



Surfing radio Waves to detect liquid water in the solar system

SUPPLEMENTARY MATERIALS

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** INAF-IAPS, Rome, Italy



Funded by
the European Union



European Research Council
Established by the European Commission



Roma Tre



Surfing radio Waves to detect liquid water in the solar system

Dielectric Characterization of Salty-Ice Analogues and Simulations of Radar Signal Propagation Through the Icy Crust of Jovian Moons

Gabriele Turchetti*, Alessandro Brin**, Sebastian Lauro*, Barbara Cosciotti*, Elisabetta Mattei*, Elena Pettinelli*

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Search for Liquid Water: Electromagnetic Properties

$$\varepsilon = \varepsilon(\omega, T, c)$$

$$\mu = \mu(\omega, T, c)$$

$$\sigma = \sigma(\omega, T, c)$$



Search for Liquid Water: Electromagnetic Properties

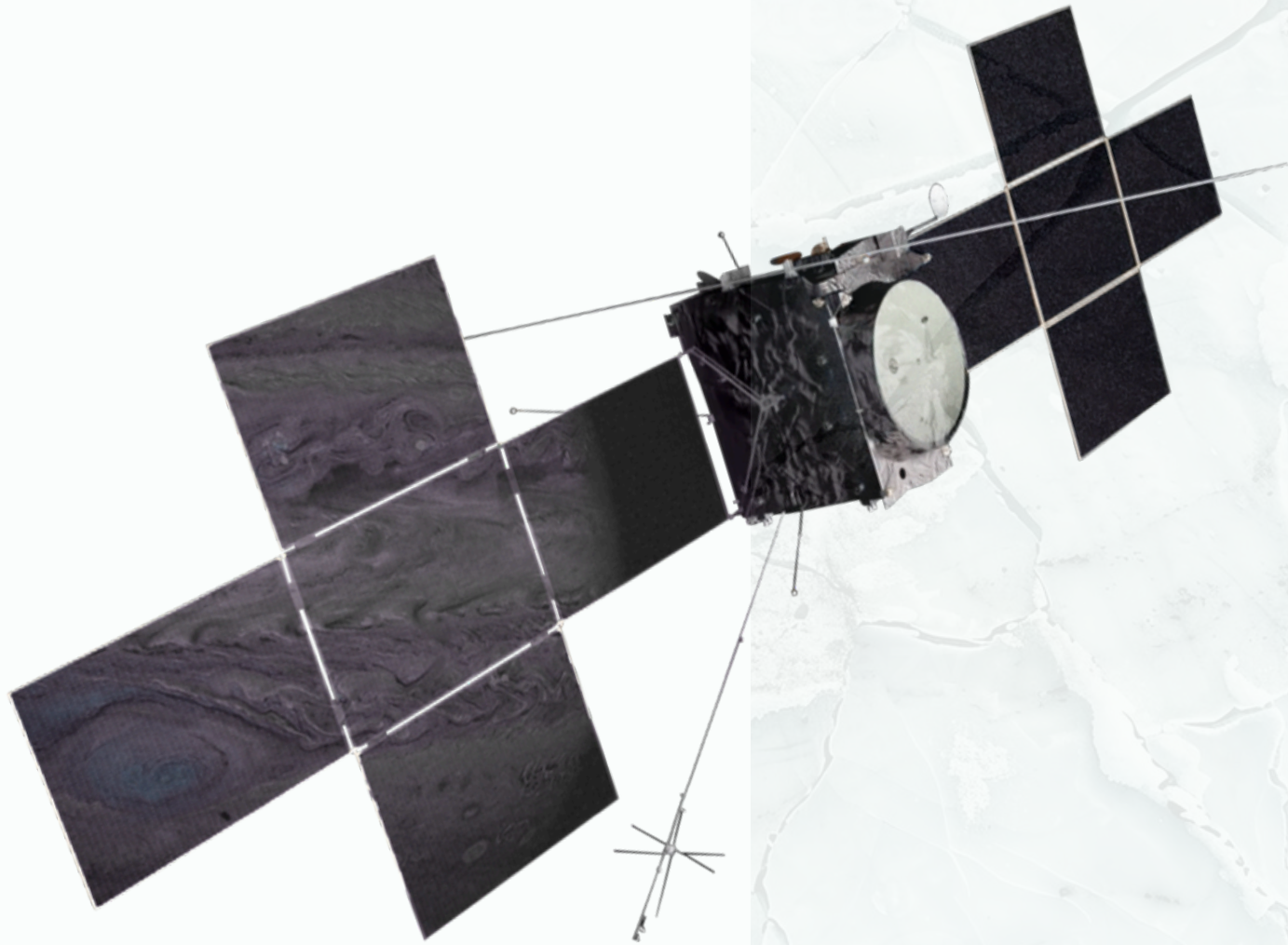
$$\epsilon = \epsilon(\omega, T, c)$$

~~$$\mu = \mu(\omega, T, c)$$~~

