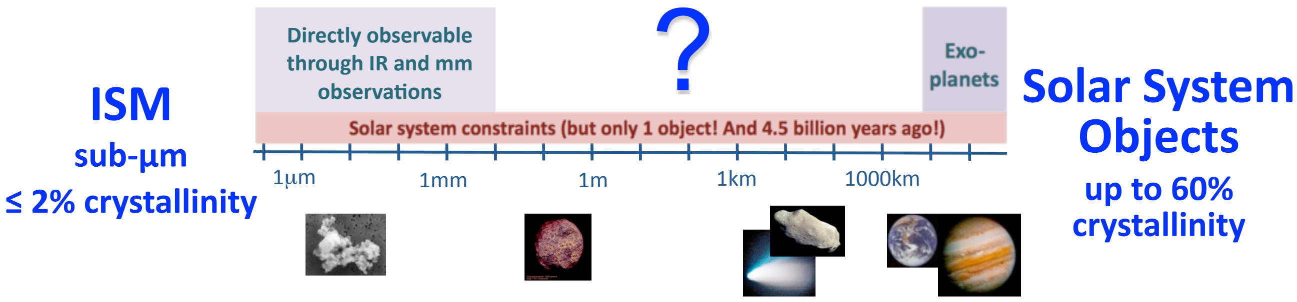
Tracing the Evolution of Dust in Protoplanetary Disks

Isa Oliveira

Sterrewacht Leiden

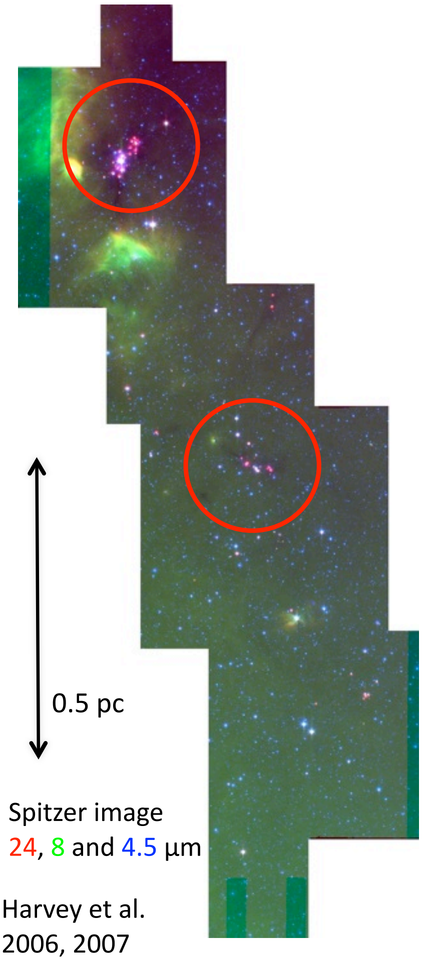
Klaus Pontoppidan, Bruno Merín, Ewine van Dishoeck,
Johan Olofsson, Jean-Charles Augereau, Loredana Spezzi,
Fernando Comerón, Vincent Geers, Joanna Brown

From dust to planets



Still unclear how and when this extraordinary change in size and composition happens

➔ Disk Evolution
(combination of external and internal processes)



Spitzer image
24, 8 and 4.5 μm

Harvey et al.
2006, 2007

Serpens

- One of the most active low-mass star-forming complexes
- High SFR ($5.7 \times 10^{-5} M_{\odot} yr^{-1}$)
- Few hundred YSOs, great variety (with mid-IR spectroscopy)
- Clustered and field population
- Complementary to Taurus

(Kenyon et al. 1994, Kenyon & Hartmann 1995, Furlan et al. 2006)

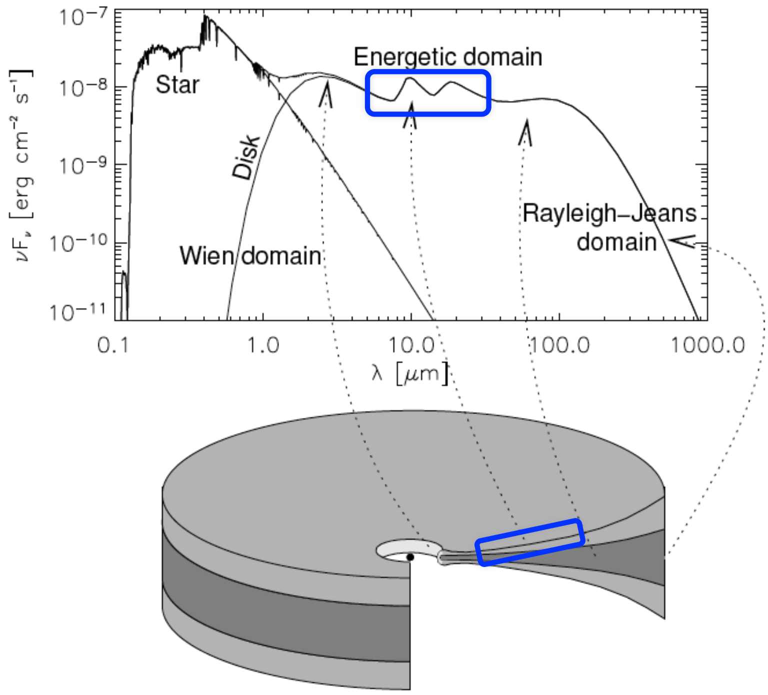
Possibility to study the parameters that drive the evolution of protoplanetary disks in the same nursery

