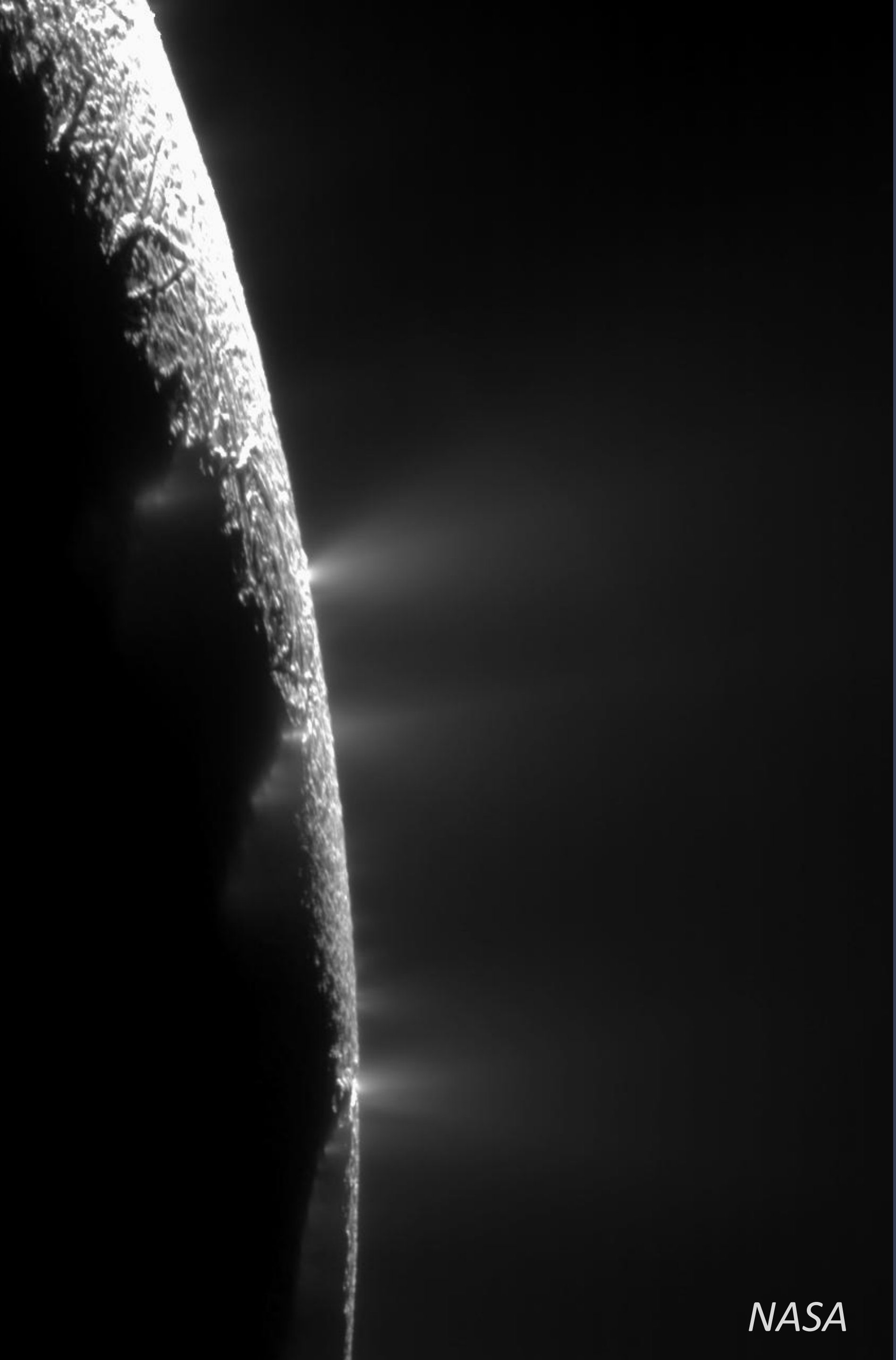
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Modeling the dielectric properties of the geyser deposited snow layer on Enceladus

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Enceladus' hidden ocean is among the most promising places to host extraterrestrial life in our solar system. On its south polar region, active geysers form a passage from the ocean to the surface, thereby depositing a layer of snow. Here we present our approach in reconstructing and modeling the thickness and the dielectric properties of the deposits as a function of the pore space, hence the ice grain/vacuum ratio.

