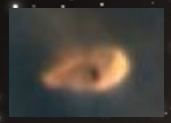
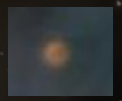
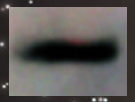
Disk Evolution And Dissipation at an Age of a Few Myr





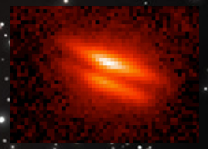


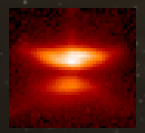
Elise Furlan

Spitzer Fellow

Jet Propulsion Laboratory,

California Institute of Technology



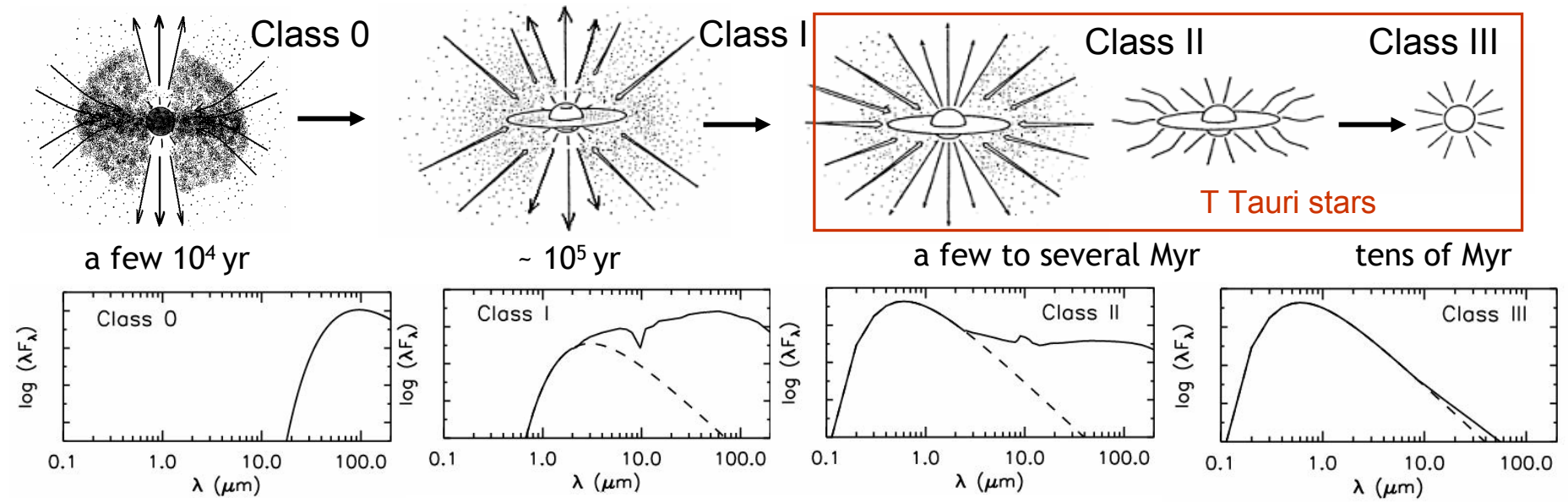


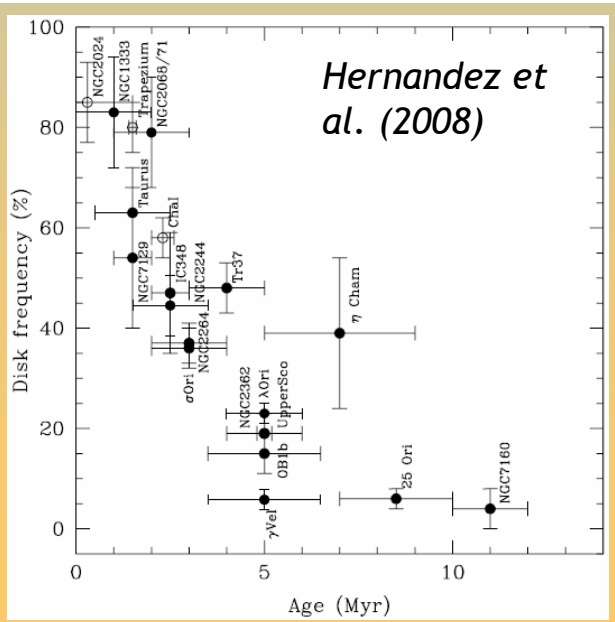
in collaboration with members of the IRS_Disks team:

D. M. Watson, W. J. Forrest, Manoj P., K. H. Kim (Rochester),
M. K. McClure, N. Calvet, L. Hartmann (Michigan), C. Espaillat (CfA),
P. D'Alessio (UNAM), K. Luhman (Penn State), B. Sargent (STScI)

Background credit: NASA/JPL-Caltech

Low-Mass Star Formation and Disk Evolution





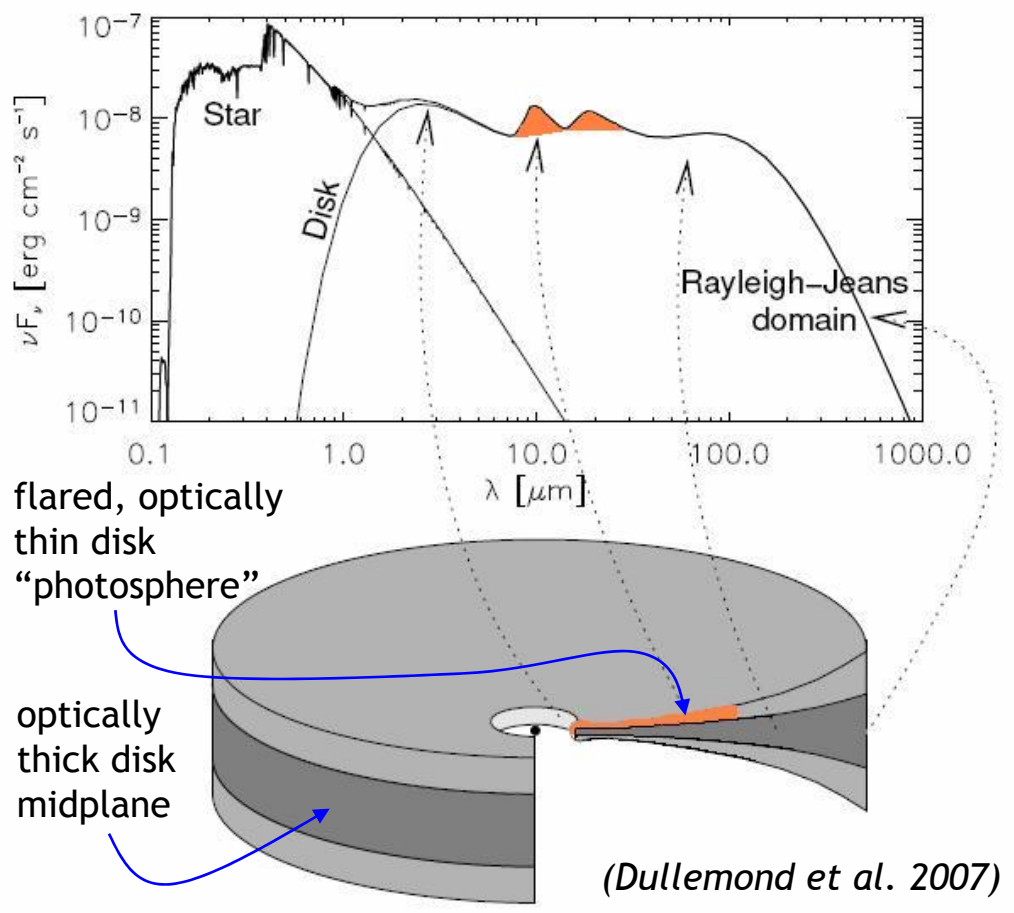
classical T Tauri stars (CTTS): primordial, gas-rich accretion disk

weak-lined T Tauri stars (WTTS): passive primordial disk, or no disk

final dissipation of the primordial disk

⇒ disk dissipation in ~ 10 Myr

T Tauri Disk Structure, Emission, and Evolution



(Dullemond et al. 2007)

