Far-infrared properties of phyllosilicates & carbonates

Lorentz Center Leiden, 3.3.2011
Workshop „Herschel and the Characteristics of Dust in Galaxies"

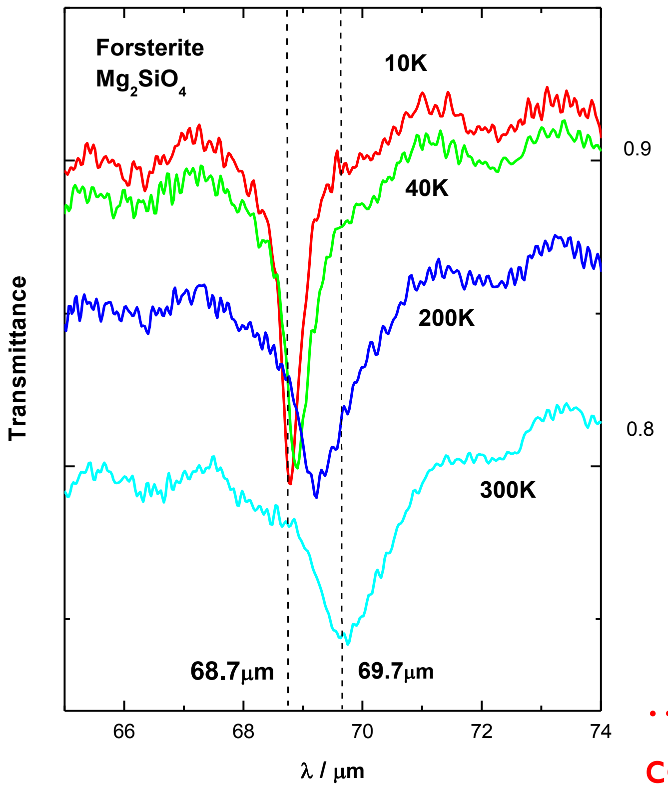
Thomas Posch *, Simon Zeidler ** & Harald Mutschke **

* Astronomy Department, Universität Wien (Vienna)

**Astrophysical Institute, (AIU), Friedrich-Schiller-Universität Jena

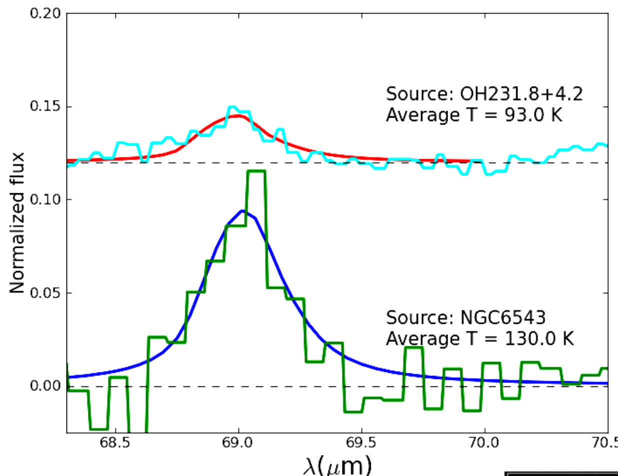
What I would wish to show you:

Interesting FIR lab spectra…



Mutschke et al. 2005

…compared to nice new spectra…



De Vries et al. 2011

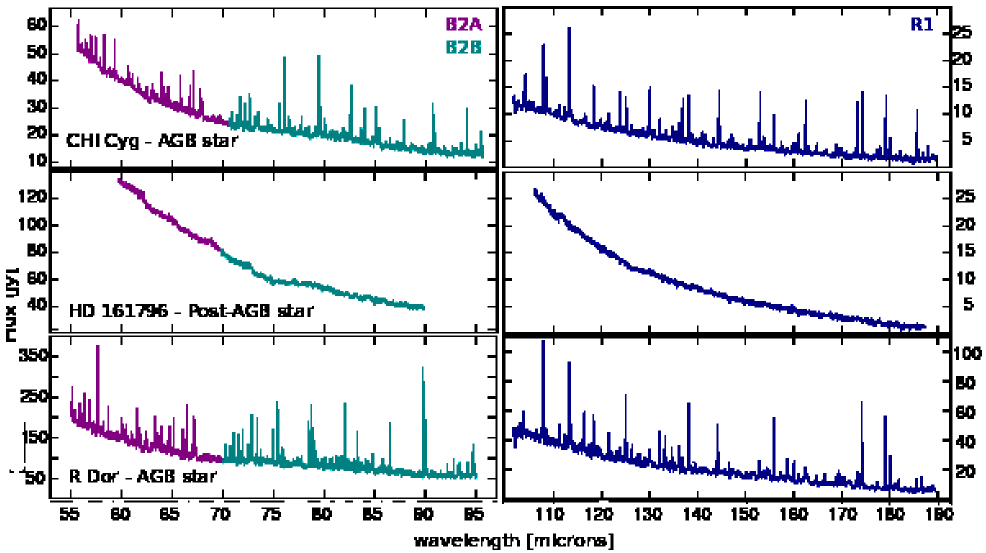
& cool crystals…

… such that we could
constrain physical/chemical/mineralogical
conditions in dust-rich environments.

But this cannot be done yet!

… since there are still problems with Herschel-PACS spectroscopy:

- Removal of molecular lines
- Reliable determination of background slopes of spectra
- Especially important / problematic for broad bands



De Vries et al., in preparation

Herschel-PACS spectroscopy vs. imaging

- Herschel-PACS imaging has already revealed a lot about dusty stellar environments
- But: PACS' spectroscopy of dust still causes some headache.


A&A 518, L140 (2010)
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Astronomy & Astrophysics
Special feature

Herschel: the first science highlights

Letter to the Editor

The detached dust shells of AQ Andromedae, U Antliae, and TT Cygni*,**

F. Kerschbaum[1], D. Ladjal[2], R. Ottensamer[1,5], M. A. T. Groenewegen[3], M. Mecina[1], J. A. D. L. Blommaert[2], B. Baumann[1], L. Decin[2,4], B. Vandenbussche[2], C. Waelkens[2], T. Posch[1], E. Huygen[2], W. De Meester[2], S. Regibo[2], P. Royer[2], K. Exter[2], and C. Jean[2]

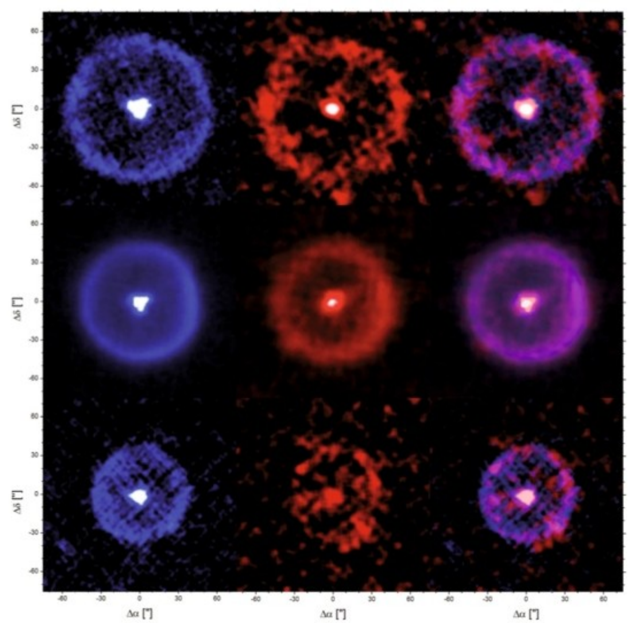
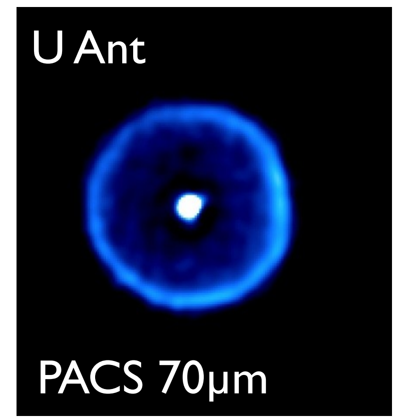


Fig. 1. *Herschel*-PACS scan maps (*left to right*: at 70 μm, 160 μm, two colour composite) of AQ And, U Ant, and TT Cyg (*top to bottom*).



