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Location and composition of micro-inclusions in deep ice from the EDML ice core (Antarctica) using optical microscope and cryo-Raman spectroscopy

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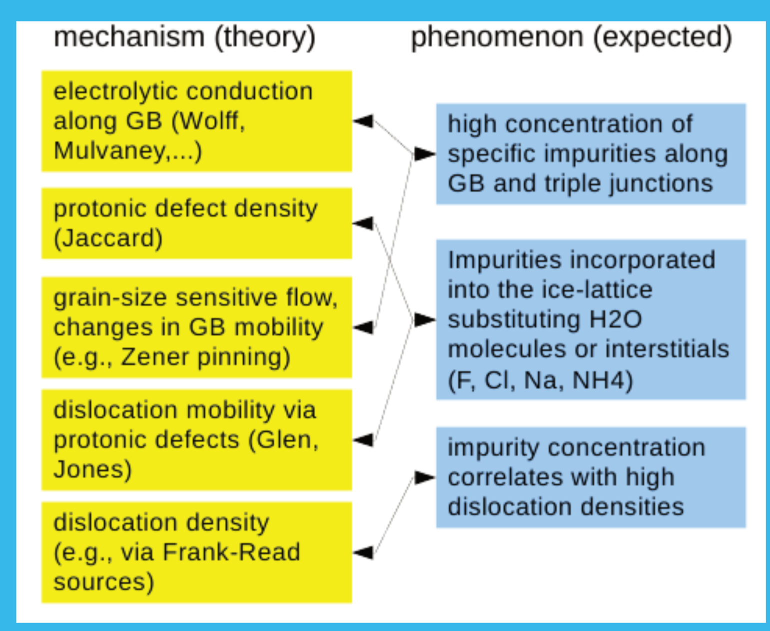
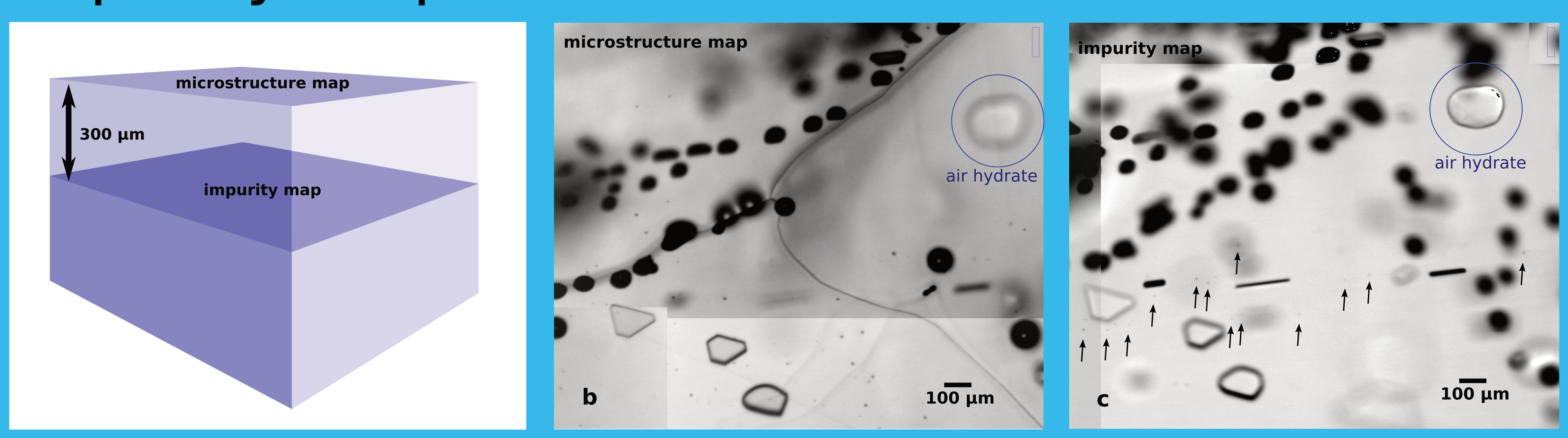
Motivation

The impurity content in meteoric ice from polar regions is relatively low compared to other natural materials. However, it controls a variety of physical properties of ice - from dielectric response to its mechanical behavior. Links between impurity concentration, changes in ice microstructure and deformation rate have been reported on several scales. In order to approach the responsible mechanisms, a better understanding is needed regarding the in-situ form, location, and distribution of the different species within the polycrystal.



