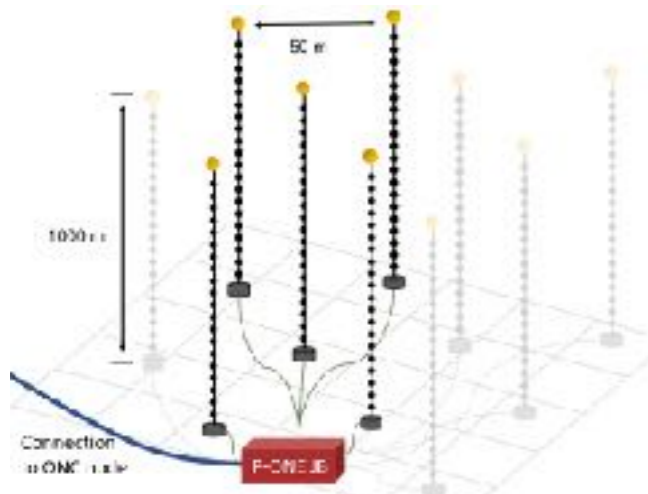


# The P-ONE Neutrino Experiment and Prototype

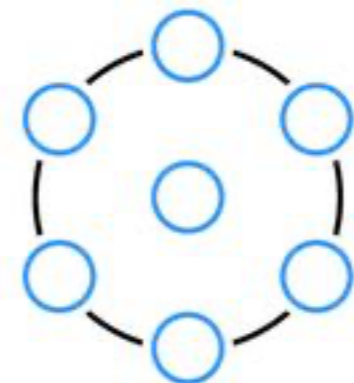
Carsten B Krauss  
University of Alberta

June 20, 2023

CAP Congress Fredericton, NB



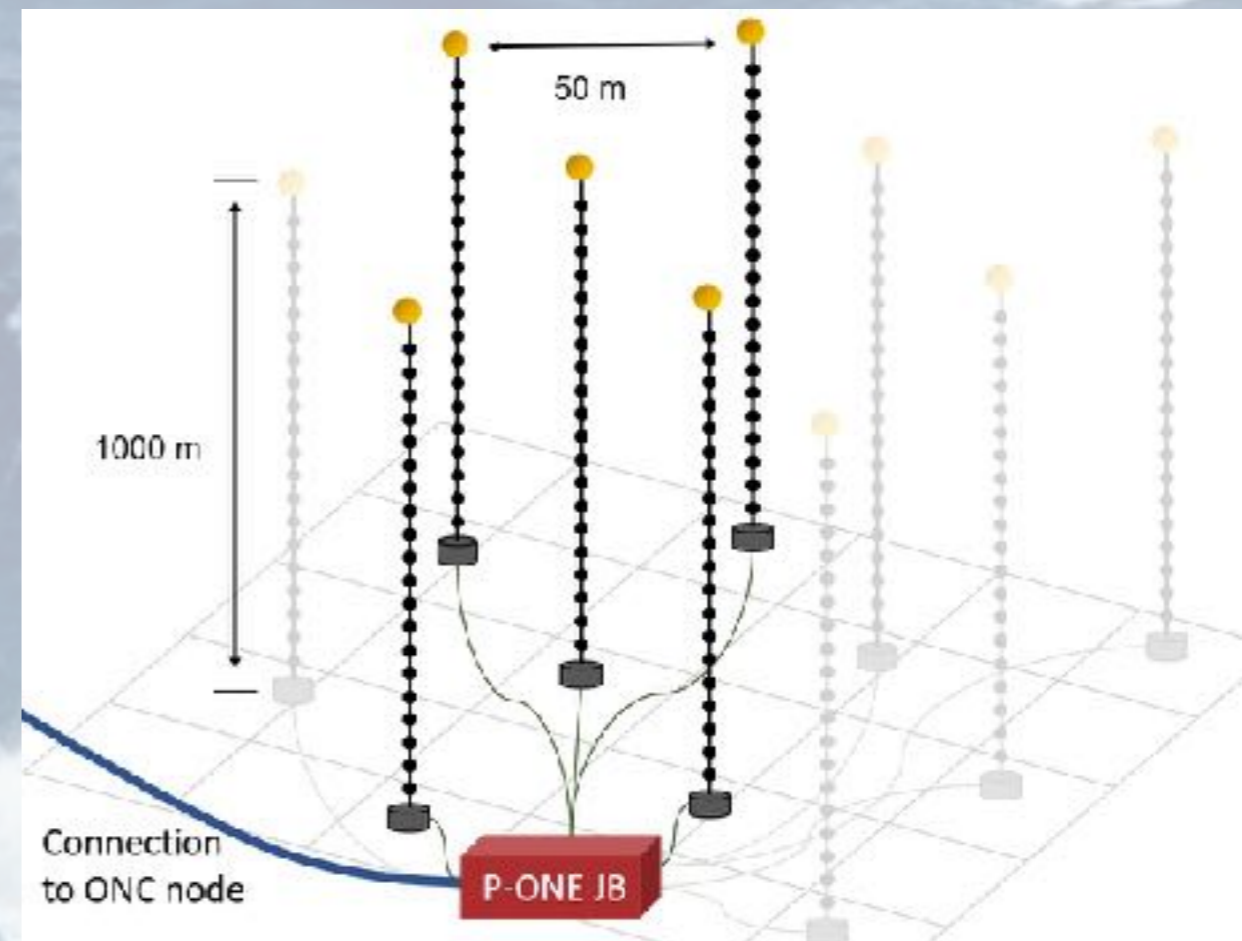
UNIVERSITY OF ALBERTA



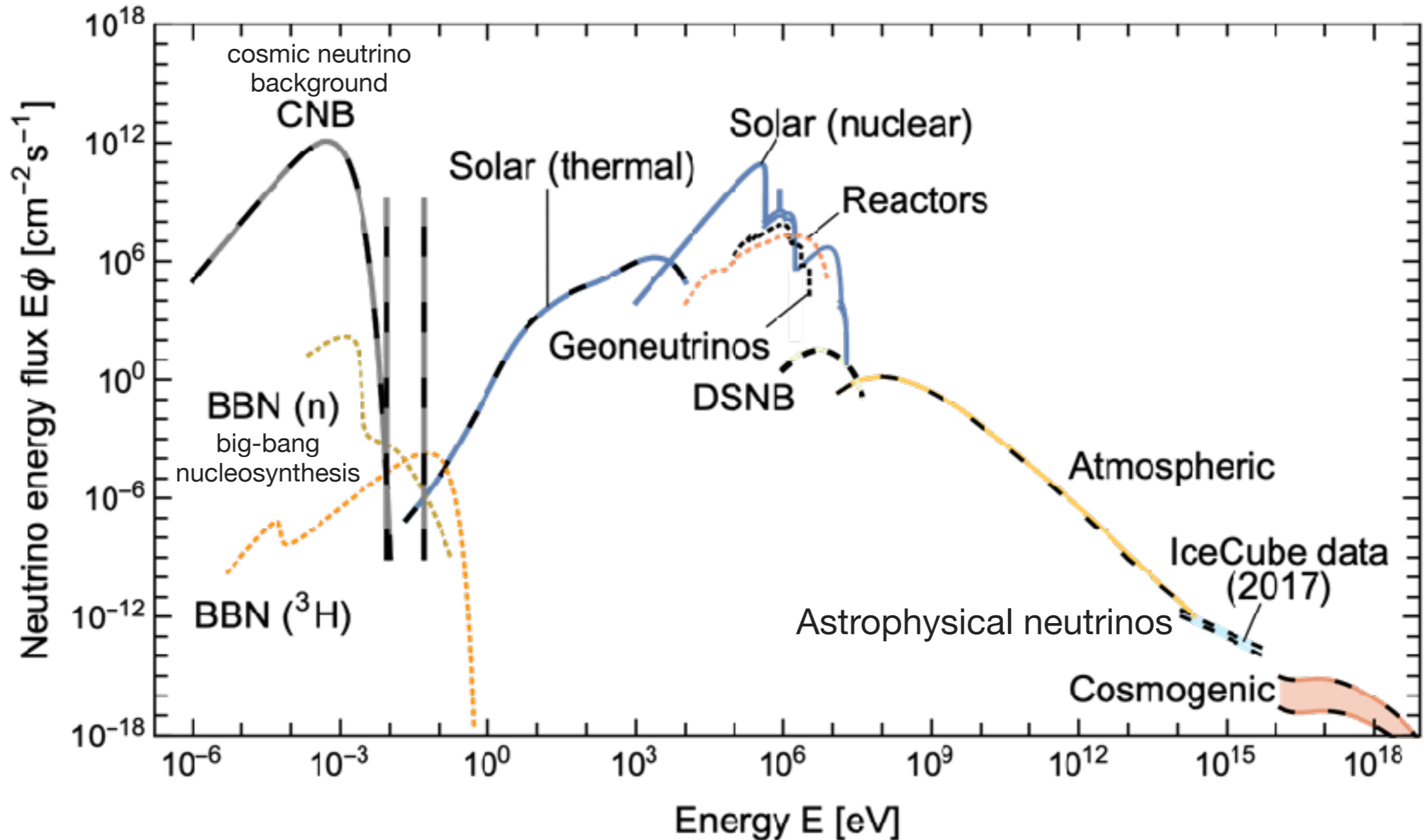
P-ONE

# Outline

- Neutrino Astronomy & Particle Physics
- Neutrino Telescopes
- **P-ONE**
  - P-ONE Physics
  - P-ONE Site: Cascadia Basin
  - STRAW and STRAWb
  - P-ONE Physics & Canadian Activities

