# MORPHOLOGICAL EFFECTS OF DUST GRAINS ON MID-IR EXTINCTION SPECTRA

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CPS seminar

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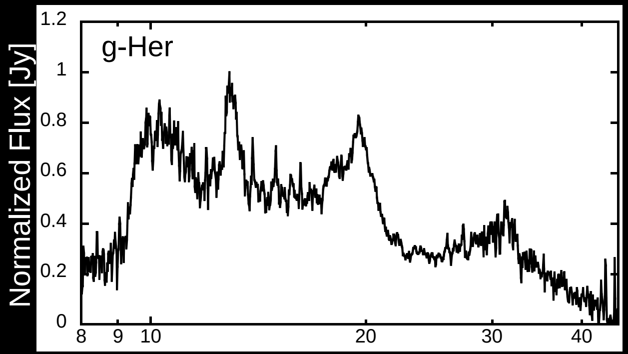
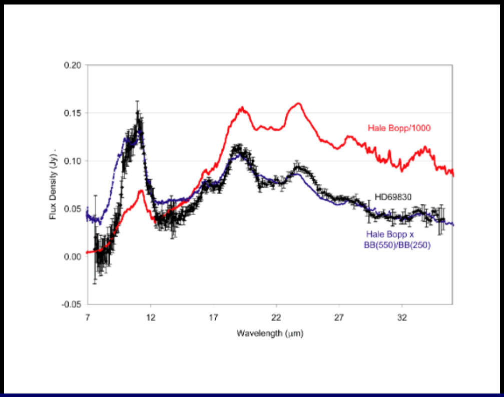
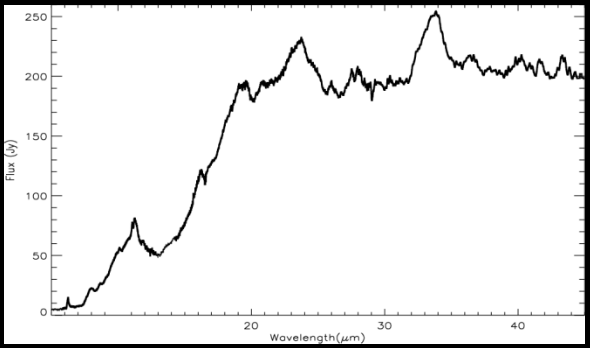
# Outline

- Dust grains
- Experiment
- Results
- Astronomical application
- Database
- Summary

Presence of dust grains appear especially in N and Q bands via spectroscopy.




Wav

AGB

star:

(Posch e

1998)

(Crovisier et al. 1996)

**At what condition does the planet formation start actively?**

What kinds of dust grains in these observed spectra?
The chemical path way of dust grains
↓
Which substance will be the first condensed species out of the gas phase?
At which temperature?
At which abundance it occurs?

# Sorts of Dust Grains

Fe-rich olivine

Mg-rich olivine

Corundum
(Ruby: $Al_2O_3$)

Enstatite
($MgSiO_3$)

Decisive role for planet formation,
esp. Terrestrial planets

Amo-$MgSiO_3$

Fayalite
($Fe_2SiO_4$)

Quartz
($SiO_2$)

Corundum
(Sapphire: $Al_2O_3$)

The rocky planets form in high metallicity environments, where the dust grains are dominant (e.g. Shen et al. 2005)

# Meteorite

Meteorites hold a key to understand a formation of dust grains.

✓ CAIs (calcium-aluminum inclusions) consist minerals which are predicted via a condensation model.

✓ Minerals in CAIs are condensed from protoplanetary nebula.

✓ Minerals in CAIs are
- Spinel ($MgAl_2O_4$)
- Corundum ($Al_2O_3$)
- Rutile ($TiO_2$)
- Hibonite ($CaAl_{12}O_{19}$)
- Olivine
- Pyroxene more….

Carbonaceous chondrite Allende (CV3.2)

NWA869 L4-6 Chondrite

# Factors to influence on MIR band profiles

***Crystallinity***

Polymorph （多形）

同一物質が複数の異なった結晶構造を取る

e.g. **$SiO_2$**

α-quartz

(trigonal: 三方晶系)

α-tridymite

(orthorhombic: 斜方晶系)

α-cristobalite

(tetragonal: 正方晶系)

***Chemical compositon***

Mg, Fe, Al, Si, Ti, Ca, S, …

e.g. Olivine

San Carlos

$Mg_{1.9}Fe_{0.1}SiO_4$

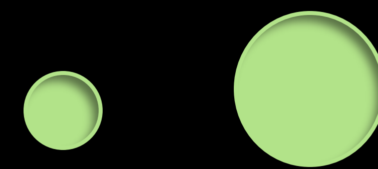
Sri Lanaka

$Mg_{1.6}Fe_{0.4}SiO_4$

(Koike et al. 2003)

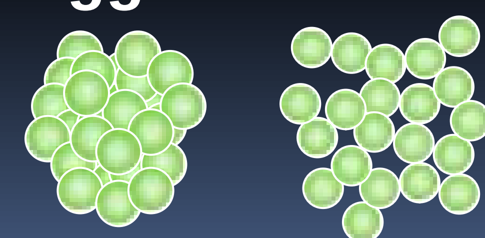
***Morphology***

✓ **Size**

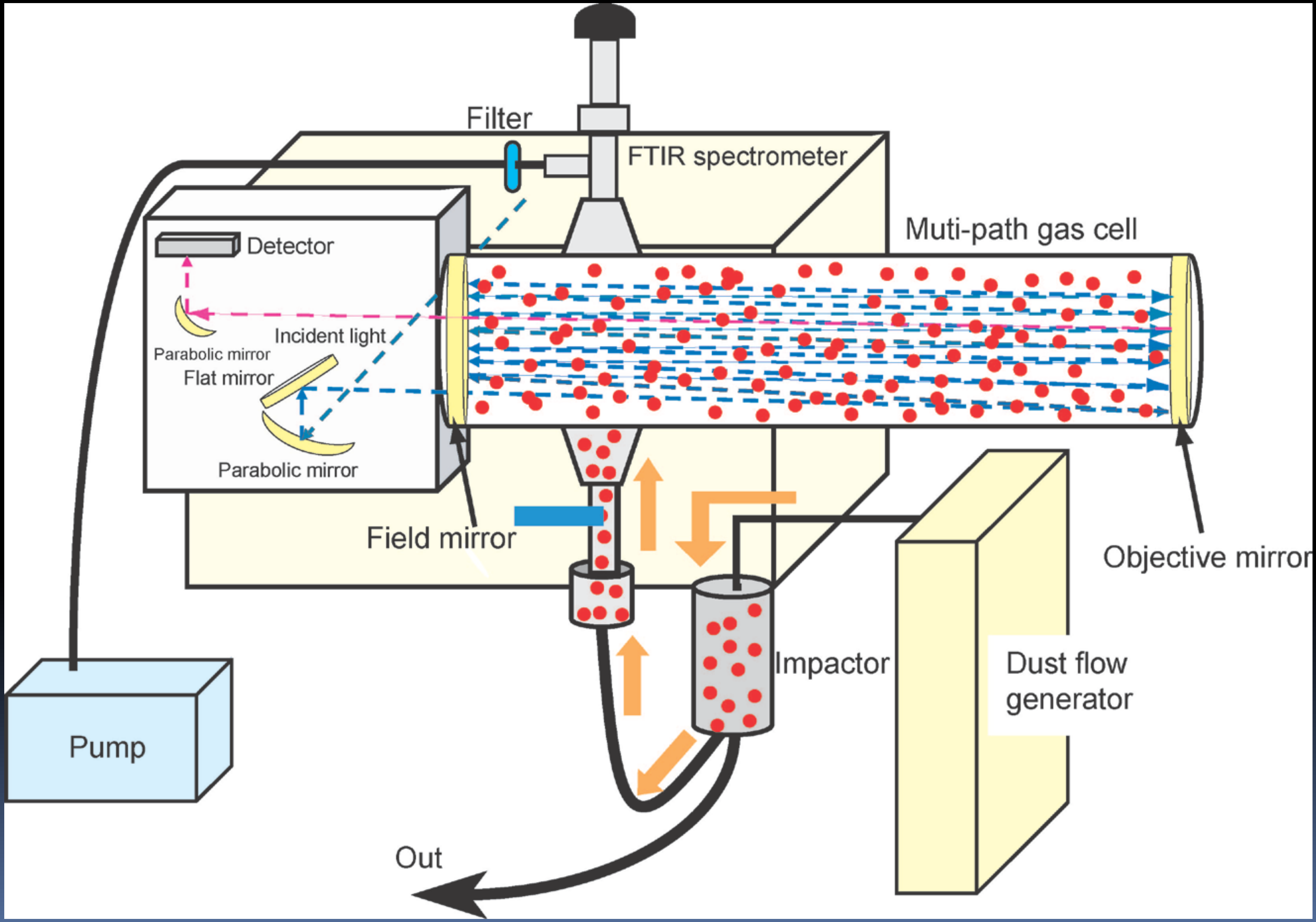


✓ **Shape**

✓ **Agglomeration**



# Experiment


Filter
FTIR spectrometer
Muti-path gas cell
Detector
Incident light
Parabolic mirror
Flat mirror
Parabolic mirror
Field mirror
Objective mirror
Impactor
Dust flow
generator
Pump
Out

# Samples

**Silicate**

- ✓ Forsterite ($Mg_2SiO_4$)
- ✓ Fayalite ($Fe_2SiO_4$)
- ✓ Olivine (e.g. $Mg_{1.9}Fe_{0.1}SiO_4$)
- ✓ Enstatite ($MgSiO_3$)
- ✓ Diopside ($CaMgSi_2O_6$)
- ✓ Hypersthene ($(Mg,Fe)SiO_3$)
- ✓ Wollastonite ($CaSiO_3$)
- ✓ Kaolinite ($Al_2Si_2O_7 \cdot 2H_2O$)
- ✓ Talc ($Mg_{3.33}Fe_{0.1}Si_4O_{10}(OH)_2$)

**$Al_2O_3$**

- ✓ Corundum ($\alpha$-$Al_2O_3$)
- ✓ $\gamma$-$Al_2O_3$
- ✓ $\chi$–$\delta$–$\kappa$-$Al_2O_3$

