Evolution of Surface Dust in Protoplanetary Disks

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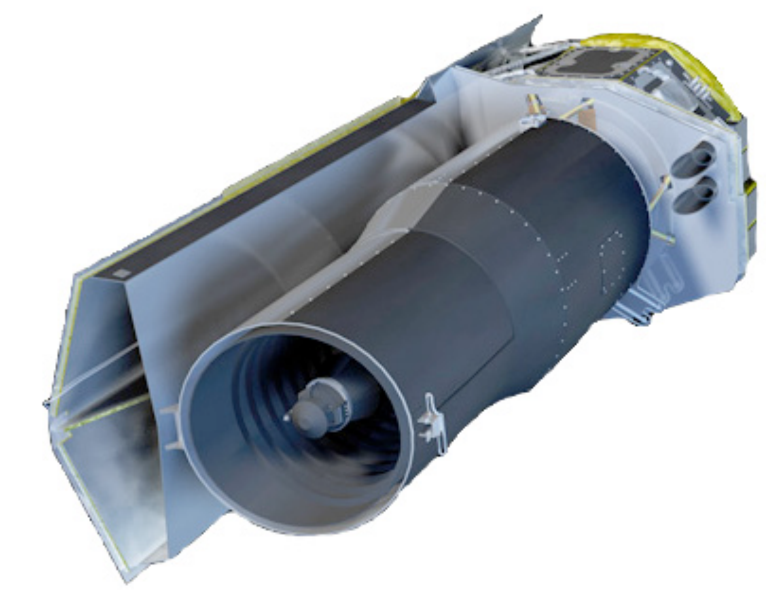
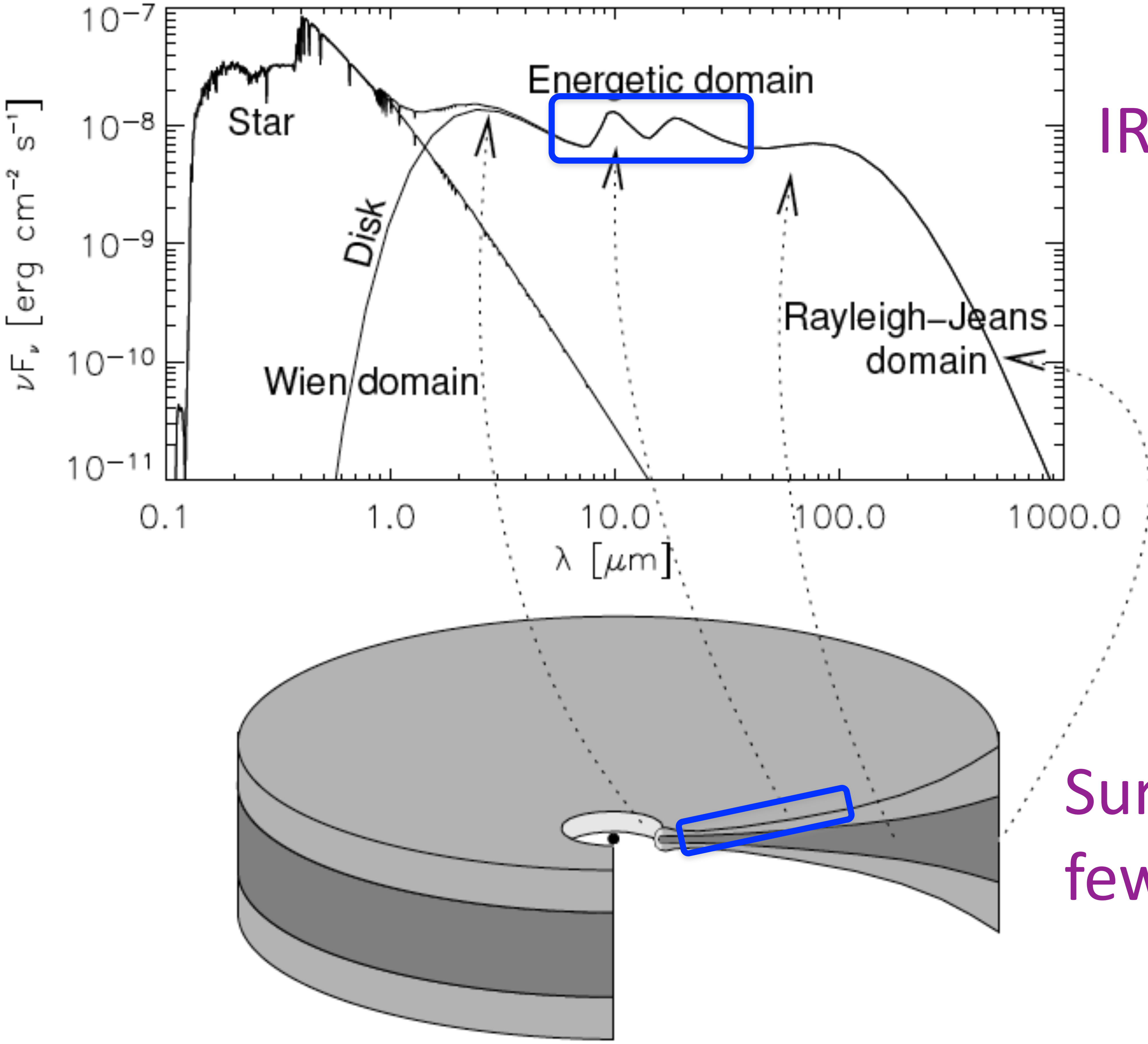
Oliveira et al. 2011, 2013

Spitzer Observations





IRS spectra

Surface dust
few AU from star

Silicate emission features at 10 and 20 μm are sensitive to grain size and composition of silicate dust in disk surface

