Measuring the absorption length of the deep Pacific Ocean: Results from STRAW, a pathfinder mission for the proposed P-ONE neutrino telescope

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10/06/2021

Neutrino telescopes

- Detect Cherenkov light of secondary particles created in neutrino interactions
- Large grid of optical modules (photomultiplier tubes) placed in transparent medium
- Good telescope site is characterized by long optical attenuation length

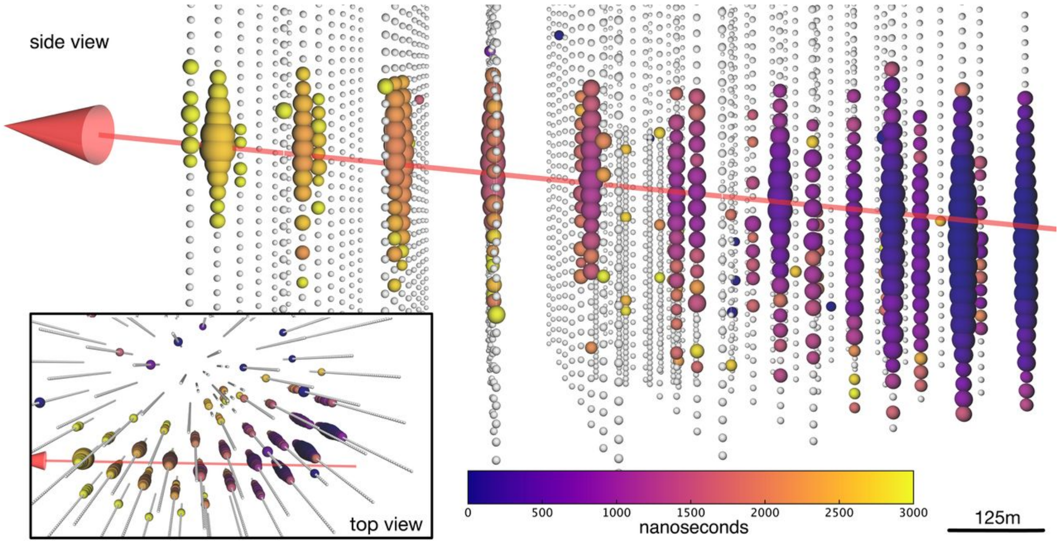


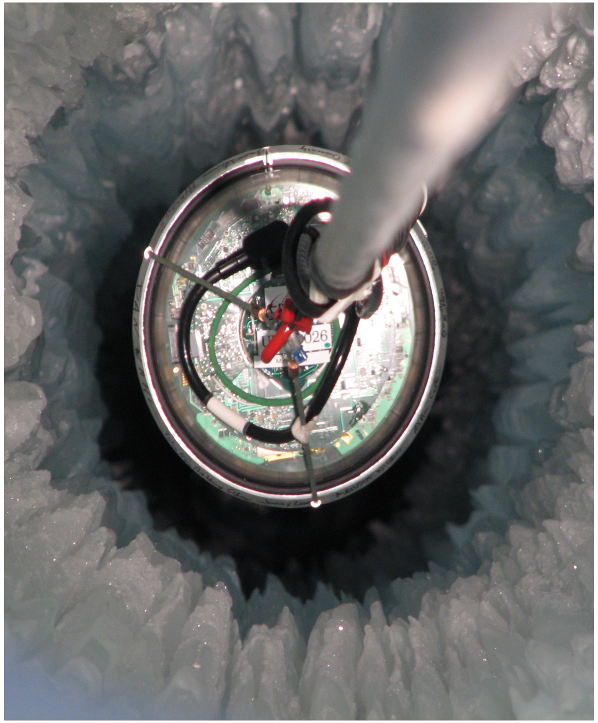
Image: IceCube Collaboration

Neutrino telescopes

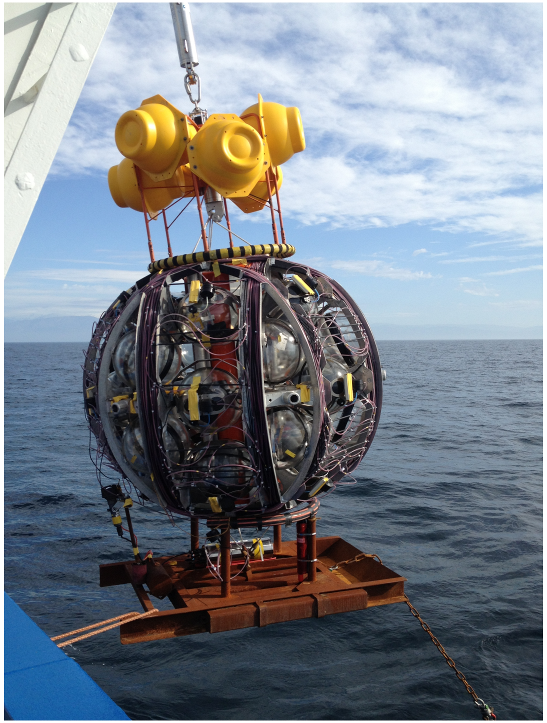
Natural sources of transparent Cherenkov medium

- Fresh water
  - Gigaton Volume Detector, Lake Baikal
- Ice
  - IceCube, Antarctica
- Sea water
  - KM3Net, Mediterranean
  - **P-ONE, Northern Pacific**

- Each medium has different challenges in detector construction and infrastructure



IceCube string being lowered into a borehole
Image: Mark Krasberg, IceCube/NSF



KM3Net mooring line before deployment
Image: KM3NeT

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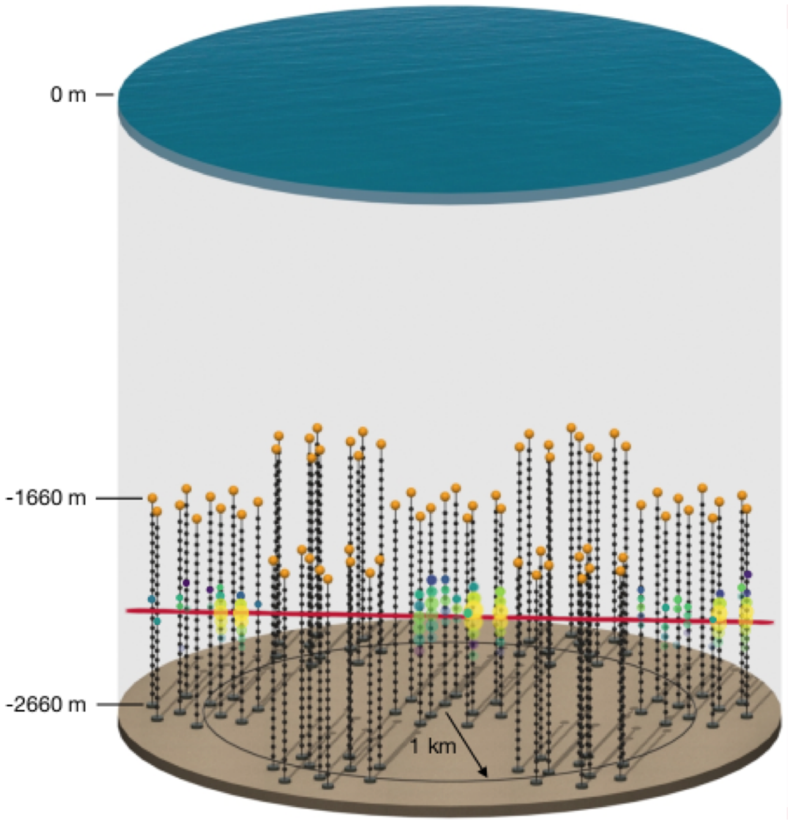
Pacific Ocean Neutrino Experiment

