News in laboratory Astrophysics

Seminar talk for the guest seminar on the University of Vienna

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First: where I do my PhD

Jena, Germany

seit 1558

Großschwabhausen

University of Osaka

Content:

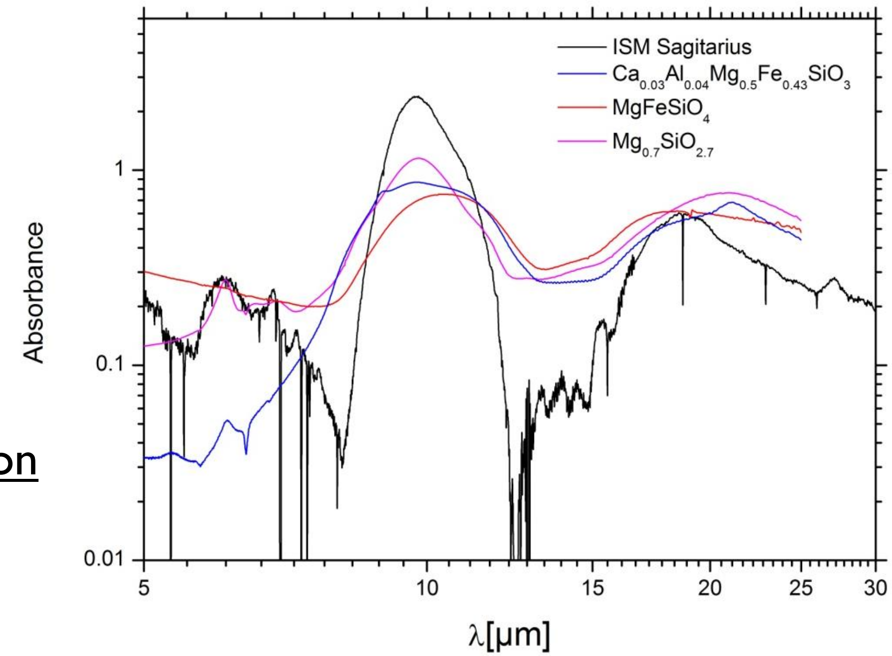
- motivation
  - aims of laboratory astrophysics
  - the “zoo” of cosmic dust
  - why (far) infrared spectroscopy of dust?
- low temperature spectroscopy on hydrous silicates
- crystallization experiments
- low temperature spectroscopy on amorphous silicates

motivation

aims of laboratory astrophysics:

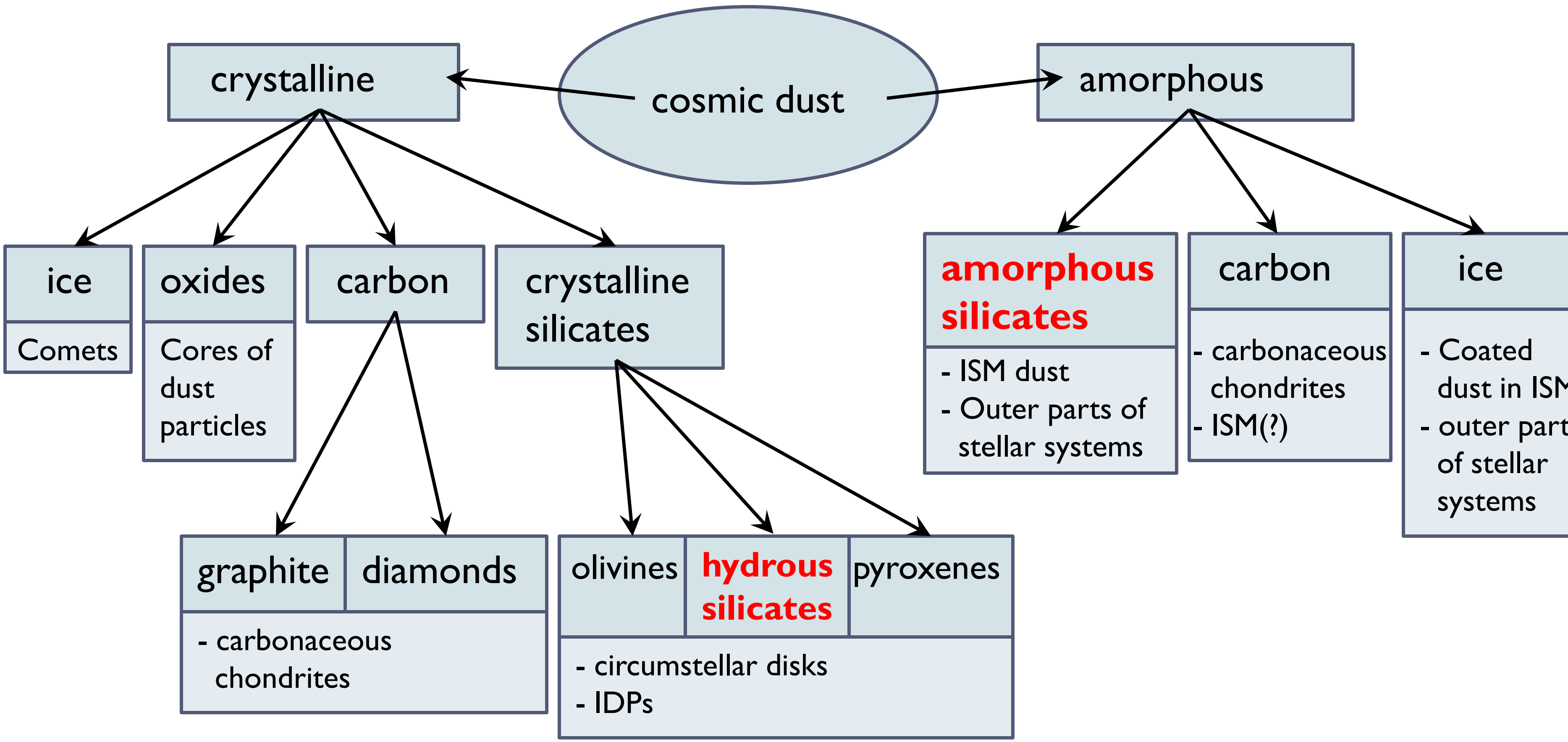
- developed to investigate solid phases in astrophysical environments
- Now: cosmic material science

- Material informations important for theory (creating models) and observation (knowledge about cosmic materials)



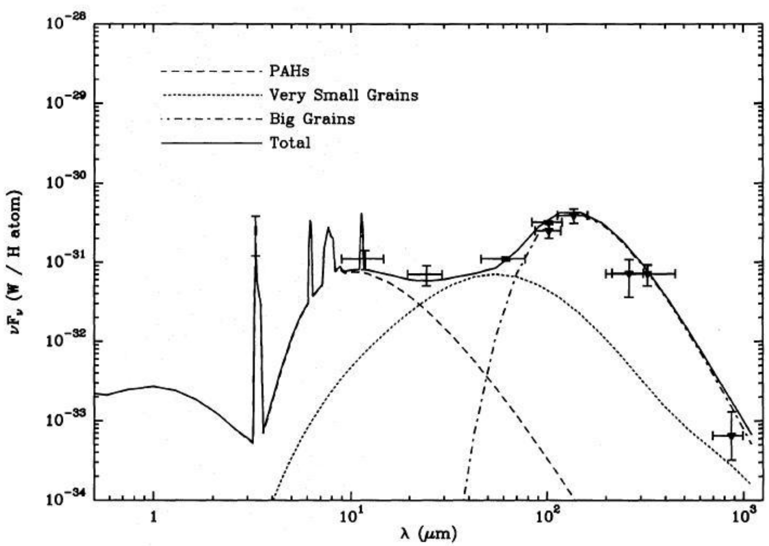
Issues: - absorption and emission spectra of dust, molecules and radicals
- "mineralogy" of dust
- reaction of molecules and ions in the gas phase and on grain surfaces
- interaction of dust with UV, ion radiation and heat, coursing structural changes
- properties of interplanetary dust, cometary and meteoritic grains
- aggregation, growth and destruction of grains, leading to planet formation

The "zoo" of cosmic dust:

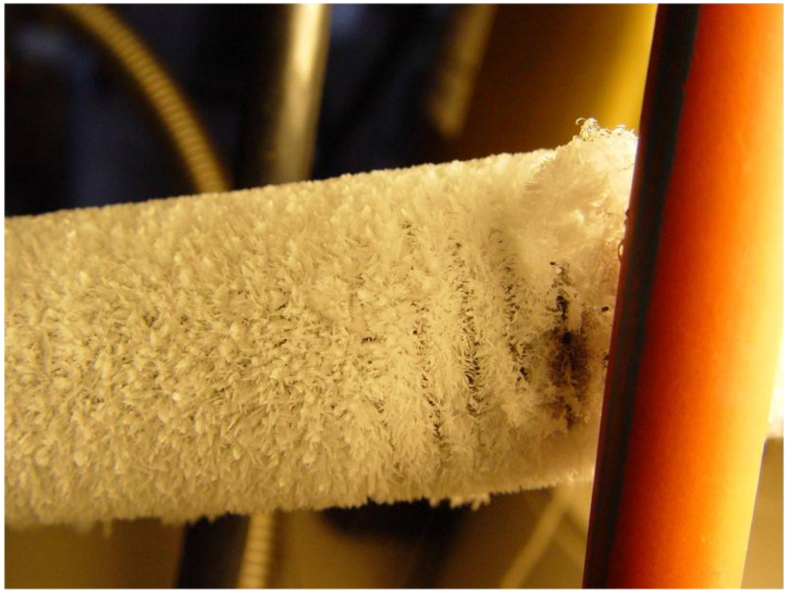


Why (far) infrared spectroscopy of dust?