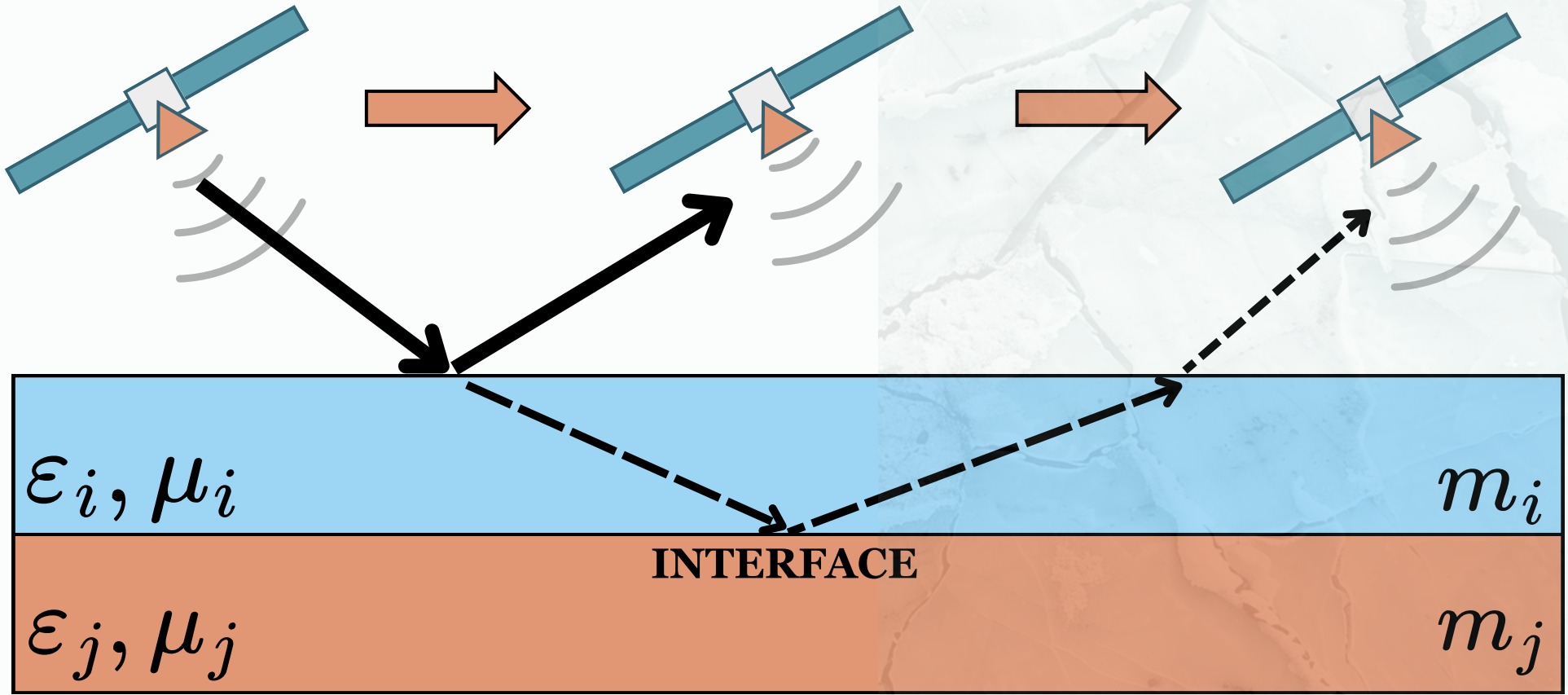
$$\sigma = -\omega\epsilon\epsilon''$$

Material	ϵ
Pure Ice	3 - 3.5
Snow	2
Water	80
Rocks	4 - 10
Dry Ice	2 - 2.5
Salt	5-6

Search for Liquid Water: Radio Echo Sounding



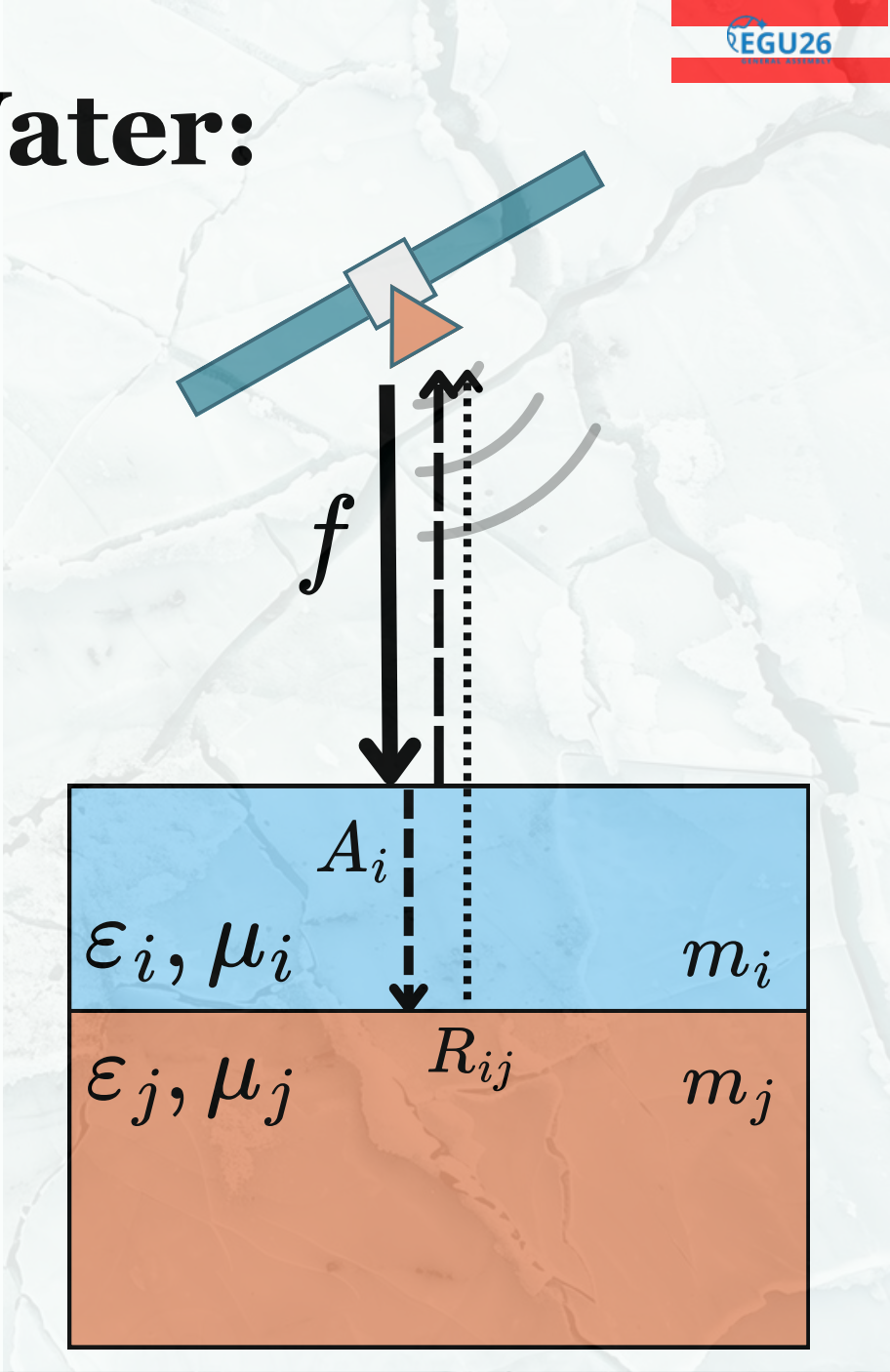
Search for Liquid Water: Radio Echo Sounding



Search for Liquid Water: Radio Echo Sounding

$$A_i = A(\epsilon_i'', \mu_i'')$$

$$R_{ij} = R(\epsilon_i, \mu_i, \epsilon_j, \mu_j)$$



The Missions

- 2030-2031
- JUICE and EUROPA CLIPPER
- **RIME** and **REASON** Radars
- Icy Crust and **Liquid Water**
- **Habitability** Conditions



EUROPA
CLIPPER

The Targets: Jovian Icy Moons

Europa

- Thin **Salty** Icy Crust
- Exchange Processes Ice-Ocean
- Cryovolcanism



The Targets: Jovian Icy Moons

Europa

**Signal Propagation
Effects of Salts (NaCl)
Target Detectability**



Measurements: Laboratory Setup

Glass and salt are not real pictures: they are included for illustrative purposes only.



