AEROSOL SPECTROSCOPY MEASUREMENTS OF AMORPHOUS AND CRYSTALLINE SIO_2

Dust in Planetary Systems
September 28, 2010
Jena, Germany

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- Outlook

Significance of SiO_2 Dust Grains

SiO_2 dust grains are not abundant like silicates
(e.g. olivine & pyroxene)

✓ Interplanetary Dust Particles (IDPs) → tridymite
(Rietmeijer 1988)

✓ Tridymite & Cristobalite > Quartz in meteorites
(e.g. Hezel et al. 2004 & 2006; Kimura et al. 2005; Lehner et al. 2010)

Complex thermal process

Quartz formation → through rapid cooling
Tridymite & Cristobalite formation → undergoes high T process
Possibility: a product of the transition from tridymite or cristobalite during a long period of low T metamorphism

Polymorph

Low Pressure Silica Polymorphs

α-quartz (trigonal) $\overset{573^\circ C}{\rightleftharpoons}$ **β-quartz (hexagonal)** $\overset{870^\circ C}{\rightleftharpoons}$ **β-tridymite (hexagonal)** $\overset{1470^\circ C}{\rightleftharpoons}$ **β-cristobalite (cubic)**

$\overset{1705^\circ C}{\rightleftharpoons}$ **Melt** $\overset{2477^\circ C}{\rightleftharpoons}$ **Vapor**

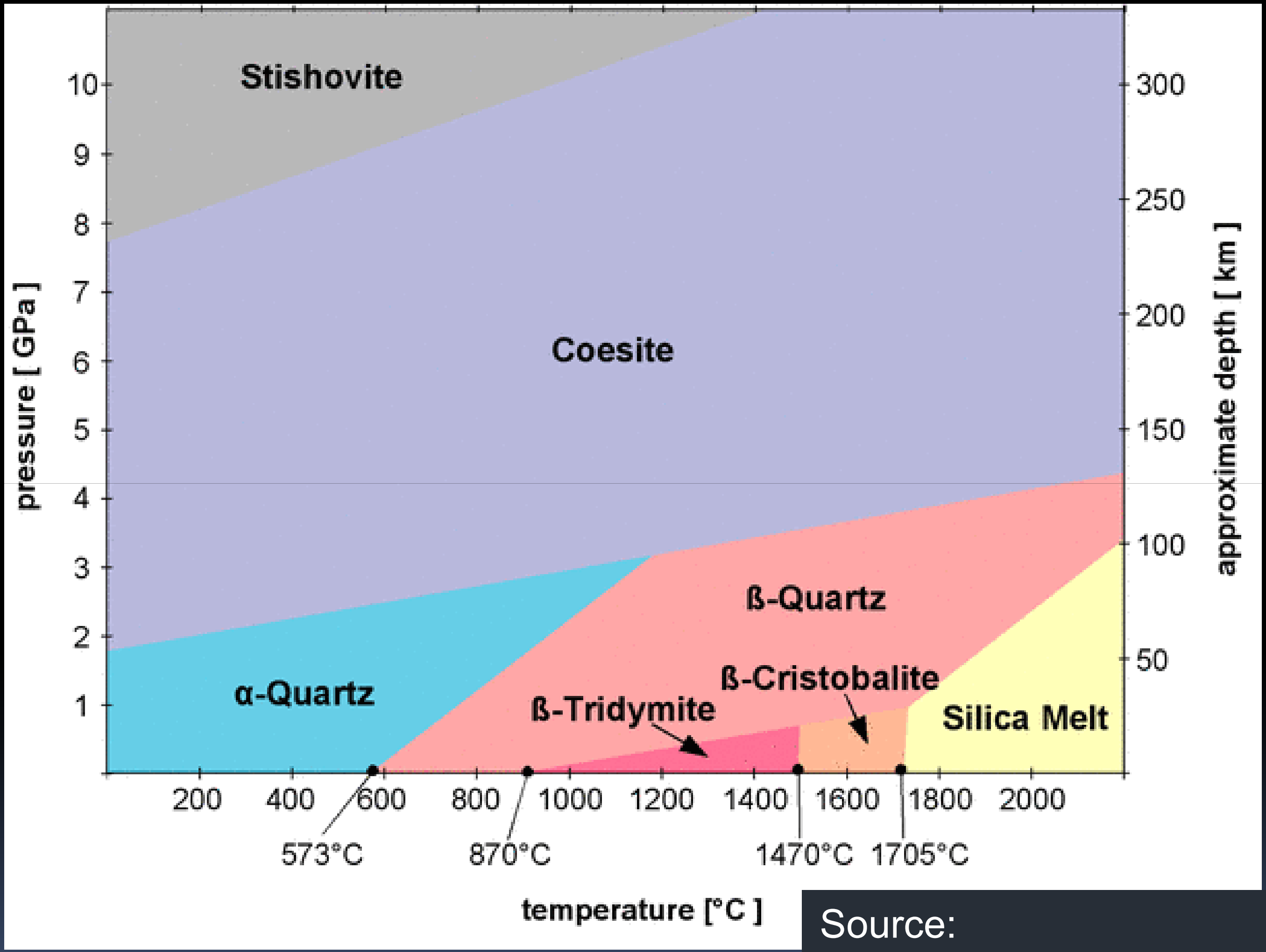
α-tridymite (rhombic) $\overset{117^\circ C}{\rightleftharpoons}$ **β-tridymite (hexagonal)**

α-cristobalite (tetragonal) $\overset{270^\circ C}{\rightleftharpoons}$ **β-cristobalite (cubic)**

Silica glass $\xrightarrow{\sim 1000^\circ C}$ **β-cristobalite (cubic)** $\xrightarrow{1705^\circ C}$ **Silica melt**

(Holleman & Wiberg 2001)

Polymorph



Source:
http://www.quartzpage.de/gen_mod.html
Hollemann & Wyberg 1985
Wenk & Bulakh 2003
Rykart 1995

Complexity of SiO_2 Transformation

SiO_2 crystalline and phase transformations are very intricate

- Temperature
- Pressure
- Catalyst

Example (Arahoshi & Suzuki 1987):

Transformation from *tridymite* to *cristobalite*

Catalyst --- Al_2O_3

The amount of Al_2O_3 ↑ → the transformation T (1470°C) ↓

The presence of suitable catalysts speeds the process of conversion

Catalyst: CaO, MgO (quartz → cristobalite)

