A multimodal endoscopic approach for characterizing sea ice optics, physics, biology and biogeochemistry at small scale

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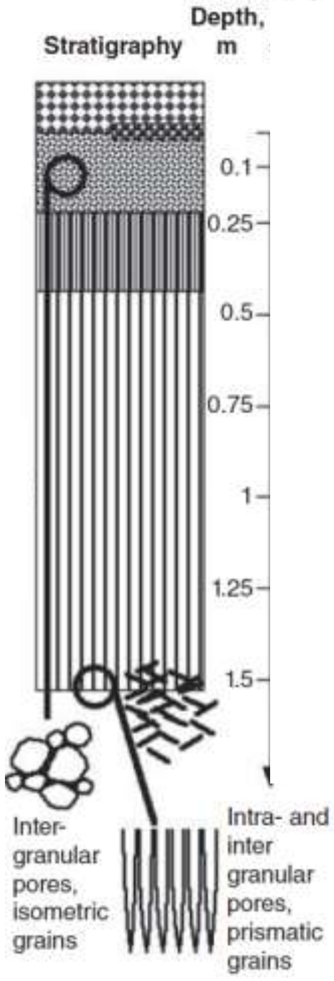
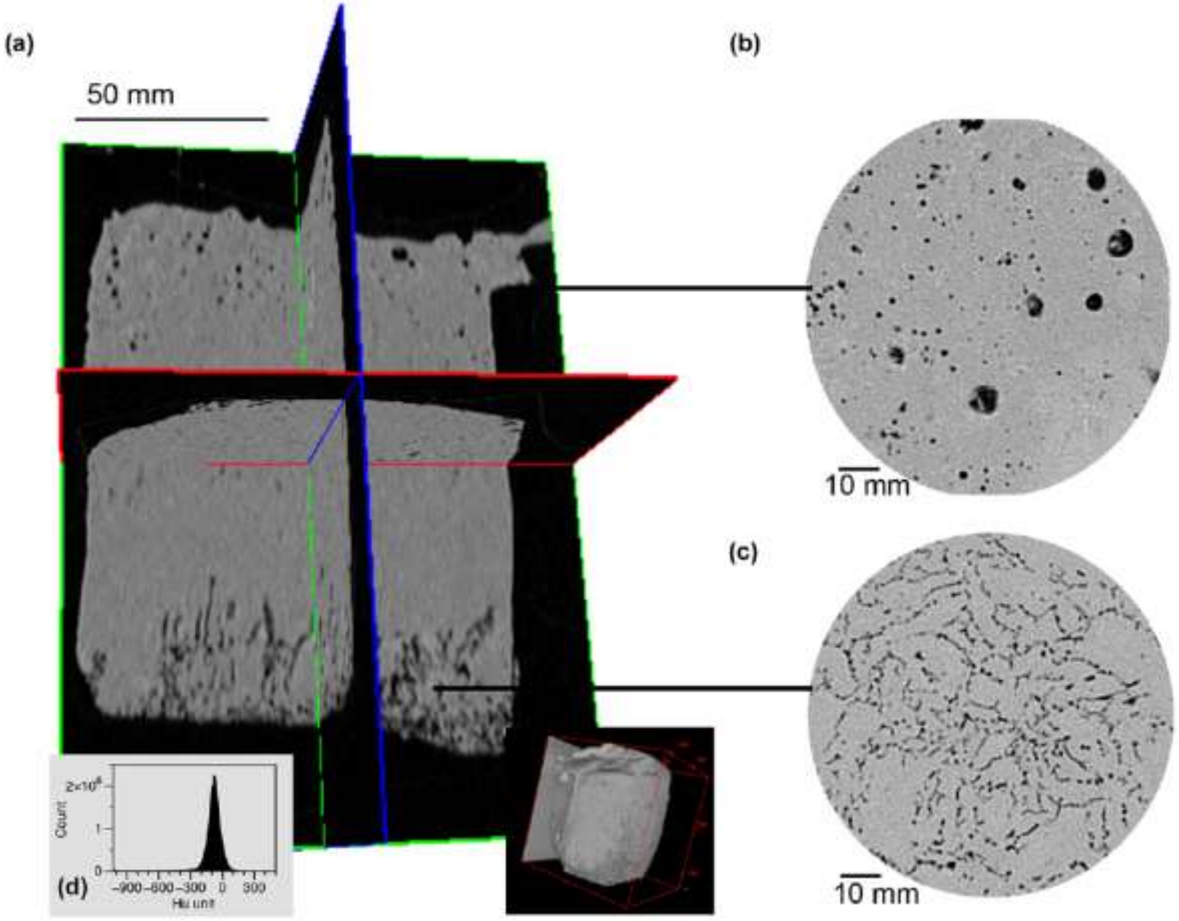
Coring is the common method for sampling sea ice: It **is quite brutal!**

The reality of sea ice physical properties is not compatible with such sampling methods



Petrich and Eicken 2017



Crabeck et al. 2016

Objective:

To develop a **radically different approach** for sensing and sampling the sea-ice interior, that is compatible with the scales relevant to physical, optical, biogeochemical and biological in-ice processes

Concept

- An **endoscopic platform** inspired from medical applications

- As small as possible and able to **gently penetrate sea ice** through a hole made by melting

- A **science payload** including various sensing modalities

Sentinel North

Prototyping the endoscopic platform

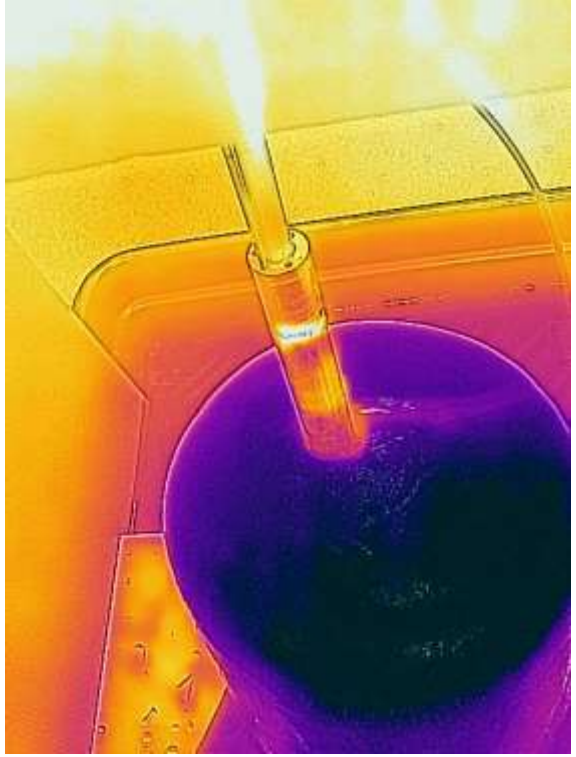
First lab prototype for developing the boring method