**$MgAl_2O_4$** (Spinel)

**$TiO_2$** (Rutile & Anatase)

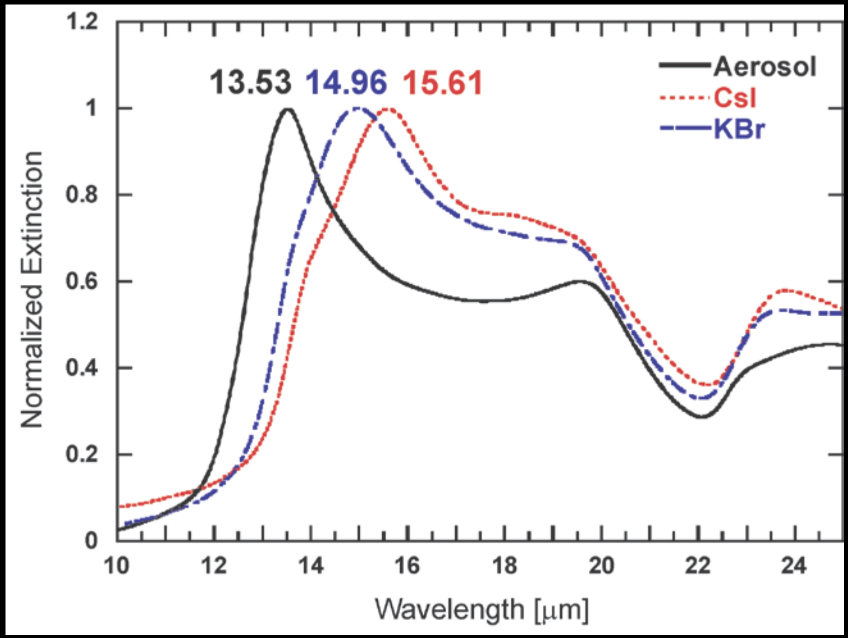
**$CaTiO_3$** (Pervoskite)

**$Al_2TiO_5$** (Tialite)

**$SiO_2$**

*www.elbe.astro.uni-jena.de*

# <Medium effect>




$\varepsilon_m$

$N_2$ → 1.0

KBr → 2.3

CsI → 3.0

The influence of its electromagnetic polarization.

Tamanai et al. 2009

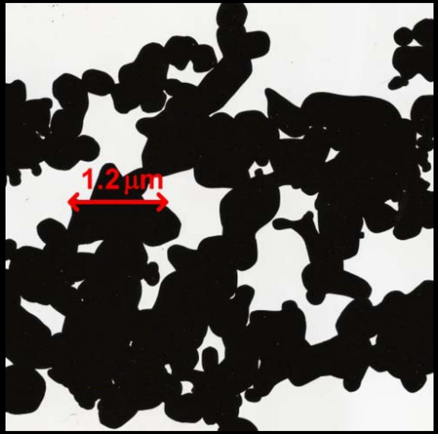
KBr :
(Potassium Bromide)
Mixing ratio 1:500
(sample:KBr)
d=13mm ; mass=0.2g

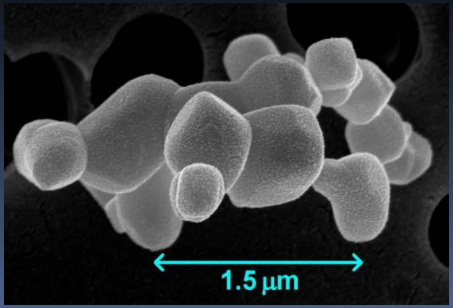
CsI :
(Cesium Iodine)
Mixing ratio 1:500
(sample:CsI)
d=13mm ; mass=0.22g

# <Morphological effects>

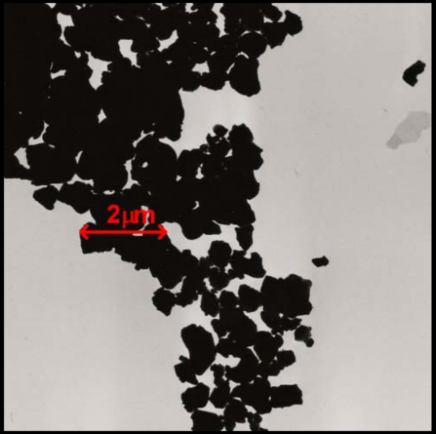
$TiO_2$ (Rutile)