Impurity maps



Method

Surfaces are polished with a microtome knife and exposed to air for a few hours. Sublimation smoothens the surface and creates grooves at sites of high energy, where grain and subgrain boundaries intersect the surface. In this way 2D maps of grain boundary networks and subgrain structures can be created (microstructure maps). When focusing into the ice volume and choosing transmission light mode µ-inclusions appear as dark dots of the size of few microns.

Samples

Three samples from the EDML ice core (Antarctica) were analyzed:

Depth (m)	Age (ka)	Period
2371.4	129	interglacial
2371.9	129	interglacial
2392.2	138	glacial

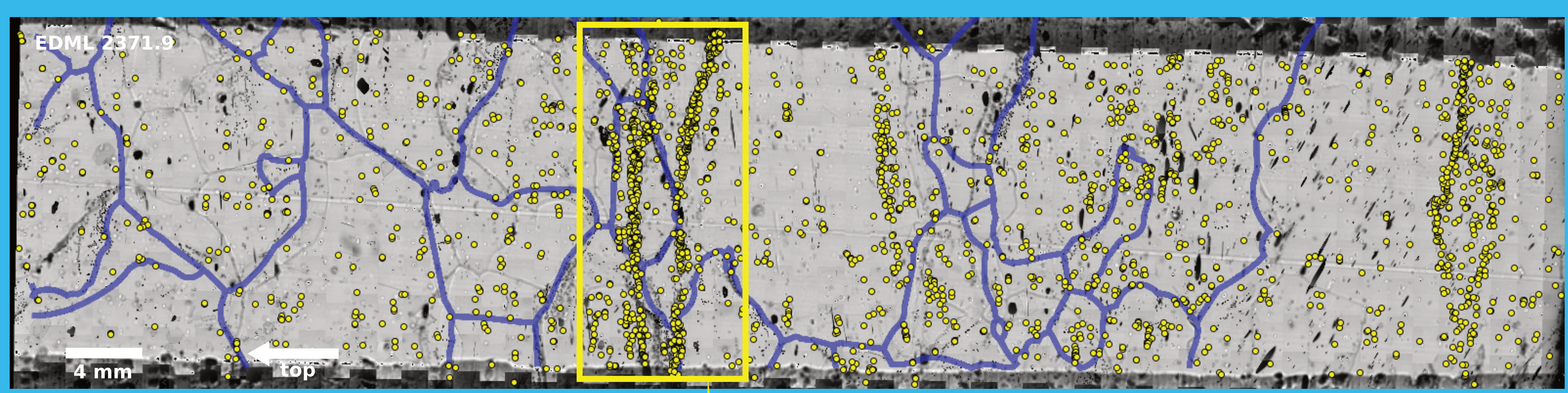
Distribution of micro-inclusions is in-homogeneous (Eichler et al., 2017). In the warm-prefer samples horizontal layers can be distinguished with concentration reaching 40,000 particles/cm^3. On the µm-mm scale, small clusters and chains are frequent.
In general no correlation between micro-inclusions and grain boundaries could be detected. Only around 10% of µ-inclusions are located within the distance of 300 µm to a grain boundary. More than 90% of µ-inclusions are found in the grain interiors. The concentration of µ-inclusions and clusters seems not to depend on shape, size or crystal orientation of individual grains. Instead, high accumulations of secondary gas inclusions along grain boundaries are observed. These micro-bubbles do not occur insitu, but are secondary artifacts due to relaxation of the material.