- 1-inch ⦰ with heating tip (55 W)
- Boring by gravity
- Power optimized to make a hole of the quasi same diameter as the endoscope

- Boring speed: ca. 0.06 mm s^{-1}
- Ca. 40 min for 1.5 m of sea ice
- Ultrasound increases boring speed by 15%

Under development:

- Temperature control feedback loop
- Smaller diameter
- Directional boring



Payload: different measuring systems under development

(see the corresponding posters)

1. **Reflectance probe** for determning sea ice optical properties **Christophe Perron, Poster 80**

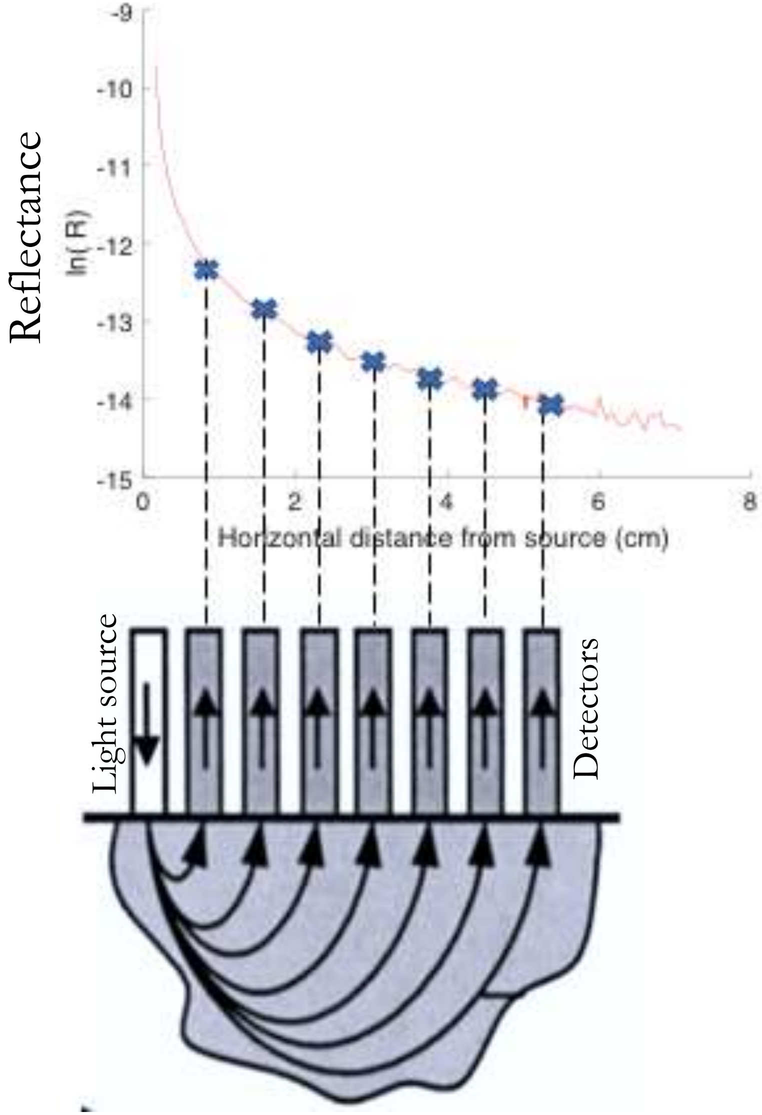
2. **Radiance camera** for measuring in-ice structure of the light field **Raphaël Larouche, Poster 79**

3. **Measuring nitrate concentration** using UV- Absorption and Raman spectroscopy
   Yasmine Alikacem, Poster 81

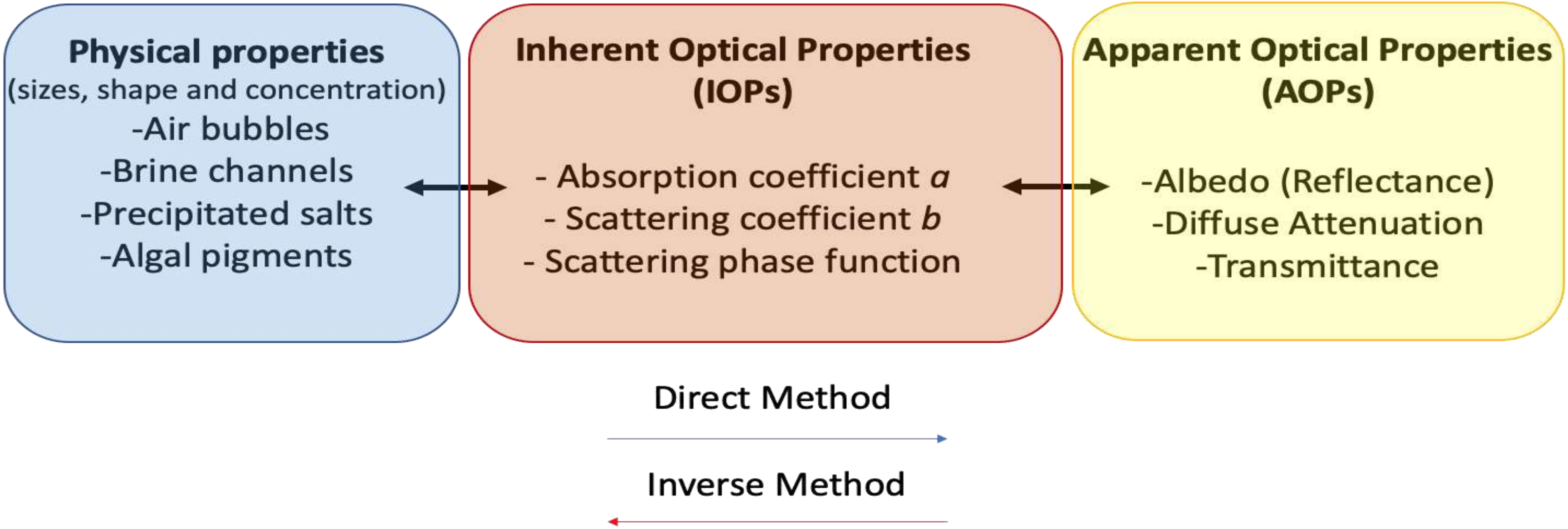
4. **High resolution imaging:** in-ice microscopy