Dullemond, Dominik & Natta 2001

Observing Evolution

ISM-like dust
sub-μm
≤ 2% crystallinity

→

Solar System-like objects
up to ~60% crystallinity

Observing Evolution

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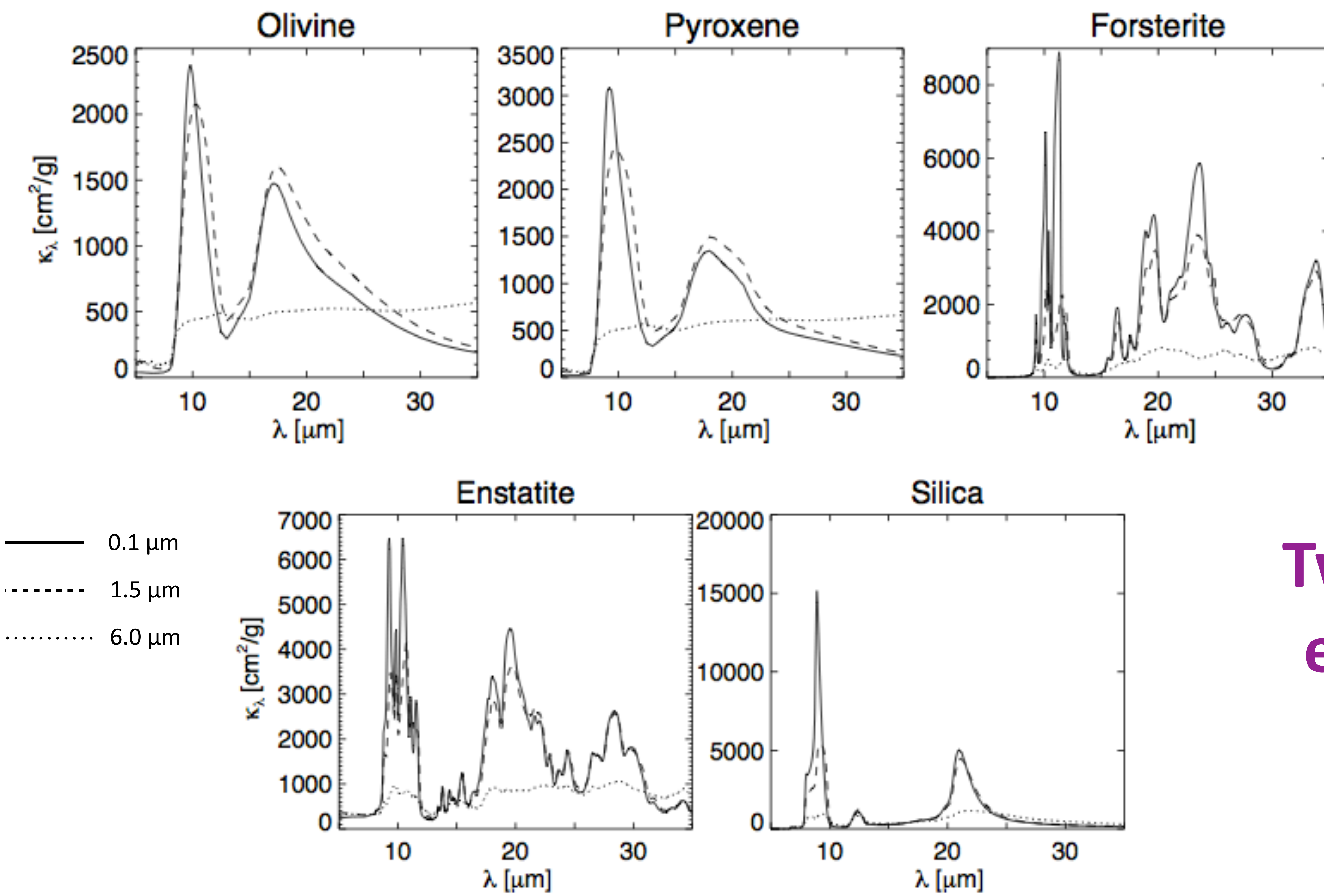
Young bin of Disk Evolution (1-3 Myr)

Serpens (60)
Taurus (66)

Old bin of Disk Evolution (5-11? Myr)

η Chamaleontis (4)
Upper Scorpius (9)