near-IR (1-4 μm): <0.05-0.1 AU

mid-IR (4-30 μm): 0.1-10 AU

far-IR (30-100 μm): 10-100 AU

decrease of infrared excess over time

→ accretion of material onto the star

→ grain growth and settling towards the midplane

→ MRI-induced inner disk draining

→ photoevaporation

→ planet formation

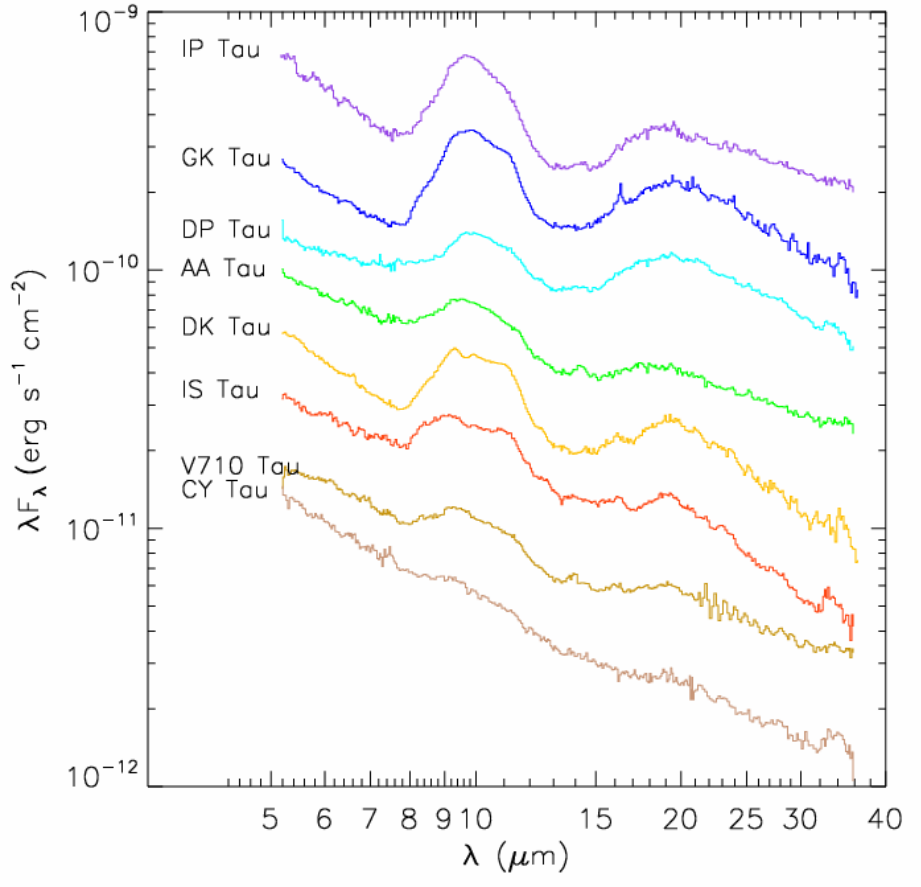
⇩

faster evolution in inner disk (i.e, at shorter wavelengths)

⇒ disk clearing from the inside out

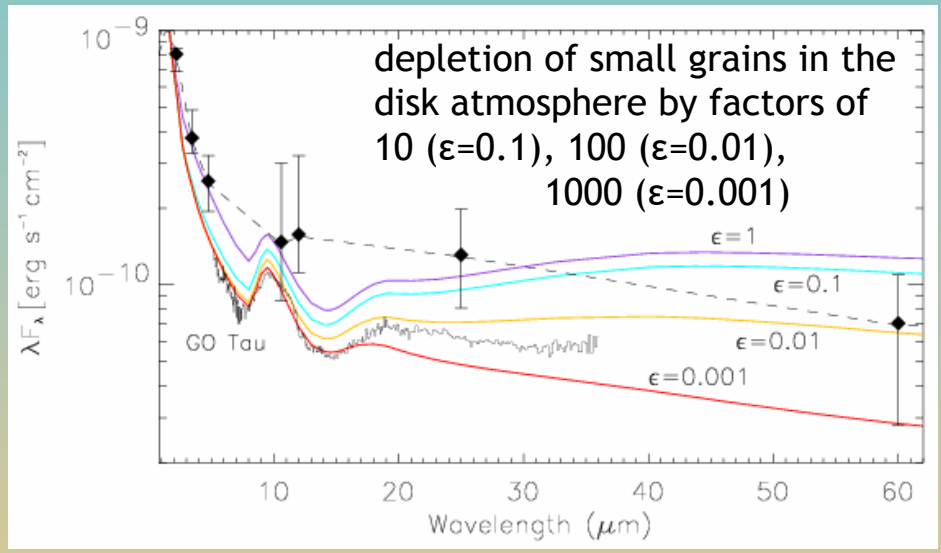
Dust Growth, Processing, and Settling

some of the Spitzer/IRS spectra of T Tauri stars in the Taurus star-forming region (1-2 Myr old):

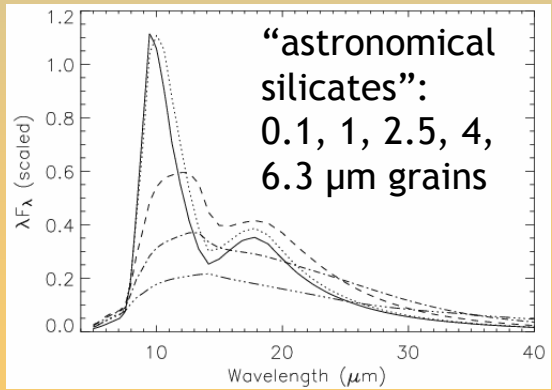


Furlan et al. (2006)

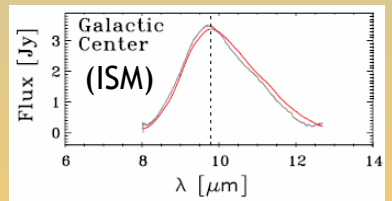
models with various amounts of dust settling:



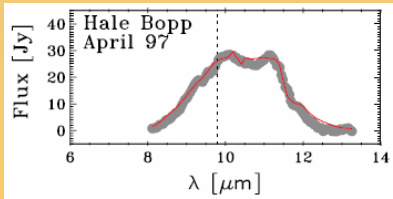
Furlan et al. (2005b), D'Alessio et al. (2006)



Draine & Lee (1984)



grain processing

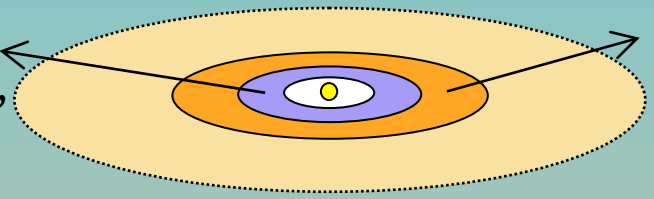


Bouwman et al. (2001)

Disk Evolution with the IRS: Dust Processing

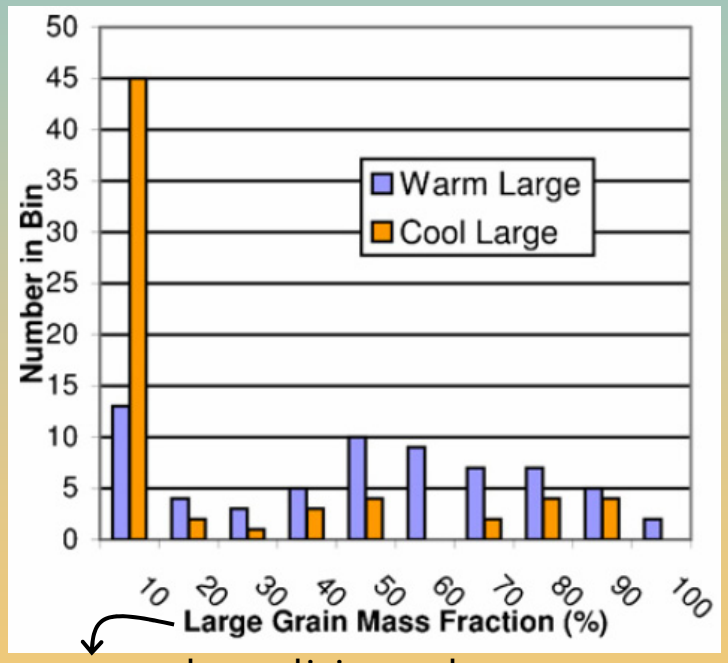
dust feature fits of 65 T Tauri star spectra in Taurus:

warm, inner disk (~0.5 AU, ~600 K)