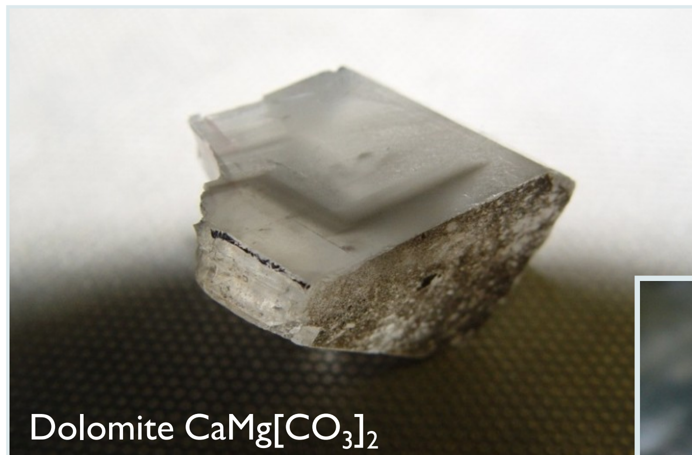
Kerschbaum et al. 2010

What can be done:

Discussion of FIR properties of selected dust species
as measured in the Jena lab

Talc $Mg_3Si_4O_{10}(OH)_2$

www.mineralatlas.com



Dolomite $CaMg[CO_3]_2$

Pictures by Th. Posch

Calcite $Ca[CO_3]$

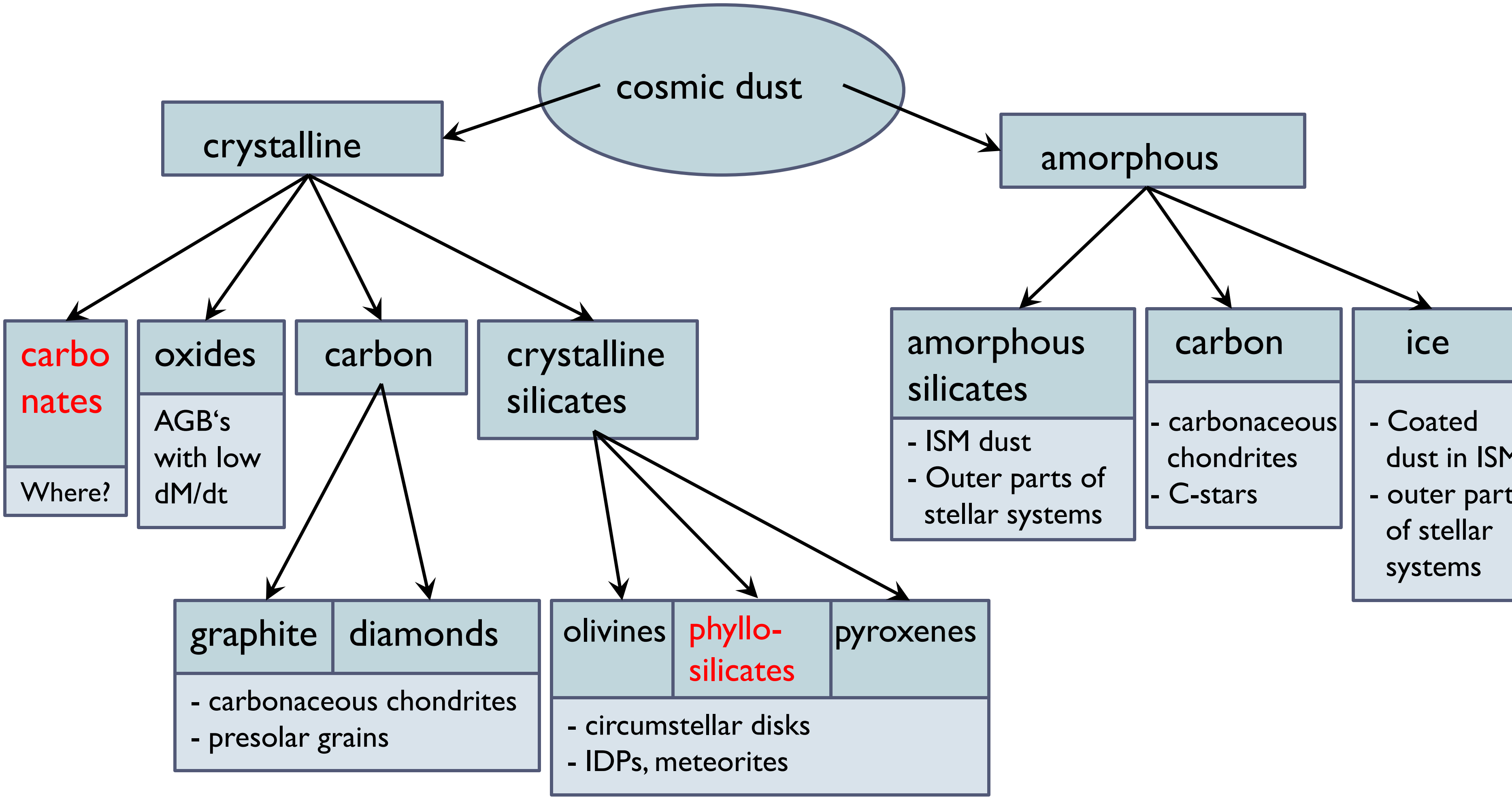
Dust features in the far-infrared

- Most (diagnostically relevant) dust features are in the MIR: 8-40μm
- Mineral spectroscopy also focuses on the MIR
- But there do exist FIR dust features
- Among the carriers: heavy ions / larger parts of lattices

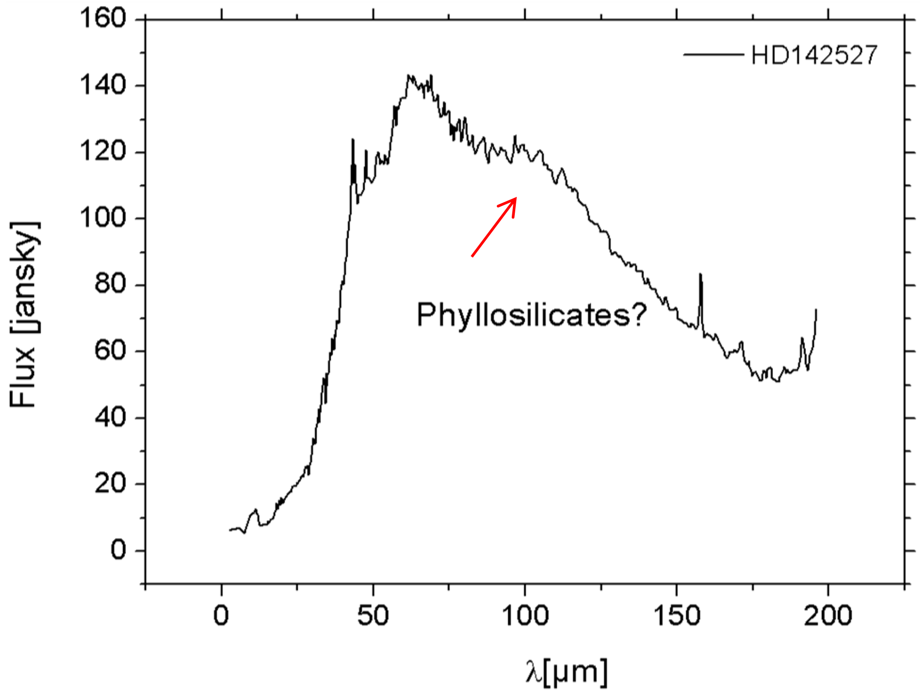
$$\lambda_{vib} \propto \sqrt{\frac{\mu}{k}}$$

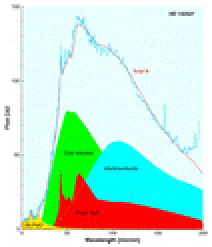
- E.g., ion groups or lattice sheets in vibration
- To actually see astronomical FIR, need additionally:
  cool dust