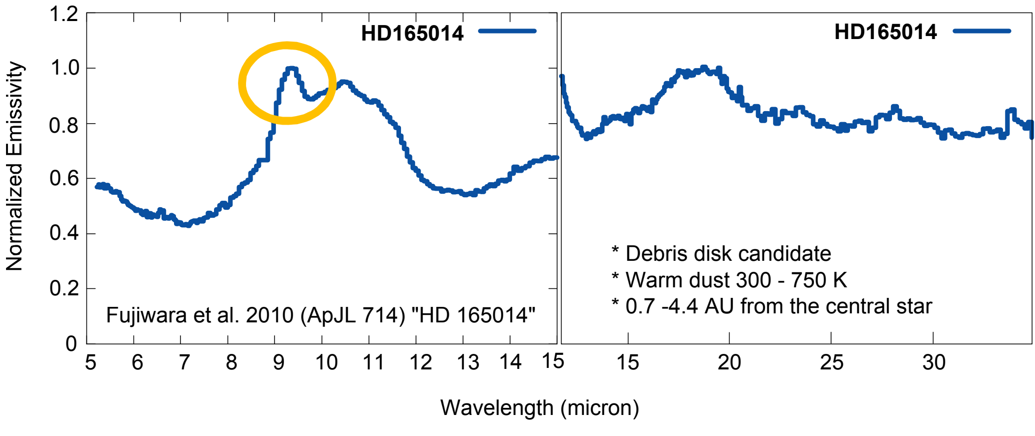
Catalyst: Oxides of K, Na, Al, Fe, Feldspar ($KAlSi_3O_8$, $NaAlSi_3O_8$, $CaAl_2Si_2O_8$)
(quartz → tridymite)

Question

Fact: Different crystalline forms of SiO_2 have been discovered in IDPs and meteorites

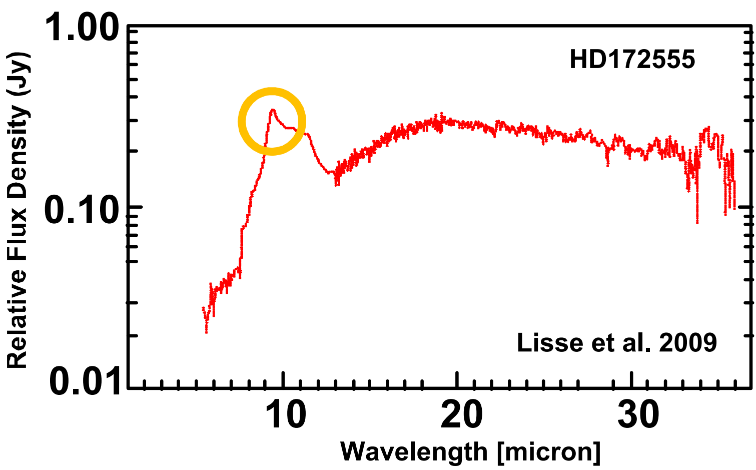
One of building block for planet formation

Why doesn't SiO_2 feature appear clearly on many observed spectra???



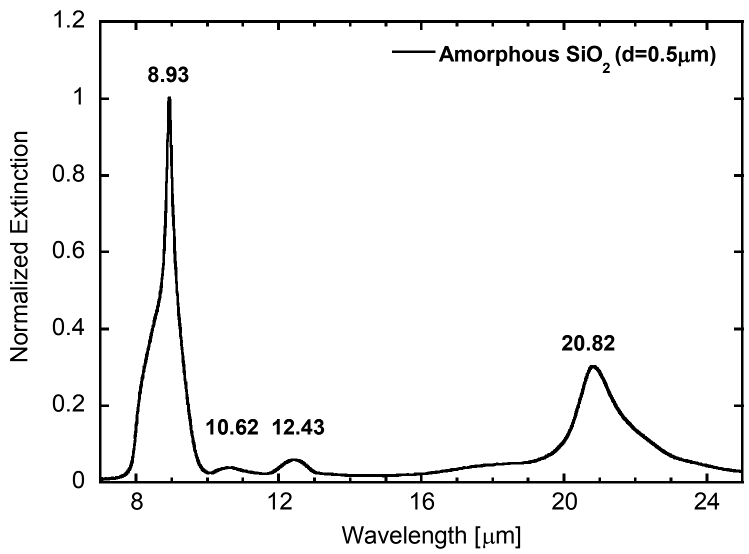
Fujiwara et al. 2010 (ApJL 714) "HD 165014"

* Debris disk candidate
* Warm dust 300 - 750 K
* 0.7 -4.4 AU from the central star

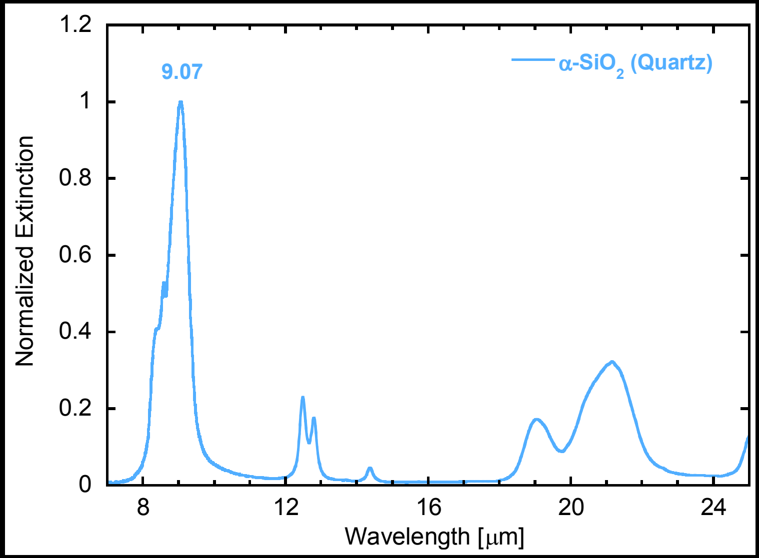


Lisse et al. 2009

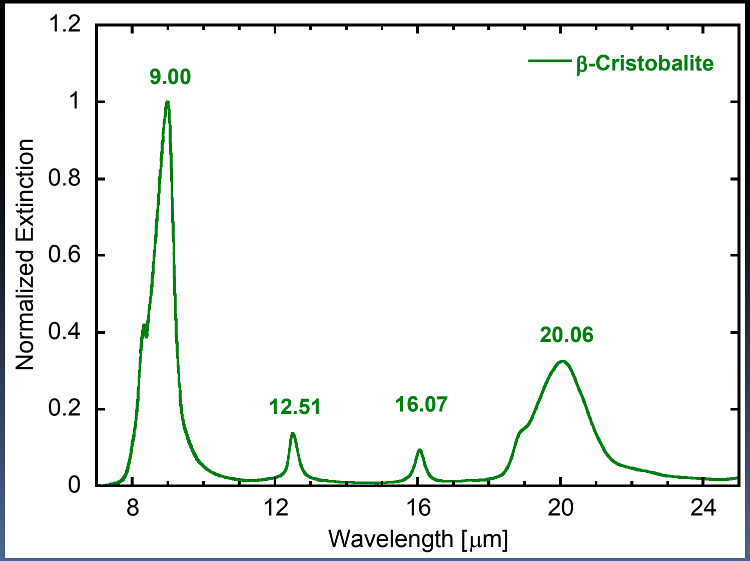
Question (SiO_2 vs Pyroxene)



