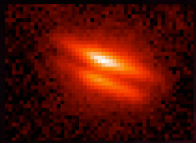
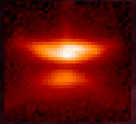
Disk Evolution in Taurus, Ophiuchus, and Chamaeleon I



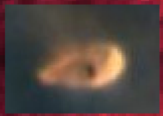
Elise Furlan



Spitzer Fellow

Jet Propulsion Laboratory,

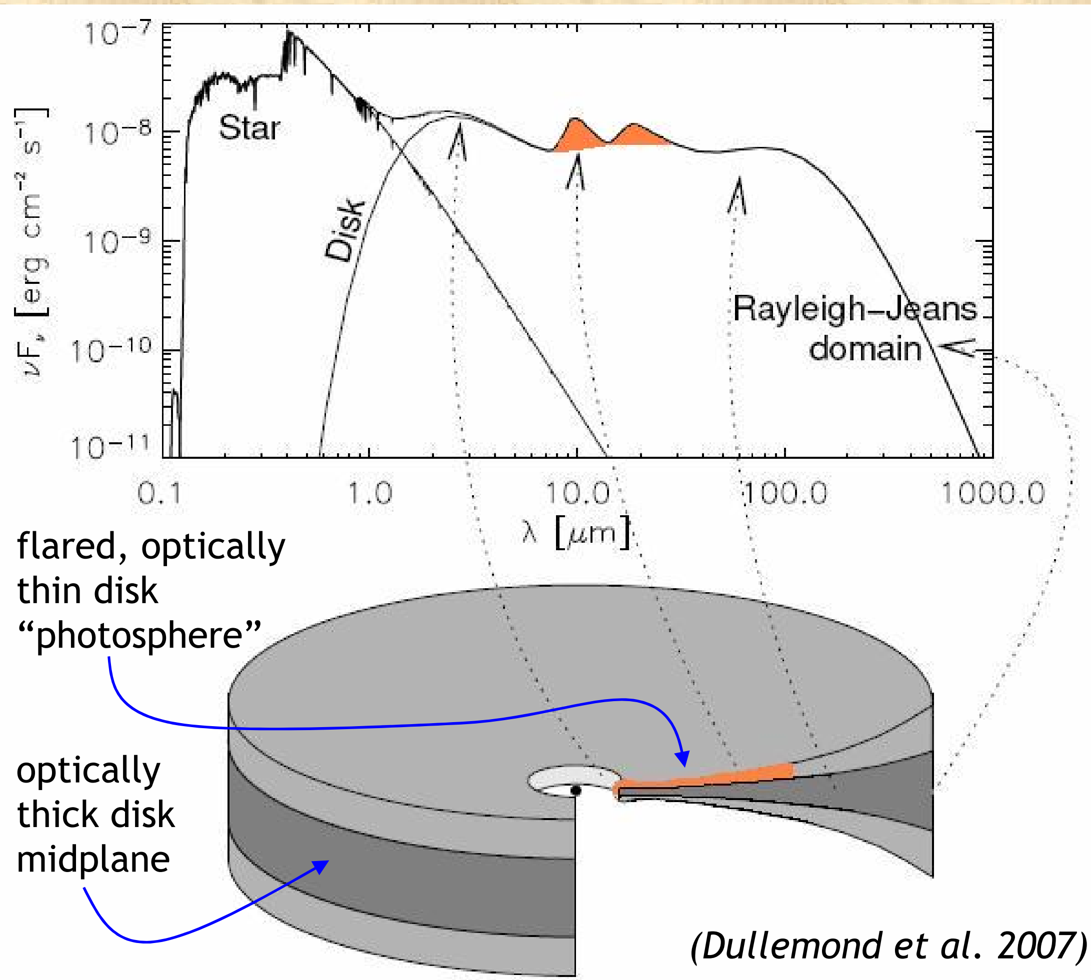
California Institute of Technology



in collaboration with members of the IRS_Disks team:

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

T Tauri Disk Structure and Emission

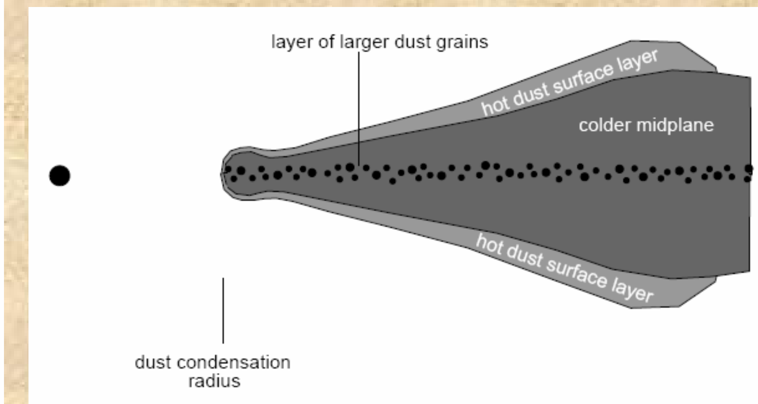


near-IR (1-4 μm): <0.05-0.1 AU

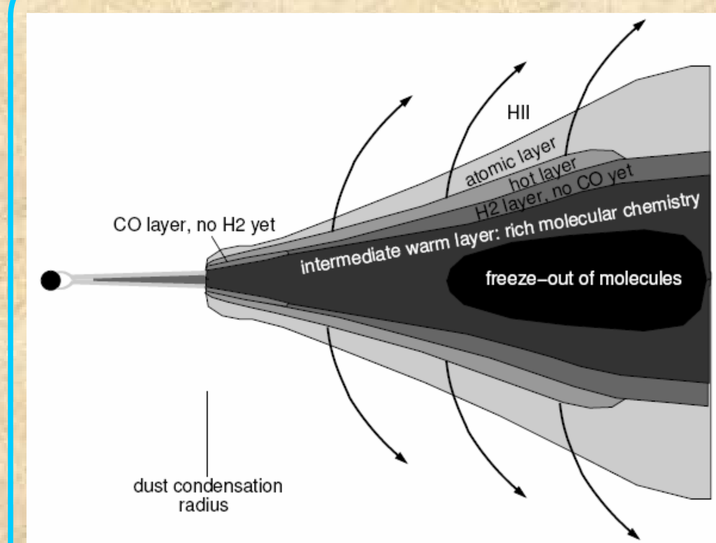
mid-IR (4-30 μm): 0.1-10 AU

far-IR (30-100 μm): 10-100 AU

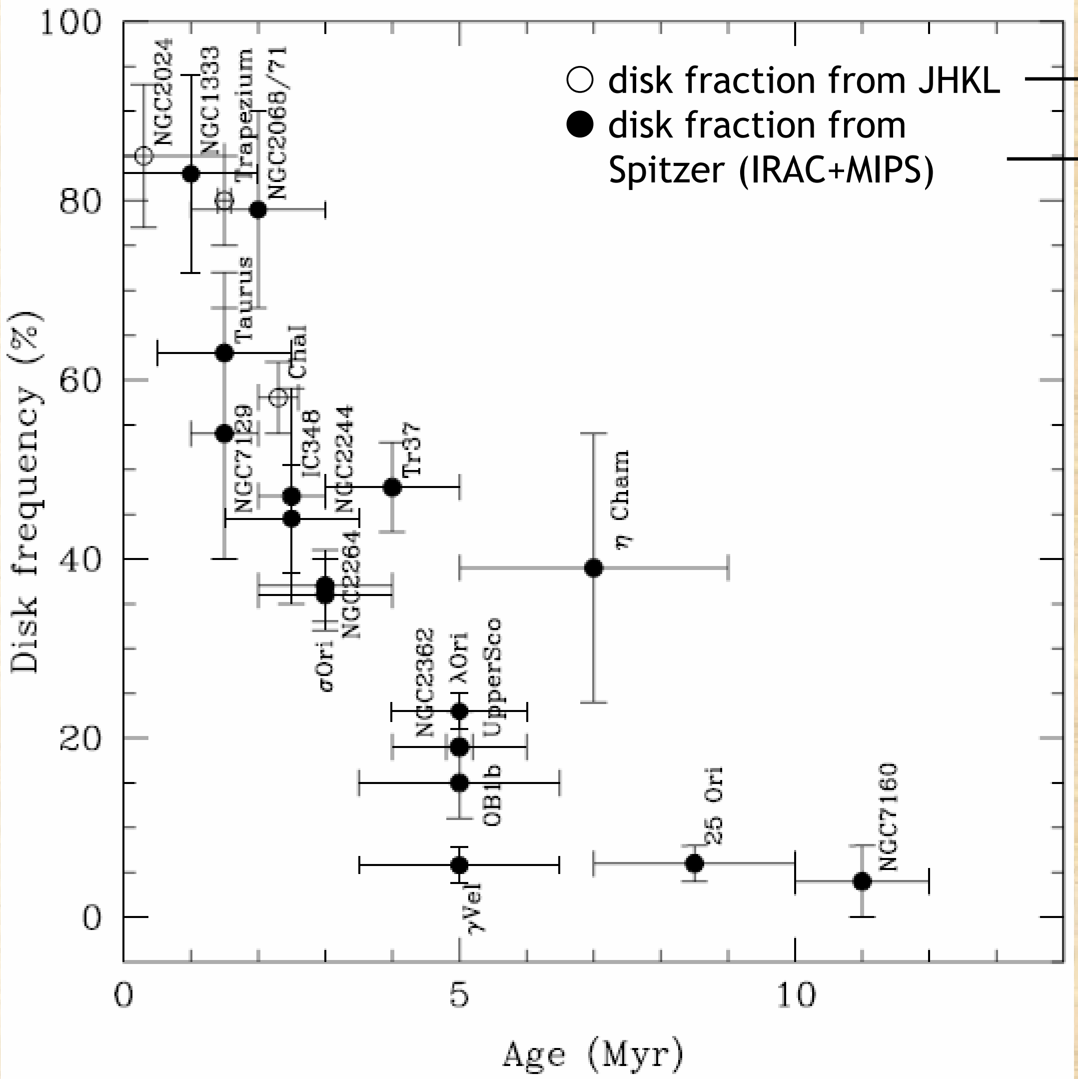
Dust structure



Gas structure



Disk Fractions from 1 to 10 Myr



→ 1.25-3.5 μm

→ 3.6-8 μm, 24 μm

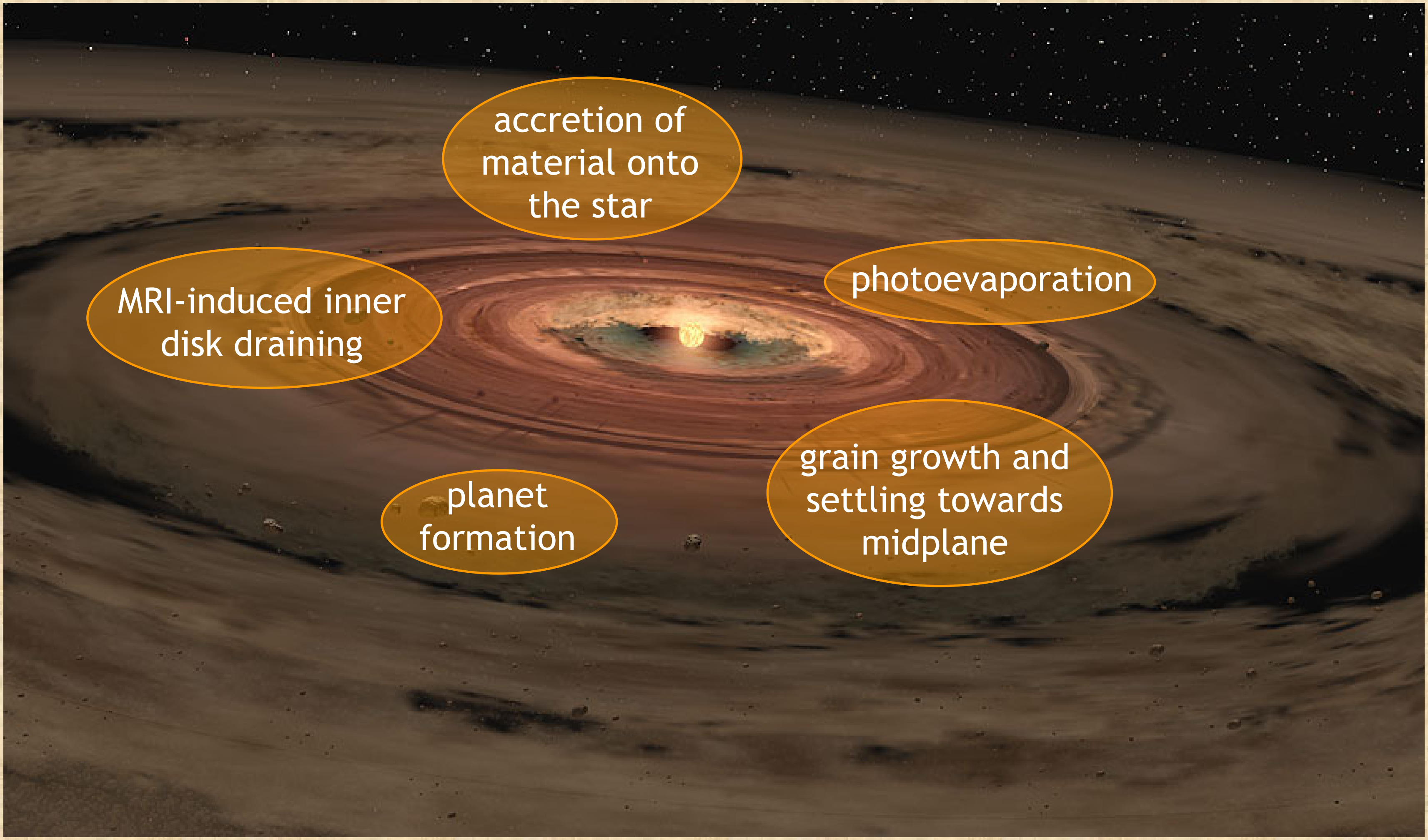
(disk fraction depends somewhat on λ range)

Hernandez et al. (2008)

⇒ disk dissipation in ~ 10 Myr

Disk Clearing

decrease of infrared excess over time
→ faster evolution in inner disk (i.e, at shorter wavelengths)



Disk Clearing

decrease of infrared excess over time
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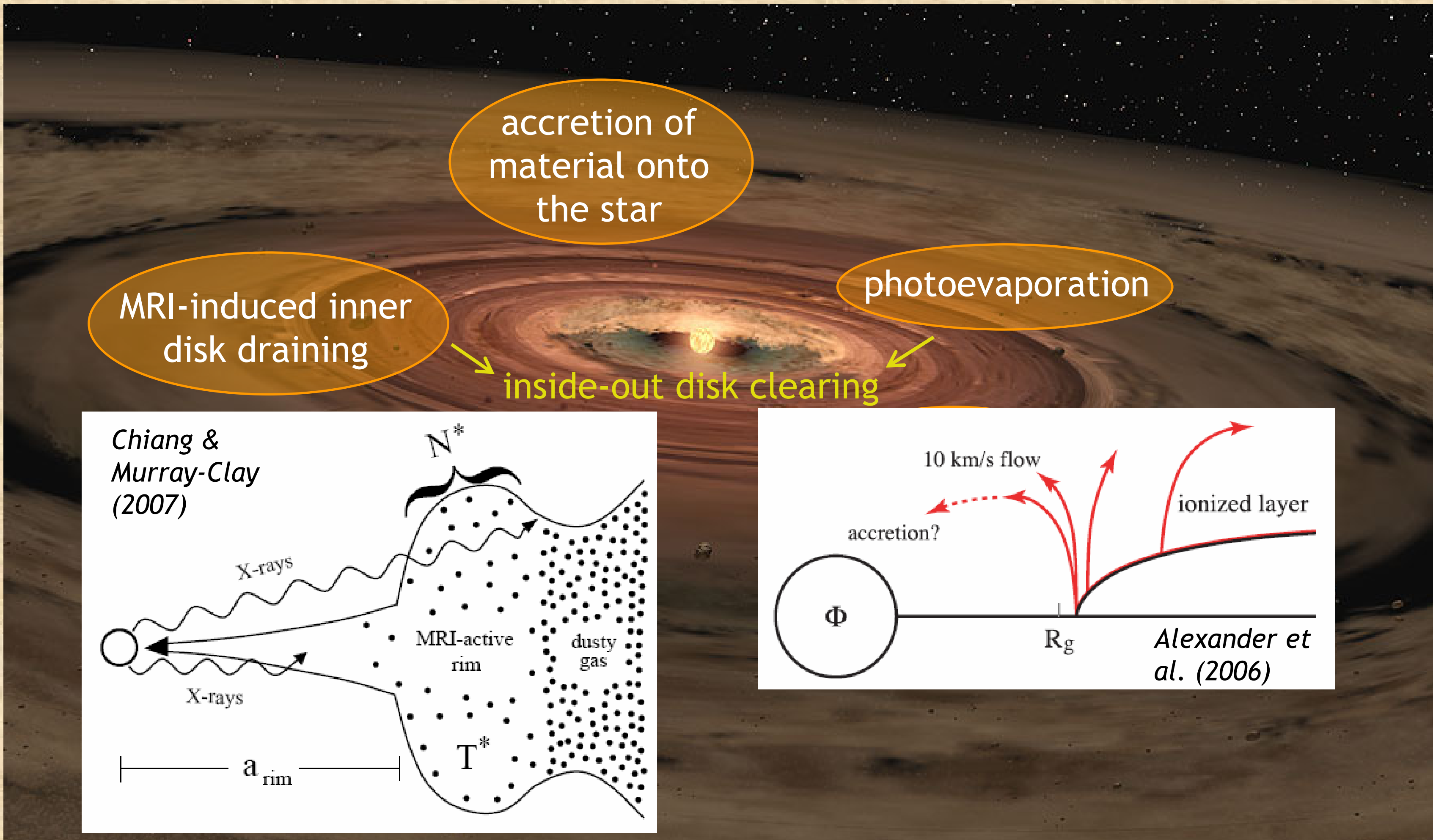

Disk Clearing

decrease of infrared excess over time
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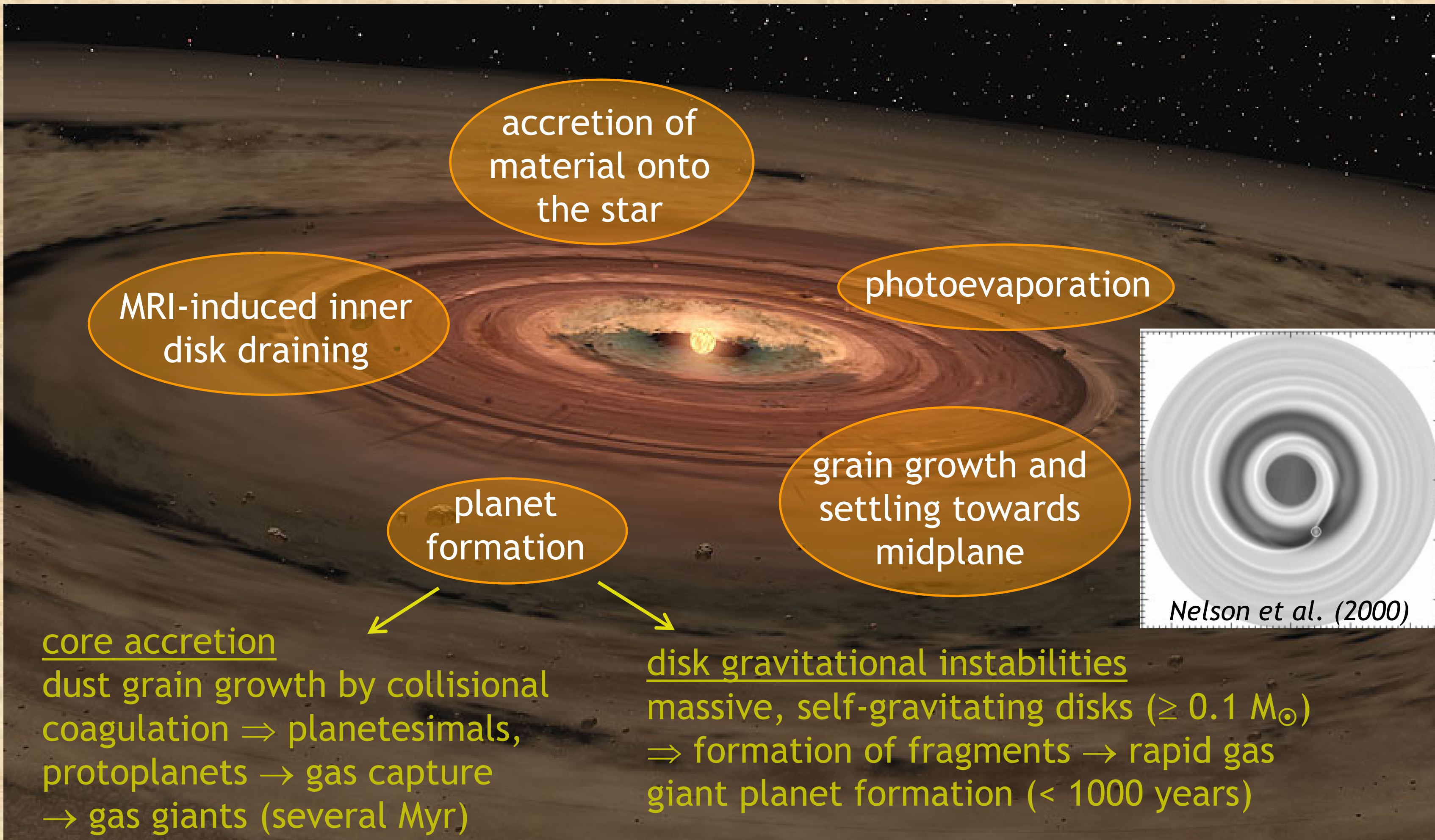
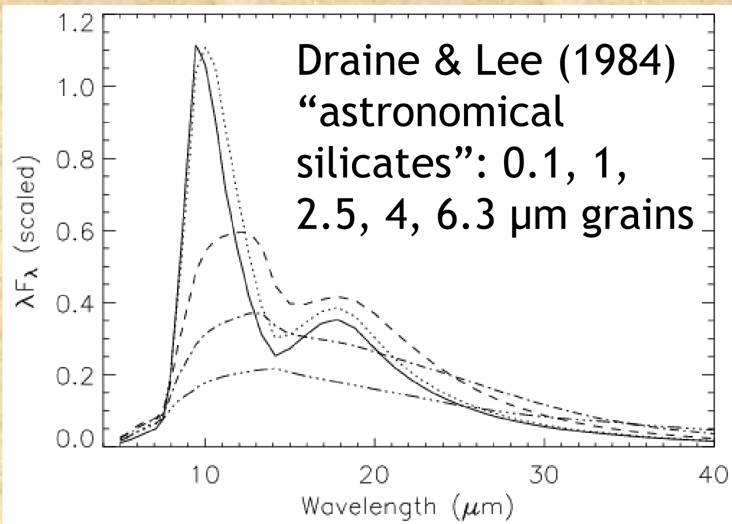