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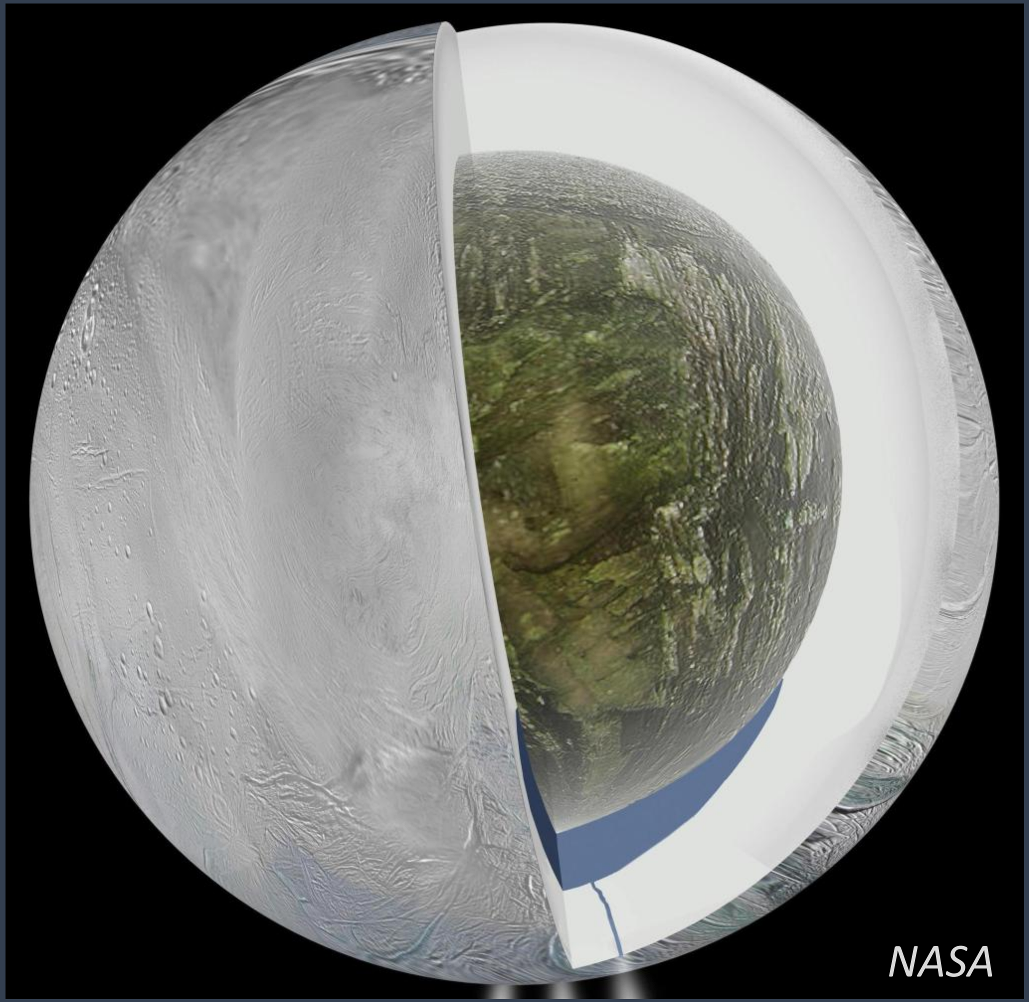
Enceladus – an icy world



Artistic representation of Enceladus with south polar ocean.

- With a diameter of only 500 km , the Saturn moon Enceladus is one of the smallest geological active and differentiated bodies.
- Its outer shell is composed of ice, with a liquid ocean beneath (possibly of global extend).
- The ocean's water in turn passes through the underlying porous core of chondritic composition, thereby leaching alkaline elements.
- Saturn's tidal forces acts strong enough on Enceladus to maintain a cryo-volcanism.
- On its south polar region, active geysers originate from the ocean and erupt gas and mainly ice particles.