- Proposed new neutrino telescope near Vancouver Island
- Cubic kilometer detector, optimized for 10TeV-10PeV
- Complementary sky coverage to other neutrino telescopes
- Uses existing ONC infrastructure



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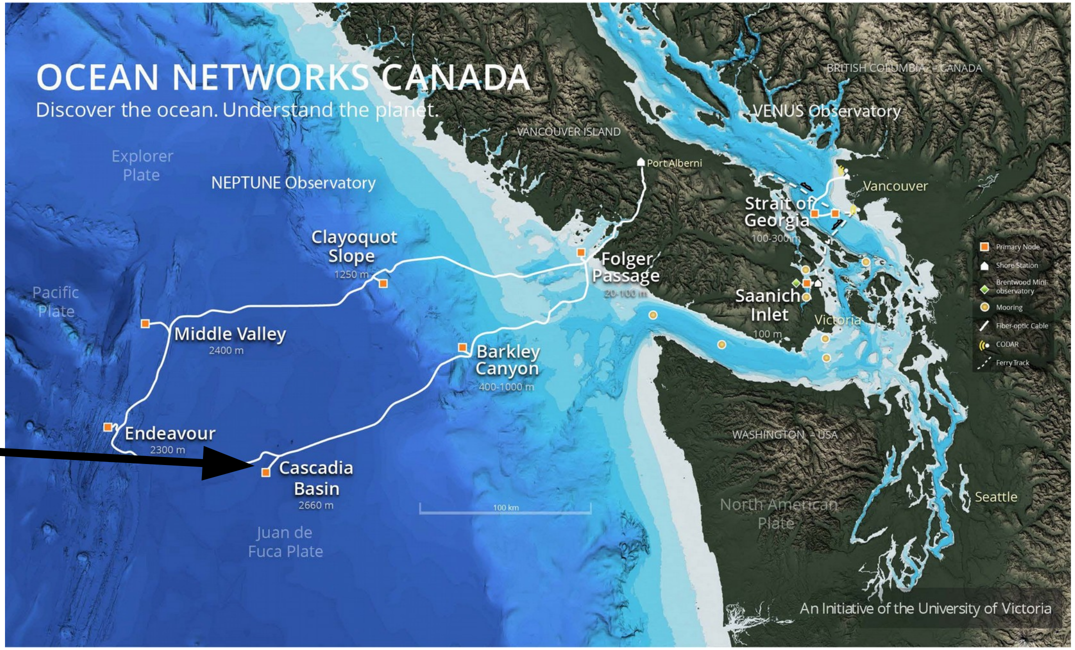
Ocean Networks Canada (ONC)

- Main challenge of marine neutrino telescopes: infrastructure
- Ocean Networks Canada provides infrastructure for various scientific disciplines in Pacific, Atlantic and Artic Sea
- “Plug and play” power and network connection
- Neptune observatory: 800km underwater cable loop with several nodes, operating since 2009
- Cascadia Basin node
  - 2600m deep abyssal plain
  - 2°C year-round
  - Low currents (0.1m/s)

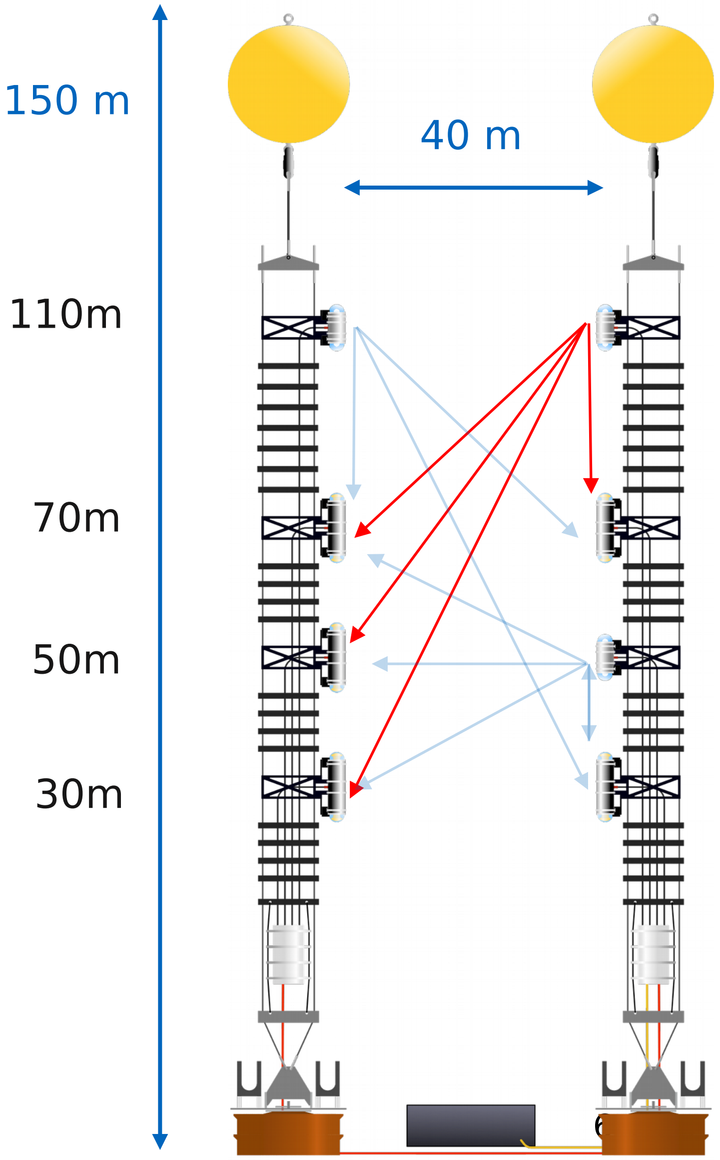


Images: Ocean Networks Canada

First pathfinder - STRAW

- Test optical properties and infrastructure of the site by mimicking a neutrino detector

- Two strings (150m, 4 modules each)
- Detectors for background (radioactivity, (bio-)luminescence) measurement
- Flashers emit calibrated light pulses that can be used for attenuation measurements at 4 different wavelengths