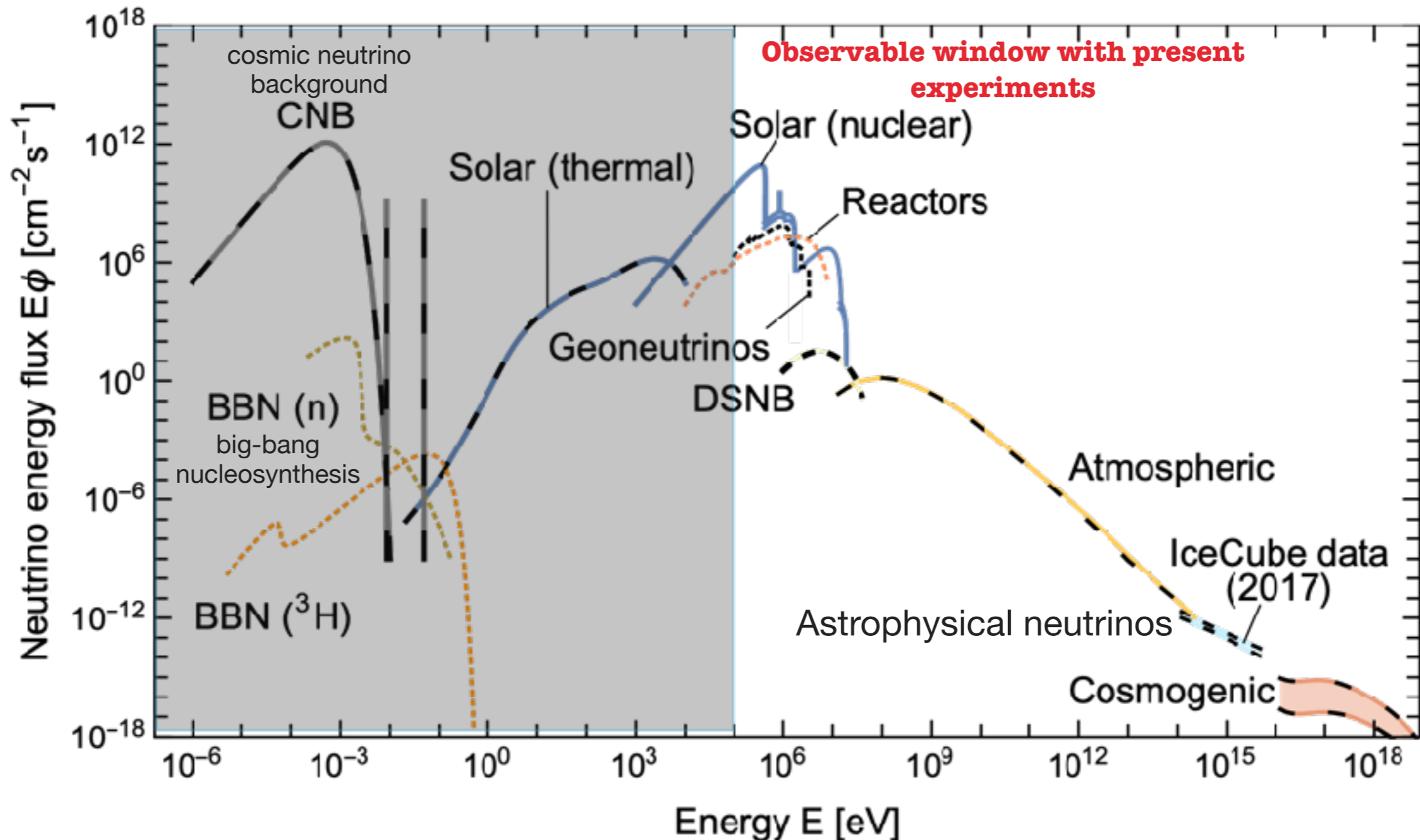


# Neutrinos from the Universe



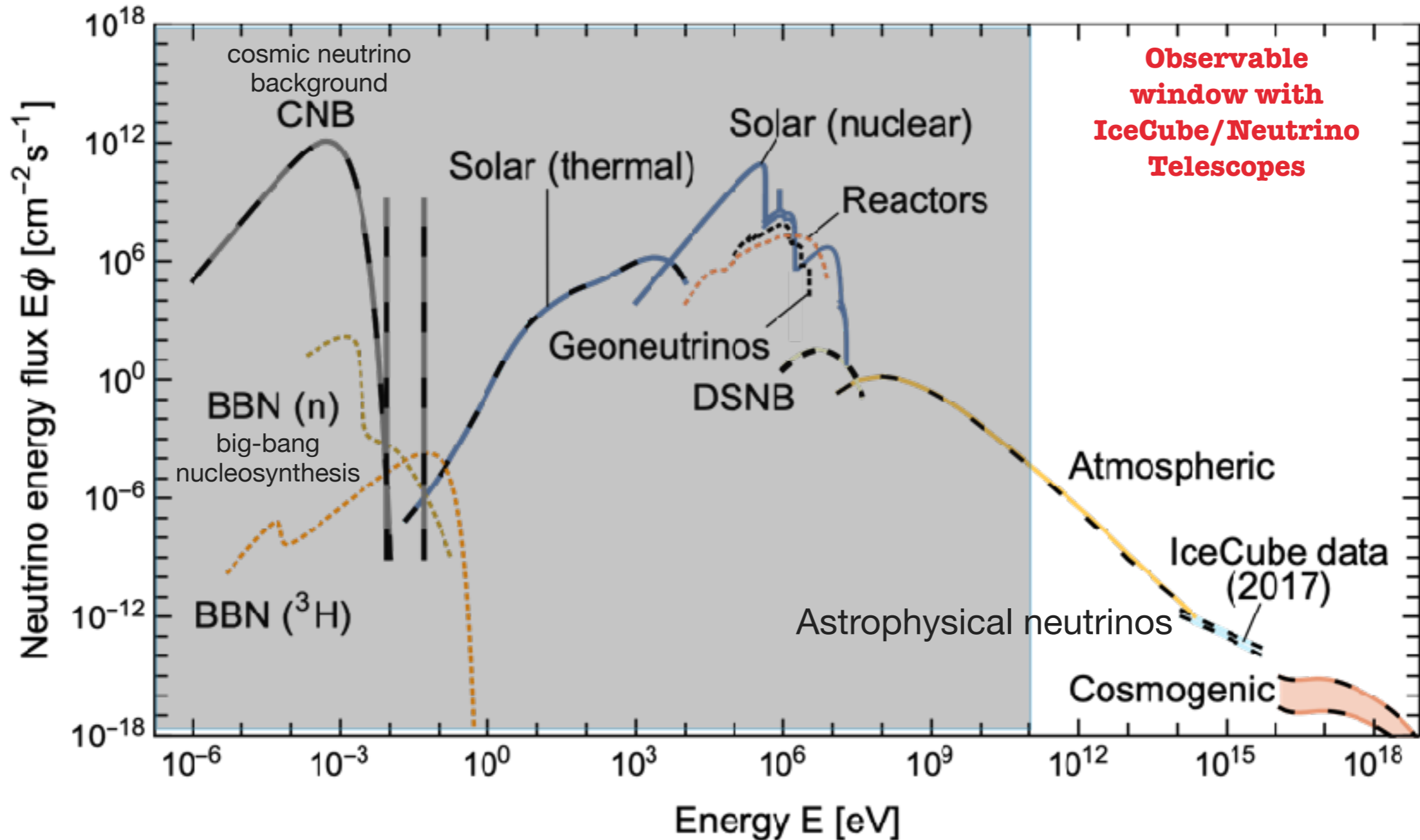
Grand Unified Neutrino Spectrum (GUNS) at Earth integrated over directions and flavours

# Neutrinos from the Universe



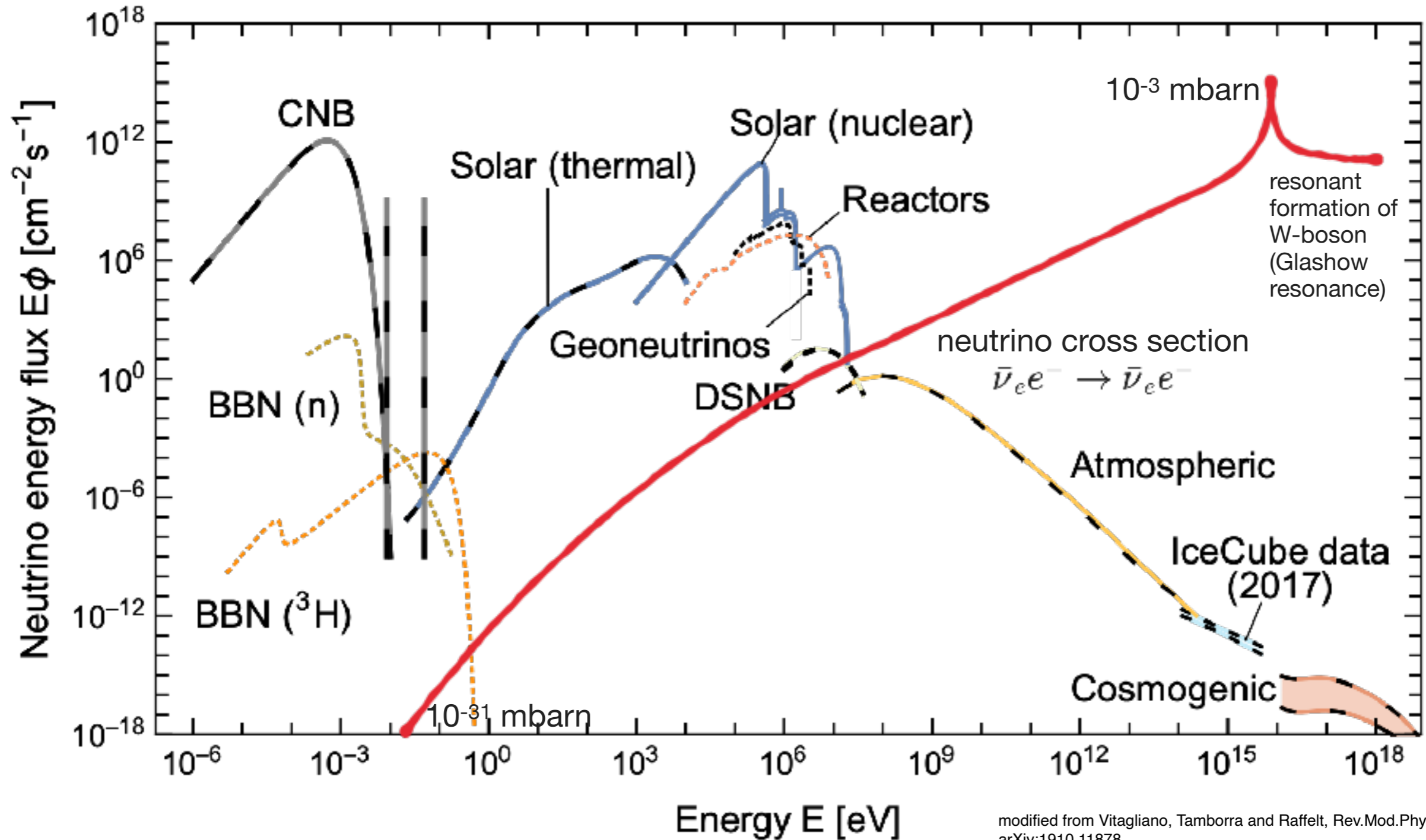
Grand Unified Neutrino Spectrum (GUNS) at Earth integrated over directions and flavours