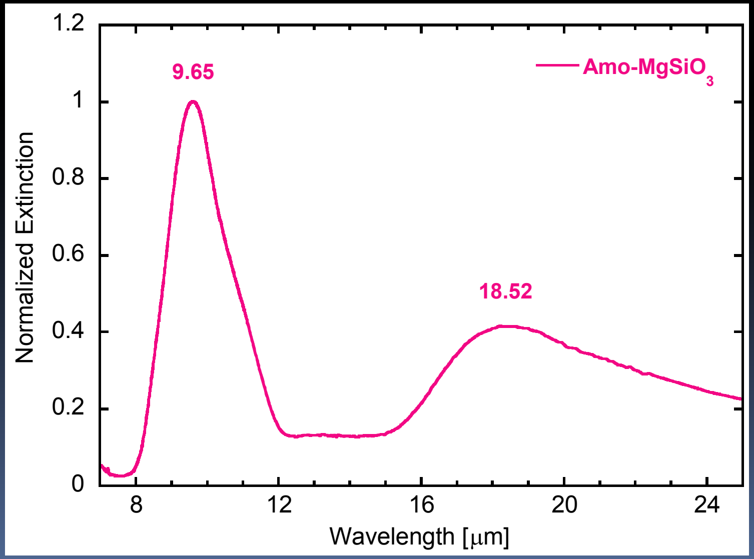
(Tamanai et al. 2006)



(Tamanai et al. in prep.)



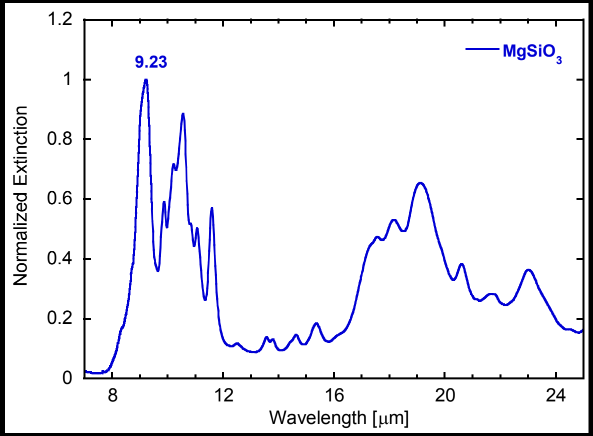
(Tamanai et al. 2007)



(Tamanai et al. 2006)

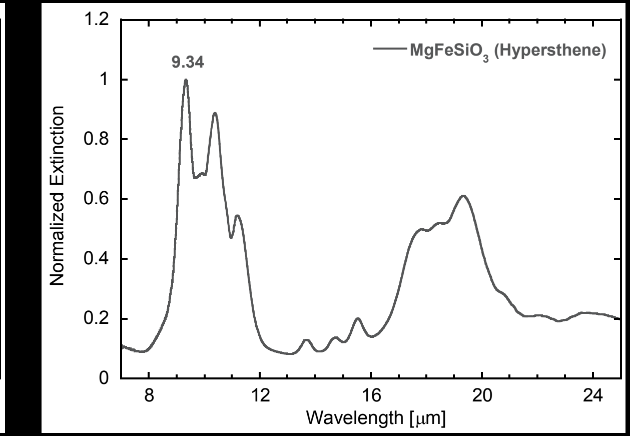
Pyroxene

$MgSiO_3$



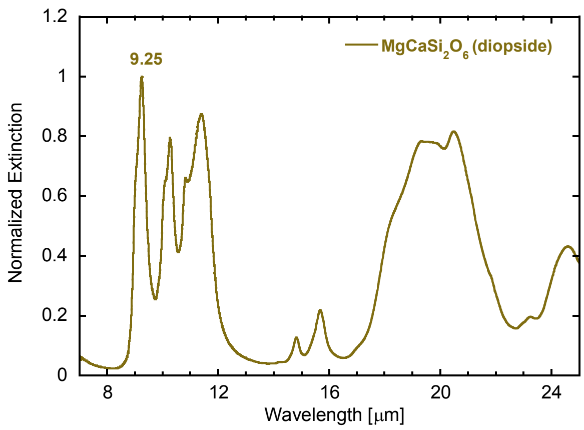
(Tamanai et al. 2006)

$MgFeSiO_3$



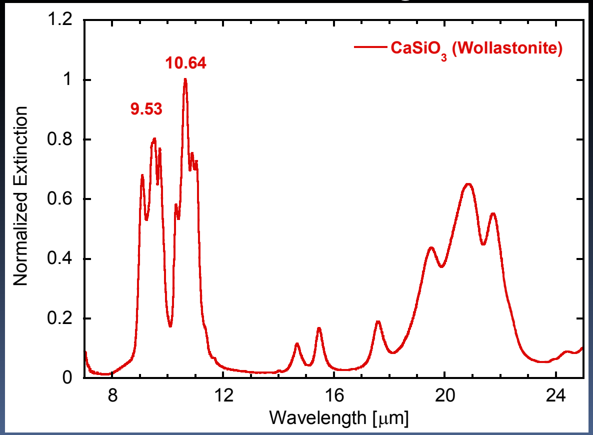
(Tamanai et al. 2009)

$MgCaSi_2O_6$



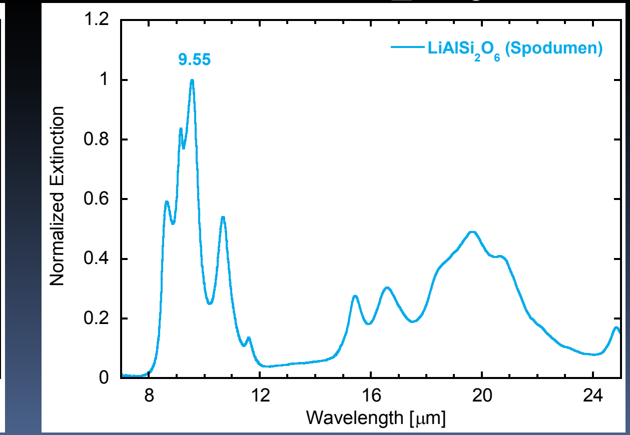
(Tamanai et al. 2009)

$CaSiO_3$



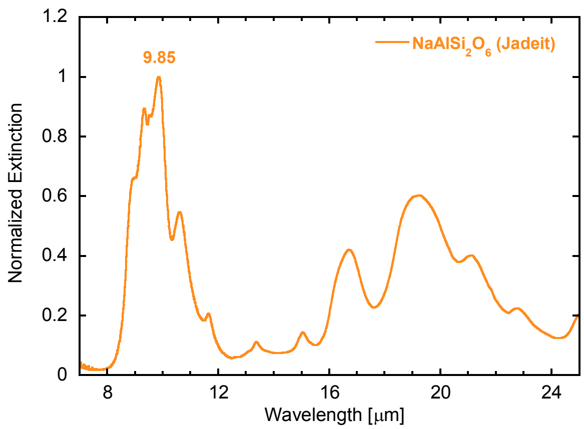
(Tamanai et al. 2009)

$LiAlSi_2O_6$



(Tamanai et al. in prep.)

$NaAlSi_2O_6$



(Tamanai et al. in prep.)

Possibilities --- possible reasons ---

- Amount of SiO_2 is too less ?
- SiO_2 dust grains may be exhausted by another grain formation?
- Simply we fail to notice the existence of SiO_2?