<u>core accretion</u>
dust grain growth by collisional coagulation ⇒ planetesimals, protoplanets → gas capture → gas giants (several Myr)

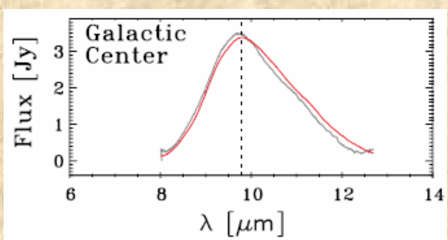
<u>disk gravitational instabilities</u>
massive, self-gravitating disks ($\geq 0.1\ M_{\odot}$) ⇒ formation of fragments → rapid gas giant planet formation (< 1000 years)

Dust Growth, Settling, and Processing

Dust grain growth and processing:

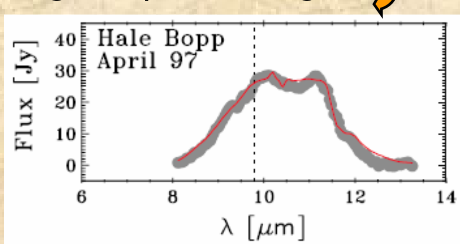


amorphous silicates



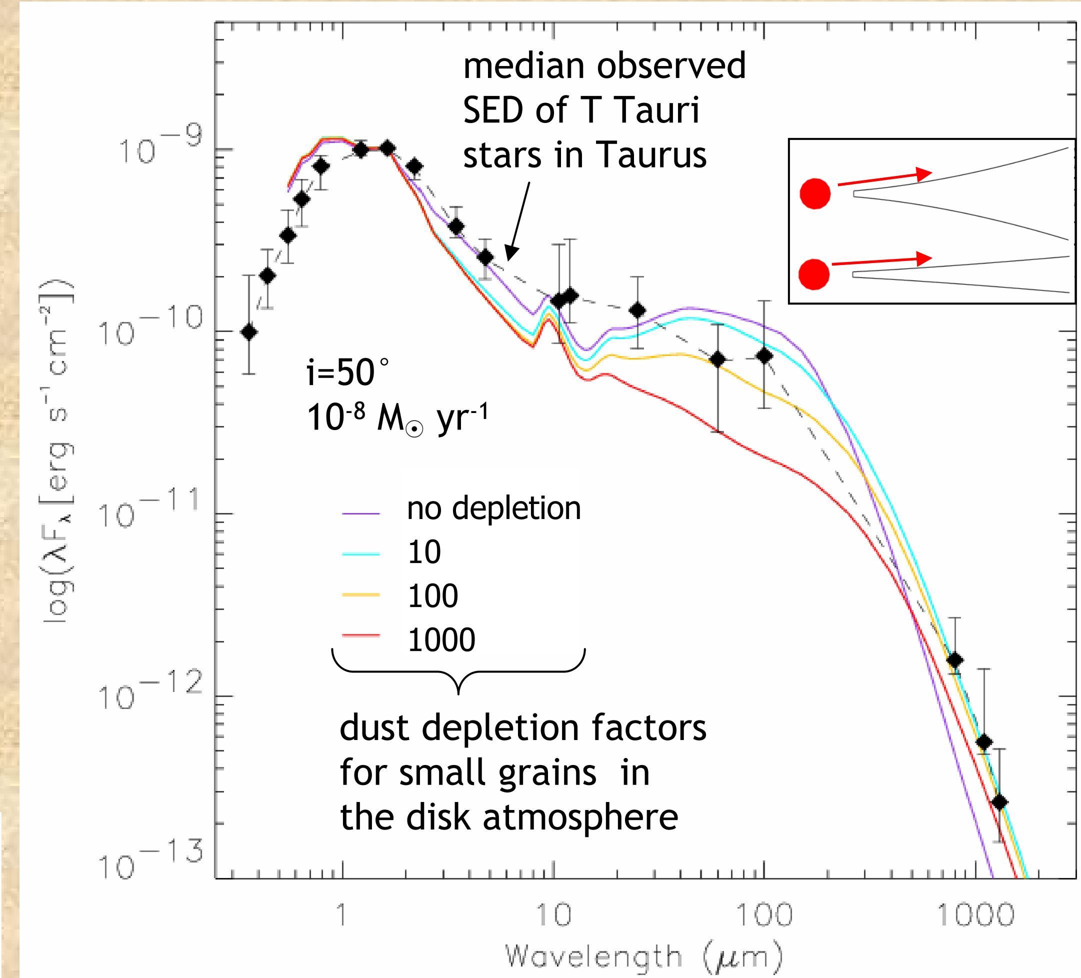
grain processing

crystalline silicates



Bouwman et al. (2001)

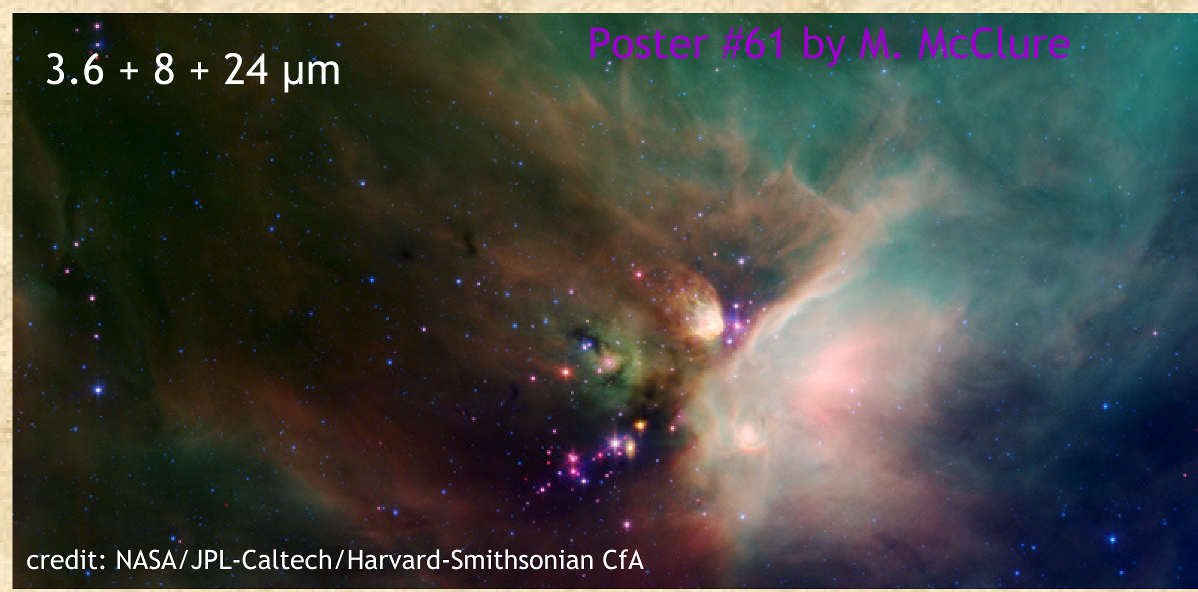
Dust settling: SED models of a typical T Tauri star with various amounts of settling



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

Poster #45 by N. Crockett

Disk Evolution in Three Nearby Star-Forming Regions

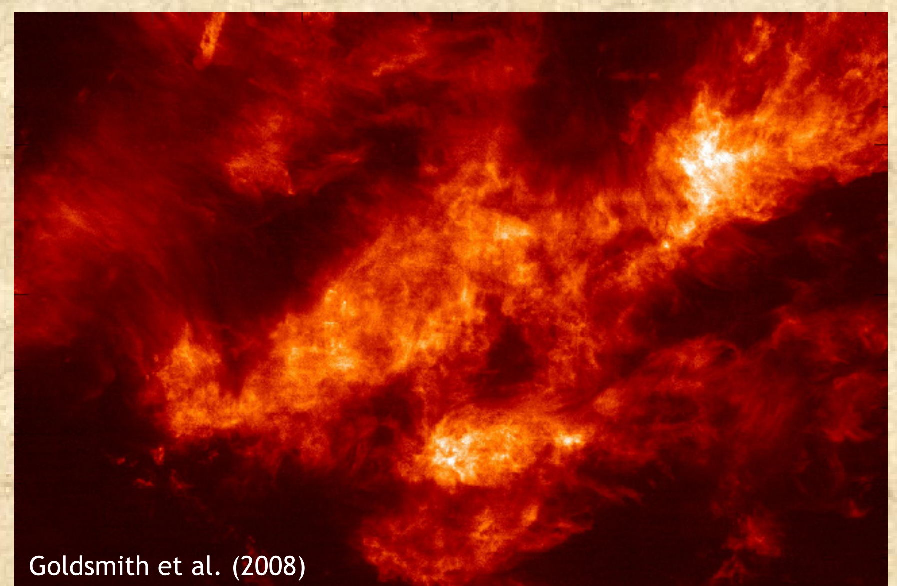


Lynds 1688 in the **ρ Ophiuchi** cloud (Ophiuchus core)

age of ~ 1-2 Myr

distance of ~ 150 pc (1” → 150 AU)

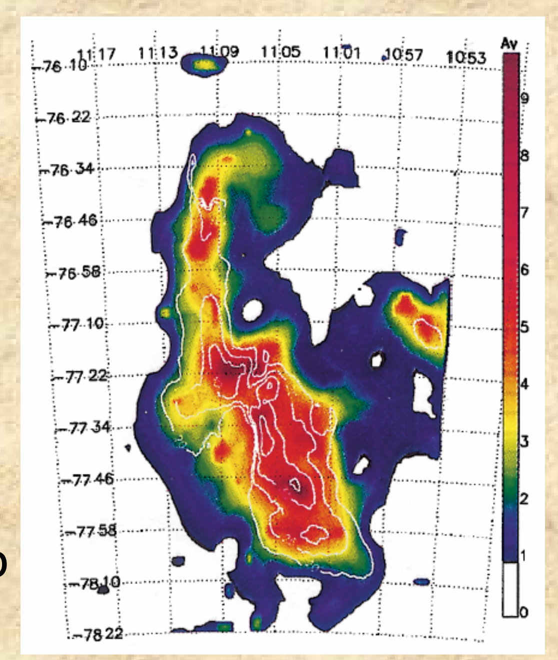
low-mass (≤ 2 $M_{\odot}$) star formation



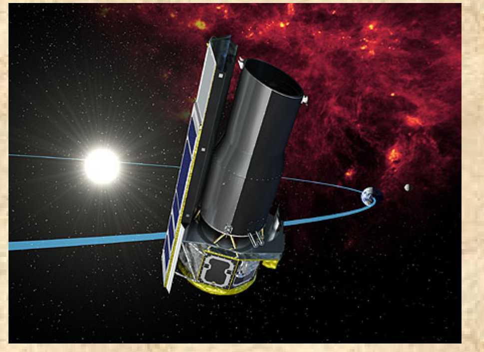
^{12}CO map of the **Taurus** molecular cloud

Chamaeleon I extinction map

Cambresy et al. (1997)



