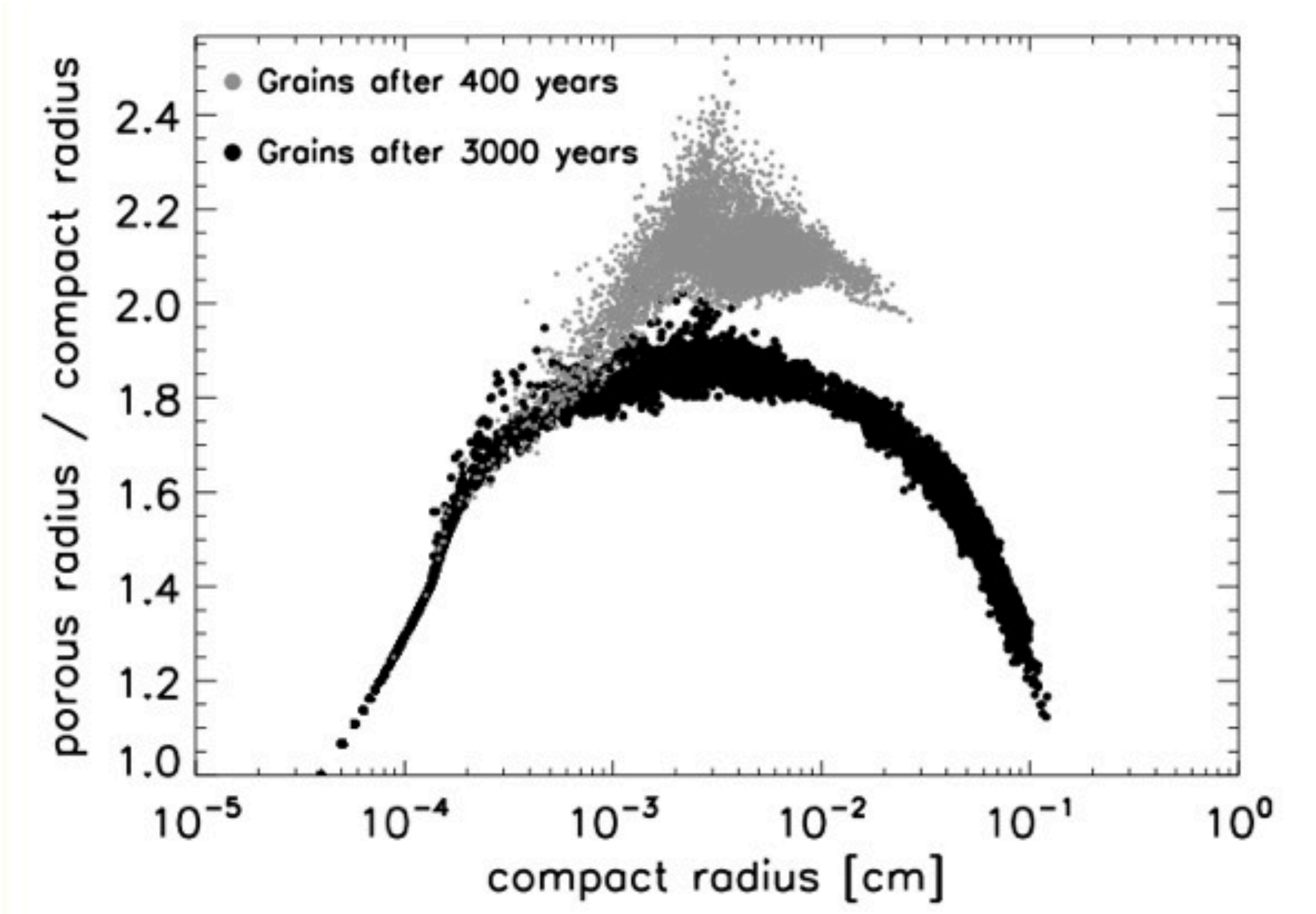
Photoevaporation



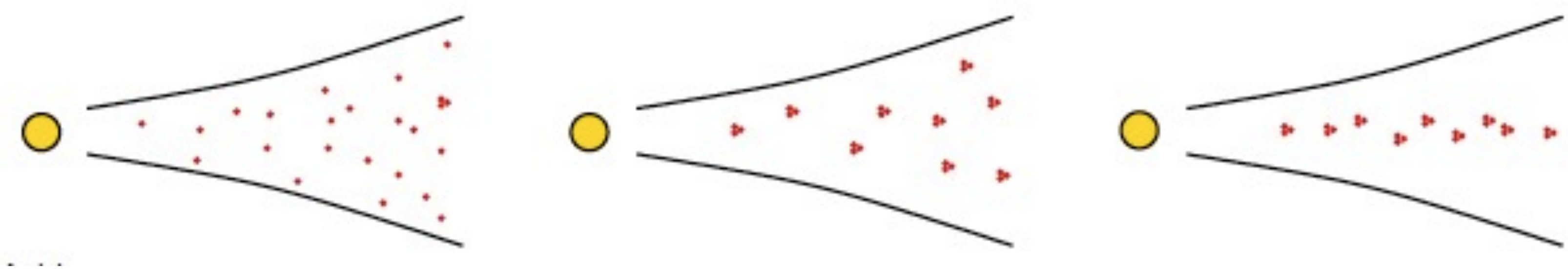
Photoevaporation



Disk evolution: grain growth



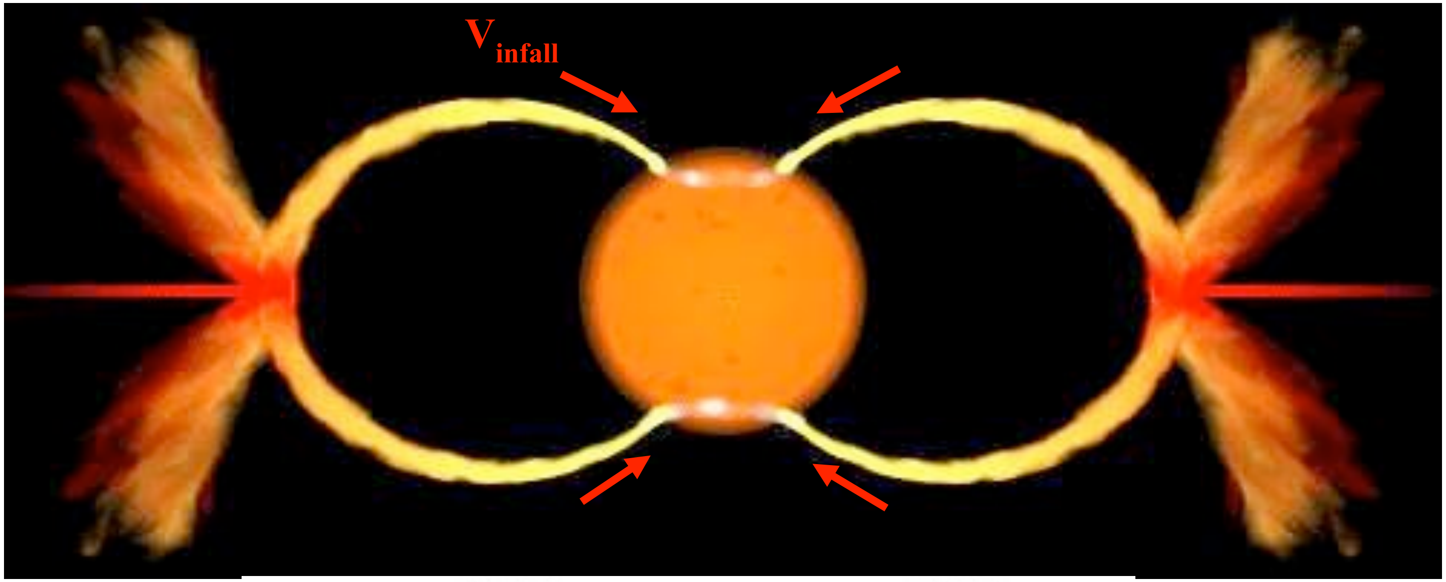
Dust settling

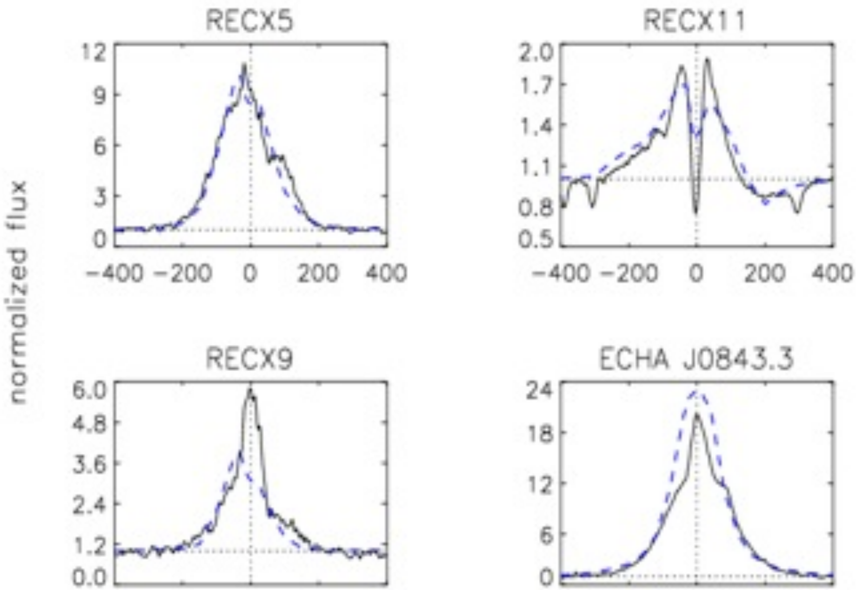


- without the gas: dust particles would oscillate around the midplane!
- drag forces let them fall slowly
- grain growth supports dust settling