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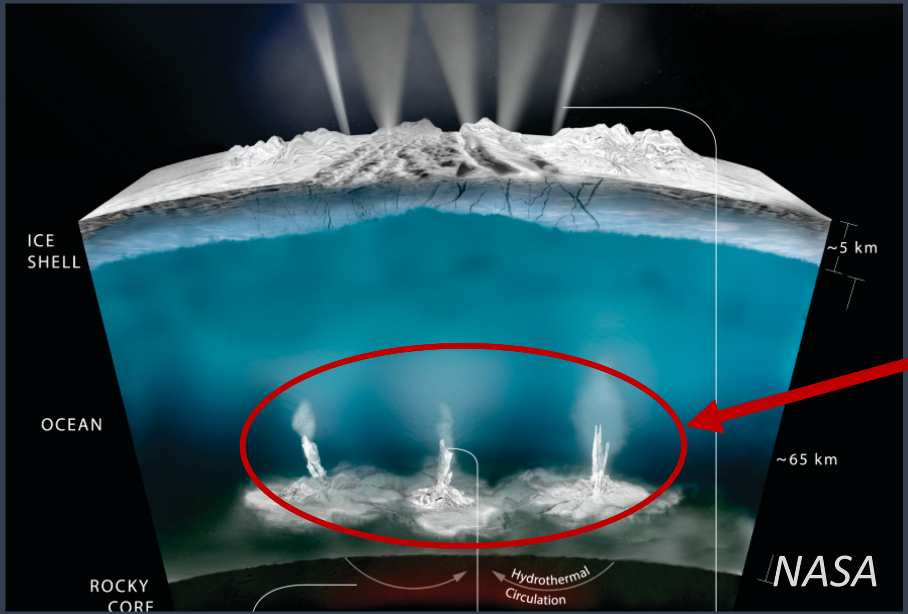
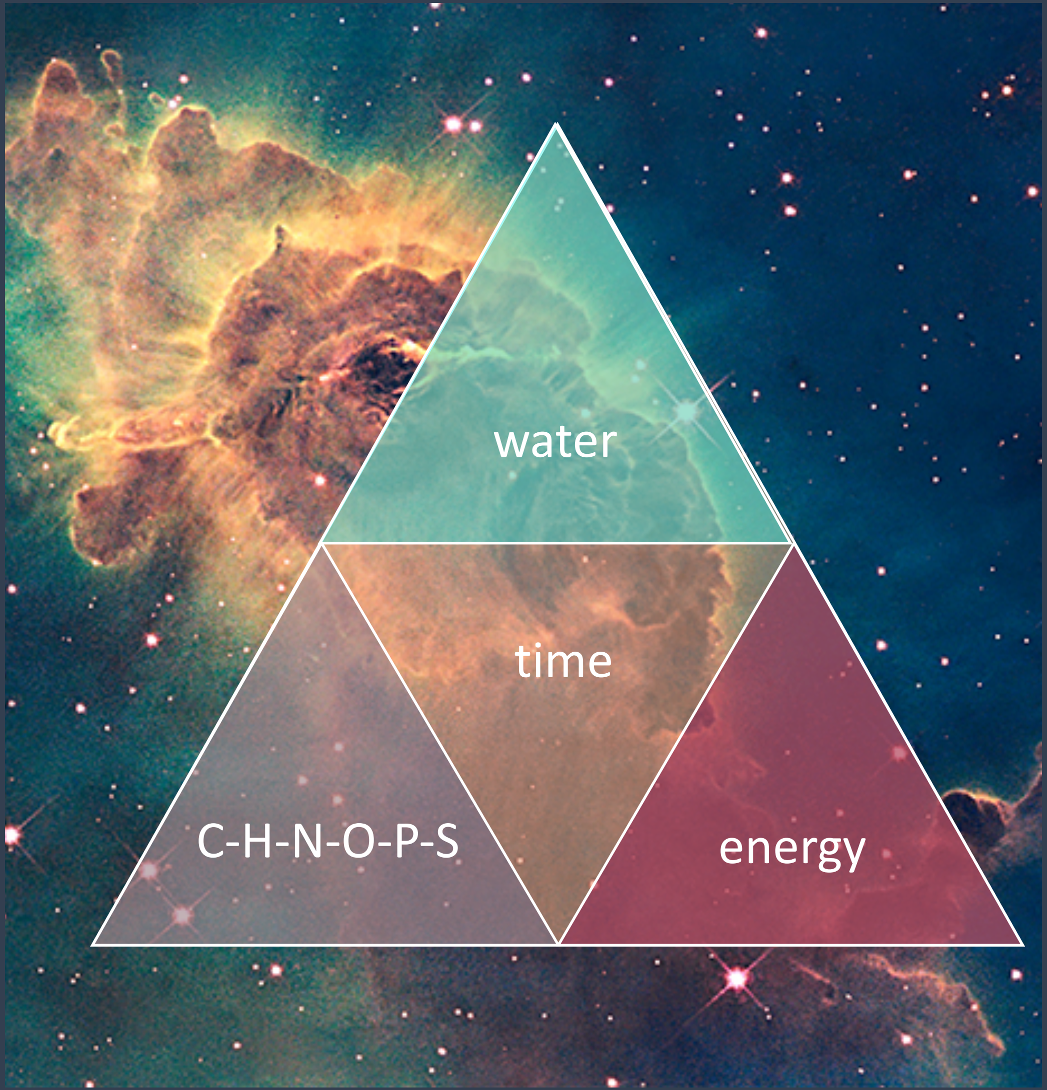
Enceladus – home of extraterrestrial life?

- Thus, this small planetesimal, far beyond the habitable zone, combines the three necessary components to develop life – liquid water, suitable chemistry and energy.

- Hence is the question whether it bears extraterrestrial life.