Disk Evolution in Three Nearby Star-Forming Regions

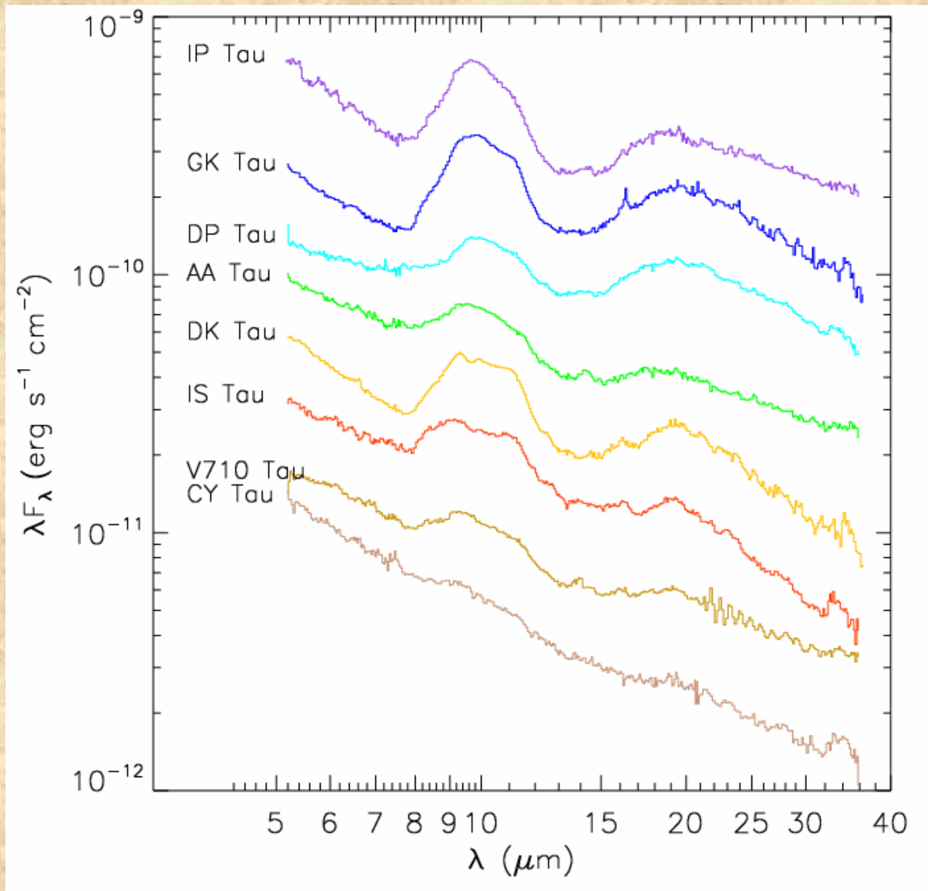


Credit: NASA/JPL-Caltech

Credit: Russ Underwood, Lockheed Martin Space Systems

Infrared Spectrograph (IRS) on the Spitzer Space Telescope:

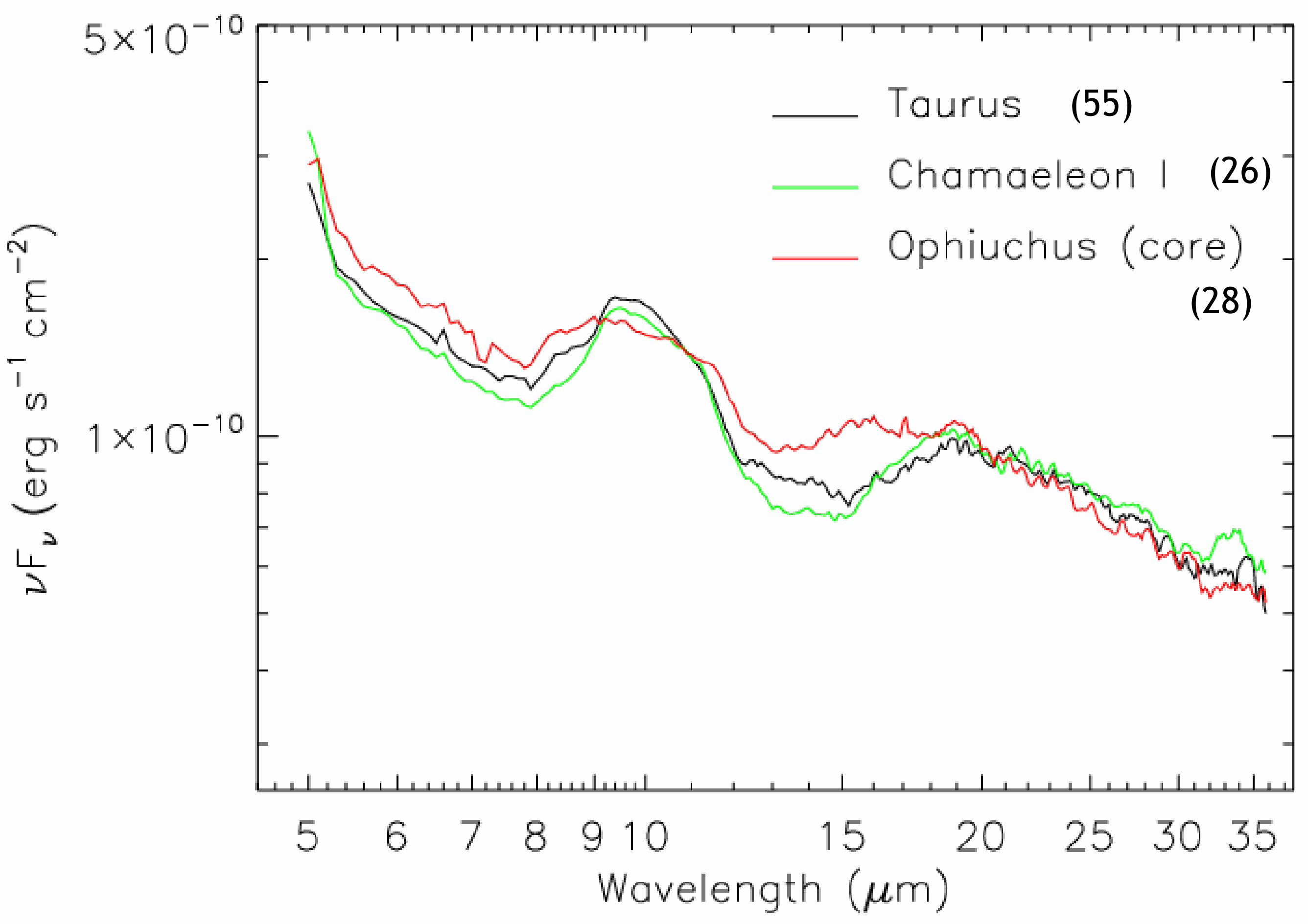
- low-resolution spectra: 5-38 μm
- medium-resolution spectra: 10-37 μm



some of the Spitzer/IRS spectra of T Tauri stars in Taurus

Furlan et al. (2006)

Median IRS Spectra



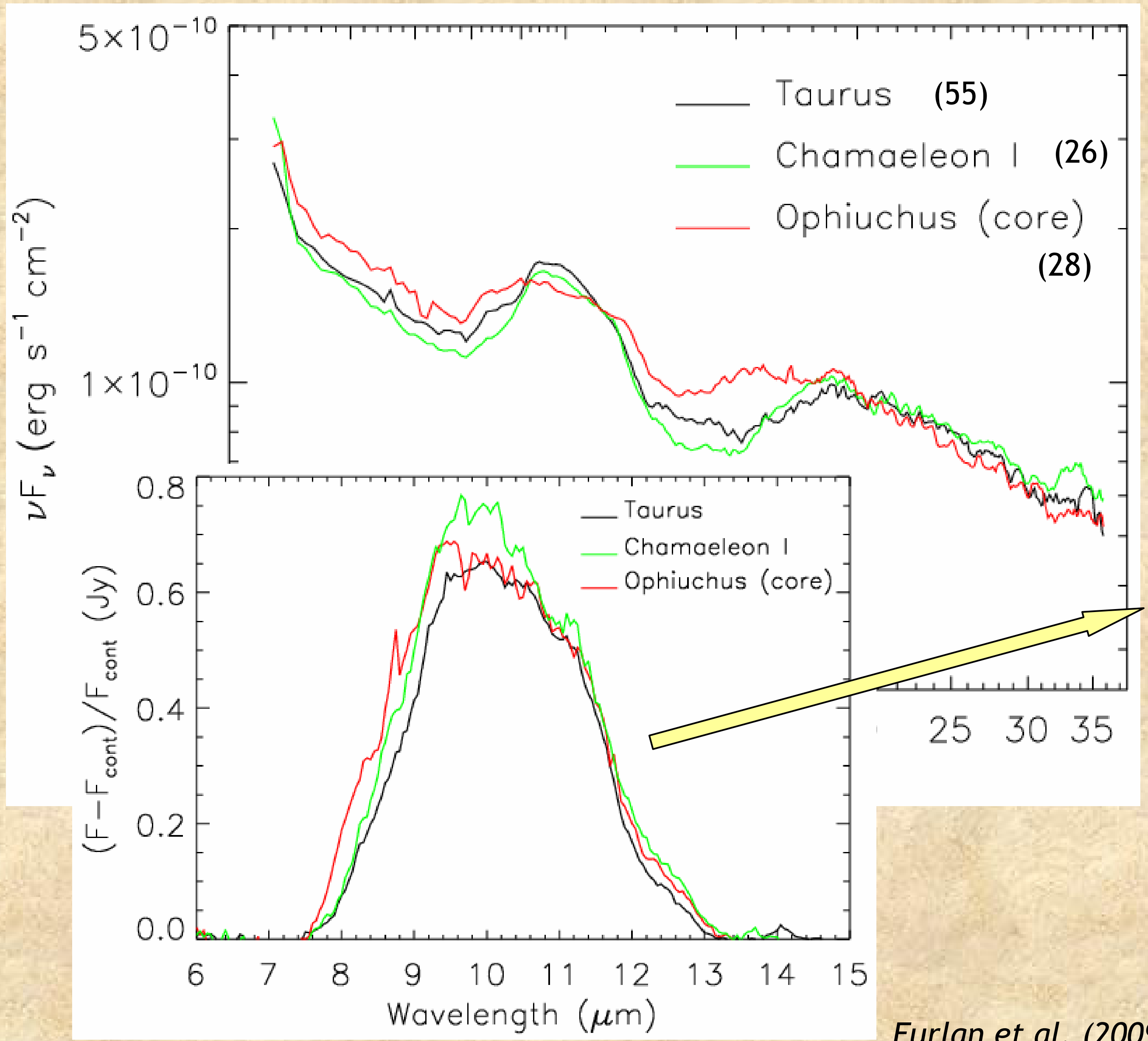
Median IRS spectra of objects with K5-M2 spectral type, normalized at the H-band flux

⇒ similar mid-infrared excess emission

→ on average, similar disk structure

Furlan et al. (2009)

Median IRS Spectra



Median IRS spectra of objects with K5-M2 spectral type, normalized at the H-band flux