- matter in space very cold: interstellar gas and dust clouds have temperatures 10-50K, cold components of dust disks around stars in average ~30-100K
- thermal emission maxima in FIR to sub-mm wavelength range
- many dust emission bands in FIR to sub-mm range have still unknown origin – investigations of FIR data of many kind of different materials are neccessary
- preparation work for project HERSCHEL, spectroscopy in range ~57-672µm

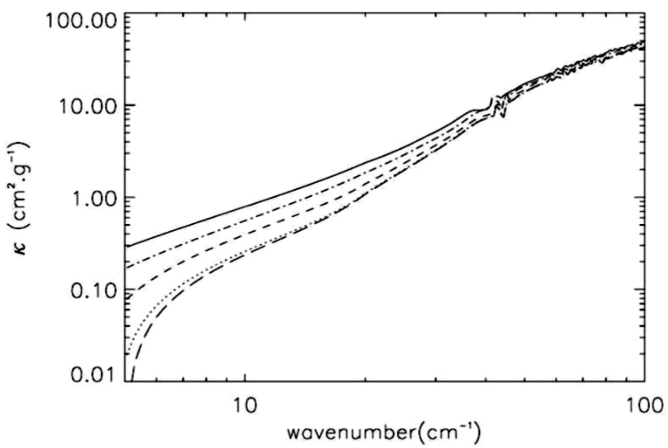


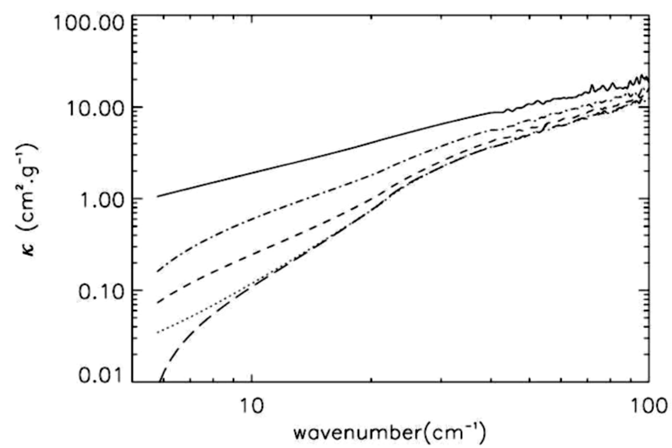
Low temperature spectroscopy on hydrous silicates



Why low temperature spectroscopy?

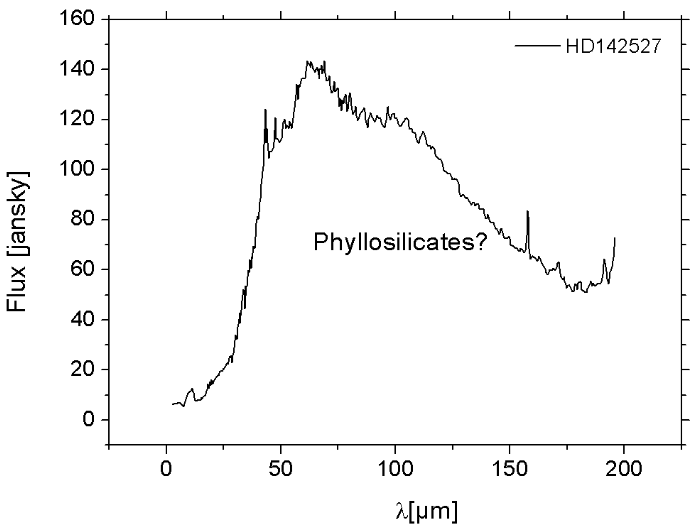
- absorption/emission behavior of crystalline matter depends on temperature (anharmonicity of the potential of binding of atoms in lattice)
- decreasing temperature – increasing energie of photons for activation of next vibrational state – band shift to shorter wavelength – band becomes narrower and more intense
- amorphous materials also show temperature dependencies in absorption (especially in FIR and mm wavelength range), Agladze et al. 1996, Menella et al. 1998, Boudet et al. 2005
- theory of absorption for amorphous materials very complicated





Why hydrous silicates?

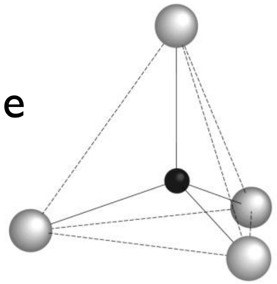
• silicates are the mean component of dust in space
• crystalline silicates only appear close to stars – developement of planetary systems
• evidences for hydrous silicates (phyllosilicates) in IDPs (interplanetary dust particles; Dorschner et al. 1978, Knacke et al. 1980, Sandford et al. 1985)
• became popular for astrophysics as a possible water reservoir in space
• due to investigations of Prof. Koike on hydrous silicates, K. Malfait proposed their existence also in protoplanetary disks (Koike et al 1982, Malfait et al 1999)



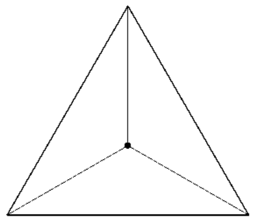
• presence of hydrous silicates in protoplanetary disks would be an important information on disk development

I. basics

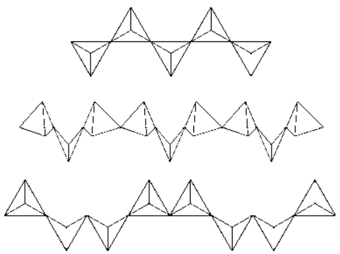
- basic units of all silicates are $[SiO_4]^{4-}$ -tetrahedra
- one oxygen atom can be a part of another tetrahedron at the same time
- huge amount of different structures can be built



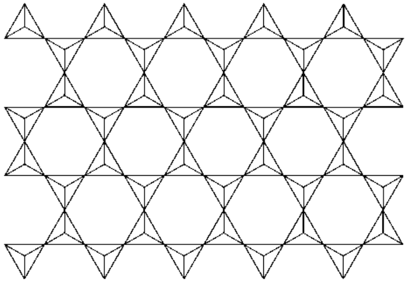
- isolated tetraedra (olivines), chains (pyroxenes), layers (phyllosilicates), …



isolated



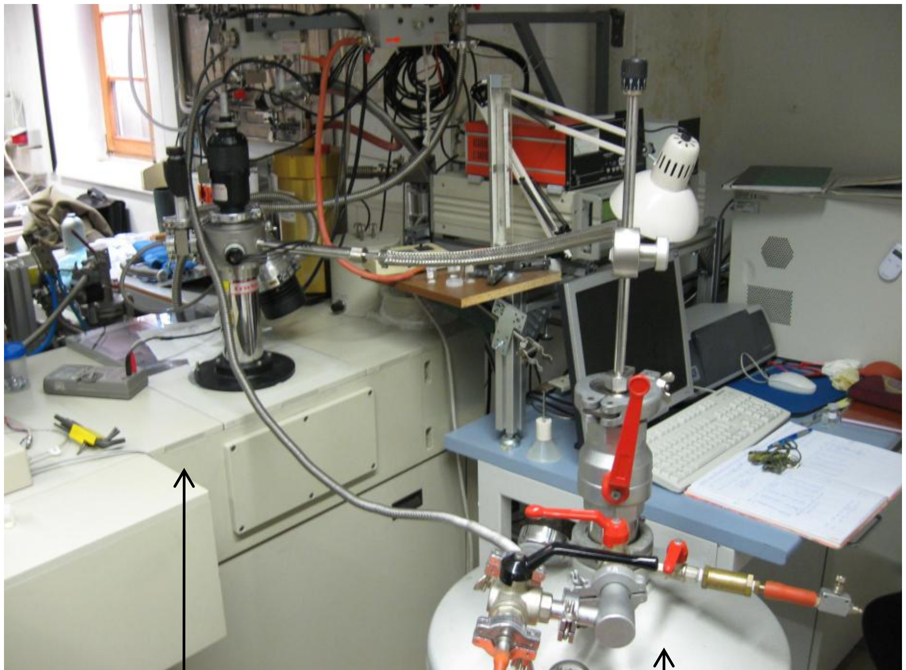
chains

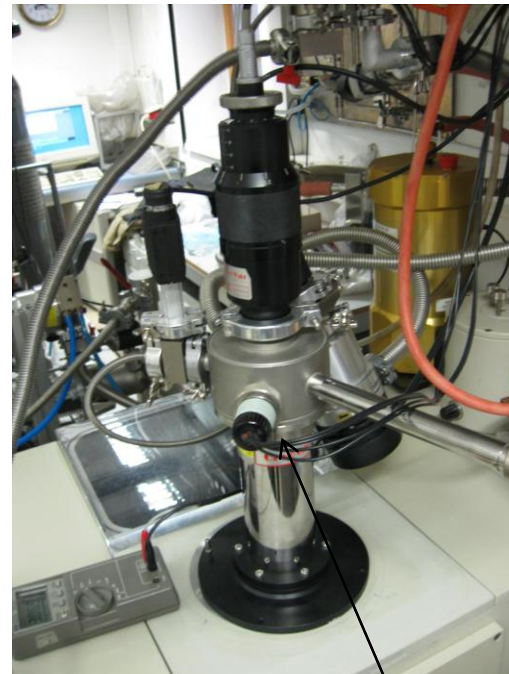


layers

<u>Phyllosilicates:</u> 3 oxygen atoms of one tetrahedron are a part of other tetrahedra in one layer – built up layerwise, between the layer: metal cations (K^+, Na^+, Ca^{2+}, Al^{3+}), OH^- and H_2O