NaCl Doped Ice



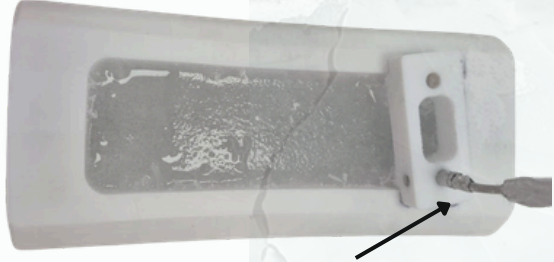
Cells: 50, 100, 150 mm



Vector Network Analyzer



Ultra-freezer 193 K



Pt 100 Sensor

Measurements: Laboratory Setup

Glass and salt are not real materials: they are included for illustrative purposes only

SUPPLEMENTARY

MATERIALS

or

COFFEE BREAK



NaCl Doped Ice



Pt 100 Sensor



Measurements:

Laboratory Setup

- Preparation of the **solution**
- Placement of the cell in the **ultra-freezer**
- **Pouring the solution** into the cell
- After a given time, **removal of the cell**
- Connection to the **VNA**
- Measurement of **scattering parameters**
- Application of **NRW algorithm**

A pt 100 sensor monitors the T inside the sample



SUPPLEMENTARY MATERIALS

Measurements: NaCl Doped Ice

- Solid
 $T < 252K$



- Mushy
 $252K < T < 273K$



- Liquid
 $T > 273K$



Material	ϵ
Pure Ice	3 - 3.5
Snow	2
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Rocks	4 - 10
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Measurements: NaCl Doped Ice