Meteorite

--- The best sample to obtain the information of existing dust grains

e.g. Carbonaceous Chondrite Allende (CV3)

Fe-rich olivine ($(Mg_{0.55}Fe_{0.45})_2SiO_4$)
Hypersthene ($MgFeSiO_3$)
Diopside ($MgCaSiO_3$)
Pervoskite ($CaTiO_3$)
Anorthite ($CaAl_2Si_2O_8$)
Chromite ($FeCr_2O_4$)
Melilite ($Ca_2Al_2SiO_7$)
(Jarosewich et al. 1987; Nagahara et al. 1987; Nozawa et al. 2009)

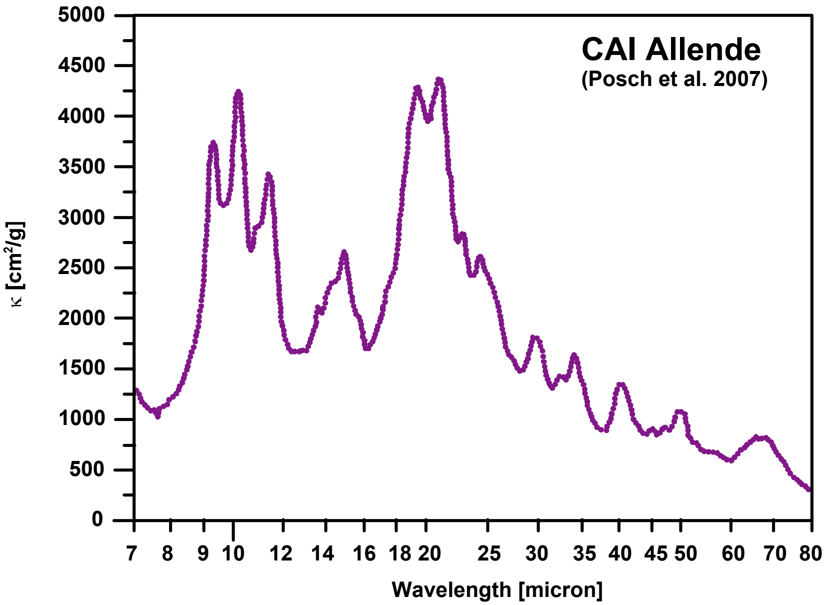
Ilmenite ($FeTiO_3$)
Wollastonite ($CaSiO_3$)
Corundum (Al_2O_3)
Rutile (TiO_2)
Tistarite (Ti_2O_3)
Spinel ($MgAl_2O_4$)
Phyllosilicates (talc, anthophyllite, …)
Fullerene-like carbon …. more
(Brearley 1996; Rubin 1997; Harris et al. 2000; Ma et al. 2010)

Allende

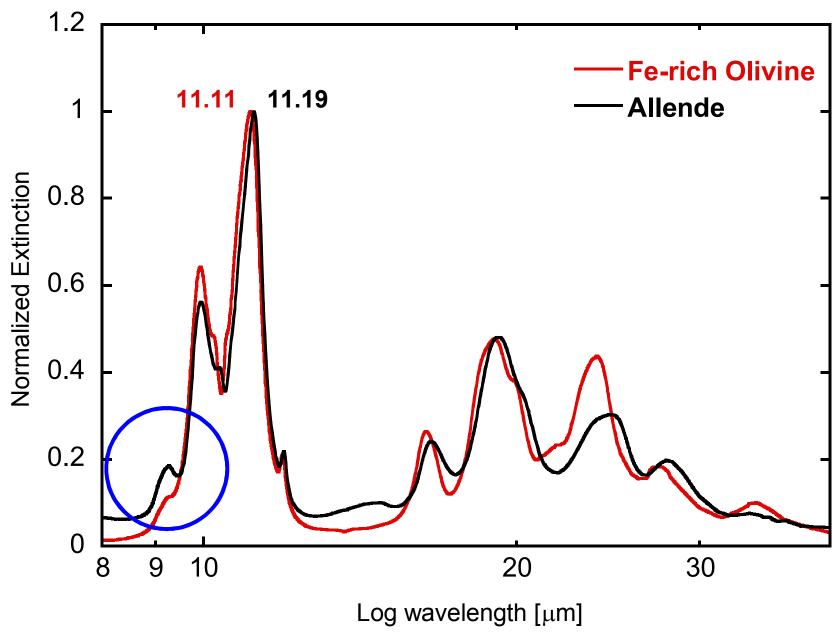
Possible chemical reactions to deplete and form SiO_2:

- $\underset{\text{(forsterite)}}{Mg_2SiO_4} + \underset{\text{(silica)}}{SiO_2} \rightleftharpoons \underset{\text{(enstatite)}}{2MgSiO_3}$
- $\underset{\text{(talc)}}{7Mg_3Si_4O_{10}(OH)_2} \rightleftharpoons \underset{\text{(anthophyllite)}}{3Mg_7Si_8O_{22}(OH)_2} + \underset{\text{(silica)}}{4SiO_2} + 4H_2O$
- $\underset{\text{(diopside)}}{CaMgSi_2O_6} + \underset{\text{(corundum)}}{Al_2O_3} + \underset{\text{(silica)}}{SiO_2} \longrightarrow \underset{\text{(anorthite)}}{CaAl_2SiO_8} + \underset{\text{(enstatite)}}{MgSiO_3}$
- $\underset{\text{(silica)}}{SiO_2} \rightleftharpoons \underset{\text{(metal)}}{Si} + \underset{\text{(gas)}}{O_2}$
- $\underset{\text{(anorthite)}}{2CaAl_2Si_2O_8} \longrightarrow \underset{\text{(melilite)}}{Ca_2Al_2SiO_7} + \underset{\text{(corundum)}}{Al_2O_3} + \underset{\text{(silica)}}{3SiO_2}$

Extinction spectrum of Allende



- ◆ Diopside ($MgCaSi_2O_6$)
- ◆ Nepheline ($Na_3KAl_4Si_4O_6$)
- ◆ Spinel ($MgAl_2O_4$)
- ◆ Melilite ($Ca_2Al_2SiO_7$)



- ☐ Fe-rich olivine from Sri Lanka (Fo_{80})
- ☐ Ferrous olivine in Allende is Fo_{56-65} (Johnson et al. 1990)

(Tamanai et al. in prep.)