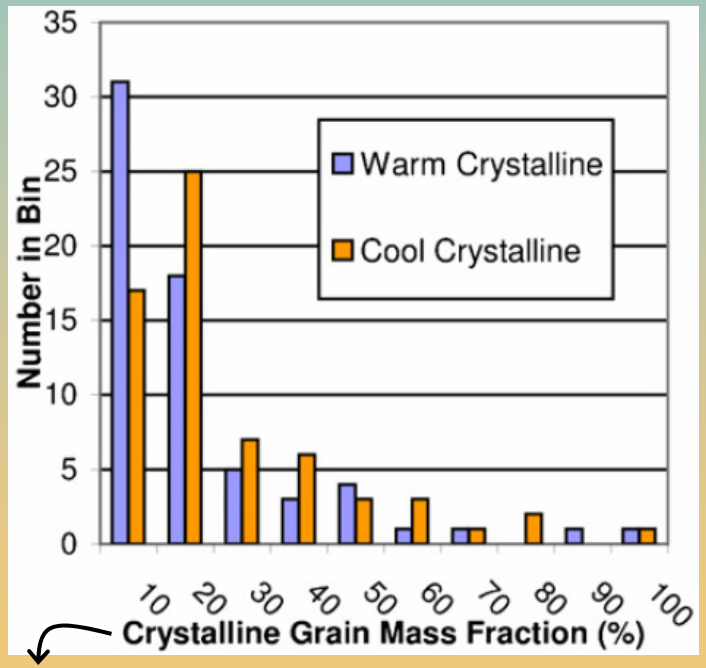


cool, outer disk (~5 AU, ~150 K)

Sargent et al. (2009b)



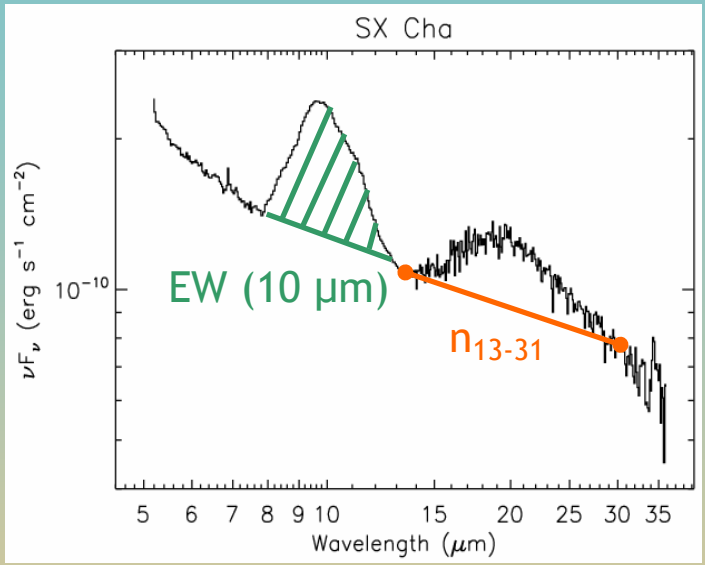
amorphous olivine and pyroxene;
5 μm porous spheres with 60% vacuum



forsterite, enstatite, silica

dispersion in individual system's dust properties
⇒ no steady dust processing and evolution
→ radial mixing; turbulence; planet formation clearing processed dust

Disk Evolution with IRS: SED Slope and 10 μm Feature

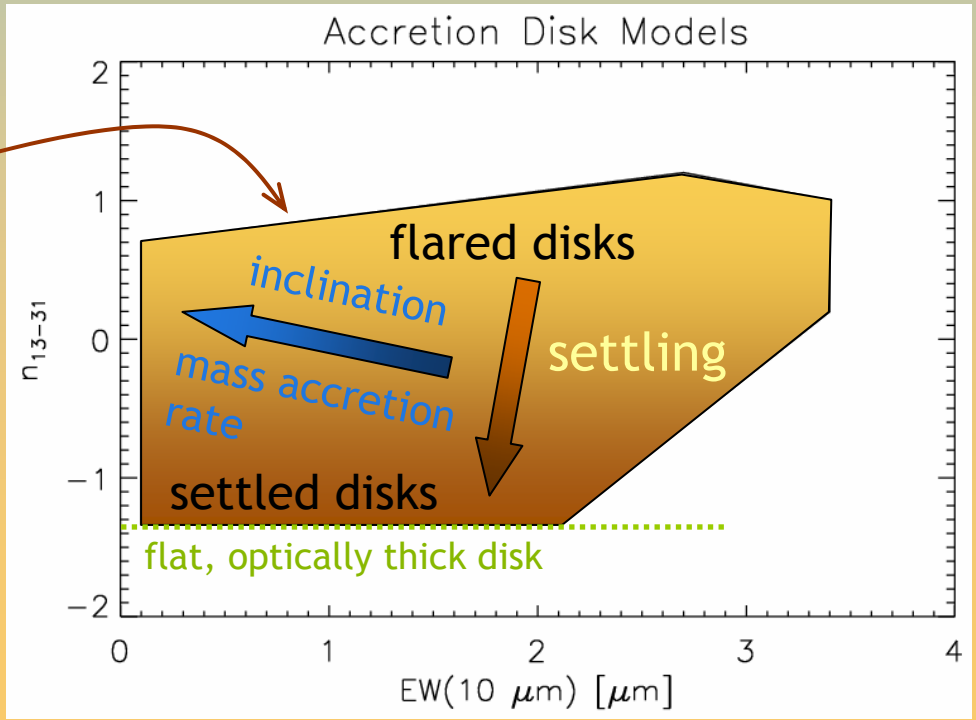


Watson et al. (2009), Furlan et al. (2009a)

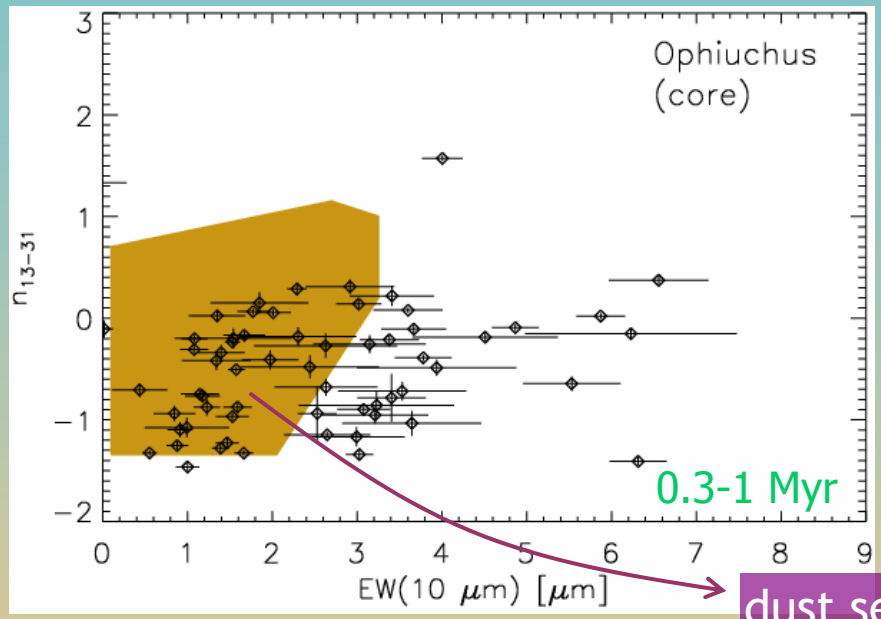
85 Class II objects in Taurus, 69 in Chamaeleon I, 63 in L1688 (Ophiuchus core), 15 in the Ophiuchus off-core regions

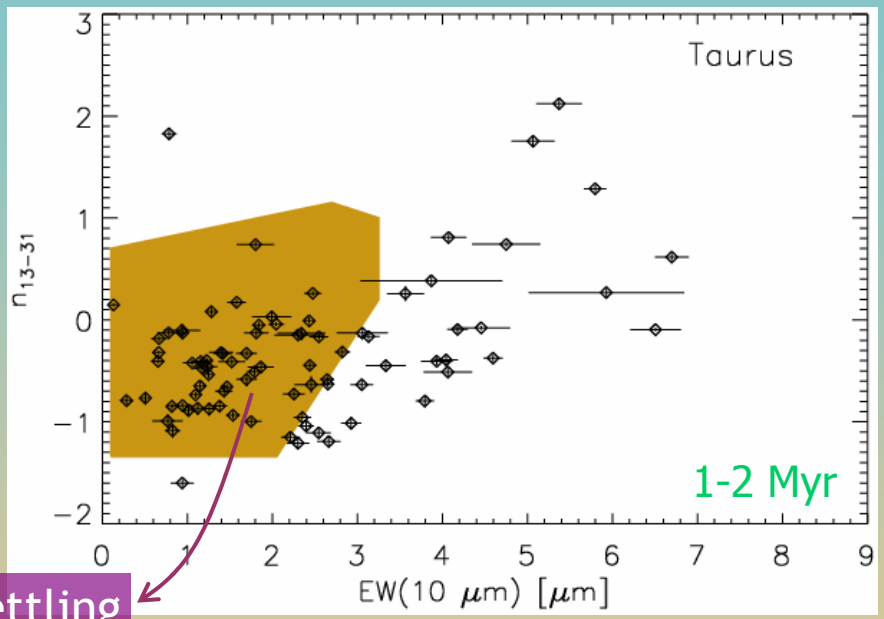
- 13-31 μm spectral index: degree of dust settling
- 10 μm feature equivalent width: optically thin dust mass per area of optically thick disk

spread from model calculations (full protoplantary accretion disks)