Comparison with Other Regions

	Mean Age	Disk Fraction
Serpens	~3	-
Taurus	~2	~60%
Upper Scorpius	~5	~17%
η Chamaeleontis	~6	~40%

In addition: c2d sample with ~100 YSOs in 5 clouds

Where does the radiation come from?

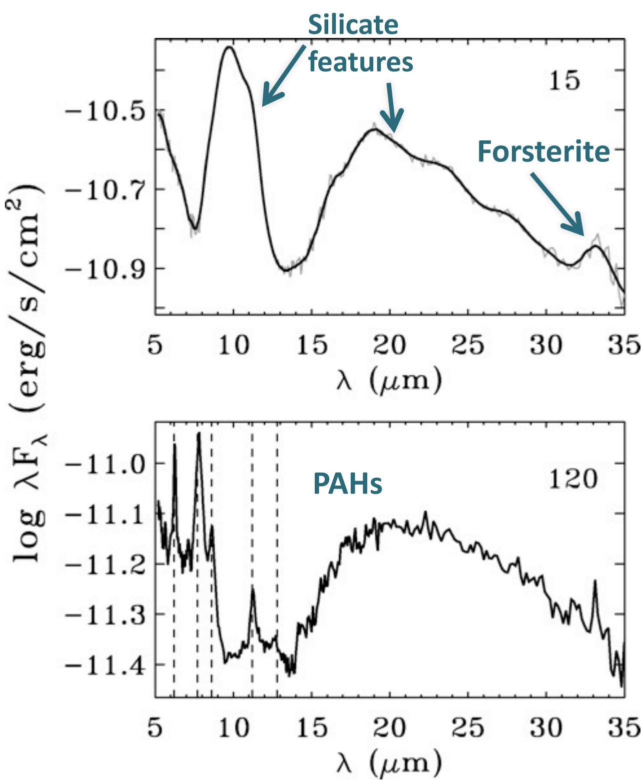


IRS spectra from Spitzer

Disk surface at few AU from star

Dullemond, Dominik & Natta 2001

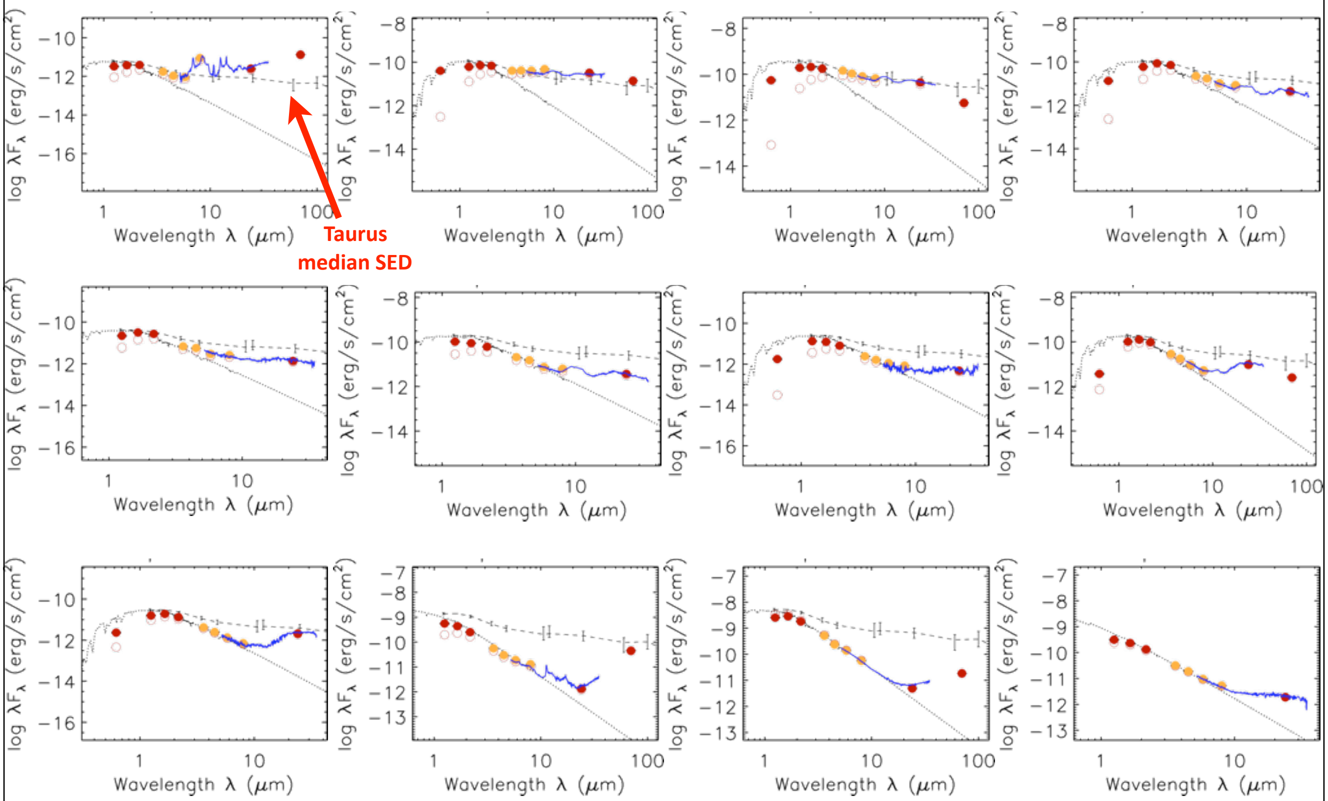
Spitzer IRS spectra



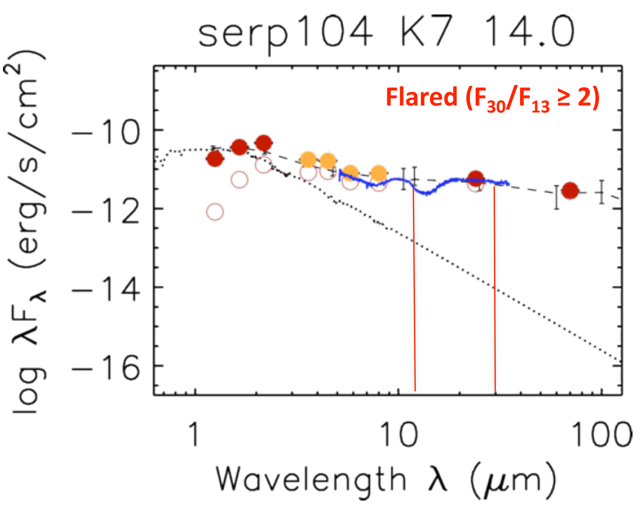
- Hundreds of YSOs observed with Spitzer/IRS
- Constraints on disk structure
  - Embedded, Flat vs. Flared, Disks with inner holes
- Dust features as probes of physical and chemical processes (in the upper layers of the disk)
  - Silicate features → grain sizes
  - Crystalline features → heating and mixing
  - PAHs → UV