- Solid
 $T < 252K$



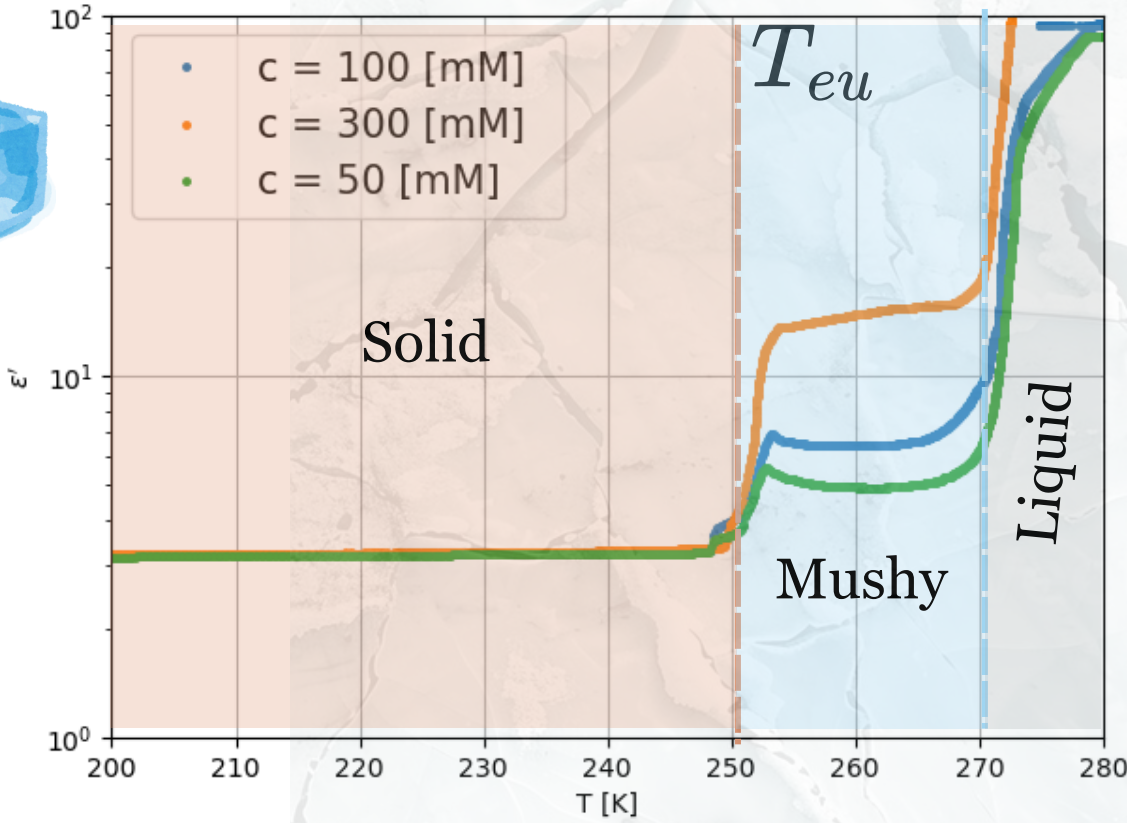
- Mushy
 $252K < T < 273K$



- Liquid
 $T > 273K$

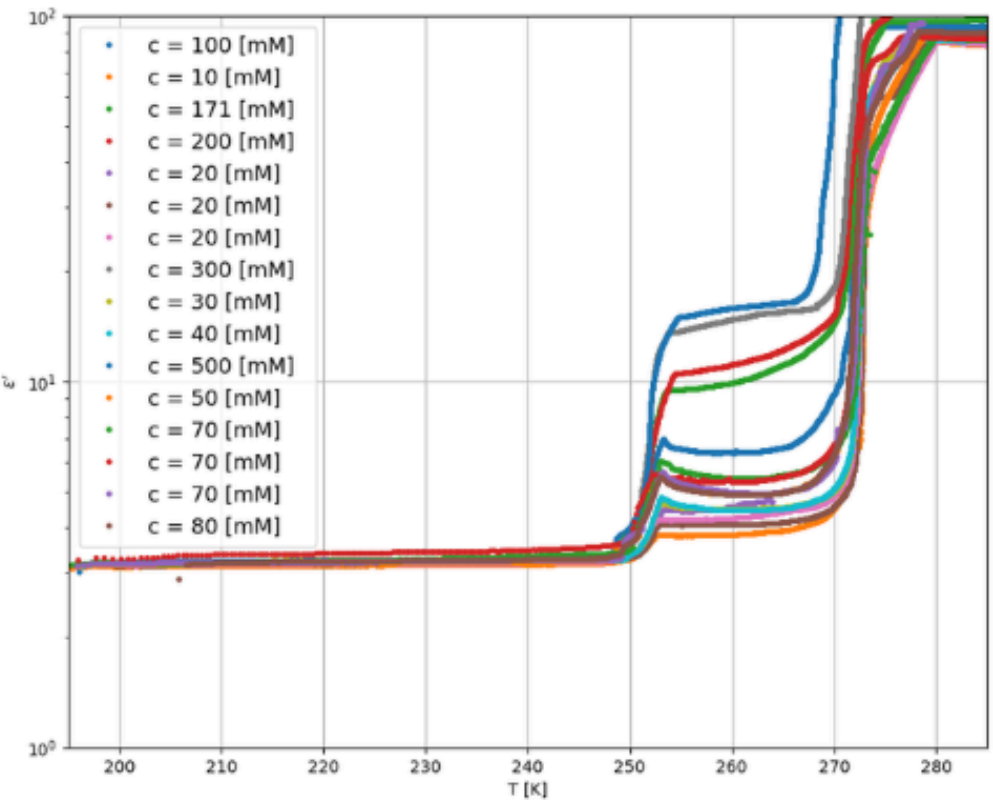


Real Permittivity

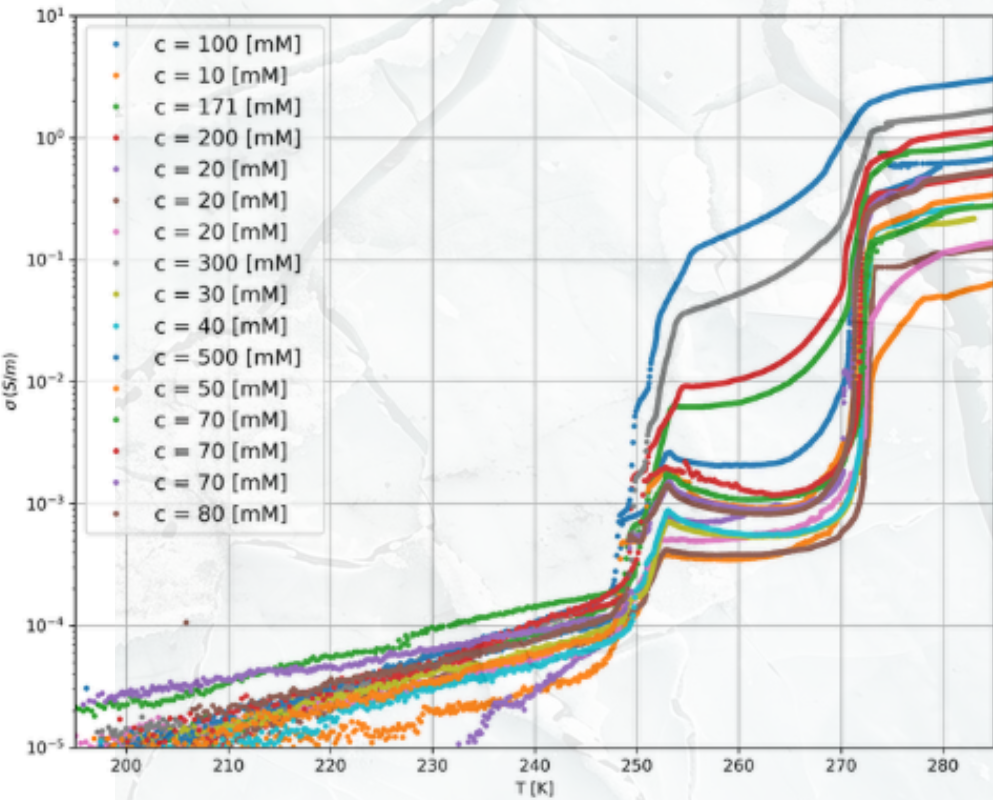


Measurements: NaCl Doped Ice

Real Permittivity

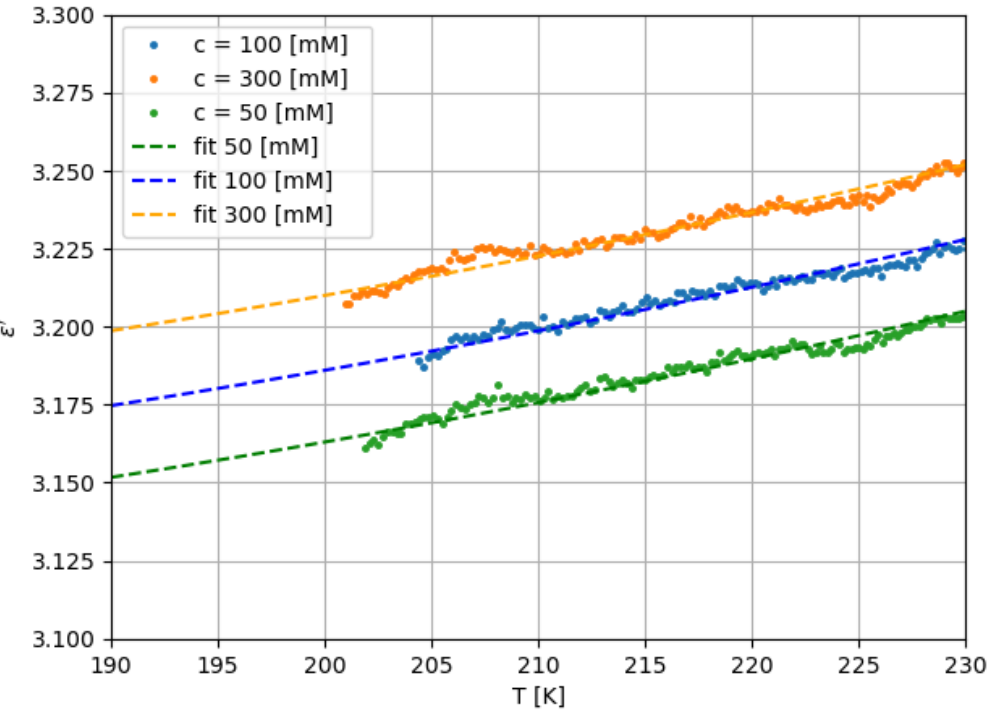


Conductivity



Measurements: NaCl Doped Ice