I. experiment





Helium tube

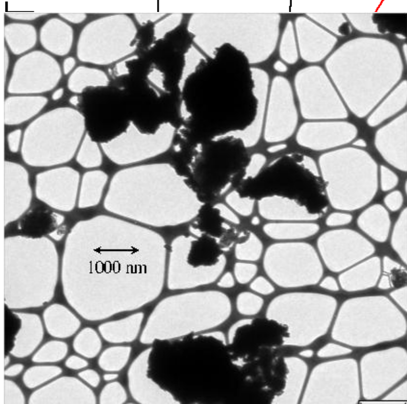
Infrared spectrometer

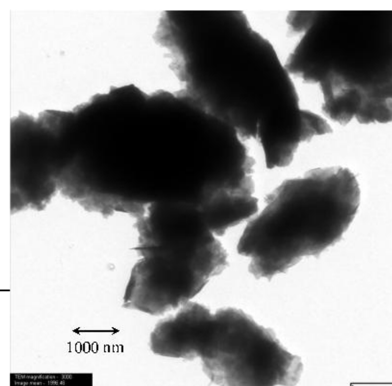
Liquid helium tank

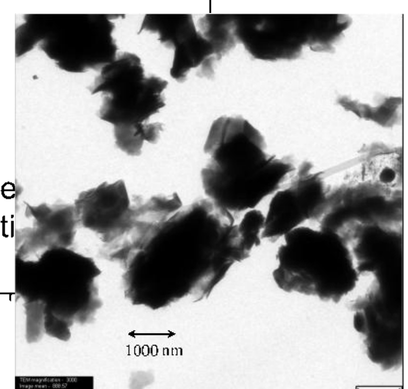
Cryostat

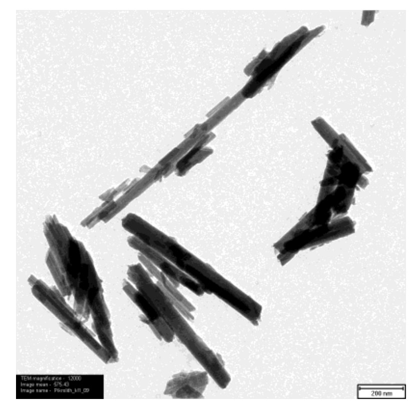
- measurements taken at 300, 200, 100, and 10K
- Sample preparation: grinding in a mortar and/or ball mill and sedimentation in acetone to grain sizes <5µm

Phyllosilicate	Formula	group
Chamosite	$Fe_{3,55}Al_{1,88}[(Al,Si_3)O_{10}(OH)_8]$	Chlorite
Talc	$Mg_{3,33}Fe_{0,1}[Si_4O_{10}(OH)_2]$	Talc-Pyrophyllite
Montmorillonite	$Al_{1,5}Mg_{0,25}Fe_{0,17}[Si_4O_{10}(OH)_2](Na,K) \cdot 1,2\ H_2O$	Clay
Picrolite	$Mg_{5,84}Fe_{0,17}[Si_4O_{10}(OH)_8]$	Serpentine





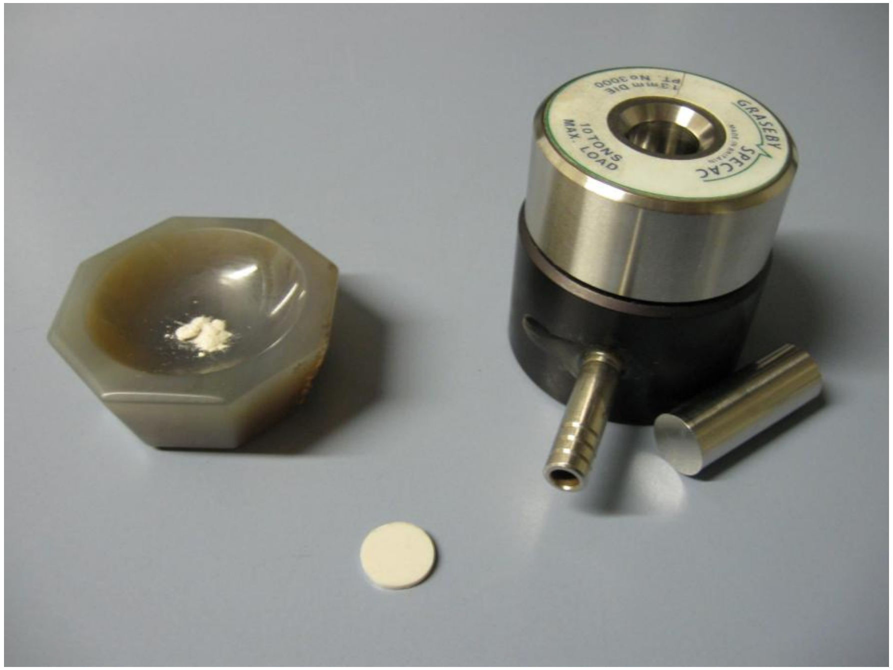




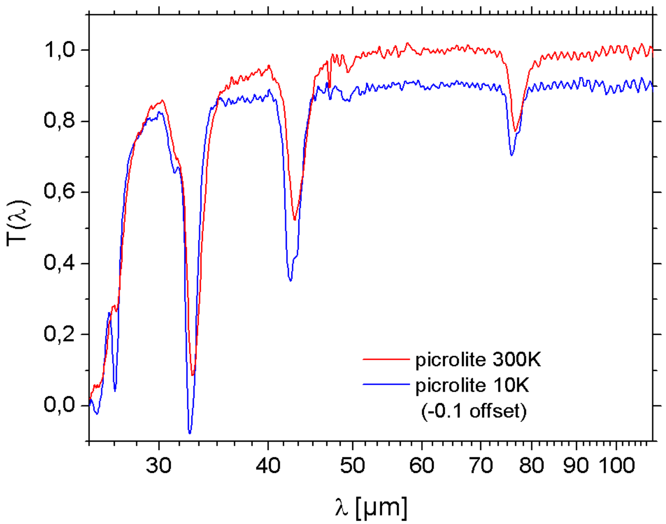
• all samples are pressed to polyethylene pellets (200mg, diameter: 13mm)

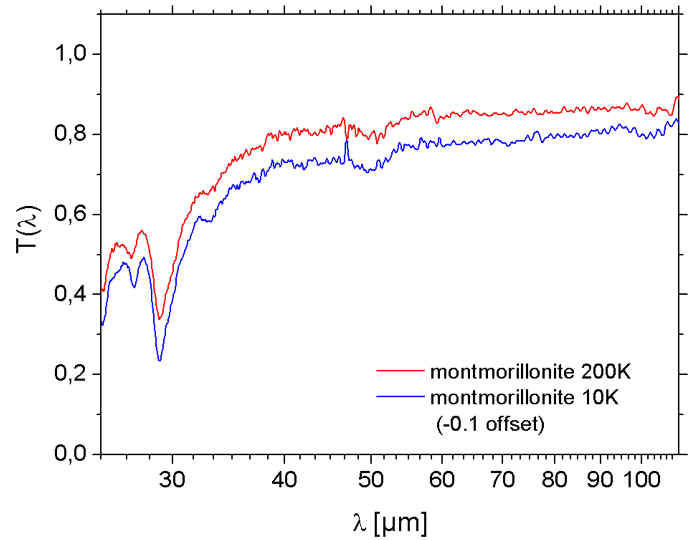
embedding ratios (sample vs. PE)

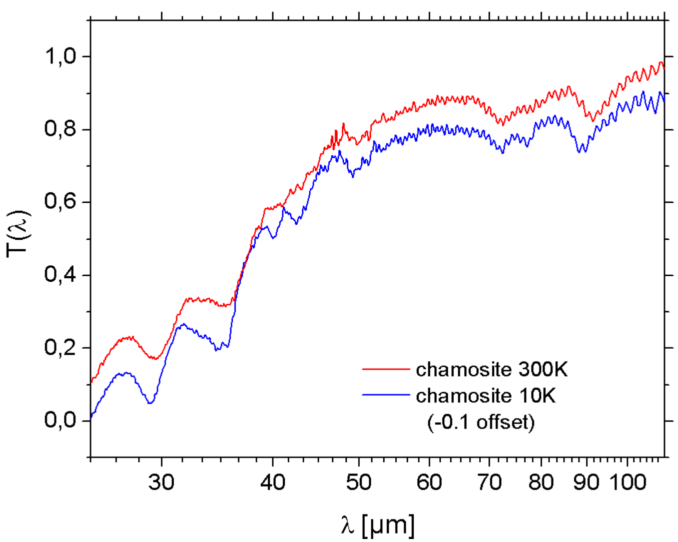
	17-67µm	67-200µm	200-600µm
Phyllosilicates	1:100	1:100/1:10	1:10