PART III: observing disk evolution

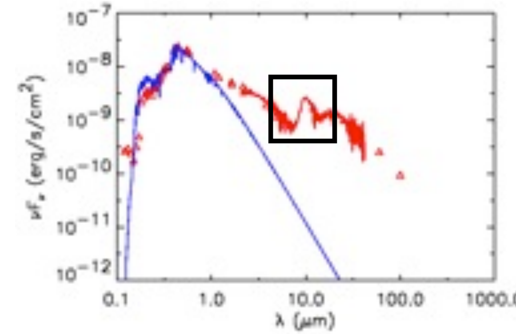
Measuring accretion rates

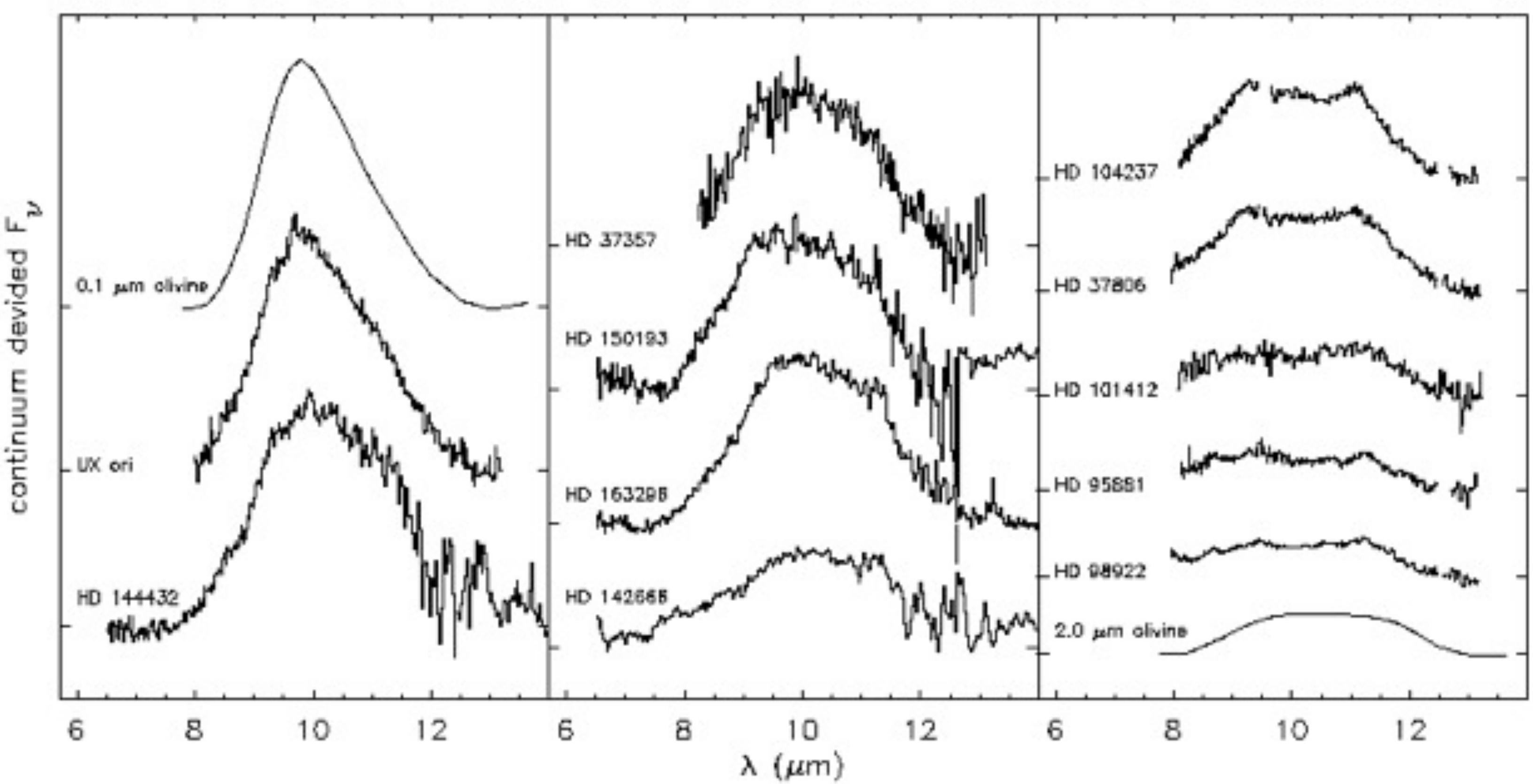




Measuring grain sizes in disks

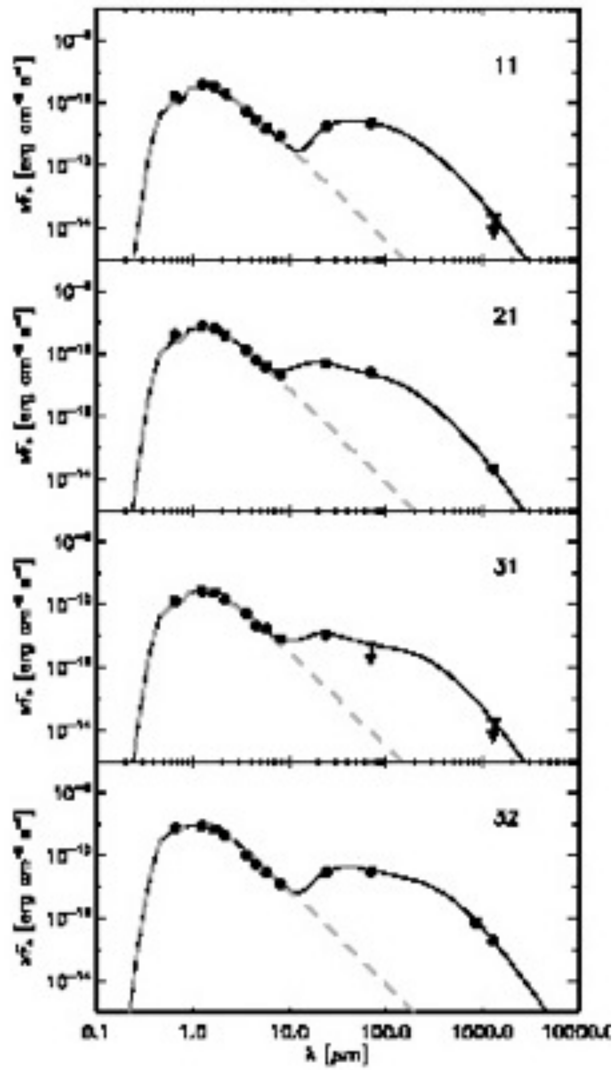
The 10 micron silicate feature shape depends strongly on grain size. Observations show precisely these effects. Evidence of grain growth.