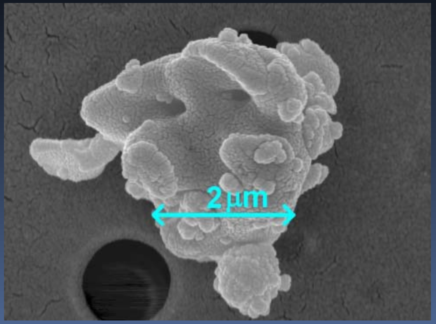
Irregular shape w/ roundish edges



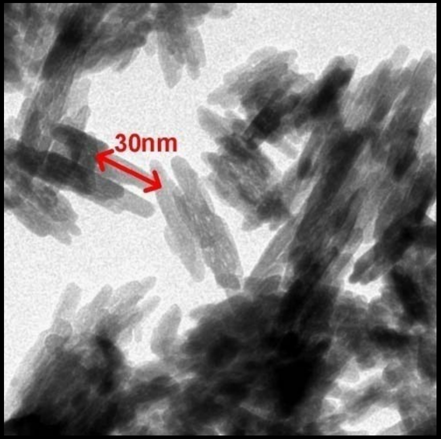



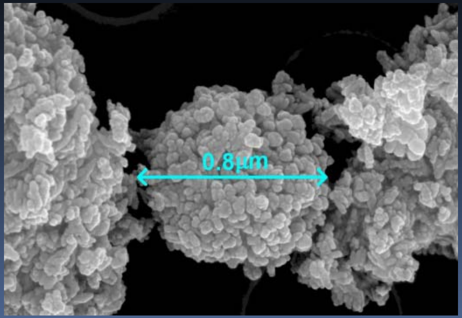

Irregular shape with not roundish edges



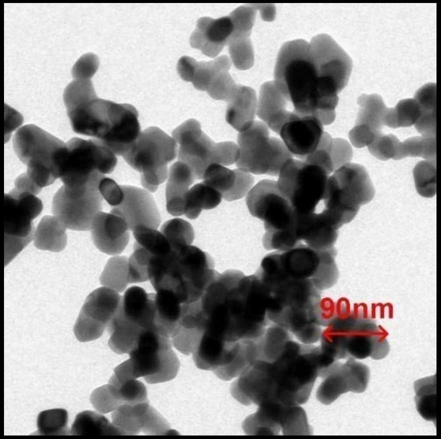



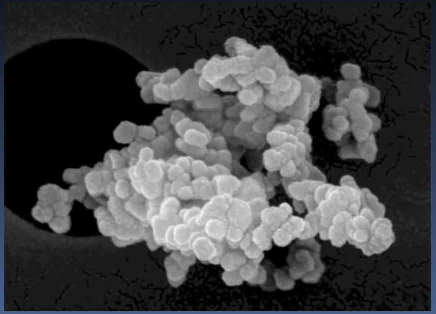

Long and thin



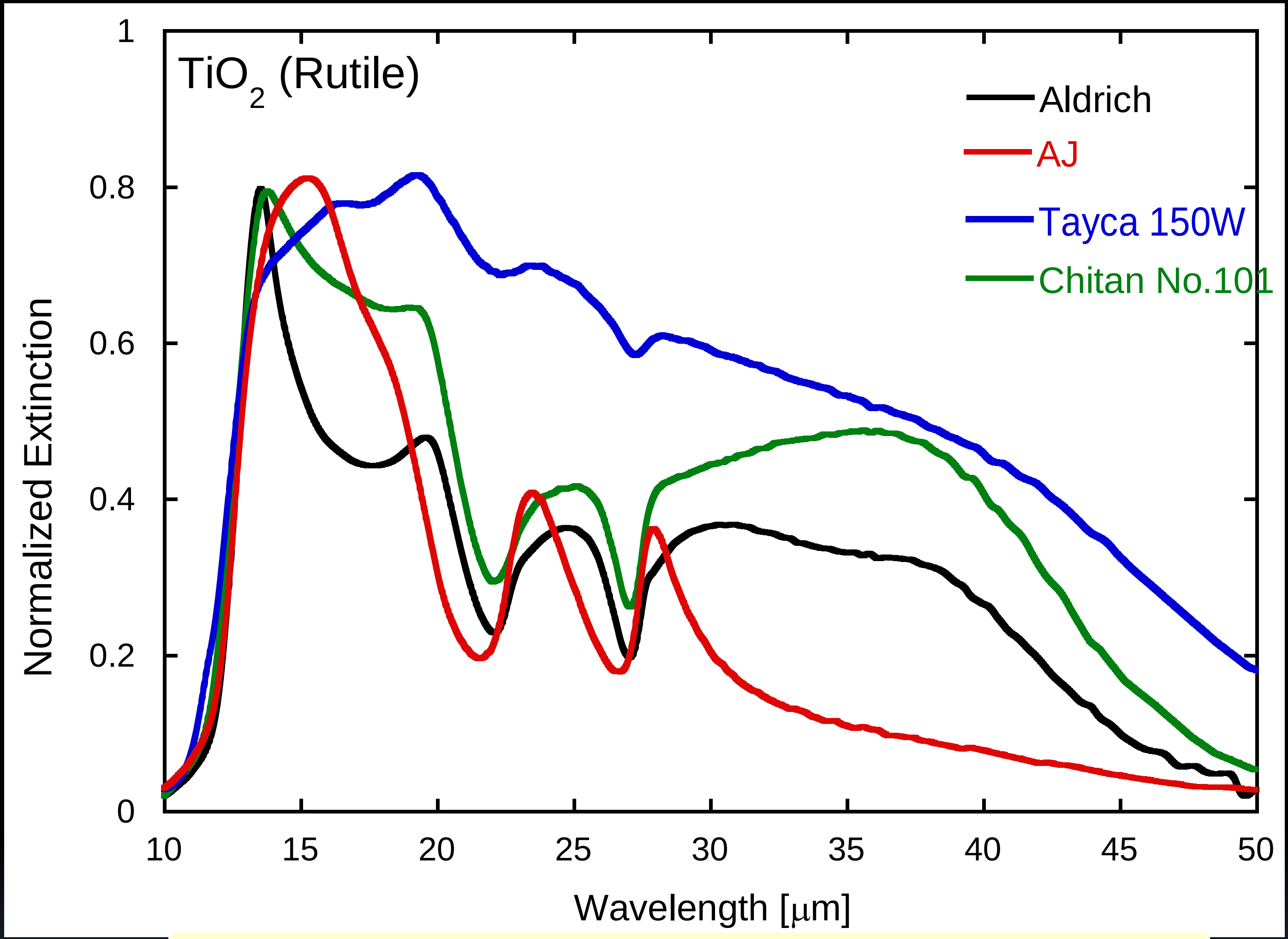




Roundish



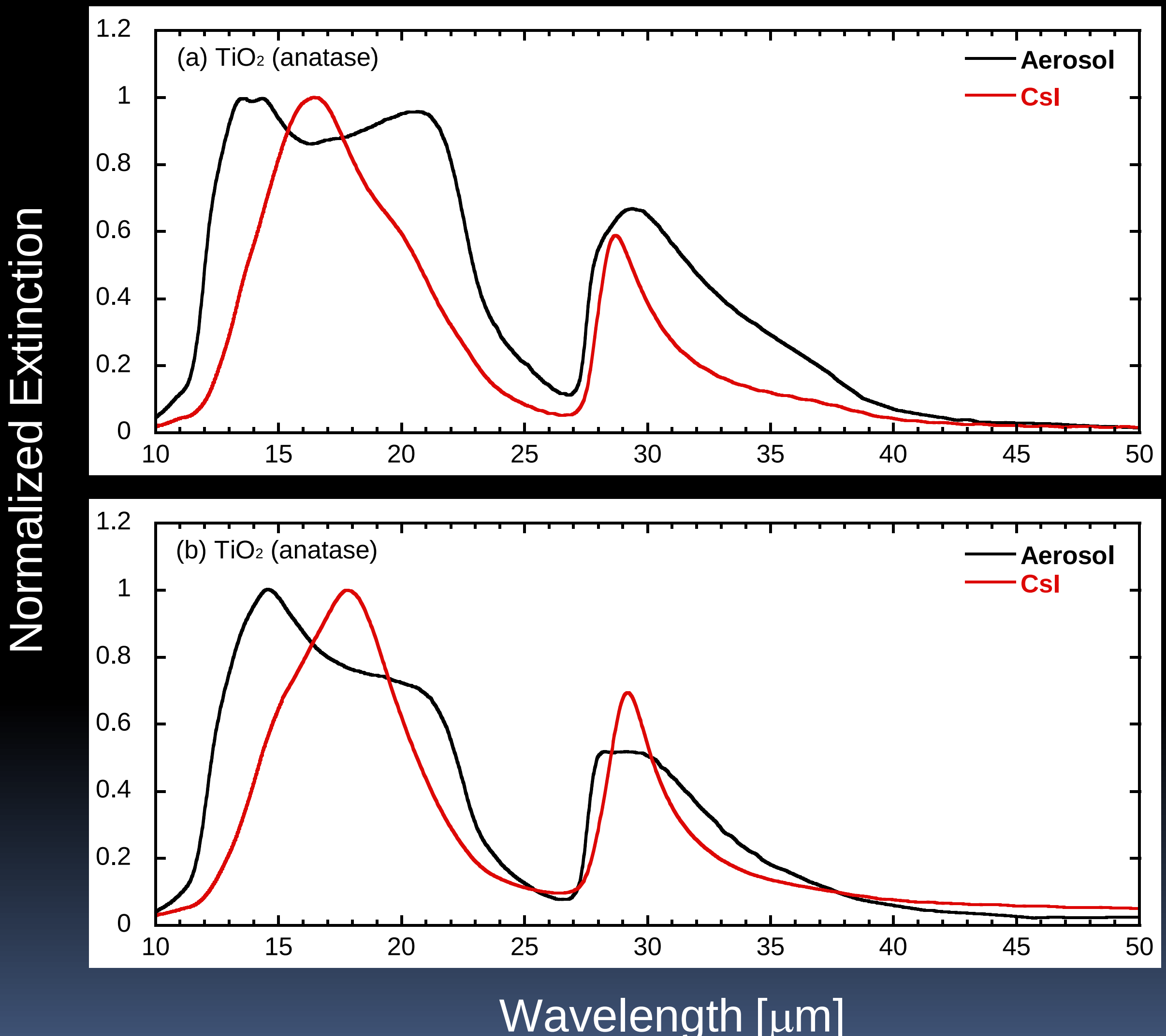
(TEM & SEM images: at Pathology w/ Dr. Nietzsche)




Peaks (microns)

| | | | | | |
|---|---|---|---|---|---|
| Aldrich | 13.53 | 19.56 | 24.70 | 30.30 | 35.80 |
| AJ | 15.33 | | 23.51 | 27.95 | |
| Tayca150 | 16.47 | 19.25 | 23.39 | 28.27 | |
| CI101 | 13.85 | 19.27 | 25.15 | 35.87 | |

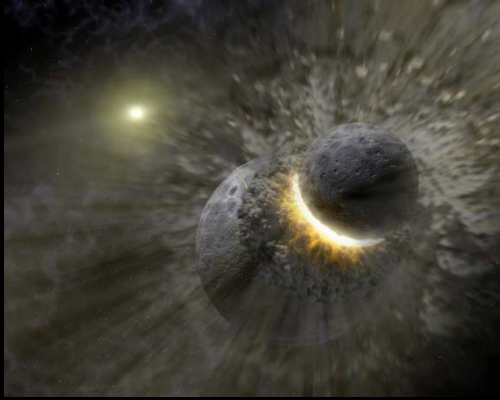
# <Aerosol vs. Pellet Measurements>




Caused by:

- Using different dispersion methods.
- Particles may transform during the grinding procedure.
- Powdered sample structure deformation caused by the high pressurization required for the CsI pellet technique.
- Particle orientation

# *Dust Grains in Debris Disks*



Dust sources → Replenished by larger objects (Weissman 1984)
- Comets strew over
- Planetesimals collide with each other

Vega-type stars are surrounded by circumstellar debris disks.

Discoveries:
- Some planets
- Planetary companions
- Planet candidates

(e.g. Mayor et al. 1995, Marcy & Butler 1998, Kürster et al. 2000, Lagrange et al. 2008)

# Dust in Debris Disks

## Question?

As the grain size increases above 1μm, the spectral features of the infrared dust emission are broadened, and grow fainter.

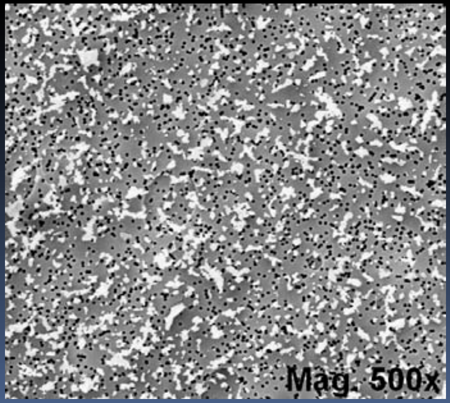
⬇

The Vega-type stars have shown strong emission features in the mid-IR range.

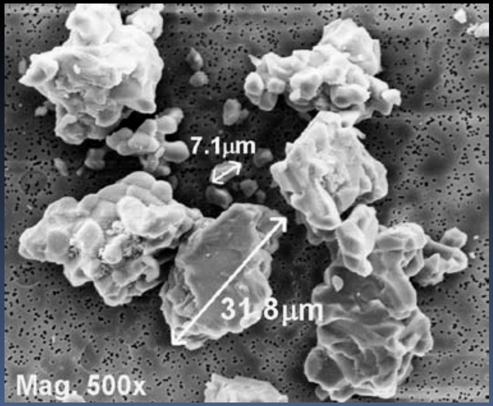
**Why?**

# Objective

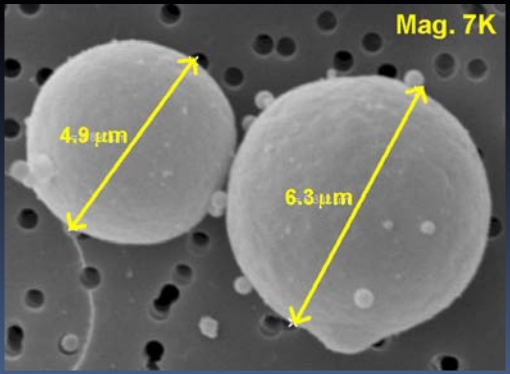
- Extinction measurements of ***large-sized particles*** (2 – 50 μm)
- ***Mixture measurements*** --- How small-sized particles exert an influence on the extinction spectra when they are present in a same environment with larger ones   (0.5 μm & 5 μm particles)
- **Fe-rich olivine** measurements



Cry-$Mg_2SiO_4$ (< 1μm)



Cry-$Mg_2SiO_4$ (~ 16 μm)



Amorphous $SiO_2$ (d=0.5 & ~5 μm)