1- Reflectance probe inspired by biomedical optics (tissue)

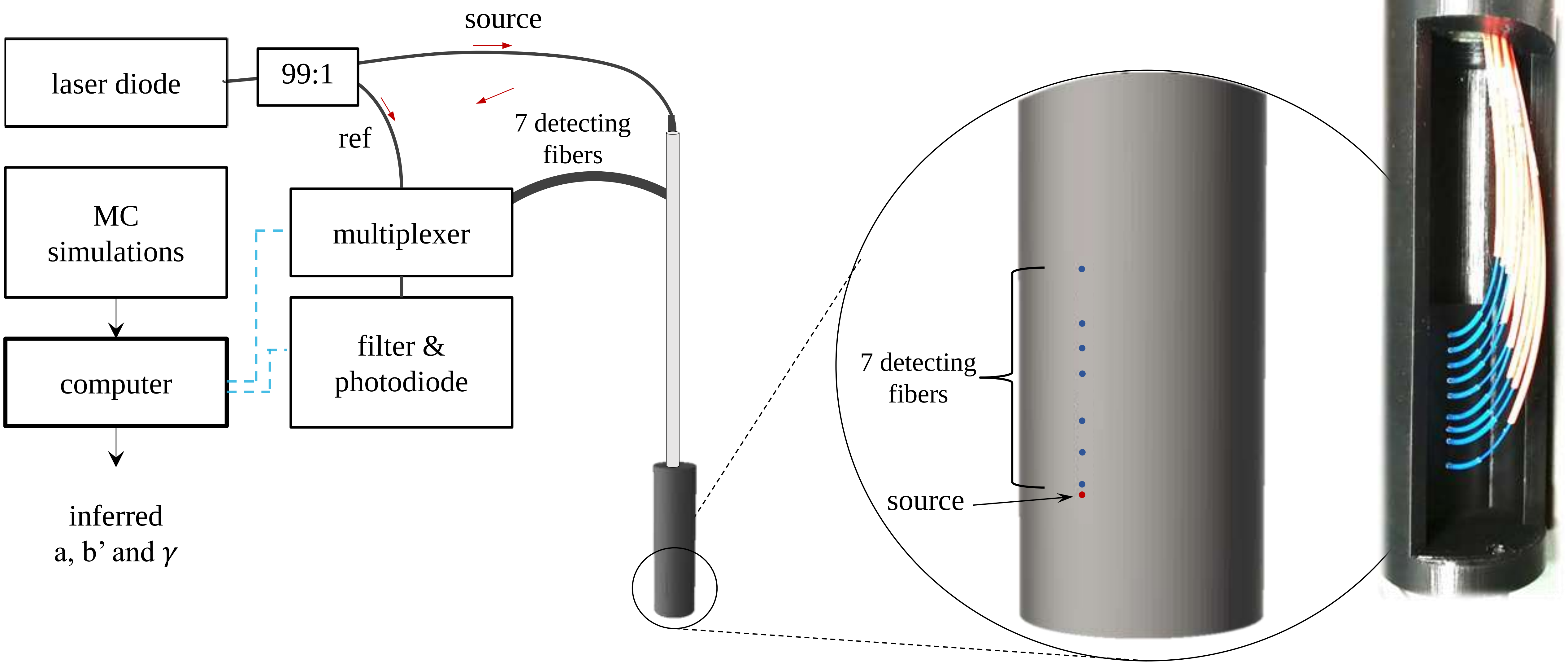
Photons from a source placed at the surface, reflected by the medium at different distances from the source, are measured by surface detectors



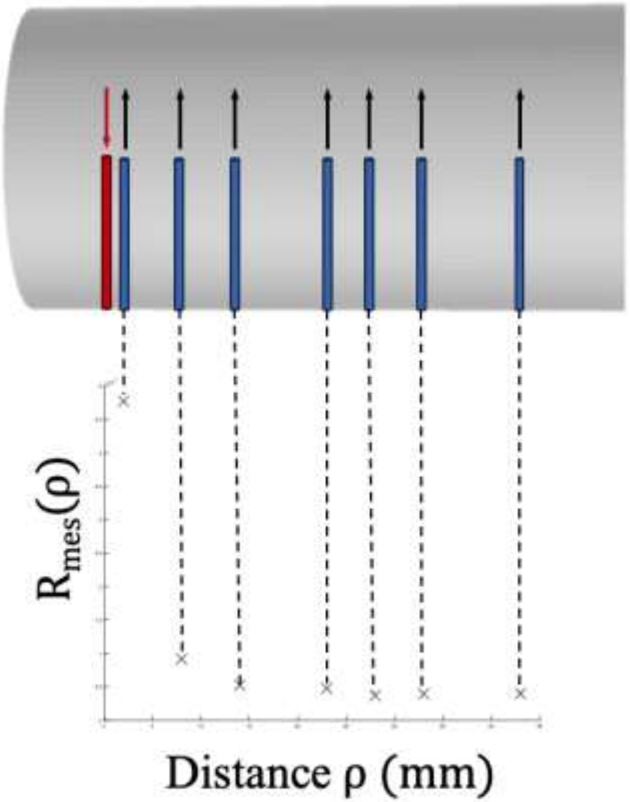
Linking physical and optical properties of sea ice



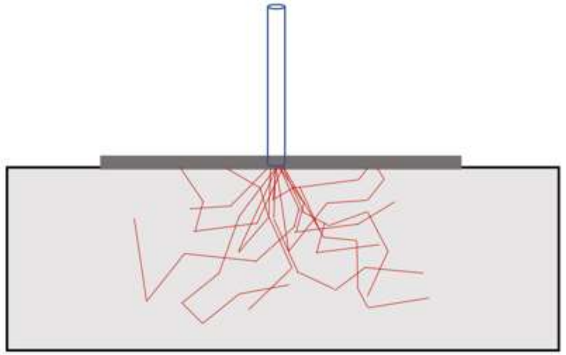
Protoype for vertical profiles



Measurement



Monte-Carlo Simulation



$a = [0.01 \ .... \ 2] \ m^{-1}$
$b' = [0.5 \ .... \ 200] \ m^{-1}$
$\gamma = [0.7 \ .... \ 1.88]$