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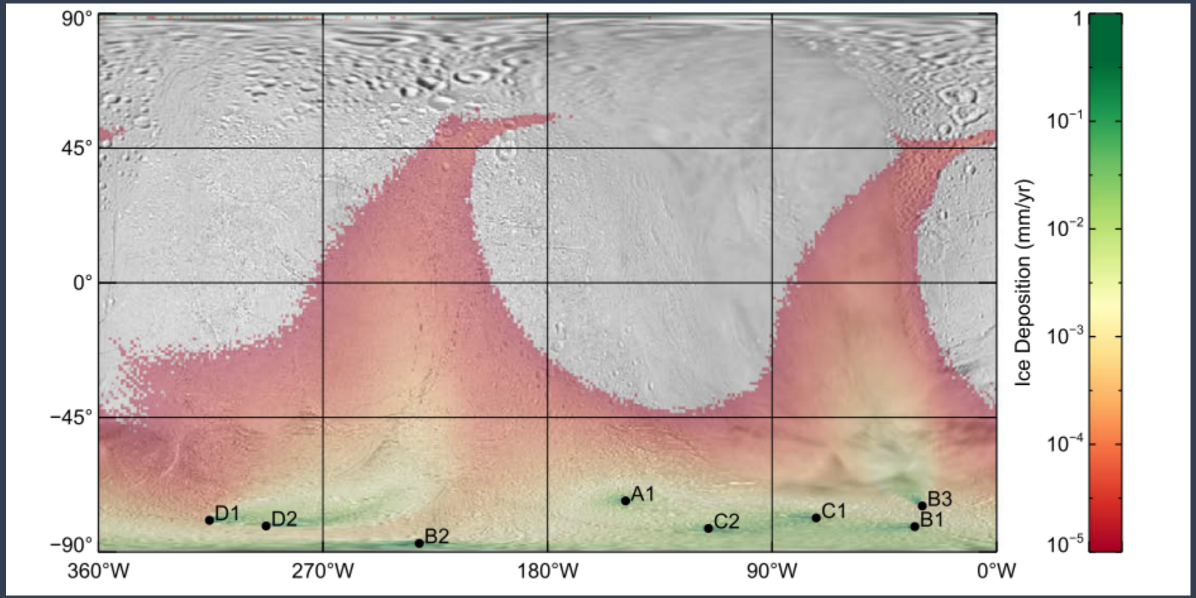
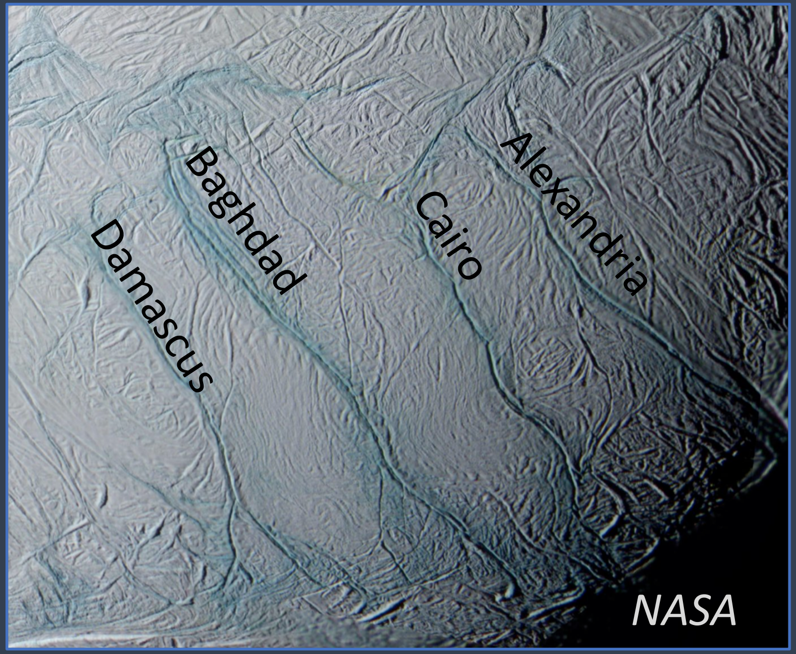
The Geyser’s Deposits

- The majority of the particles enter into orbit around Saturn, forming the E-ring. (~95 %)
- However, the heavier particles fall back to sediment a layer if snow, around the tiger stripes. As such only 10 % of the total plume mass enters into orbit (Kempf et al., 2010).
- The image on the left shows the surface mass deposition rate of grains between 0.5 µm and 5 µm.



The dots mark the location of active geysers.   Kempf et al. 2010



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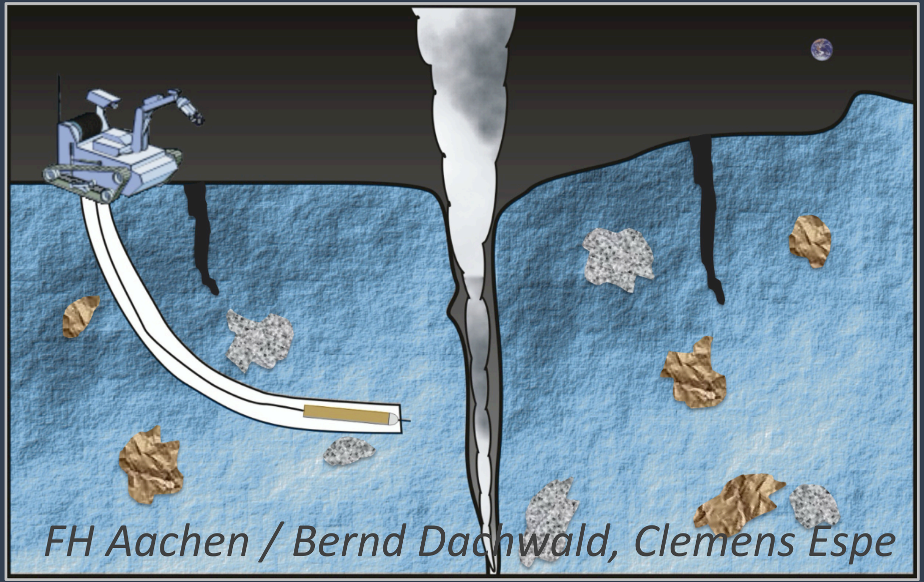
Enceladus Explorer

- Enceladus Explorer is an initiative from the German Aerospace Center (DLR)
- Aim: to build and test on Earth a melting probe that melts down in the vicinity of the geysers.
- In order to search for microbes in a near surface water pocket (which feed the cryo-volcanism).