Spectral Decomposition



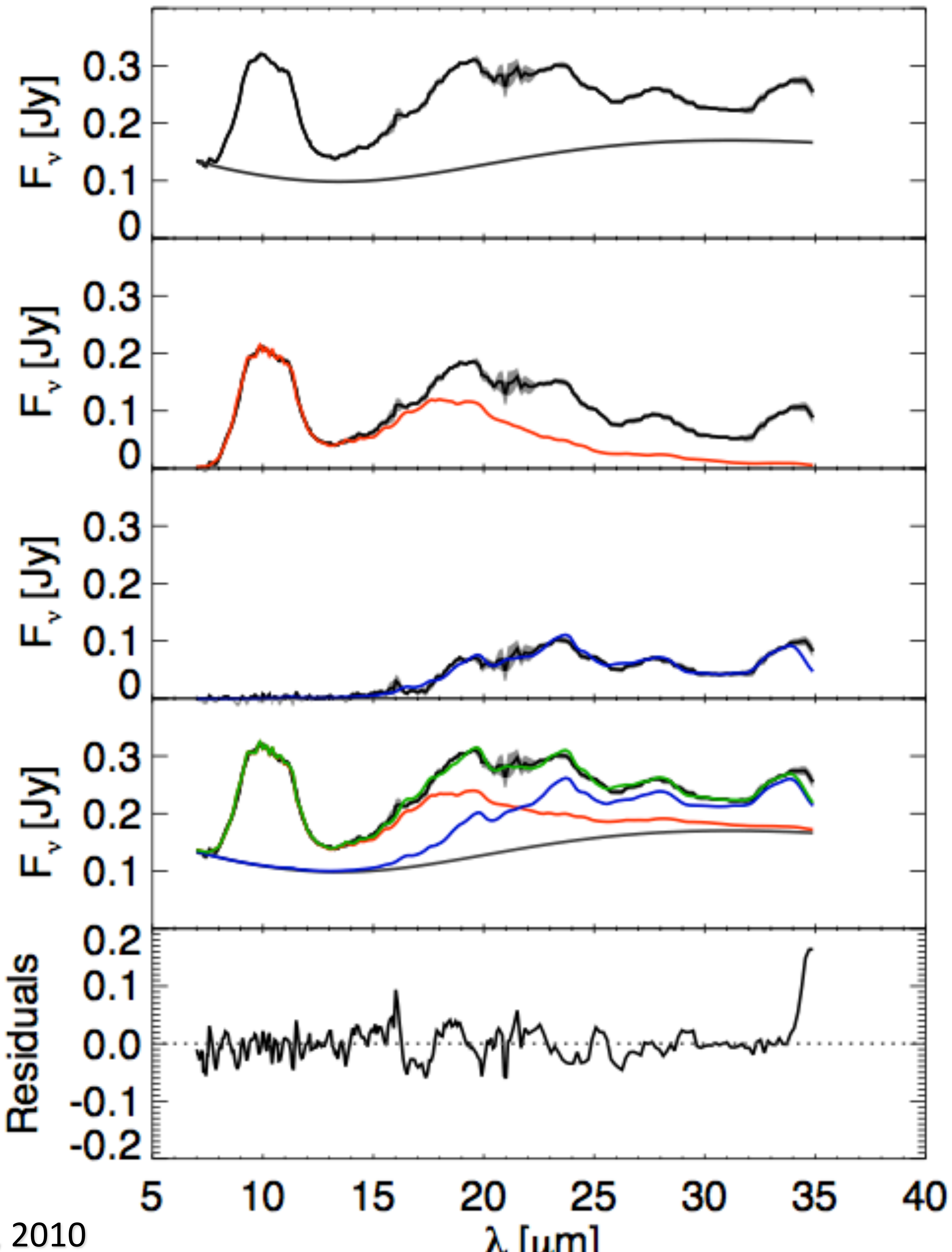
Olofsson et al. 2010

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

Results consistent with other methods Juhász et al. 2009, Sargent et al. 2009

Spectral Decomposition



Olofsson et al., 2010

Procedure:

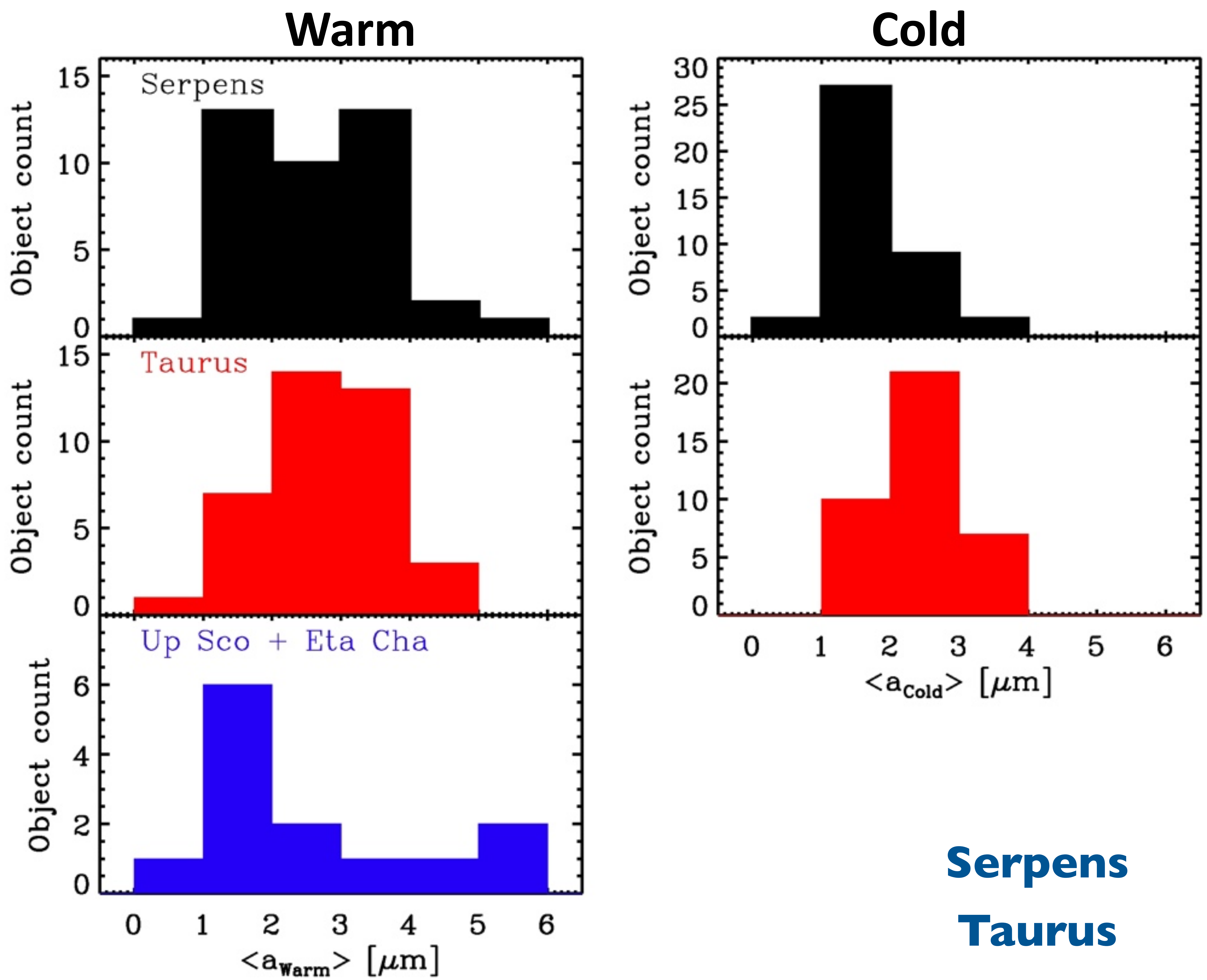
1st step: continuum subtraction

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

Mean Grain Sizes



- Different ranges for warm and cold components
- Same spread for different regions
- Warm and cold dust sizes uncorrelated

	$\langle a_{warm} \rangle$	$\langle a_{cold} \rangle$
Serpens	2.9 ± 1.3	1.9 ± 0.6
Taurus	2.6 ± 0.9	2.4 ± 0.6
Up Sco	3.1 ± 1.5	
η Cha	1.3 ± 0.4	