Look-up table

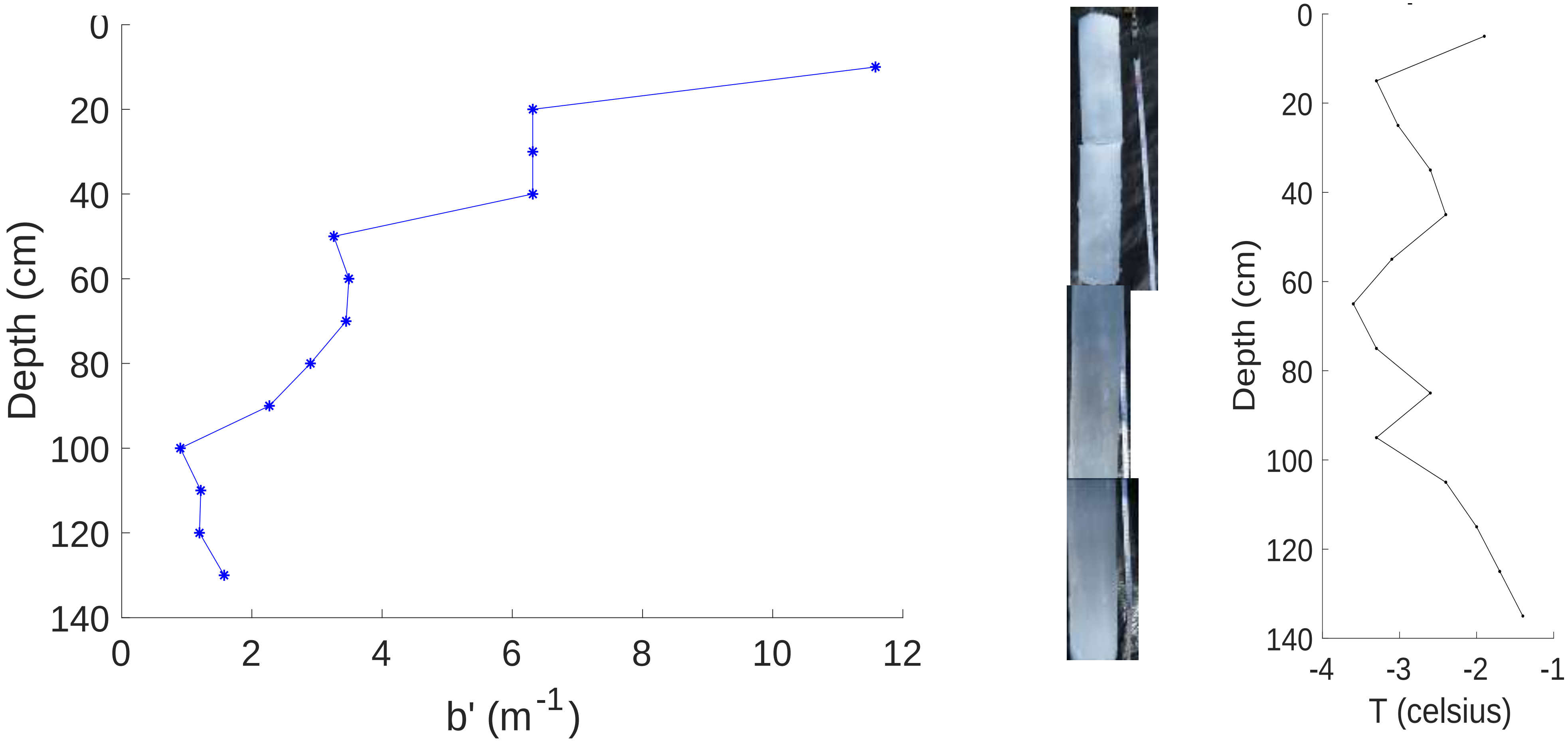
$\bar{R}_{sim}(\rho_i, a, b', \gamma)$

Least-square fitting

inferred IOP (a, b' and γ)

Test: May 2019 in Qikiqtarjuaq (Baffin Island)

Reduced scattering coefficient vs. depth and T

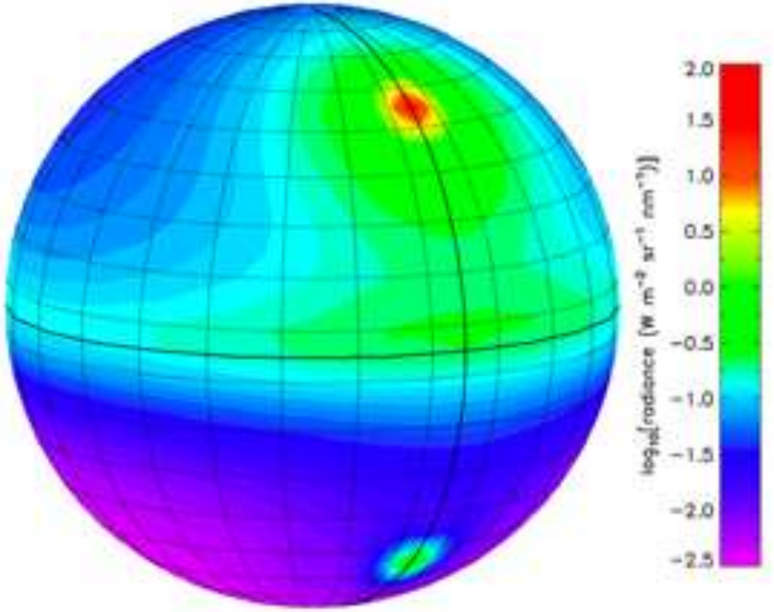


2- Radiance camera

to measure the geometry of the in-ice light field

Sea ice is a strongly heterogenous solid medium in which light propagation is difficult to measure, understand and model

Goal: to develop a small camera for measuring the most fundamental radiometric quantity, radiance, along vertical profiles in sea ice, from which all AOPs can be derived, and IOPs can be estimated.