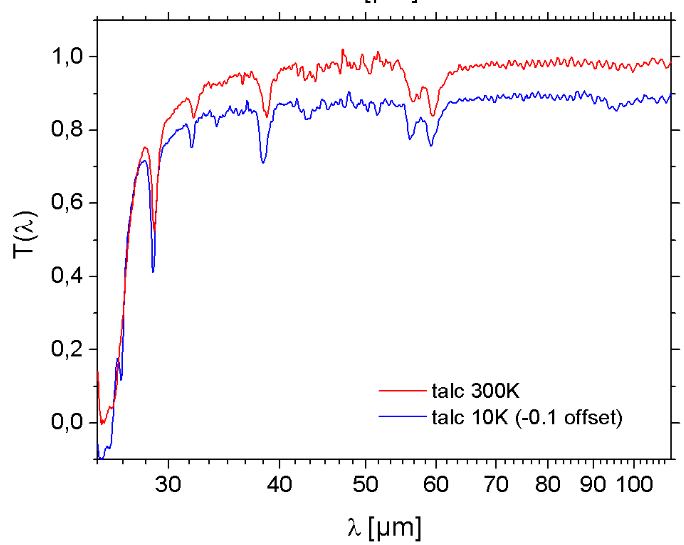


I. main results



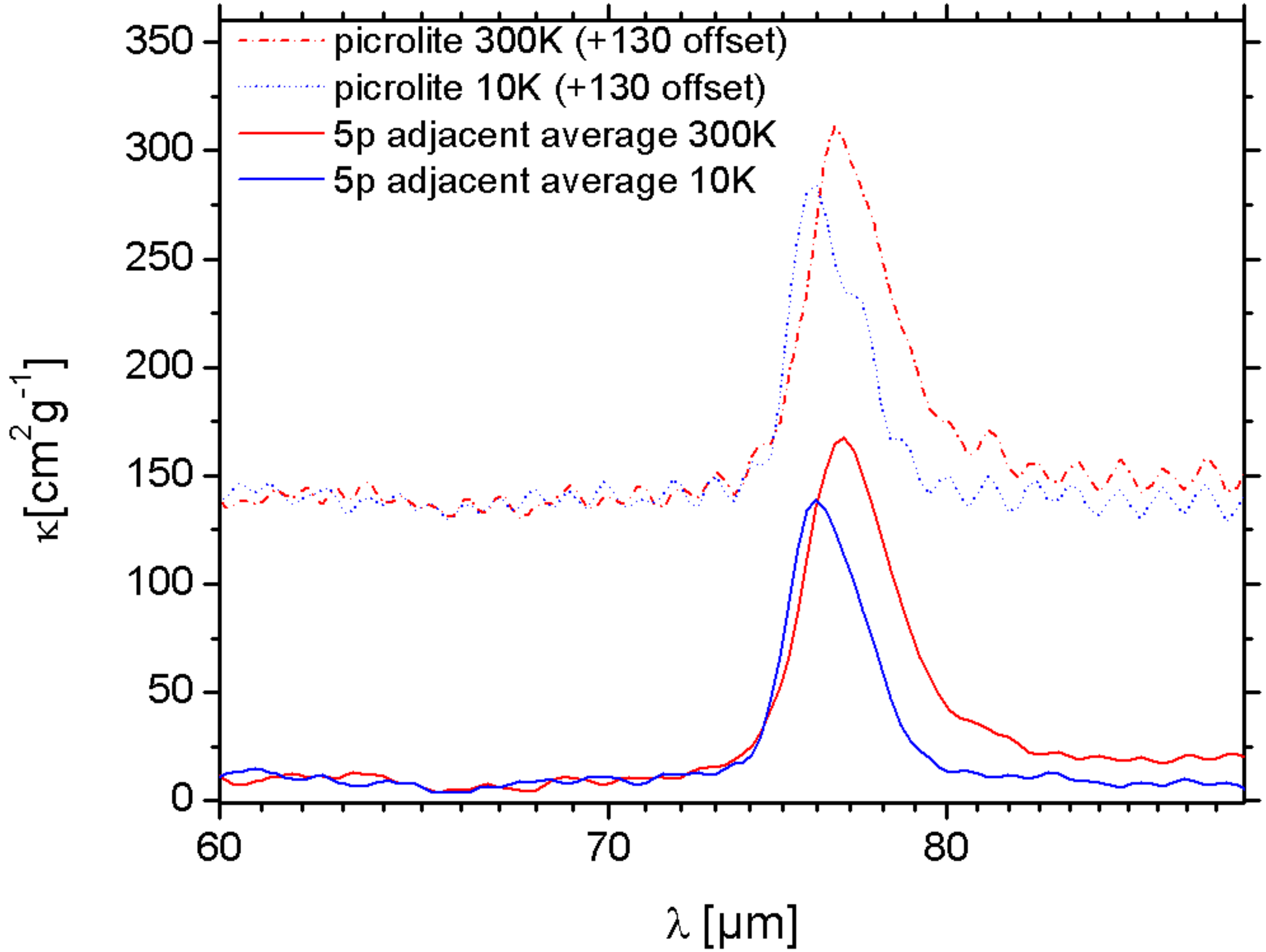




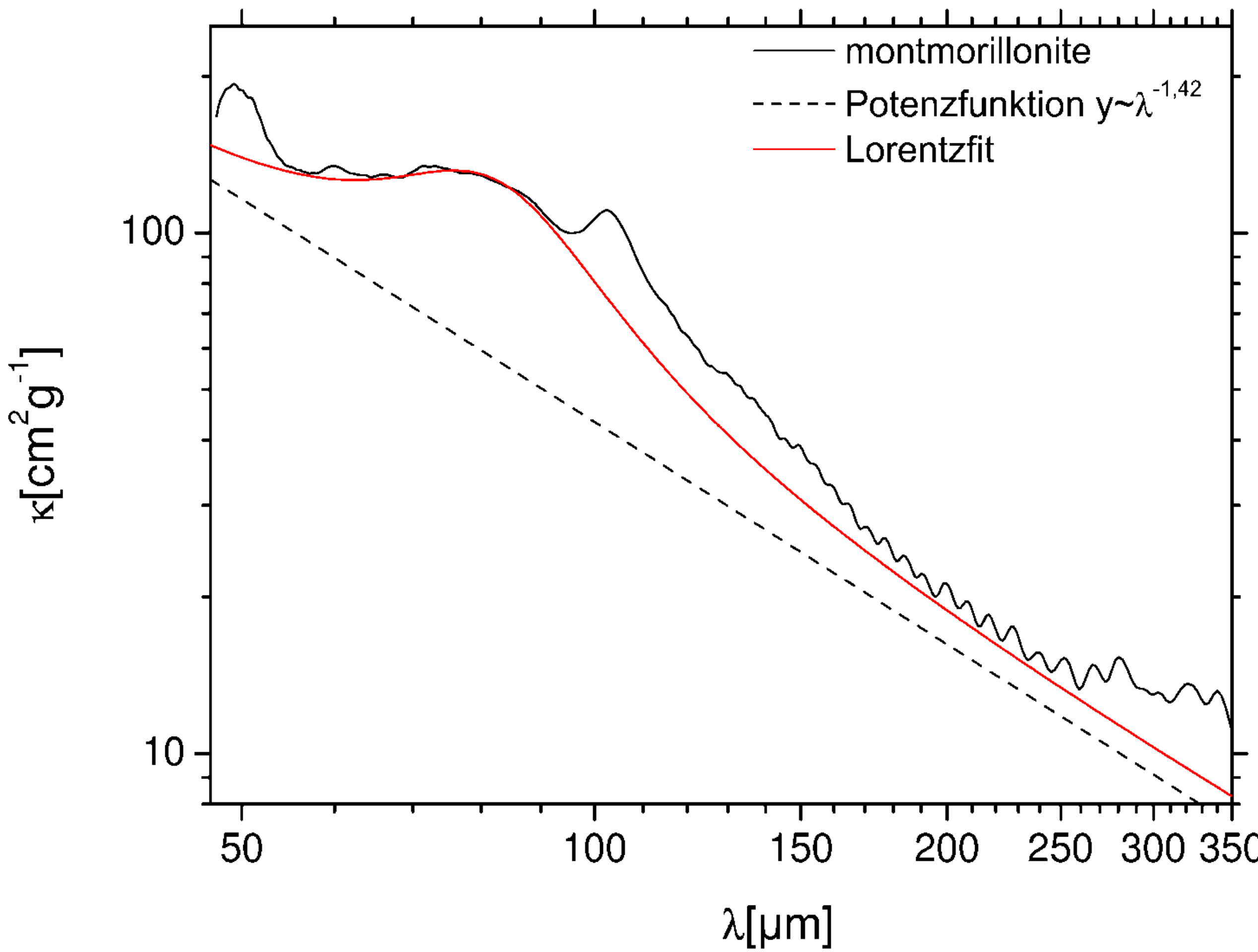


$$\kappa = -\frac{1.327cm^2}{m_{emb}} \cdot \ln(T)$$

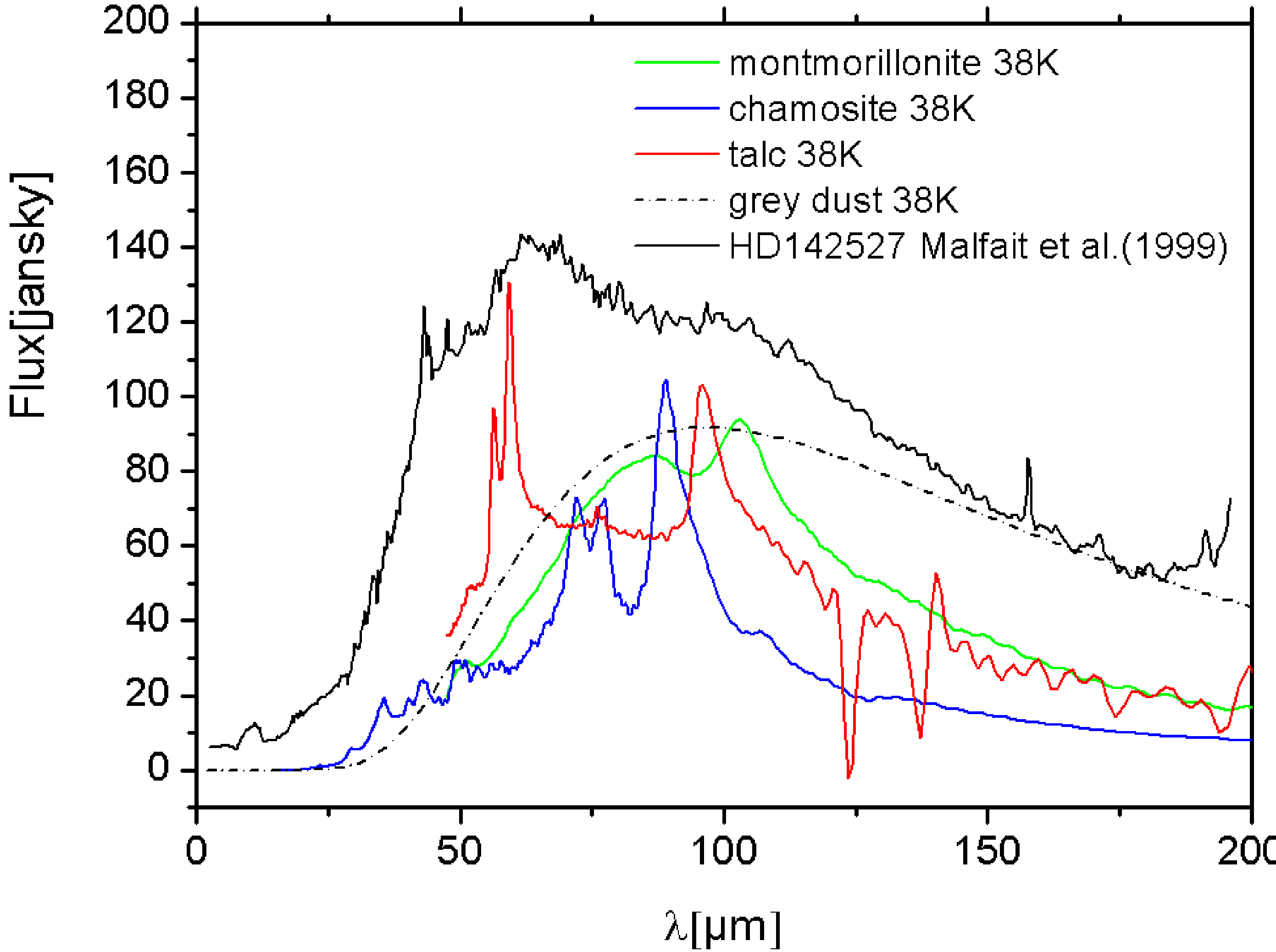
- fringes are suppressed by averaging adjacent data points



