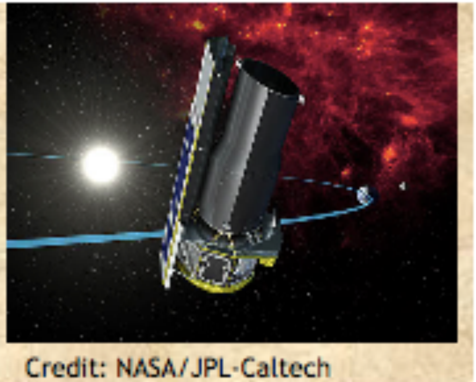
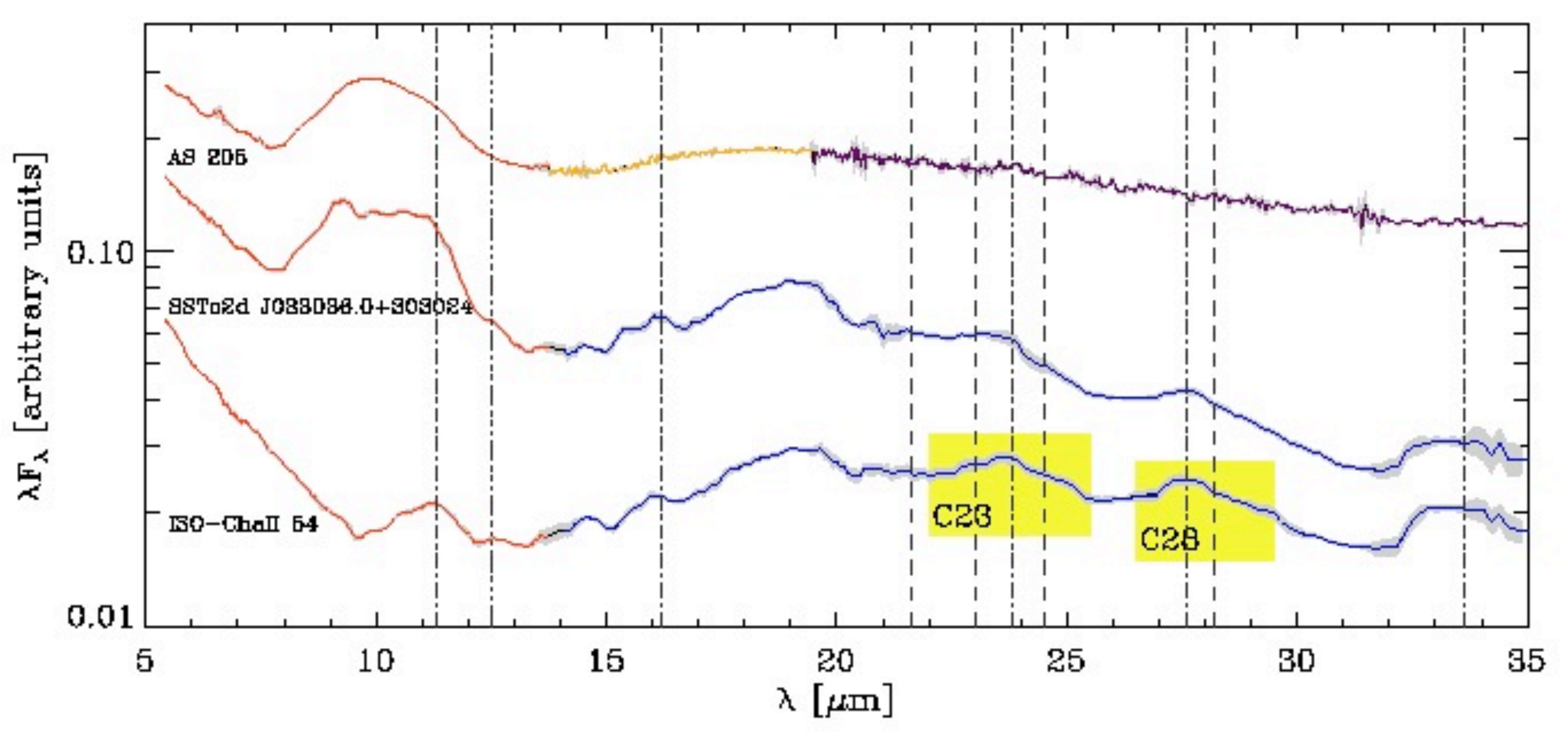
Circumstellar Disk Mineralogy in Nearby Molecular Clouds: Spitzer and the Herschel Followup