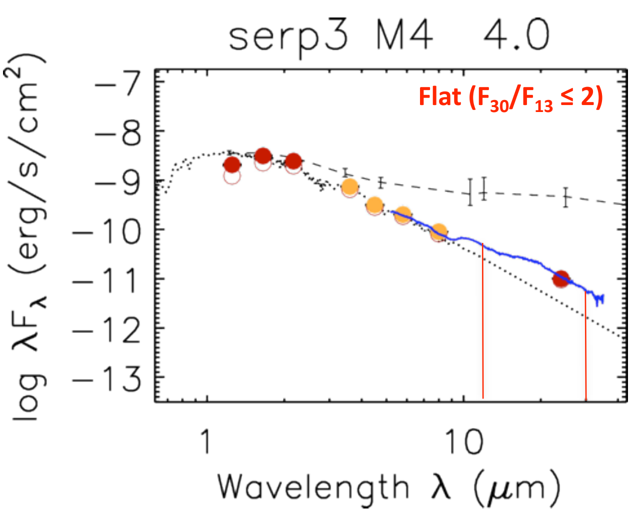
Diversity of Disks in Serpens

Complete, unbiased flux limited sample



Flared vs. Flat Disks



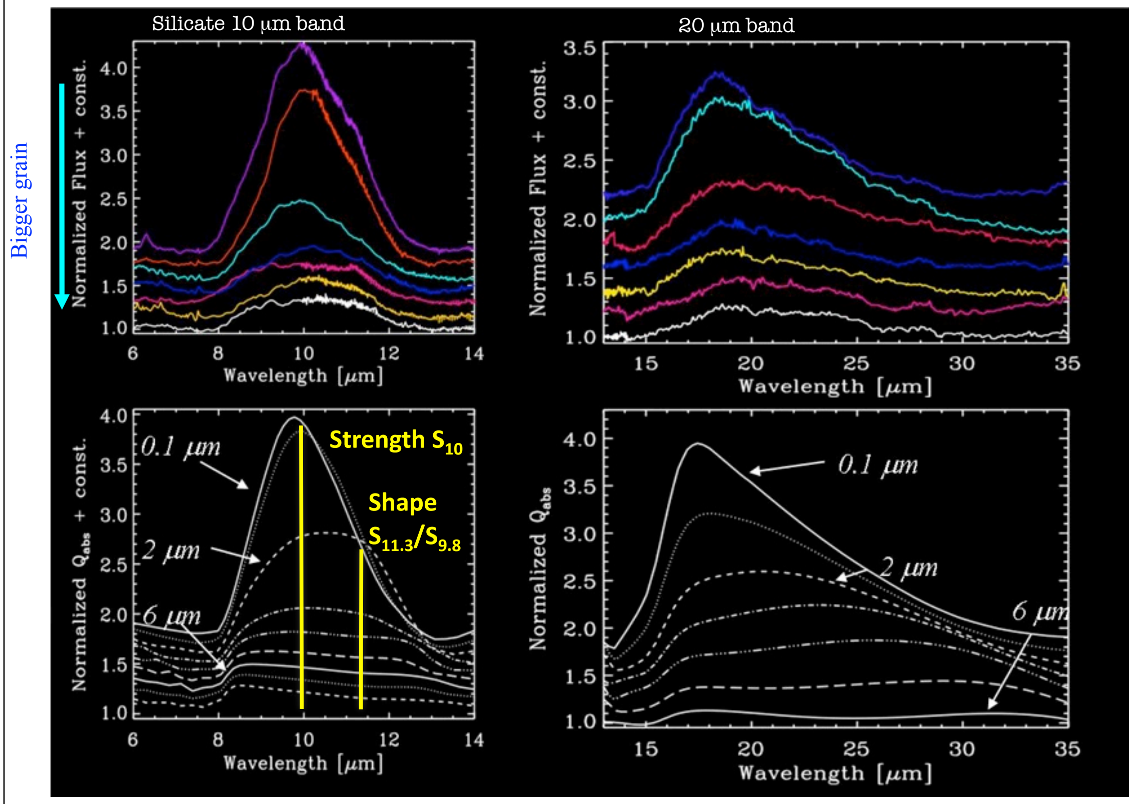


IR slope is directly associated with disk geometry (as seen from Dullemond pictogram)

Assuming that stars born in the same star-forming region are nearly coeval, the observation of disks in such different evolutionary stages sets an important constraint in disk evolution theories:

***Time* cannot be the only parameter driving disk evolution!**

Grain Sizes in T Tauri disks

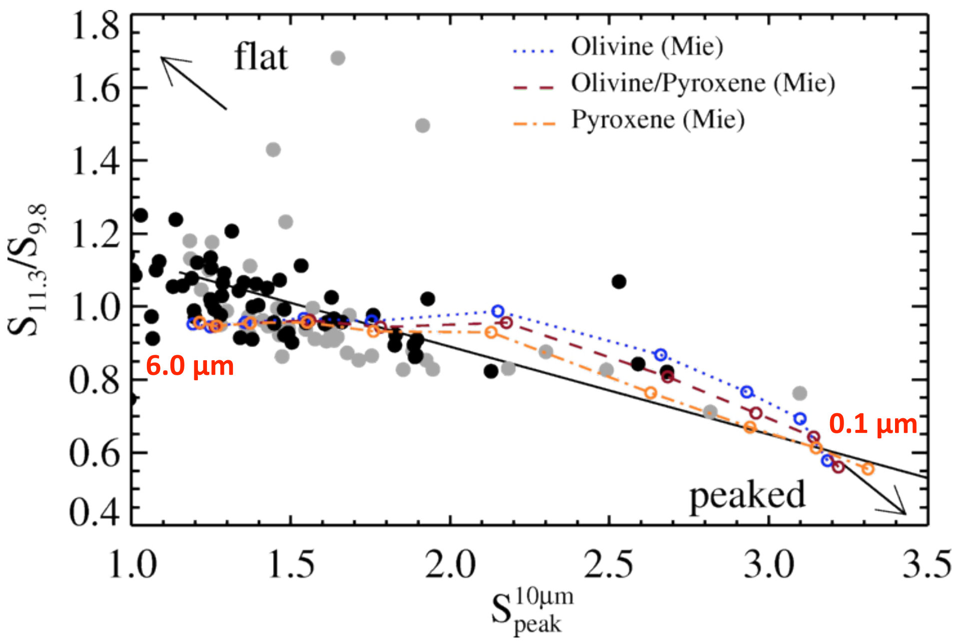


Obser-vations

Models

van Boekel et al. 2003, Kessler-Silacci et al. 2006, Bouwman et al. 2006

10 μm Silicate Feature in Serpens



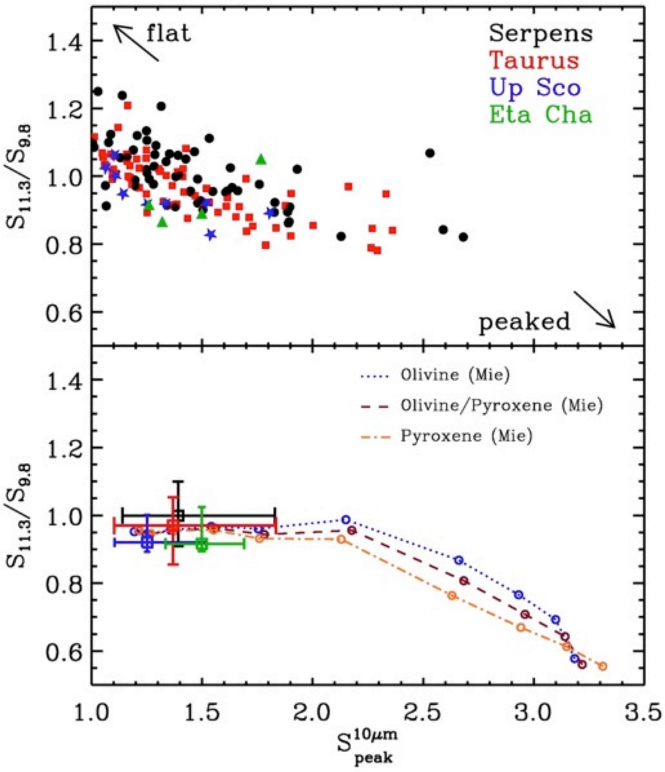
c2d (Olofsson et al. 2009)

Serpens

Serpens: flatter population,
grains in surface layer are bigger than ISM

Oliveira et al. 2010, ApJ 714, 778

Comparison with Other Regions