Zener pinning

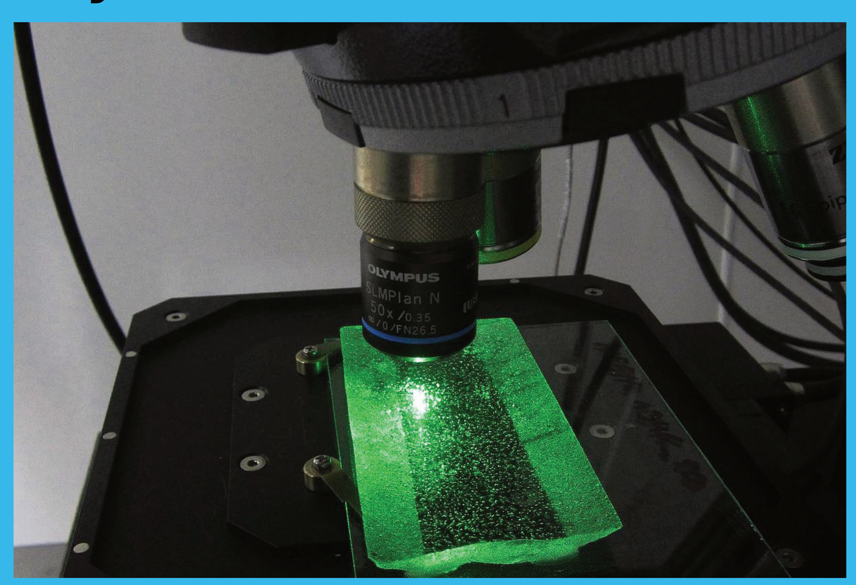
The observations indicate that the Zener interaction is not strong enough to cause harvesting and dragging of µ-inclusions by grain boundaries - "slow mode pinning" (Alley et al., 1986). In contrast, fast mode pinning - i.e., temporal particle-boundary interaction can still reduce the driving force for grain boundary migration.

Conclusion points and questions

- No slow mode pinning.
- No redistribution of µ-inclusions by Zener drag.
- Other links between µ-inclusions and grain size?
- Other links between µ-inclusions and deformation rate?
- What is the role of dissolved impurities?