Joel Green

Amorphous vs. crystalline

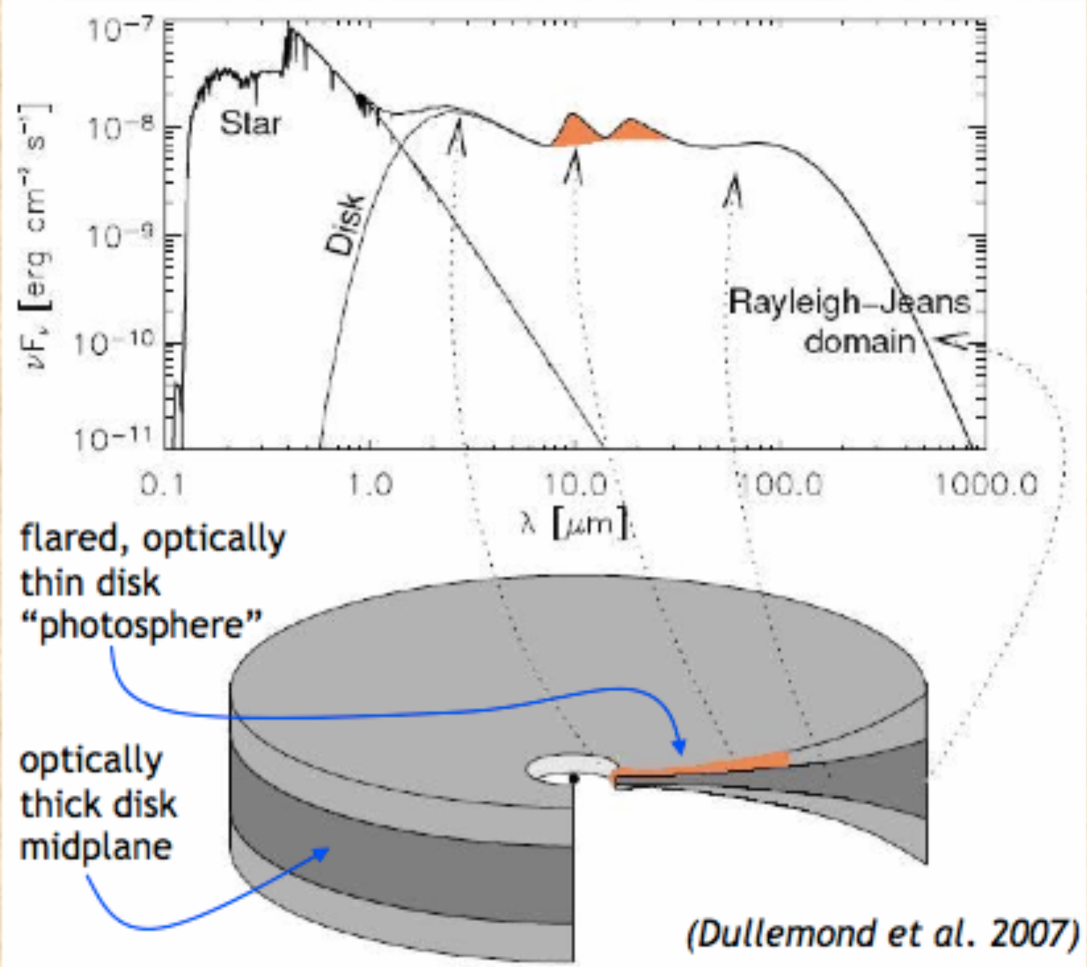

Credit: NASA/JPL-Caltech



The Harsh Life of a Dust Grain

- Planetary nebulae (circumstellar dust shells) exhibit crystalline dust grains
- Dust is damaged by radiation after entering the ISM and becomes pristine
  - No evidence for silica (SiO_2) in the ISM
- Yet we observe crystallized dust in most circumstellar disks (except for disks with radial holes) and comets (Hale-Bopp, Tempe 1, 81P/Wild 2; see STARDUST), which formed early and far out in our solar system
- Crystallization requires heating to 1000 - 1400 K and cooling
- When and where did the crystalline dust get formed?
  - In-situ vs. radial mixing

A “Typical” T Tauri Disk



(Dullemond et al. 2007)

near-IR (1-4 μm): <0.05-0.1 AU

mid-IR (4-30 μm): 0.1-10 AU

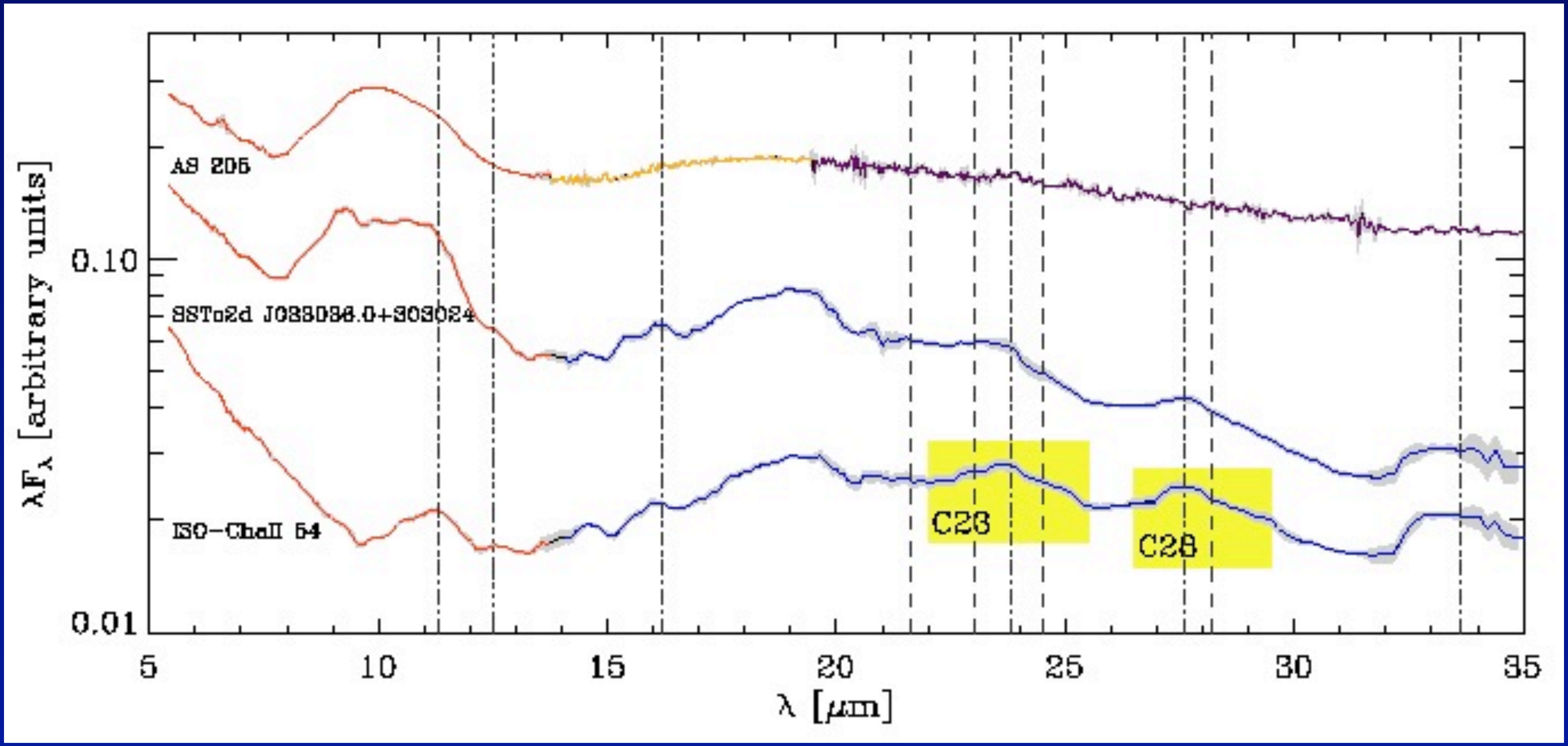
far-IR (30-100 μm): 10-100 AU

Furlan et al.

Radial Distribution of Crystals

- Many of the youngest disks, including ones that are barely beyond their embedded state, show signs of dust grain processing
- Sargent, McClure, Oloffson, Watson et al. (2009), find that disks with large amounts of any one crystalline species are likely to have some amount of other crystalline species
- Presence of Mg-rich crystalline silicate emission (forsterite; Mg_2SiO_4) at 33 μm implies that crystals should be present in the inner regions of the disk as well and contribute to the emission in the 10 μm silicate feature (forsterite, enstatite, and silica).
- Crystallinity in the innermost 1-10 AU of the disk correlates with increased dust processing in the inner 1 AU of the disk