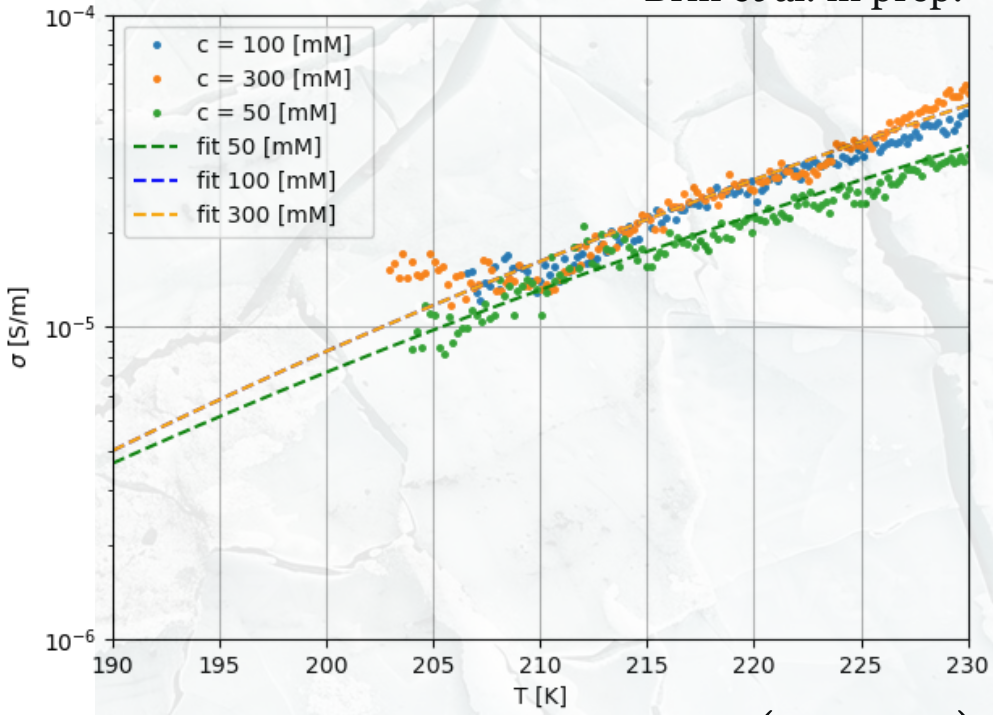
Real Permittivity



$$\epsilon' = Ac^B + C(T - T_0) + D(T - T_0)^2$$

Conductivity

Brin et al. in prep.

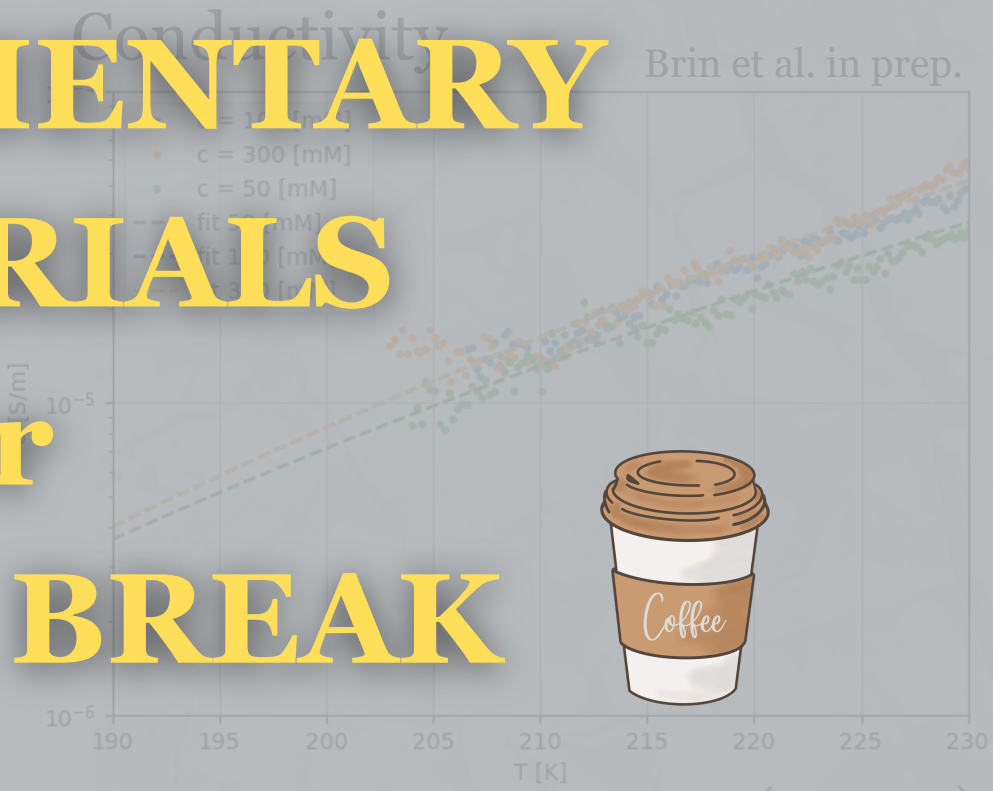


$$\sigma = \sigma_0(c) e^{-\frac{Ea(c,T)}{kb} \left(\frac{1}{T} - \frac{1}{T_0} \right)}$$

Measurements: NaCl Doped Ice

SUPPLEMENTARY MATERIALS or COFFEE BREAK

Brin et al. in prep.