# Neutrinos from the Universe



Grand Unified Neutrino Spectrum (GUNS) at Earth integrated over directions and flavours

# Neutrinos from the Universe

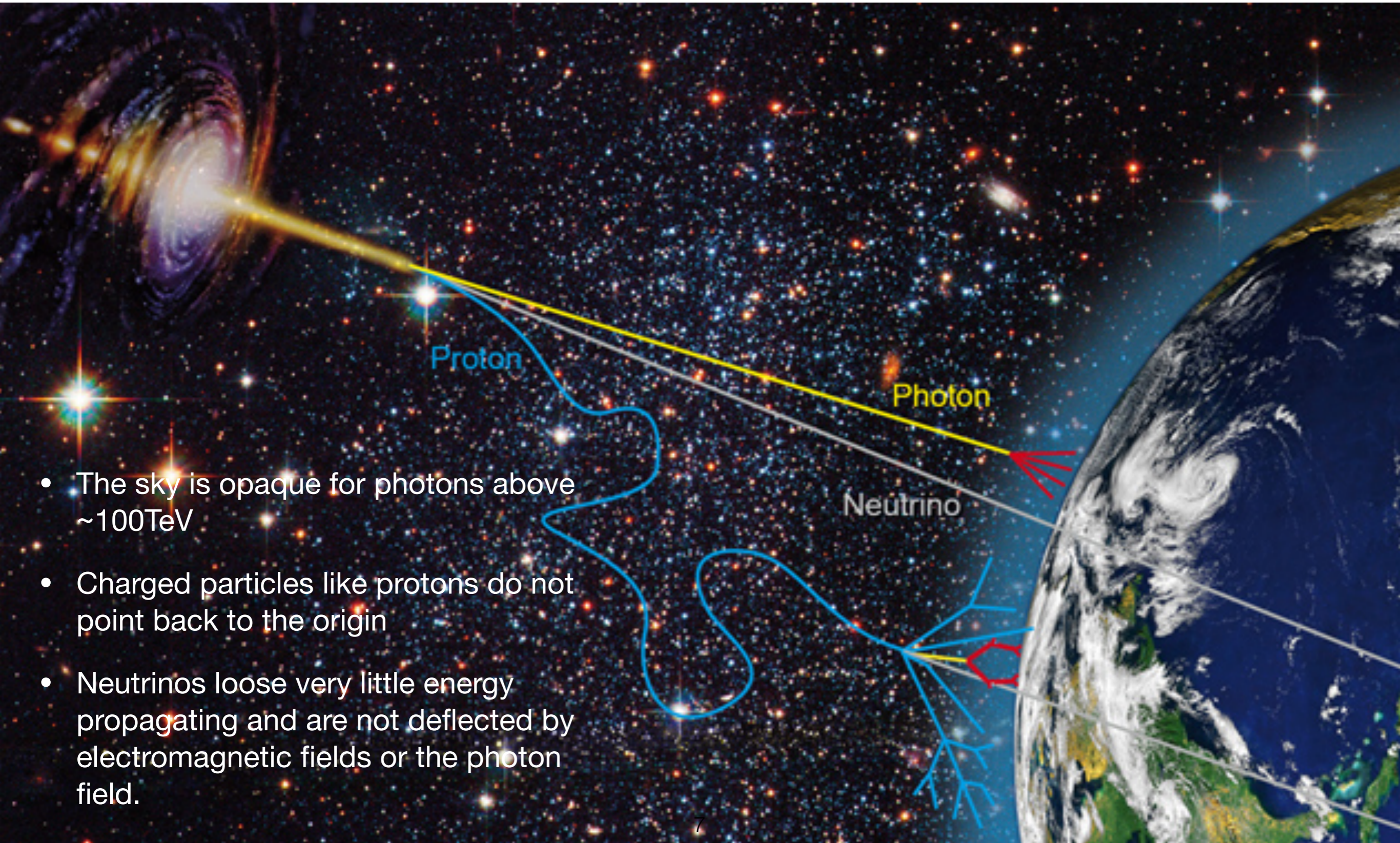


modified from Vitagliano, Tamborra and Raffelt, Rev.Mod.Phys 2019, arXiv:1910.11878

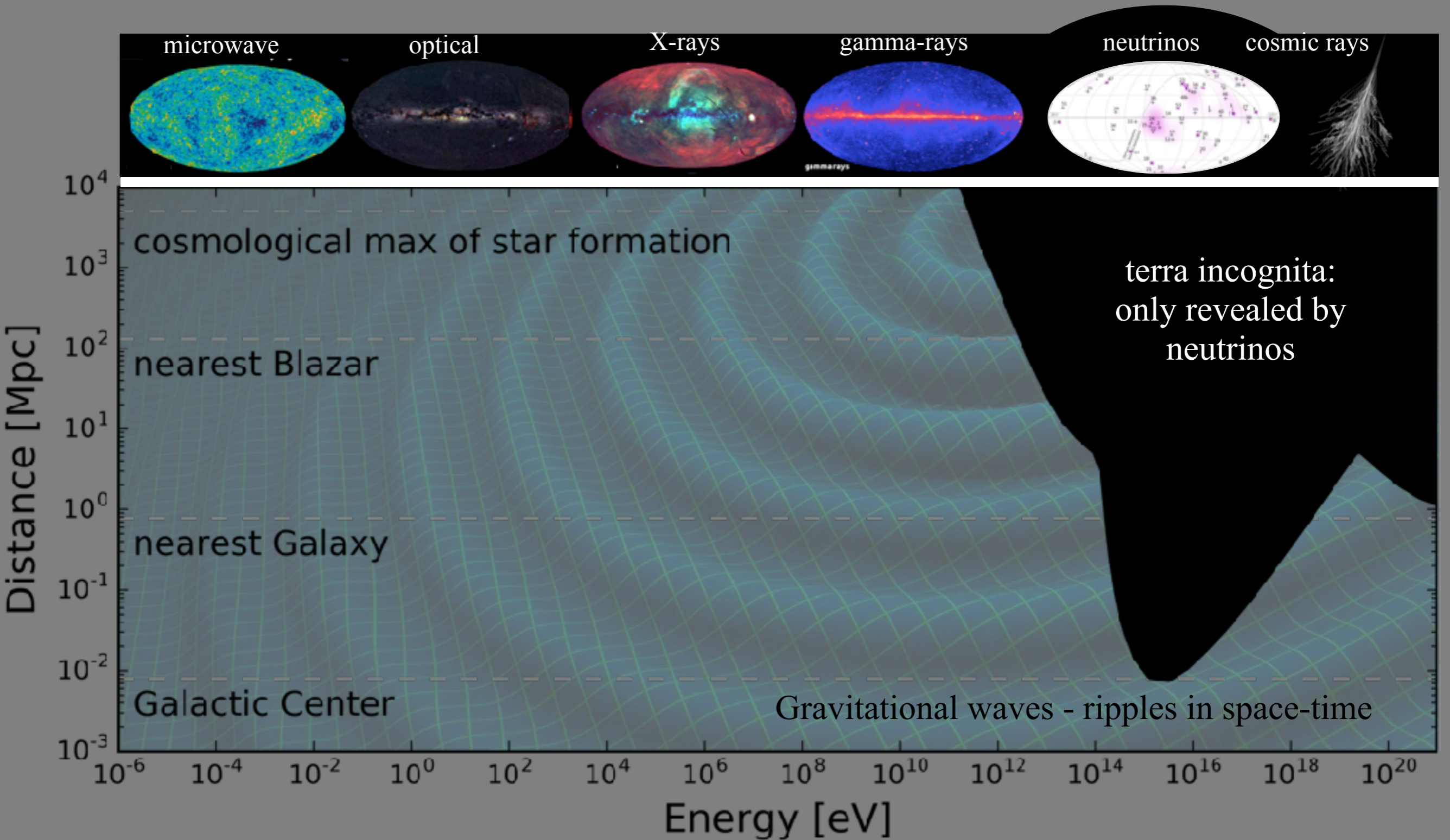
Formaggio, Zeller, Rev. Mod. Phys. 2012, arXiv:1305.7513

# Neutrino Sources?

- The sky is opaque for photons above  $\sim 100\text{TeV}$
- Charged particles like protons do not point back to the origin
- Neutrinos lose very little energy propagating and are not deflected by electromagnetic fields or the photon field.