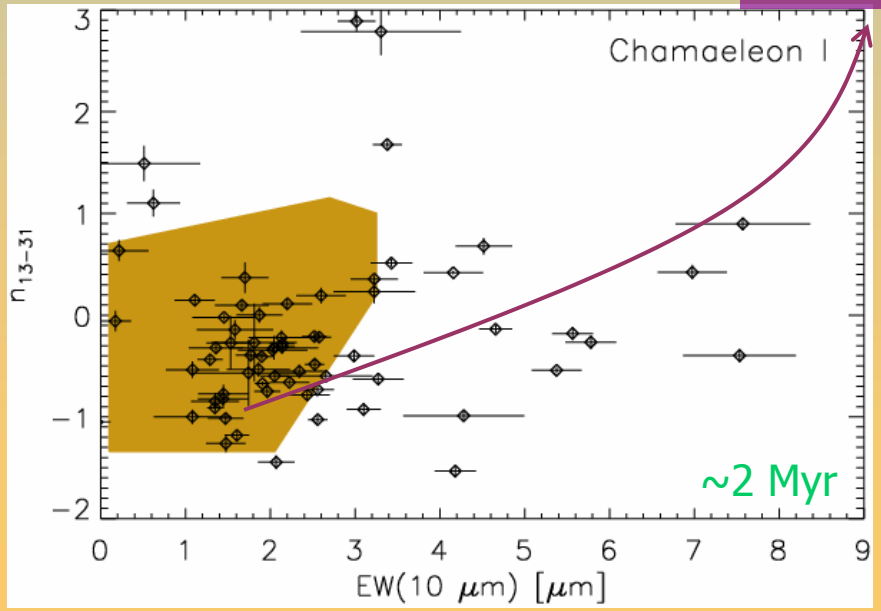


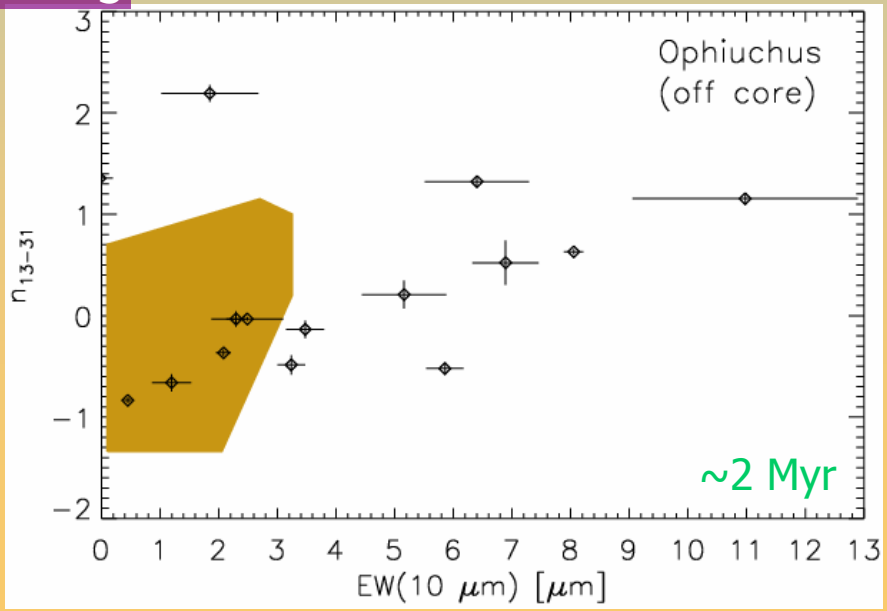
Disk Evolution in Oph, Tau, Cha



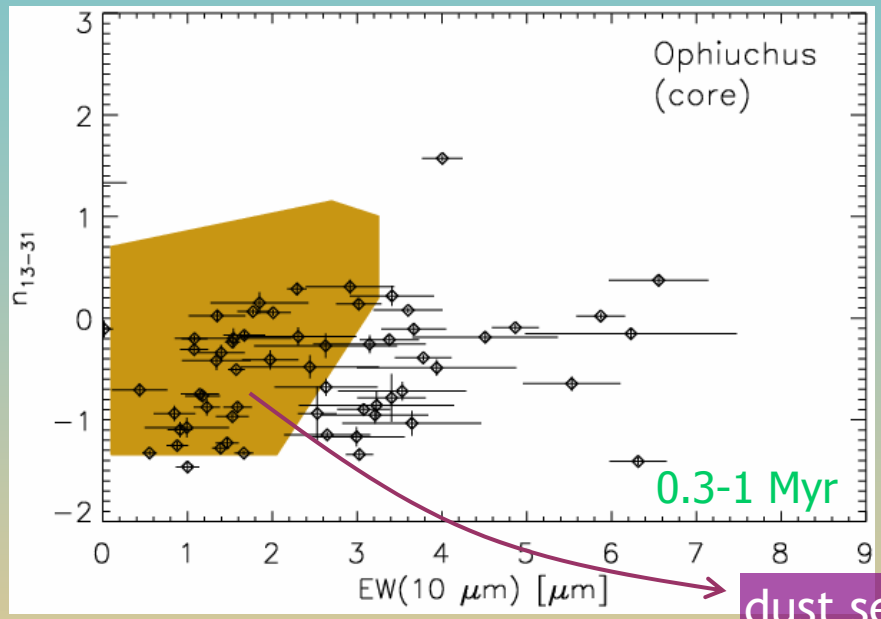


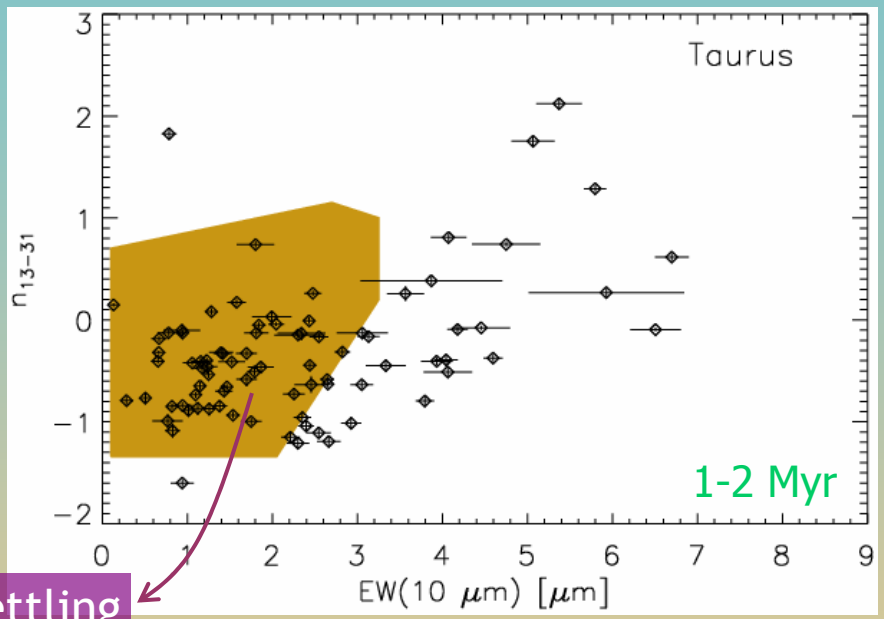
dust settling



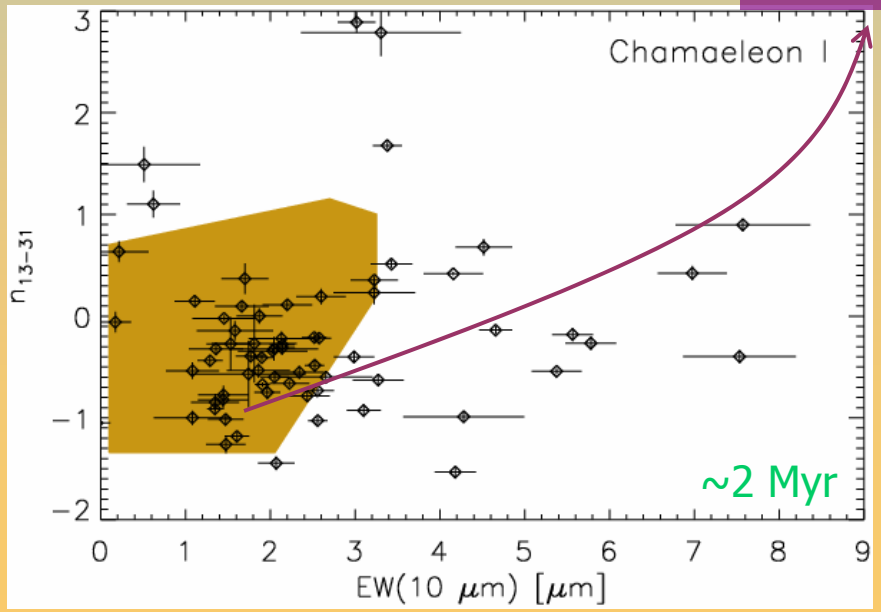