van Boekel et al. 2003

Measuring dust settling



H@100AU < 4 in all Oph cases

Measuring disk masses

$$I_\nu = B_\nu[1 - \exp(-\tau_\nu)]$$

$$\tau_\nu = \int \rho\kappa_\nu ds = \kappa_\nu \Sigma$$

$$\kappa_\nu \propto \nu^\beta < 1 \text{ for small } \nu \ \ (\text{long } \lambda)$$

$$F_\nu = \int I_\nu d\Omega \simeq B_\nu \tau_\nu \Omega = \kappa_\nu B_\nu \Sigma A / D^2$$

$$\Rightarrow M = F_\nu D^2 / \kappa_\nu B_\nu$$

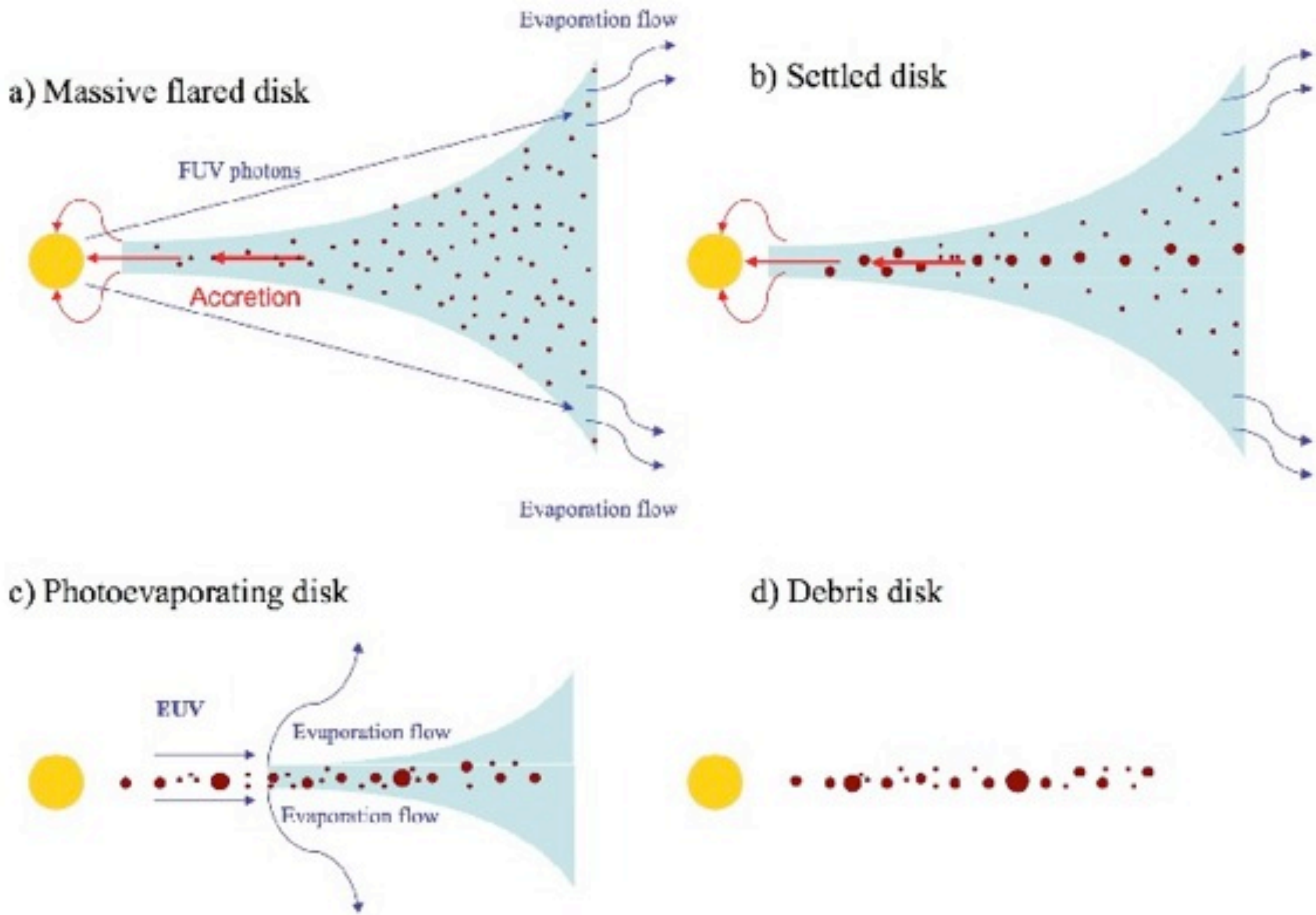
Measuring disk masses

$$M = F_\nu D^2 / \kappa_\nu B_\nu \qquad B_\nu \approx 2kT/\lambda^2$$

The main uncertainty is the opacity, κ_ν

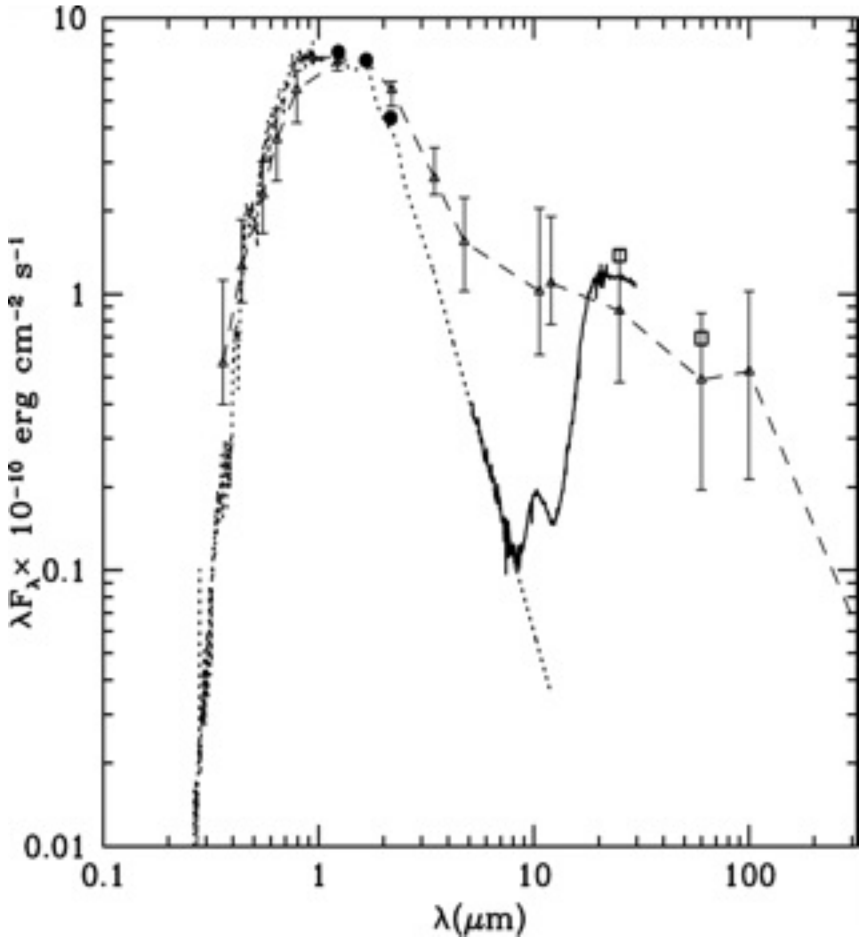
- we measure dust masses up to some maximum size, $a_{max} \approx 3\lambda$ (Draine 2006)
- total masses assume a gas/dust ratio
- *disks are NOT like the ISM !* (where $a_{max} << 1mm$, gas/dust ratio = 100)
- disk *dust* masses are uncertain by a "few"
- *total* disk masses are highly uncertain