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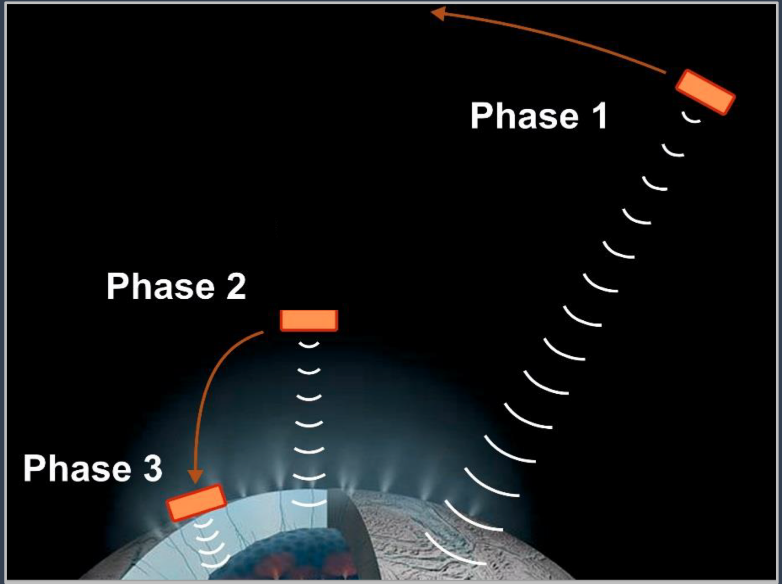

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- Radar based imaging and localisation is needed,
- To find water filled pockets and to help navigate the probe.
- Imaging from Orbit (Phase A), from near surface (Phase B) and during the descent (Phase C)

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Permittivity of Ice

- To adjust the radar signal to navigate the melting probe, effects of refraction due to different refractive indeces of vacuum and ice, or between two different ice layers must be accounted for.
- The refractive index is set by the real part of the dielectric constant, or permittivity.
- The permittivity for vacuum is ε_r= 1 while for hexagonal crystalline ice is ε_r = 3.2 for wavelengths >100 kHz.
- Neglecting possible effects of salinity or temperature,
- The permittivity of the ice layers at Enceladus south pole region can be estimated by the prevailing vacuum/ice ratio, hence the pore space or density.
- How many layers can we assume on Enceladus‘ south pole?

I. An uppermost layer of piled up snow/ice grains deposited from the geysers
II. A layer of the snow deposits which have undergone a sintering process.
III. A layer of solid crystalline ice making up Enceladus‘ outer shell.

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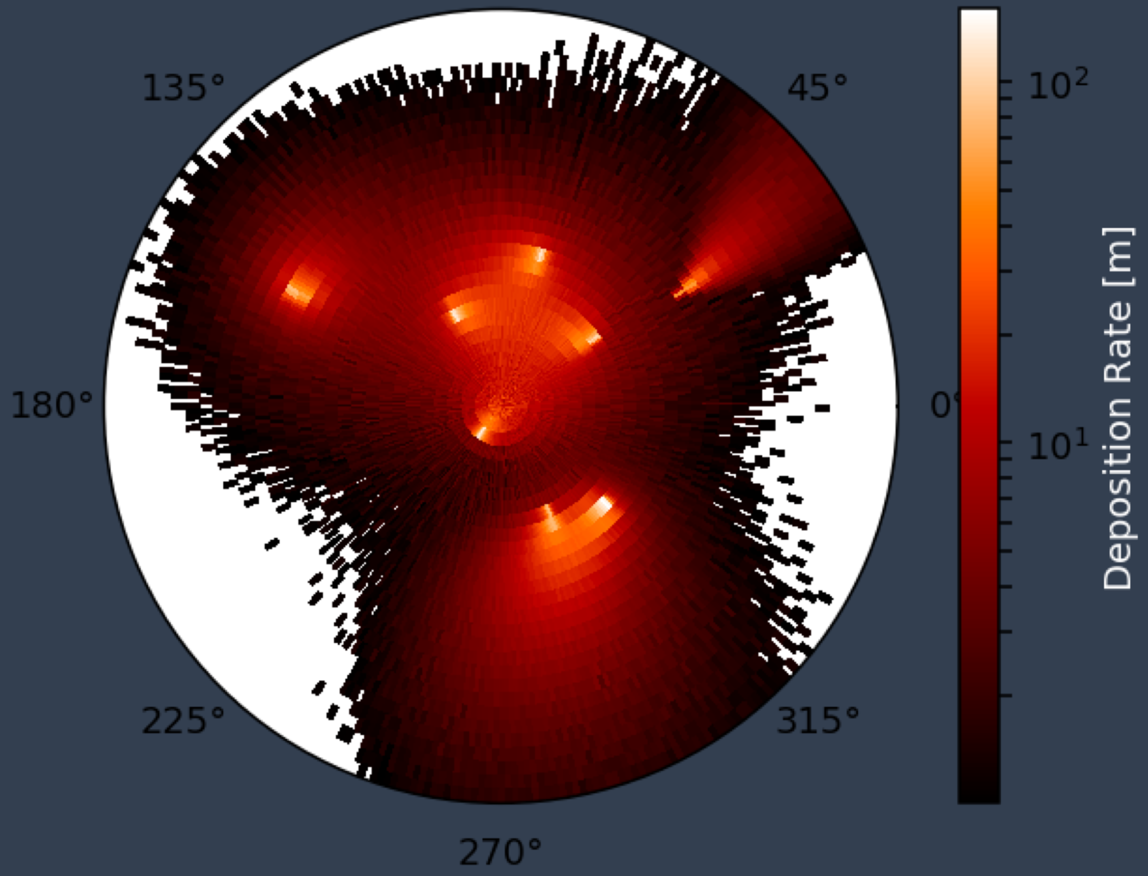
Thickness distribution of snow deposition

- In the Diagram, the distribution of the accumulated geyser deposits is shown.
- Calculated from the data used by of the deposition rate of the geysers per year (Southworth et al., 2019),
- By assuming an age of 50 Myr (Di Sisto & Zanardi, 2016) and assuming the geysers being active and locally stable since then.
- The snow deposition is concentrated to the geysers and piles up there to several km,
- while within only relatively short distance decrease rapidly to < 10^1 m.