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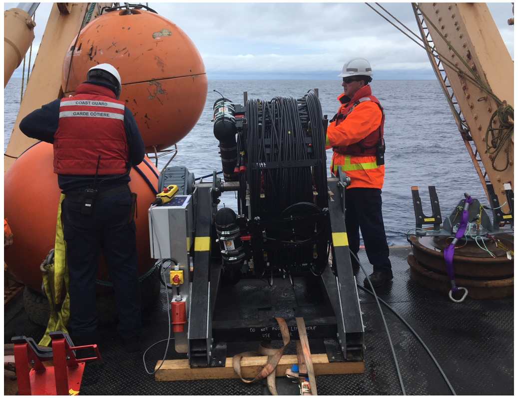
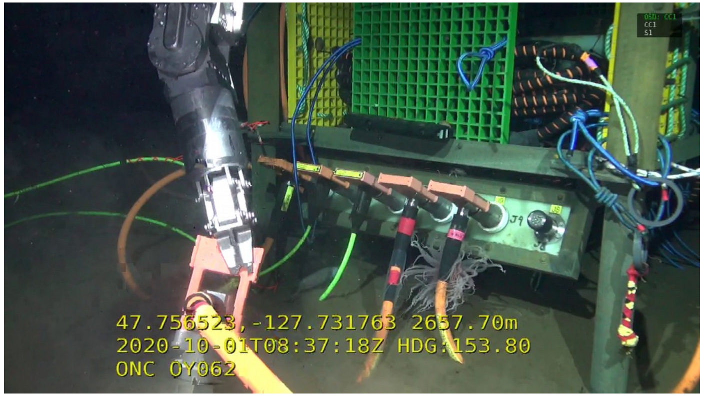
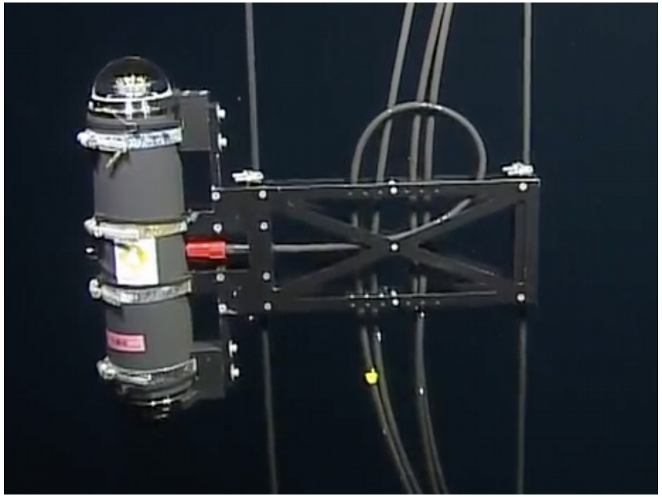
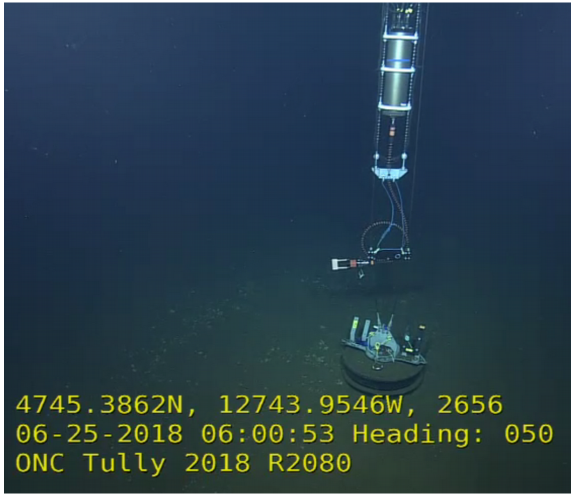
Hardware and Deployment

- built within 8 months (2017-2018) in collaboration with Ocean Networks Canada
- Construction of instruments and main structure in Munich
- Interface, anchoring and deployment operation by Ocean Networks Canada
- Deployed in June 2018
- Continuously taking data since March 2019









Images: Ocean Networks Canada

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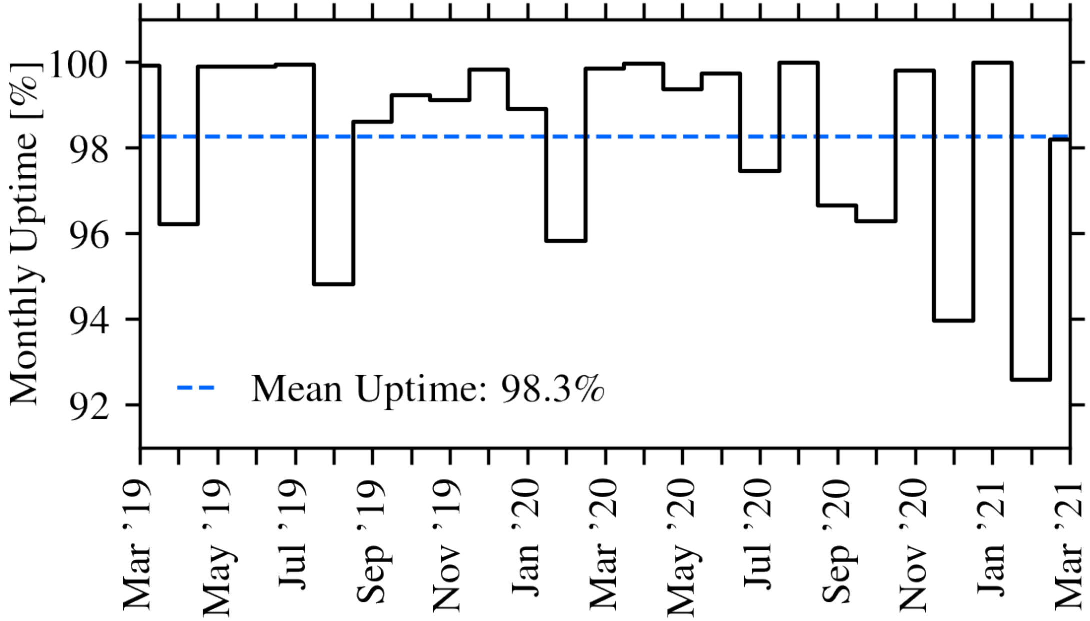

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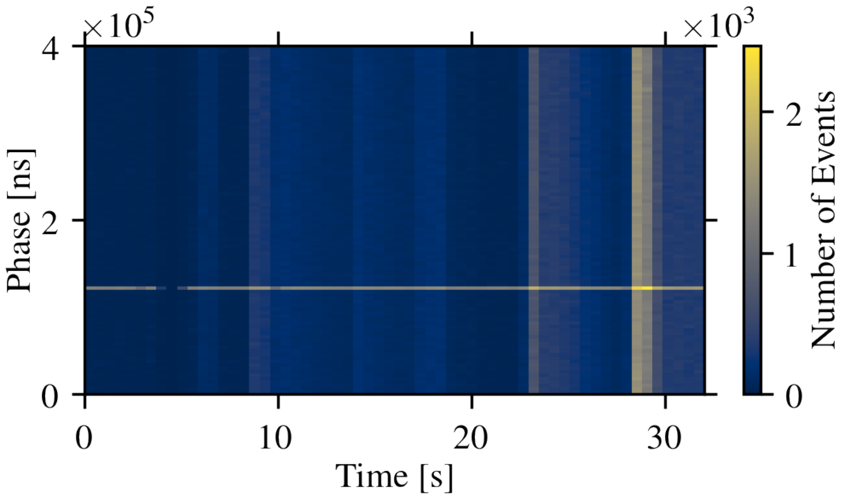
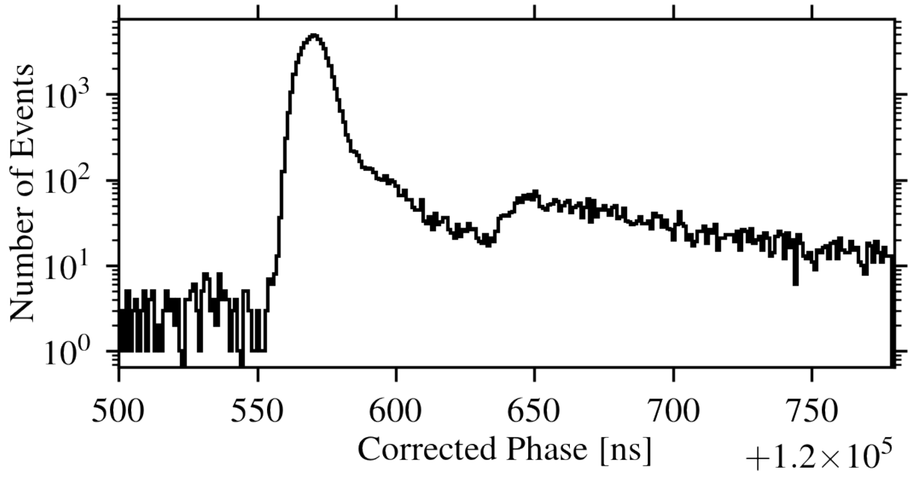
Finding the flasher signal