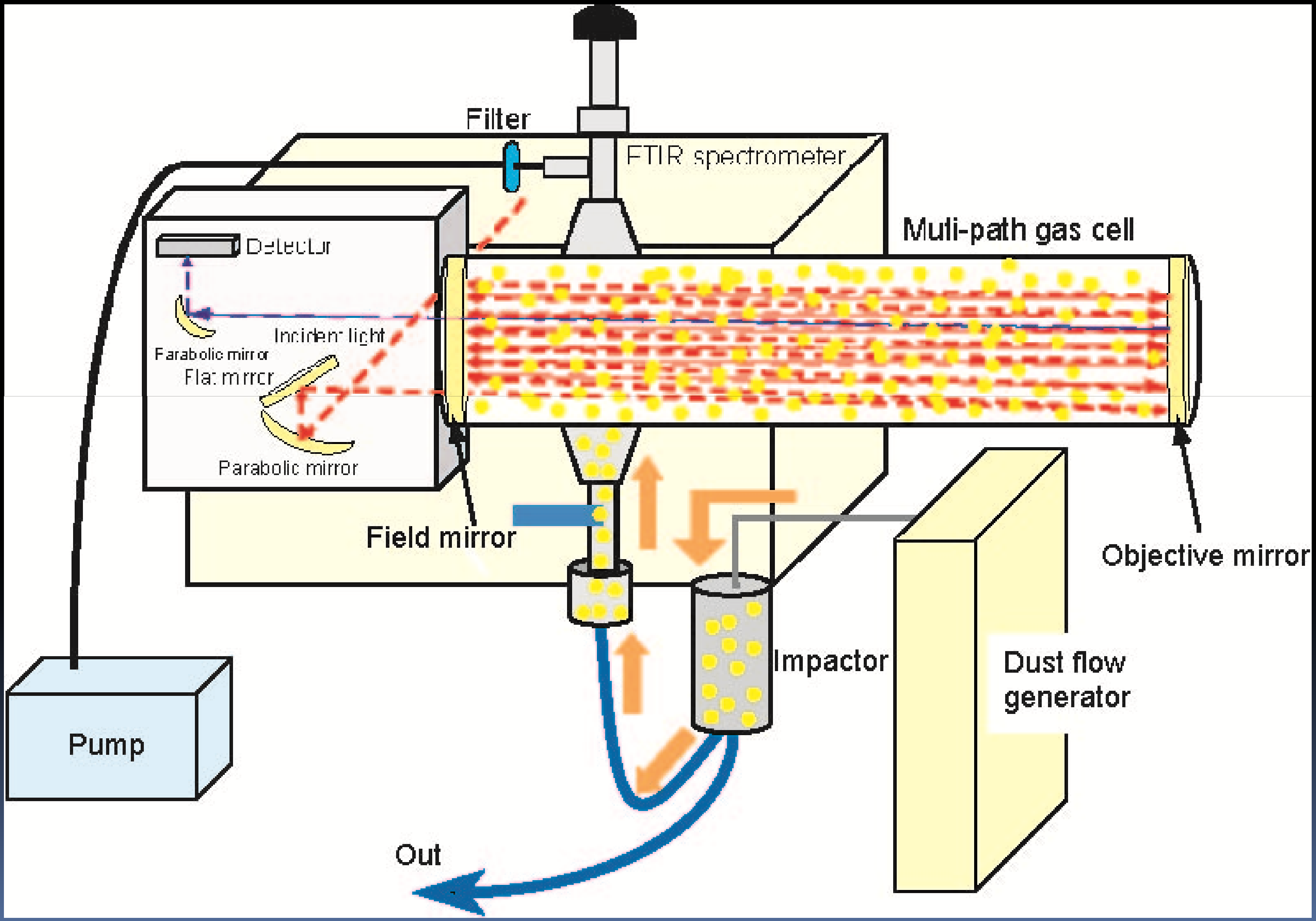
Objective

SiO_2 is not abundant like silicates, but the existence of SiO_2 is very important for different types of silicate formation.

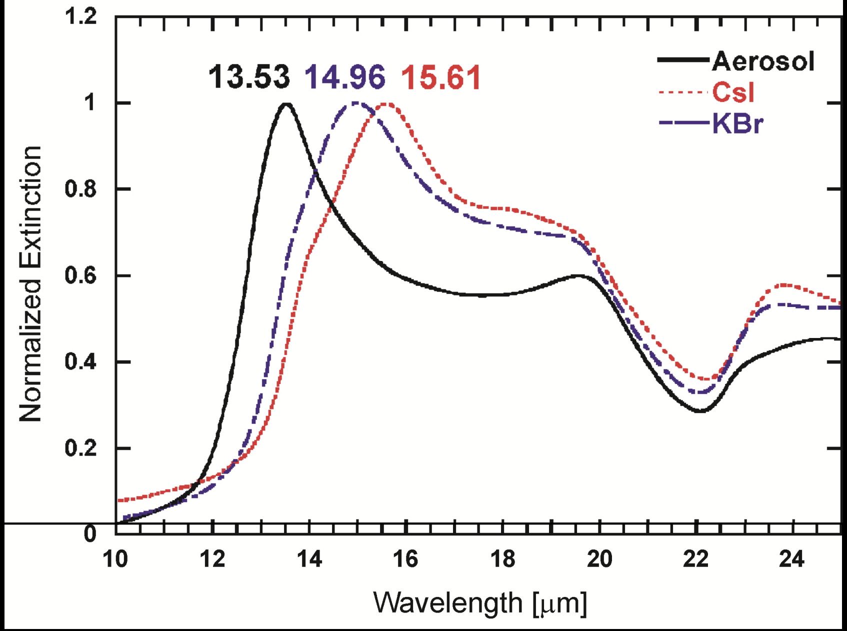
In order to trace a part of SiO_2:

- ✓ Different phases of SiO_2 (Crystalline vs. Amorphous)
- ✓ Different crystalline forms of SiO_2 (trigonal, hexagonal, cubic)
- ✓ SiO_2 formed in different conditions (by volcanic activity & by the impact of meteorites on Earth)

Experimental Setup < Aerosol Spectroscopy>



Experiment <Pellet technique>



ε_m

N_2 → 1.0

KBr → 2.3

CsI → 3.0

The influence of its electromagnetic polarization.

(Tamanai et al. 2009)

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

Sample

Amorphous SiO_2

- Sicastar d=5 μm crush
  (synthetic: irregular shape: < 2μm)
- Obsidian (natural)
- Tektite (natural)
  * Indochinite
  * Libyan Desert Glass (LDG)
  * Moldavite

Crystalline SiO_2

- **α-quartz** (trigonal: natural)
- **tridymite** (hexagonal: α-quartz sand is annealed with T 1300°C for 3 hrs: with a bit of cristobalite)
- **β-cristobalite** (cubic: amorphous SiO_2 powder is annealed with T 1450°C for 1 hr)