Composition of dust in disks

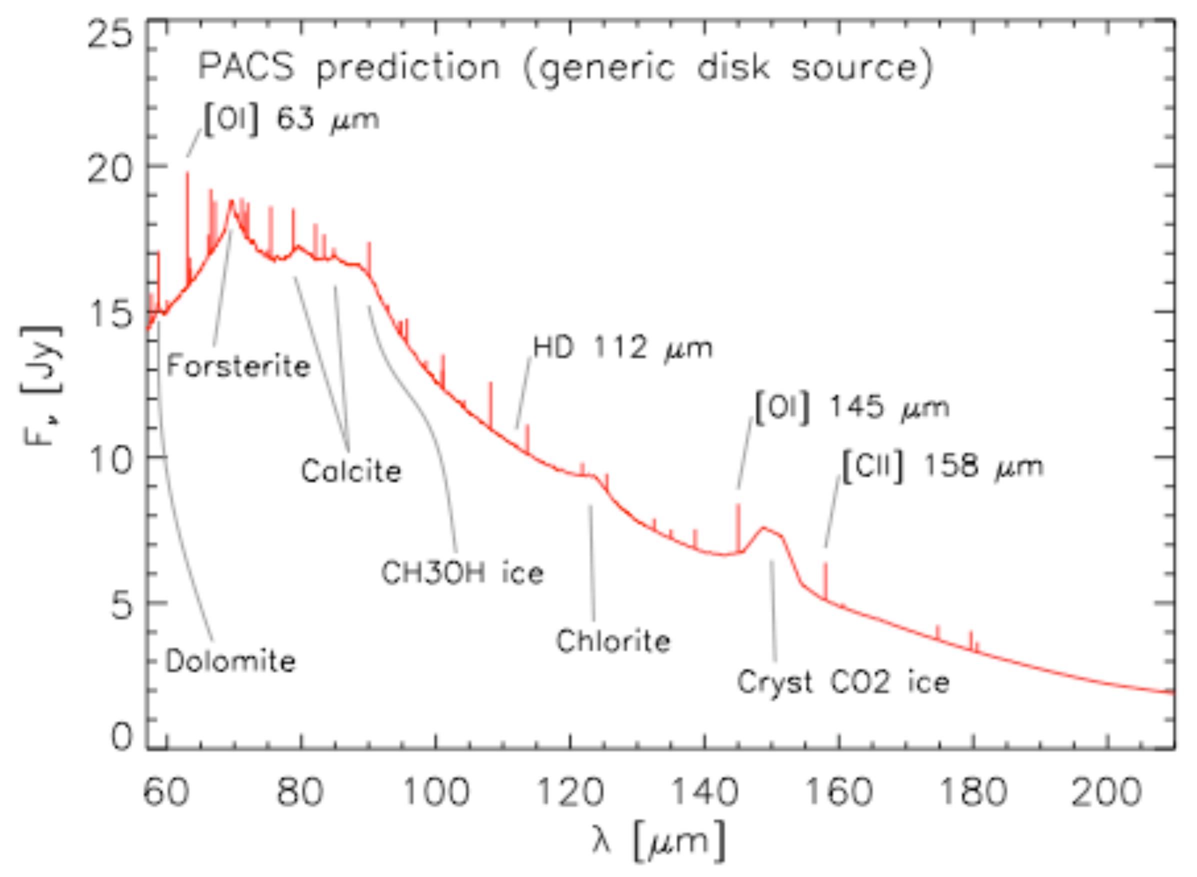


J.Oloffson et al. in press
over 100 stars in sample

DIGIT (Dust, Ice, and Gas In Time)

- A Herschel Open Time Key Project
- 250 hrs (first observations appear at the end of October!)
- 30 embedded protostars, plus 64 disk sources ranging from B to M in spectral type (intermediate and low mass), selected from nearby (a few x 100 pc) molecular clouds (Tau, Oph, Cha, Per, Ser, Lup)
- Full disks/ disks with gaps; crystalline dust vs. amorphous at Spitzer wavelengths; embedded objects will exhibit outflows, ice (water, carbon dioxide, and others); gas emission
- PACS spectroscopy (57-210 um), PACS photometry (70, 100, 160 um)
- SPIRE photometry (to determine disk masses)
- HIFI spectroscopy for embedded sources not in the WISH guaranteed time project (to detect water)

Expected Features



Outer disk: less optically thick, and we can detect larger grains (~ 20 um)

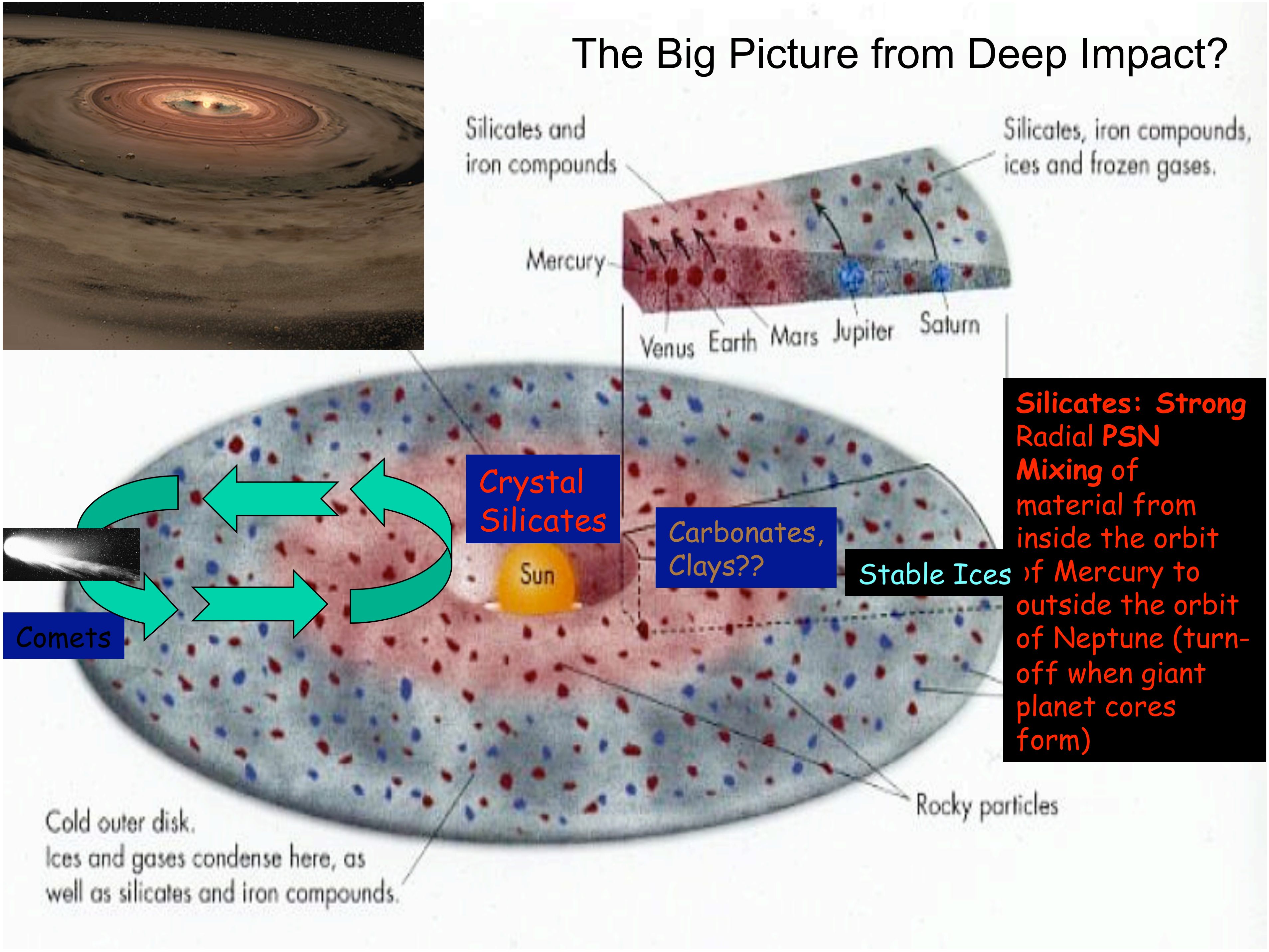
If we detect crystalline dust with PACS…

- Very efficient radial mixing is suggested (depending upon the total mass of grains in the outer disk vs. inner)…
- Or the dust was distributed in its current arrangement at very early times, during the embedded phase
- Or the dust has been lifted into the upper layers in great quantities

If we do NOT detect any dust features:

- Dust has grown beyond 20 um in size
- Crystalline dust has settled deeper into the disk
- Cold crystalline dust is not present
  - Indicates very poor radial mixing
    - An early event set the crystalline mass fraction in the inner disk

The Big Picture from Deep Impact?