Carbonates, phyllosilicates and the „landscape“ of dust



I. Phyllosilicates

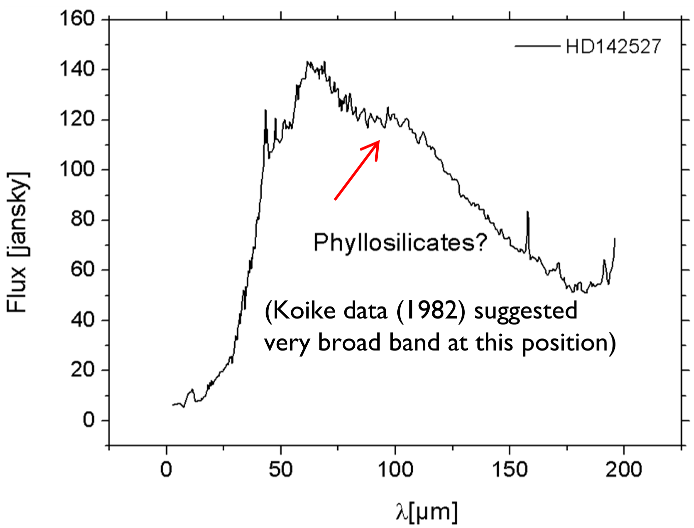


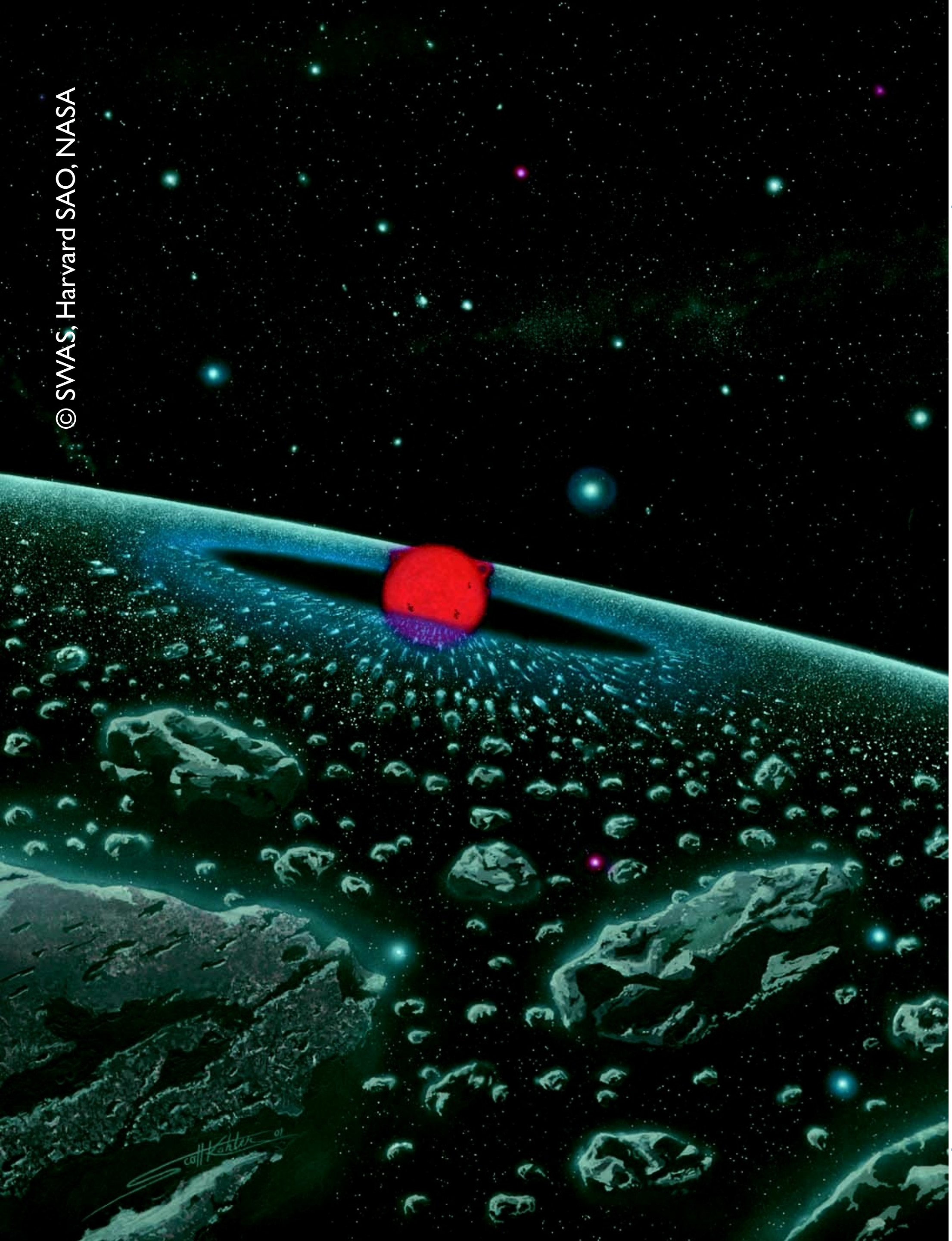


Up to 10% of phyllosilicates
In HD 142527?
(Bowey&Adamson 2002)

Why to study phyllosilicates

- Have pronounced bands in the FIR
- Form by aqueous alteration of pyroxene and olivine minerals
  (e.g. enstatite → talc; forsterite → talc)
- Important constituents of primitive meteorites (CM, CI carbonaceous chondrites)
- Occur in IDPs (Dorschner et al. 1978; Knacke et al. 1980; Sandford et al. 1985)
- Important for astrophysics as a potential water reservoir in space
- Existence in protoplanetary disks was proposed (Malfait et al. 1999 based on Koike et al. 1982)
  (see below: broad shoulder from ~85-125µm)



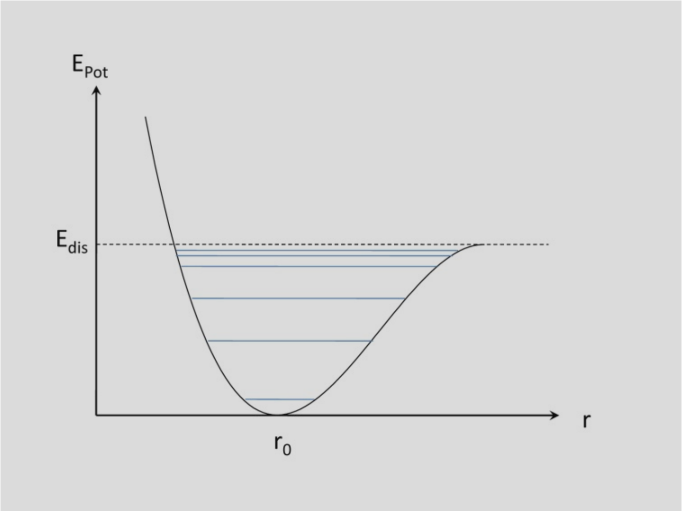


Possibly, water on Earth
actually came from
hydrous phyllosilicates
contained in meteorites
in the early solar system

The presence of phyllosilicates in protoplanetary disks would be important e.g. for “water transport”

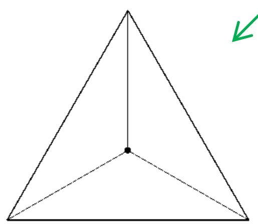
Why to do low temperature spectroscopy

- Absorption/emission behavior of crystalline matter depends on temperature (anharmonicity of the potential of binding of atoms in the crystal structure)
- Decreasing temperature → increasing energy hν of photons for activation of next vibrational state → bands shift to shorter λ's
- In some cases: FIR bands = „thermometers“ – which is interesting

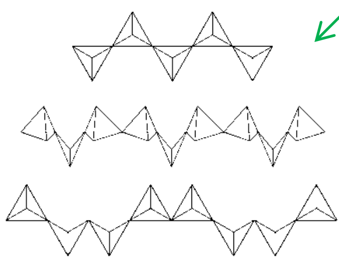


Different Kinds of Silicates

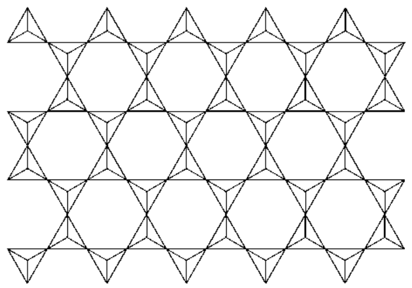
- Basic units of all silicates: $[SiO_4]^{4-}$ -tetrahedra
- One oxygen atom can be a part of another tetrahedron at the same time
- Many different structures can be built:
  Isolated tetraedra (olivines), chains (pyroxenes), sheets (φύλλον = leaf) (phyllosilicates)