Disk evolution



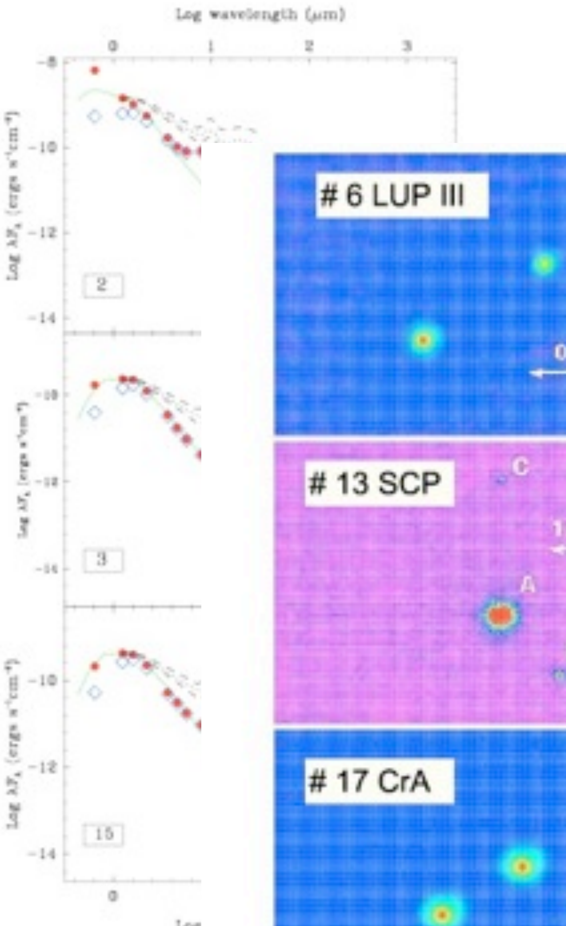
Part IV: transition disks

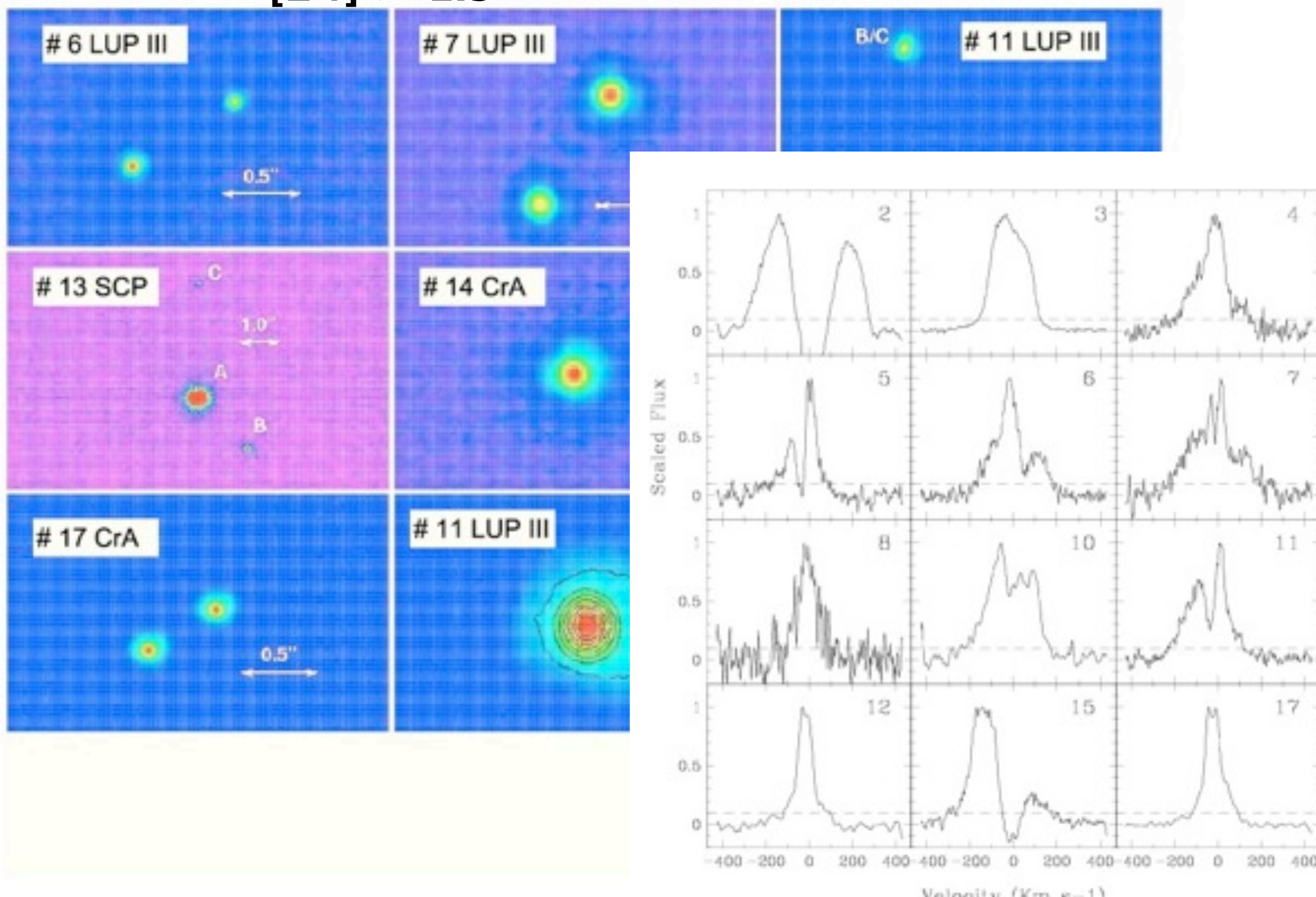
Inner opacity hole



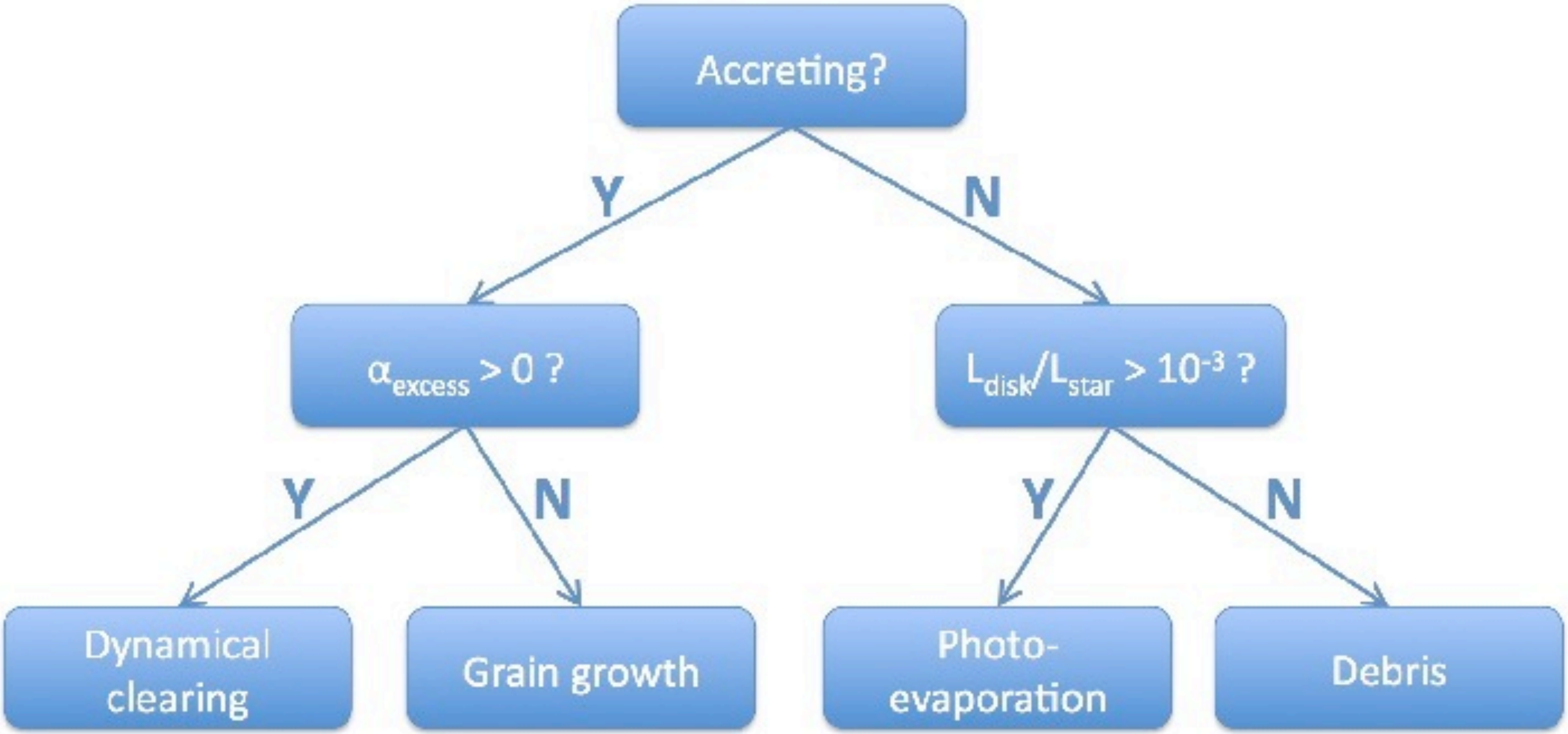