Crystal Silicates

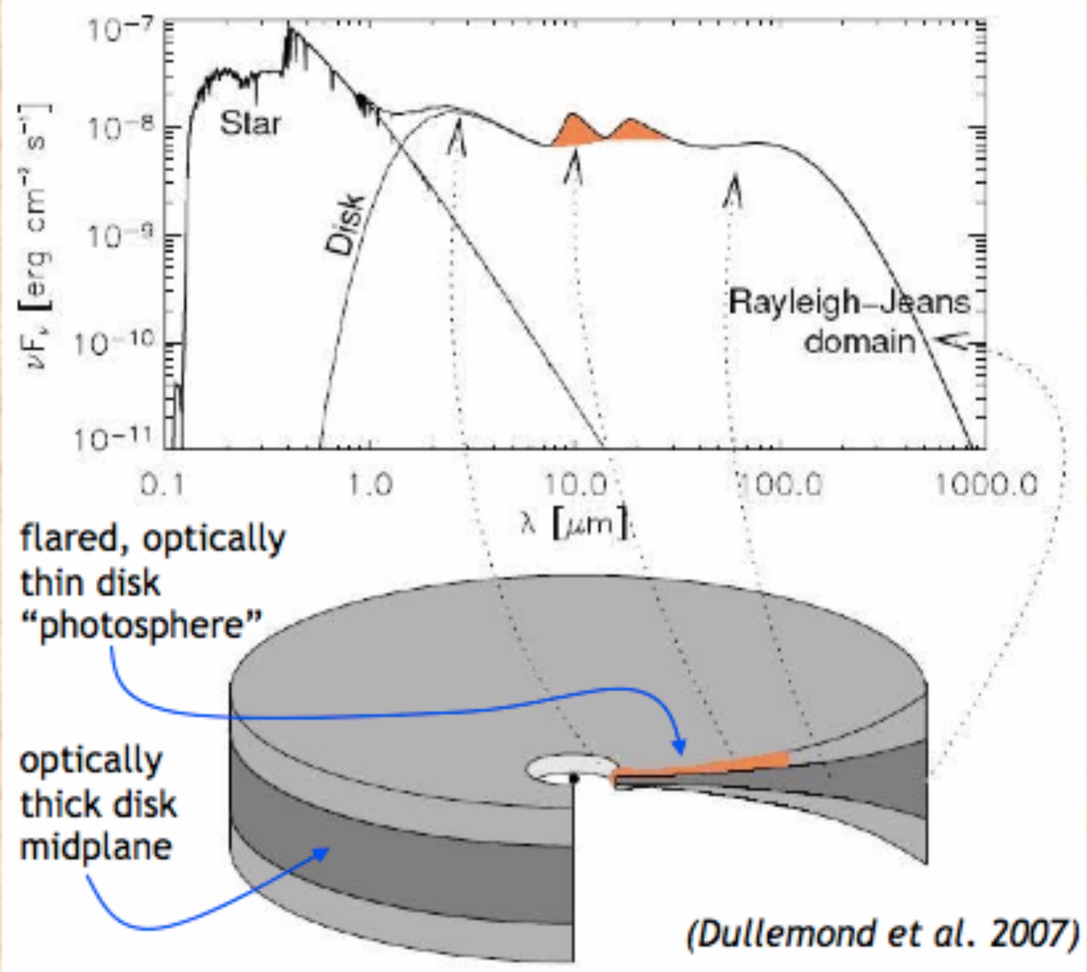
Carbonates, Clays??

Stable Ices

Comets

Silicates: Strong Radial **PSN Mixing** of material from inside the orbit of Mercury to outside the orbit of Neptune (turn-off when giant planet cores form)

A “Typical” T Tauri Disk



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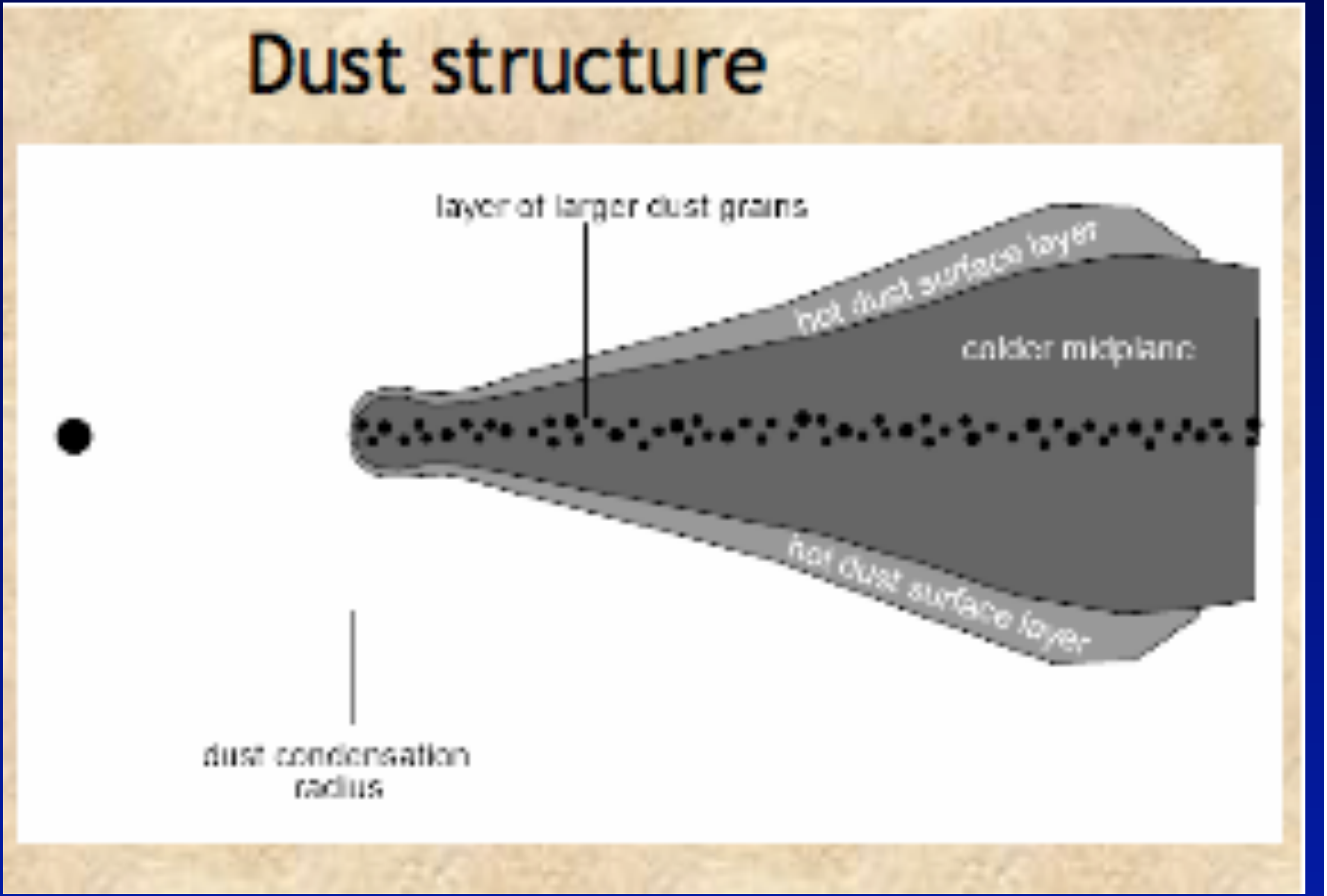