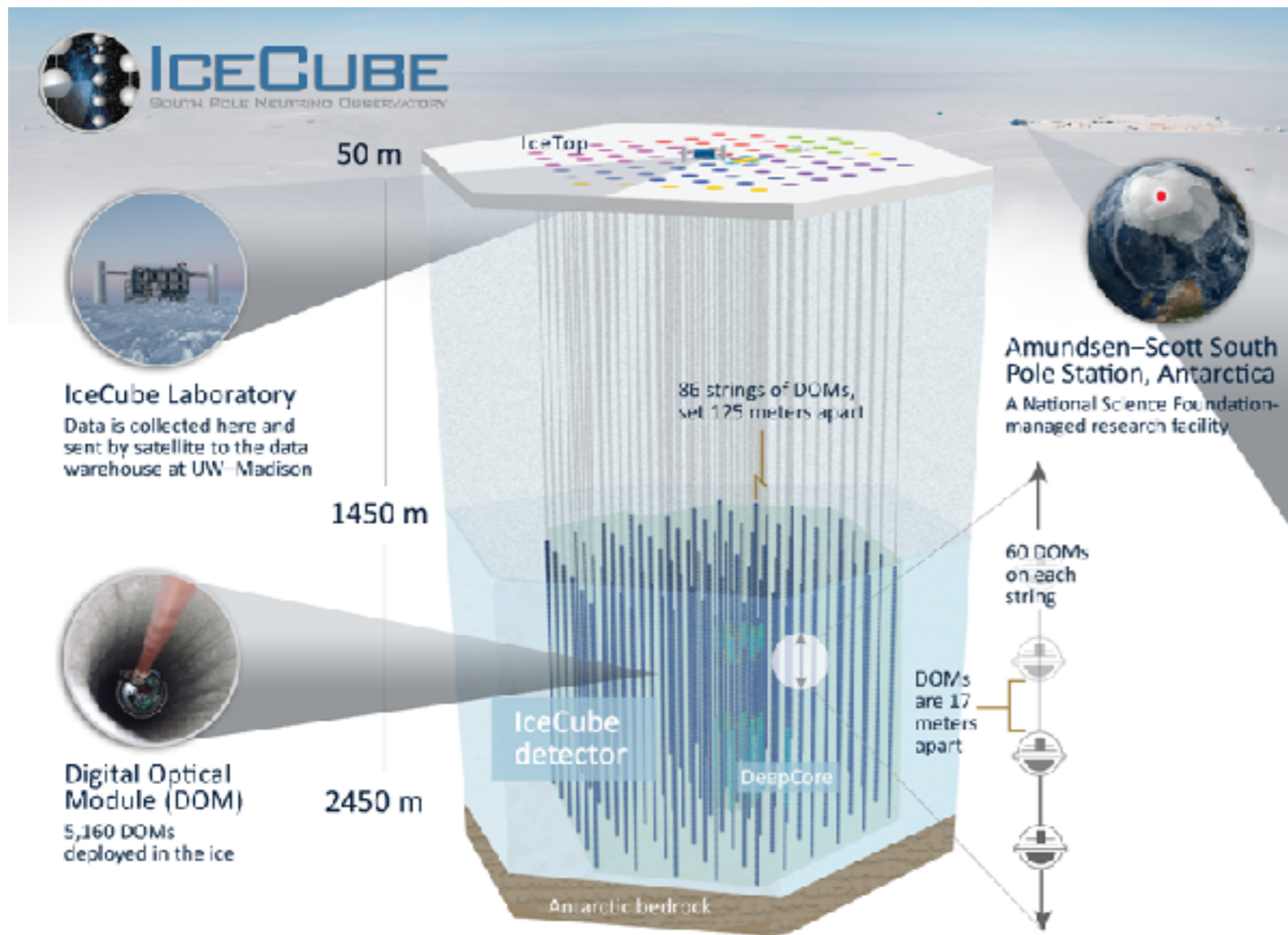
# highest energy “radiation” from the Universe: neutrinos and cosmic rays



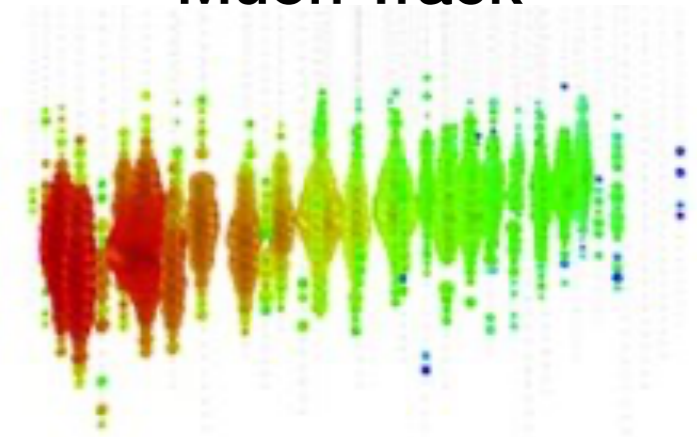
Universe is opaque above  $\sim 100$  TeV energy



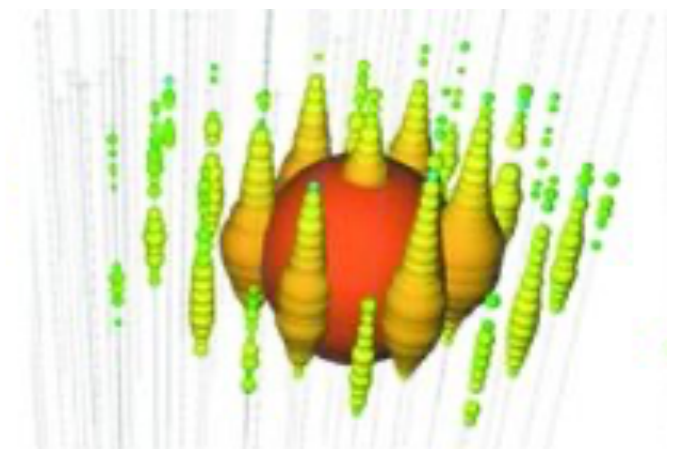
# IceCube & DeepCore



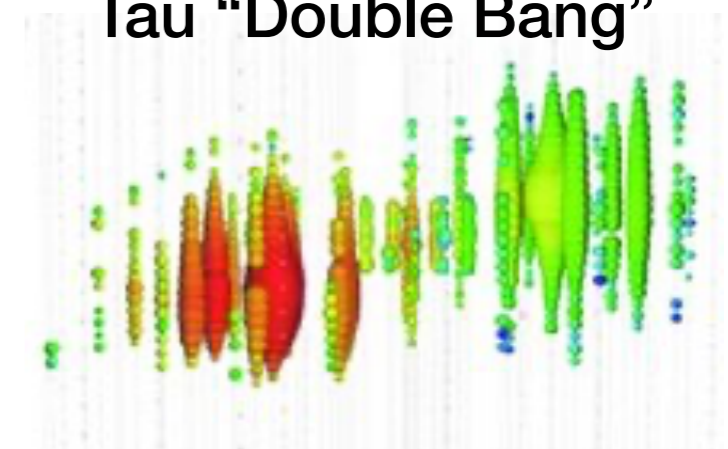
Muon Track



Electron Cascade

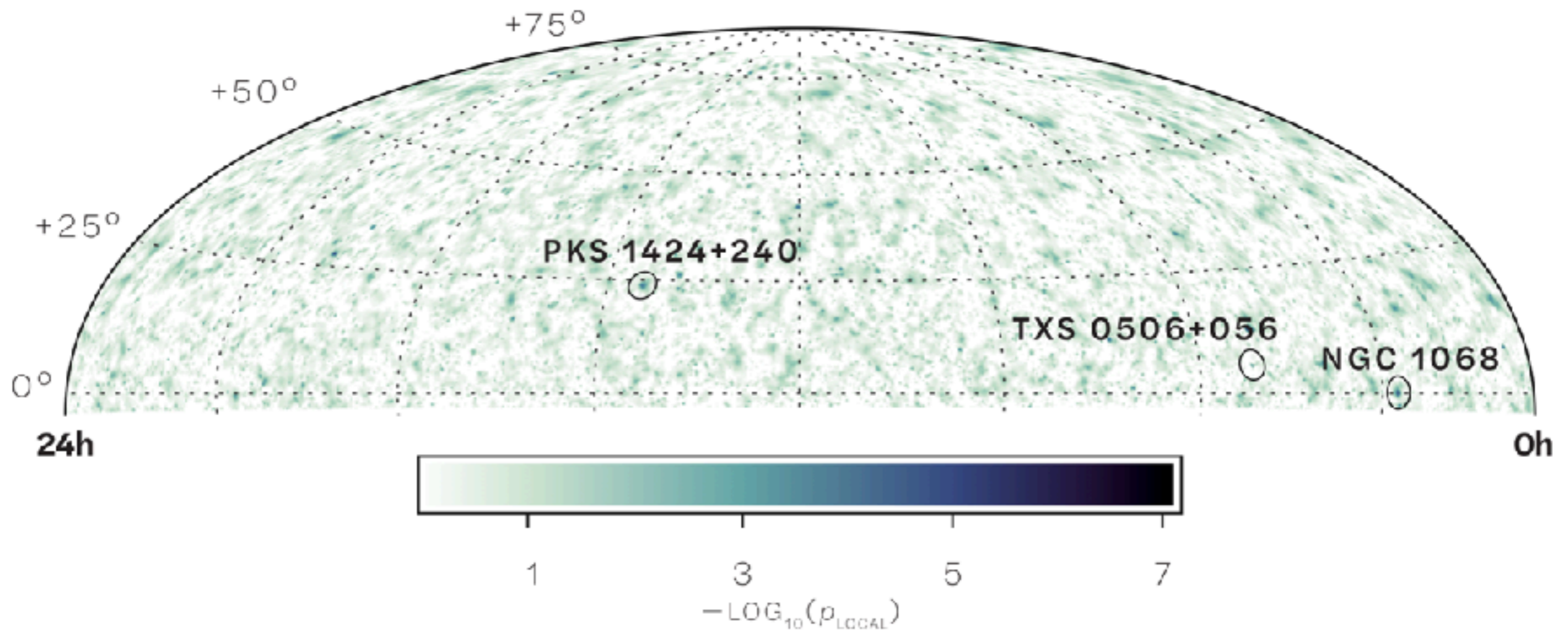


Tau "Double Bang"