- weak bands become stronger and sharper
- some bands show nearly no change
- hidden bands can be discovered
- different absorption behavior of the background – very broad band around 80µm?



Comparison with Malfait data:



From:

H. Mutschke and S. Zeidler et al.; A&A 2008

I. Summary on hydrous silicates

- we discovered a previously unknown band for talc at 98.5µm at room temperature (RT) and several „hidden“ bands in the montmorillonite spectrum at 60(RT), 66(10K) and 86µm (RT)

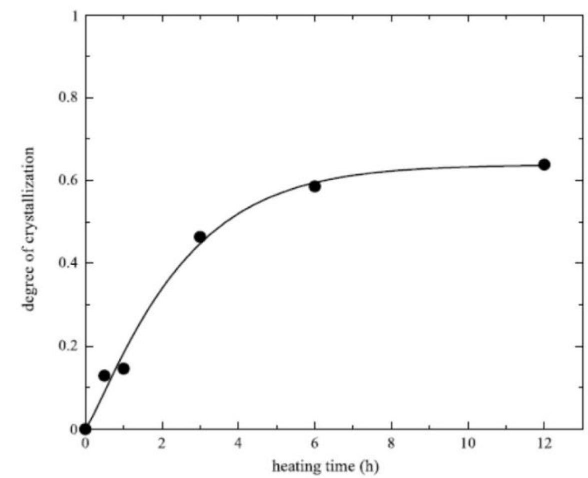
- most bands shift to smaller wavelengths by decreasing the temperature due to anharmonicity of the vibrational potential and thermal distribution of populated states

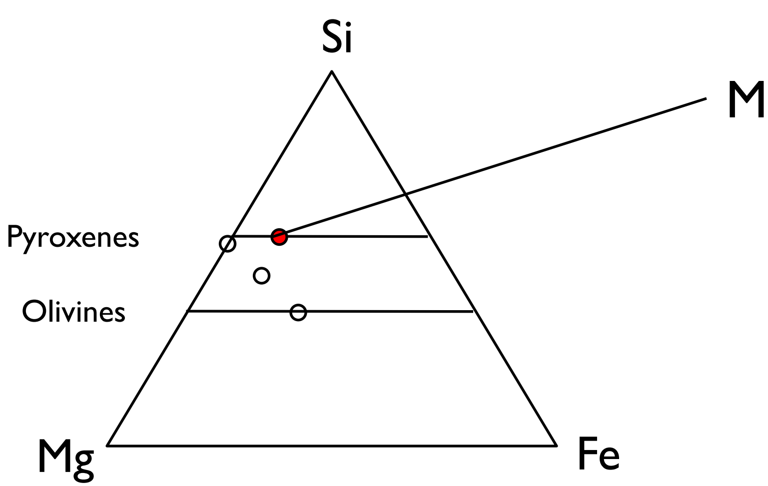
- we can not confirm the existence of phyllosilicates outside our planetary system yet, since:
  - spectra of extrasolar dust disks too indefinite → amount of phyllosilicates probably too small for a detection (maybe HERSCHEL can help)
  - depending on various parameters, the shape of the lab-spectra can be influenced (size, grain shape,…)

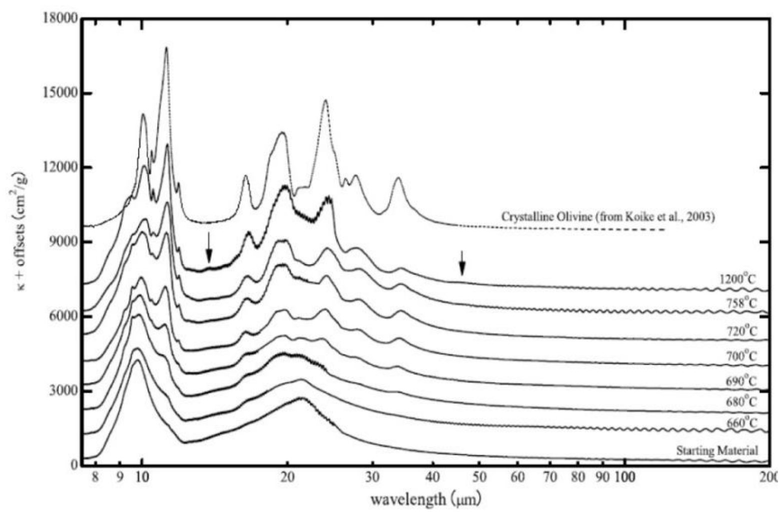
Crystallization Experiments

II. basics

- What happens to the amorphous dust grains when they‘re heated up? (dust close to stars)
- In principle they become crystalline but how do the processes depends on the composition of the amorphous precoursers and the environment?