Color-selection and follow-up

For c2d GB YSOc: [3.6]-[4.5] < 0.25 & [3.6]-[24] > 1.5

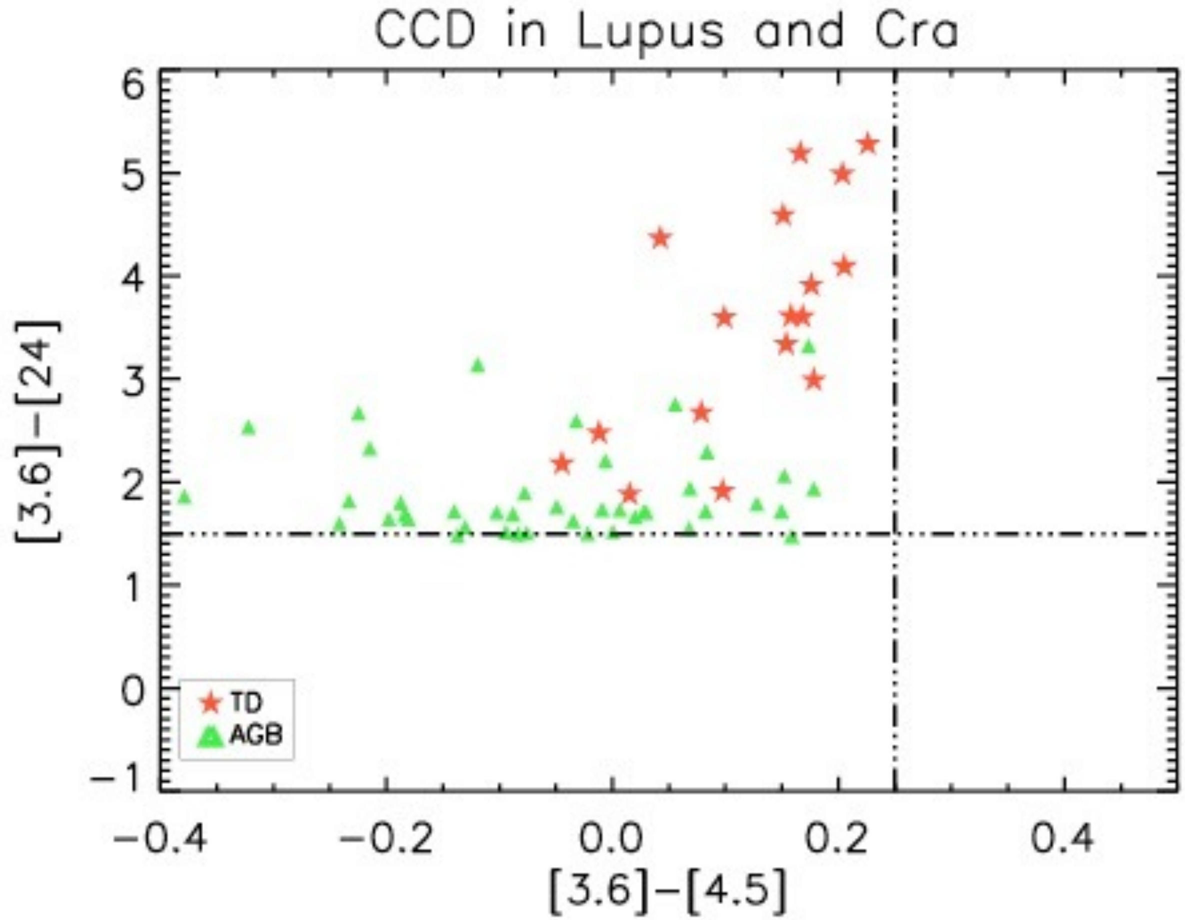




Classifying transition disks



Results: AGB contamination