⇒ similar mid-infrared excess emission

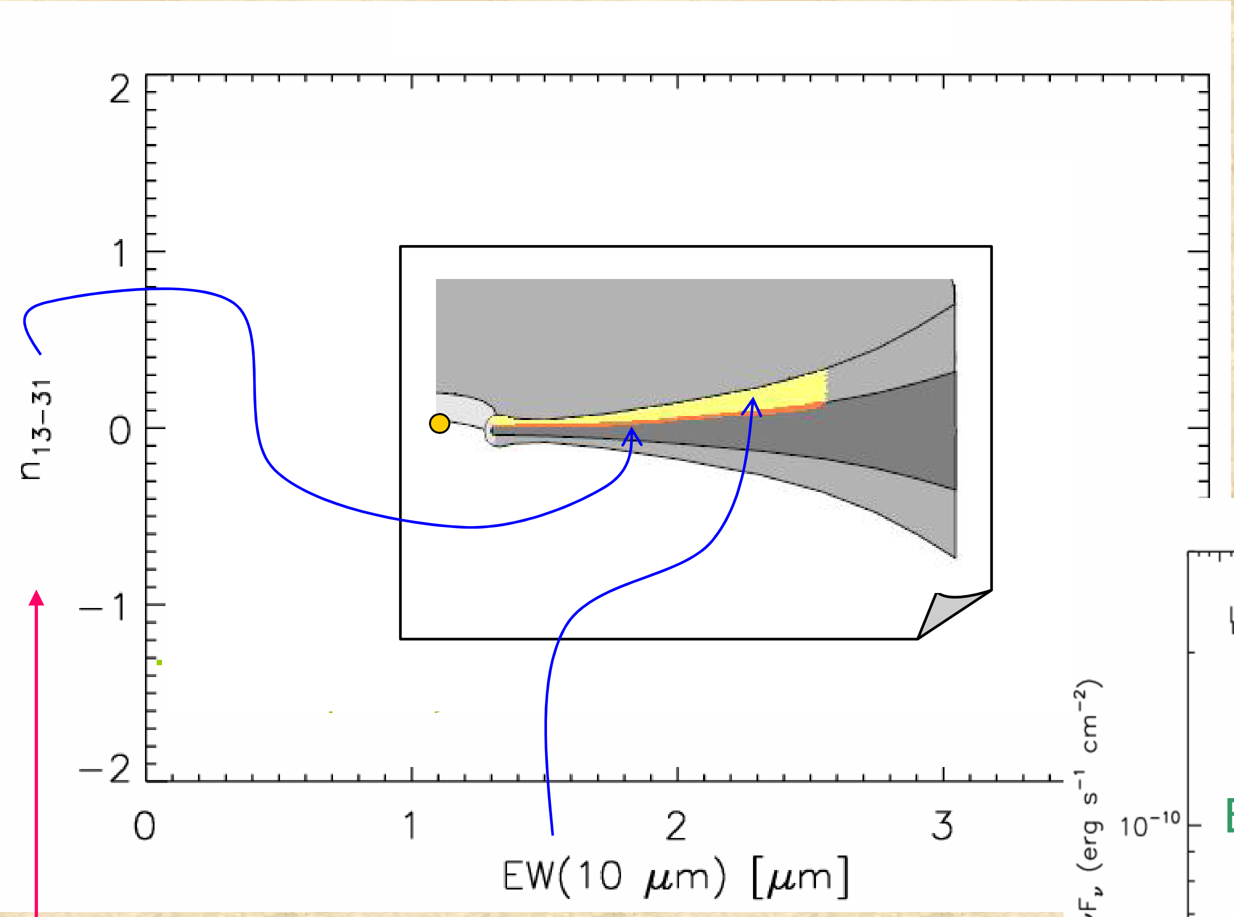
→ on average, similar disk structure

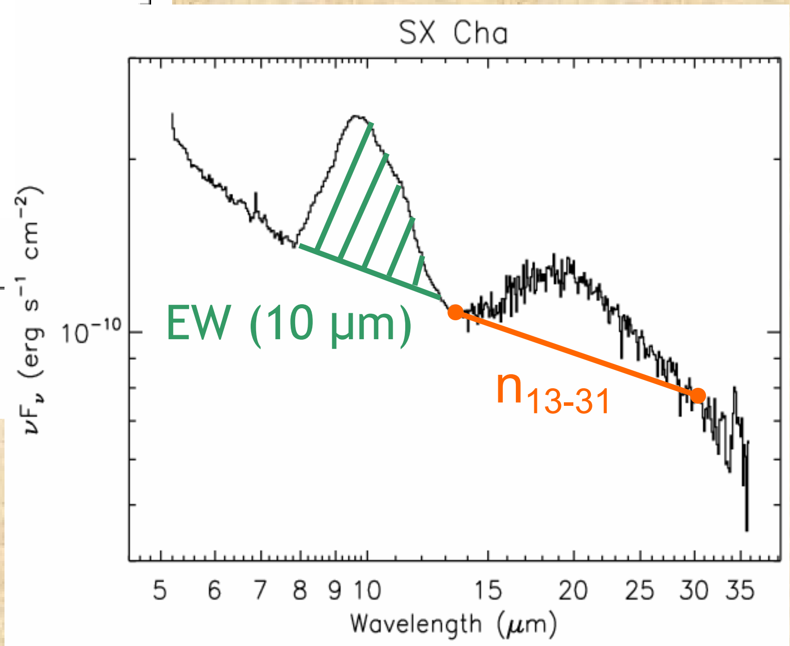
Continuum-subtracted and -normalized median 10 μm silicate emission features

⇒ possibly more crystalline silicates in Ophiuchus and Chamaeleon I

Furlan et al. (2009)

Identifying Disk Evolution with the IRS



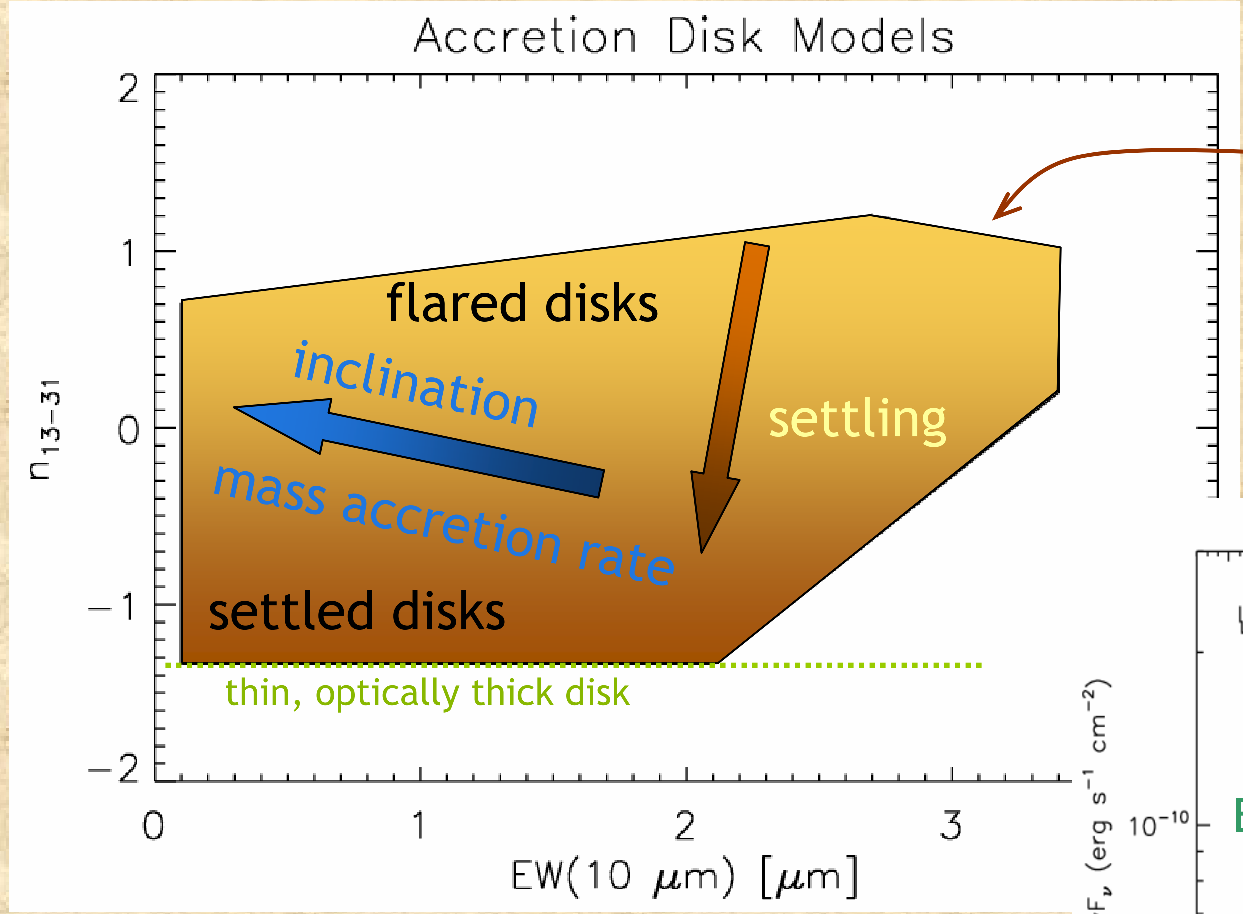


13-31 μm spectral index: degree of dust settling

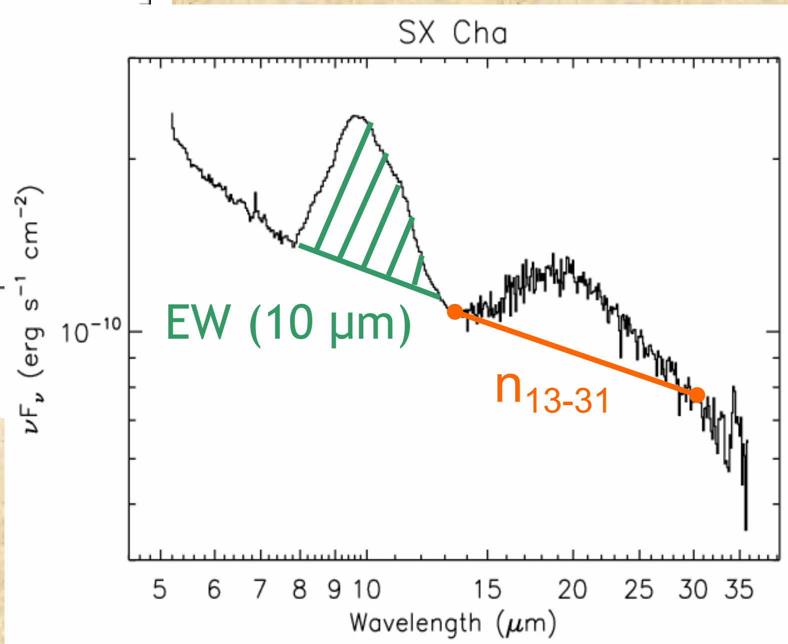
10 μm feature equivalent width: optically thin dust mass per area of optically thick disk

Watson et al. (2008), Furlan et al. (2009)