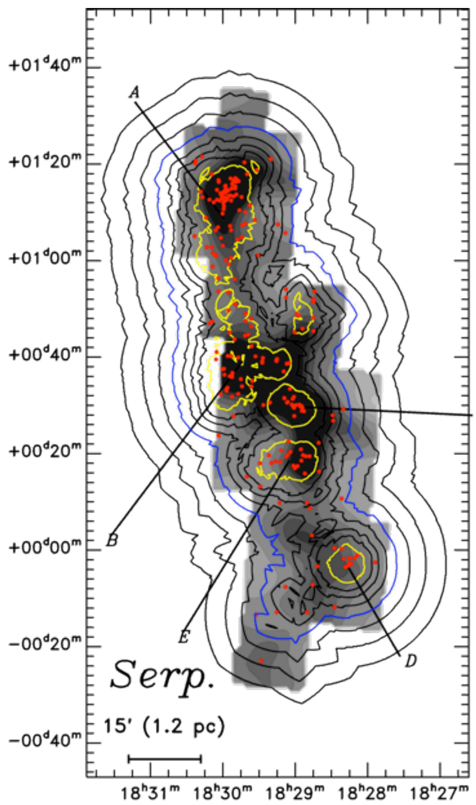


Strength vs. shape for different populations: remarkably similar distributions
(even though individual disks are very different)

➔ Difference in mean age is not reflected in concurrent evolution of average surface dust size

Oliveira et al., submitted to ApJ

Cluster vs. Field



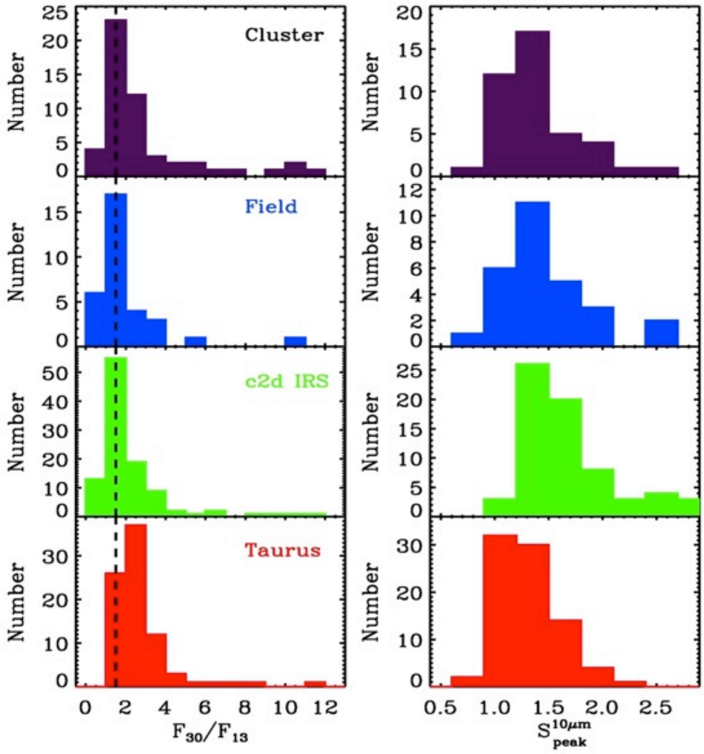
- Volume density of 25 $M_\odot$ pc^{-3}
  - Cluster: more than 35 members
  - Group: less than 35 members