- Two background components
  - Constant background caused by radioactivity, PMT noise, …
  - Highly variable background caused by bioluminescence
- Flashers emit short pulses at fixed period T
- Search for repeating signal with period T
- Use detectors with strong signal as timing reference for other detectors
- Use multiple flasher intensities to get a signal on single-photon level for each SDOM



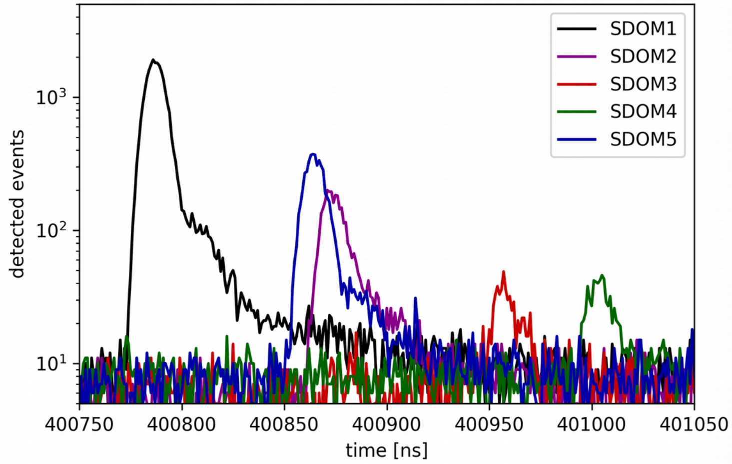
STRAW Attenuation length

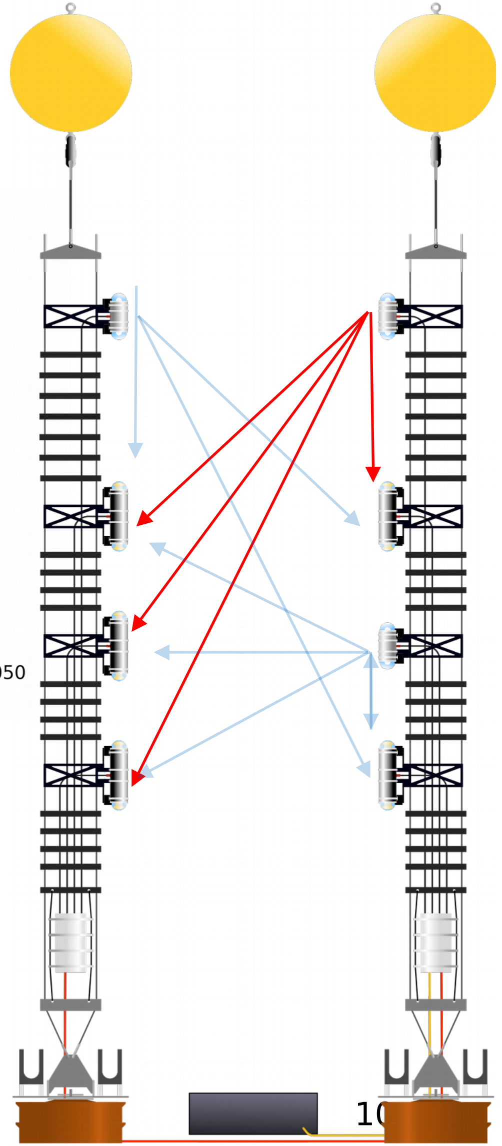
$$\mathbf{I(r)=I_0 / 4\pi r^2 \cdot exp(-r/l_{att})}$$

Important input parameters

- Angular profile of flashers and detectors
- Position of modules on string
- Lab calibration of each module

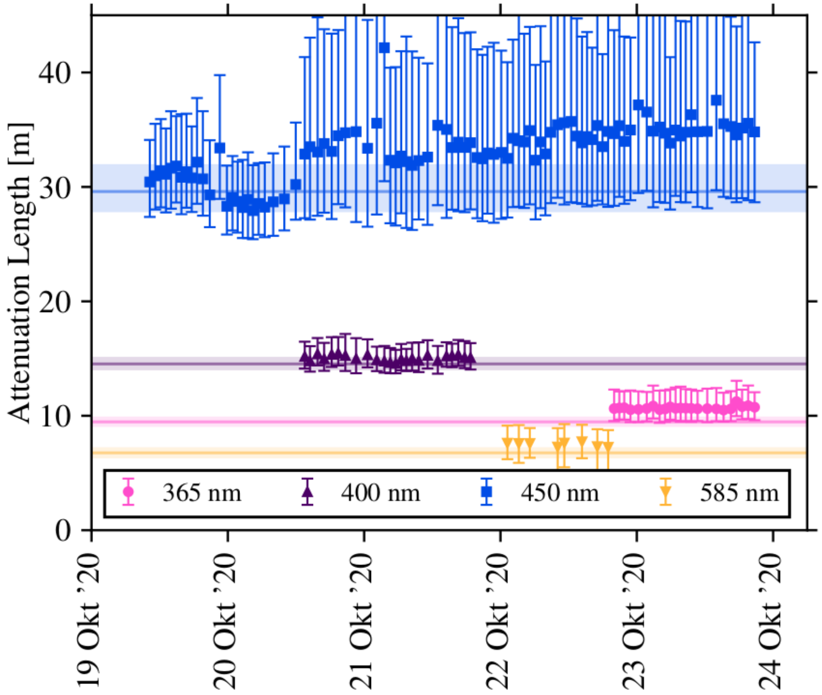
POCAM pulses as seen in all five SDOM detectors





STRAW – Attenuation length

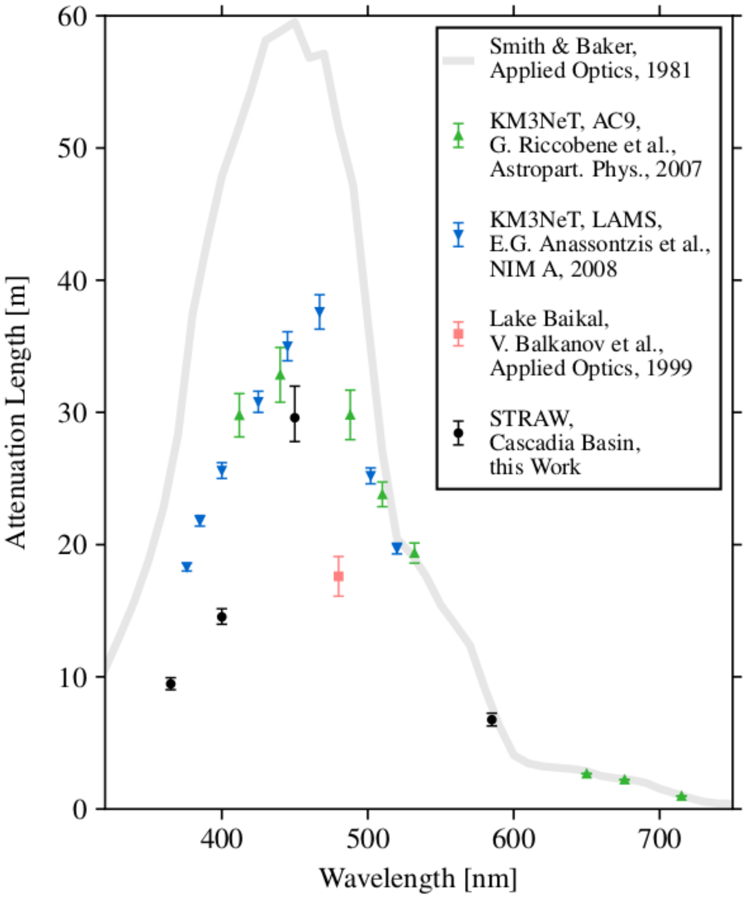
- Measure repeatedly over one day to test stability of measurement
- Measured at four different wavelengths
  - **@450nm: 30±2m**



Attenuation length measurements over a four day period. Systematic errors are included. Measurements at wavelengths other than 450nm were complemented with a low precision 450nm measurement.