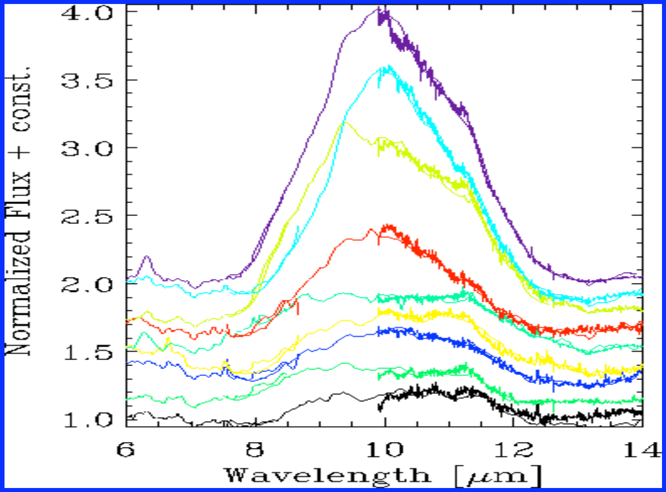
Dust structure

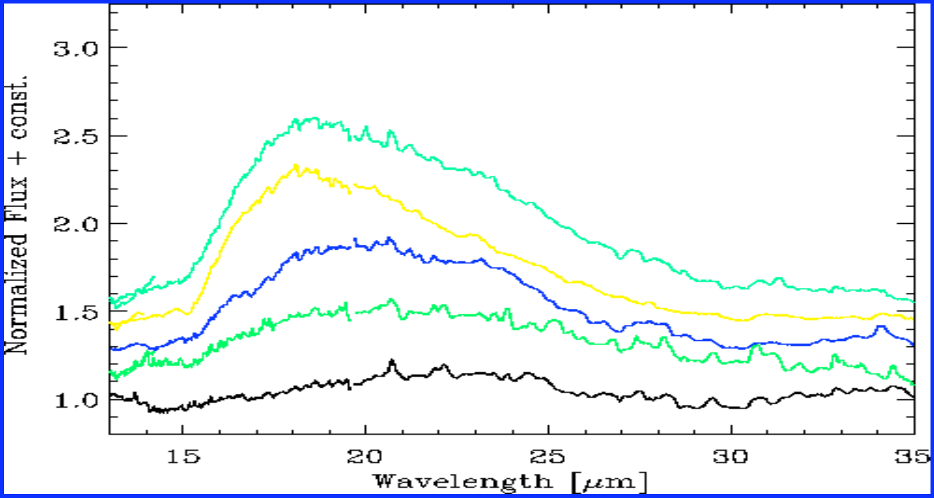
Furlan et al.