Oliveira et al. 2011

Size Evolution

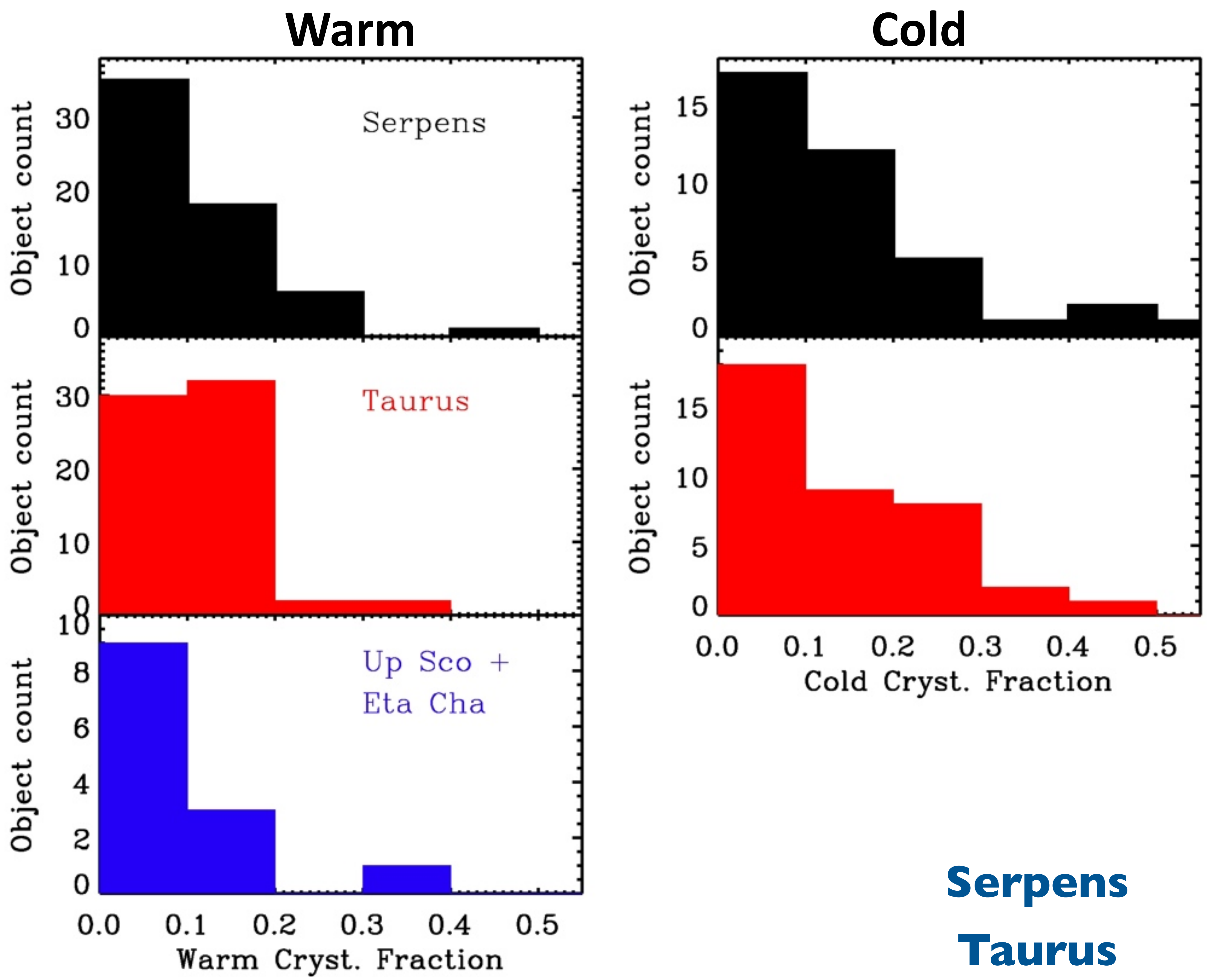
Dust coagulation is too rapid process, $<10^5$yr (Weidenschilling 1980, Dullemond & Dominik 2005)

→ Dust population observed in disks surfaces cannot be result of a progressive, monotonic change of state from small to large

Equilibrium of growth and destruction processes necessary to maintain small dust population on disk surface while there are disks (including debris disks)

Connection between disk mid-plane and surface, by replenishment

Mean Crystallinity Fraction

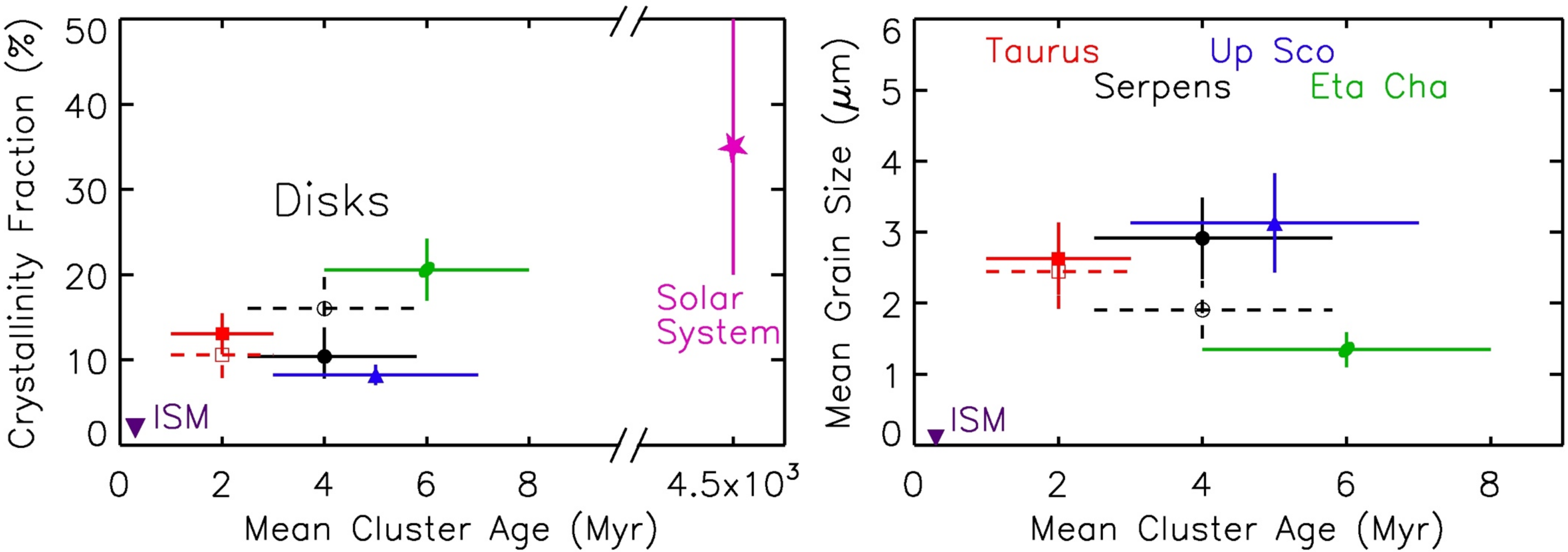


- Similar ranges for warm and cold components
- Same spread for different regions
- Warm and cold crystallinity fractions uncorrelated
- Perhaps crystallization happens in embedded phase