# Sample & Setup

*Exp. 1 Large-sized particles*

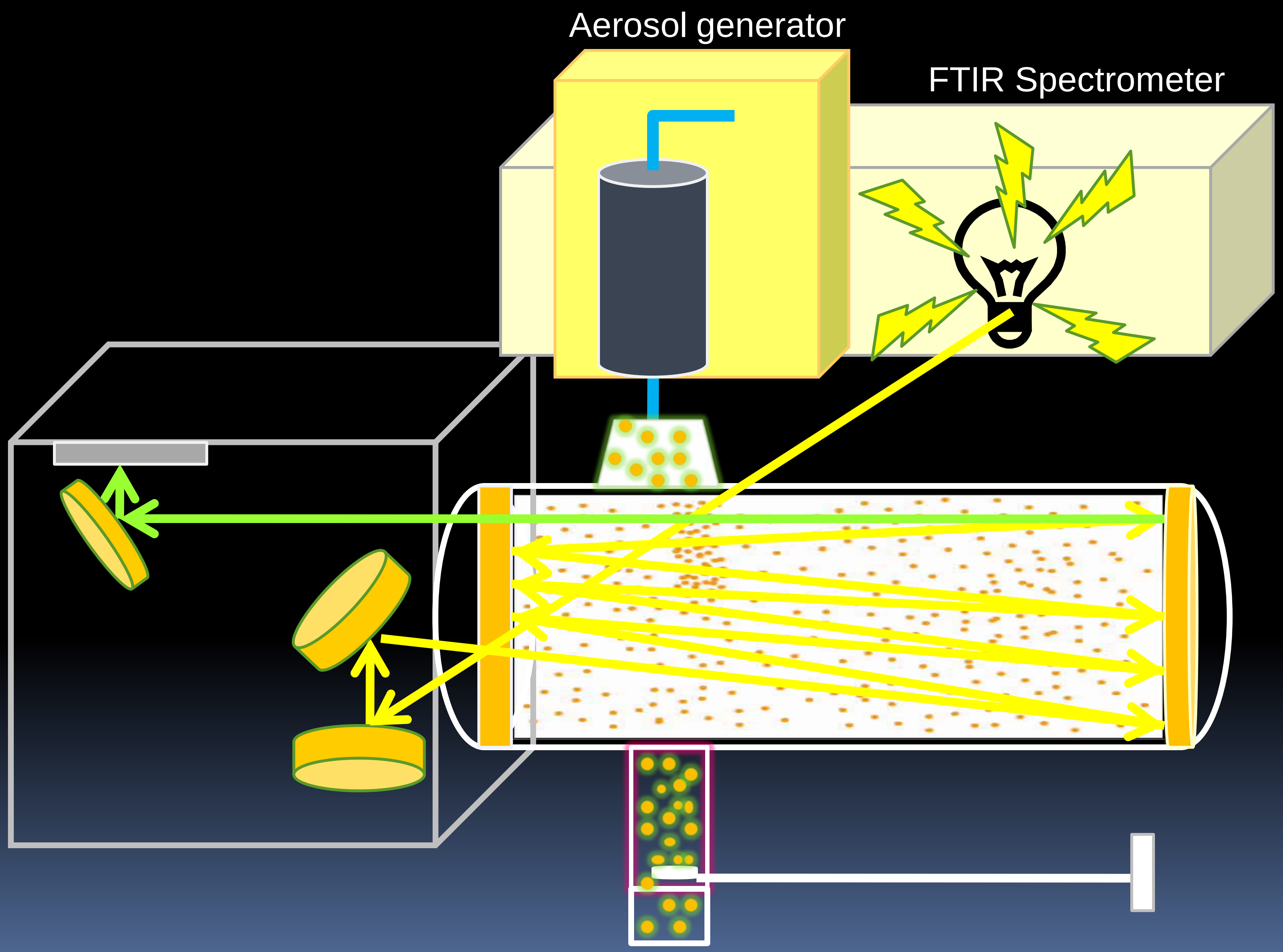
- Amorphous $SiO_2$ (monosphere)
- Crystalline $Mg_2SiO_4$

*Exp. 2 Mixture*

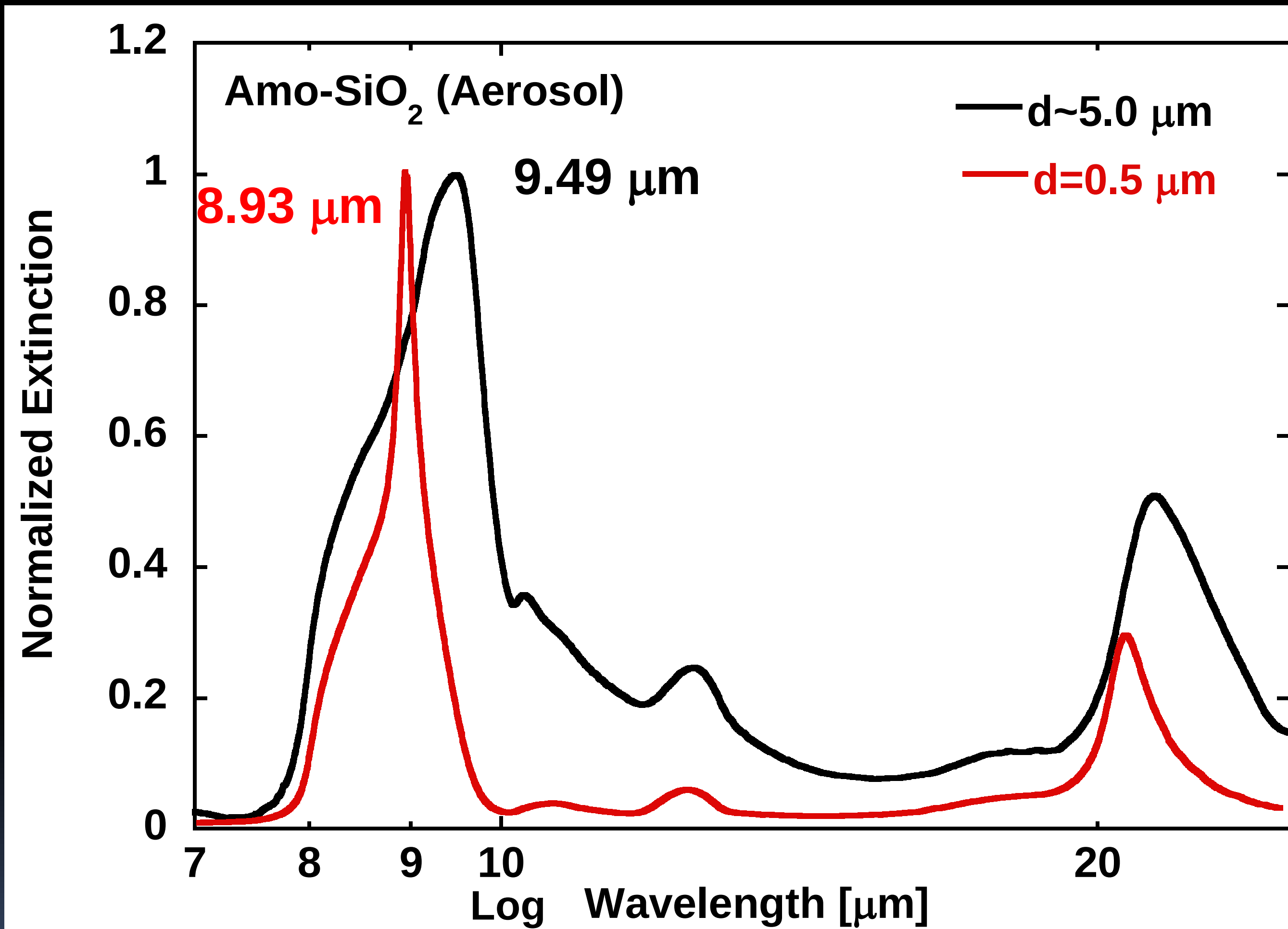
- d=0.5 & d~5 μm amo-$SiO_2$ (complete monosphere shape)
- d=0.5 & d~5 μm amo-$SiO_2$ (5 μm particle are destroyed)

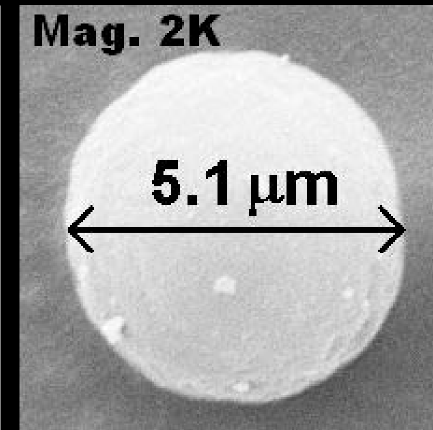
*Exp. 3 Fe-rich Olivine*

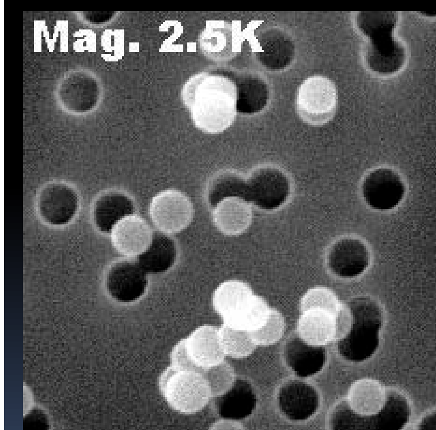
- $Mg_{1.6}Fe_{0.4}SiO_4$ (Sri Lanka) vs. $Mg_{1.9}Fe_{0.1}SiO_4$ (Peridot)