⇒ Clusters A and B and Groups C, D and E

Oliveira et al. 2010, ApJ 714, 778

Environment

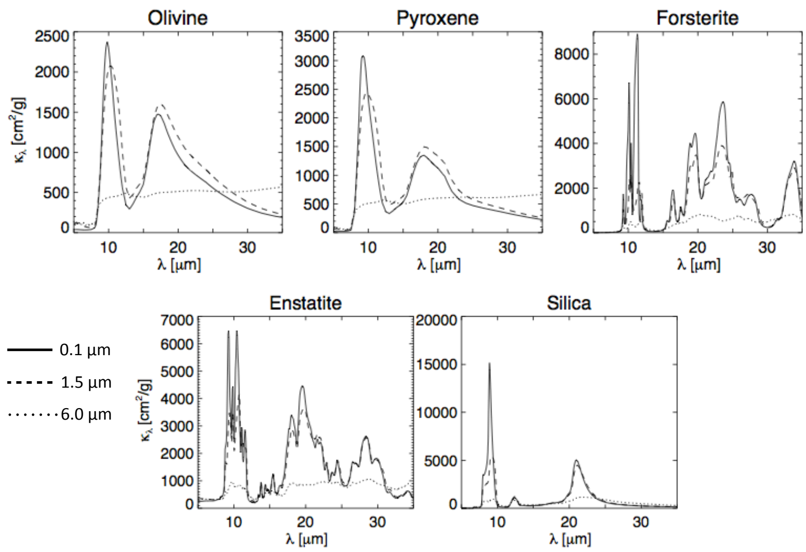
Flat vs. Flared | Grain Sizes



Environment does not seem to play a determinant role

Oliveira et al. 2010, ApJ 714, 778

Spectral Decomposition

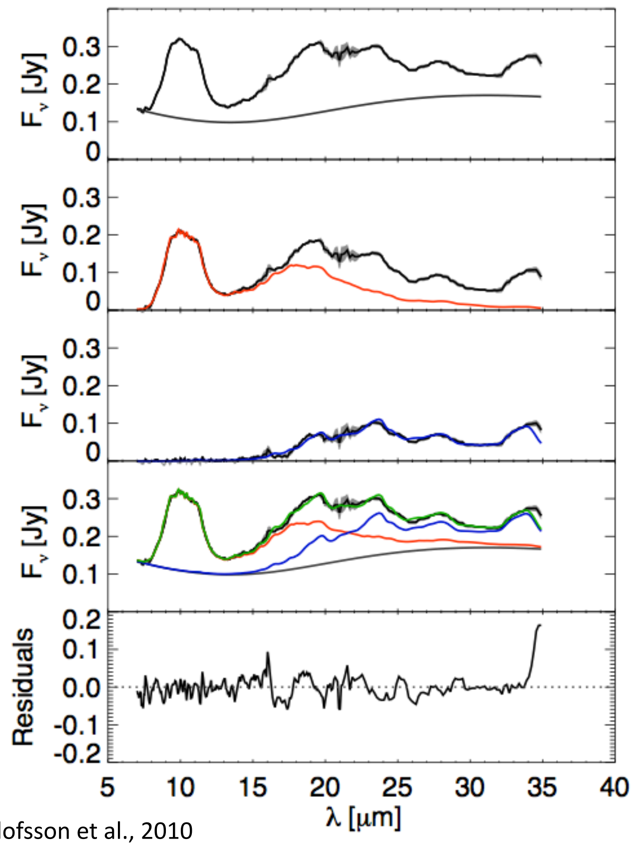


Goal is to infer the composition and dominant size of the emitting dust grains

Two temperatures (components), each composed of 3 amorphous (0.1, 1.5 and 6 μm) and 2 crystalline (0.1 and 1.5 μm) species