STRAW – Attenuation length

- Measure repeatedly over one day to test stability of measurement
- Measured at four different wavelengths
  - **@450nm: 30±2m**
- ➔ Comparable to other sites



Comparison of attenuation length measurements with other sites.
Smith and Baker represent the absolute optimum for natural water

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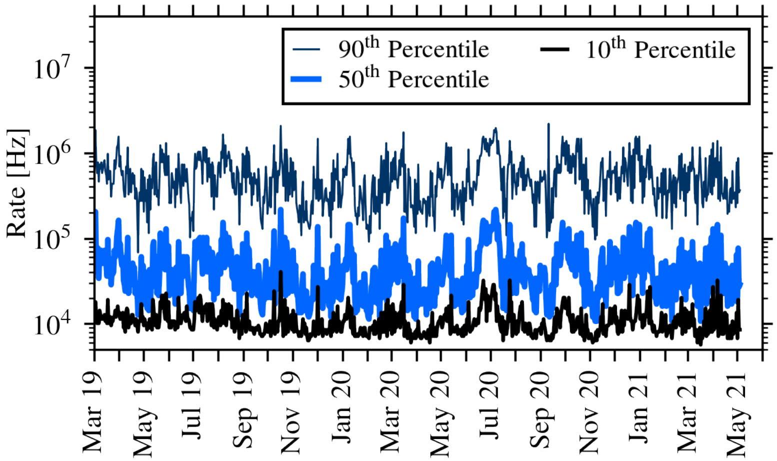
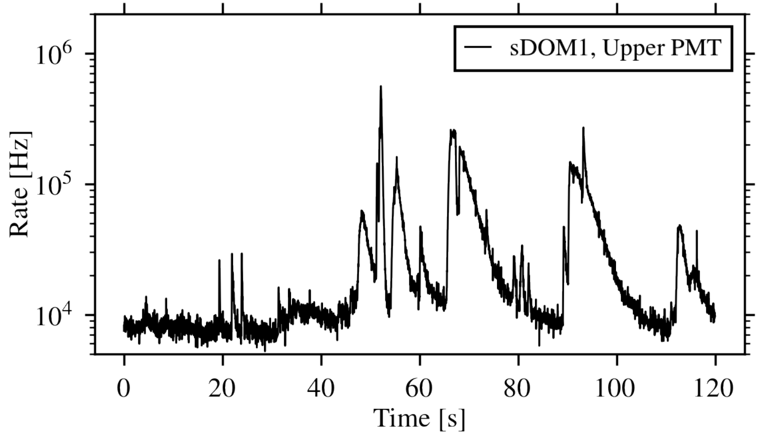
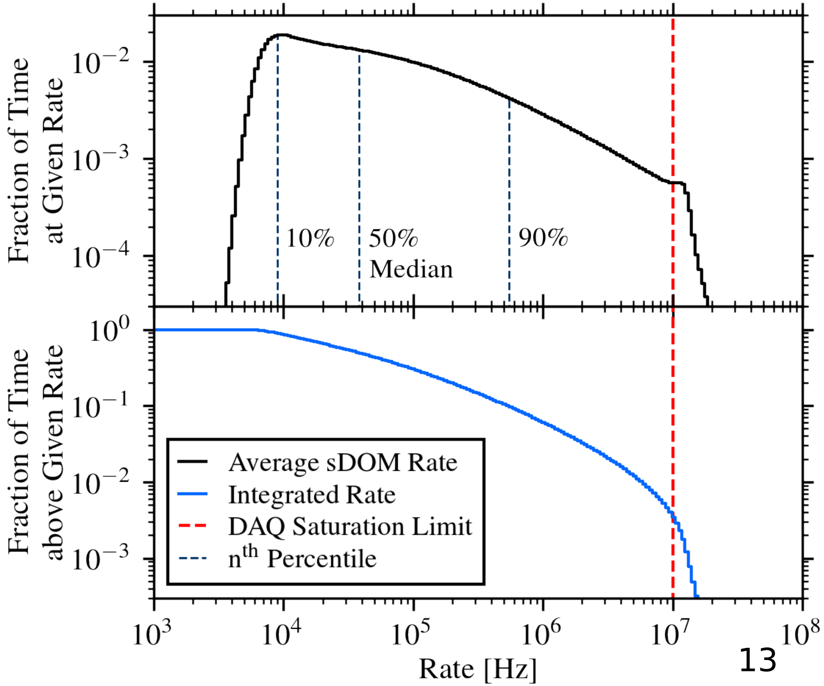
STRAW – Background

- Radioactivity (K-40): 10kHz baseline
- Bioluminescence: Spikes of few seconds, kHz to MHz
- Monitored over two years







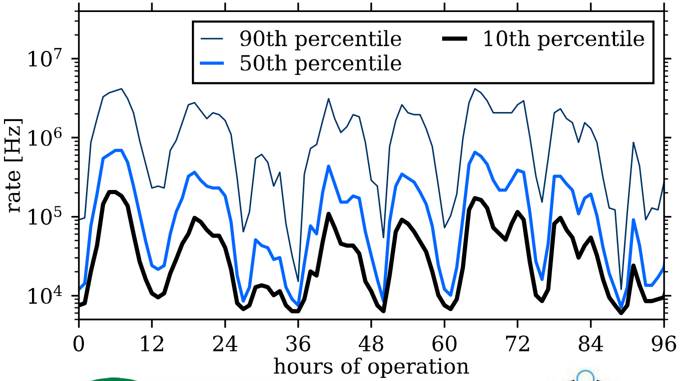
STRAW – Background

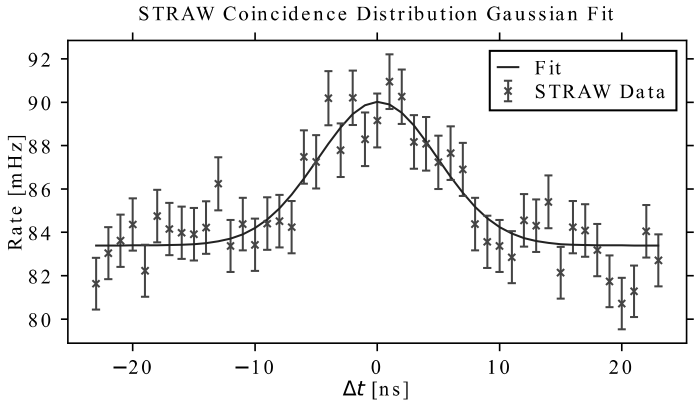
- Analysis ongoing
  - CAP presentation by Jakub Stacho "Ambient Background Modeling and Event Trigger Development for the Pacific Ocean Neutrino Explorer"