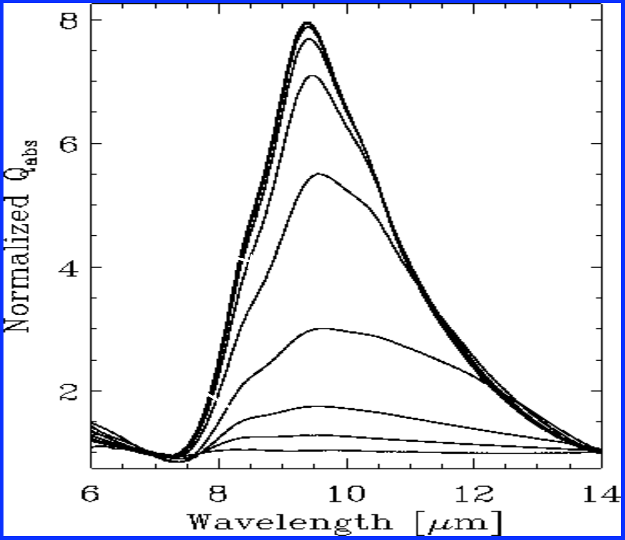
Grain Growth in Disks

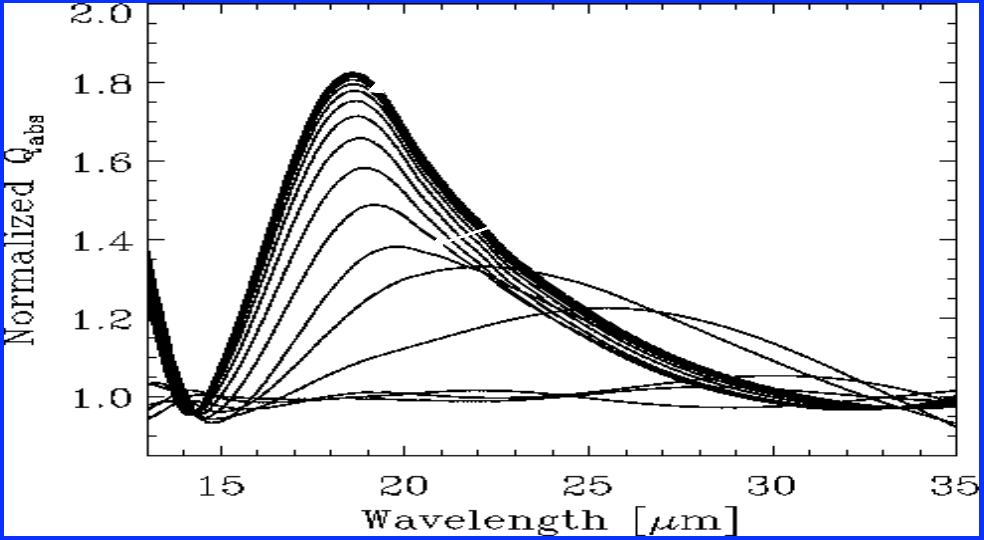
10 µm band

20 µm band









Kessler-Silacci et al., 2006

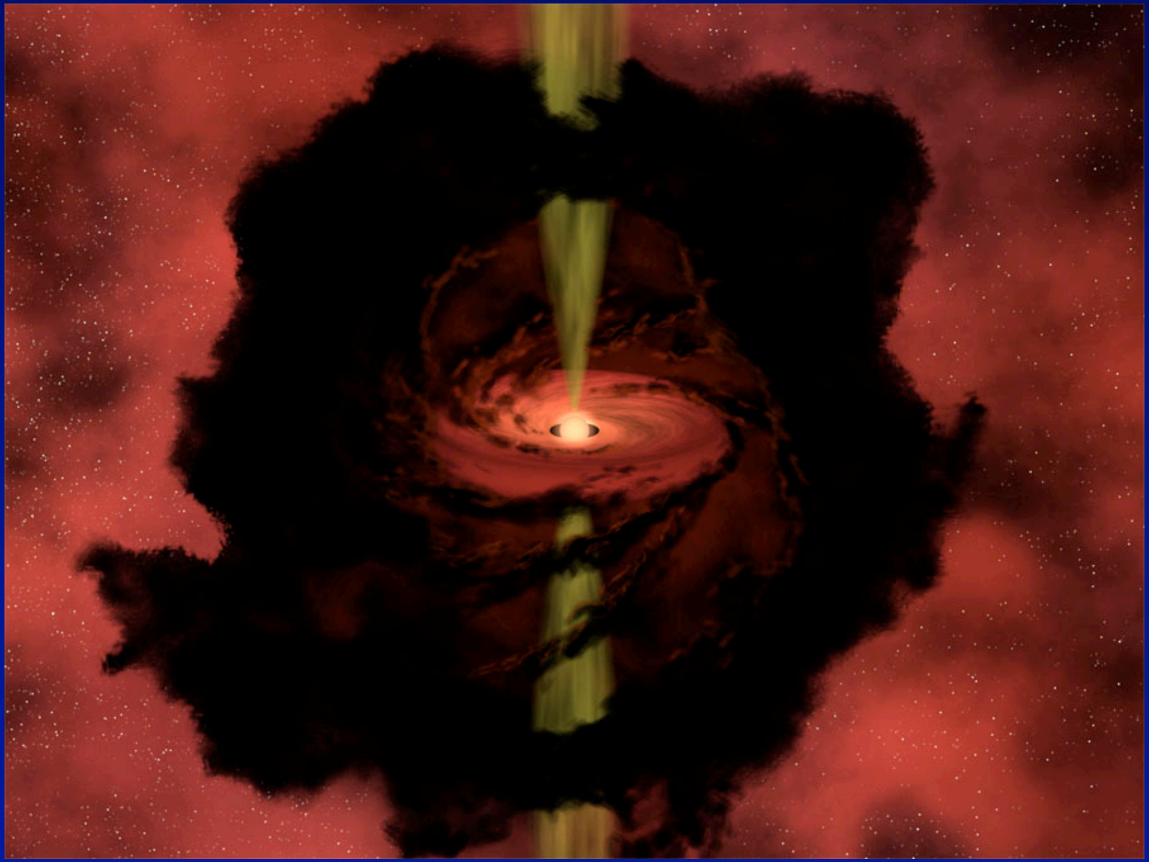
A Key Project with Herschel

A 3.5-m Telescope
Passively cooled
Launched May 14, 2009
Ariane 5 from French Guiana
At L2 point
Focus on far-infrared and submillimeter
PACS: 57- 210 microns photometry and spectroscopy
R ~ 1500
Two other instruments

Circumstellar Disks

- The disks form as part of the collapse of a dense molecular core to form a star
- Angular momentum implies most matter falls onto disk, not star
- Disk feeds star, provides raw materials for planet building
- Star-disk system sheds angular momentum in bipolar jets