Olofsson et al., 2010

Spectral Decomposition



Olofsson et al., 2010

Procedure:
1st step: continuum subtraction

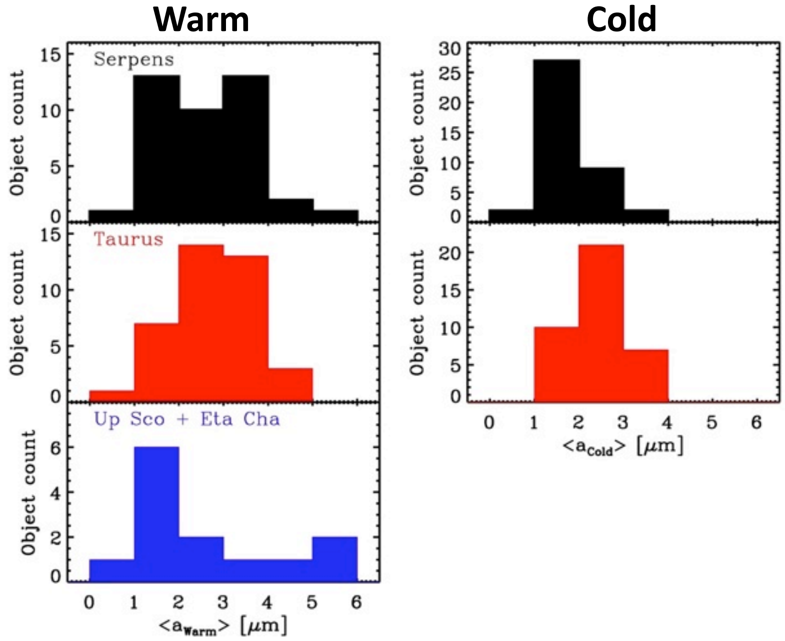
2nd step: fit warm component to reproduce 10 µm feature (red line)

3rd step: fit cold component to residuals (blue line)

Final fit (green line) reproduces very well the spectrum

Spectral Decomposition - Results

Mean grain sizes



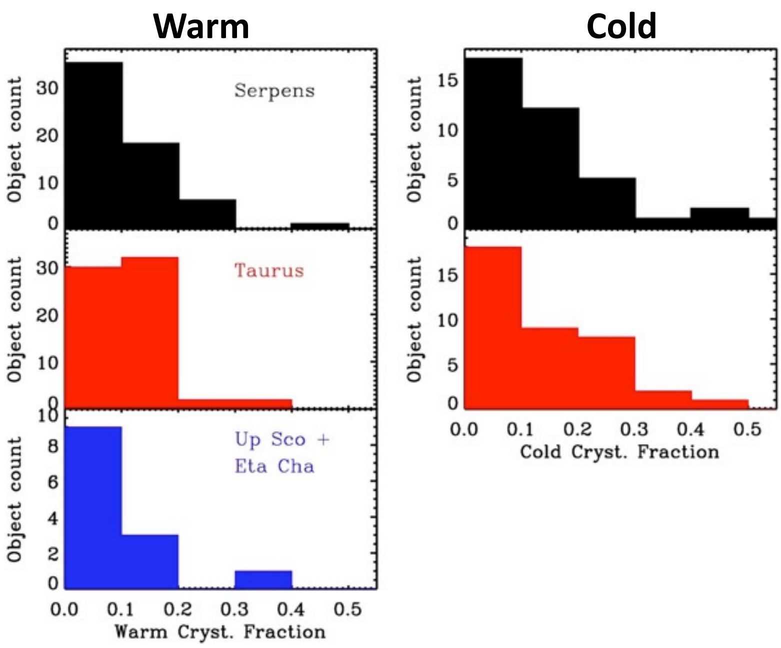
Different ranges for warm and cold components, but same spread for different regions

Lack of correlation hints at different processes being responsible for warm and cold dust in surface layers of disks

Oliveira et al., submitted to ApJ

Spectral Decomposition - Results

Mean Crystallinity Fraction



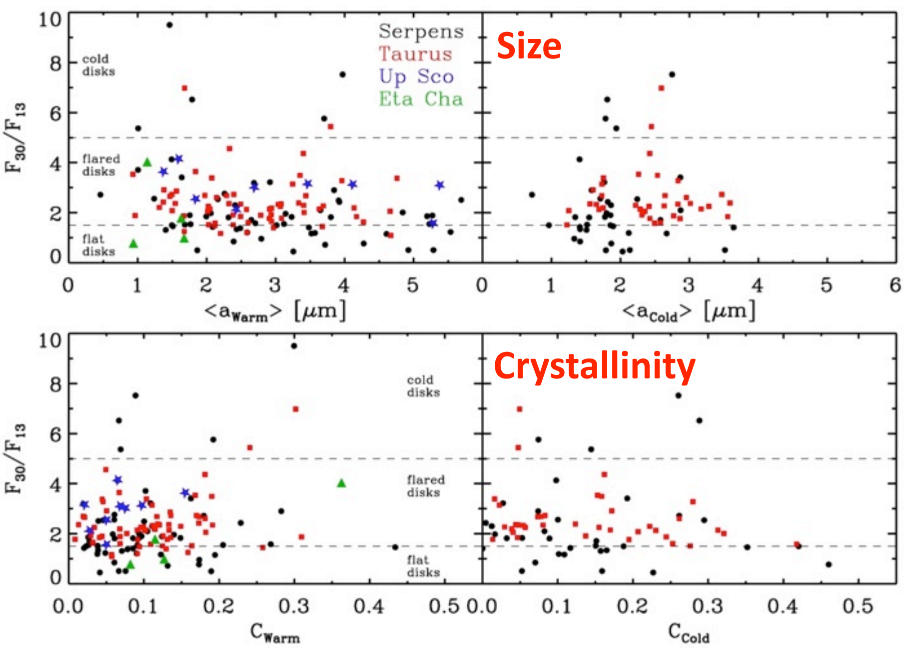
Similar ranges for warm and cold components (higher cold % than warm for only a few objects), same spread for different regions