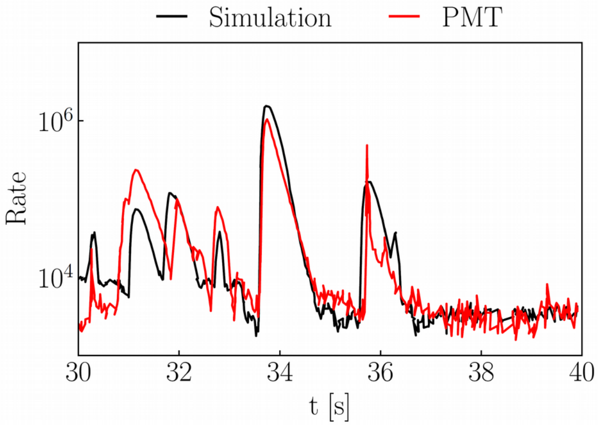
Analysis of bioluminescence
Plot: rate over 96 hours, showing dependence on tides

K-40 coincidence
Plot: time difference between events in up-facing and down-facing PMT, with K-40 coincidence peak

Bioluminescence simulation
Based on currents, detector geometry and species
https://arxiv.org/pdf/2103.03816.pdf

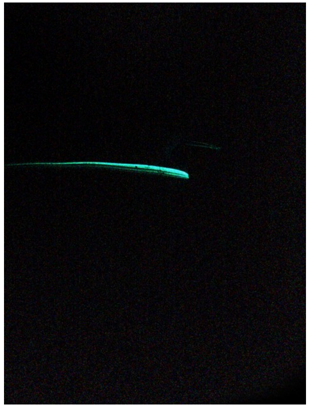






Second pathfinder - STRAW-b

- Single 0.5 km mooring line
- New deployment approach
- Fibreoptical cable for data transmission
- Ten different modules for a variety of measurements
- Deployed in September 2020, despite COVID-19 challenges
- (Analysis ongoing)



Left: Trace of a bioluminescent organism captured by a STRAW-b camera
Right: STRAW-b module after deployment

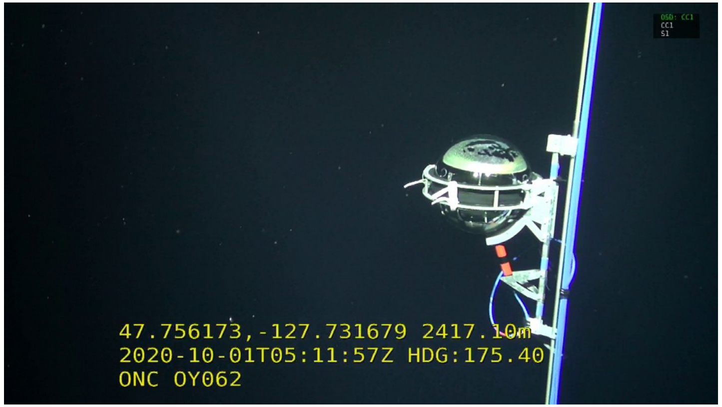
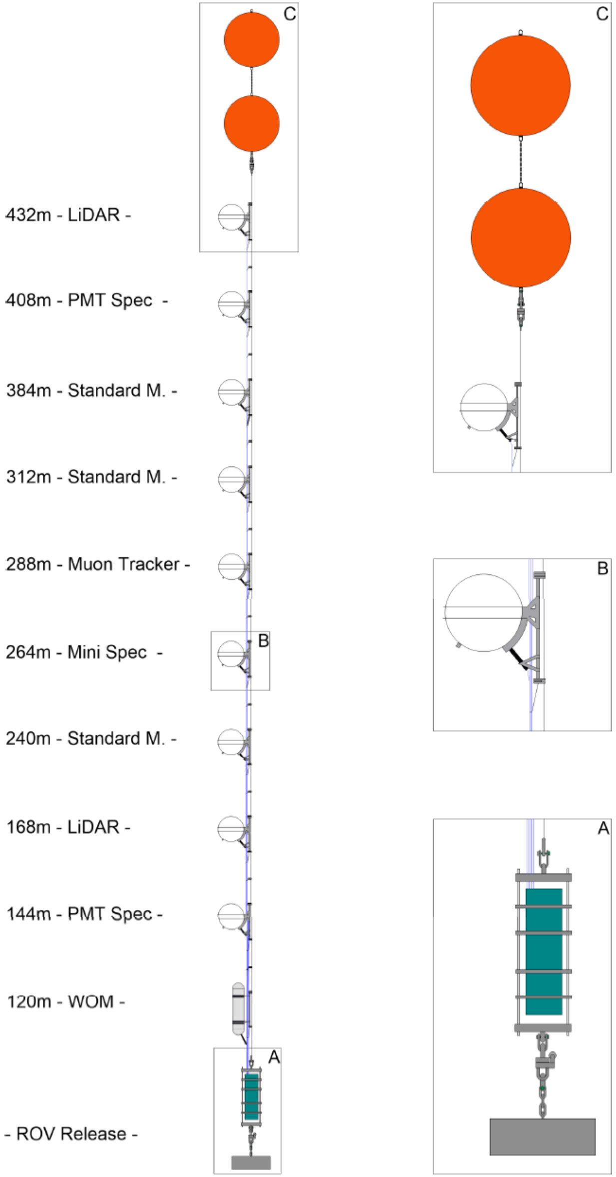


Image: Ocean Networks Canada



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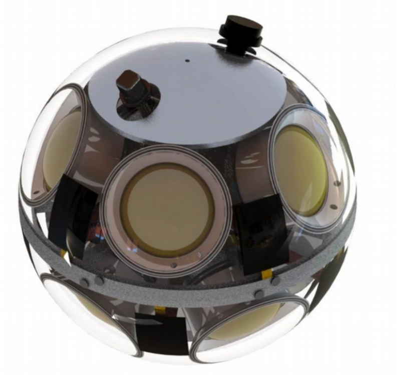
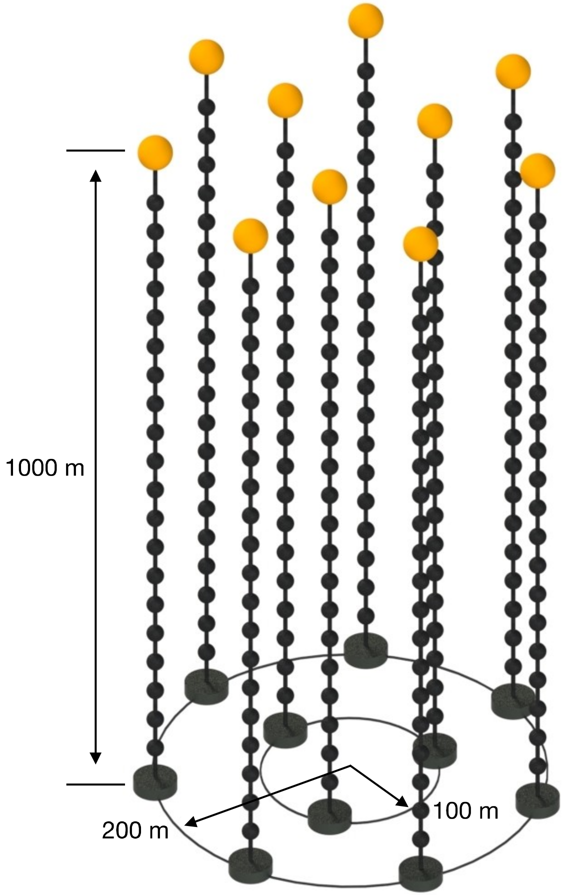
How do we proceed

- Modular approach for neutrino telescope
- → 7 clusters, with 10 strings and 200 modules each
- First cluster: **Pacific Ocean Neutrino Explorer**
- Multi-PMT modules for large detection area and directional resolution