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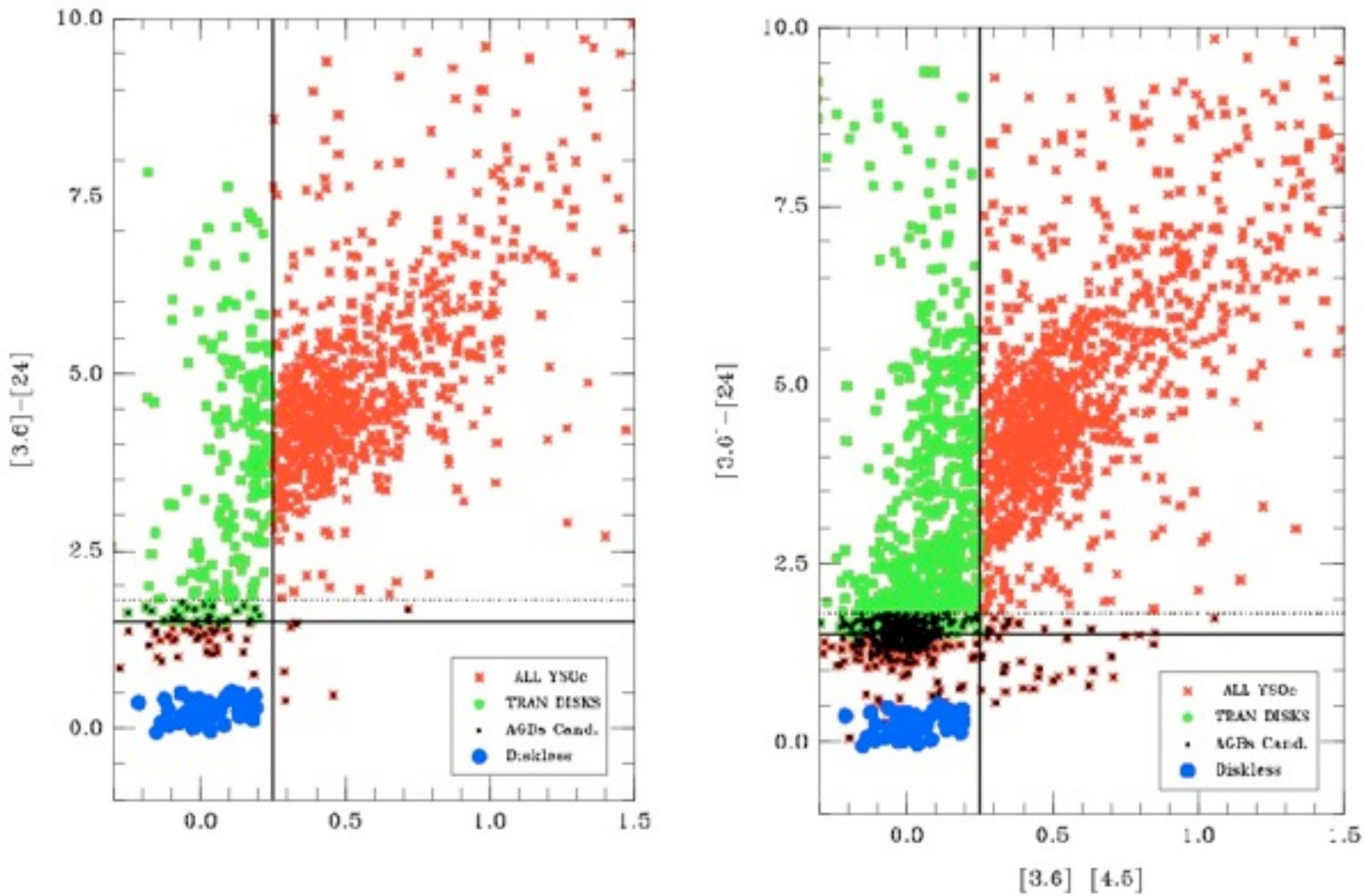
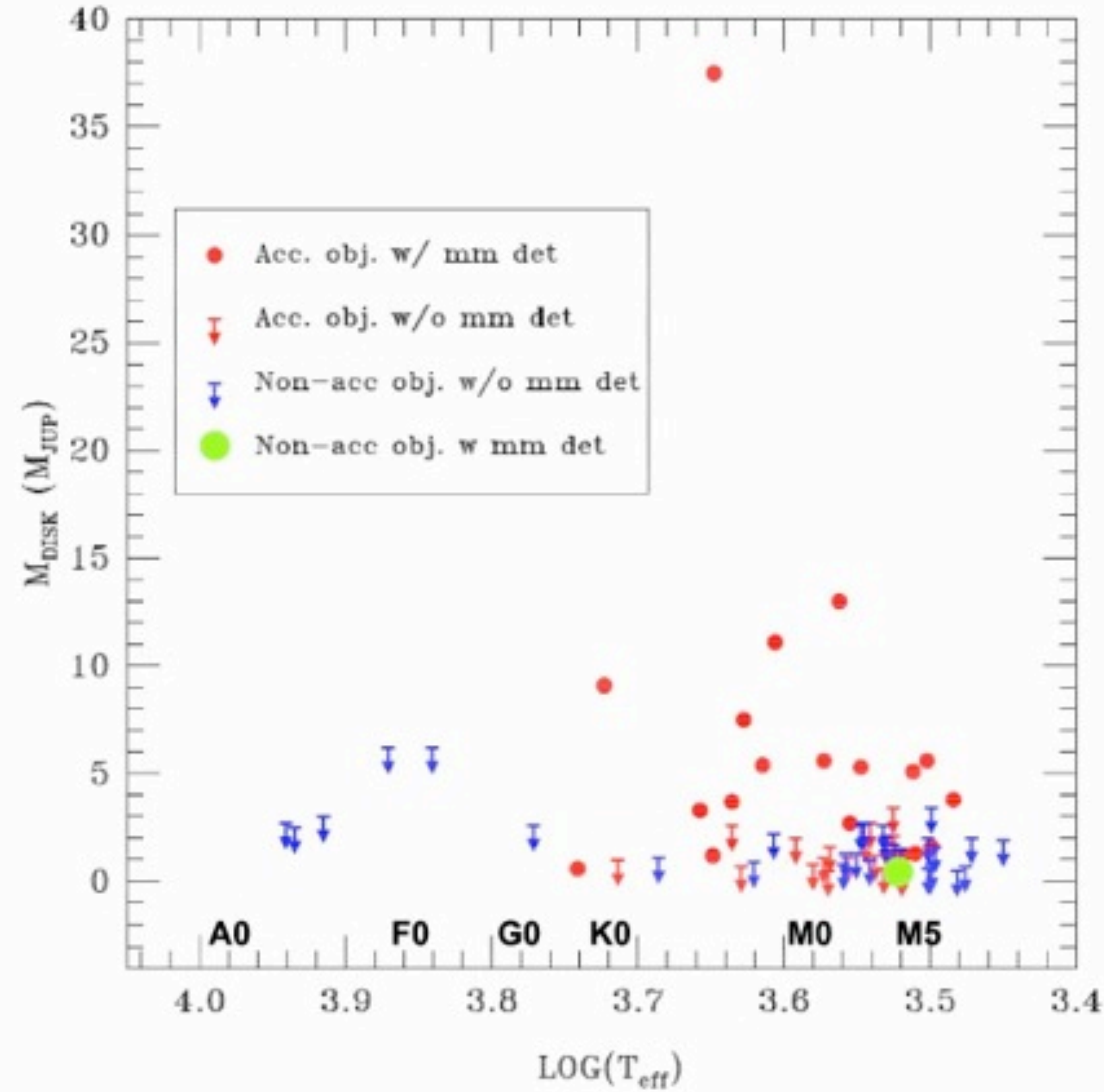
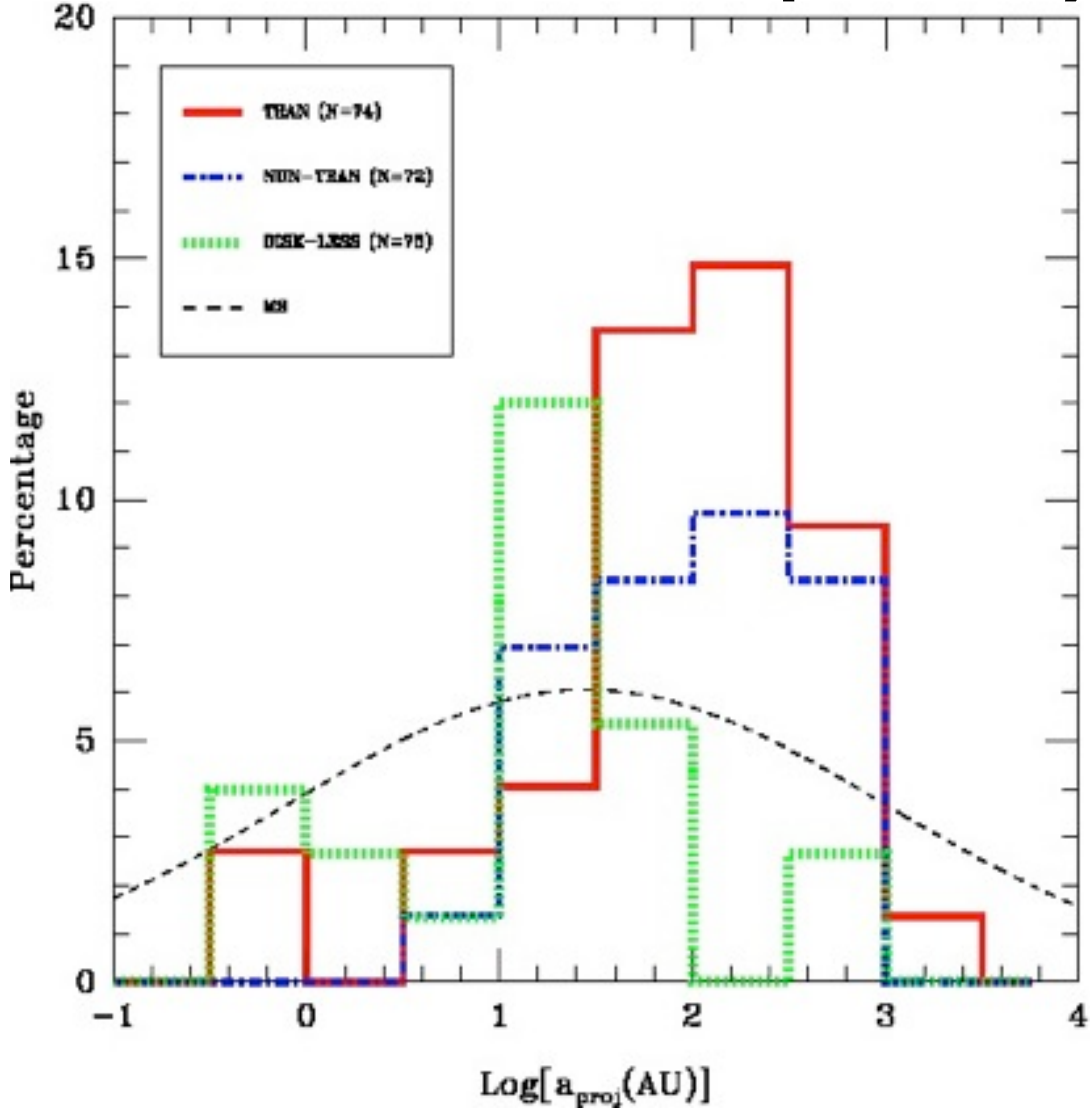