Obsidian


Indochinite

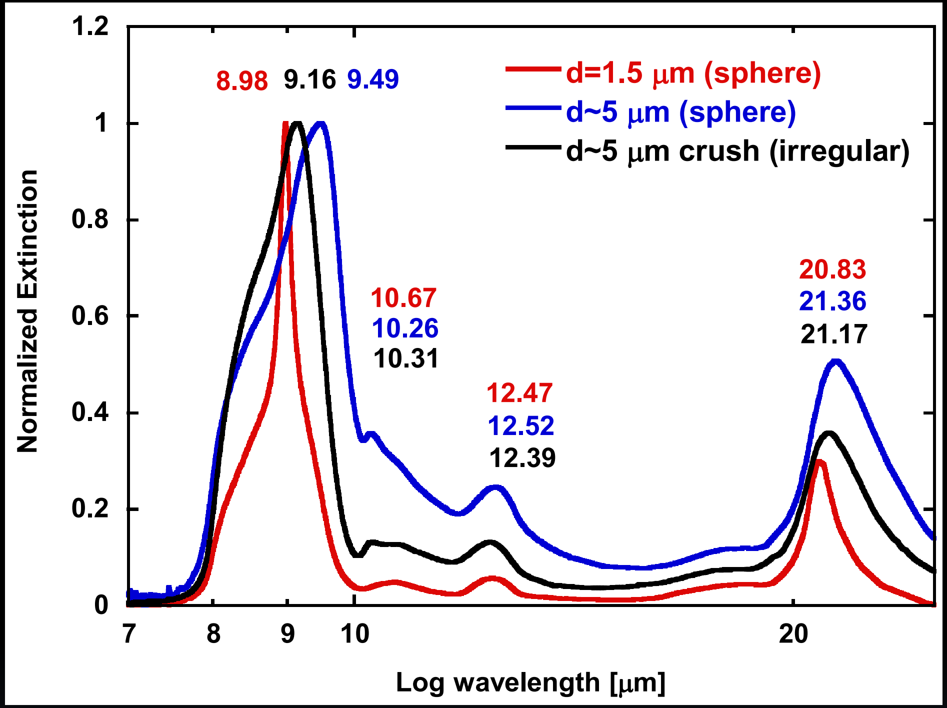

LDG

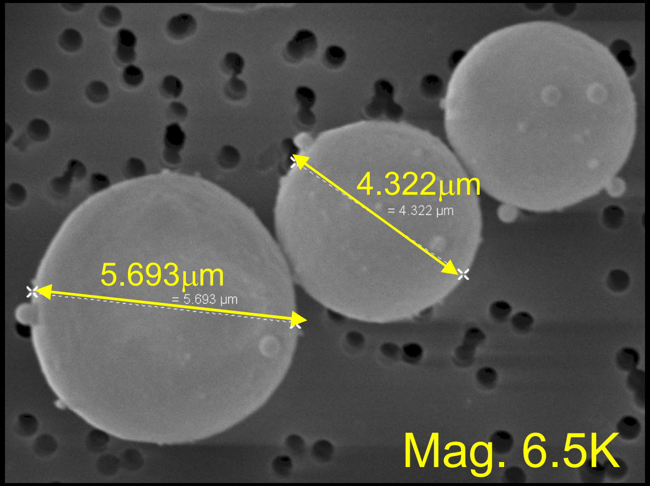

Moldavite

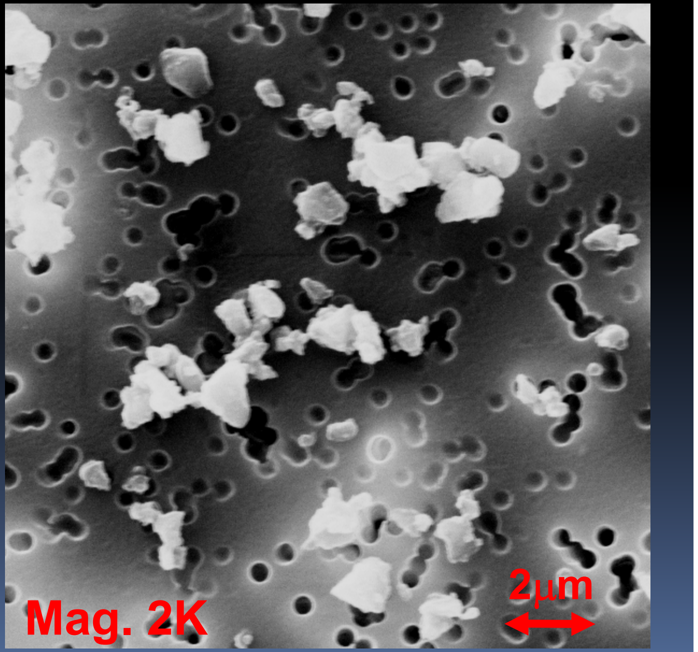

α-quartz

Result --- Morphological Effect ---

Amorphous SiO_2 (Sphere vs. Irregular)