Aerosol generator
FTIR Spectrometer

# Exp. 1 Large Particles ($SiO_2$ monosphere)

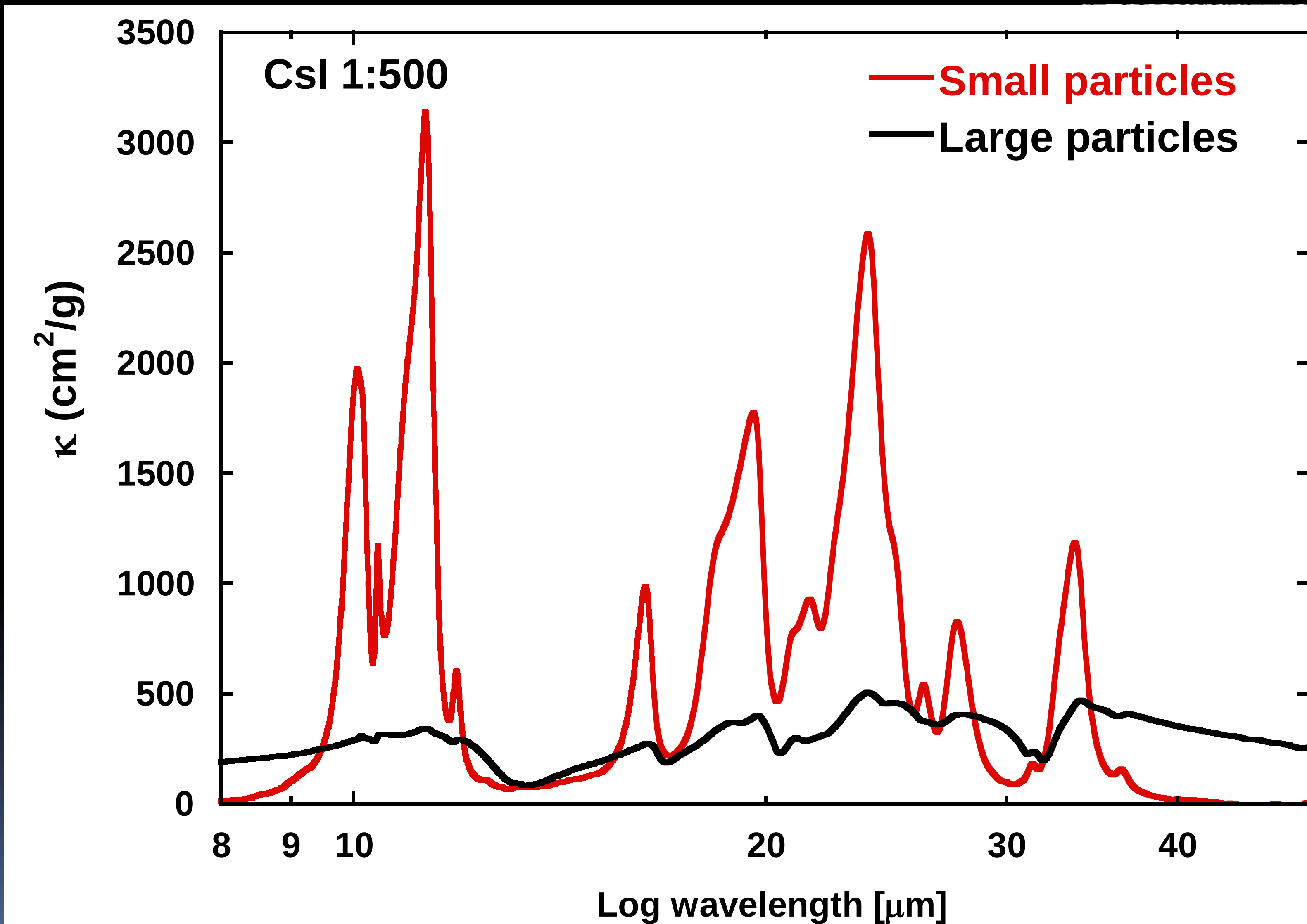


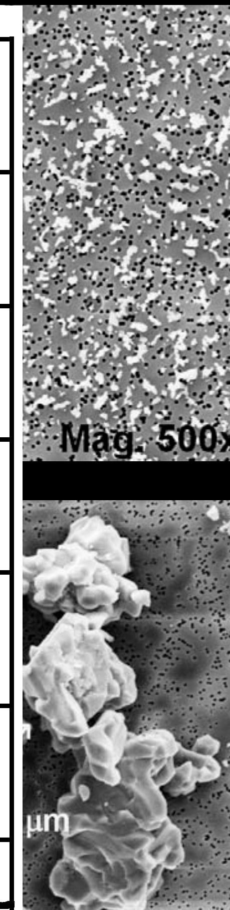




| **Peaks** | 8.93 µm | 9.49 µm | Δλ=0.56 µm |
|---|---|---|---|
| | 20.82 µm | 21.21 µm | Δλ=0.39 µm |

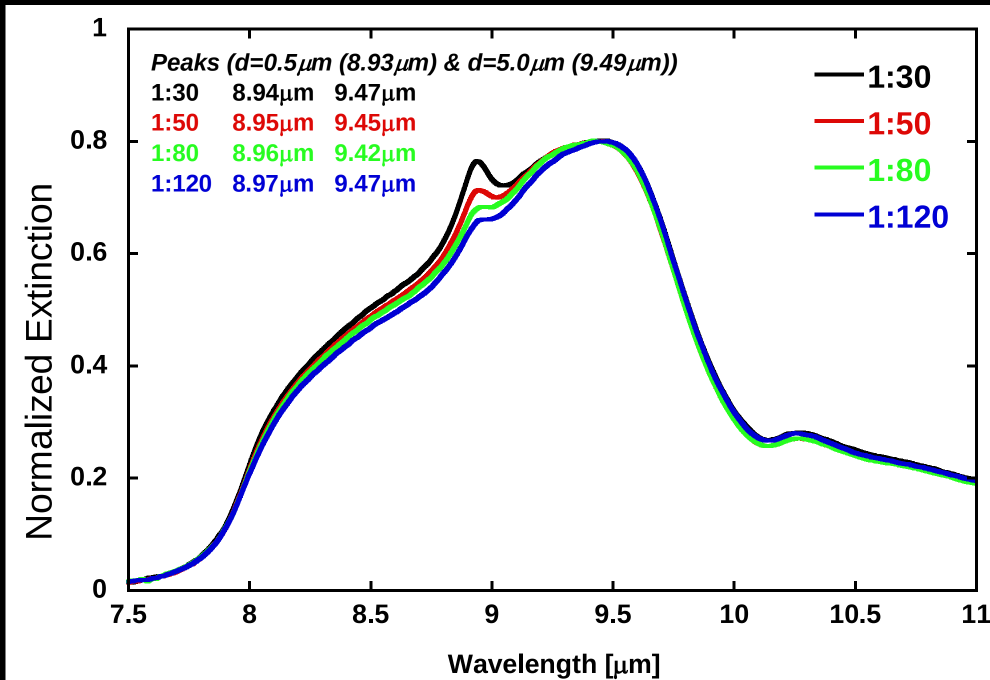
# Crystalline forsterite ($Mg_2SiO_4$)

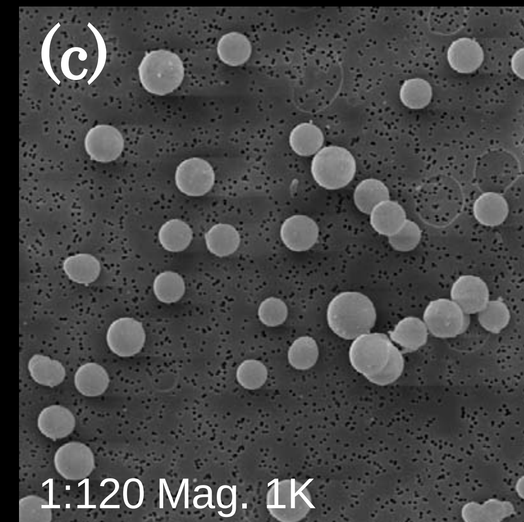


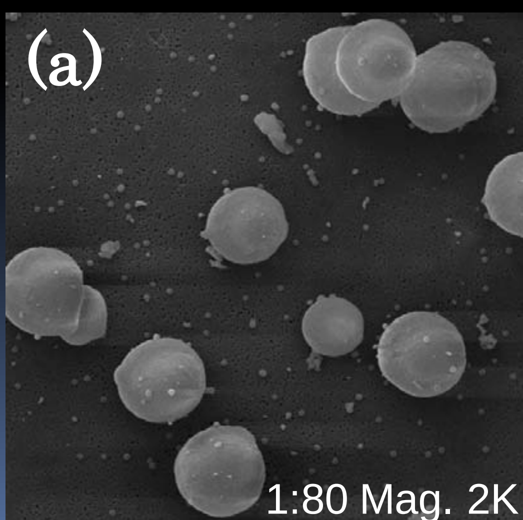



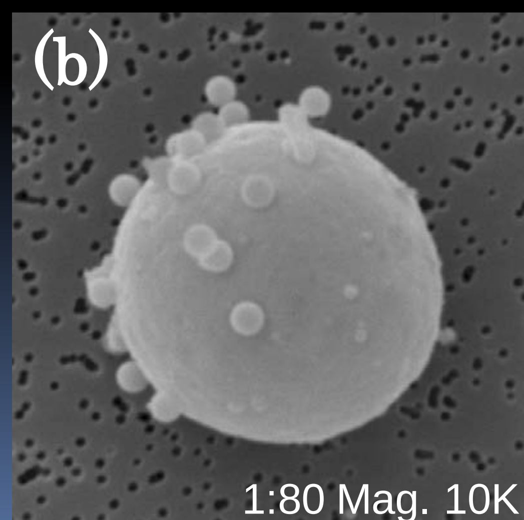

ced.

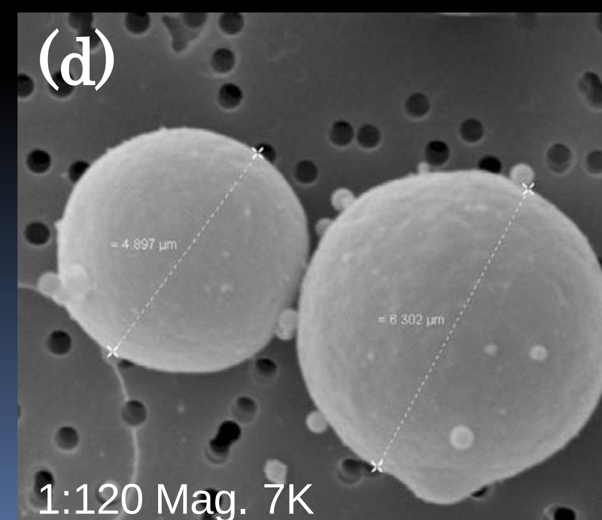
# Exp. 2 Mixture (monosphere vs. monosphere)