isolated



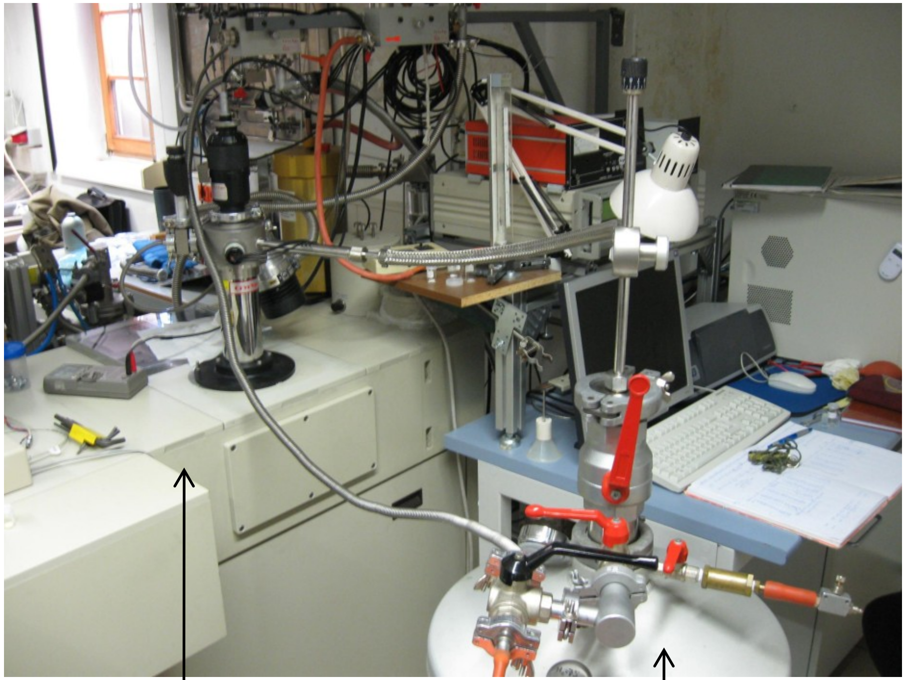
chains

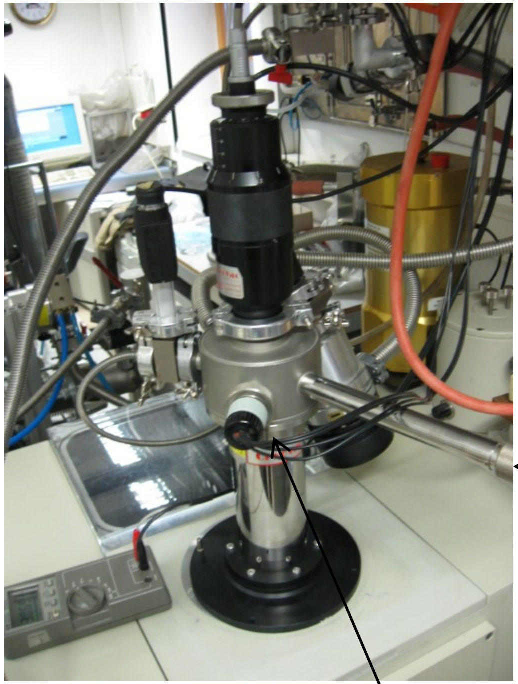


layers

<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 (→ hence: „hydrous silicates")

Experimental Setup (Jena lab)





Helium tube

Infrared spectrometer

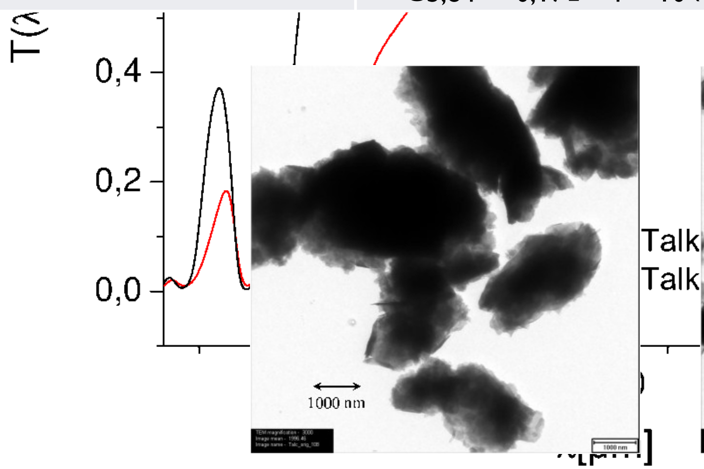
Liquid helium tank

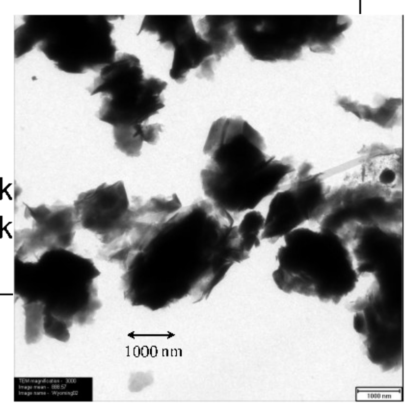
Cryostat

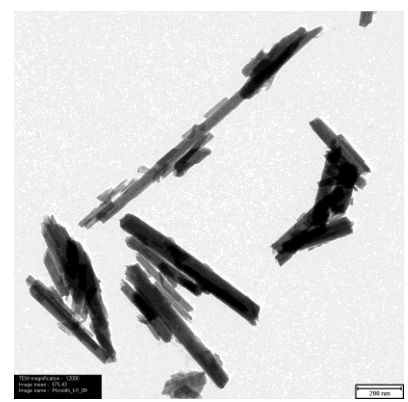
Experimental Details (I)

- Measurements taken at 300K, 200K, 100K and 10K
- Sample preparation: grinding in a mortar and/or ball mill and sedimentation in acetone to grain sizes <2µm

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





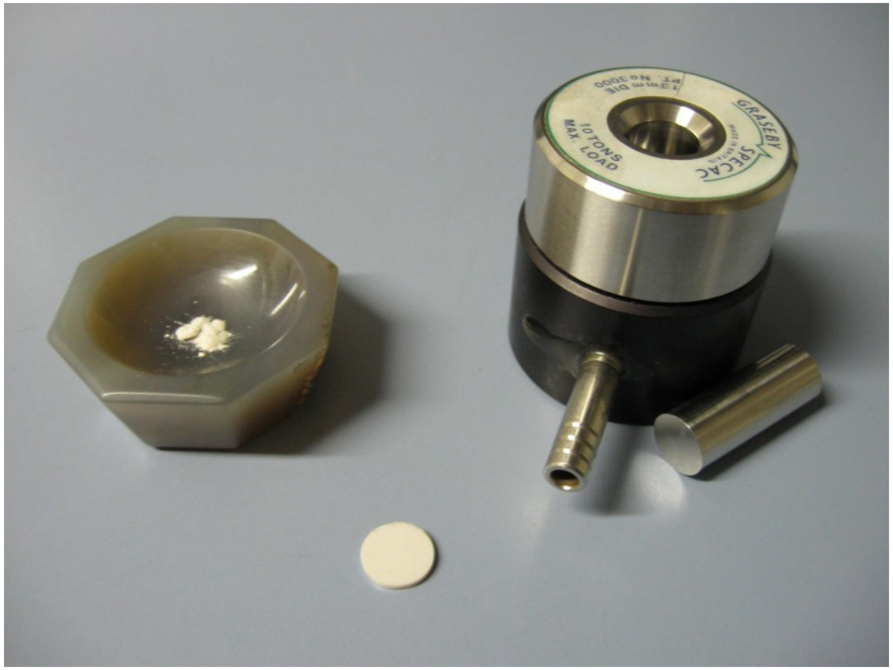


Experimental Details (II)

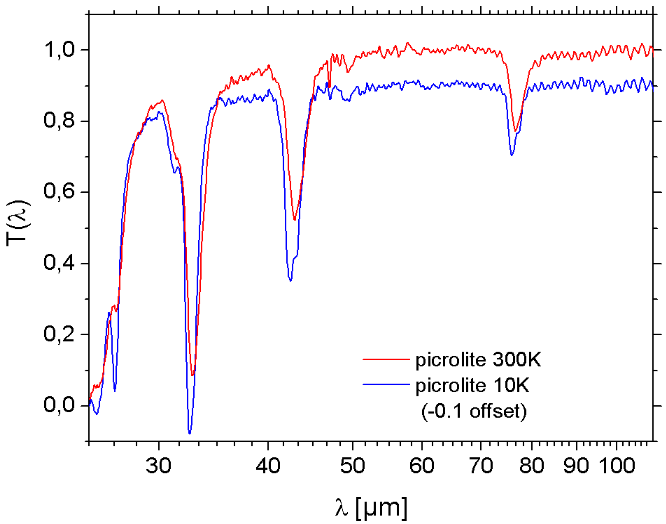
All samples were pressed to polyethylene pellets (m=200mg, d=13mm)

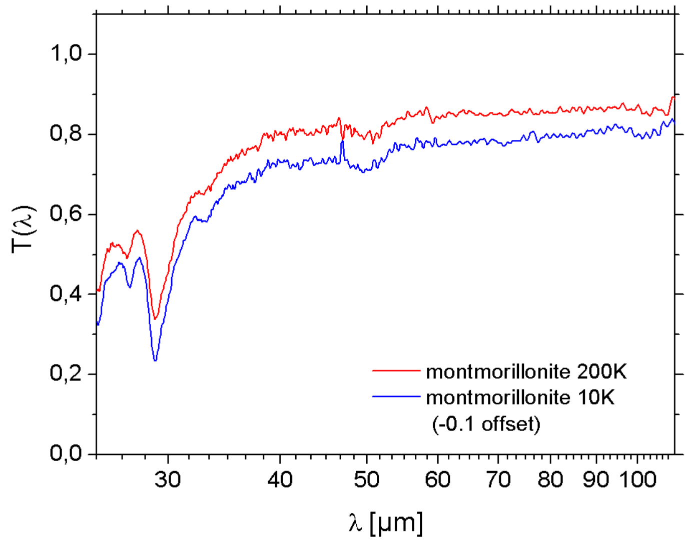
Embedding ratios (sample mass : PE mass)