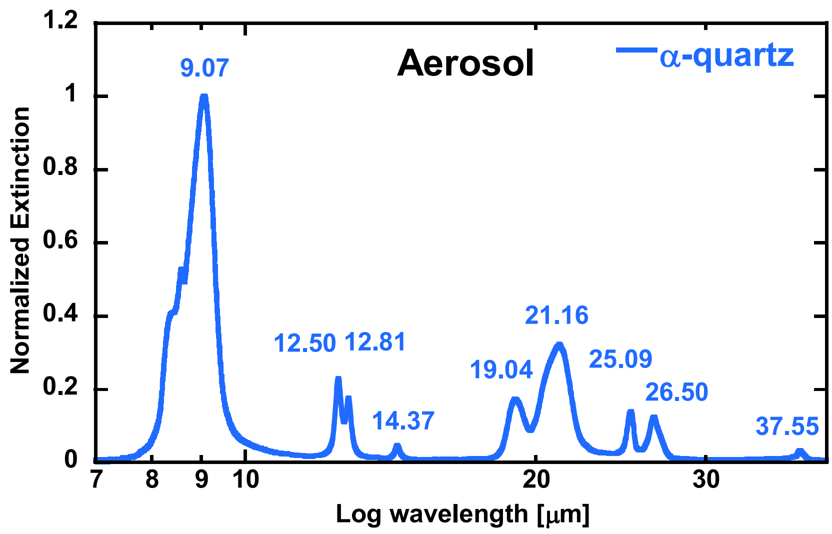


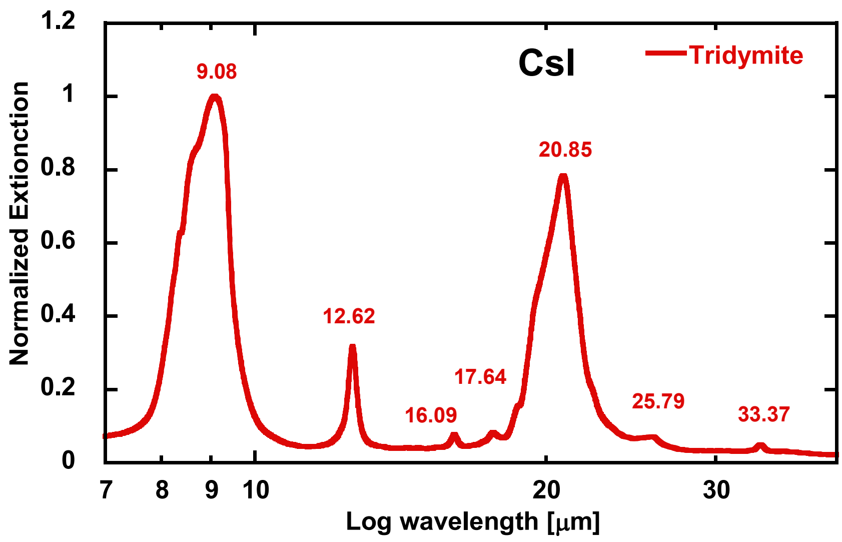


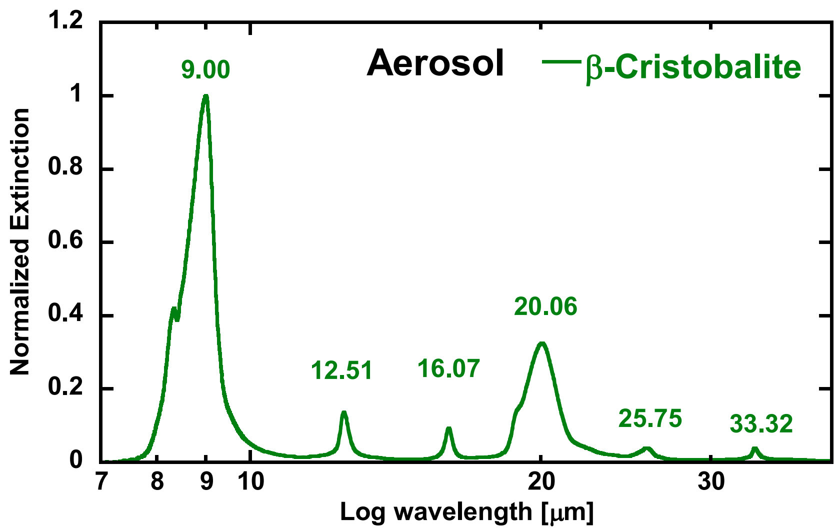
Peak shift → a larger surface area leads to more collisions by Brownian motion (irreg.)
(e.g. Blum et al. 2000)

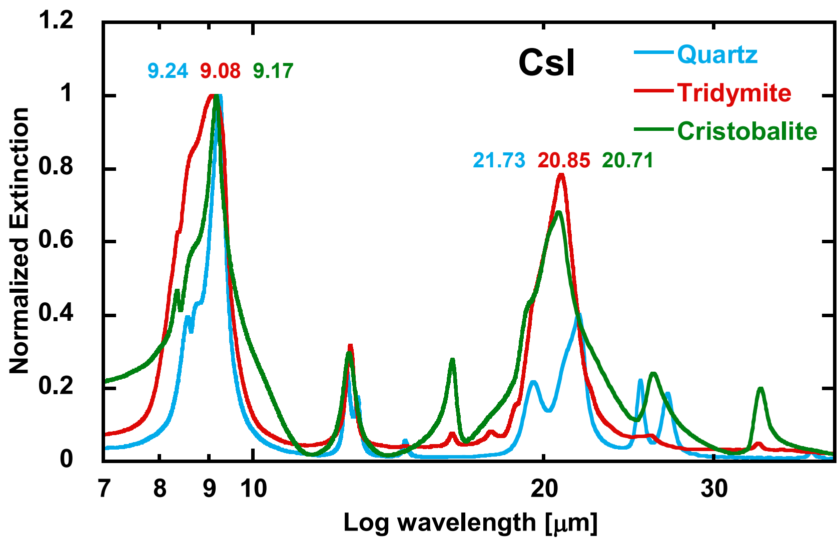
Bandwidth → size distribution broaden it
(e.g. Bohren & Huffman 1985)