Ice Deposition (>1 m) from geysers after T = 50 Myr

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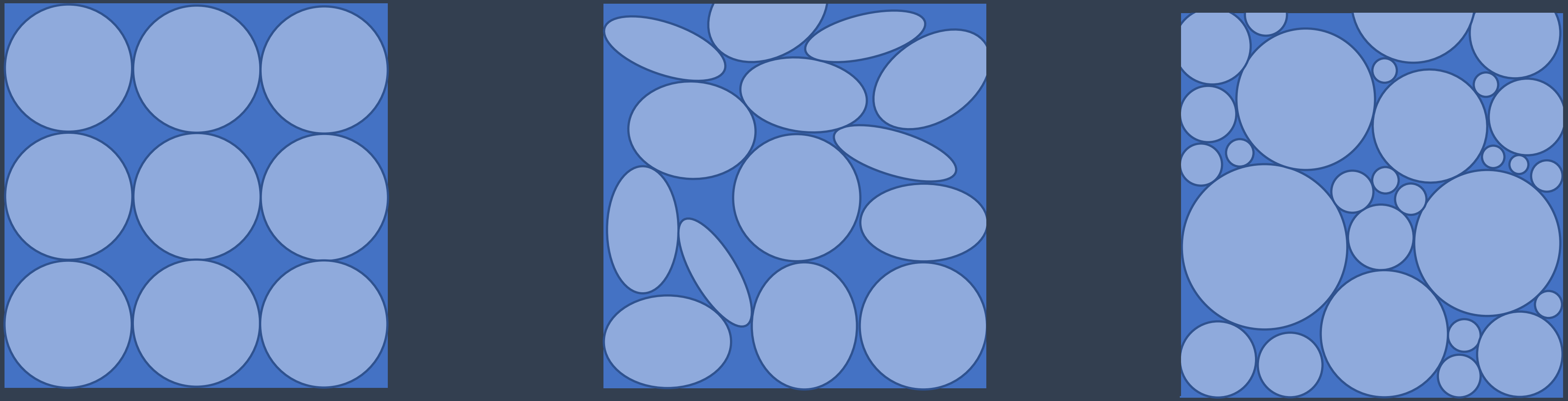
Density of snow deposition

- The pressure on Enceladus is insufficient to cause densification due to the weak gravity (0.013 g).
- Also, because of the low temperatures, no processes as melting and refreezing (as on terrestrial glaciers) acts on the density.
- The void space ratio for randomly packed equally sized spheres is about 0.64.
- With the density of ice of 920 kg/m^3, this would lead to a *density of 588* kg/m^3 *for this layer*.
- How deviation from spherical shapes decrease and/or variations in size distribution increase the density still has to be addressed!



Shape and size distribution of Enceladus snow deposits will effect the given void space ratio.

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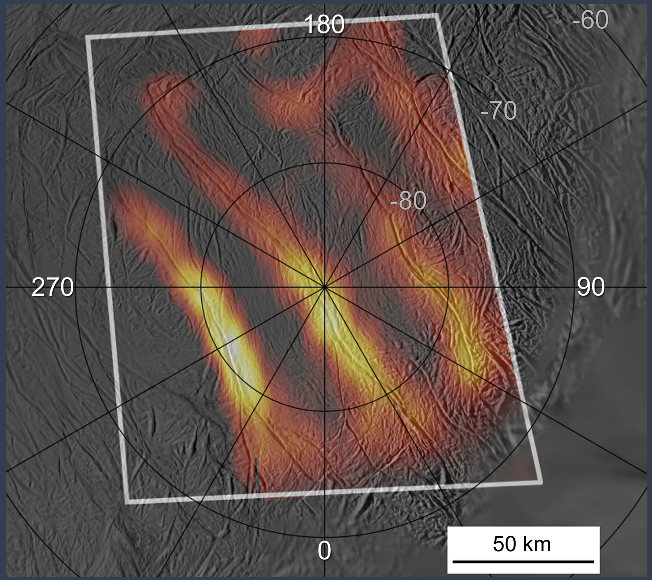
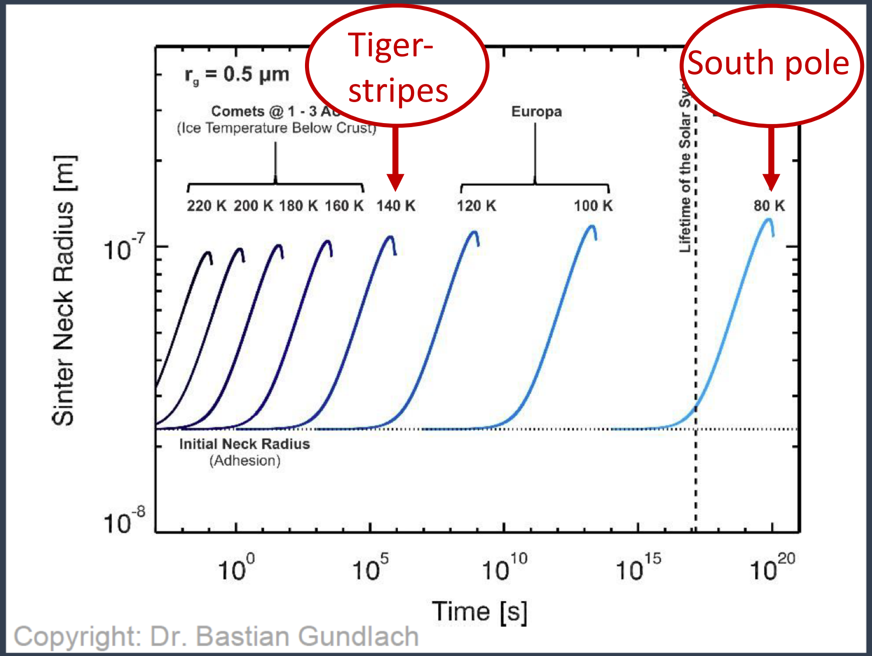
Thickness of sintered layer