Disk Evolution in Oph, Tau, Cha

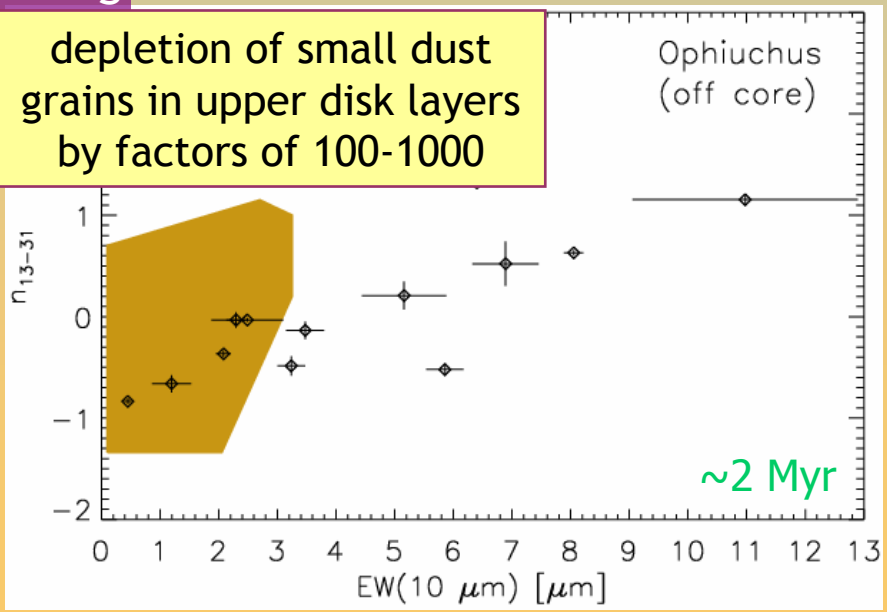




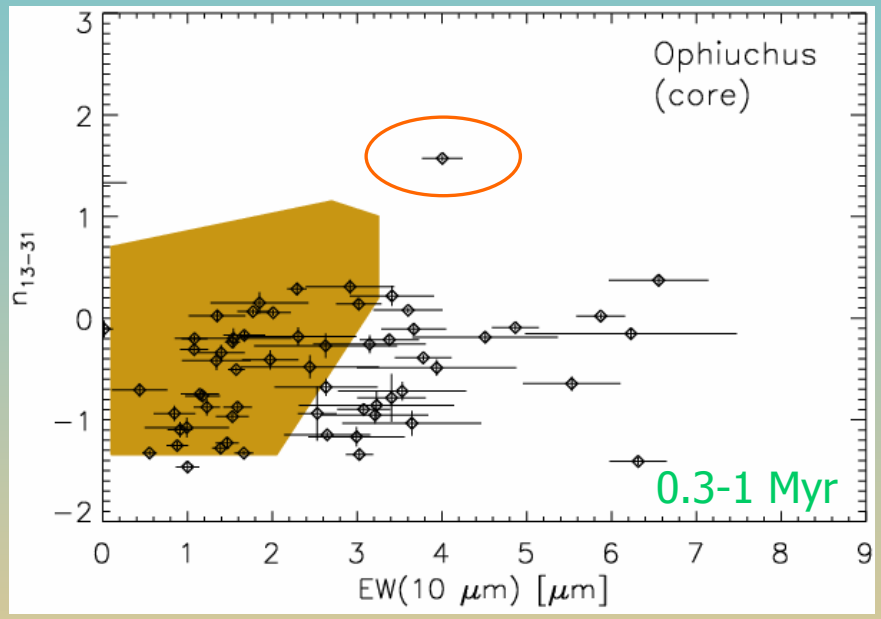
dust settling

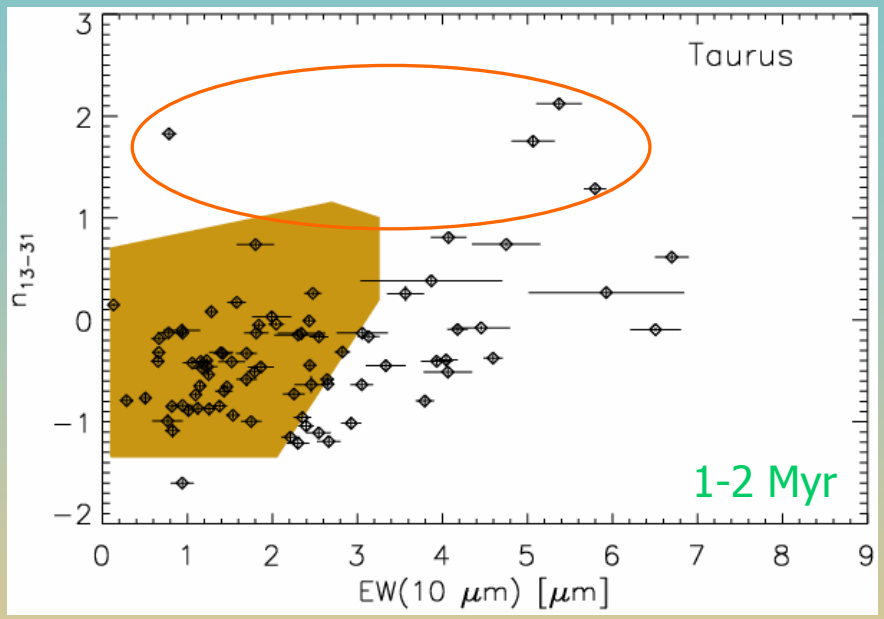


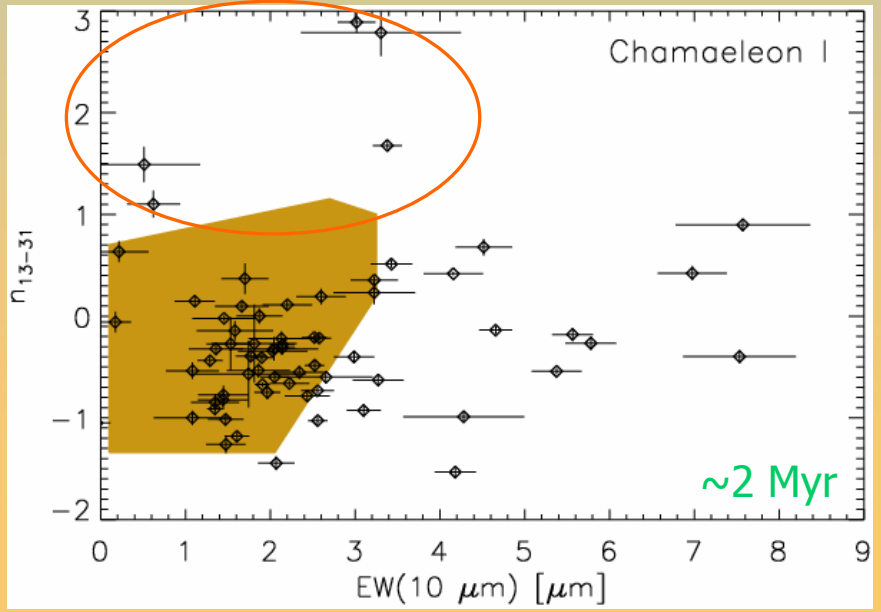
depletion of small dust grains in upper disk layers by factors of 100-1000