The Artist's Conception

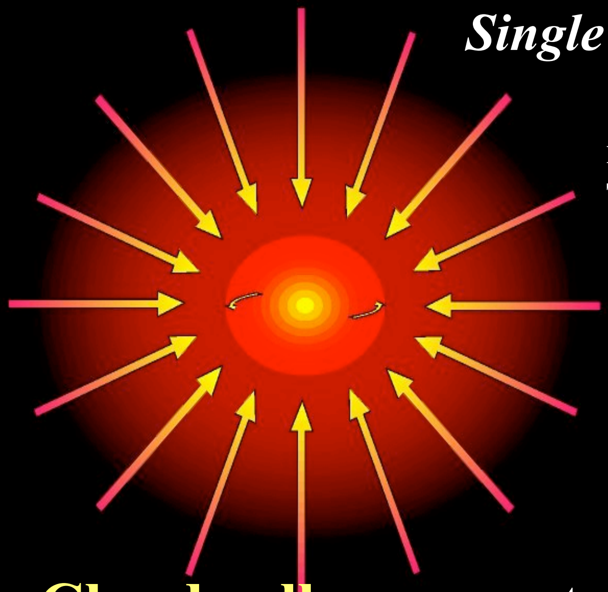


R . Hurt

Standard Evolutionary Scenario

Single isolated low-mass star

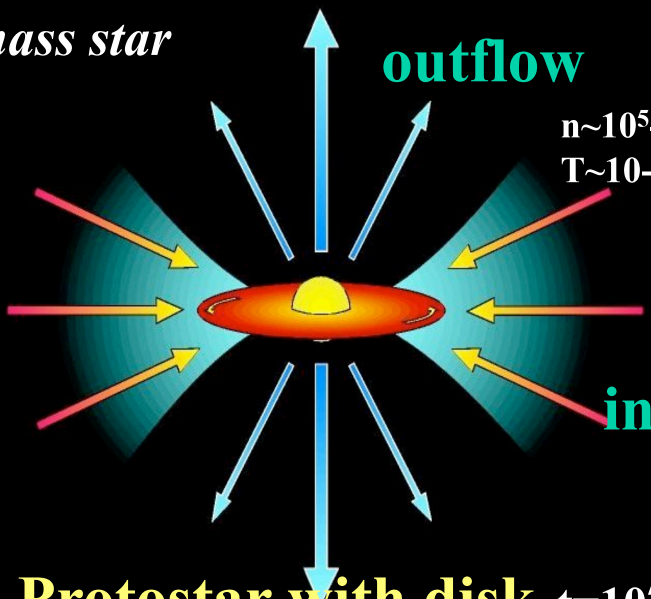
Stages



n~10^4-10^5 cm^{-3}
T~10 K

Cloud collapse t=0

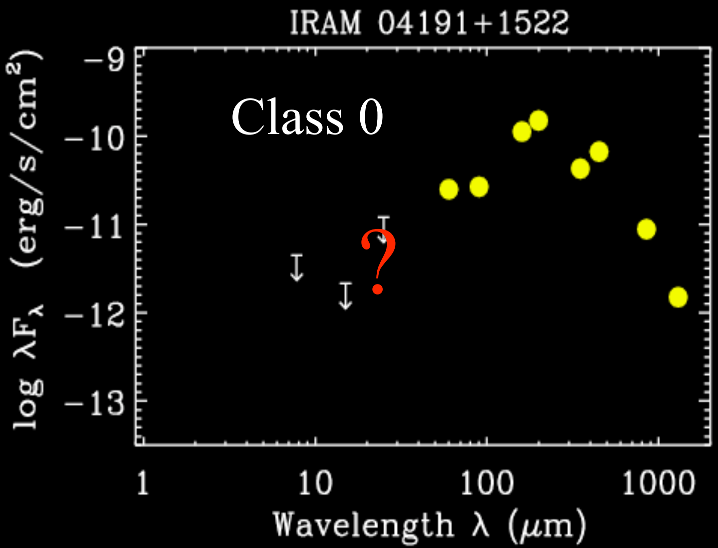
Factor 1000 smaller



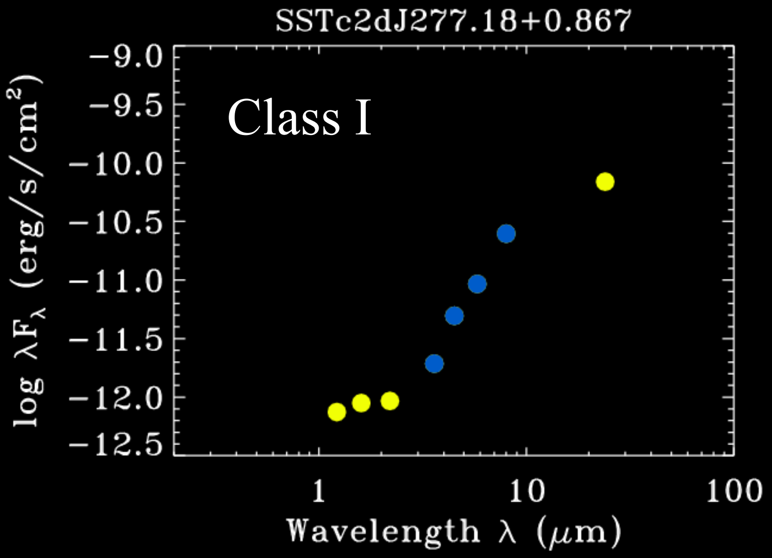
n~10^5-10^8 cm^{-3}
T~10-300 K

Protostar with disk t=10^5 ? yr

Classes

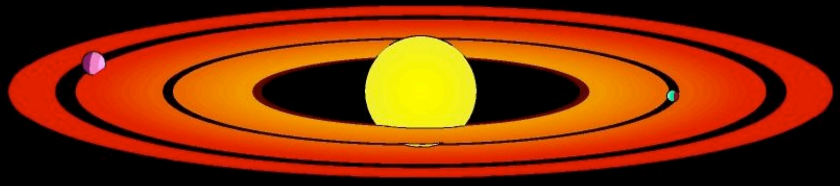


Between stages!



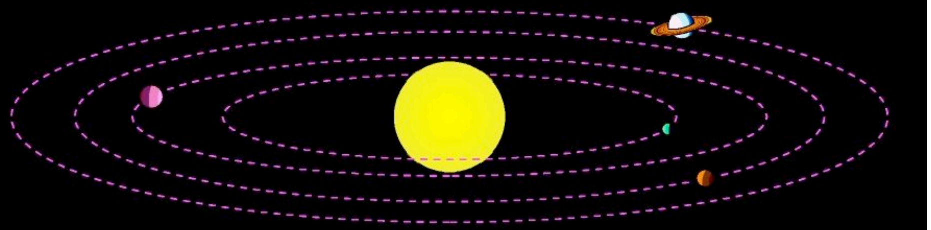
Note axis change!

Scenario for star- and planet formation

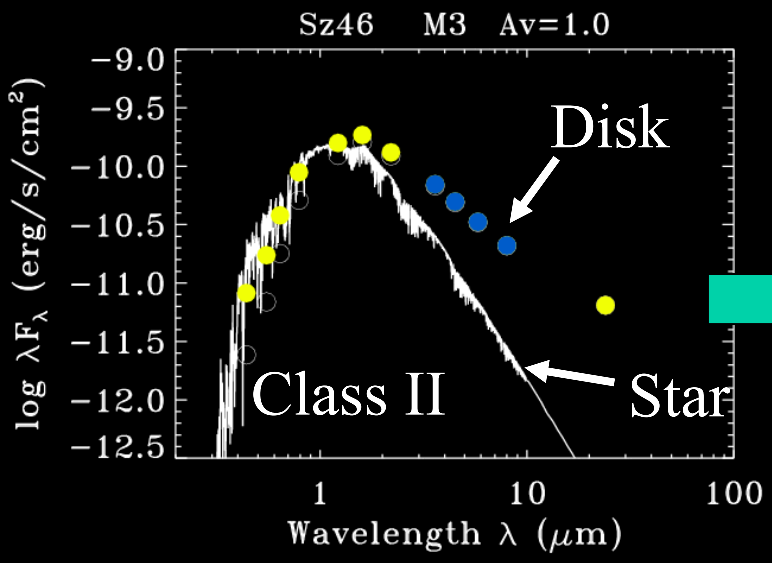


Formation planets t=10^6-10^7 yr

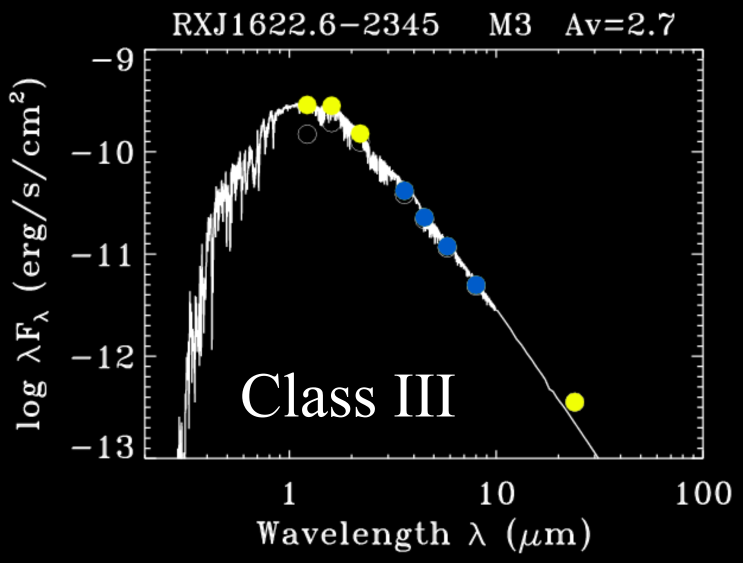
?



Solar system t>10^8 yr (?)