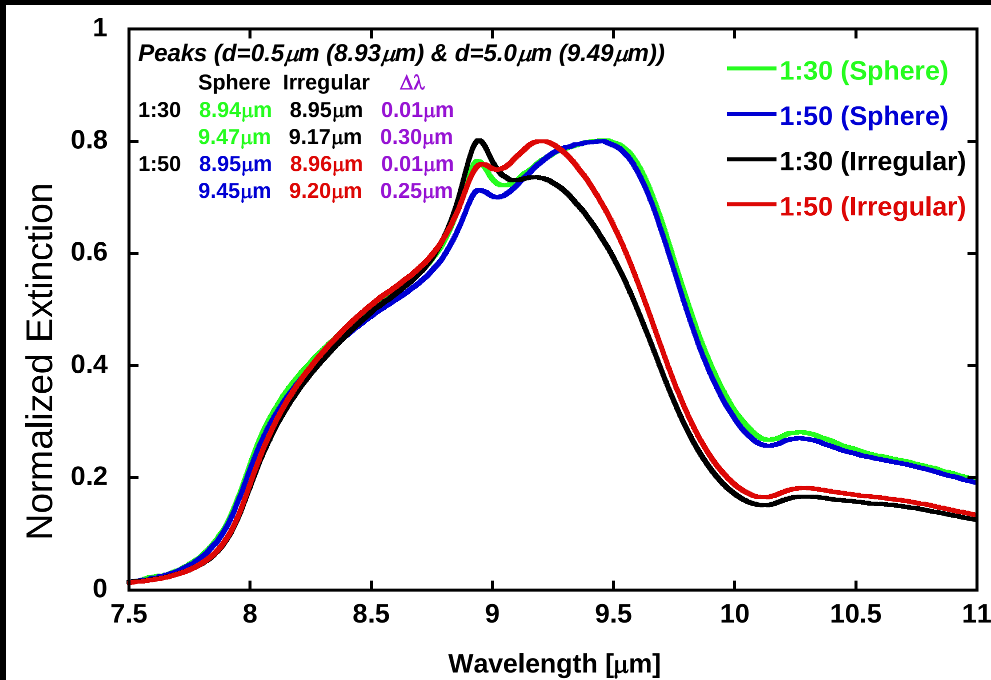



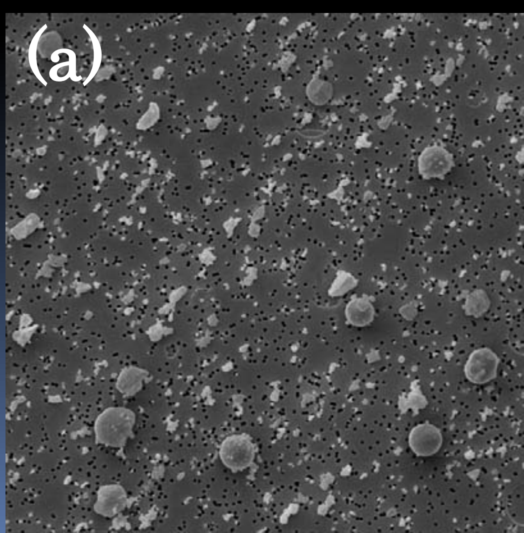



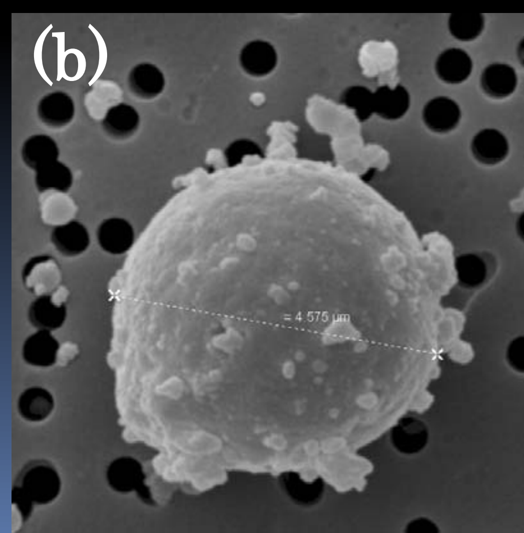
# Exp. 2 Mixture ( monosphere vs. irregular shape)




0.5 μm monosphere : crashed 5 μm particles

- Survived 0.5 μm particles show a clear peak at 8.94 μm.
- The peak at 9.5 μm of the 5 μm particles is strongly influenced by the morphological changes (size & shape).



# Exp. 3 Metal Content

***Olivine*** $Mg_xFe_ySiO_4$

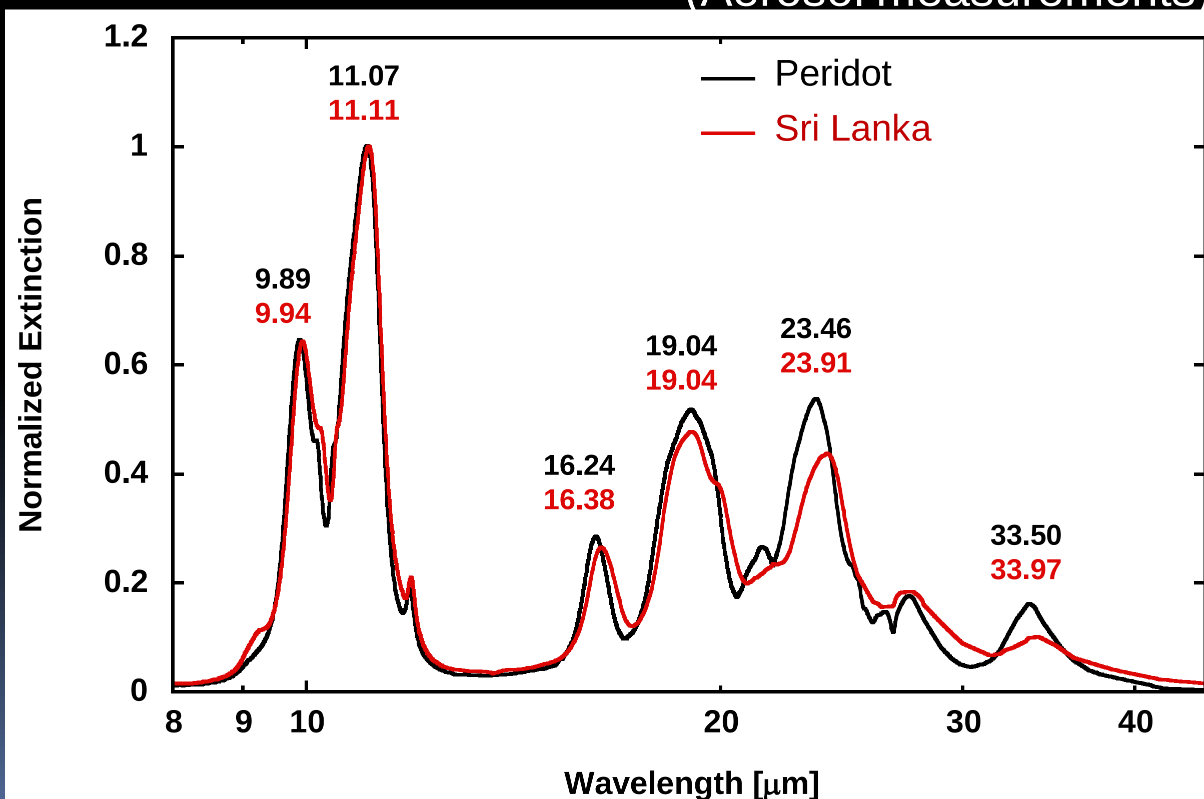
$Mg_{1.9}Fe_{0.1}SiO_4$ (Peridot)

$Mg_{1.6}Fe_{0.4}SiO_4$ (Sri Lanka)

Peridot

Sri Lanka

(Aerosol measurements)




More Fe

spectra shift to longer WL

(Koike et al. 2003)

# Astronomical Application

## *Warm dust thermal emission: Infrared excess*

- About 30 main sequence stars known to have warm-dust emission (i.e. at 10-50 μm)
- a few objects have strong emission at λ ~10 μm (requires T > 200K)
- Best for mineralogical analysis

| Name | Spec. type | Distance (pc) | Age (Myr) | planets | IRS spectrum | Remarks | Reference |
|---|---|---|---|---|---|---|---|
| β Pic | A5 V | 19 | 12 | + | + | - | Chen `07 |
| η Tel | A0 V | 48 | 12 | | + | Wide binary | Chen `06 |
| HD 169666 | F5 | 51 | 2200 | - | + | - | Abraham `08 |
| HD 202406 | F2 IV/V | - | - | - | - | - | Smith `08 |
| HD 106797 | A0 V | 96 | >10 | - | - | - | Fujiwara `09 |

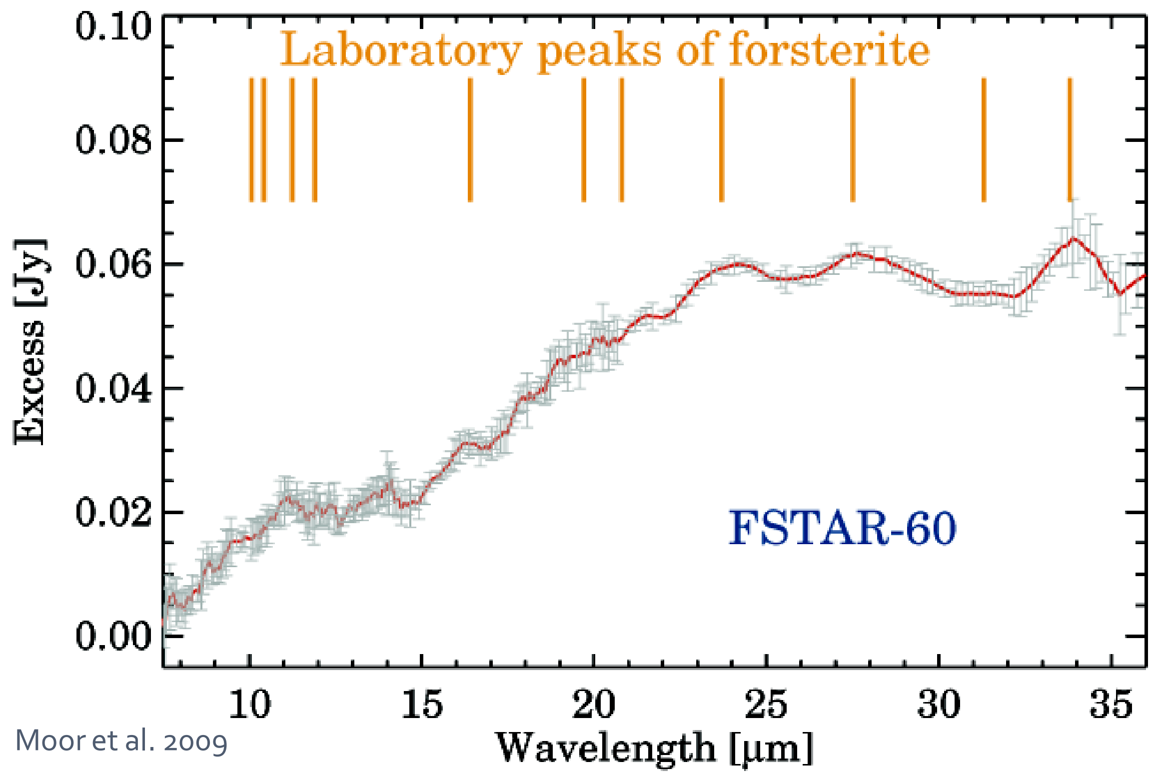
Some main sequence stars known to have warm dust