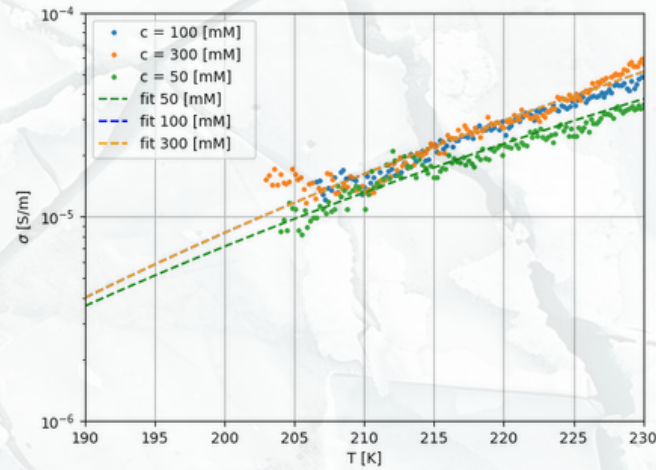
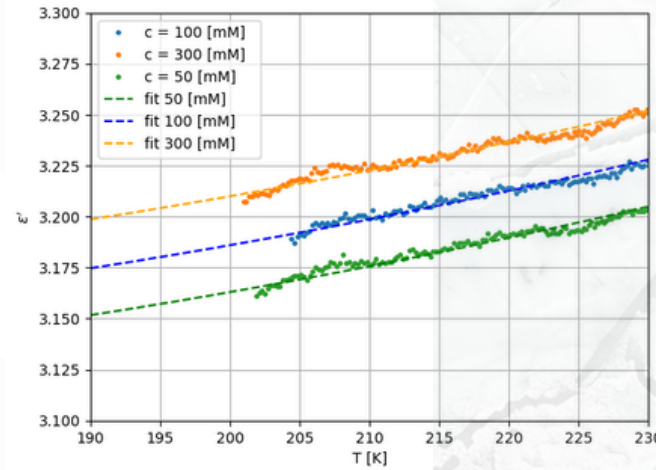
$$\epsilon' = Ac^B - CT + DT^2$$

$$\sigma = \sigma_0(c) e^{-\frac{Ea(c,T)}{kb} \left(\frac{1}{T} - \frac{1}{T_0} \right)}$$

Measurements: NaCl Doped Ice

$$\epsilon' = Ac^B + C(T - T_0) + D(T - T_0)^2$$

$$\sigma = \sigma_0(\text{conc}) e^{-\frac{E_a^\sigma}{k_b} \left(\frac{1}{T} - \frac{1}{T_0} \right)}$$



The **activation energy E_a increases until** the concentration of **100 mM**, around 6wt% of the solution. The solutions with **higher concentrations** show a different behavior that is **not dependent on the concentration**. Even σ_0 is almost the same for solution with concentration above the limit of 100mM. While the **behavior of the permittivity is different for different concentration, the conductivity is concentration-dependent only until the limit of 100mM.**

SUPPLEMENTARY MATERIALS

Measurements: NaCl Doped Ice

$$\sigma = \sigma_0(\text{conc}) e^{-\frac{E_a^\sigma}{k_b} \left(\frac{1}{T} - \frac{1}{T_0} \right)}$$

AND THAT'S NOT ALL

The **activation energy E_a increases until** the concentration of **100 mM**, around 6% of the solution. The solutions with **higher concentrations** show a different behavior that is **not dependent on the concentration**. Even σ_0 is almost the same for solution with concentration above the limit of 100mM. While the **behavior of the permittivity is different for different concentration, the conductivity is concentration-dependent only until the limit of 100mM.**

SUPPLEMENTARY MATERIALS

Measurements:

NaCl Doped Ice

$$\sigma = \sigma_0(\text{conc}) e^{-\frac{E_a^\sigma}{k_b} \left(\frac{1}{T} - \frac{1}{T_0} \right)}$$

AND THAT'S NOT ALL

The **conductivity**, then the imaginary part changes its behavior with the **interval of temperature**. There are two slopes with solution with concentration above the limit of 100mM, and three different slopes for solution with lower concentrations.

The **slopes change** is a **change in the parameter of activation energy E_a** . The temperature interval are:

- 251-220
- 220-190
- 190-100

SUPPLEMENTARY MATERIALS

Simulations: Signal Penetration

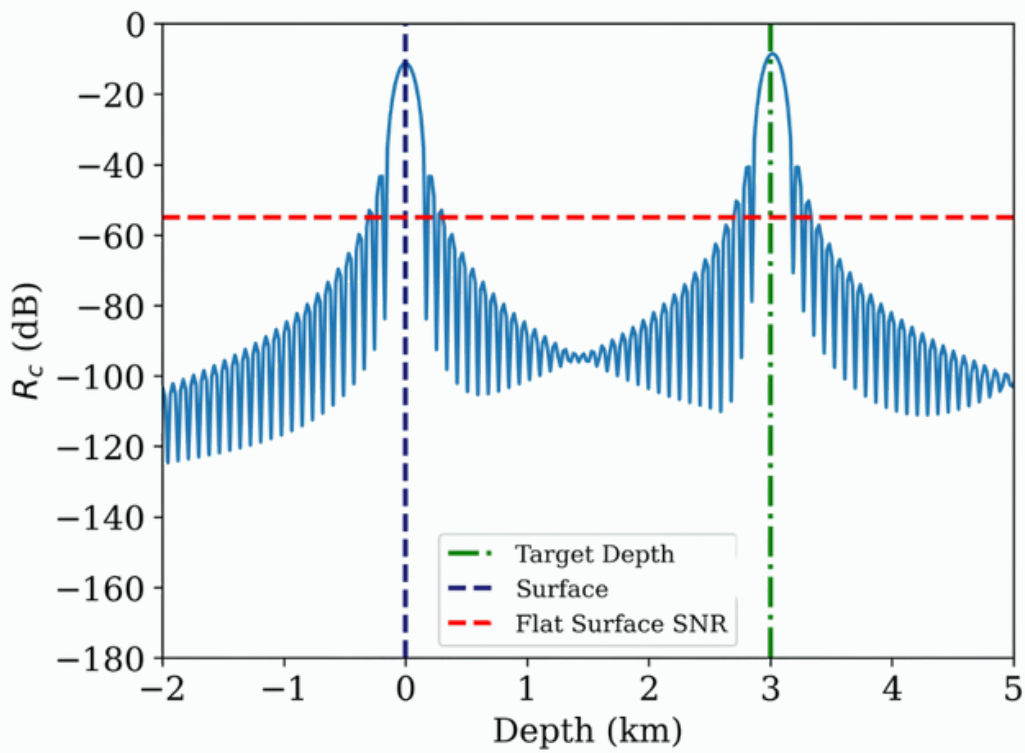
Target Detectability:

- Thickness of the crust
- Depth of the Target
- Crust Composition
- Temperature Gradient