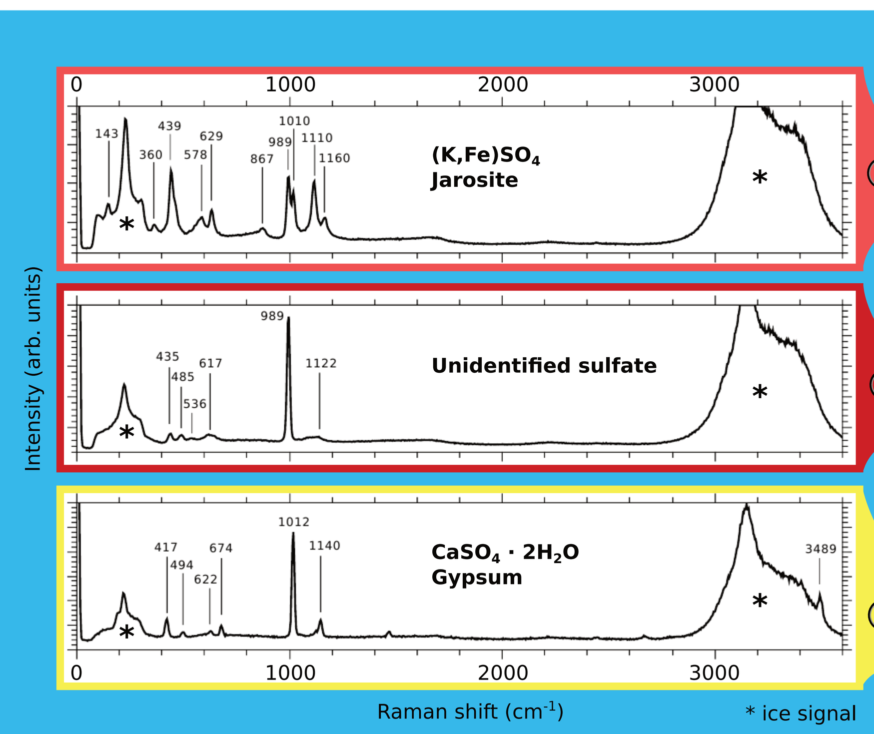
Cryo-Raman

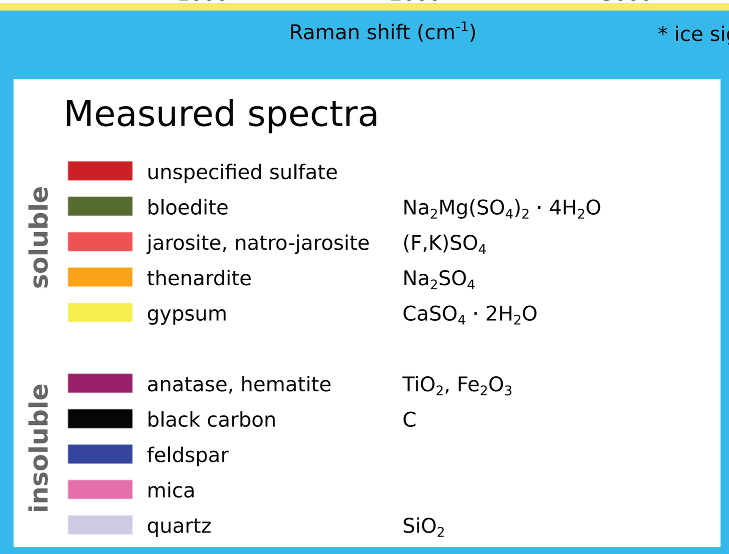


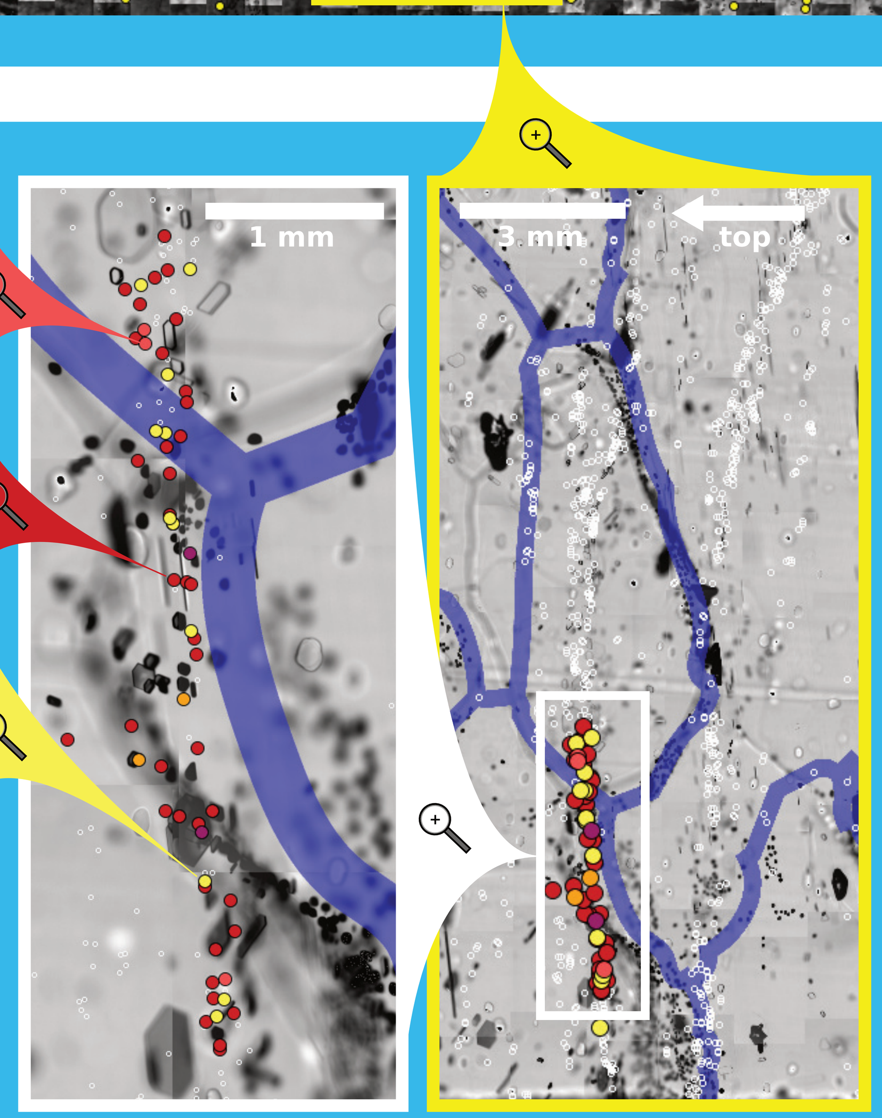
The Cryo-Raman system

WITec alpha 300 M+ with UHTS 300 spectrometer and Nd:YAG laser (532 nm) set up in the AWI cryolab at −15°C.

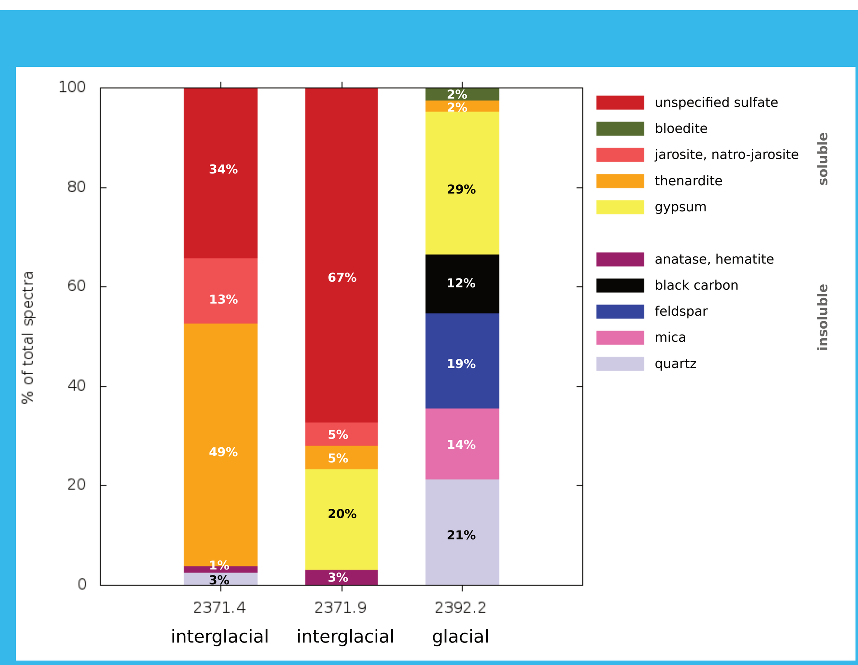
Raman spectra are decomposed into discrete vibrational modes and compared to reference spectra. A good quality spectrum includes several modes which enable confident identification of the species.







The different species are well mixed. No evidence of segregation or special partion has been found.



Impurity composition

The glacial ice (2392.2) contains mostly insoluble particles such as silicates and black carbon.
Interglacial samples (2371.4, 2371.9) contain almost exclusively sulfate salts such as Na_2SO_4 (thenardite), $CaSO_4 \cdot 2H_2O$ (gypsum) and others.

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