Identifying Disk Evolution with the IRS

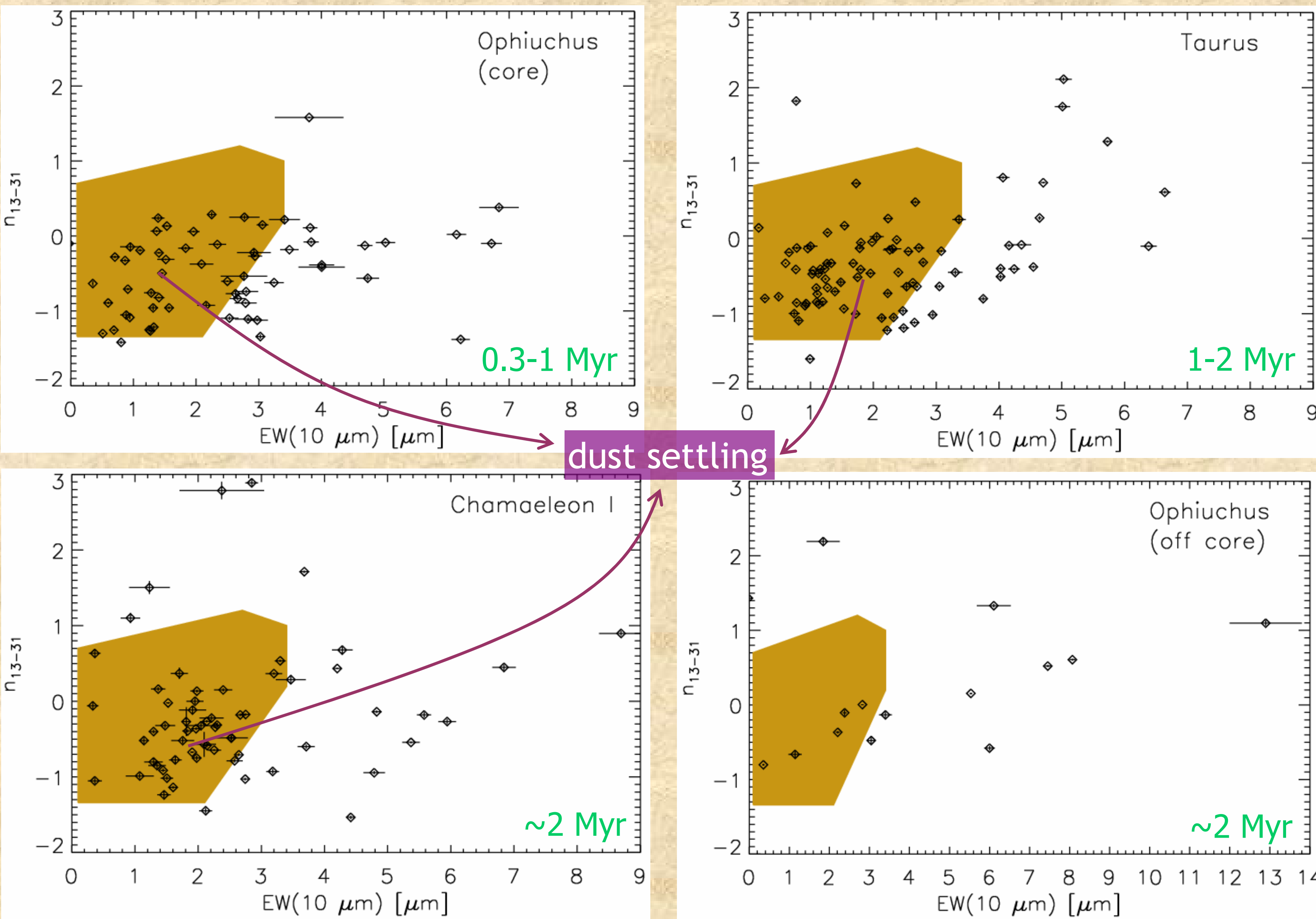


spread from model calculations (full protoplantary accretion disks)

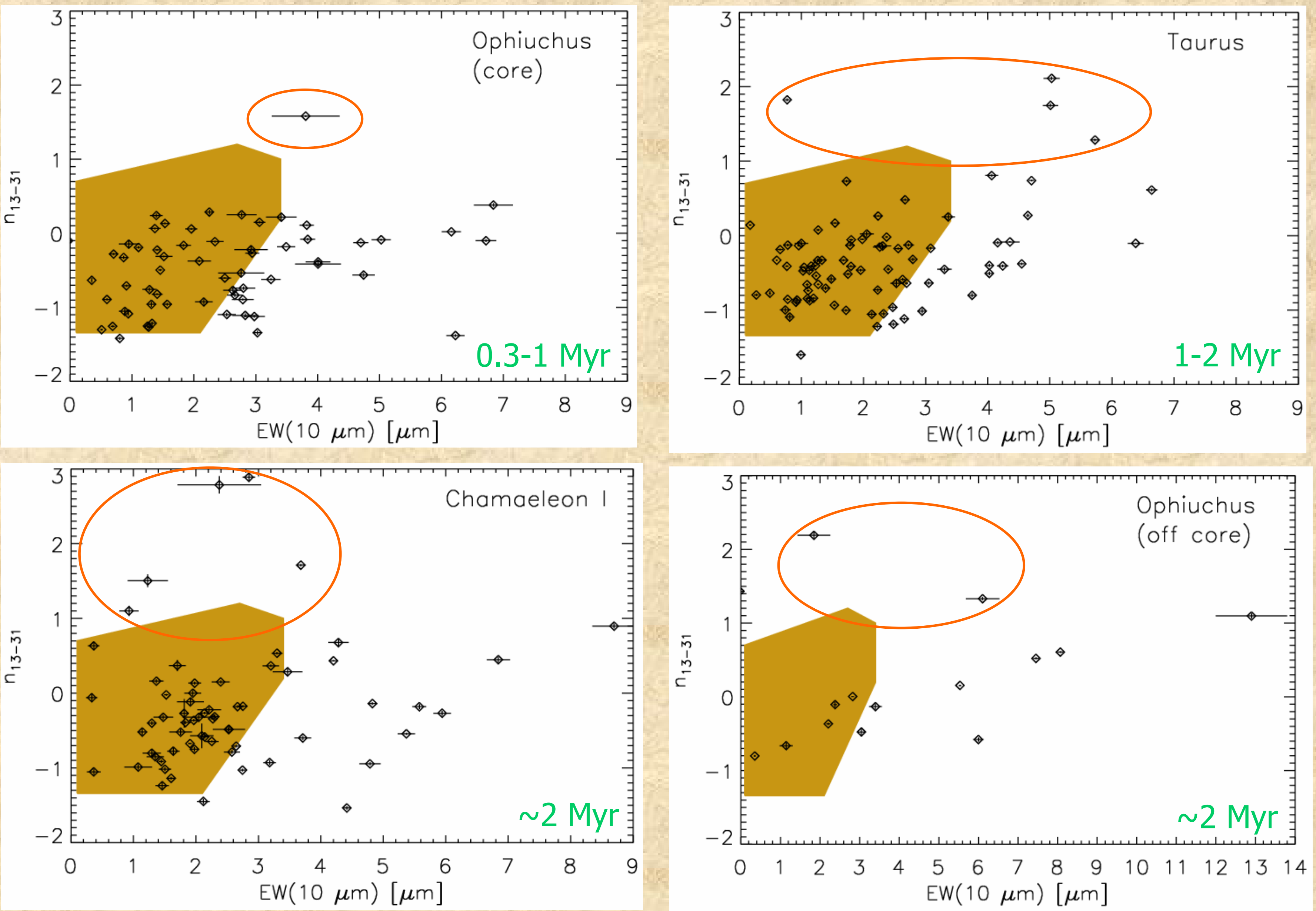


Watson et al. (2008), Furlan et al. (2009)

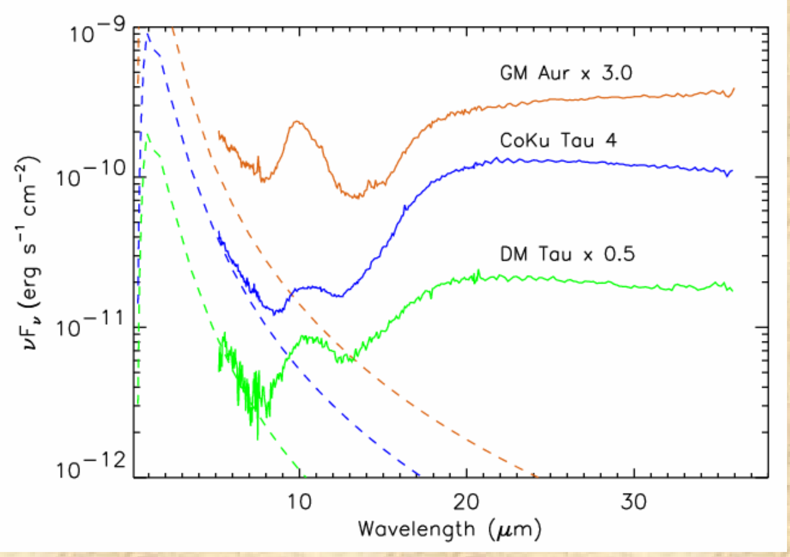
Disk Evolution in Oph, Tau, Cha



n_{13-31} Outliers



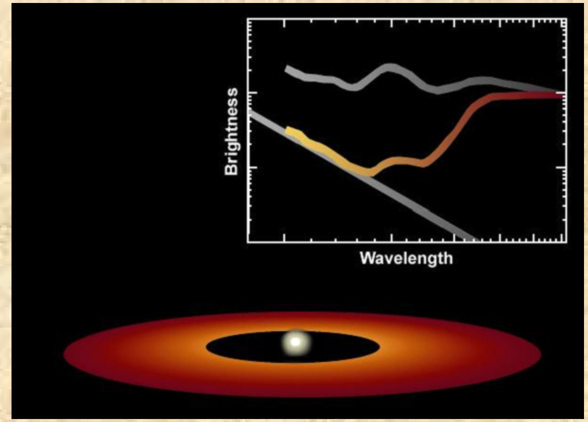
n_{13-31} Outliers: Transitional Disks



- large excess > 8 μm, steep SED rise
- little/no excess < 8 μm

⇒ inner disk cleared or optically thin (i.e., no inner accretion disk); outer, optically thick disk remains

→ small dust grains are depleted from the inner regions of the disk



credit: NASA/JPL-Caltech/ D. Watson (University of Rochester)

- ➢ MRI-induced inner disk clearing ~ 1 Myr
- ➢ Photoevaporation ~ 0.1 Myr
- ➢ Planet formation ~ 10 Myr or ~ 1000 yr

fraction of transitional disks:

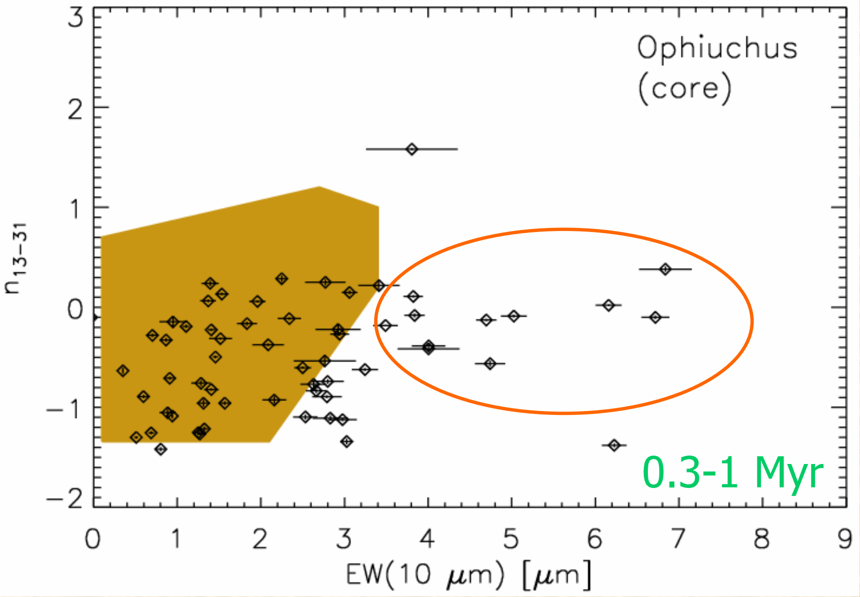
- 13±9 % in the Ophiuchus off-core region
- 3±2 % in the Ophiuchus core (L1688)
- 6±3 % in Chamaeleon I
- 3.5±2 % in Taurus

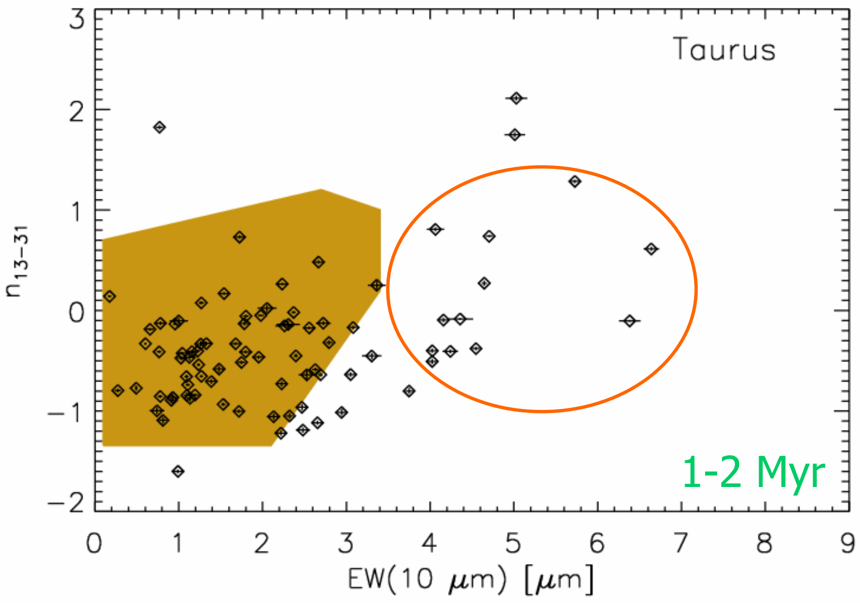
Poster #80 by Manoj P.