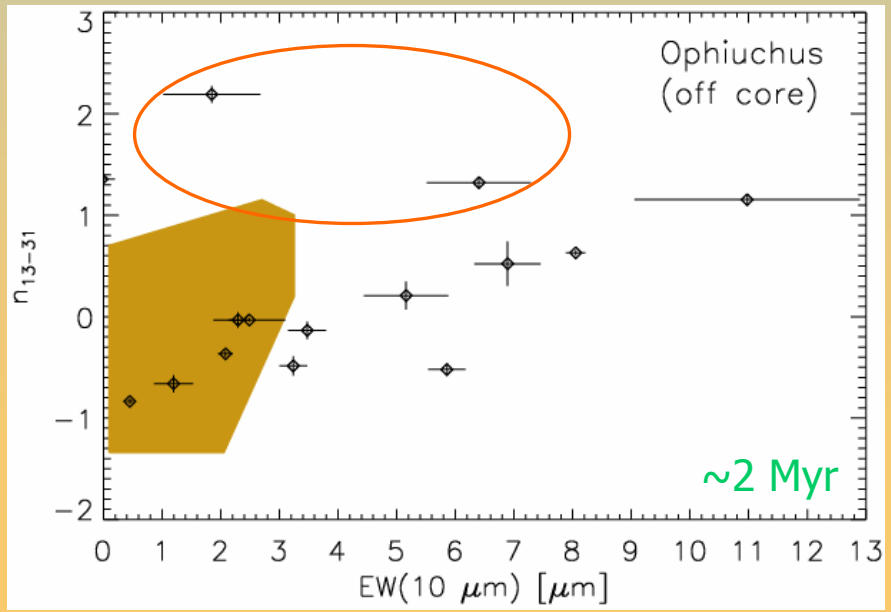


$n_{13\text{-}31}$ Outliers

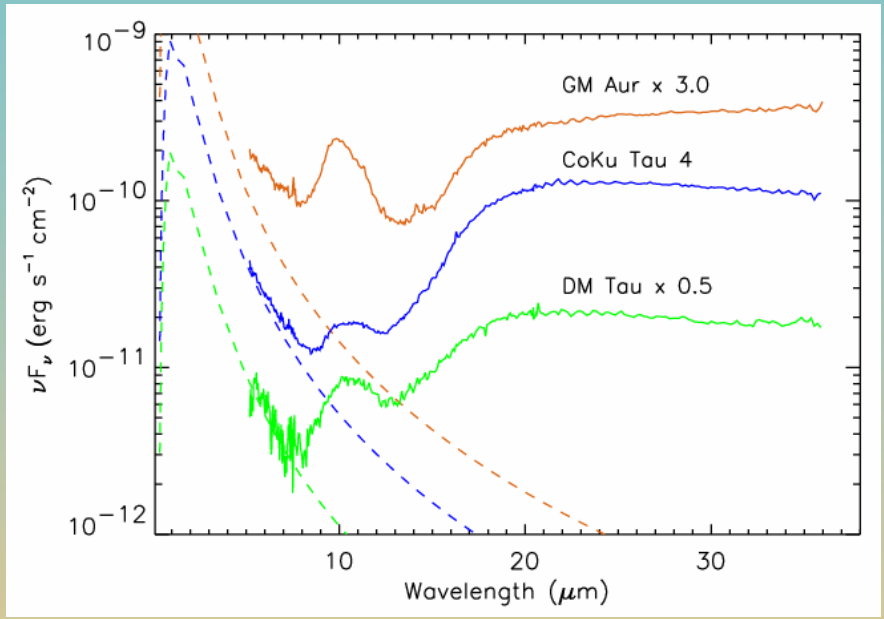




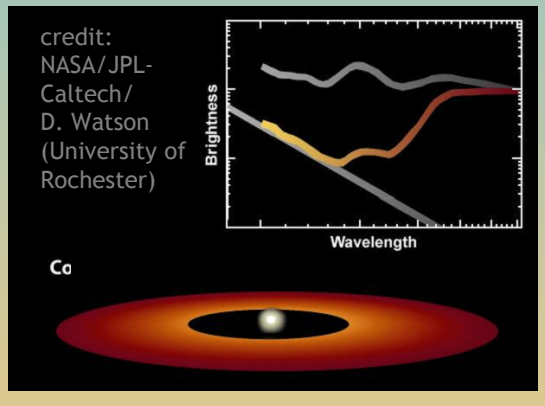




$n_{13\text{-}31}$ Outliers: Transitional Disks



- large excess > 8 μm, steep SED rise
  → single-temperature blackbody
- little/no excess < 8 μm
  → small dust grains are depleted from the inner regions of the disk

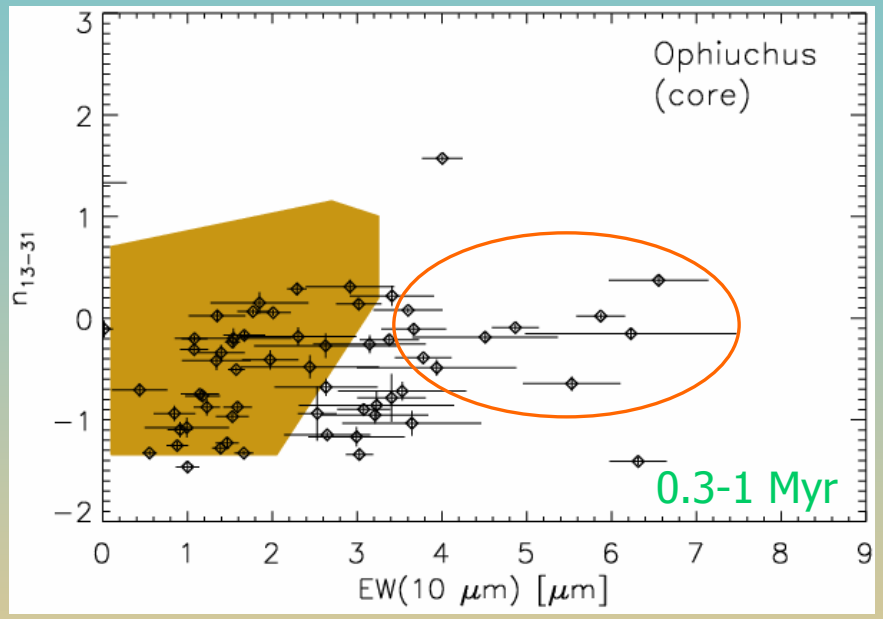


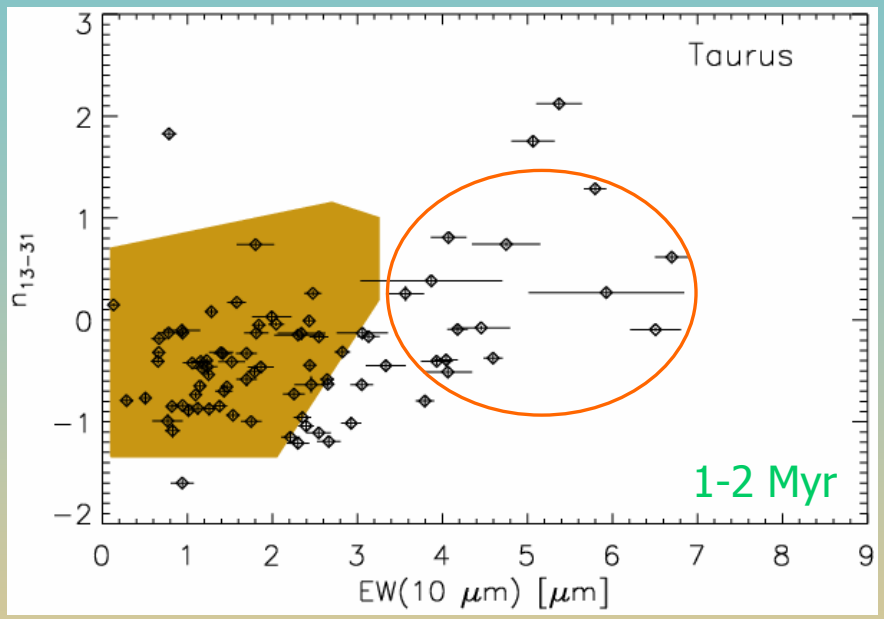
- ➢ MRI-induced inner disk clearing ~ 1 Myr
  (remnant outer disk, mass accretion)
- ➢ Photoevaporation ~ 0.1 Myr
  (vanishing outer disk, low/no mass accretion, but only if low X-ray luminosity)
- ➢ Planet formation ~ 10 Myr or ~ 1000 yr
  (grain growth, settling, remnant outer disk, mass accretion, gap formation; massive disk for instability)