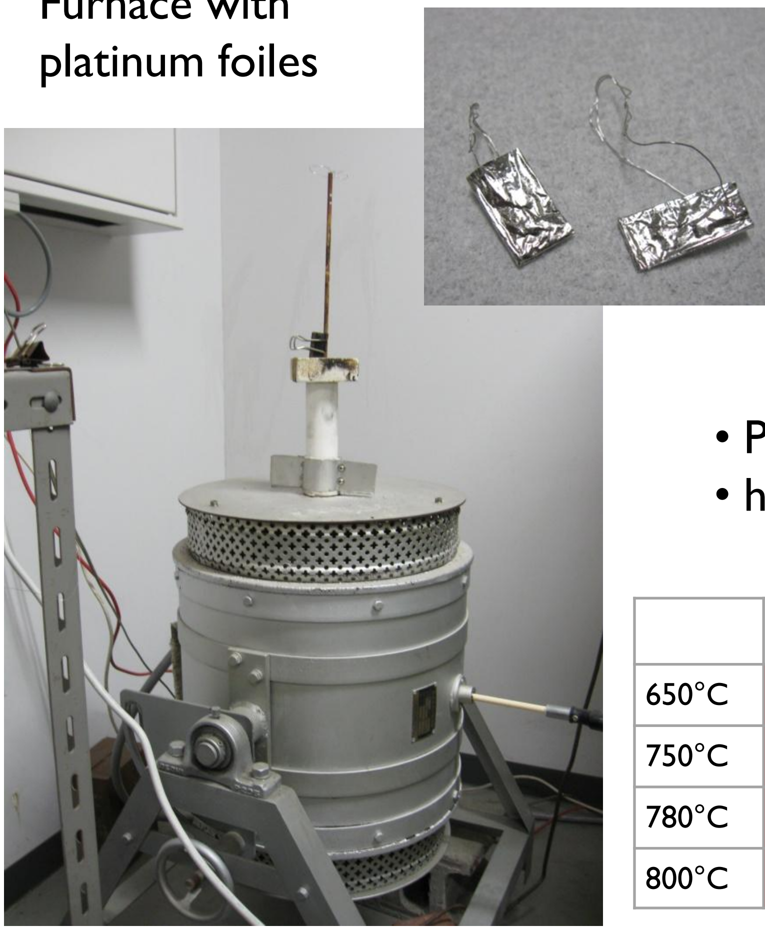






II. experiment

Furnace with platinum foiles



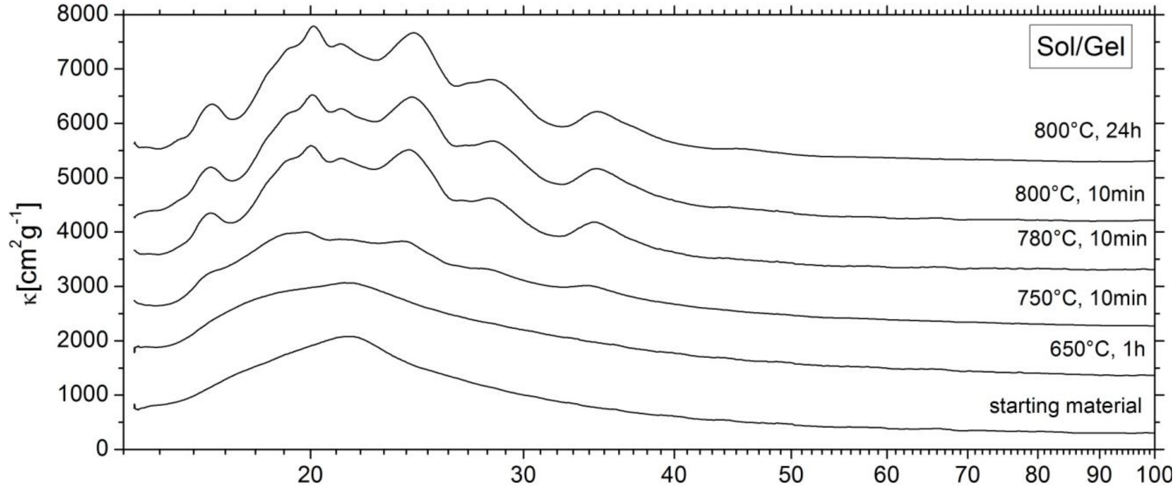
Sol/Gel

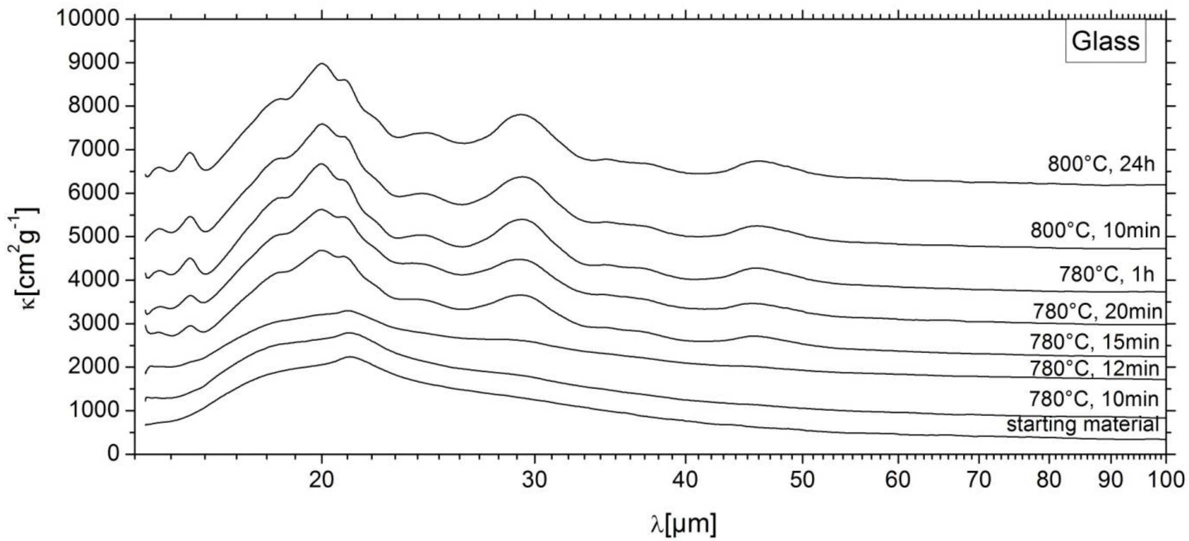
glass

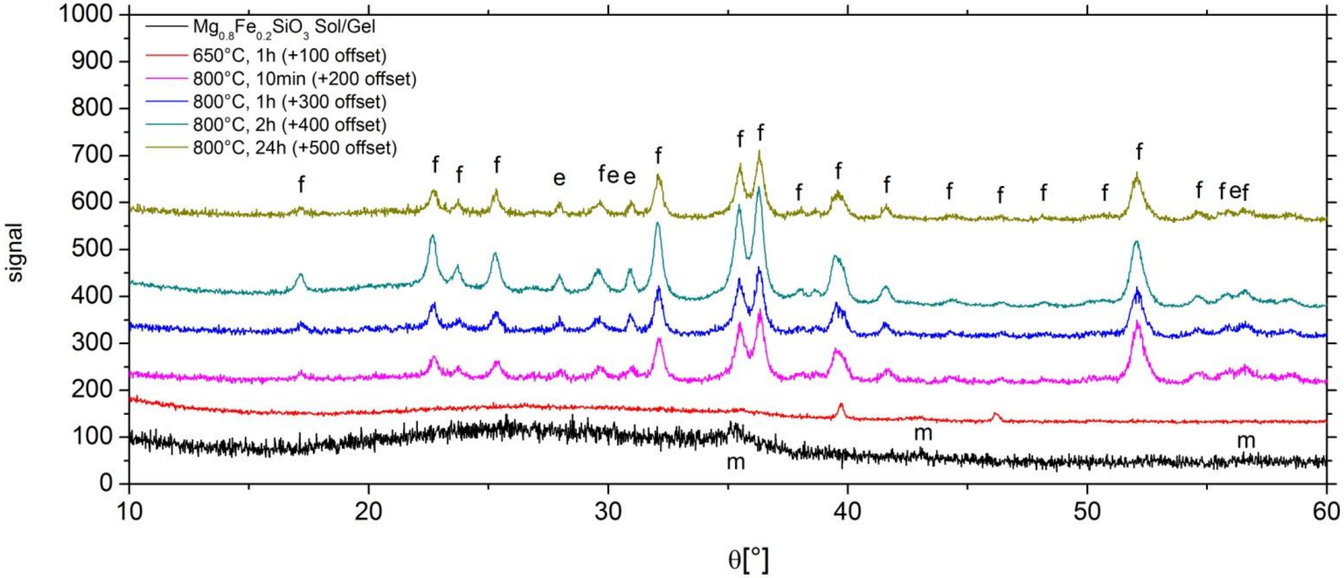
- Precursor materials in platinum foiles
- heated at temperatures and durations:

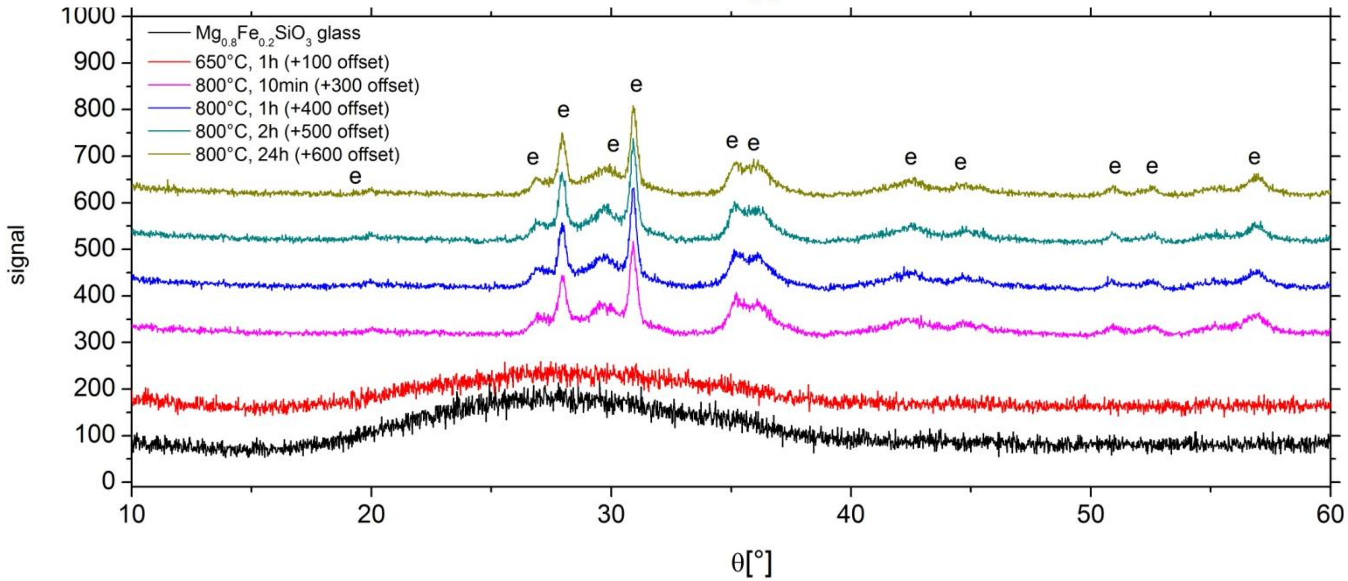
	10min	12min	15min	20min	1h	2h	24h
650°C	glass only			glass only			
750°C	Sol/Gel only		Sol/Gel only				
780°C		glass only	glass only	glass only	glass only		
800°C							

II. main results









X-ray Diffraction results

e – Enstatite (Pyroxene)

f – Forsterite (Olivine)

II. summary and outlook on crystallization experiments

- Different crystallization behavior from Sol/Gel and glass material with the same composition: ($Mg_{0.8}Fe_{0.2}SiO_3$) :
  - crystallization appears at ~750°C (Sol/Gel) and ~785°C (glass), respectively (duration: 10 min)
  - resulting crystalline material differs depending on the precursor material:

    Sol/Gel → Olivine
    glass → Pyroxene

- have to continue the experiments with more materials of different compositions

- calculation of crystallization degree from the obtained data

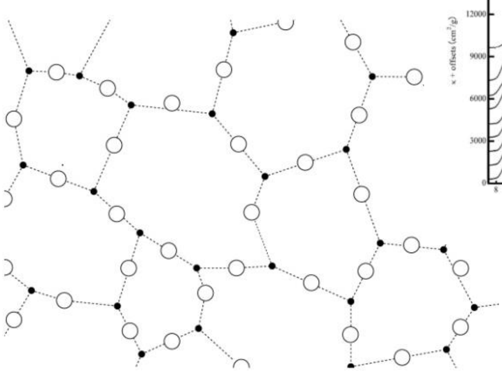
Many Thanks to:

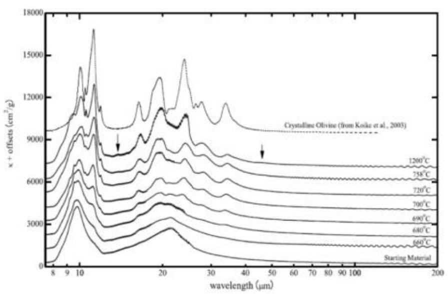
- Hiroki Chihara
- Prof. Chioye Koike
- Prof. Akira Tsuchiyama