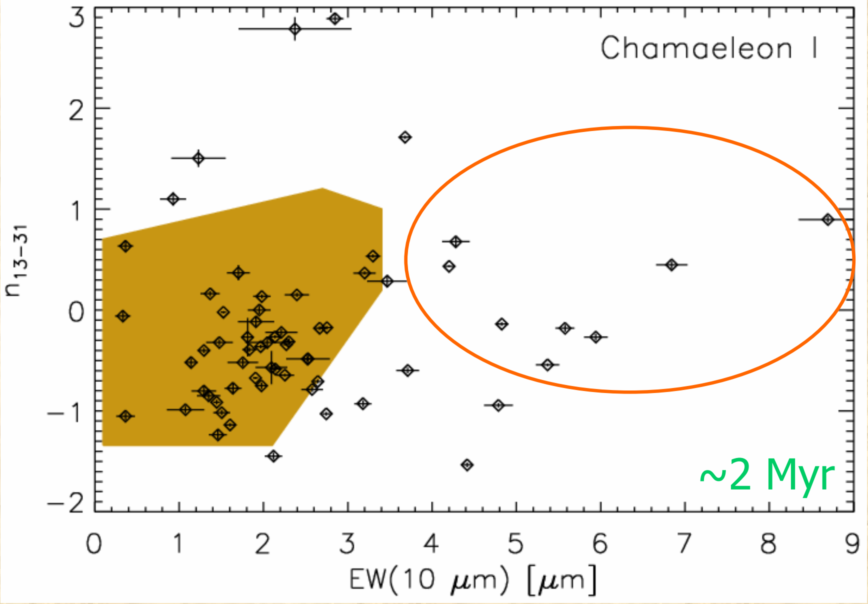
Poster #92 by K. H. Kim

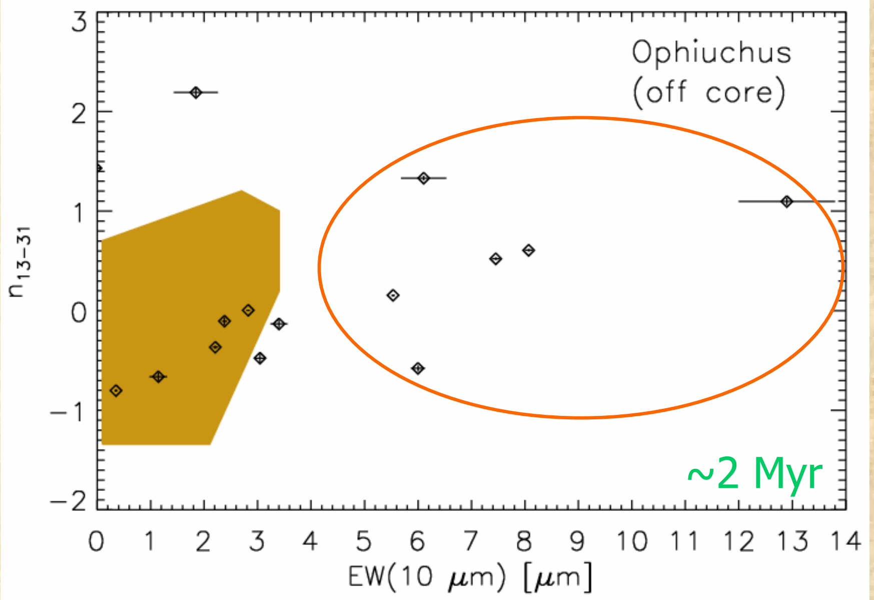
Furlan et al. (2009)

EW(10 μm) Outliers

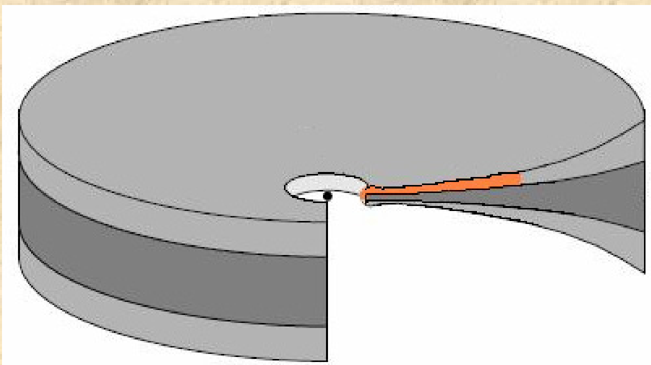


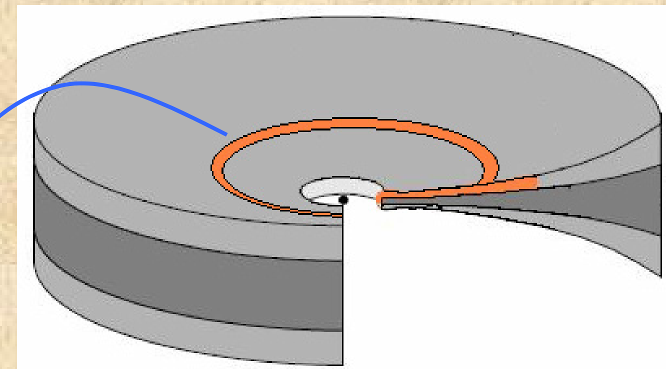




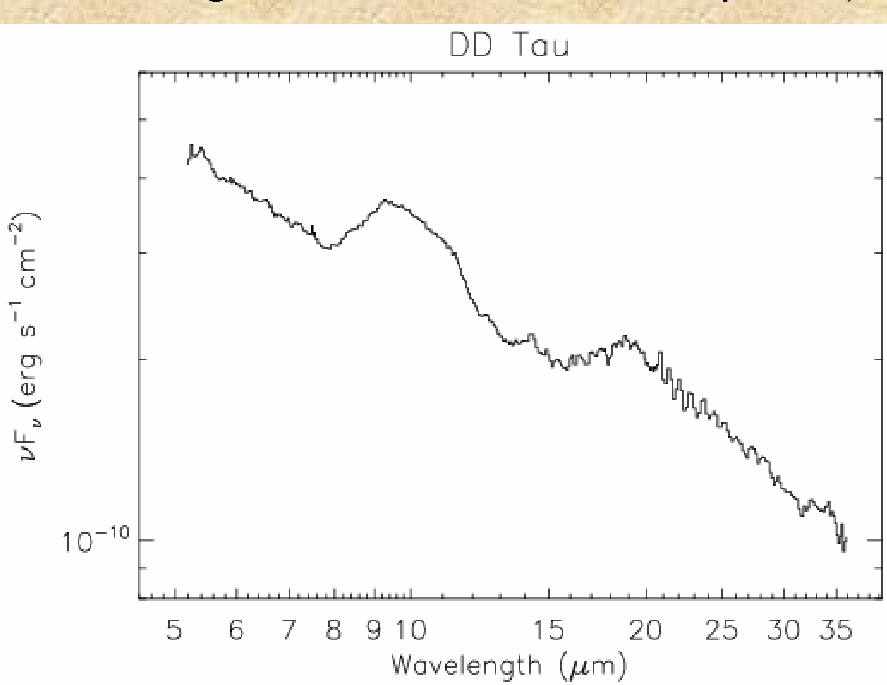


Formation of Disk Gaps

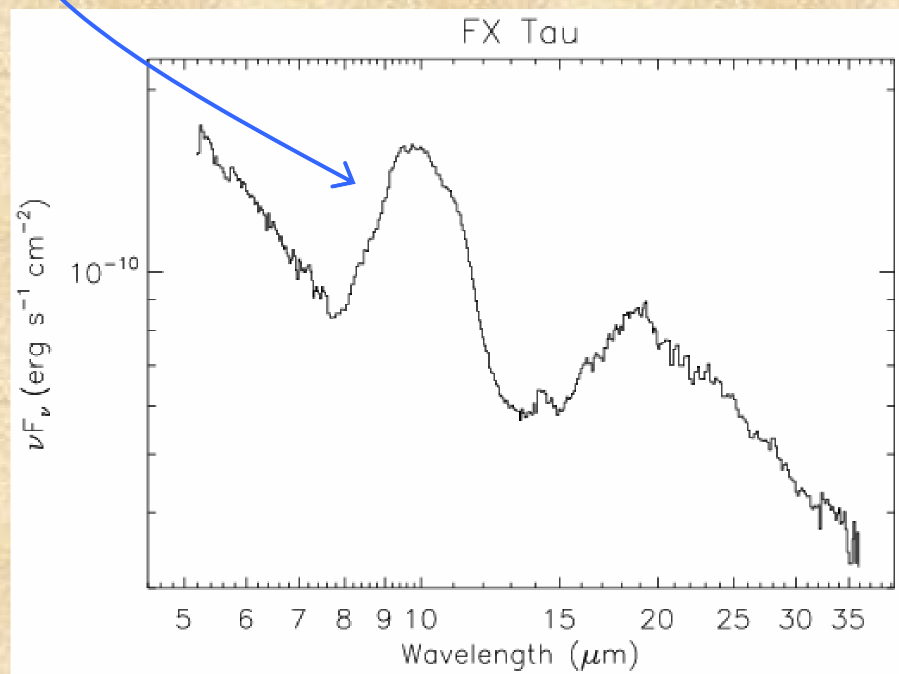




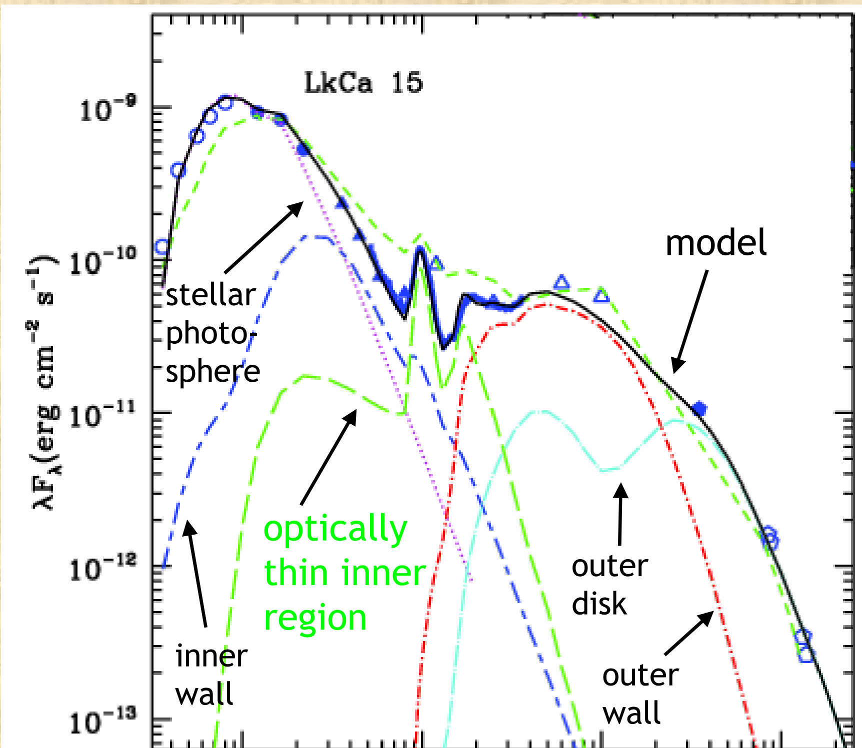
full accretion disk (10 μm silicate feature generated in disk atmosphere):