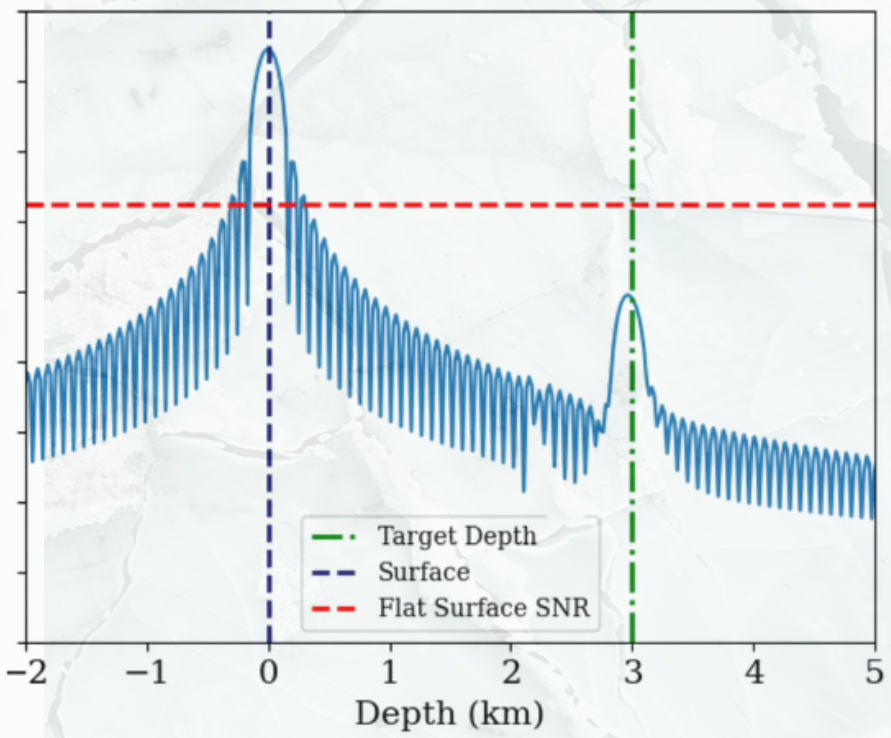


Simulations: Signal Penetration

Pure Icy Crust

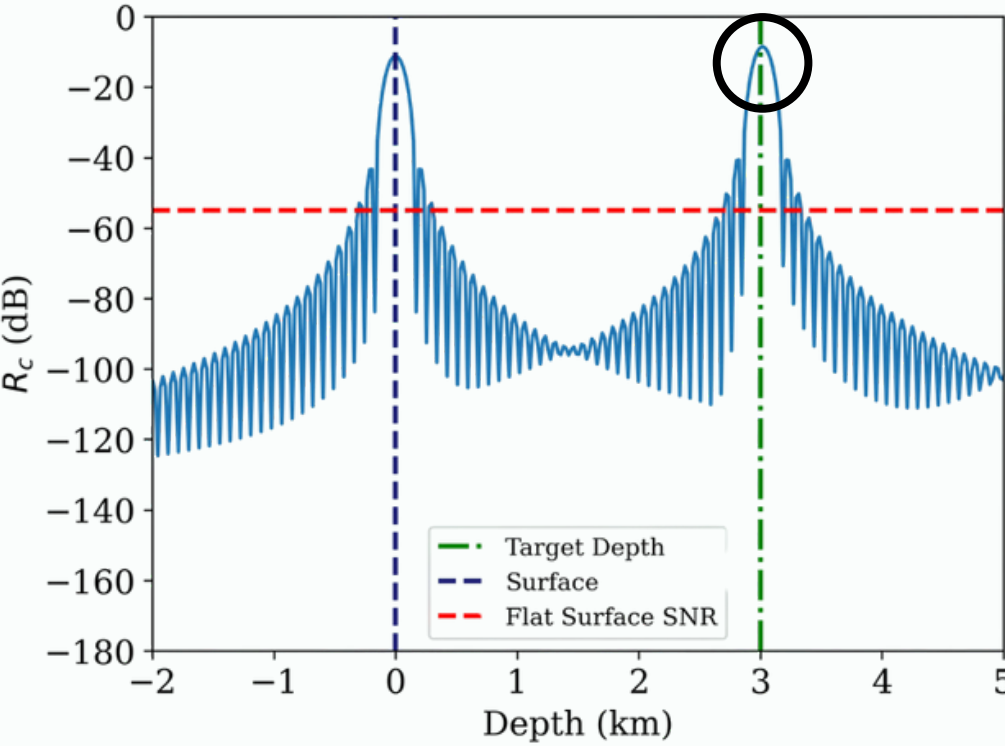


Salty Icy Crust - NaCl

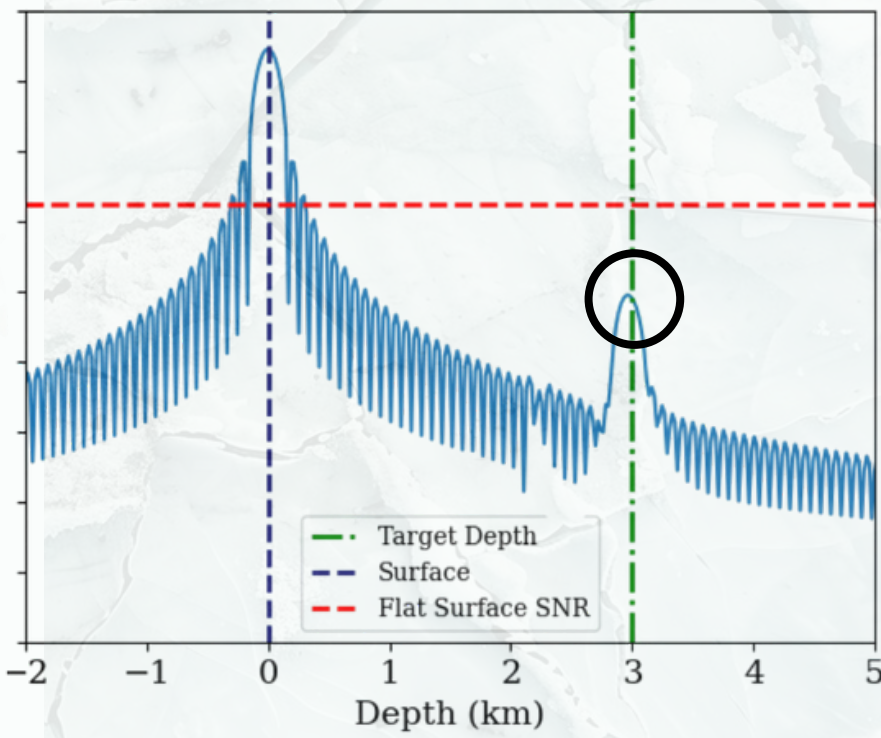


Simulations: Signal Penetration

Pure Icy Crust

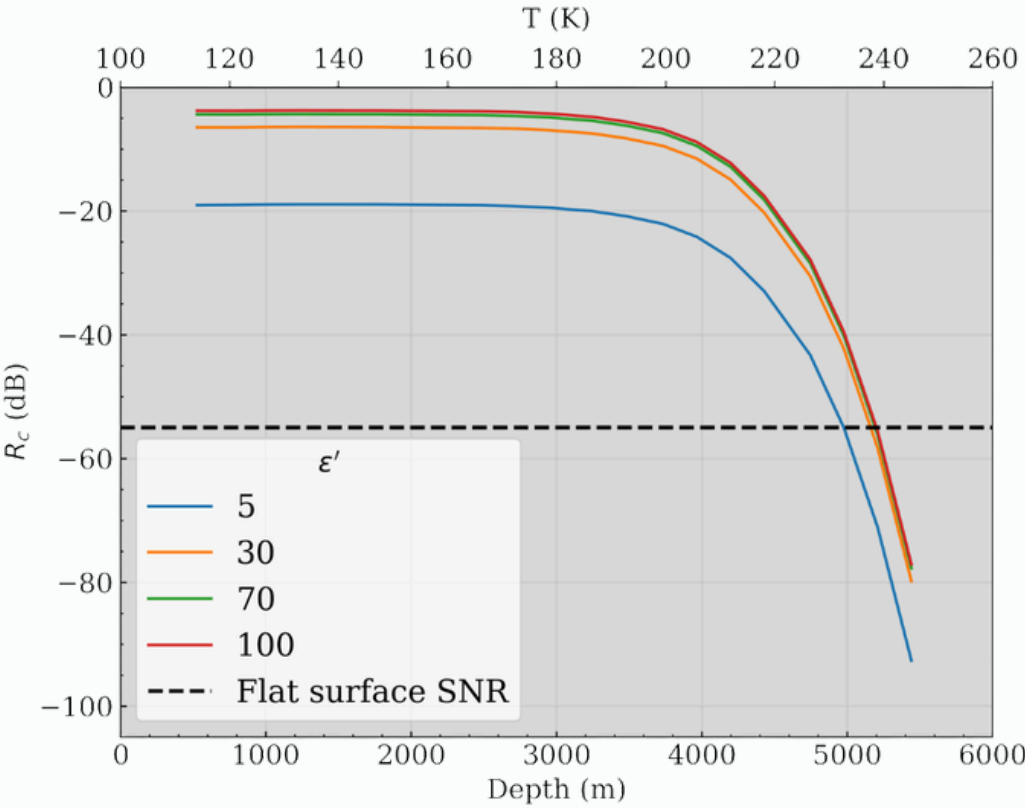


Salty Icy Crust - NaCl

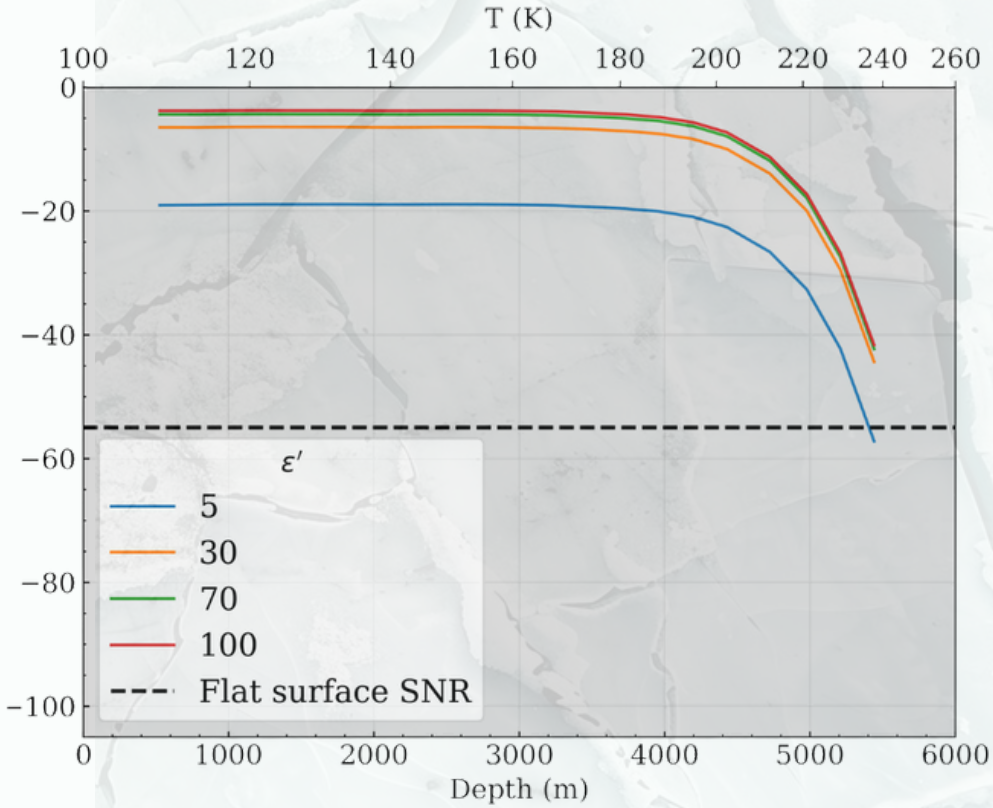


Simulations: Signal Penetration

Linear T Profile



Power Law T Profile



Conclusions

Radar performance is affected by:

- **Presence of salt** (hoping there is not much)
- **Distribution of salt** (hoping it is just near the surface)
- **Temperature profiles**
- **Dielectric contrasts** (hoping there is water)

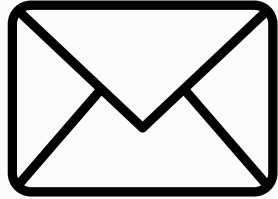
Permittivity of NaCl Doped Ice is very challenging to study



Next Steps

- **Signal Propagation** through other **Scenarios** of the icy crust
- **Additional Measurements**
- Different Measurement **Cells**
- **Climatic Chamber**
- **Lower Temperature**
- **Salty Ice Tomography**

Contacts



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