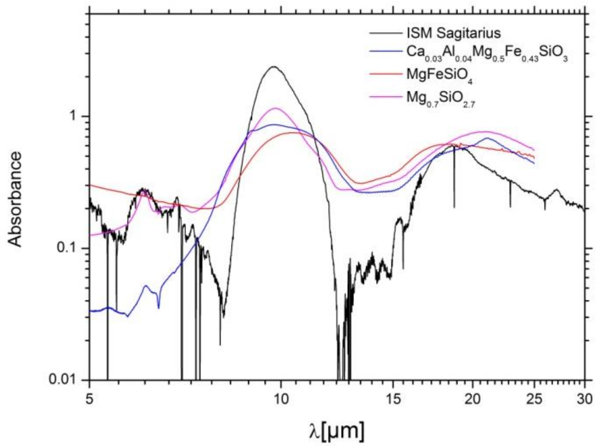
Low temperature spectroscopy on amorphous silicates

III. amorphous silicates: *basics*

- no periodic order of the tetrahedra (only statistical arrangements)
- only broad IR bands
- rare on earth
- main component of interstellar matter (especially amorphous magnesium silicates with unknown iron content)
- in FIR evidences for temperature dependences of the continuum absorption (Boudet et al. 2005) measured for SiO_2 and some Mg-silicates
- question of inner composition (relation of Mg to Fe) and its influence on the FIR to sub-mm spectra







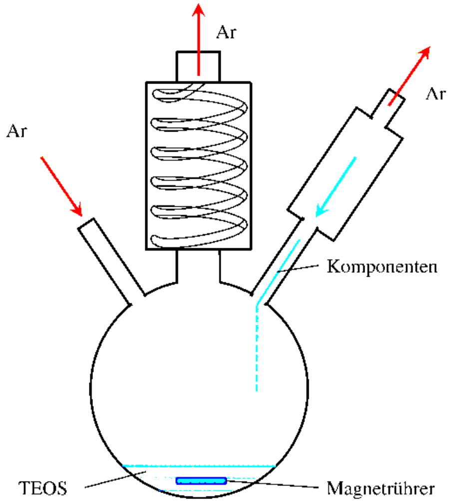
III. experiment

embedding ratios and list of measured samples:

	17-67µm	67-200µm	200-2000µm
Amorphous silicates	-	-	8:1 (400mg pellets)

Amorphous Silicate	Formula	Structure
Magnesium silicate S/G	Mg_2SiO_4	Amorph
Magnesium silicate S/G	$Mg_{1.5}SiO_{3.5}$	Amorph
Magnesium silicate S/G	$Mg_{0.7}SiO_{2.7}$	Amorph
Mg-Fe silicate melting	$Ca_{0.03}Al_{0.04}Mg_{0.5}Fe_{0.43}SiO_3$	Glassy
Mg-Fe silicate melting	$Mg_{0.5}Fe_{0.5}SiO_3$	Glassy
Mg-Fe silicate melting	$Mg_{0.8}Fe_{0.2}SiO_3$	Glassy
Mg-Fe silicate melting	$Mg_{0.95}Fe_{0.05}SiO_3$	Glassy

Sol-Gel process:



Principle built up

Drying process

$$Si(C_2H_5O) + xMg(OCH_3)_2 + (2+x)H_2O \overset{H_2O_2}{\rightleftarrows} Mg_xSiO_{2+x} + 4C_2H_5OH + 2xCH_3OH$$

melting process:

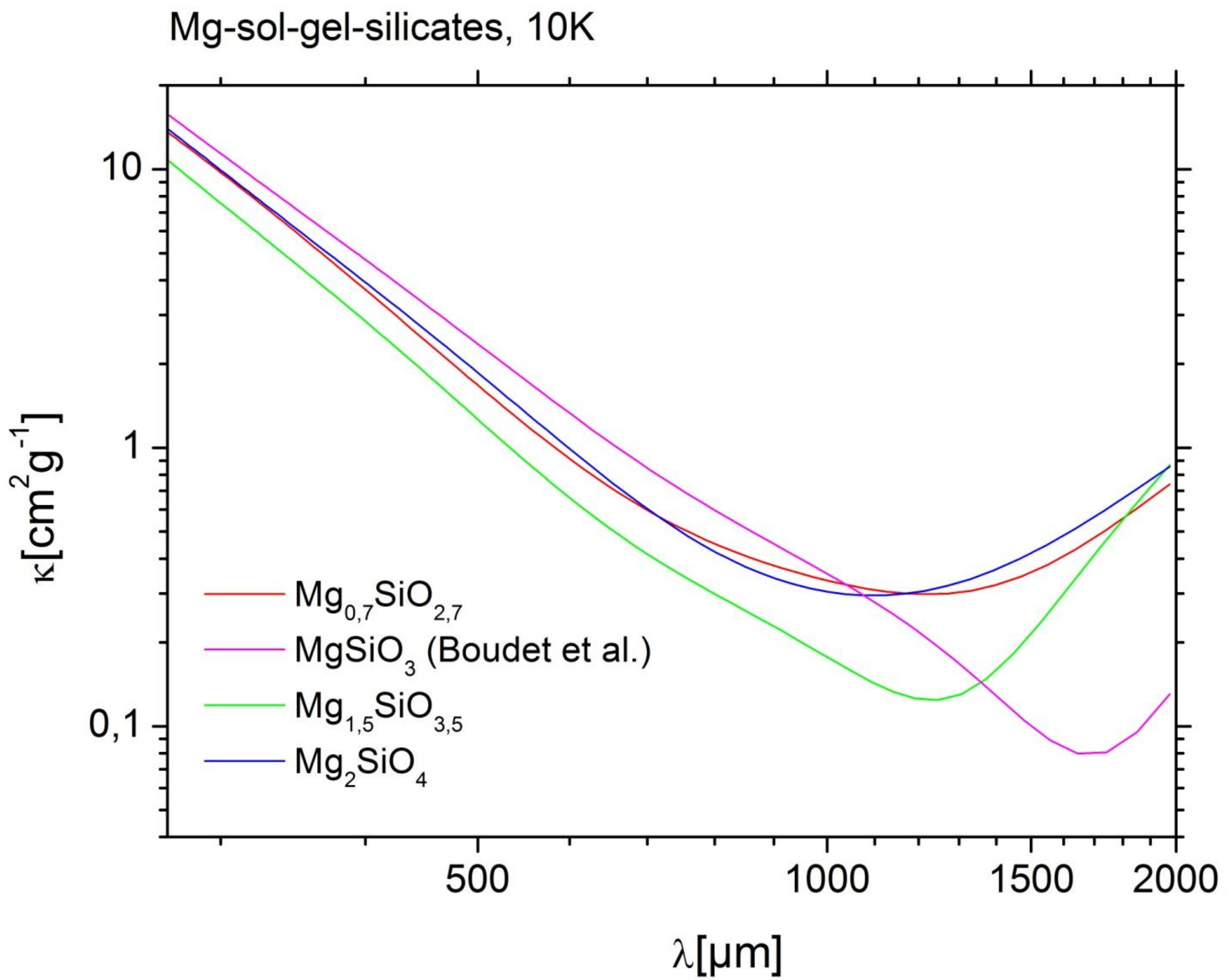
High temperature oven
1600°C, 1h

Iron oxalate, SiO_2, Magnesium-carbonate

Glassy Fe-Mg-silicate

III. main results

- Minima in all spectra around 1000-1500µm
- shift of the Minima to shorter wavelength with decreasing temperature - Band?
- decreasing absorption for Sol-Gel samples until $Mg_{1.5}SiO_{3.5}$, afterwards increasing absorption again



III. Summary on amorphous silicates

- general decrease of absorption with decreasing temperature

- unexpected behavior for all amorphous materials: distinct minima around 1000-1500µm – shift to shorter wavelength with decreasing temperature; but probably just a calculation error of the FTIR spectrometer

- for Sol-Gel samples: decreasing absorption with increasing Mg-content up to $Mg_{1.5}SiO_{3.5}$; after that, increasing absorption again

- for meltings: - general decrease of absorption with increasing Mg-content
  - by reaching a specific Mg-Fe ratio in glassy Mg-Fe silicates almost no change in absorbance any more (for 10K spectra all Mg-Fe-meltings even show the same absorption up to 400µm)

General outlook and acknowledgement

- confirmation of absorption behavior of amorphous materials with independent measurements (at other institutes, with other devices,…)

- investigation of correlation with amophous structure (how is the amorphous structure influencing the absorption of the silicates with varying Mg-content)

- comparison with astronomical spectra in the FIR (i.e. data from HERSCHEL)

- Further extension of wavelength range is ongoing:
  - spectroscopy of all measured amorphous silicates at wavelengths >2mm
  - continue low temperature measurements also at wavelengths >2mm

Many Thanks to:
- Harald Mutschke
- Thomas Posch
- Gabriele Born
- Walther Teuschel