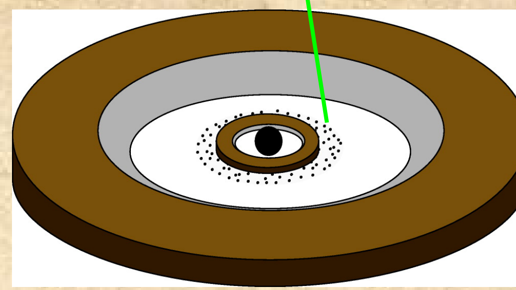
inner disk gap forming, filled with optically thin dust that increases the 10 μm feature strength:



"Pre-Transitional Disk": LkCa 15

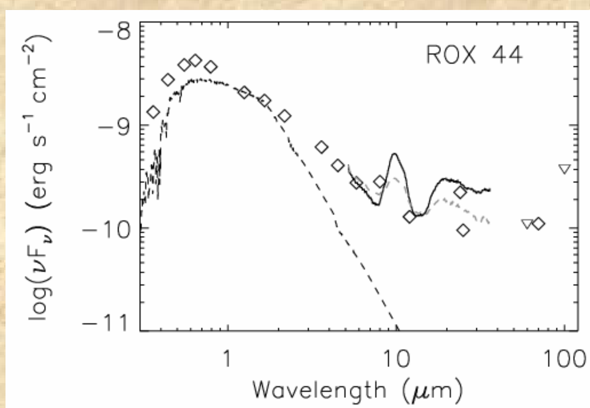


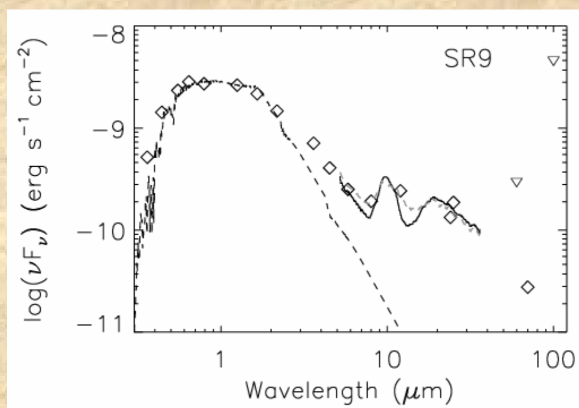
inner wall: 0.12-0.15 AU,
a_{max}=1 μm
outer wall: 46 AU, a_{max}=0.25 μm
outer disk: 0.1 $M_\odot$
optically thin inner region: 0.15-5 AU,
a_{max}=0.25 μm,
4 x 10^{-11} $M_\odot$



Espaillat et al. (2007b, 2008)

Poster #91 by C. Espaillat





fraction of EW(10 μm) outliers:

- 32±7 % in L1688
- 21±5 % in Taurus
- 20±6 % in Chamaeleon I
- 47±18 % in Ophiuchus off-core

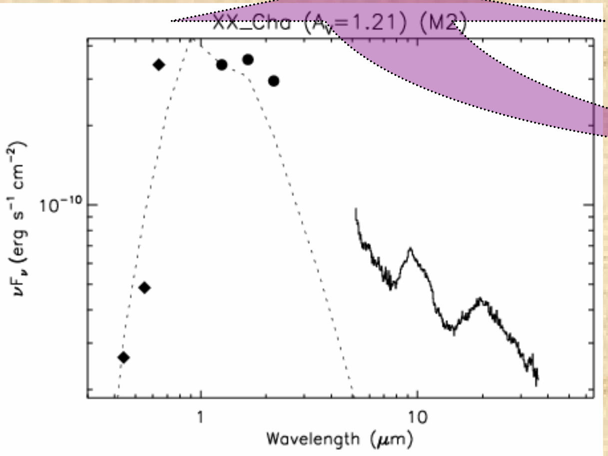
Furlan et al. (2009)

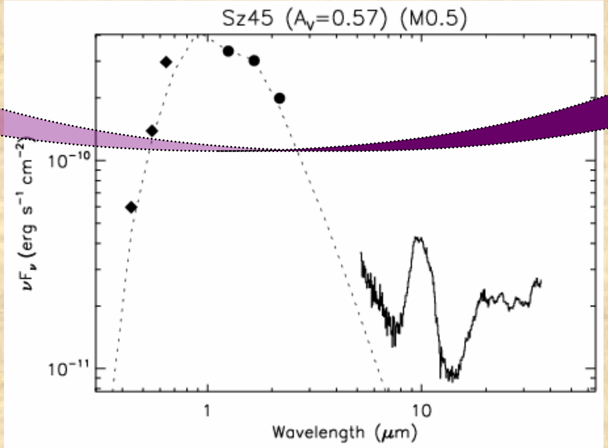
Disk Evolution

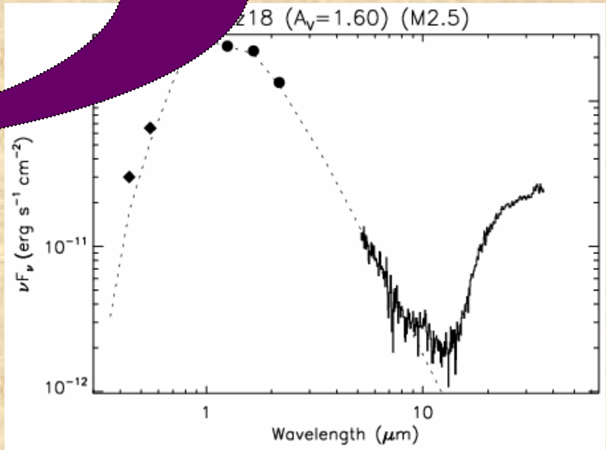

credit: NASA/JPL-Caltech/T. Pyle (SSC)


credit: NASA/JPL-Caltech/T. Pyle (SSC)

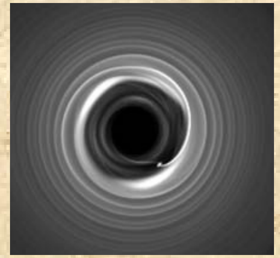

credit: NASA/JPL-Caltech/T. Pyle (SSC)

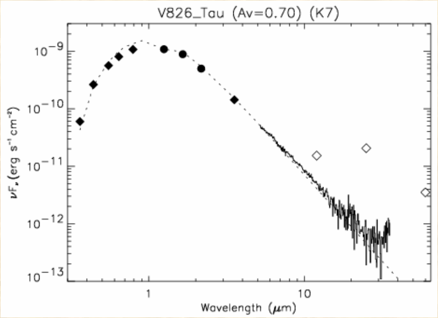






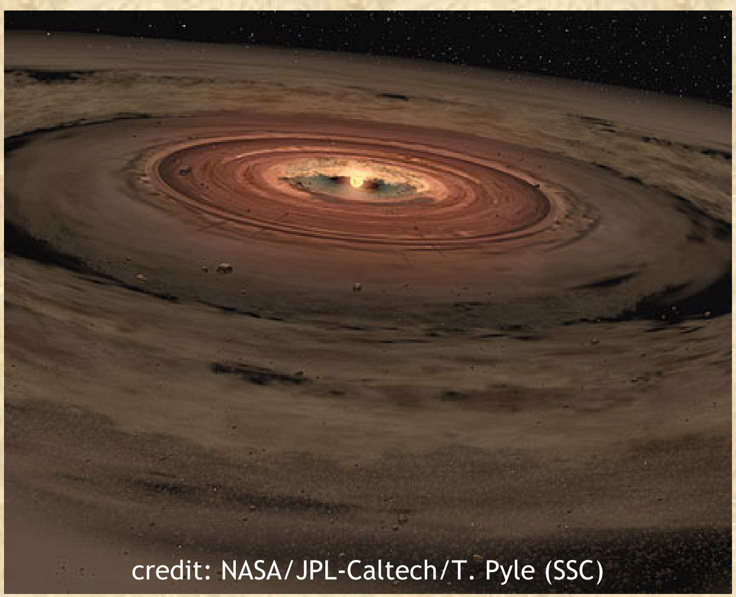
evidence for planet formation?


Rice et al. (2006)

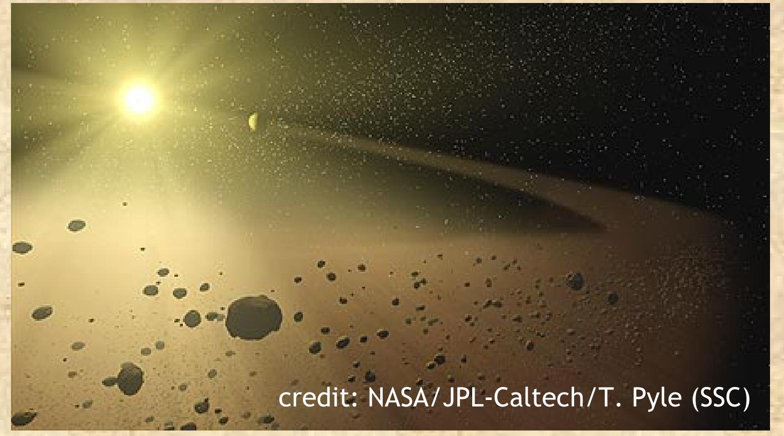


Conclusions

- disk dissipation in ~10 Myr; starts in the inner disk, proceeds rapidly outward



- median mid-infrared excess is similar in Taurus, Ophiuchus, Chamaeleon I
  $\Rightarrow$ similar average disk structure
- mid-IR spectral index vs. equivalent width of the silicate emission feature at 10 μm
  $\rightarrow$ transitional disks: key to understanding disk evolution and dissipation (photoevaporation; MRI-induced disk draining; planet formation)
  $\rightarrow$ early-stage transitional disks: disks with optically thin gaps



- first steps of planet formation already at ~ 1-2 Myr in Tau, Oph, Cha:
  - ✵ dust settling
  - ✵ gap formation: ~20-30 % of all disks
  - ✵ more evolved disks in Ophiuchus off-core region (?) and Chamaeleon I (~2 Myr)