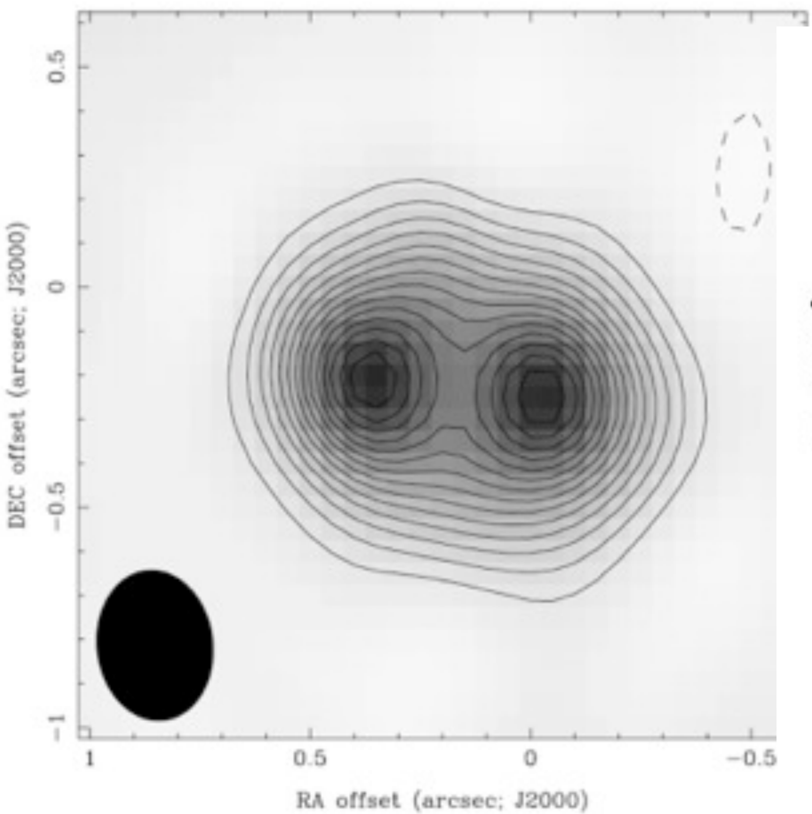
Results: photoevaporation

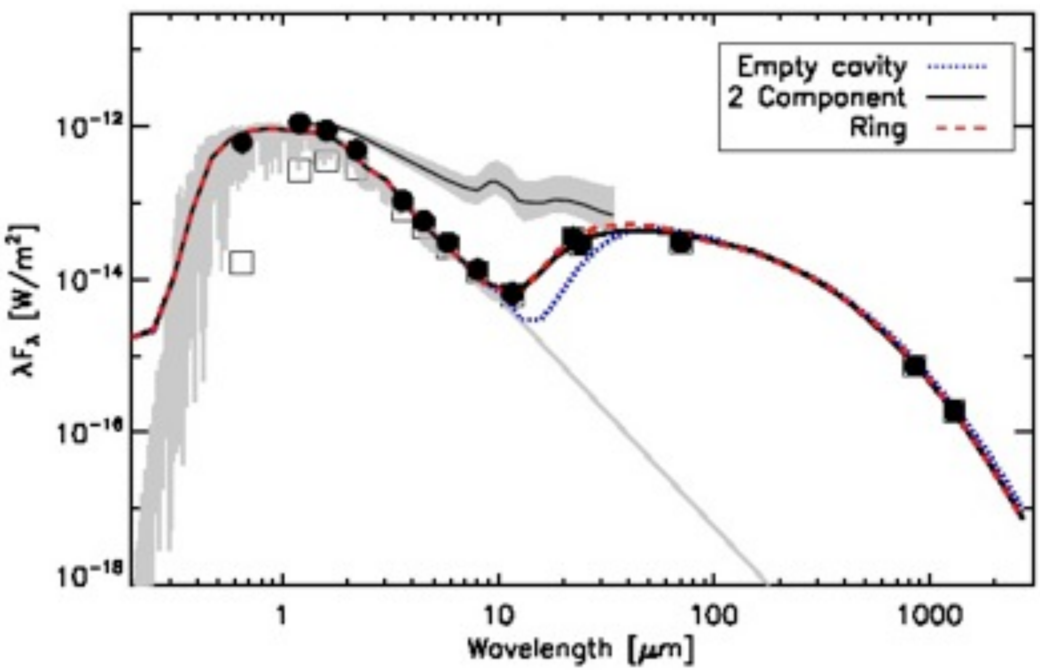


Results: multiplicity



Results: planet formation the case of Tran 32





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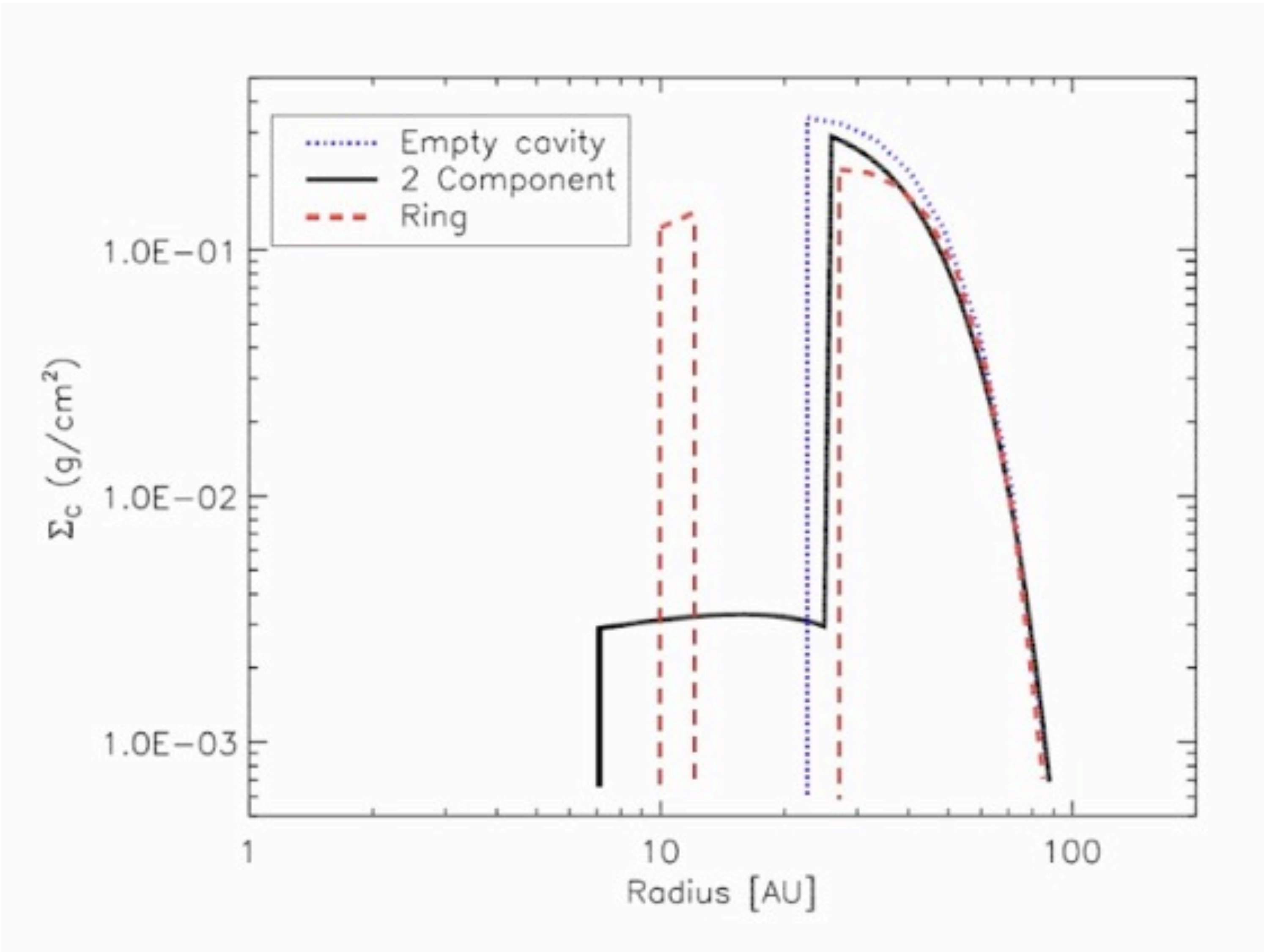
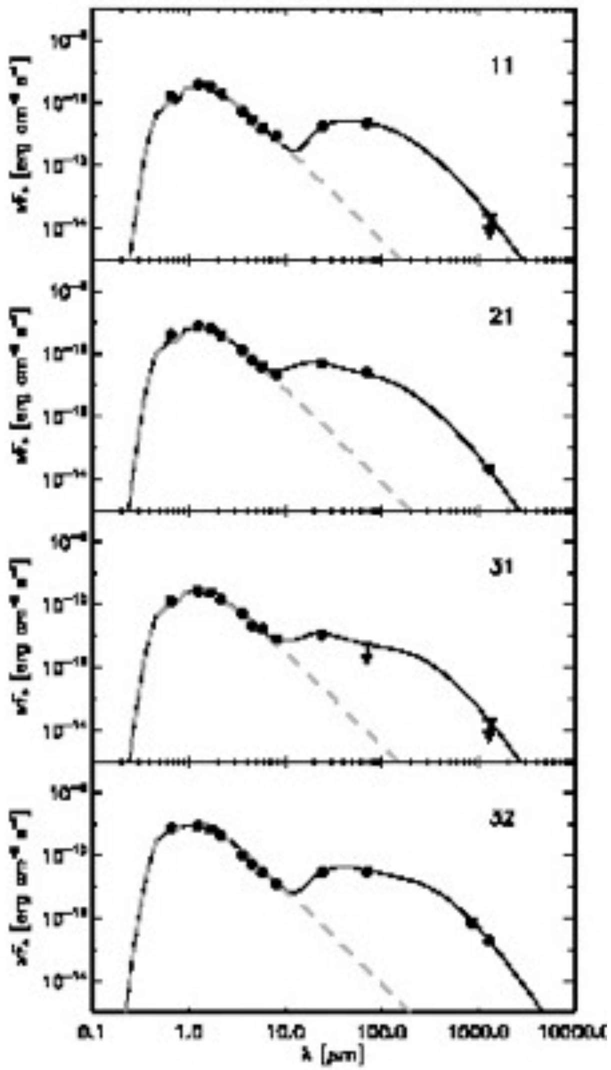
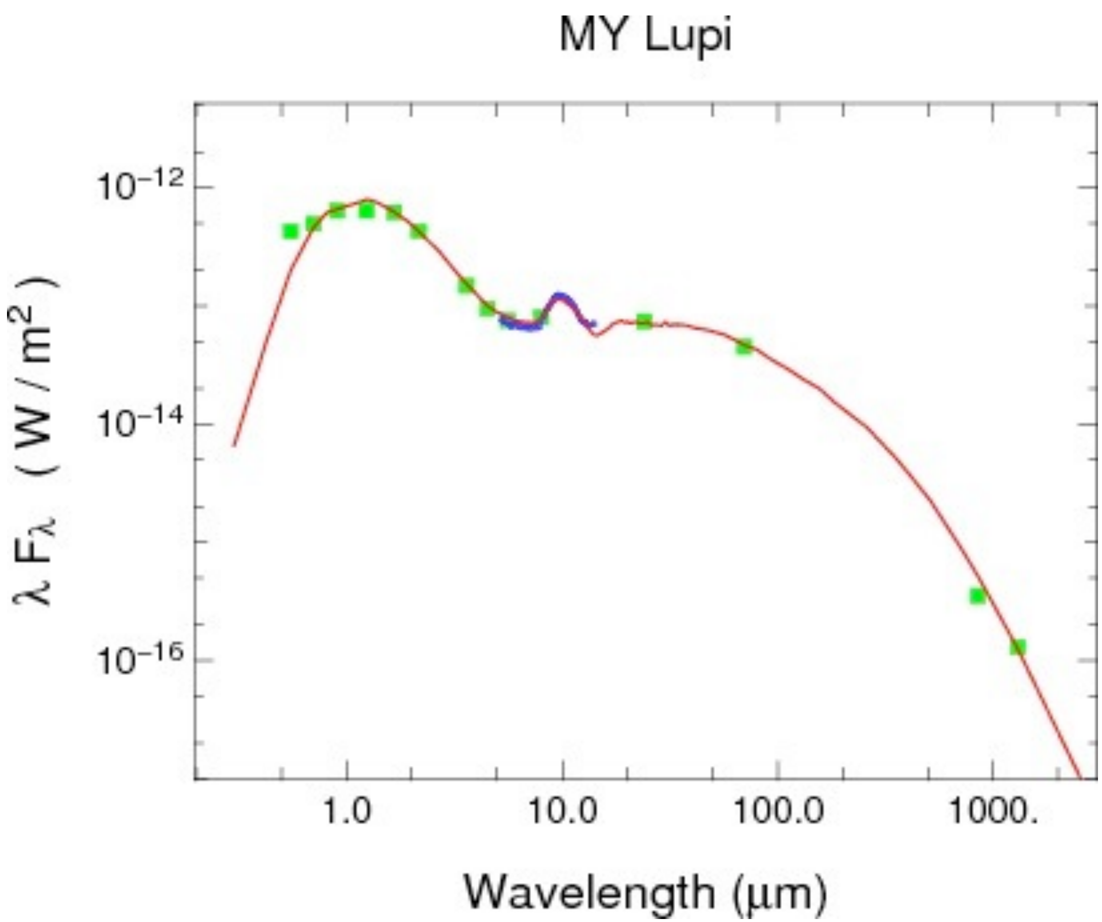