- Completed in 2011

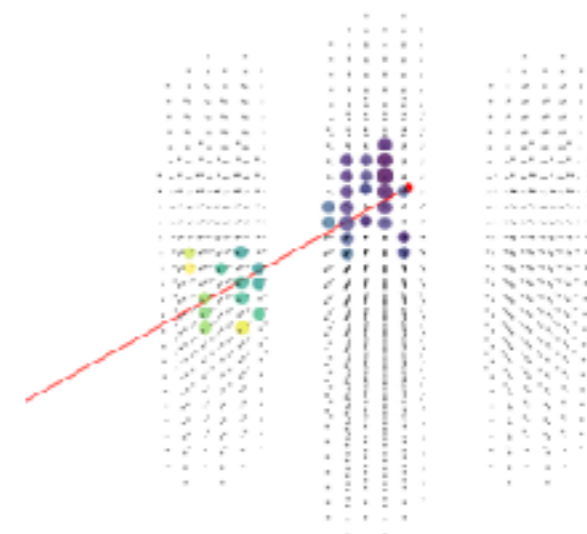
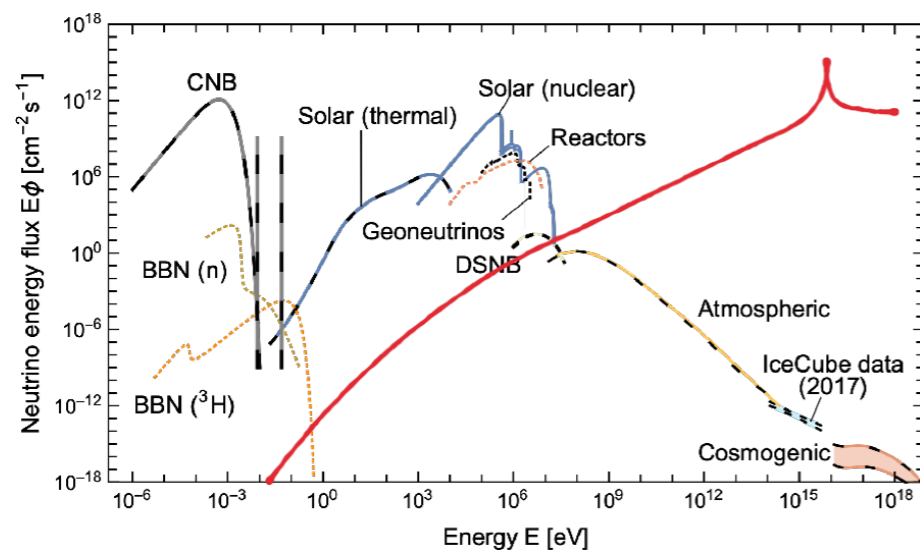
# Search for Neutrino Sources



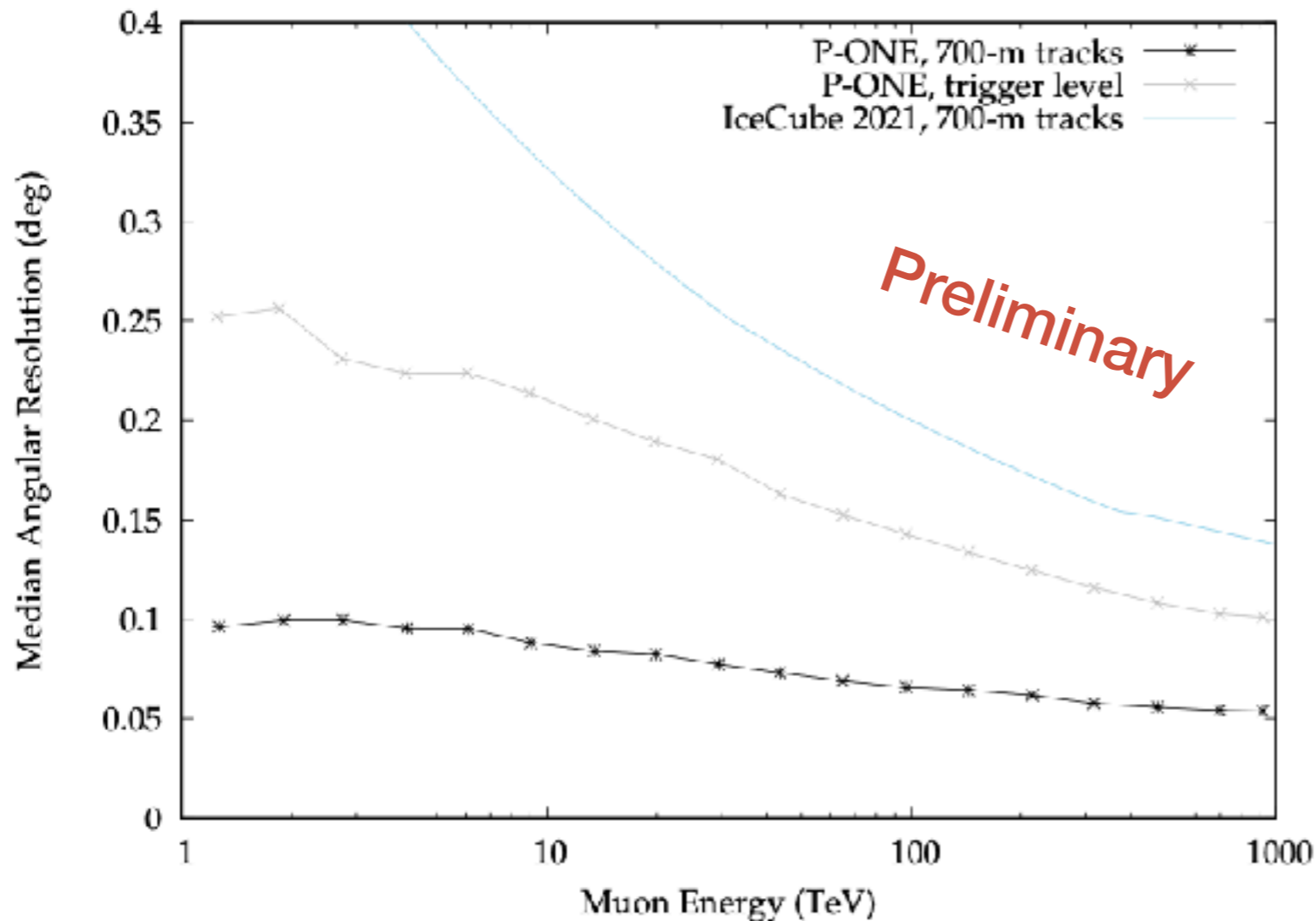
- The first neutrino sources have been identified using IceCube!

# P-ONE Physics

- P-ONE will be optimized for particle identification, making it ideal for high energy neutrino flavour physics. Our system development focuses on the identification of track vs cascade vs double bang signatures, benefiting from the superior scattering properties of ocean water
- With a large P-ONE detector it will be possible to study BSM effects and the Glashow resonance
- Even a ~small detector will be able to join the larger detectors to contribute to point source searches, especially in the sky region not covered by the other detectors in the northern hemisphere and even improve overall sensitivity as the pointing accuracy is so much better in water



# The P-ONE Advantage



- Both angular resolution, particle identification ability and sensitivity of P-ONE are designed to be leading in class
- The choices of calibration tools, trigger systems, timing resolution and readout technology are chosen to optimize

# P-ONE

- Alberta, Queen's, SFU, TRIUMF, TUM, Erlangen (Germany) and Drexel, Maryland, MSU (USA), Krakow (Poland), UCL (UK) Collaboration
- Started in 2018 with the deployment of a test setup to assess the water quality
- Funding in Germany for the first strings was secured in 2022
- The first US, Canadian and Polish funding was also secured in 2022, allowing for a robust effort to start prototype development and testing



# The Cascadia Basin Site



**Sea spider**  
(Pycnogonida)

4745.7177N, 12745.72609W, 2659m

2020-09-13 22:52:55, Hdg: 154

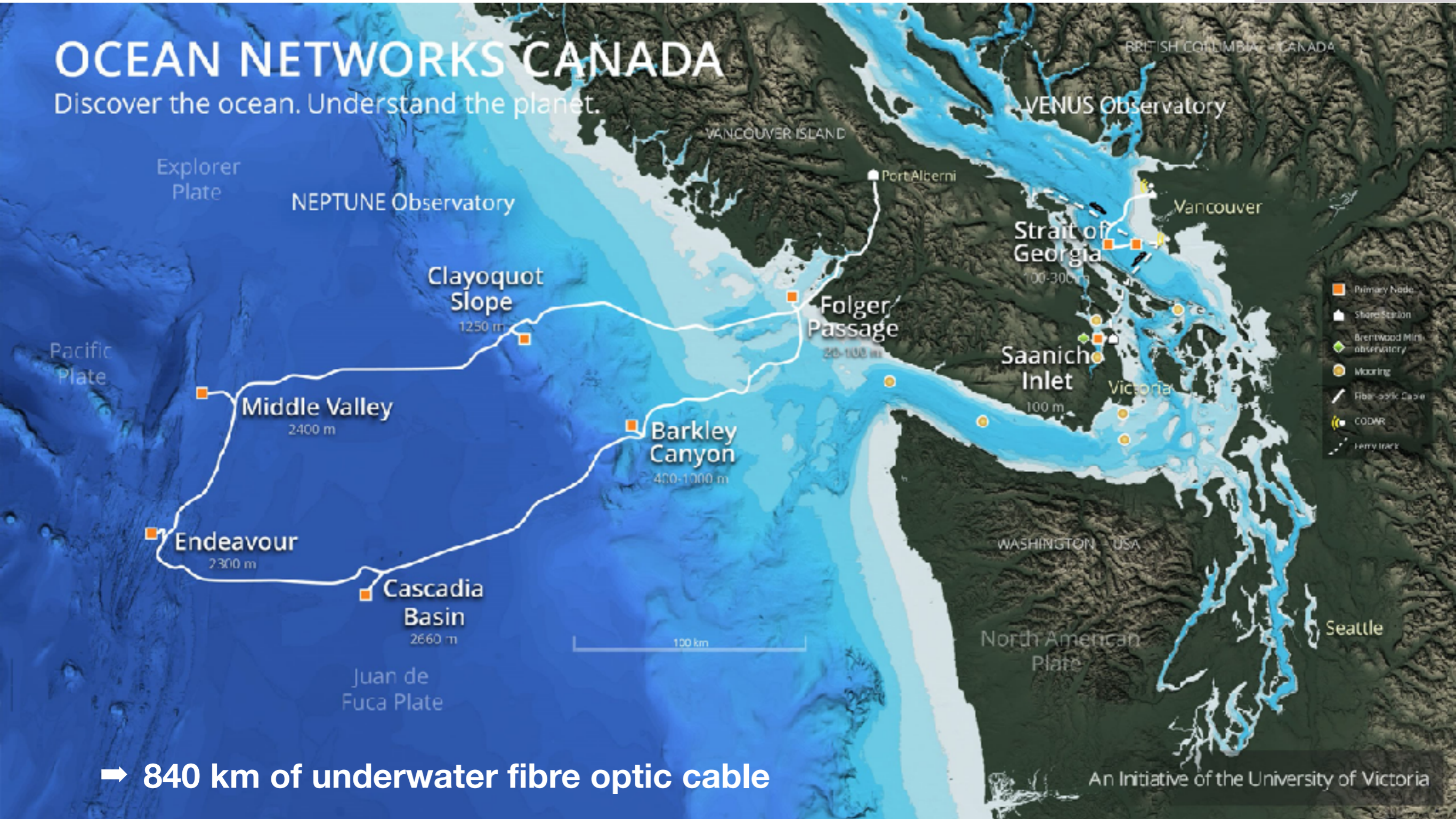
NA120, ONC Dive#: H1807

# ONC



## OCEAN NETWORKS CANADA

Discover the ocean. Understand the planet.