# Spitzer IRS Spectra – what can be infered from them?

- Crystalline olivine bands vs. 9.8 µm amorphous silicate band
- Short-wavelength wing (9.3µm) indicates presence of pyroxenes or $SiO_2$
- Grain sizes: large grains (> 1 µm) should broaden 10 µm band to longer wavelengths lack of small grains should flatten the band strongly

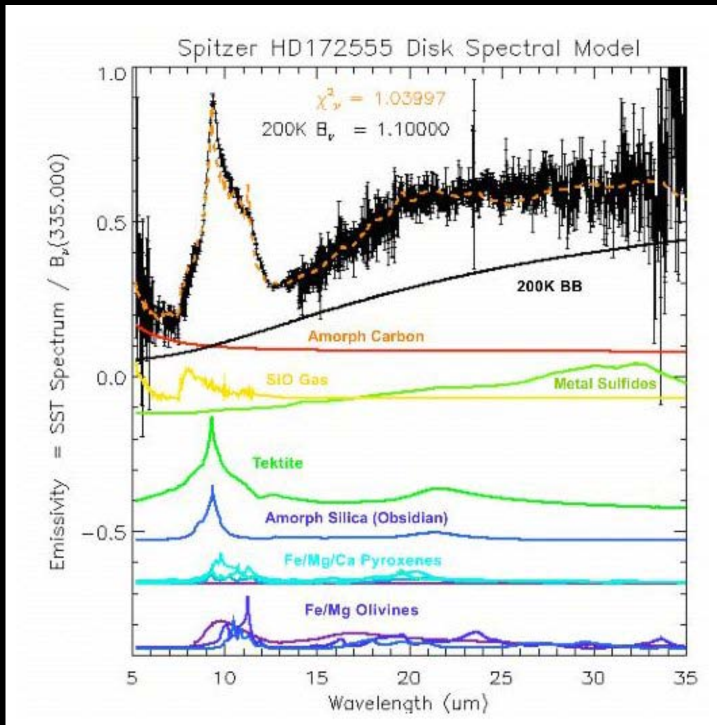
- Small grains dominating (surprising because of blowout limits, but biased by selection)

Example of a large-grain emission spectrum

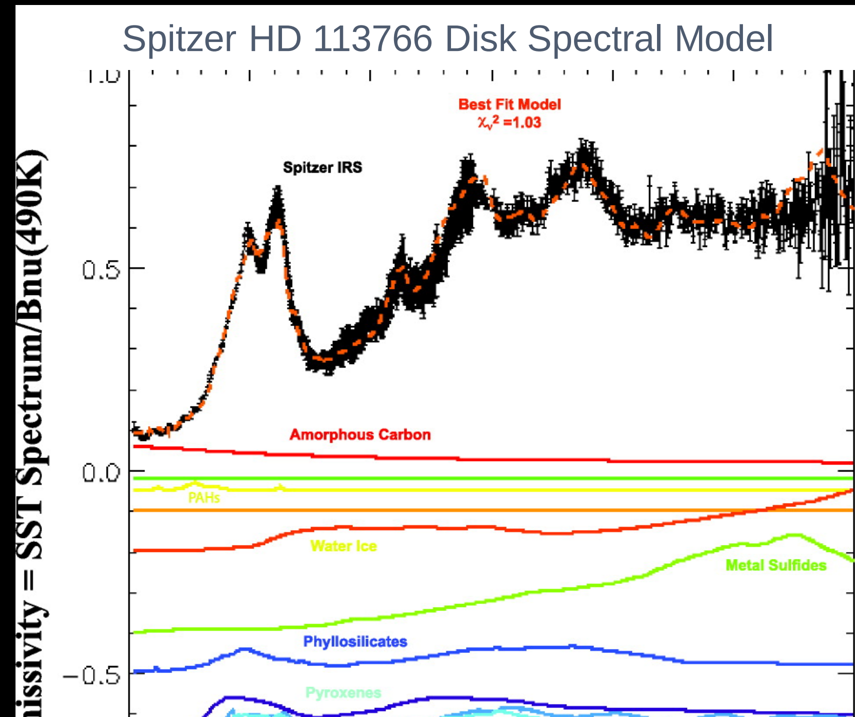



Moor et al. 2009

# Detailed mineralogical analyses (Lisse et al.)




Lisse et al. 2009 (accepted)




## HD 172555 (A5 star)

- 40 % silica and tektite,
- 35% olivines and pyroxenes,
- SiO gas, hypervelocity collision

## HD 113766 (F3/5 binary)

- 29 % olivines, 14 % pyroxenes, 12 % amorphous silicate
- 21 % FeS, 12 % ice
- Warm asteroidal dust (T=450K) at 1.8 AU
- Icy dust at 4-9 and 30-80 AU

# Some concerns:

- Some of the identified minerals do not have distinct bands, they just contribute to continuum emission and they can hardly be distinguished.
- Most of the comparative spectra have been obtained by the embedded dust samples, which make a different band profile.
- The grain shape influences the band profiles.

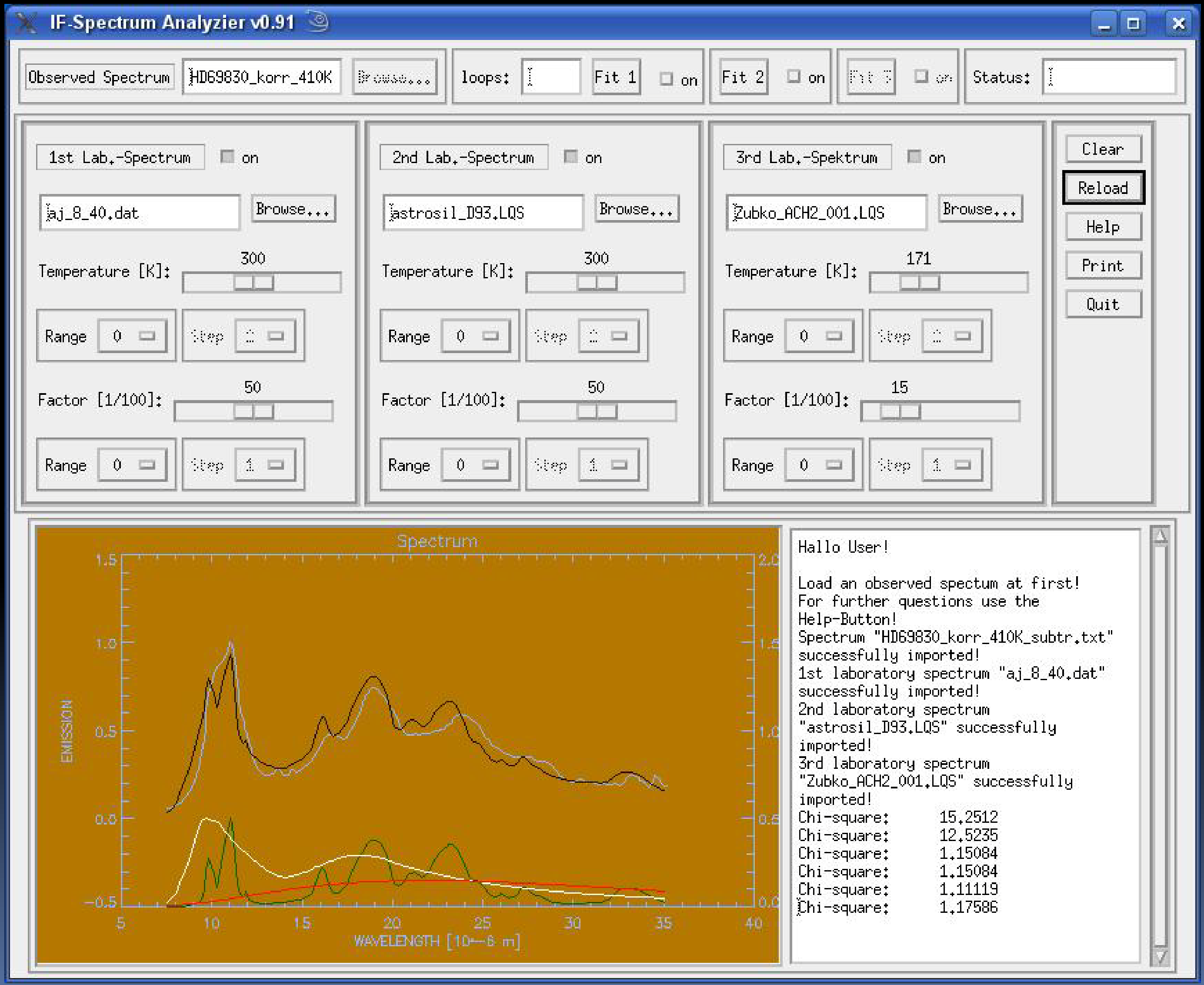
Are such detailed fits possible at all?