Results: planet forming disks are flat



H@100AU < 4 in all Oph cases

Results: planet formation direct detection?



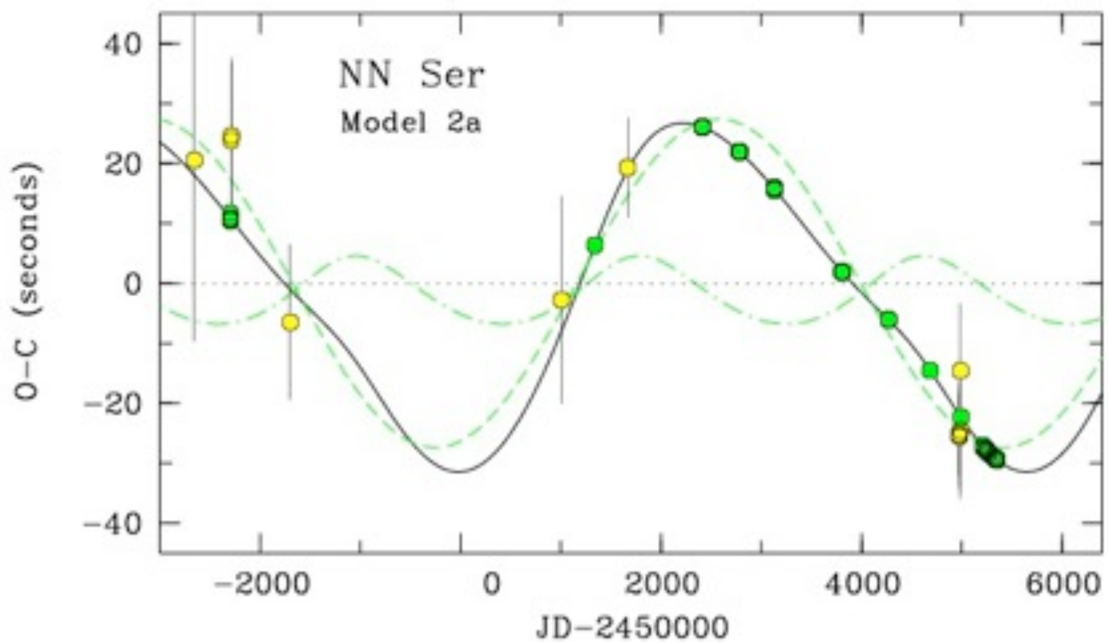
Summary

- Dust dominates IR–mm emission.
- Disk evolution is affected by grain. growth and photoevaporation.
- Evolution becomes visible in transition disk.
- We detected signs of planet formation in several systems.

Results: planet formation direct detection?

- The Dream-Team March VLT/NaCo SAM-run:
- Probable detections in 4 systems potentially currently forming planets.
- SAM experts are currently discussing.

Weirdos: Planets around compact binaries



Recent and future papers

- Beuermann et al. 2010
- Cieza et al. 2010, 2012ab
- Romero et al. 2012
- Orellana et al. 2012

In prep.:

- Schreiber et al.: MY Lup
- Cieza et al.: T35
- Zorotovic & Schreiber: second generation planets

Future Projects

ALMA cycle 1:
1) Resolving disk structure of MY Lup, T35, Tran32
2) Testing for gas-content in photoevaporating and debris disks
3) Measuring gas to dust ratio of TDs (see talk by Menard)
4) Completing our survey of TDs in Serpens (measure disk masses)

Others:

a) Radial velocity survey of TD without (detected) companion
b) Eclipse timing survey of PCEBs

The Valpo-dream-team

- Hector: transition disk catalogue, SAM, polarymetry, ALMA
- Gisela: Apex, ALMA
- Caludio: ALMA, APEX, TD models, eclipsing PCEBs
- Steven: eclipsing PCEBs (arriving June/July)
- Alberto: stellar parameters, optical spectroscopy
- Monica: second generation planets around

External collaborators

- Lucas Cieza
- The SAM experts (Lacour, Ireland, Kraus, Tuthill)
- ULTRACAM experts (Marsh, Gaensicke)

Dielectric function