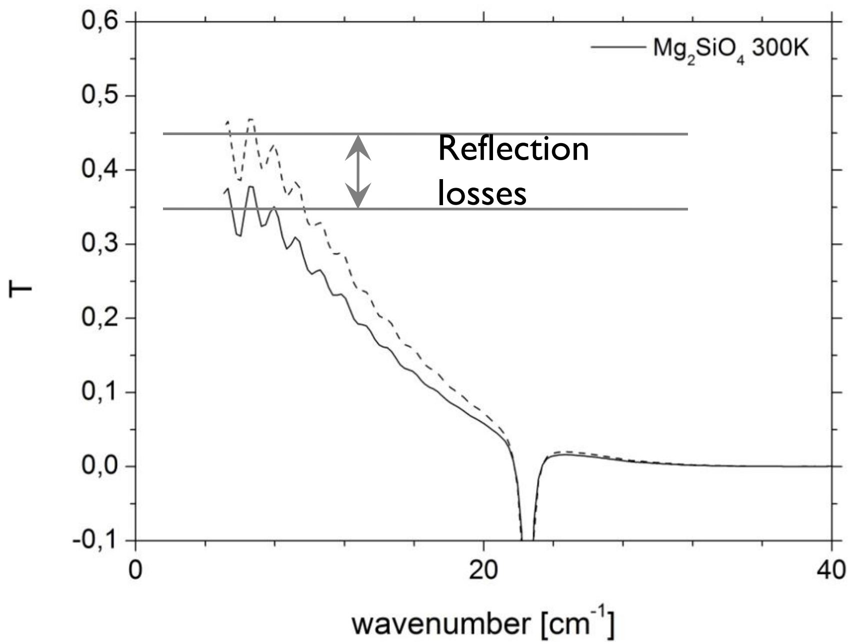
Thank you for your attention

III. main results

- due to high embedding ratio average dielectric constant of pellets very high – high reflectivity – need for correction factor
- Bruggemann model of effective-media-theory

$$R = \left(\frac{n_{eff} - 1}{n_{eff} + 1} \right)^2$$

$$n_{eff} = f\,(n_{\mathrm{sample}}, n_{\mathrm{PE}}, \mathrm{porosity})$$

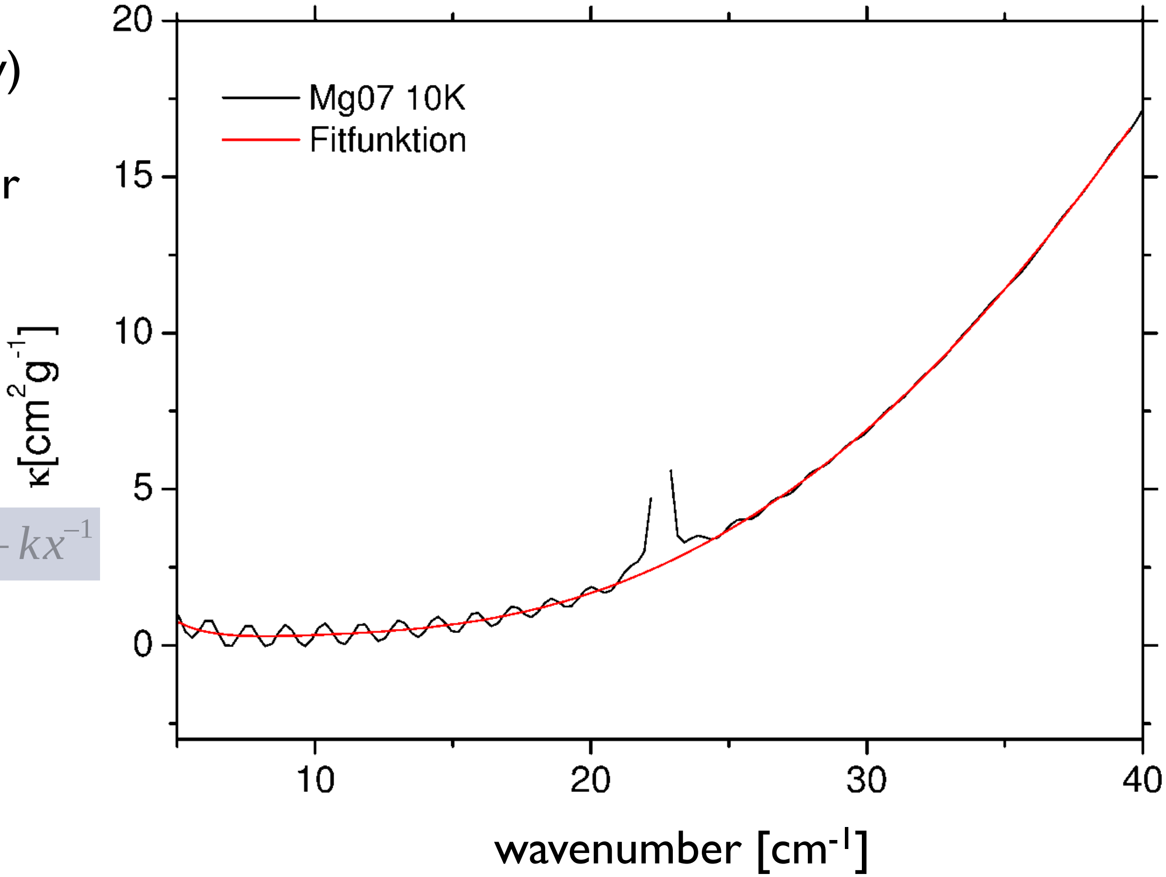


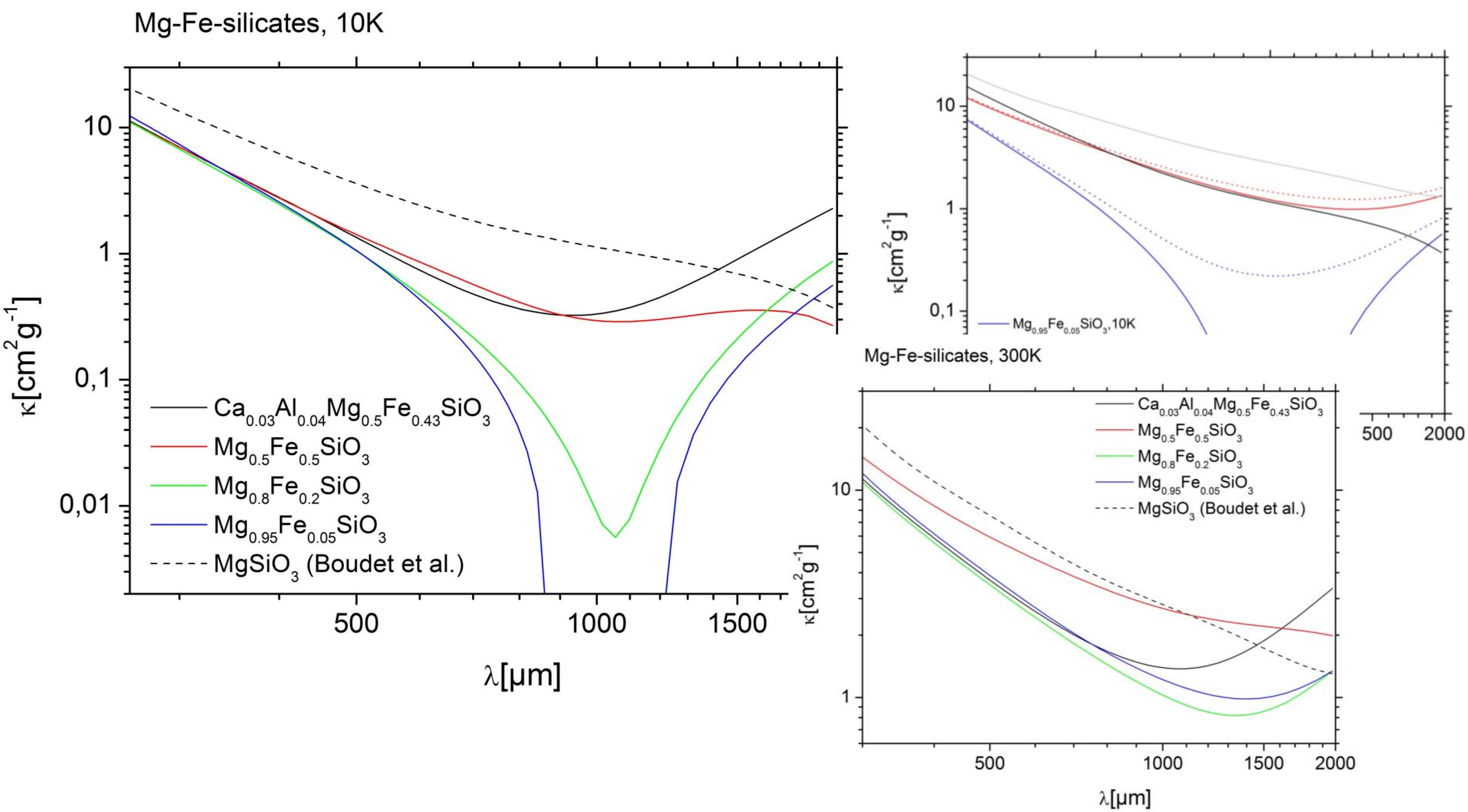
$$\kappa = -\frac{1.327cm^2}{m_{emb}} \cdot \ln\left(\frac{T}{(1-R)^2} \right)$$

- strong noise (minima in intensity) at 22,5cm^{-1} (444,5µm) in all spectra due to used Beamsplitter (125µm Mylar)

- fitting curve:

$$ax^6 + bx^5 + cx^4 + dx^3 + fx^2 + gx + h + kx^{-1}$$




Mg-Fe-silicates, 10K
κ[cm^{2}g^{-1}]
λ[μm]
$Ca_{0.03}Al_{0.04}Mg_{0.5}Fe_{0.43}SiO_3$
$Mg_{0.5}Fe_{0.5}SiO_3$
$Mg_{0.8}Fe_{0.2}SiO_3$
$Mg_{0.95}Fe_{0.05}SiO_3$
$MgSiO_3$ (Boudet et al.)
$Mg_{0.95}Fe_{0.05}SiO_3$,10K
Mg-Fe-silicates, 300K

- newest measurements between 2.5 and 4 mm from Cologne don‘t show any kind of Maxima
- By fitting the new results with the old data the Minima can be completly removed
- Minima probably a result of a calculation error of the used FTIR-spectrometer