	$\langle C_{warm} \rangle$	$\langle C_{cold} \rangle$
Serpens	11 ± 7	17 ± 12
Taurus	11 ± 6	14 ± 10
Up Sco	7 ± 3	
η Cha	17 ± 10	

Oliveira et al. 2011

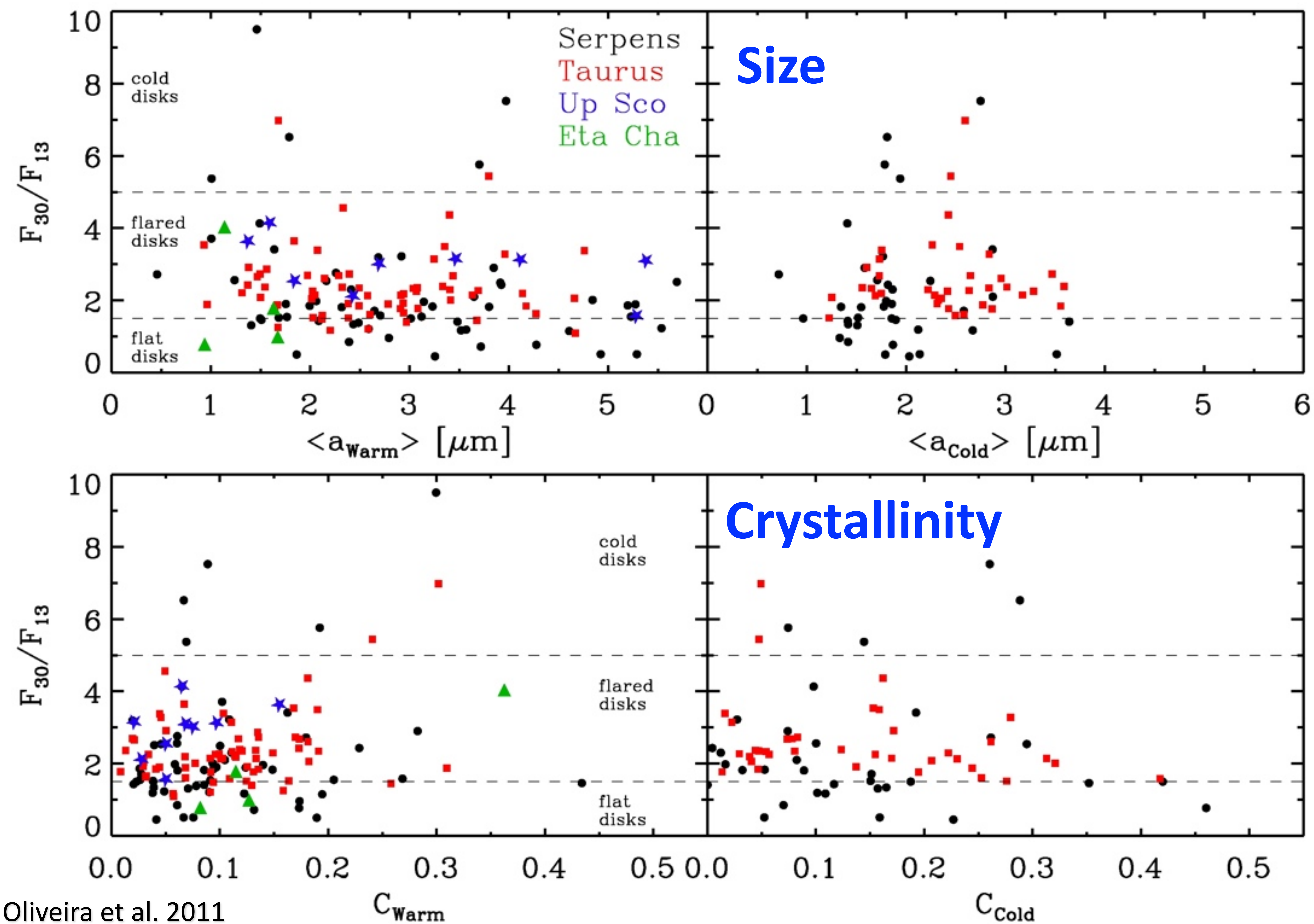
Dust Evolution



Equilibrium reached very quickly, lasting until disks dissipate

Oliveira et al. 2011

Disk Geometry (from IRS spectra)