Radiance angular distribution over 4π steradians at a given location in space

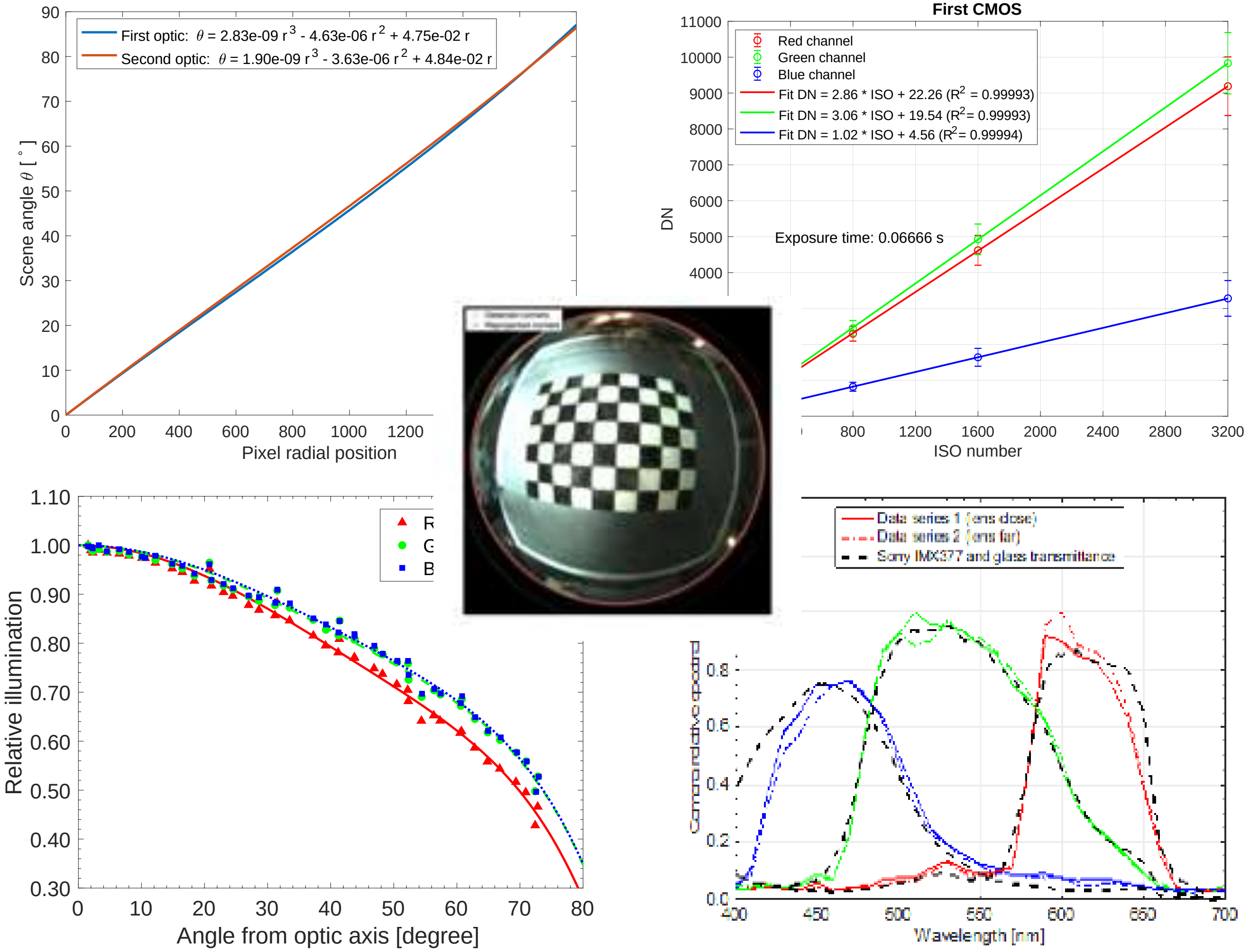
Commercial 360° camera:

5.82 cm

Insta360 ONE™

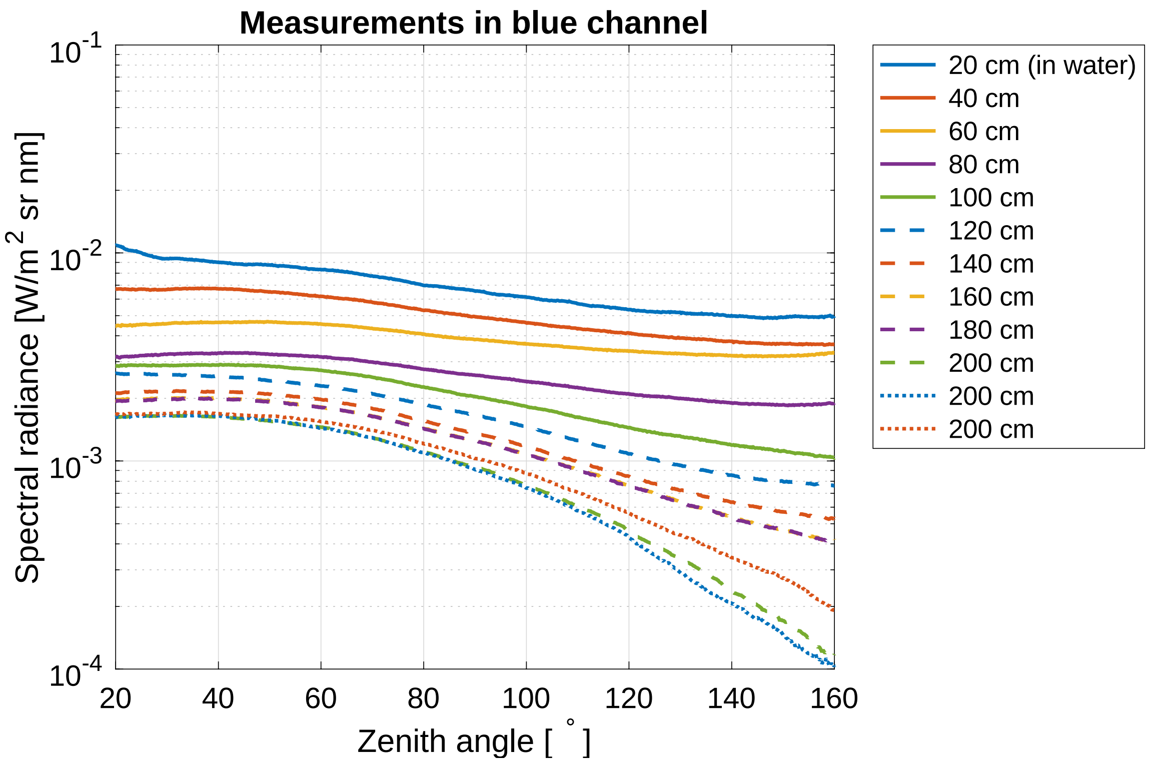
Calibration and characterization:

- Geometric calibration
- Relative illumination
- Gain and integration time linearity
- Relative spectral response
- Absolute radiance calibration

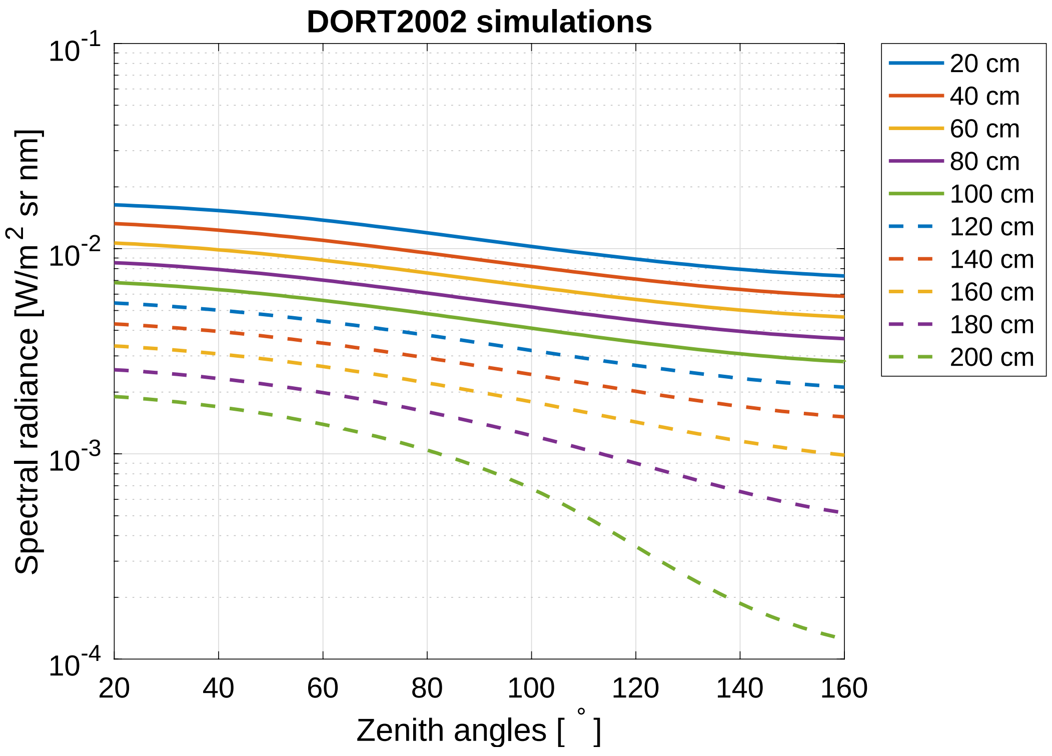


First results:

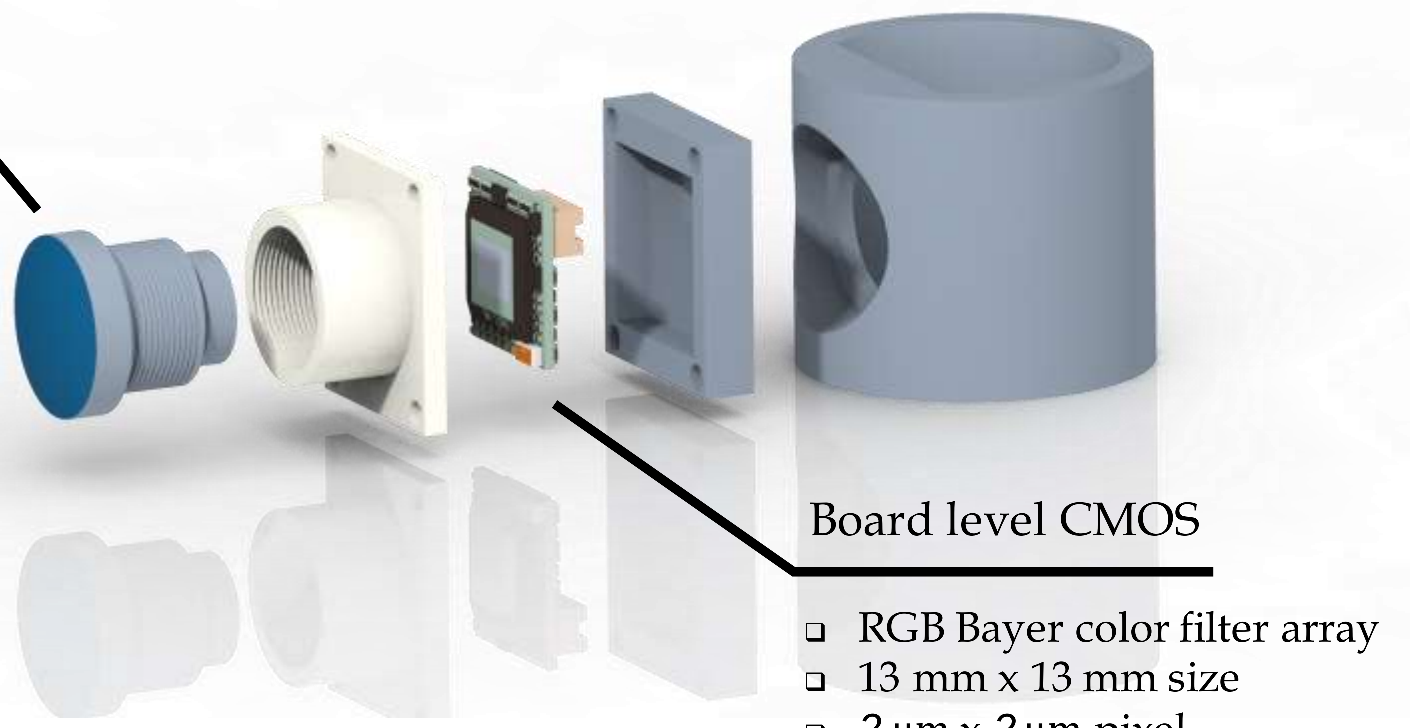
Field measurements on ODEN icebreaker (August 2018)