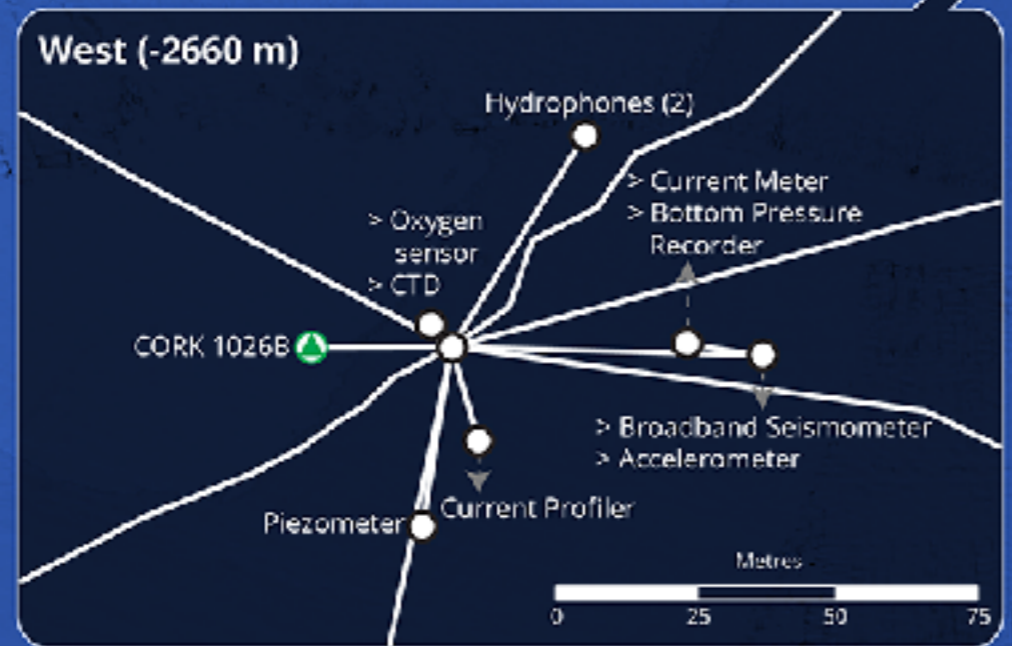
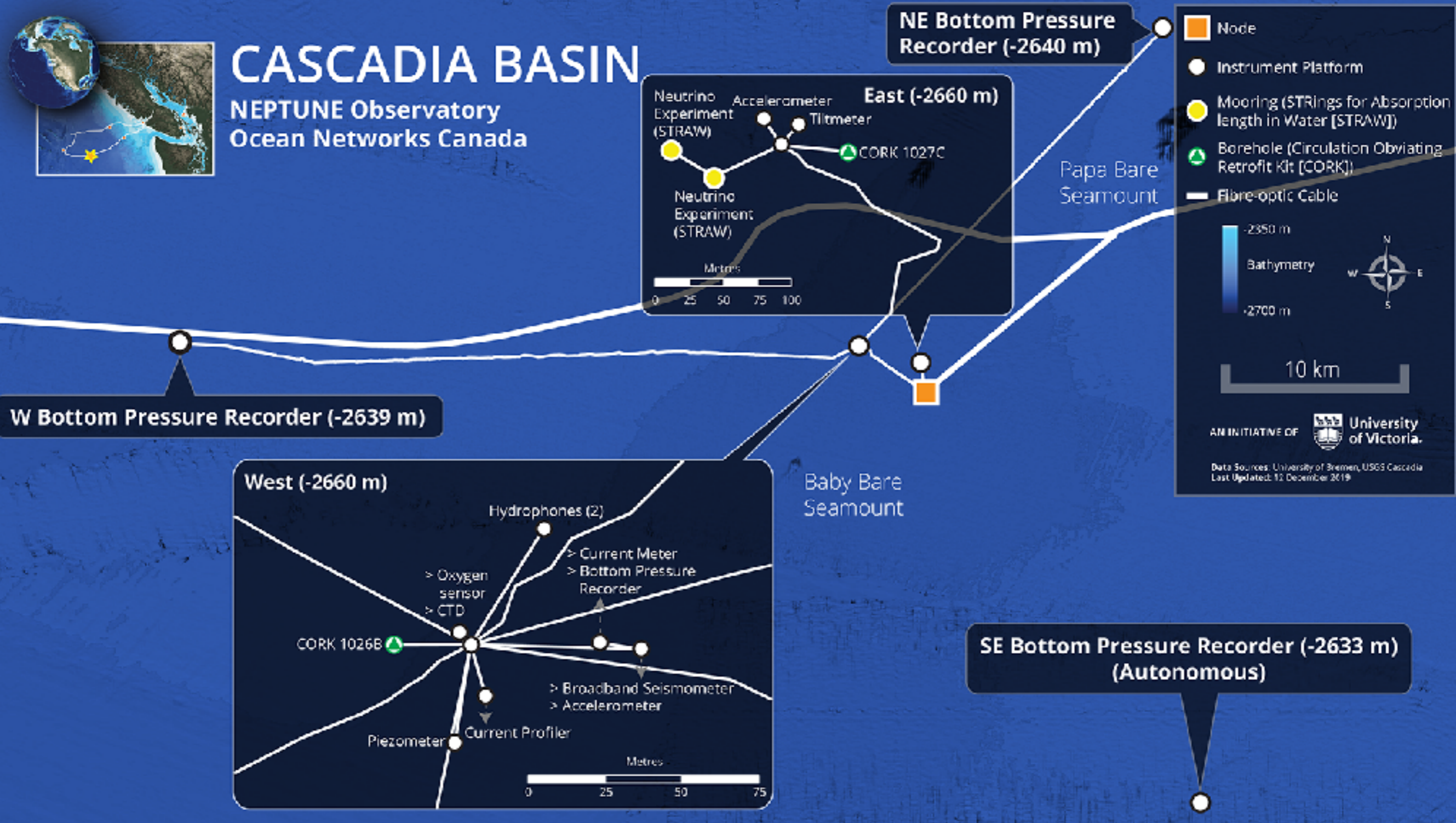
➔ 840 km of underwater fibre optic cable

An Initiative of the University of Victoria

# Cascadia Basin Site



**CASCADIA BASIN**  
 NEPTUNE Observatory  
 Ocean Networks Canada



**Legend**

- Node
- Instrument Platform
- Mooring (STRINGS for Absorption length in Water [STRAW])
- Borehole (Circulation Obviating Retrofit Kit [CORK])
- Fibre-optic Cable

Bathymetry: -2350 m to -2700 m

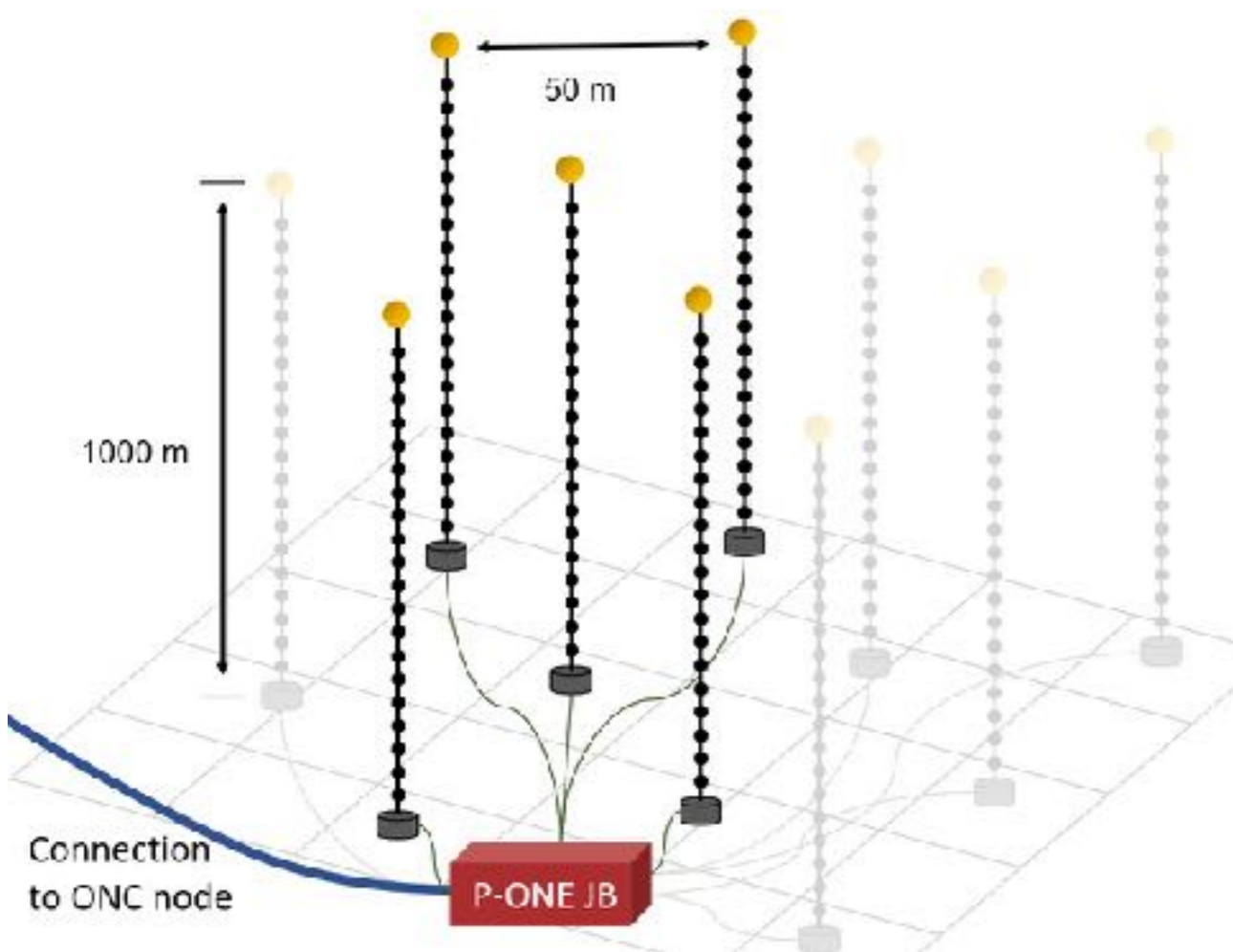
Scale: 10 km

AM INITIATIVE OF University of Victoria

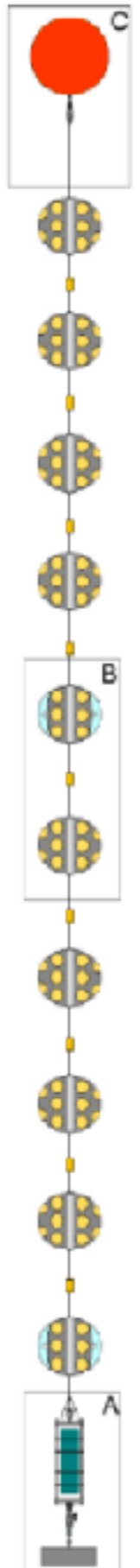
Data Sources: University of Bremen, USGS Cascadia  
 Last Updated: 12 December 2019