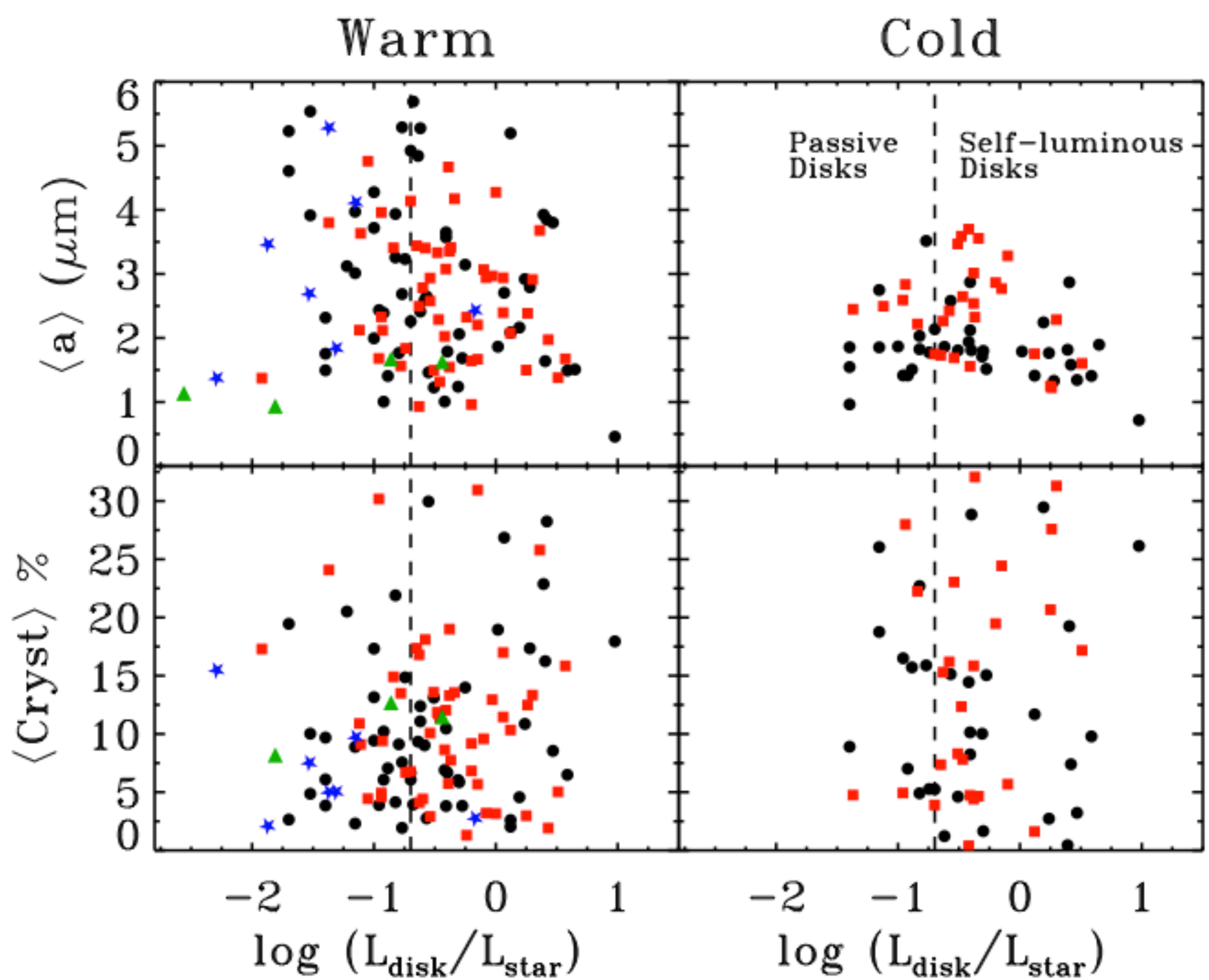


Oliveira et al. 2011

No preferred grain size or crystallinity fraction for a given disk geometry

No separation for different regions (different mean ages)

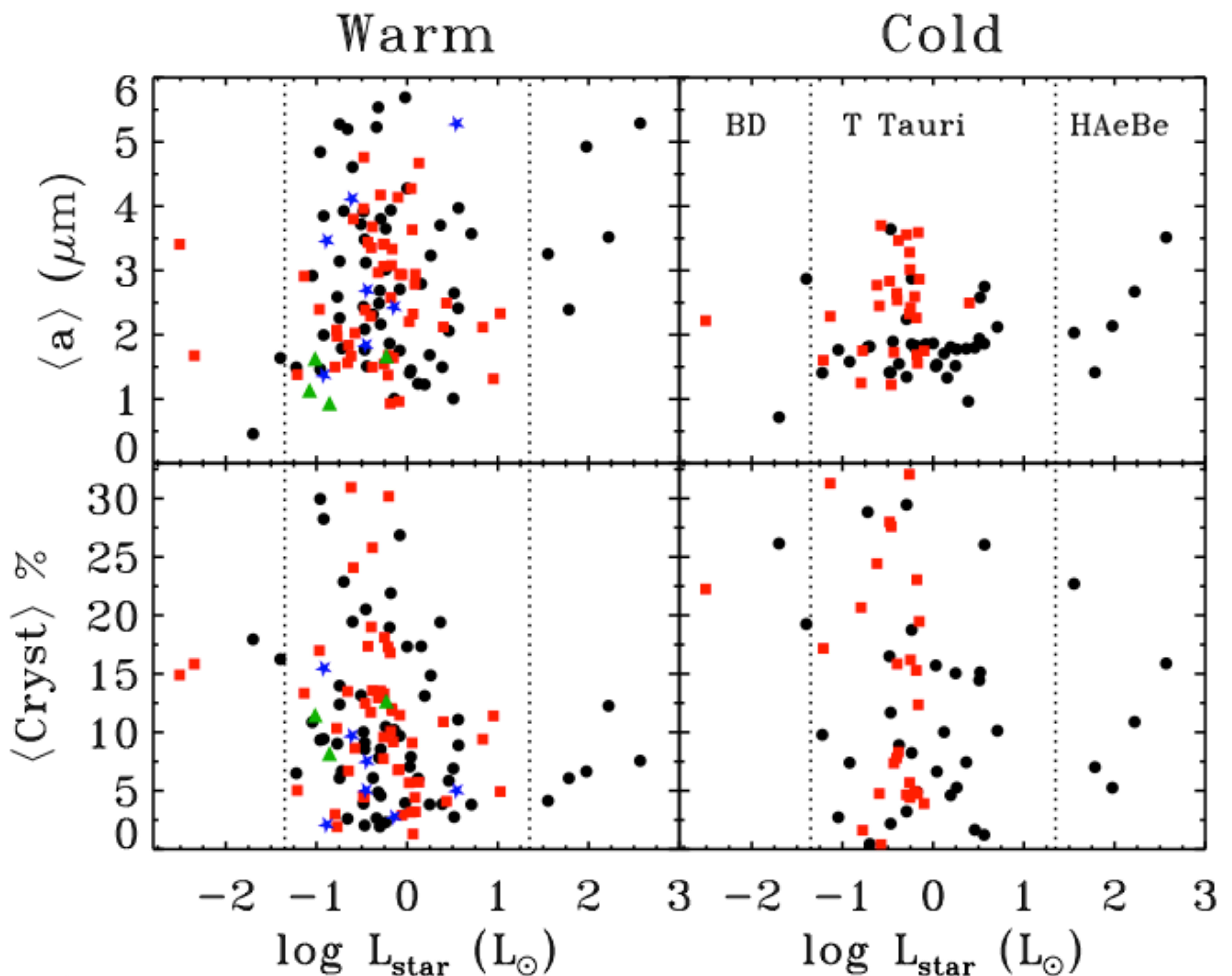
Fractional Disk Luminosity



Neither grain size or crystallinity fraction correlated with fractional disk luminosity