DORT 2002 radiative transfer simulation



Custom-made camera



- Miniature hyper fisheye lens and CMOS
- Allows more control of the camera than commercial ones
- SMALLER! The system will fit in a tube less than 30 mm in external diameter

3- Absorption-meter and Raman spectroscopy for measuring nitrate concentration

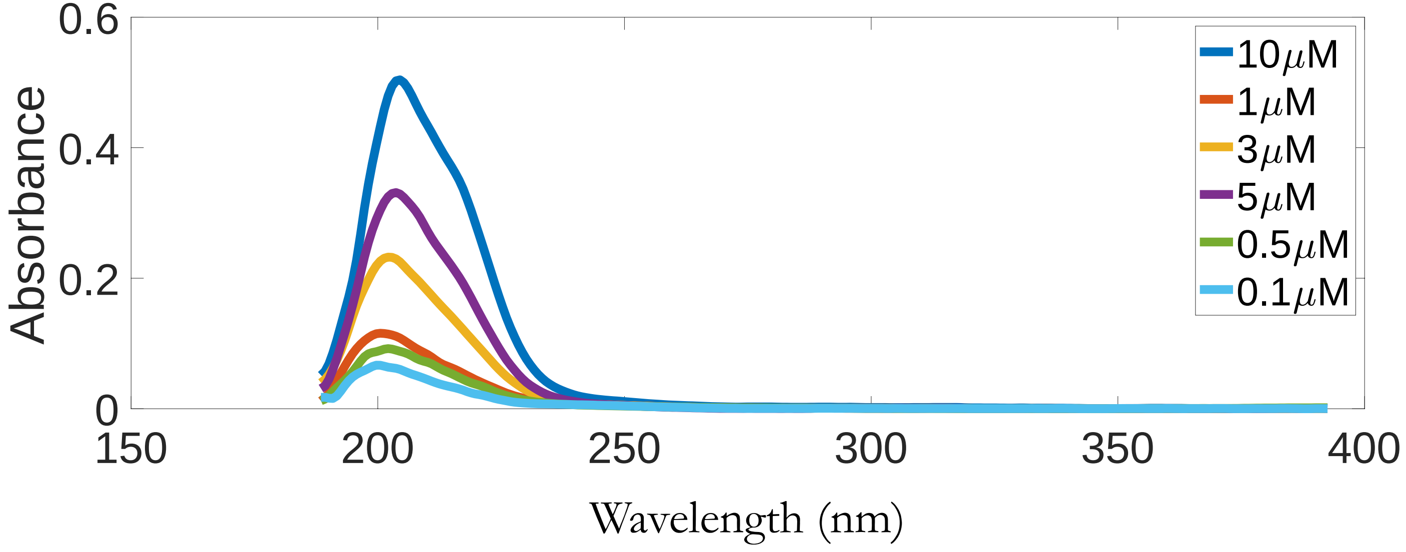
Nitrate distribution in sea ice is strongly heterogenous.

Classical sampling methods for nutrients have limitations (e.g. brine loss …).

Existing optical methods for nitrate determination may be adapted to measurements directly in sea ice.

- UV absorption spectroscopy

With an optical pathlength of 10 cm, nitrate concentration in pure water as low as 0.1µM could be detected.

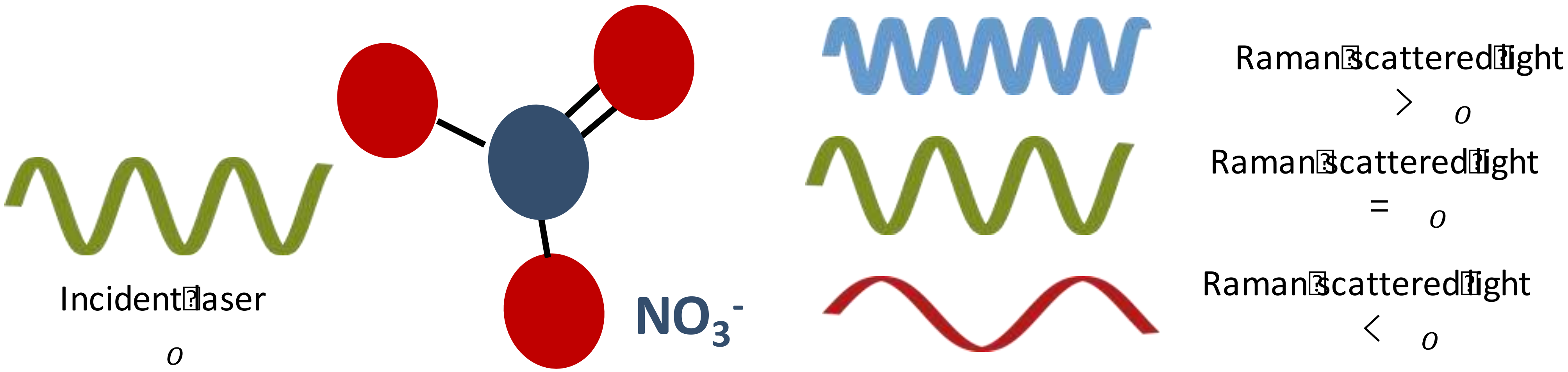


Absorption measurements, for several nitrate concentrations in milliQ water with a commercial liquid waveguide capillary cell.

Could be used on very small volumes of water sampled by the endoscope while boring

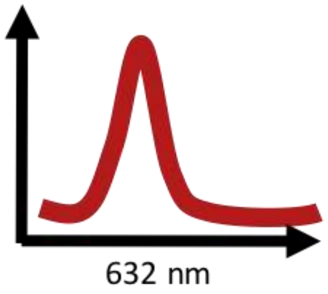
- Raman spectroscopy

When a sample is illuminated with a monochromatic light, inelastic scattering, also known as Raman scattering, can occur. The frequencies of the scattered light provide a fingerprint information about a sample's molecular composition. Nitrate has a Raman peak at 1045 cm^{-1} .

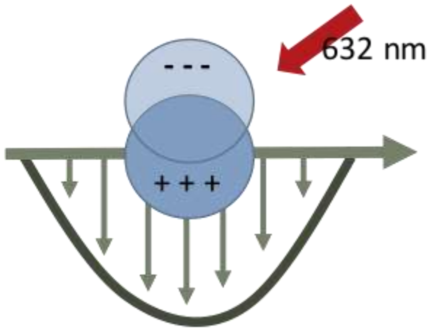


A Raman signal is typically very weak, but it can be enhanced by the use of nanoparticles assembled together to form a plasmonic surface.