- Currently working on prototype mooring line



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Summary

- Suitable site for future neutrino telescope
- Attenuation length ca. 30m
- 2 years of background data
- Working, reliable infrastructure by Ocean Networks Canada
- Two successful experiments already deployed
- First real detector string under development
- Plan: 10 strings by 2025 (tentatively)

M. Agostini et al., “The Pacific Ocean Neutrino Experiment”, https://arxiv.org/pdf/2005.09493.pdf

M. Boehmer et al., “STRAW (STRings for Absorption length in Water): pathfinder for a neutrino telescope in the deep Pacific Ocean”, DOI: 10.1088/1748-0221/14/02/P02013

https://www.pacific-neutrino.org/

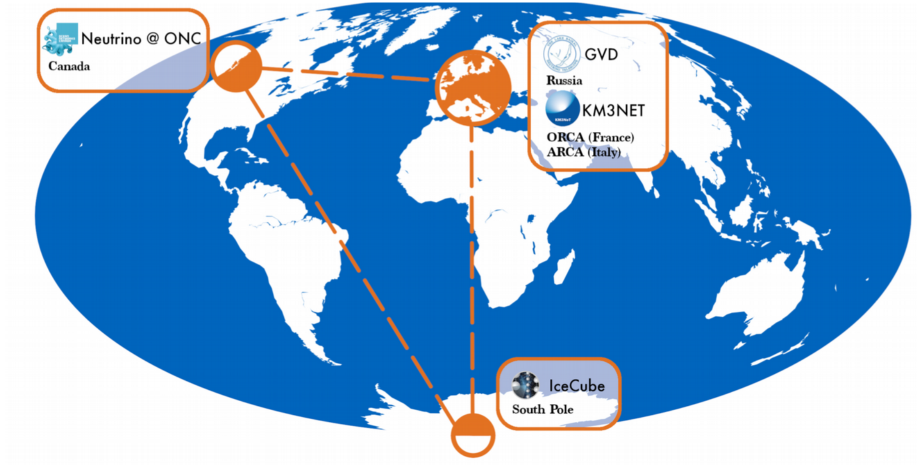
Backup

Sky coverage

- Looking up: Atmospheric muons are orders of magnitude more frequent than astrophysical neutrinos
- Looking down: Earth is opaque at high neutrino energies

➔ Only small band around the horizon for high-energy neutrino observations

- Current neutrino telescopes leave large gap in sky coverage that can be filled by new telescope in the northern Pacific



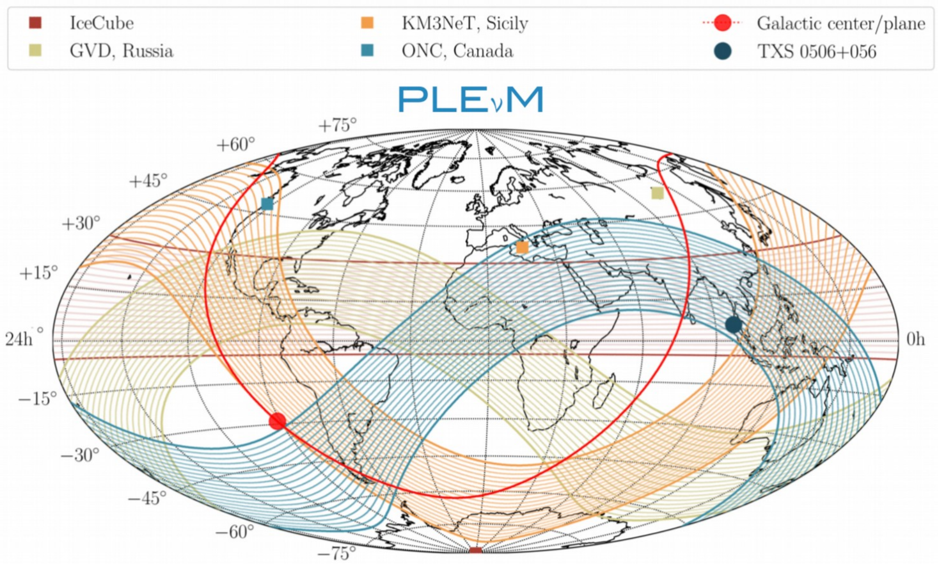


Image: Matthias Huber, TUM

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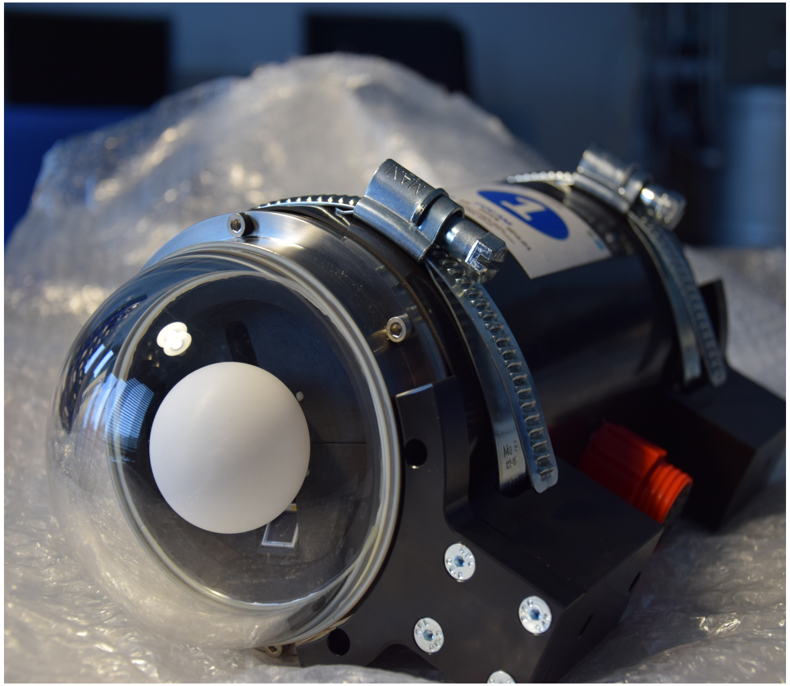
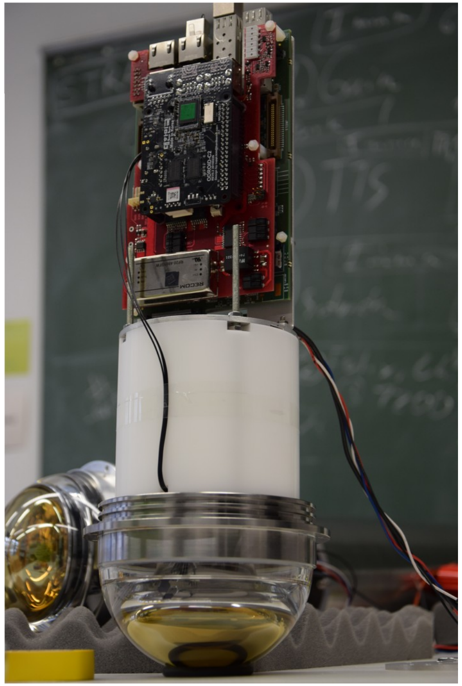
Instruments



POCAM module showing the hollow PTFE sphere used for creating isotropic light pulses