Oliveira et al. 2013

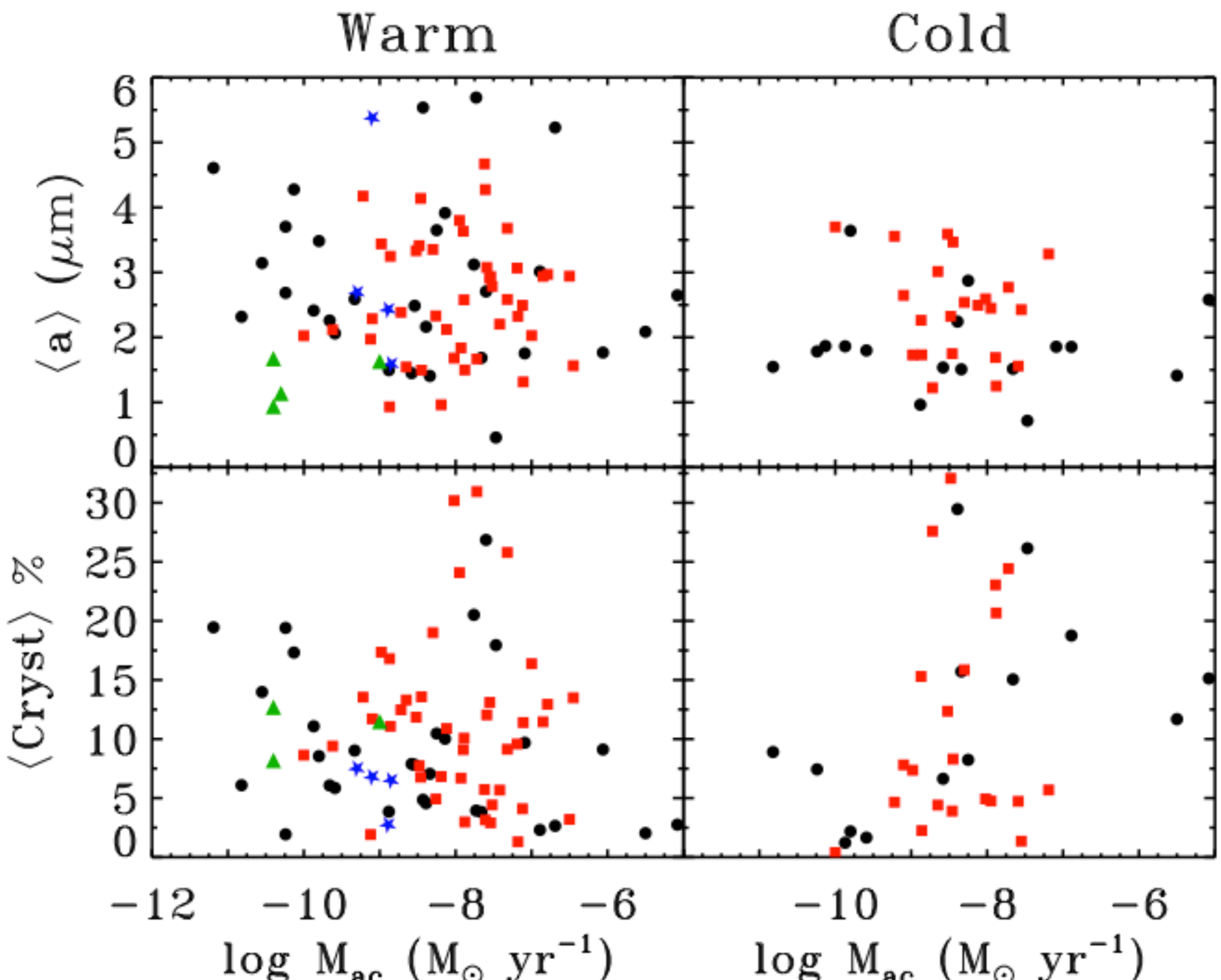
Stellar Luminosity



Neither grain size or crystallinity fraction correlated with stellar luminosity

Oliveira et al. 2013

Mass Accretion Rate



Neither grain size or crystallinity fraction correlated with mass accretion rate

Similar results for Tr 37 and NGC7160 (Sicilia-Aguilar et al. 2007), Taurus (Watson et al. 2009), Cep OB2 (Sicilia-Aguilar et al. 2011)