Result --- Crystalline SiO_2---

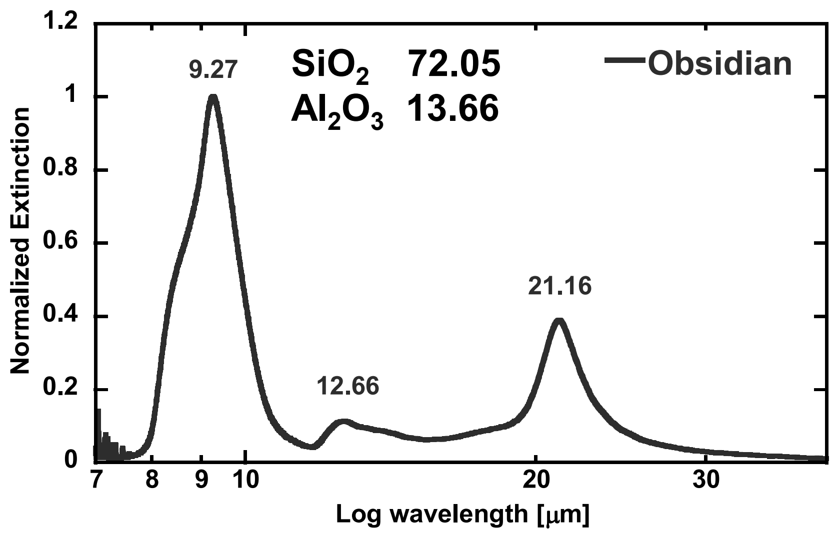


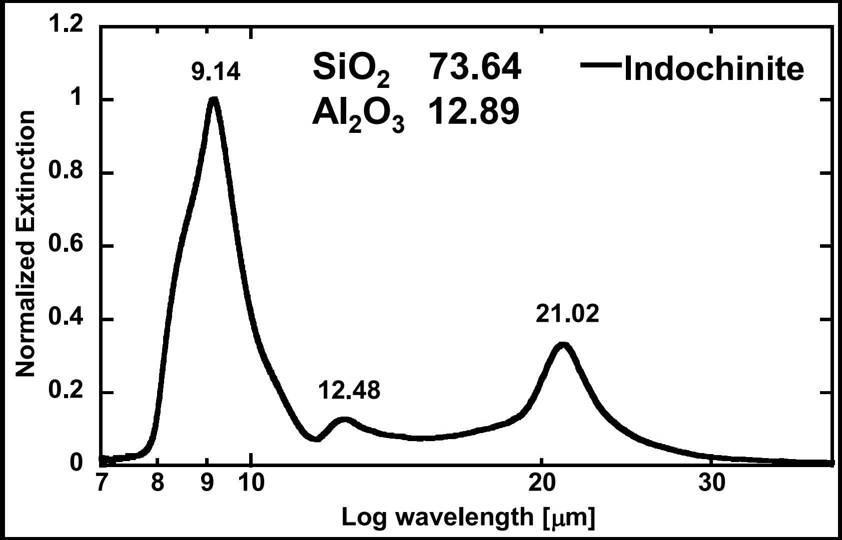


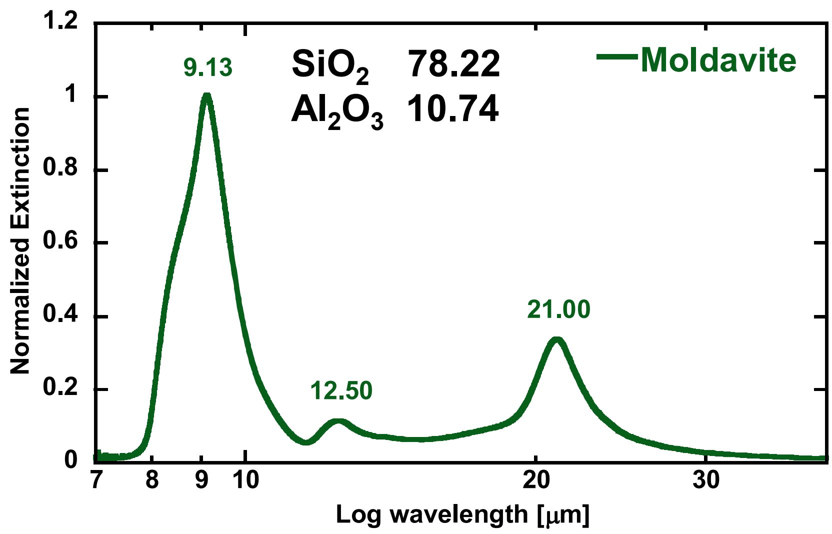


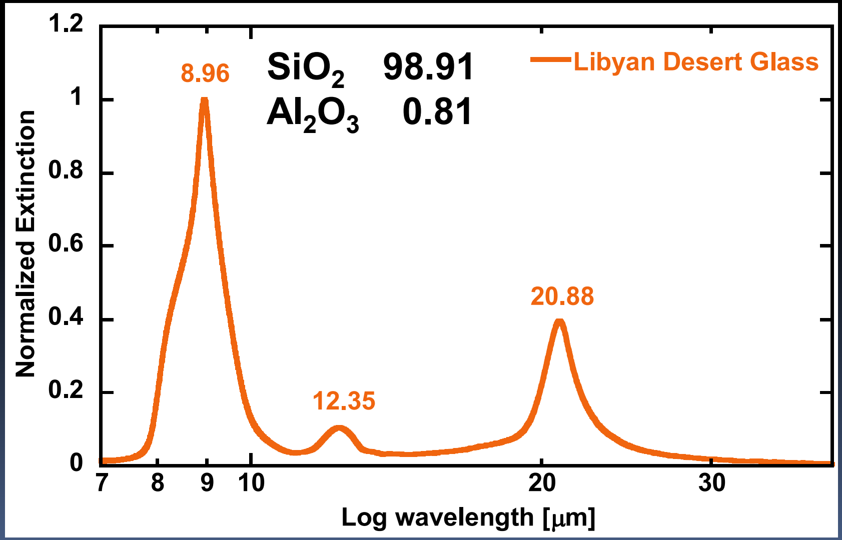


Result --- Amorphous SiO_2 ---



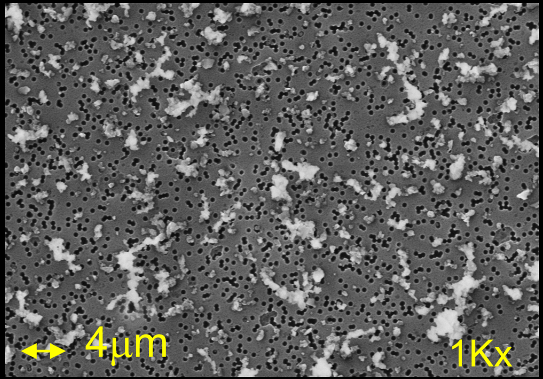




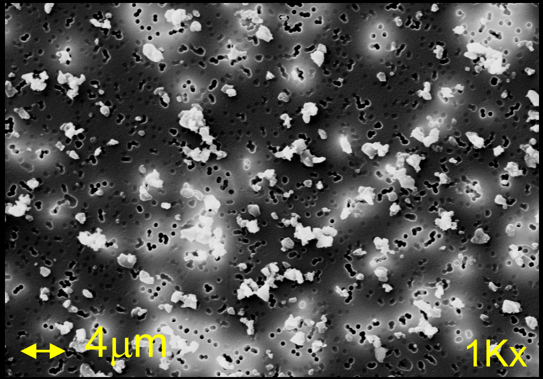


* SiO_2 ↑ , the peaks shift to the short wavelengths (Koike et al. 1987)

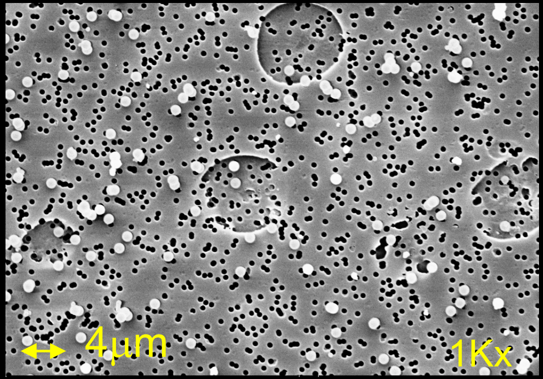
LDG - d5crush - d1_sphere



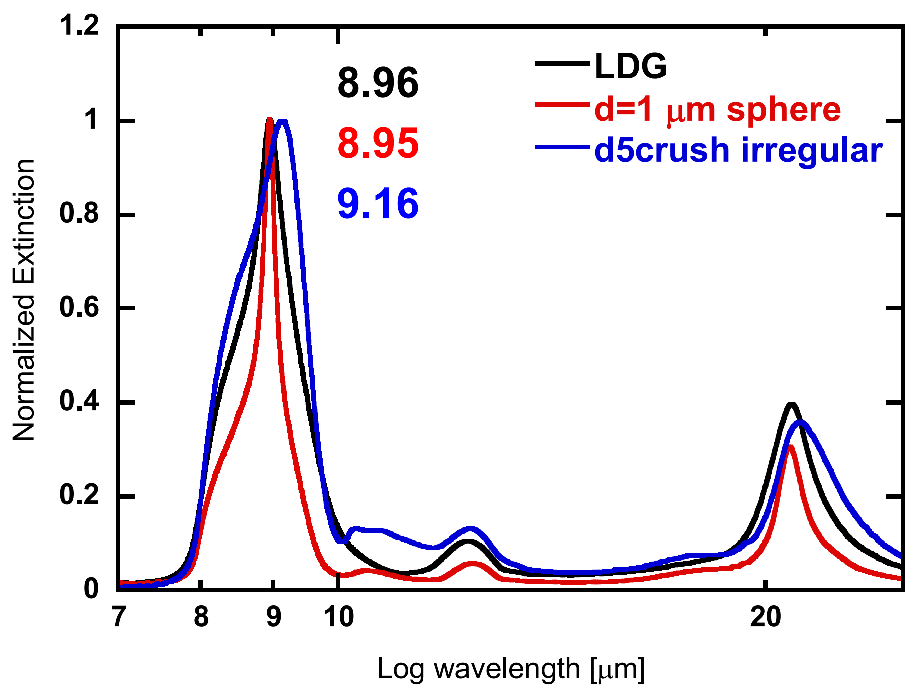
LDG



d5crush



d=1μm sphere



- LDG → the peak at short wavelength is due to very small sized particles (<0.5μm) cf. to d5crush ones
- d5crush → S.D. is narrower than LDG with a slightly larger size range
- d=1μm → The peak position was very much like the case of d=1μm (monosphere); however, a clear difference appears on the bandwidth due to the size distribution

Outlook

Investigate:

- Peak shift regarding the chemical compositions and different crystal structures (e.g. Moganite)
- Relationship between SiO_2 and pyroxene

Need:

- Condensation information
- More observational data with strong 9 μm feature