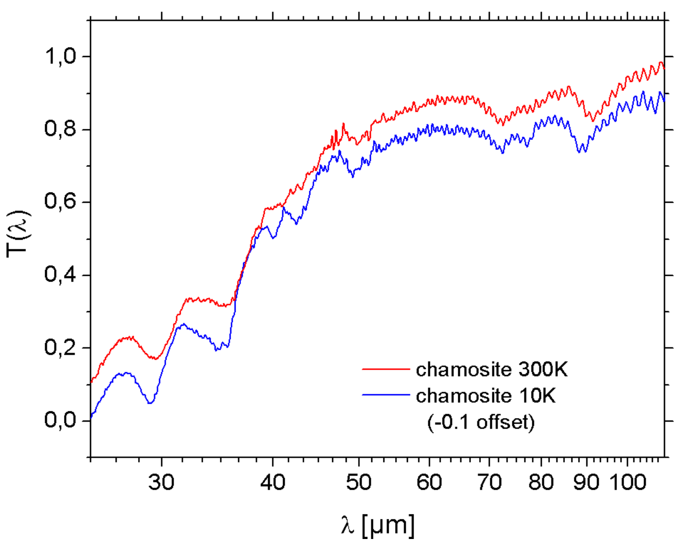
	17-67µm	67-200µm	>200µm
Phyllosilicates	1:100	1:100/1:10	1:10

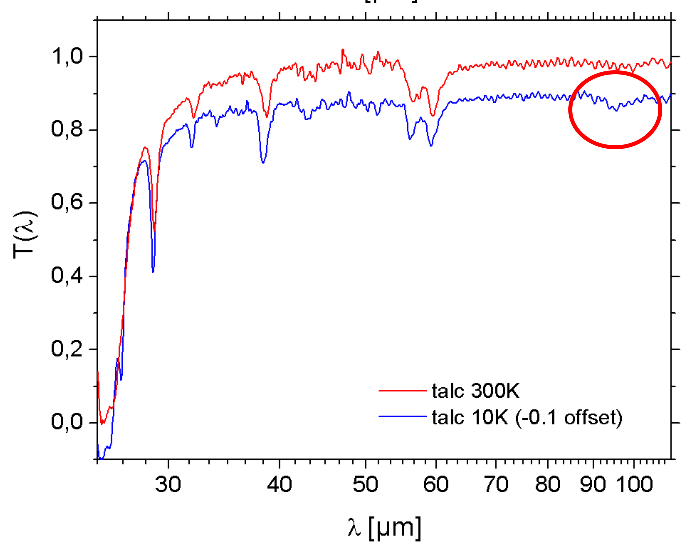


Measured transmittance spectra









From transmittance to MAC spectra

Deriving κ
from the transmittance:

$$\kappa = -\frac{A}{m_{emb}} \cdot \ln(T)$$

Fringe correction by averaging adjacent data points

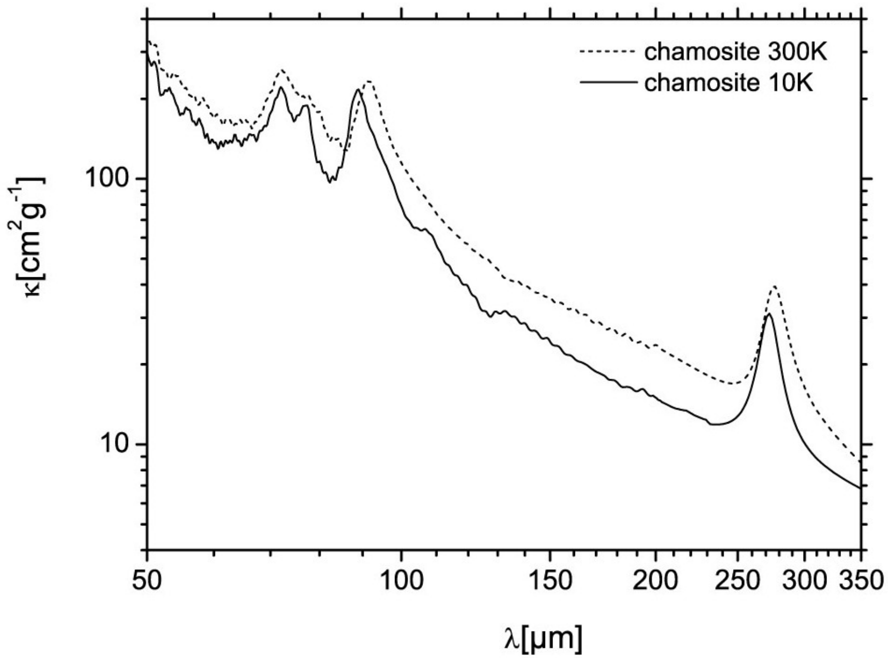
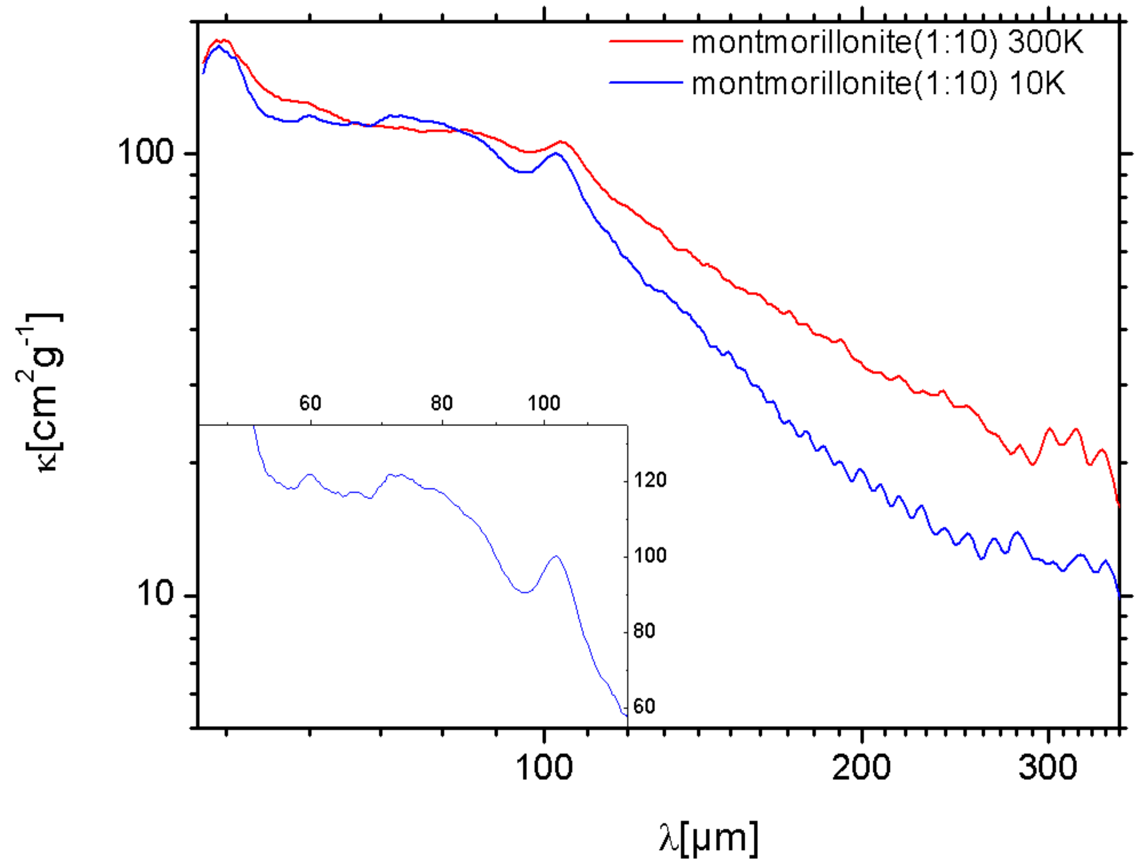