- At the south pole region the average temperature is about 80 K, where sintering time is beyond the life time of the solar system (no sintering).
- In contrast, around the geysers temperatures rise up to about 140 Kelvin, at which sintering processes take place within hours (Grundlach et al., 2018).
- Combining a temperature map of Enceladus' south pole region and of the deposition rate, should give the respective thickness of the sintered layer.



IR intensity map showing regions of 140 K (Spencer et al., 2011).



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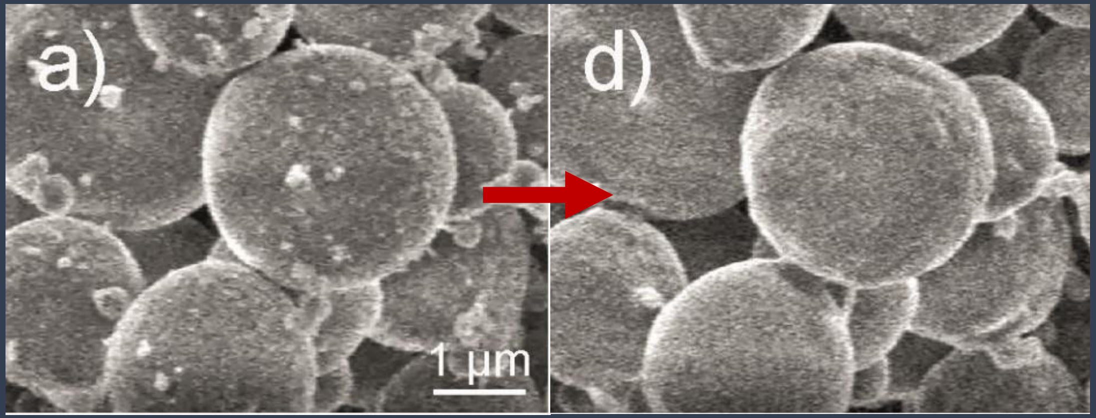
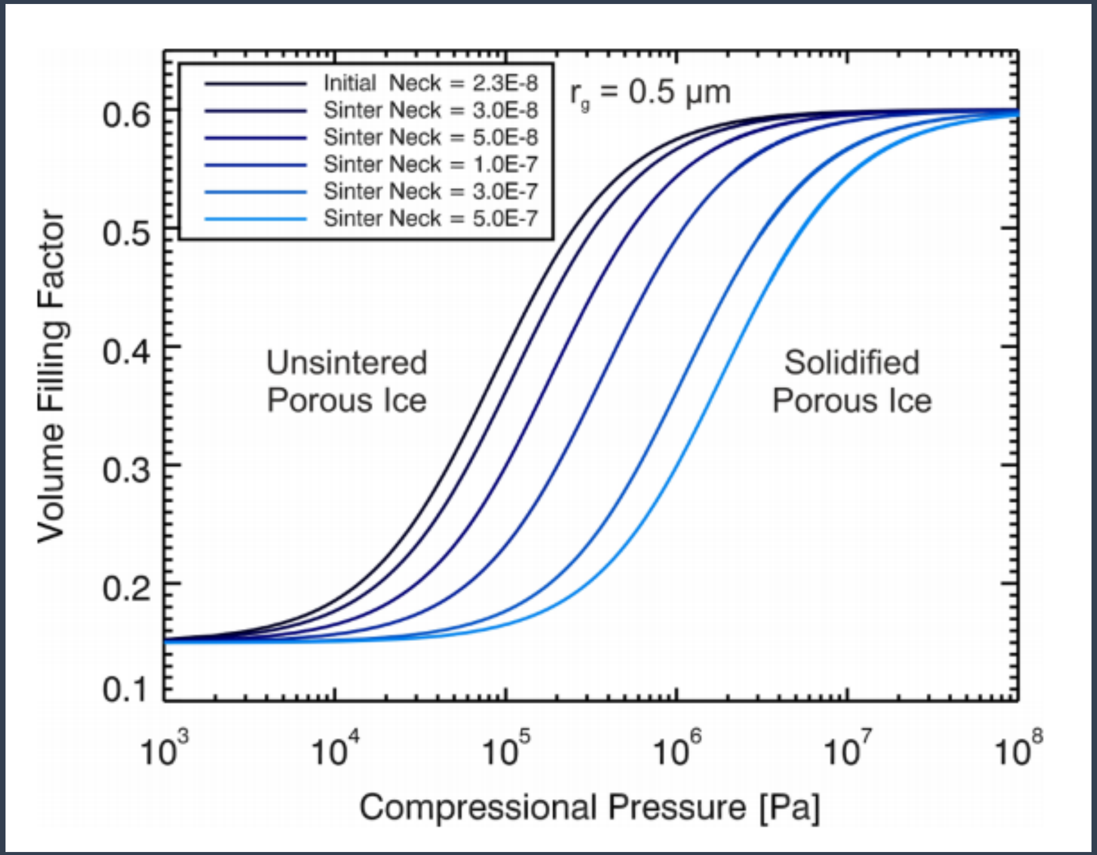
Density of sintered layer