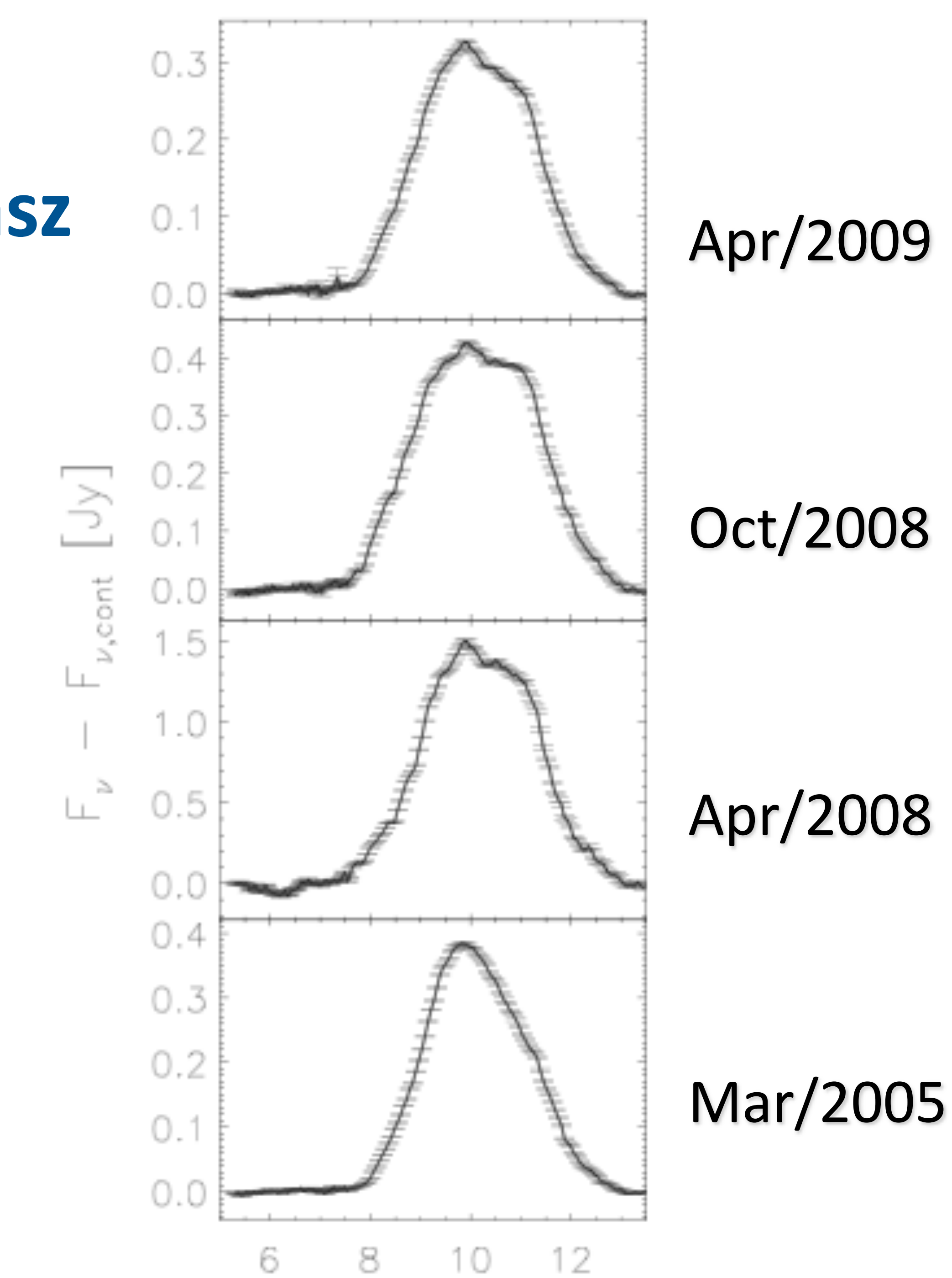
Oliveira et al. 2013

Implications

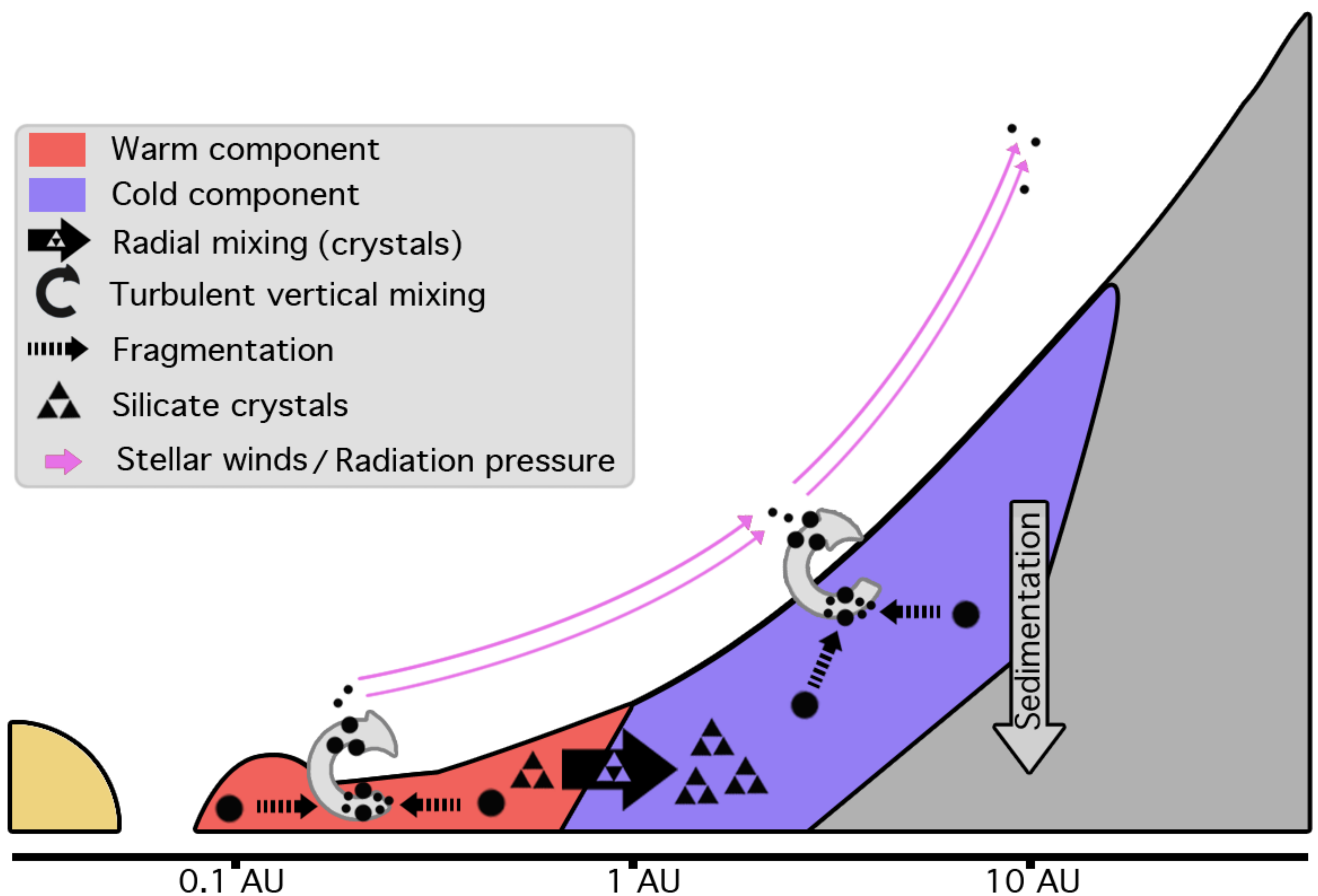
Processes affecting surface dust must have short timescales, and happen repeatedly, such that long lasting evolutionary effects are difficult to see

- **Variability** (Carpenter et al. 2001, Eiroa et al. 2002, Bouvier et al. 2007, Muzerolle et al. 2009)
- **Vertical/Radial Mixing** (Ciesla 2007, Visser & Dullemond 2010, Juhász et al. 2012)
- **Dust crystallization/ amorphization** (Glauser et al. 2009)

Example: EX Lupi
(Ábrahám et al. 2009, Juhász et al. 2012)



What we learned from Spitzer



Olofsson et al., 2009

- **Equilibrium between dust growth and fragmentation processes is reached early in disk evolution**
- **A modest level of crystallinity is established very quickly (<1 Myr)**
- **Different regions show same spread of mean grain sizes and crystallinity fraction, regardless of spread in age**
- **Dust mineralogy uncorrelated with stellar and disk characteristics**

Processes that change structure and size distribution of dust in disks are recurring and of short timescales