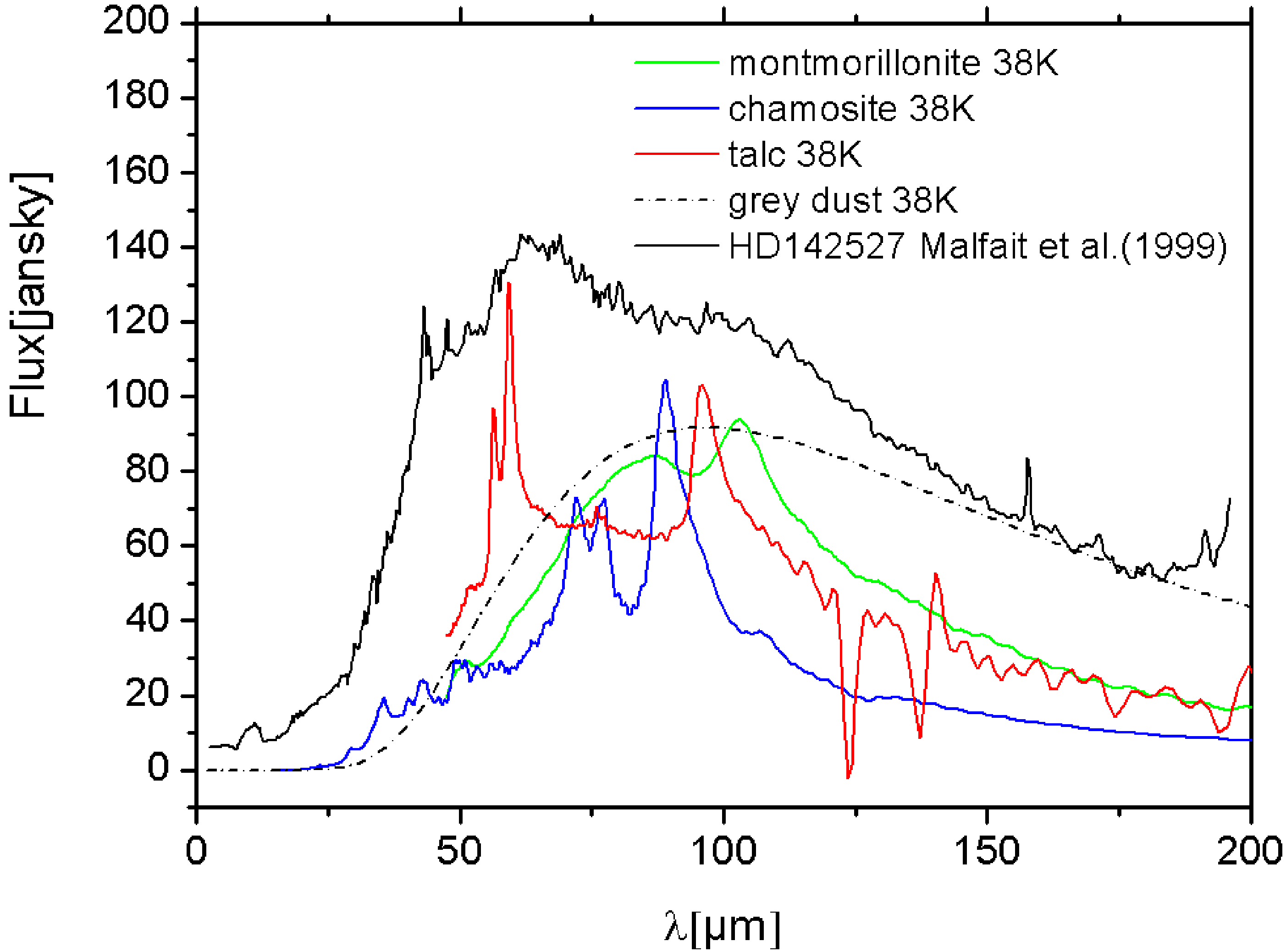
Fig. 6. Mass absorption coefficient spectra of the chamosite sample in the FIR range. The spectra are a combinations of measurements at two different column densities (see text). The fringes in the original data have been removed by a sliding average method used up to a wavelength of about 200 μm and by Lorentzian fitting for the 277 μm band. The structure at about 130 μm is due to imperfect compensation of a PE absorption band.

Further findings at low temperatures

- Weak bands become stronger and sharper
- „Hidden“ bands can be discovered
- For montmorillonite, the FIR gradient changes from ~$1/\lambda$ to $1/\lambda^2$ upon cooling



Comparison with ISO-LWS data



Mutschke, Zeidler, Posch et al., A&A 492 (2008), p. 117-125

Summary on Phyllosilicates

- Montmorillonite does <u>not</u> only show a broad, 85-125μm FIR band!

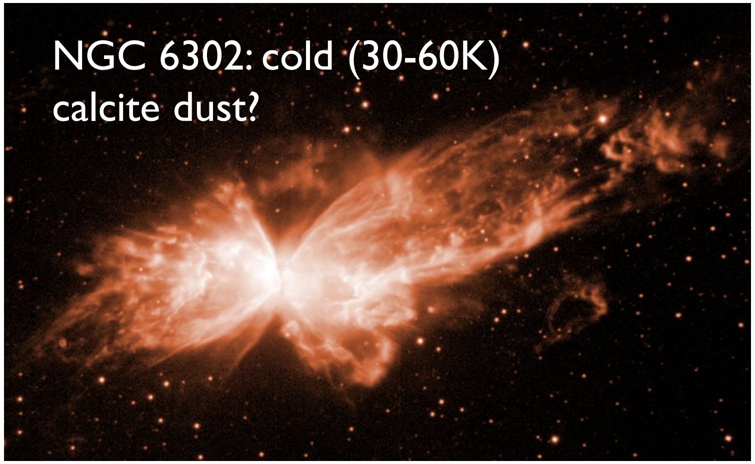
- We discovered a previously unknown band of **talc** at 98.5μm (300K value) and several „hidden" bands of **montmorillonite**

- **Most bands shift to smaller λ's at decreasing temperatures**
  → „thermometer" effect

- We can't confirm the existence of phyllosilicates outside our solar system yet: Spectra of protoplanetary dust disks are too inconclusive

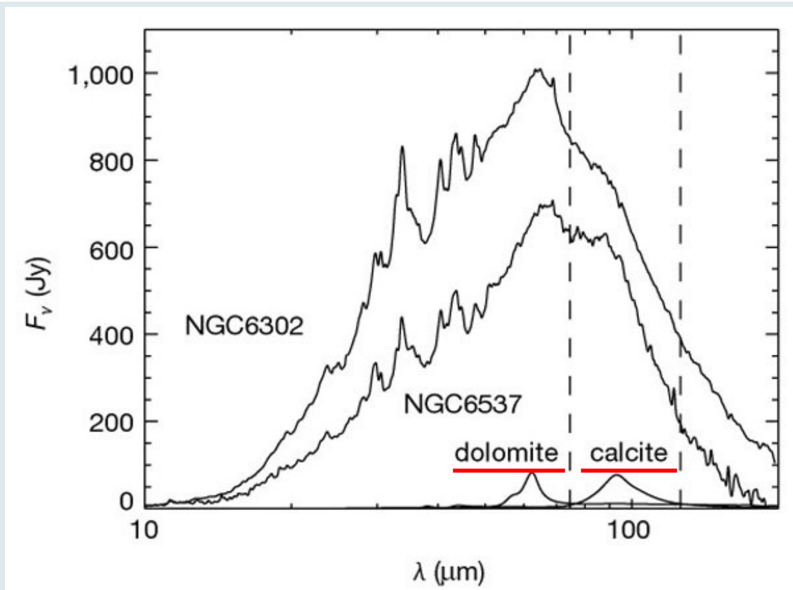
- Search for talc / montmorillonite bands: must focs on **relatively sharp rather than broad bands**

II. Carbonates

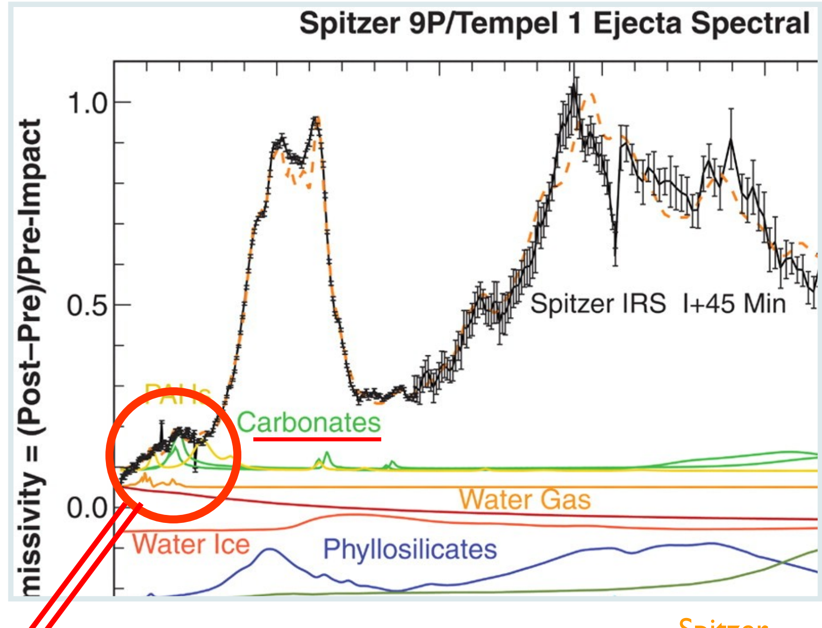


- Cold dust in Planetary Nebulae
- Environments of protostars
- Mars' atmosphere: $CaCO_3$, $FeCO_3$ aerosols
- IDPs (e.g. Sandford 1986): contain solid solutions of $MgCO_3$ and $FeCO_3$
- Comets, e.g. Tempel 1