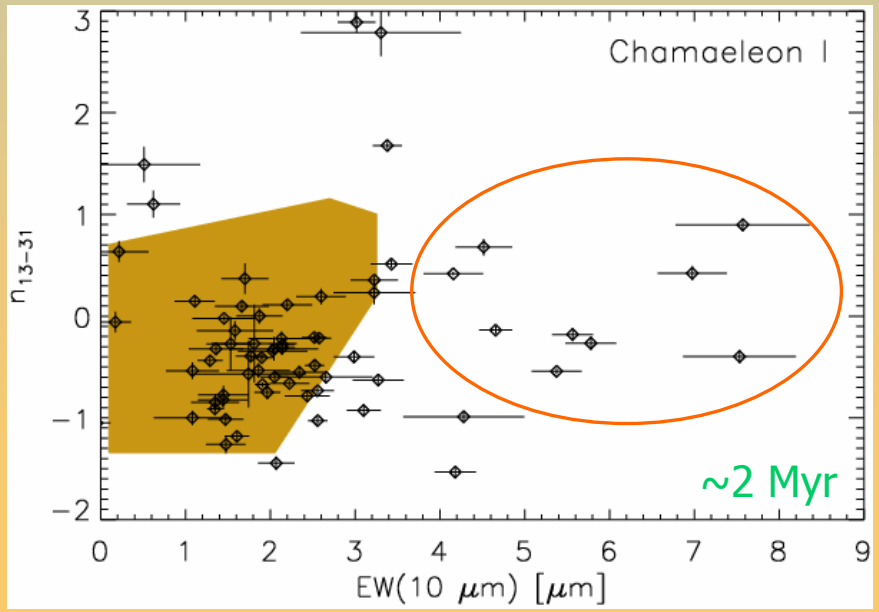
fraction of transitional disks:
a few % at an age of 1-2 Myr,
but ~15-20 % at an age of >3 Myr
⇒ slower transition timescale for older (>3 Myr) — and lower-mass — objects?
→ different disk clearing mechanisms

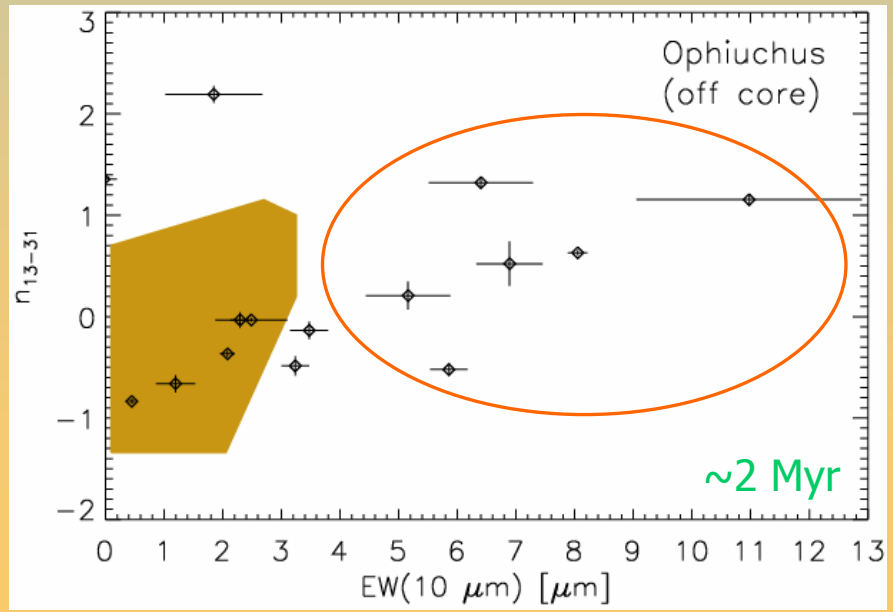
Furlan et al. (2009a), Muzerolle et al. (2010)

EW(10 μm) Outliers





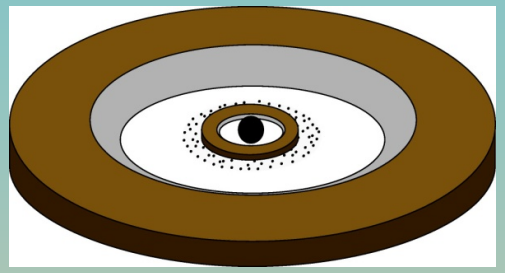


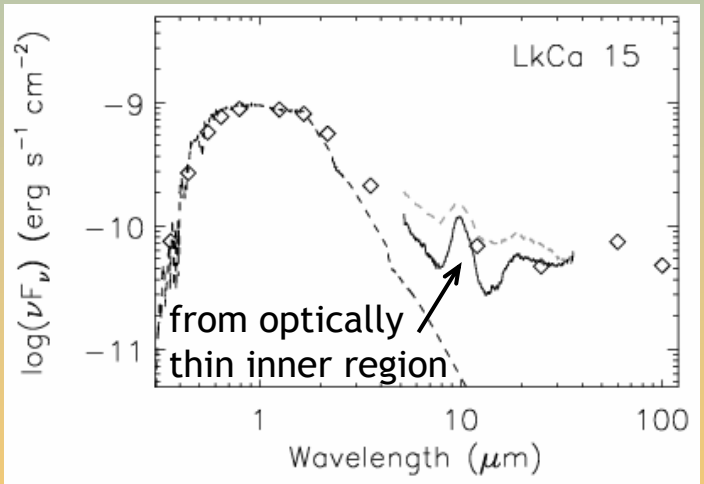


Formation of Disk Gaps

inner disk gap, possibly caused by a (massive) planet, filled with optically thin dust that increases the 10 μm feature strength
→ filtration of dust particles at the outer edge of the disk gap (pressure gradient)

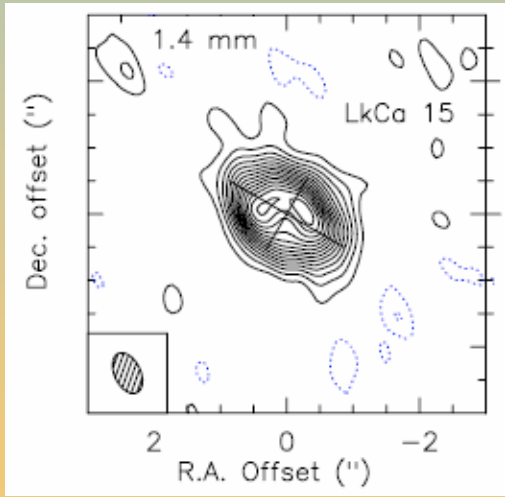
Rice et al. (2006), Lubow & D'Angelo (2006)





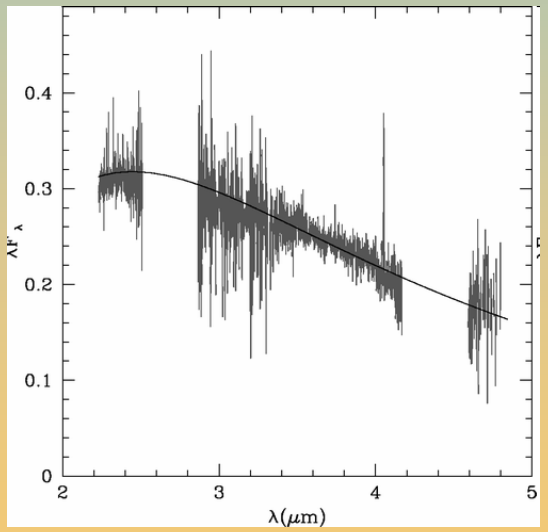
SED model: inner wall at ~ 0.1 AU, optically thin inner region at 0.15-5 AU, outer wall at 46 AU

Espaillat et al. (2007b)



1.4 mm image ⇒ ~ 50 AU inner cavity

Pietu et al. (2006)

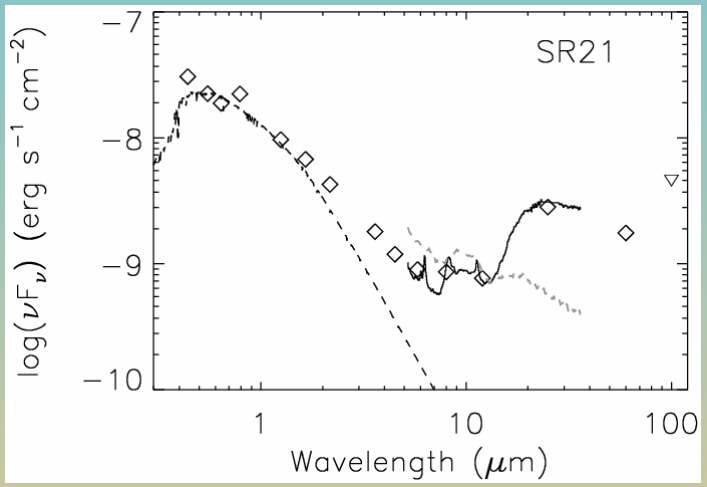


near-infrared excess fit with a 1600 K blackbody ⇒ inner wall emission

Espaillat et al. (2008)

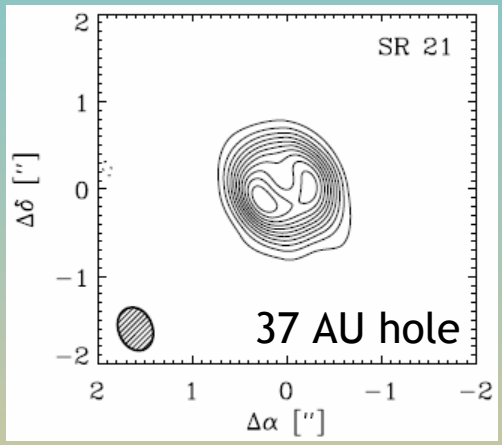
Other Disks with Gaps?