# Our approach:

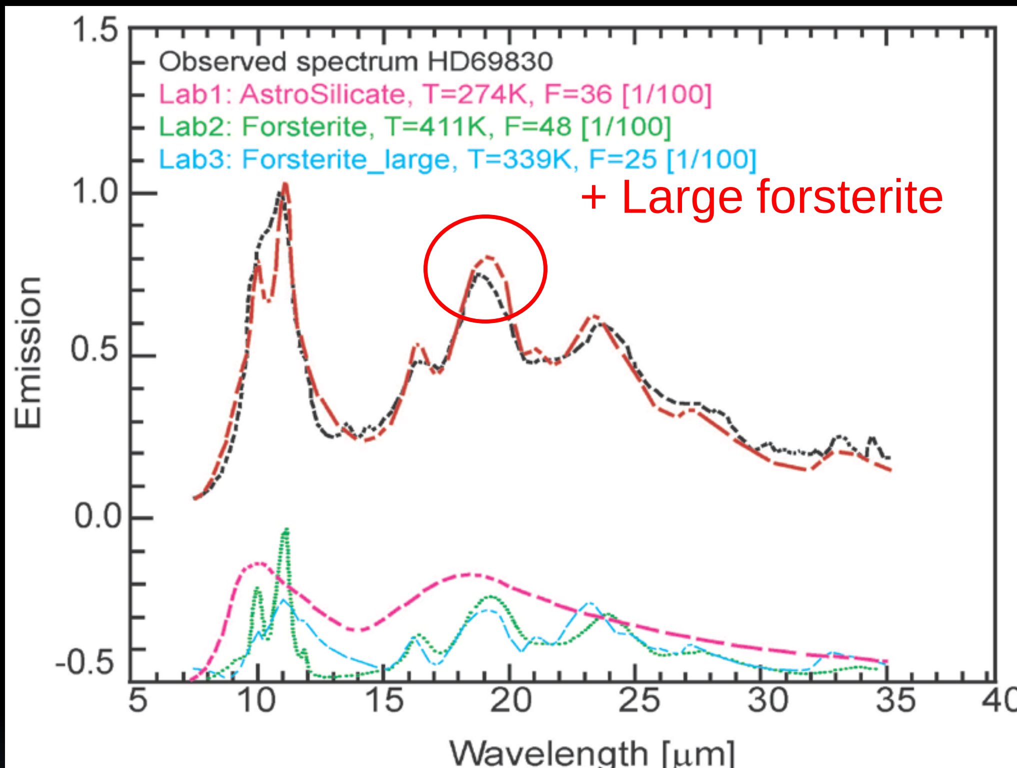
- Dominating minerals first, consider grain shape effects (also composition and size effects) on sharp bands

- Use spectra of well-defined particulates (known shape and size) dispersed in $N_2$-gas – aerosol spectra

# First steps: Some own fitting tests for HD 69830
# – IDL programme IRSA by Lutz Bornschein



# Some own fitting tests for HD 69830




Intention: simplification, search for real „hard facts“ (constraints on dust mixture)

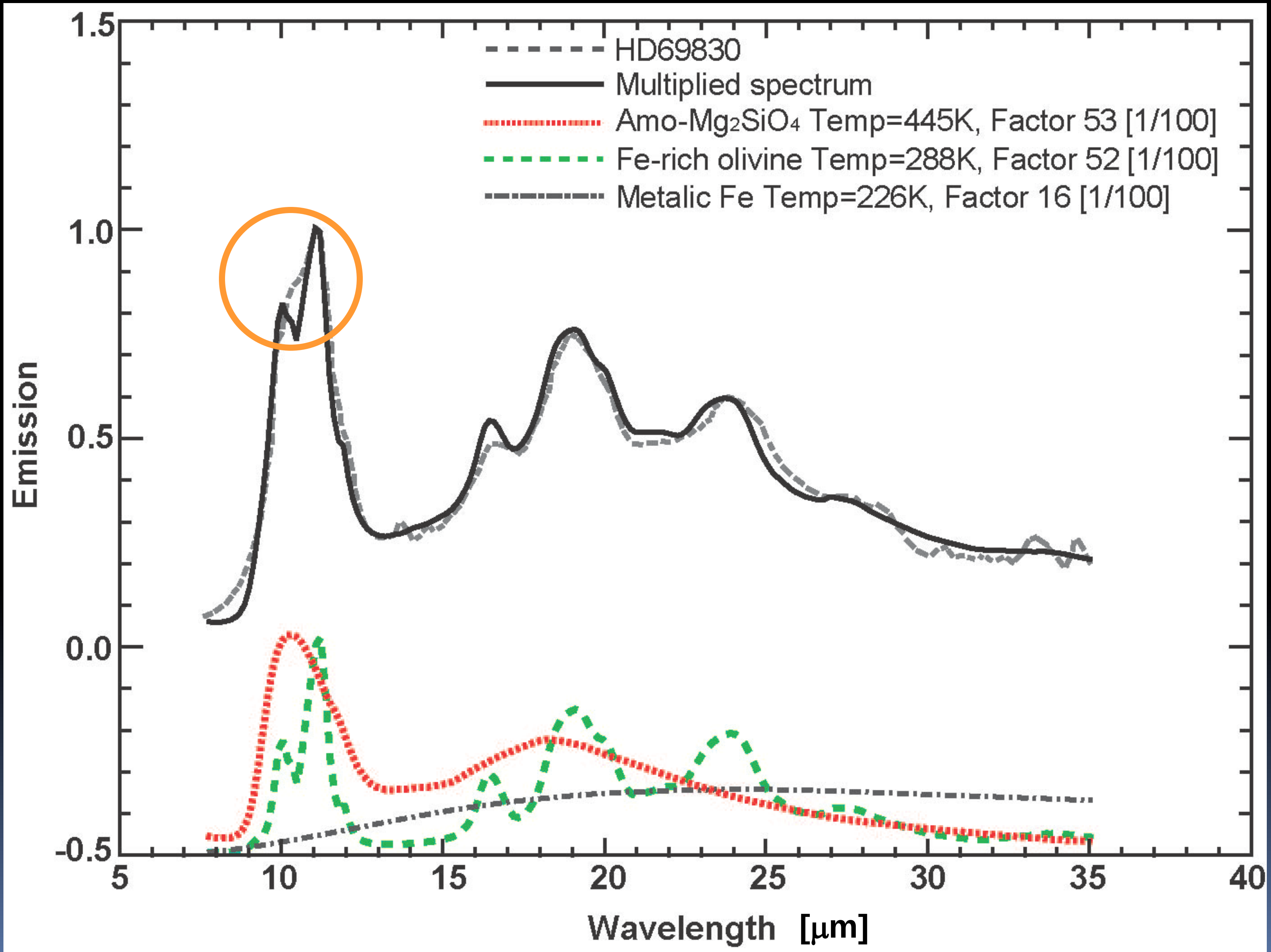
Used dust spectra:
- olivines and pyroxenes from aerosol measurements
- Koike et al. (2003) olivines
- amorphous silicates
- „carbon“ for grey emission (may also mimic colder dust component)

- Beichman et al. (2005): Spitzer IRS
- T(dust) ~ 400K
- M(dust) ~ 1000 zodi

**K0 V**
**13 pc**
**2000 Myr ?**
**3 planets**

Three-component model:
- Fo60+ olivine (synthetic, Koike)
- Astronom. Silicate (amorphous, D&L93)
- „carbon“ cold dust

# Best fit for HD69830



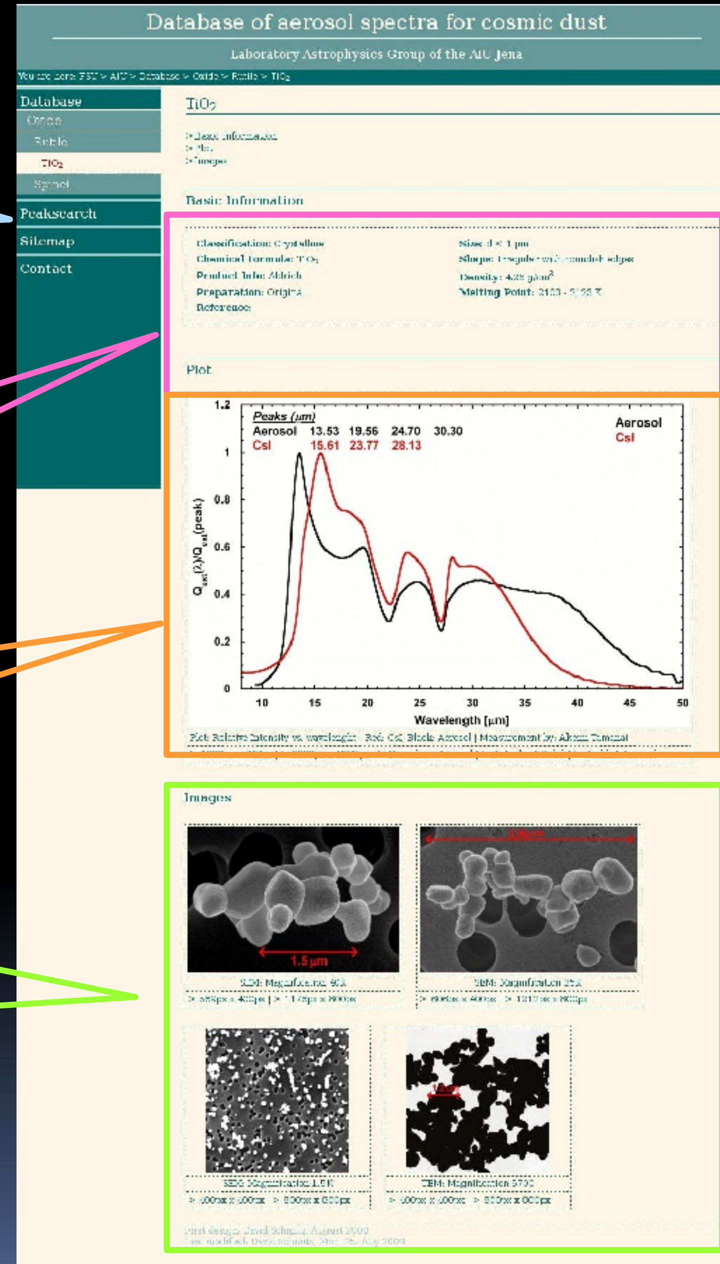
# Database

***Peak Search***: to search for your desired spectra via inputting a peak position.

***Basic information***: Chemical formula, density, particle size, product info., etc…

***Plot***: Aerosol and CsI pellet measurements. Numerical data sets are downloadable.

***Images***: obtained by scanning and transmission electron microscopes (SEM & TEM)




Created by David Schmitz

http://elbe.astro.uni-jena.de

# Summary

*<Large-sized particles vs. Small-sized particles (Forsterite)>*

- Peak positions are not strongly influenced by the particle size, but the bandwidth beyond the 11 $\mu$m peak is significantly broadened.

*<Mixture of Small- and Large-sized particles ($SiO_2$)>*

- Even mass of the 0.5 $\mu$m monosphere particles is 120x less than that of the 5 $\mu$m ones, the peak of the 0.5 $\mu$m particles clearly appears on the extinction spectrum.

*<Metal Content in Olivine>*

- Peaks of Fe-rich olivine take place at slightly longer WL in aerosol measurements as well.

*<HD69830>*

- Emission spectrum of HD69830 fits well with Fe-rich olivine spectrum obtained by aerosol measurement.