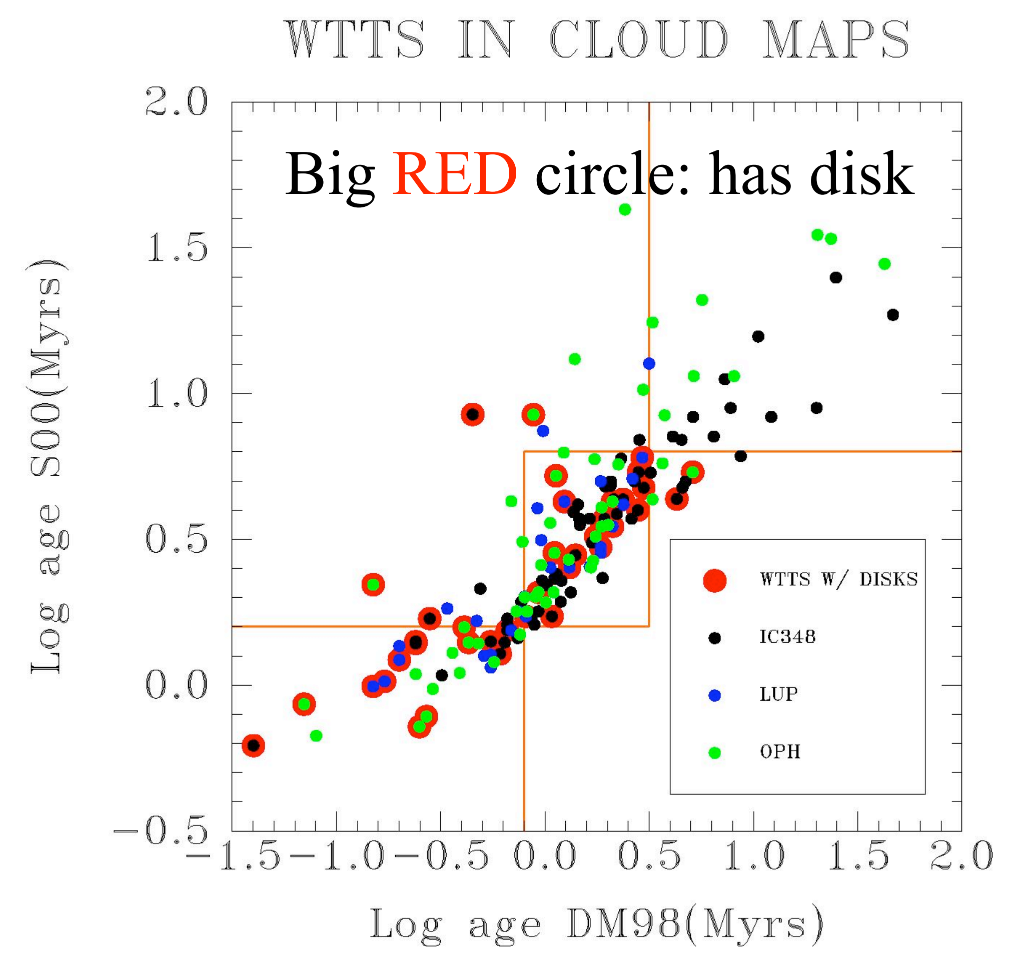
?



Studies of disks

- Survey of star forming regions, known disks with Spitzer Space Telescope
  - c2d (Evans et al.) and IRS team (Joel Green)
  - Constrain timescales
  - Study structure and composition
- Studies of gas phase species in disks
  - IR spectroscopy from ground (Lacy, Jaffe, Salyk)
- Far-infrared spectroscopy of disks with Herschel Space Telescope
  - Dust, Ice, Gas In Time (DIGIT) Key project

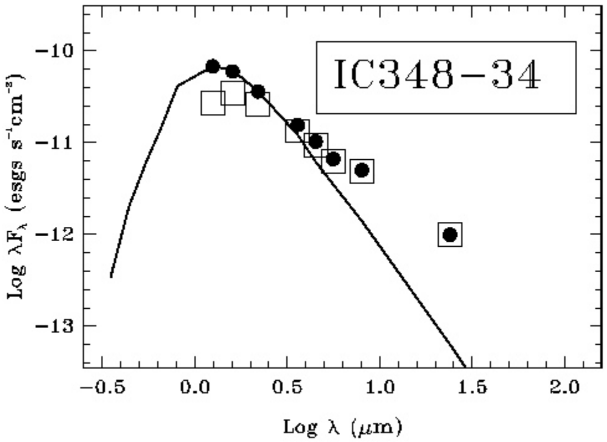
Disk Timescales



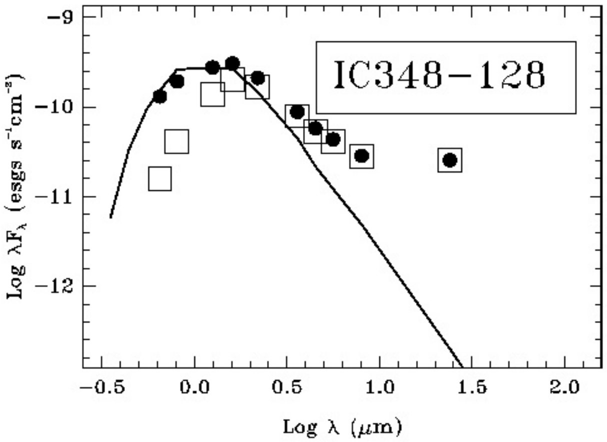
Some wTTs do have disks
Not seen before
But only the young ones
(age < 3 to 6 Myr)
Ages are uncertain due to
models
Half the young ones lack
disks (even at 0.8 to 1.5
Myr)
Time is NOT the only
variable. Think of half-life.

Padgett et al., 2006; Cieza et al., 2006

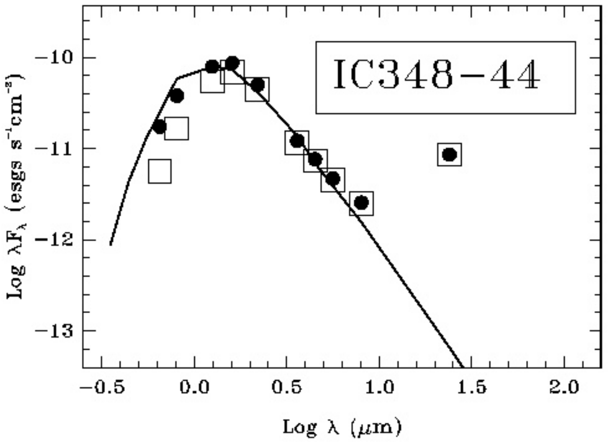
Diversity in disk SEDs



Traditional III



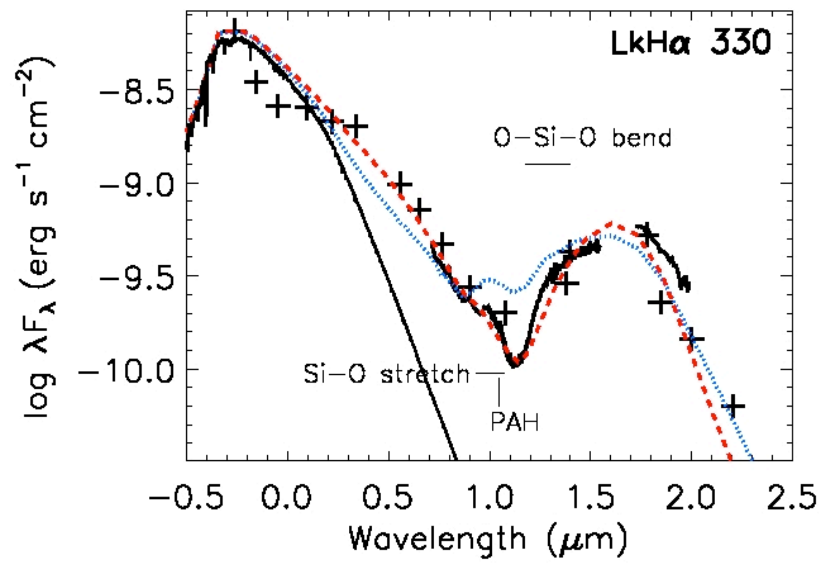
III, then flat



III, then rising

Some excesses start only at long wavelengths but are substantial: We call these cold disks. The dust is mostly colder, which means that it is farther from the heating source (the star).

A Case Study LkHα330



Brown et al. 2007b

Some excess at short λ, but much more beyond 20 μm. Blue line has no gap, red has gap.
Implies large gap; models predict about 40 AU radius. Submm interferometer should show ring.
J. Brown et al. 2007