SEDs, with IRS spectrum:



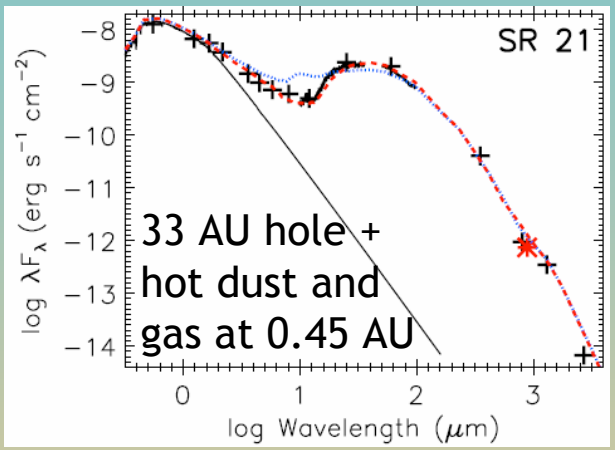
Furlan et al. (2009a)

870 μm continuum images:

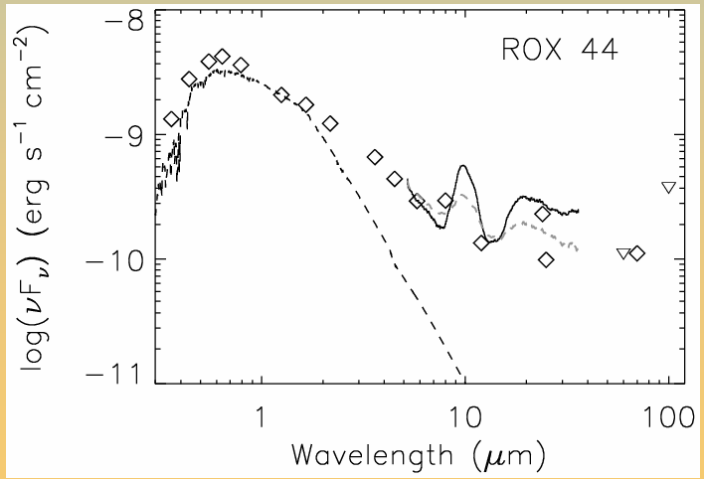


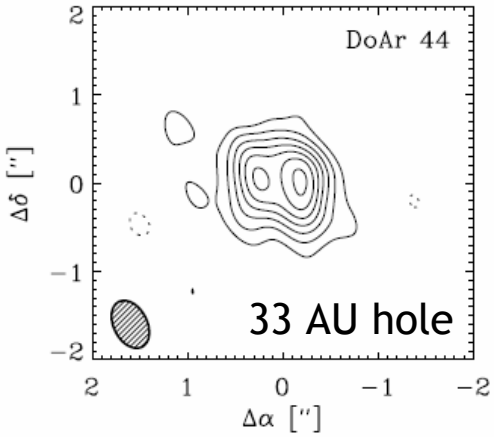
Andrews et al. (2009)

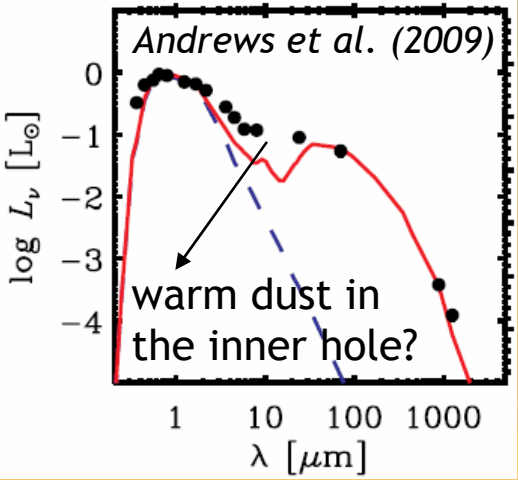
models:



Brown et al. (2009)

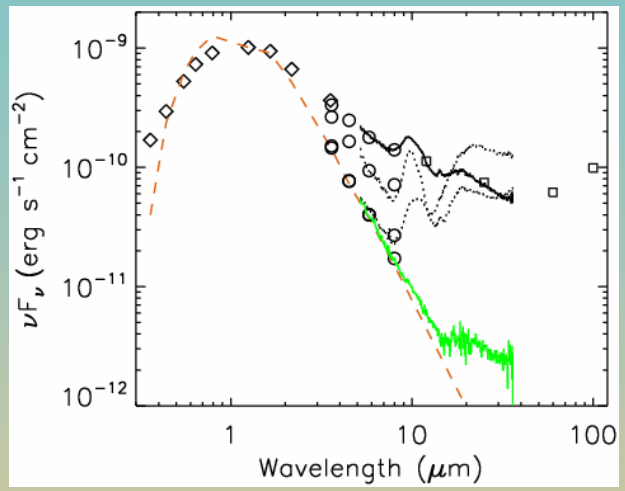






fraction of EW(10 μm) outliers: 20-30 % at an age of 1-2 Myr
→ evidence for disk gaps and planet formation?

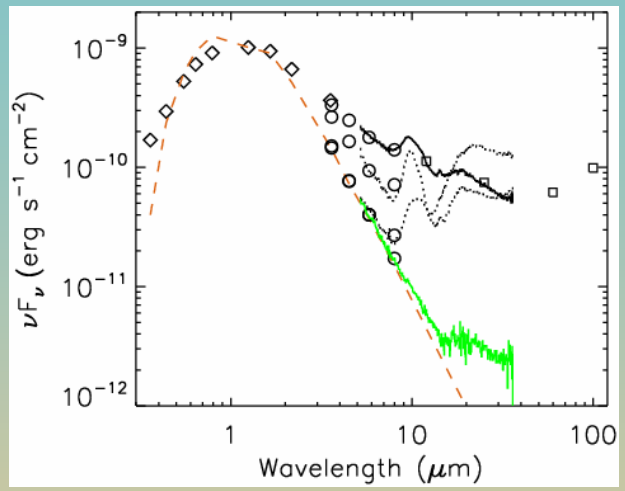
Pathways of Disk Evolution and Dissipation

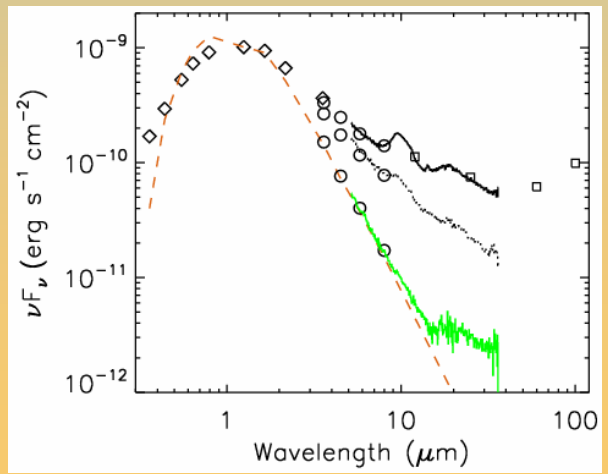


➢ formation of inner gaps, holes, then dissipation of the disk from the inside out?

- gaps: indicative of planet formation
  → require planet to grow to a few tens of Earth masses in ~1 Myr → migrating protoplanet accumulates mass quickly
  → issues with gap formation, planet migration, dust in the inner regions; possibly cyclic event
- inner (dust) holes: caused by dust growth, planets, photoevaporation, MRI-induced disk draining
  → different mechanisms likely operating in different disks and/or at different times (depending on disk mass, accretion rate,…)
  → issues with timescales and difficulty in determining main processes in a given disk

Pathways of Disk Evolution and Dissipation





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    → issues with timescales and difficulty in determining main processes in a given disk
- steady depletion of material in the disk?
  → disk develops from flared to flat, optically thick, then to optically thin
  → main mechanism for late-type stars (with lower-mass disks)?