# Pacific Ocean Neutrino Experiment (P-ONE) Demonstrator

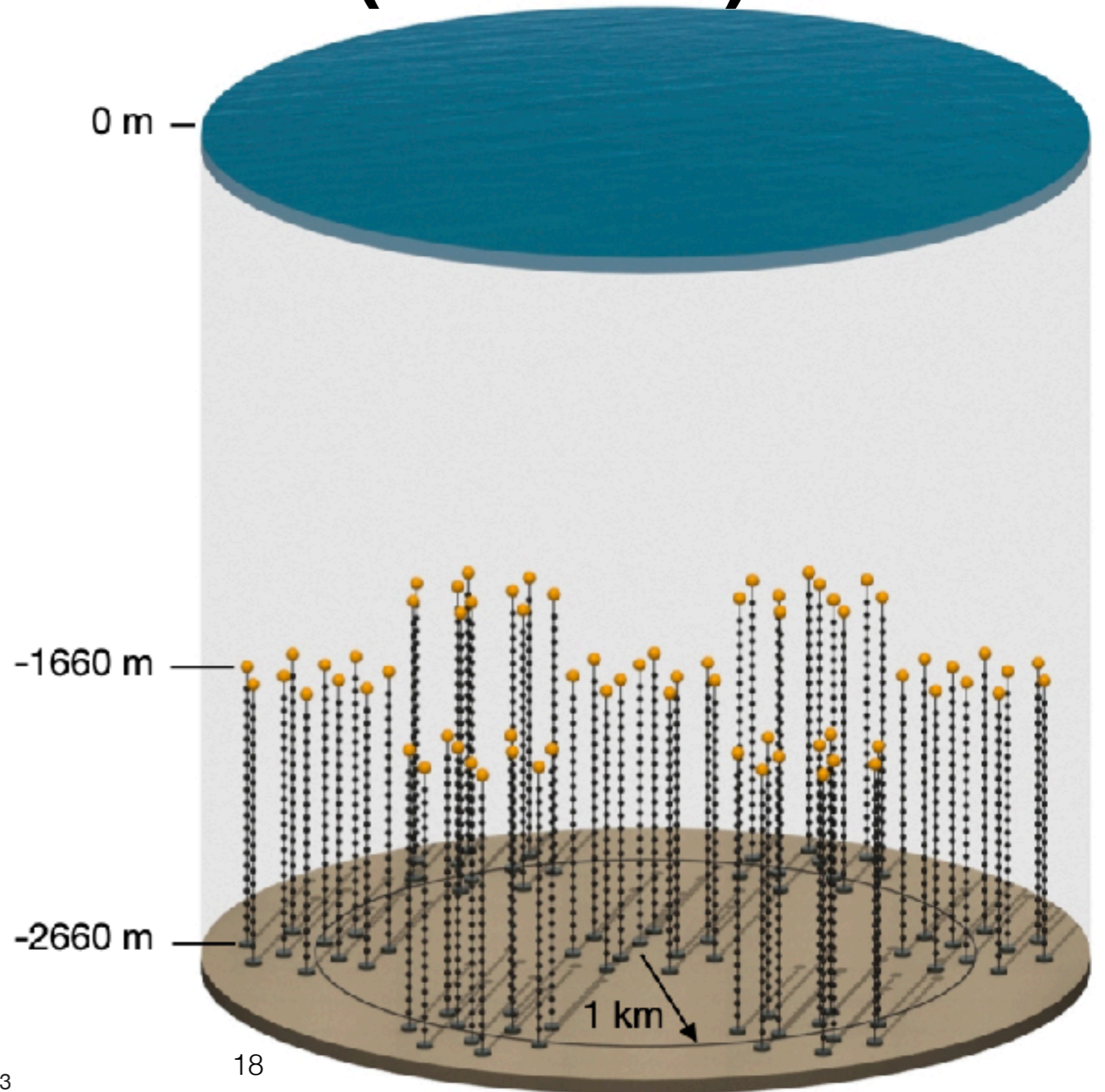


- Time scale for realization: 2024, first mooring line, more in the following years
- Up to 10 strings with 20 optical and calibration modules each
- 1 km long mooring line
- Instrumented volume  $>1/8 \text{ km}^3$



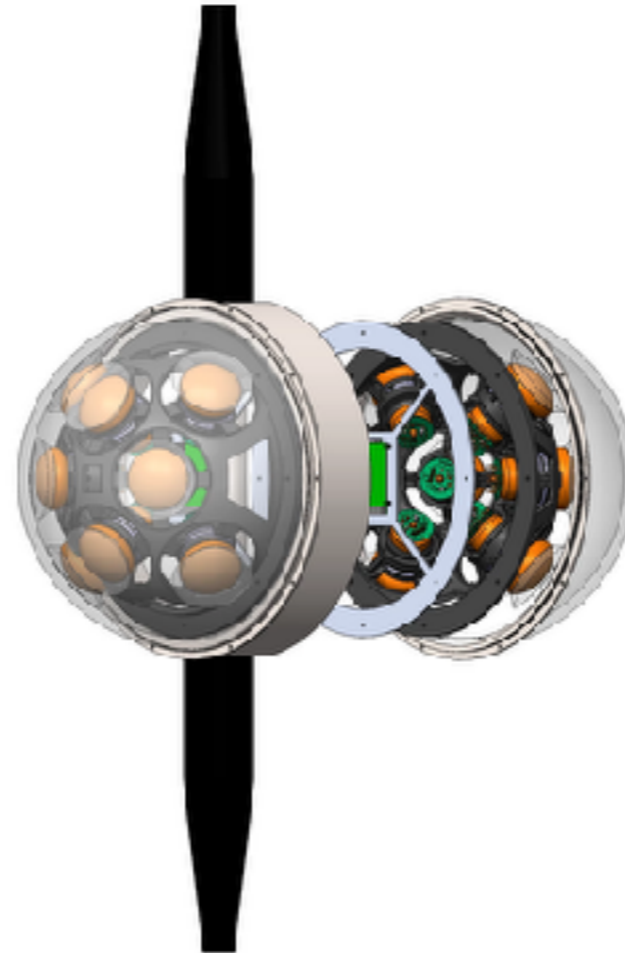
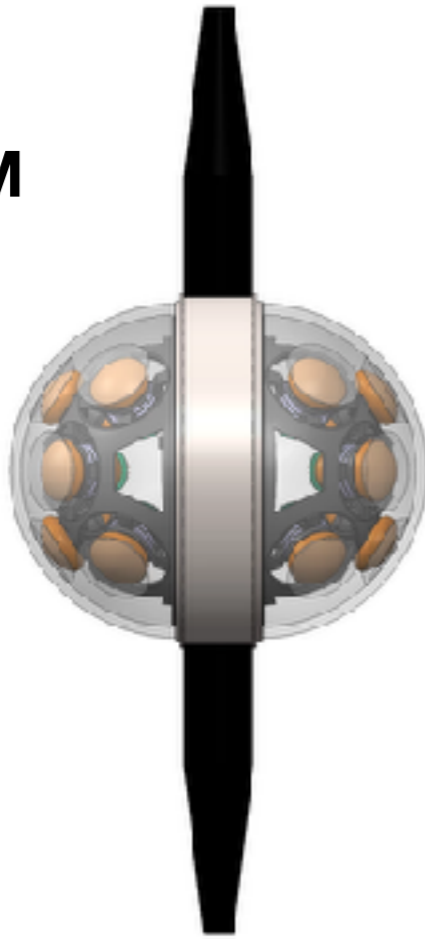
# Pacific Ocean Neutrino Experiment (P-ONE)

- The P-ONE collaboration aims to construct a  $\text{km}^3$  scale detector by constructing seven identical modules of the *Demonstrator* type
- The optimal final arrangement is currently under study