Examples of potential carbonate bands



ISO-SWS&LWS

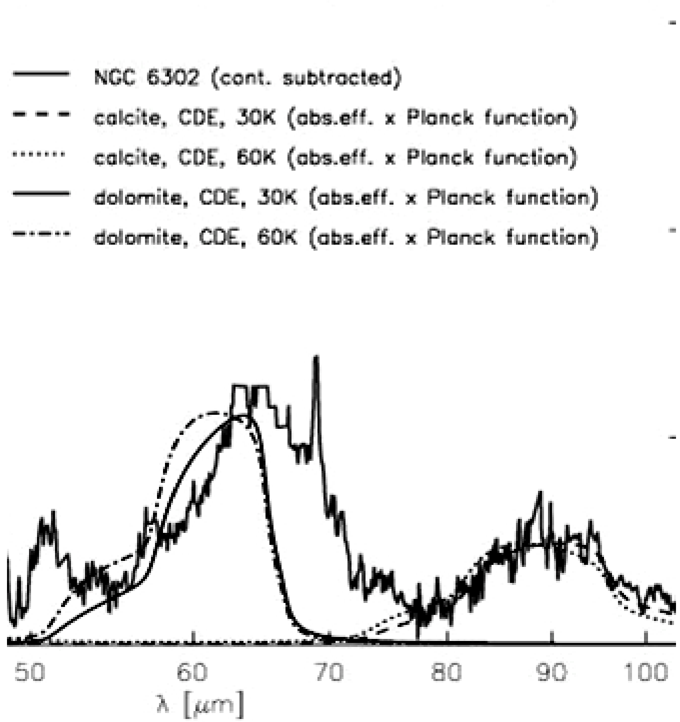


Spitzer

<u>Planetary Nebulae</u> <u>NGC 6302 & 6537</u>: FIR bands at ~65µm and ~90µm ascribed to $CaMg[CO_3]_2$ and $CaCO_3$ dust by Kemper et al. (2002), Nature 415, 295

<u>Comet 9P/Tempel 1</u>: NIR bands around 6.8µm, detected by Spitzer in "Deep Impact" ejecta, ascribed to $MgCO_3$ and $FeCO_3$ by Lisse et al. (2006), Science 313, 635

Small particle spectra (I)

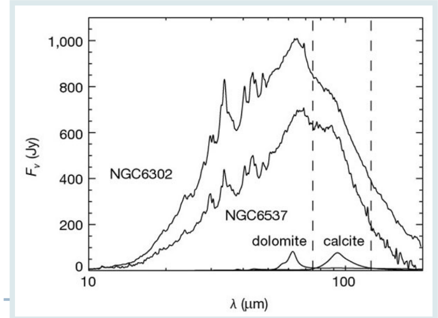


Posch, Mutschke et al., ApJ 668, 993

Key results in comparison to stardust spectra:

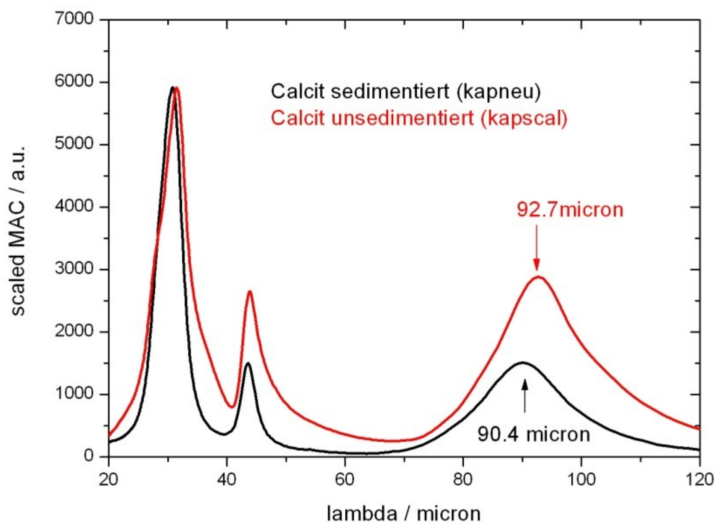
- Dolomite has strong ~65μm emission band.
Profile strongly dependent on shape and temperature.
In no case, ~65μm band in NGC 6302 explainable by dolomite dust

- Calcite has strong ~90μm emission band.
For T<45K, all other calcite bands suppressed & observed band profile compatible with irregularly shaped $CaCO_3$ grains

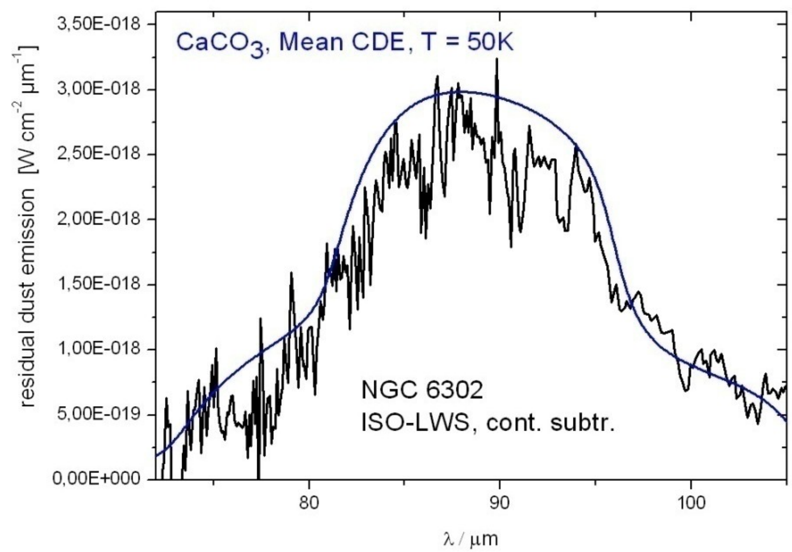


Small particle spectra (II)

Powder spectra were also measured (at room temperature)



Results of measurements agree well with CDE calculations



NB: Presence of large grains in unsedimented powder

New measurements lead to different band positions and relative strengths

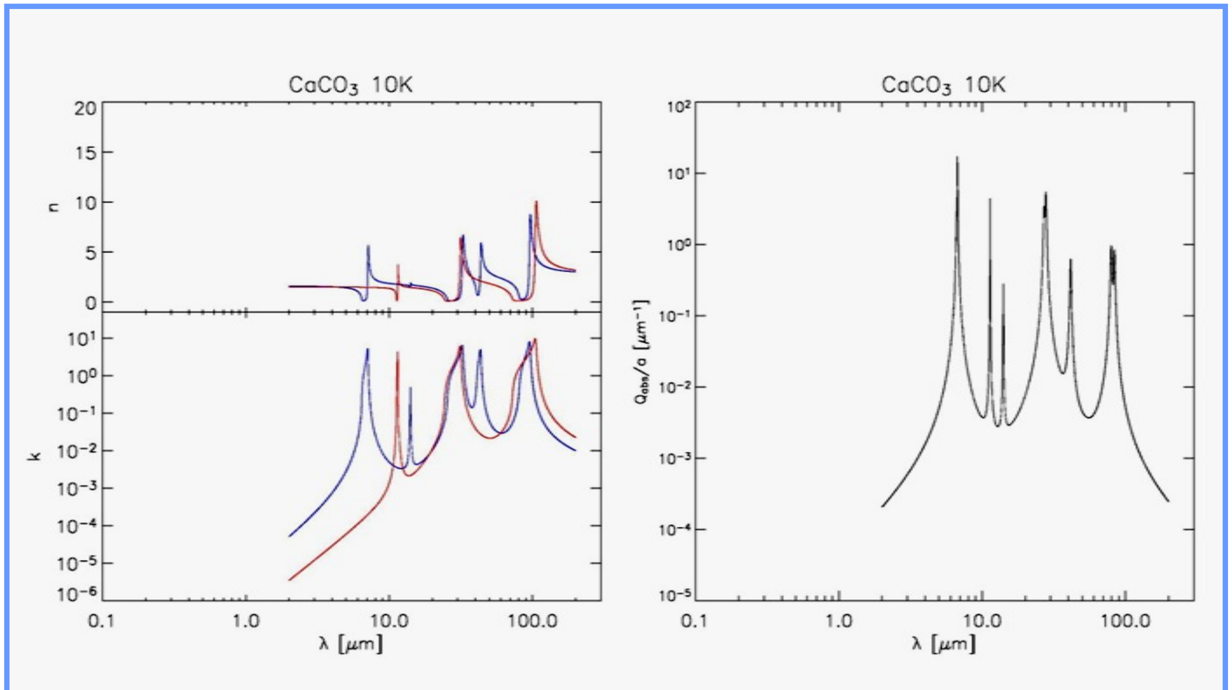
Compatible with ISO observations of NGC 6302, but setting more narrow constraints on possible temperatures (below 50K)