- How much the sintering process increase the density, mainly depends on the neck radii, that form between the grains,

- And is mainly dependent on time and temperature.
- The extend of sintering will be addressed in the analysis.



(Grundlach et al., 2018).



(Grundlach et al., 2018).

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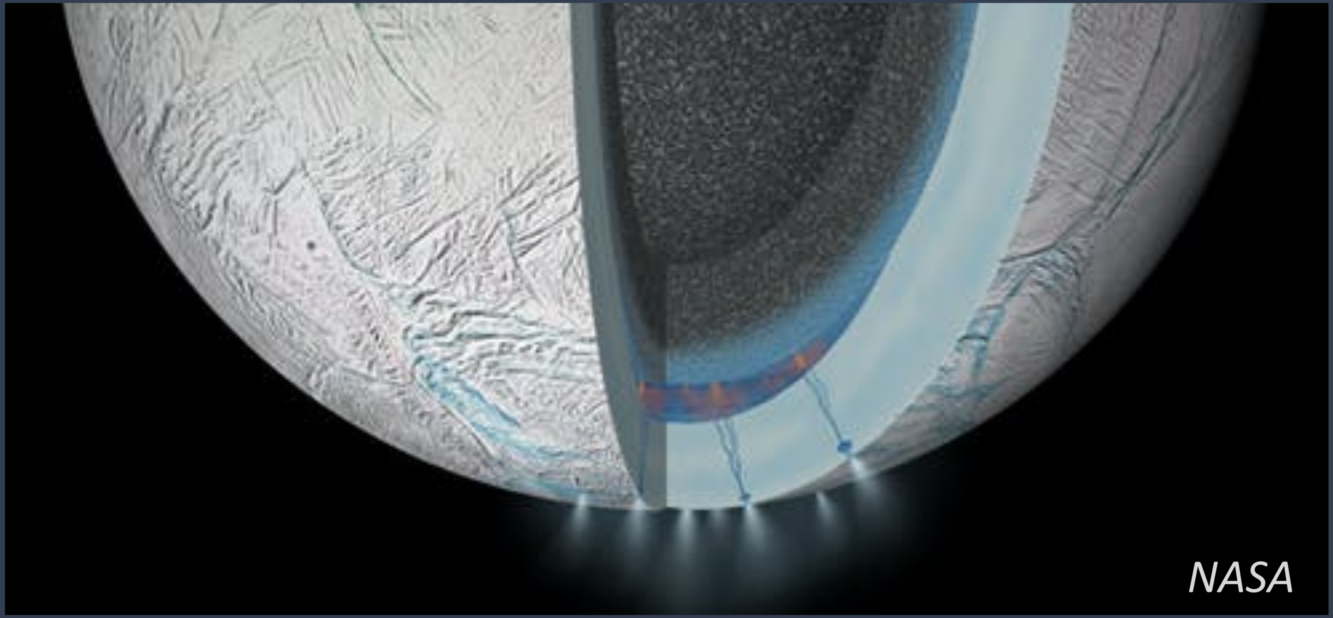
Enceladus icy crust

- The third layer in our model represents the outer crust of the small planetesimal.
- We assume it to consist of homogenous hexagonal crystalline ice with a density of 920 kg/m^3, and should have a permittivity value of $\varepsilon_r = 3.2$.
- As the melting probe is supposed to tap a near surface water filled crevasse from the geysers, the question of the thickness of the ice crust lays beyond the scope of this study.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Conclusion and Outlook

- A melting probe and a radar based navigation system as supposed for the Enceladus Explorer will have to deal with three different types of icy layers:
  - An uppermost layer of piled up snow/ice grains deposited from the geysers, with relatively low density of *588 kg/m³*.
  - A layer of the snow deposits which have undergone a sintering process, with an elevated density.
  - A layer of solid crystalline ice making up Enceladus' outer shell, with a density of 920 kg/m^3.
- From the density given by the void space, the respective permittivity of the layers can be calculated.
- To complete the picture, some open questions have to be addressed for:
  - Were the geysers locally stable within the last 50 Myr?
  - How does grain shapes and size variations affect the pore space within the snow layer?
  - How does the sintering process affect the density?

Feedback Welcome!

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