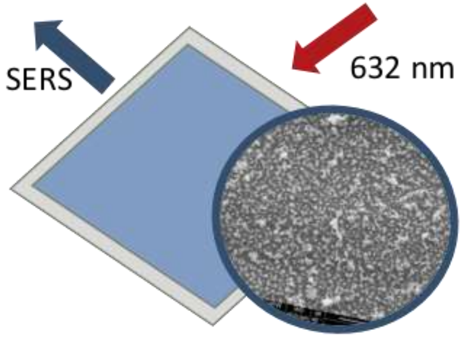
Gold nanoparticle



Gold nanoparticle absorption spectrum



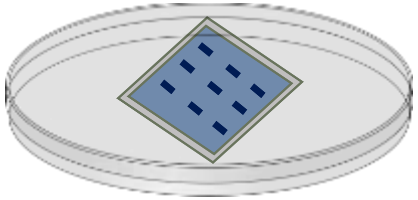
Excited gold nanoparticle



Plasmonic surface

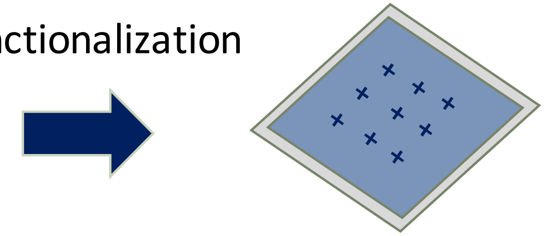
Surface-Enhanced Raman spectroscopy (SERS)

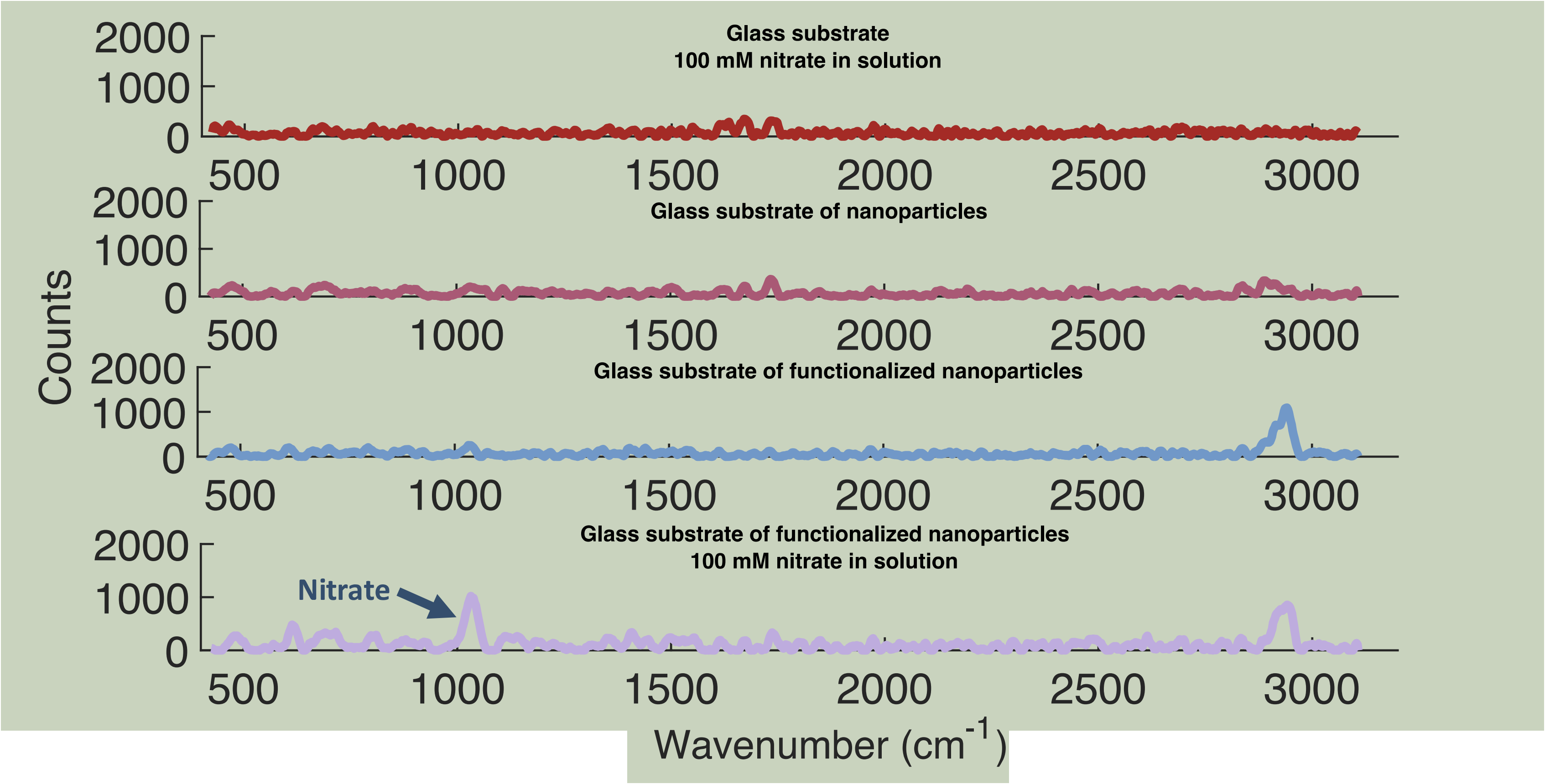
First attempt at functionalizing gold nanoparticles for nitrate detection



2(Dimethylamino)ethanethiol
hydrochloride (DMAE)

Functionalization





Promising, but not yet sensitive enough

What's next?

- **Endoscopic platform:** finalize the boring method
- **Reflectance probe:** finalize a rugged field version of the instrument →MOSAiC
- **Radiance camera:** collect more data with the commercial camera, and finish the custom-built one
- **Nutrient optical measurement:** test the optical absorption method on pumped melted sea ice, and improve sensitivity of SERS
- **Integrate** the endoscopic platform and the payloads
- **High resolution imaging**

Check out the posters 79-81 !

TAKUVIK