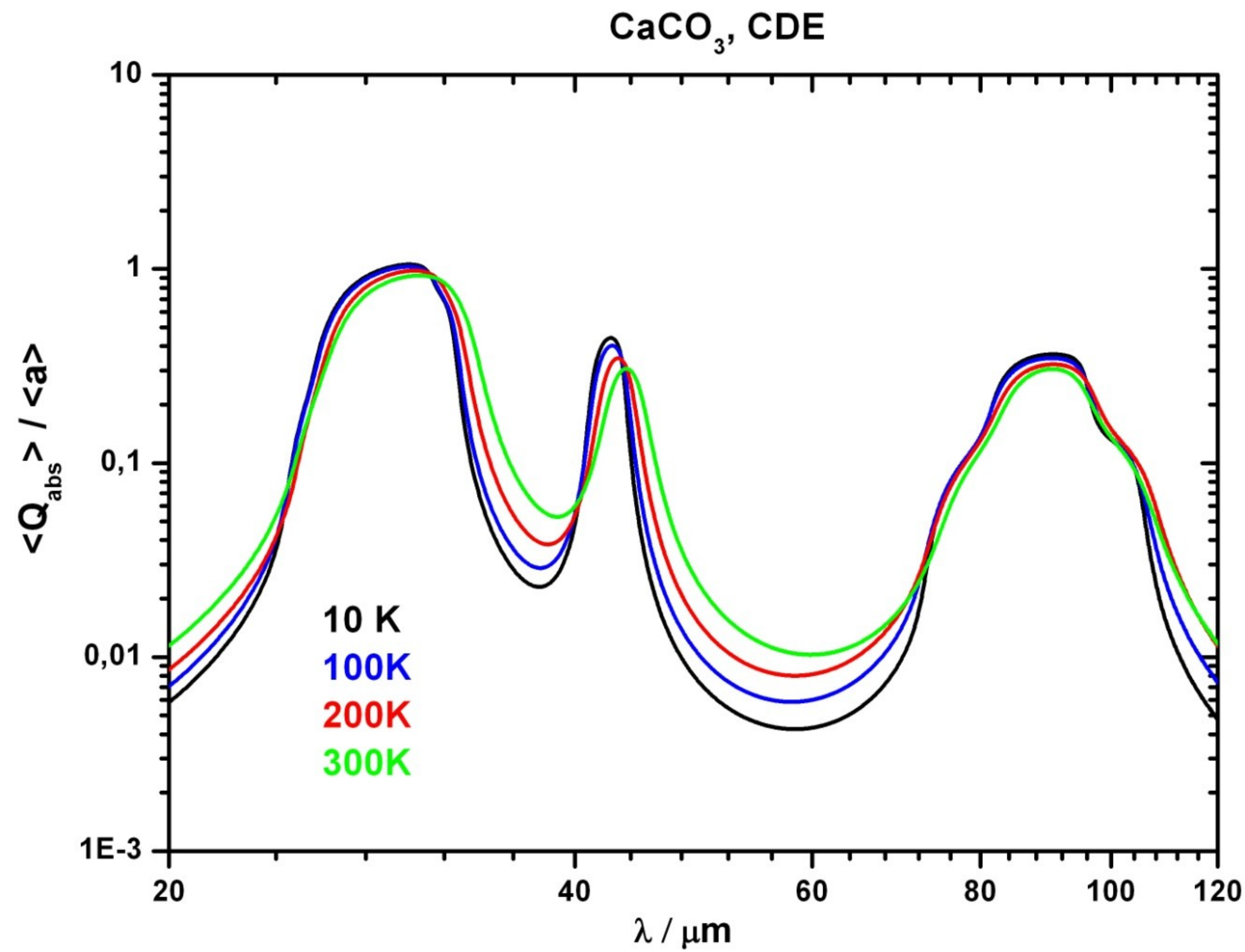
Carbonate data: available online

- Optical constants for calcite and dolomite available at:

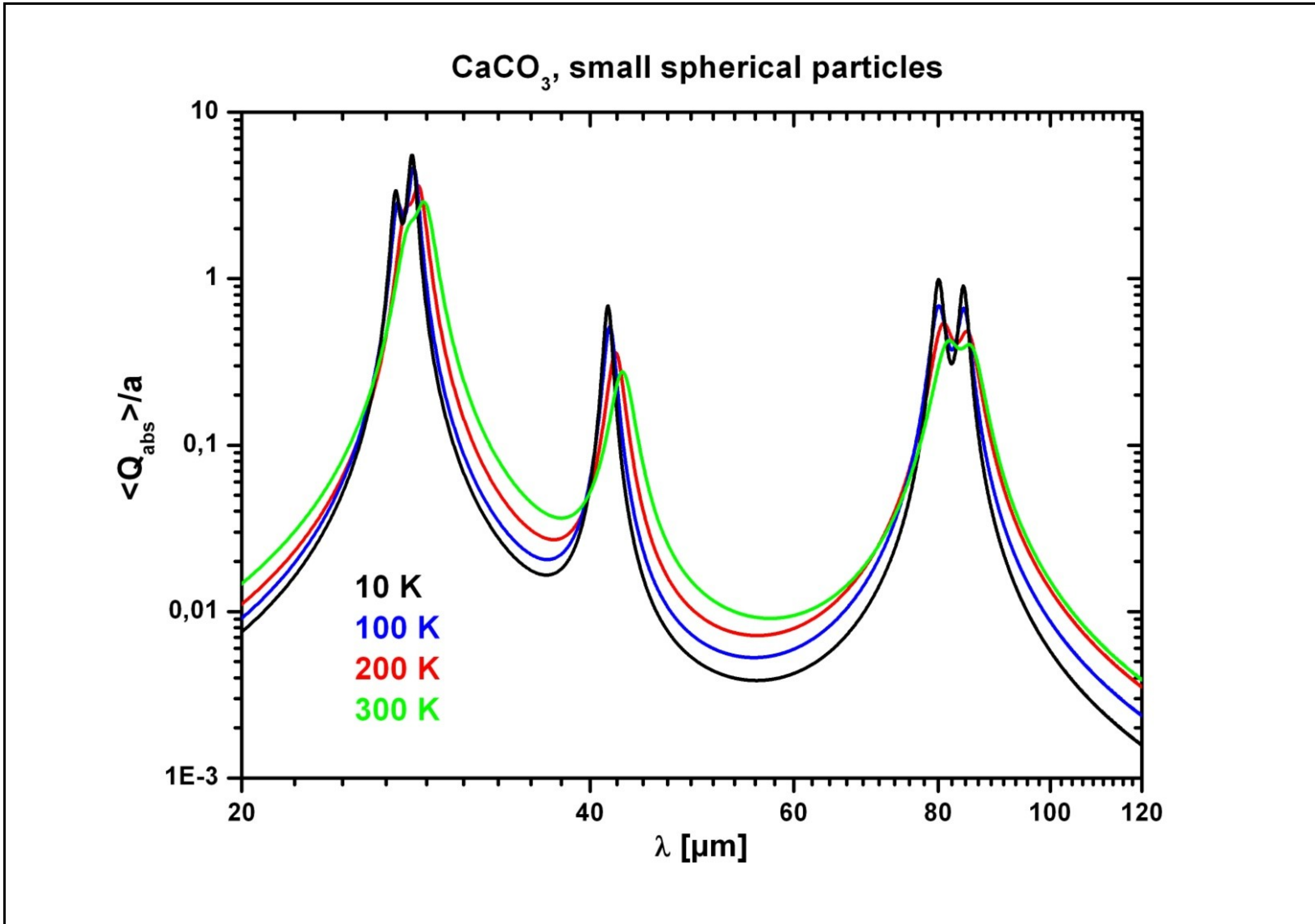
  http://www.astro.uni-jena.de/Laboratory/OCDB

- Including plots of n(λ), k(λ) and Q_{abs} (λ)





CaCO3, CDE
10
1
0,1
0,01
1E-3
<Qabs> / <a>
20
40
60
80
100
120
λ / μm
10 K
100K
200K
300K



CaCO3, small spherical particles
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0,1
0,01
1E-3
<Qabs>/a
20
40
60
80
100
120
λ [μm]
10 K
100 K
200 K
300 K

Places of work & Acknowledgements

Jena

Vienna

Space *(Herschel)*

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- Thomas Henning
- Walter Teuschel