SDOM electronics and one of the two PMTs

One of the two STRAW strings spooled onto the deployment winch

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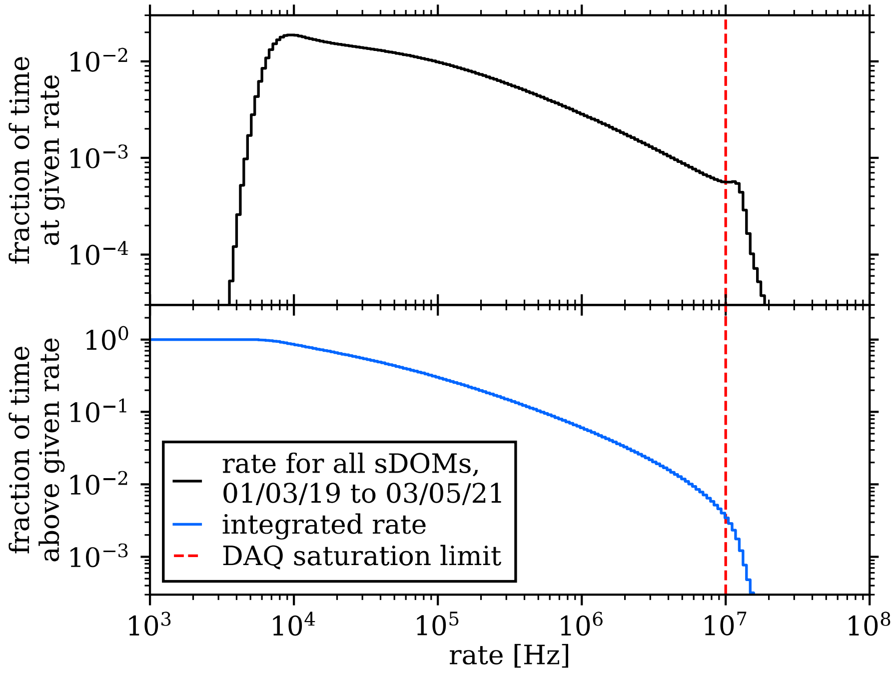
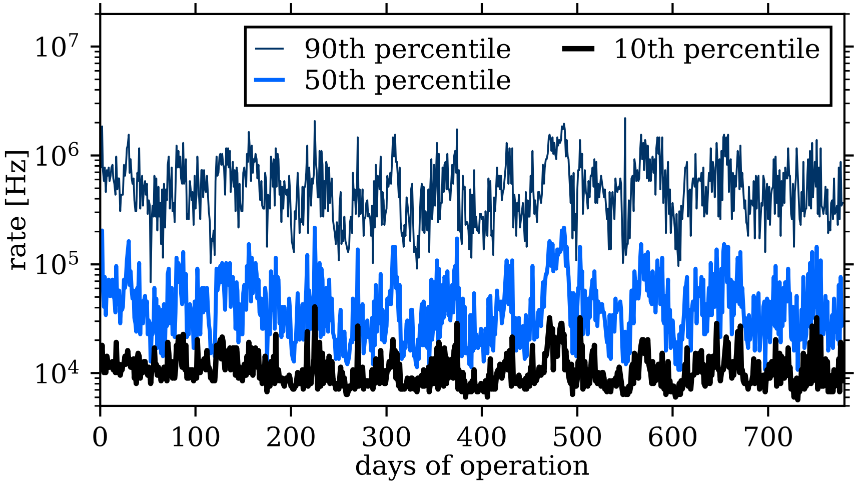
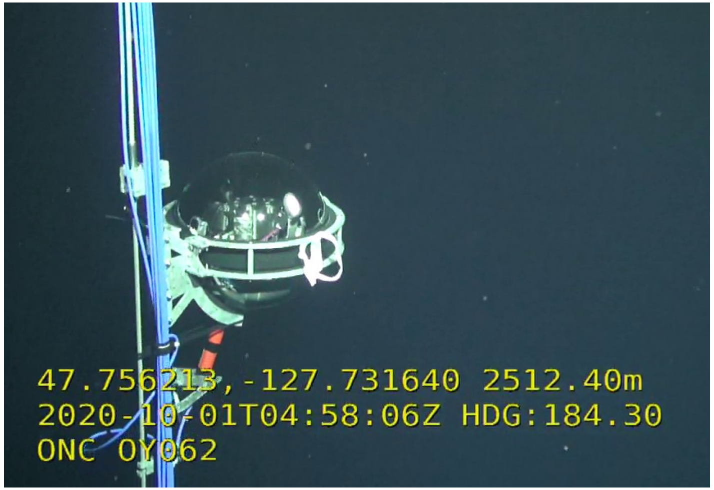
STRAW background rates





STRAW-b instruments

LIDAR x2
PMT Spectrometer x2
Mini-Spectrometer x1
Muon Tracker x1
WOM x1
Standard Module x3



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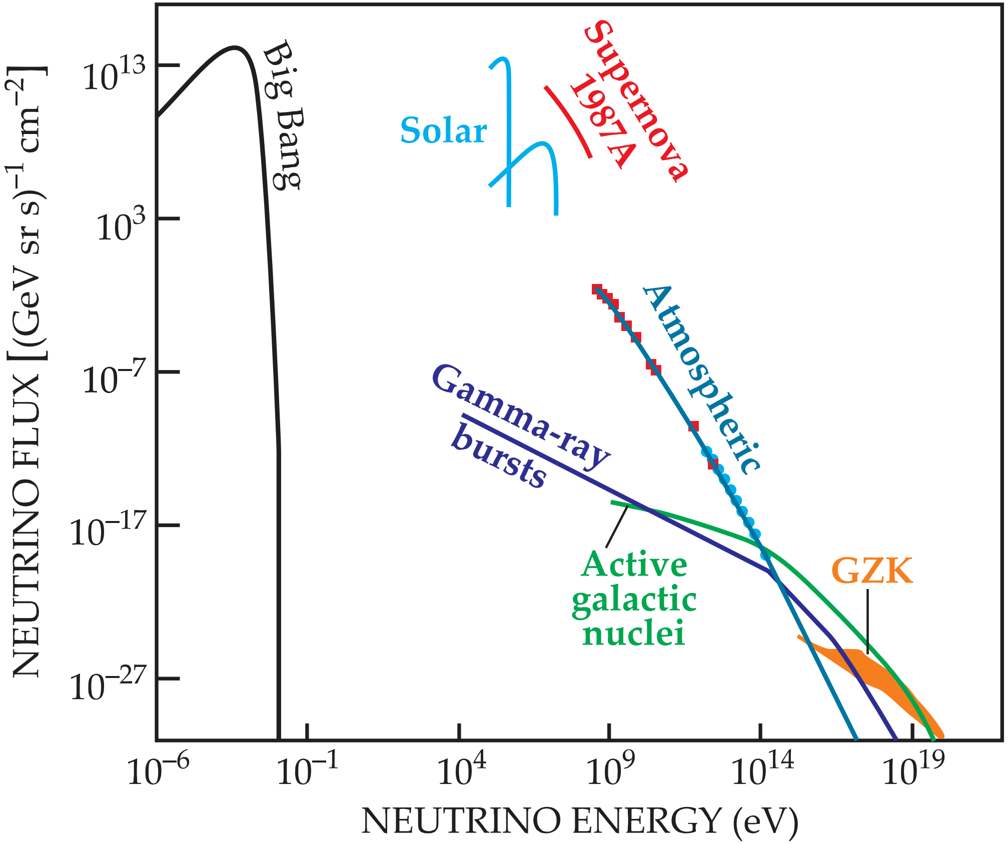
Neutrino Spectrum



F. Halzen and S. R. Klein. "Astronomy and astrophysics with neutrinos". In: Physics Today 61, 5, 29 (2008), pp. 29–35. doi: 10.1063/1.2930733.

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