Lack of correlation hints at different processes being responsible for crystallizing dust in inner and outer disk

Oliveira et al., submitted to ApJ

Spectral Decomposition - Results

Disk Geometry



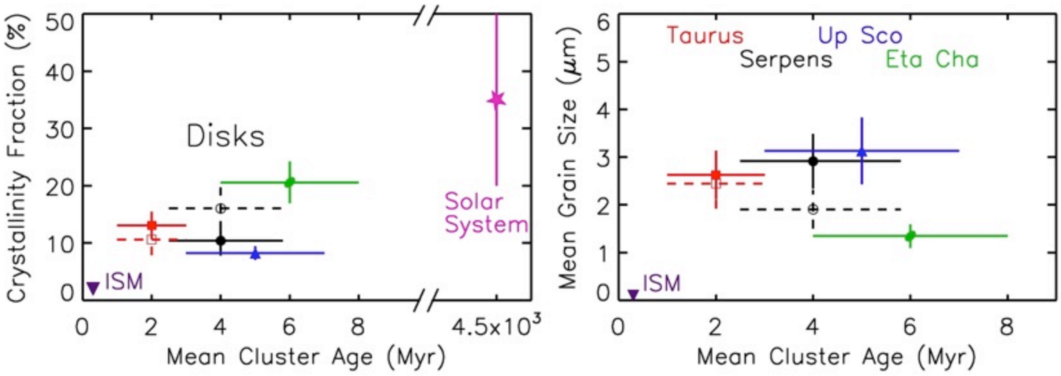
No preferred grain size or crystallinity for a given disk geometry

No separation for different regions (different mean ages)

Oliveira et al., submitted to ApJ

Spectral Decomposition - Results

Evolution



As for grain sizes, the mean crystallinity fraction of a given star-forming region does not statistically change with time (or disk fraction)

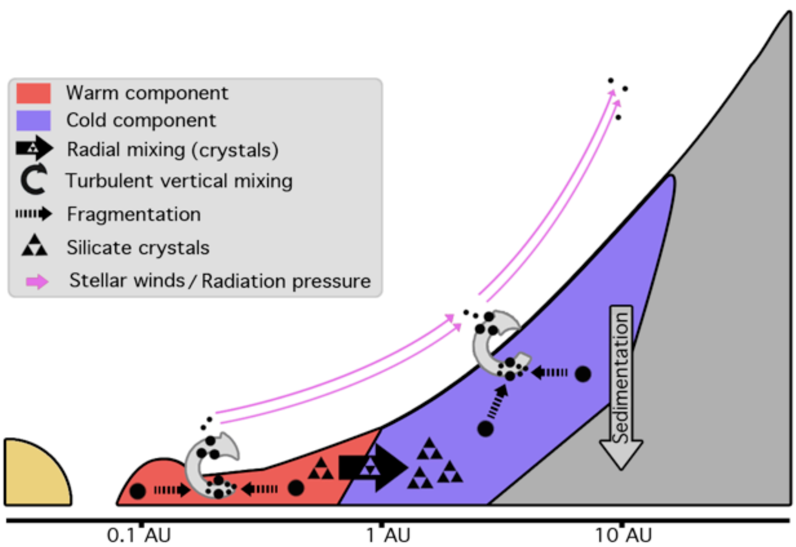
→ No real evolution in both parameters is observed essentially until disks dissipate

Equilibrium reached very quickly, lasting until disks dissipate

→ Dust at surface and midplane evolving differently?

Oliveira et al., submitted to ApJ

The Picture



- **Dust growth and sedimentation**
- **Bigger particles in midplane collide (fragmentation/ bouncing) producing smaller particles**
- **Turbulent mixing keeps a small dust population in upper layers at all times**
- **Different processes may be responsible for small dust at a given time**

Olofsson et al., 2009

Scenario consistent with evidence from Solar System (small particles after formation of big particles)

Oliveira et al. 2010, ApJ 714, 778

Summary

- Statistical trends for hundreds of YSOs → constraints on important processes for evolution of disks
  - No seen effects on disk surface characteristics from environment, mean cluster age, stellar mass (K-M stars) ...
- Equilibrium of processes of growth and destruction maintains a small dust population in the disk surface even for older, or flatter, disks
- No strong evidence of increase in crystallinity fraction with mean age in surface layers
  - Equilibrium reached quickly (~1 Myr) and lasting essentially until disks dissipate

➔ Pointing to different evolution of surface layers and midplane, even though the populations are connected through vertical mixing (perhaps radial mixing occurs at different ratios?)