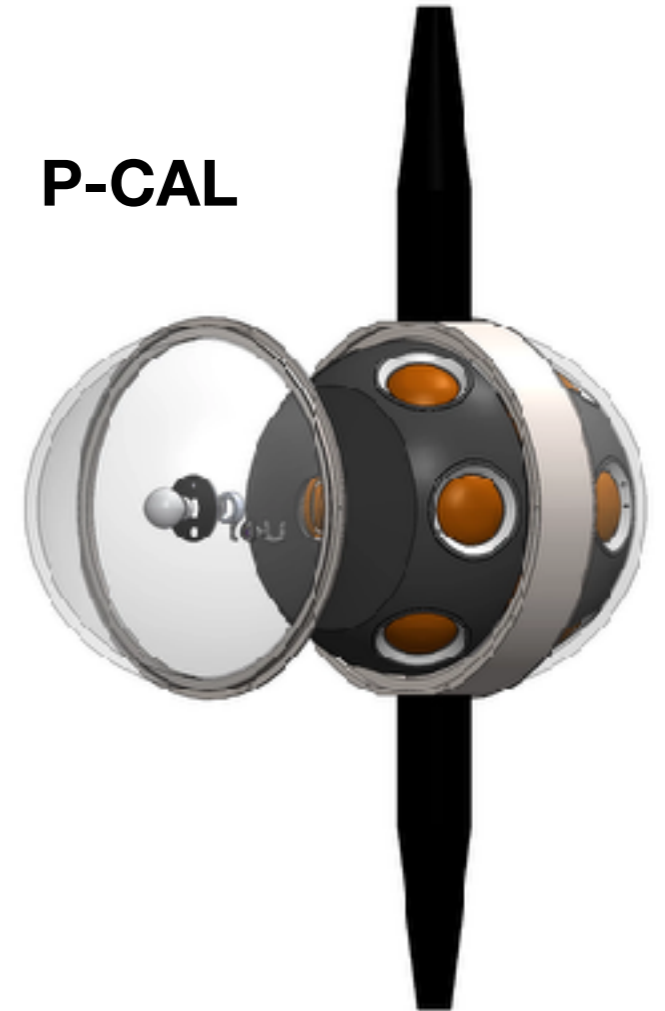


# Large Area Photon Detection

P-OM



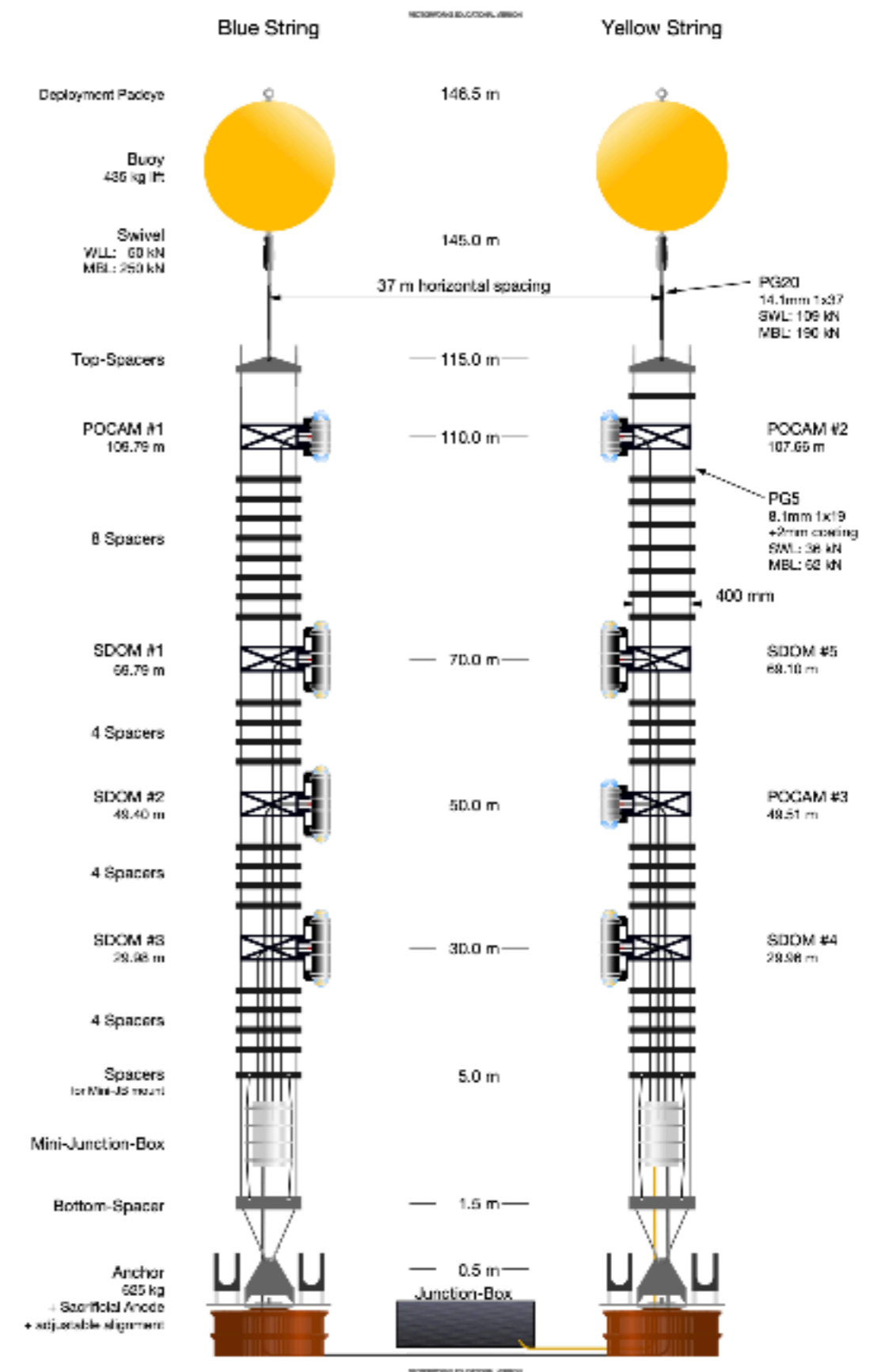
P-CAL



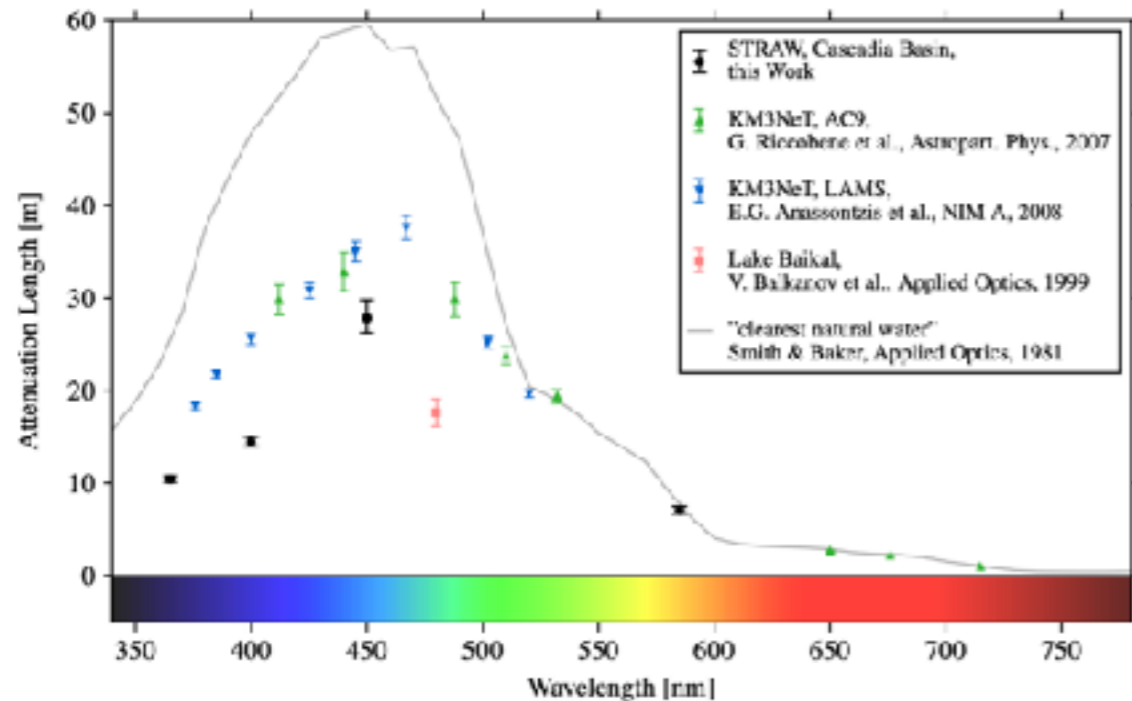
- The instrumentation of the ~200 optical modules of P-ONE will use KM3NeT/IceCube-like multi PMT digital optical modules
- 3" PMTs offer a good cost to surface area ratio
- Using a novel, side mounted housing allows obstruction-free observation

# STRAW

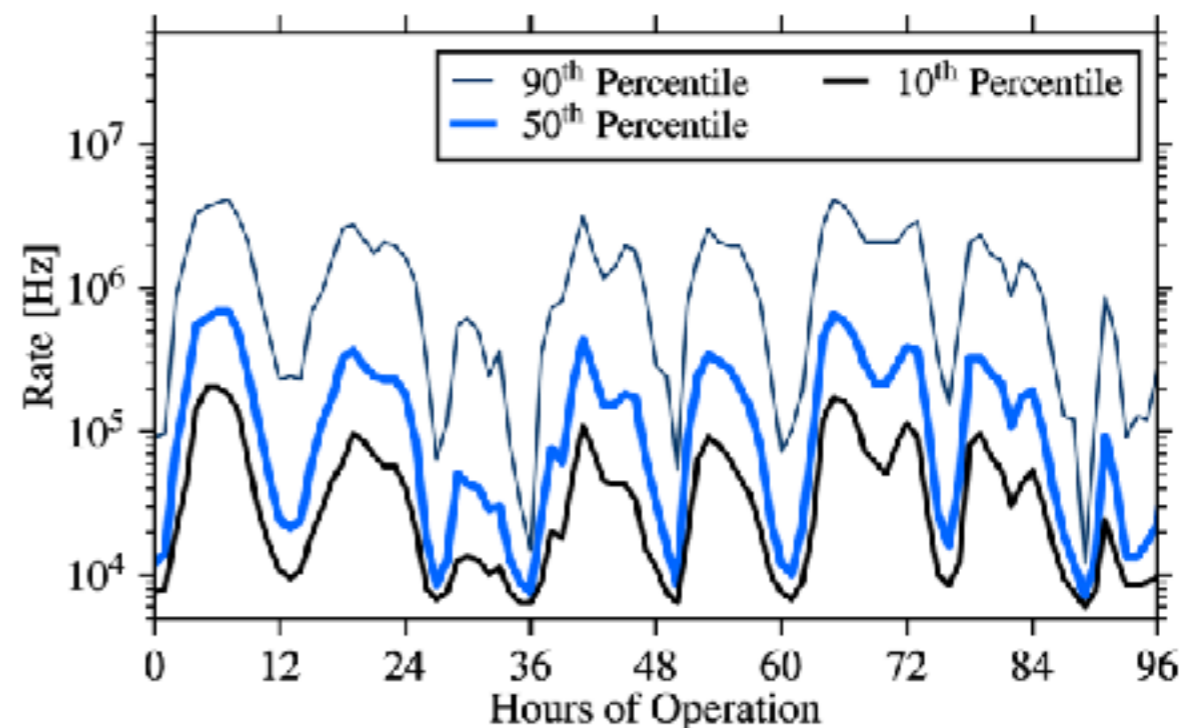
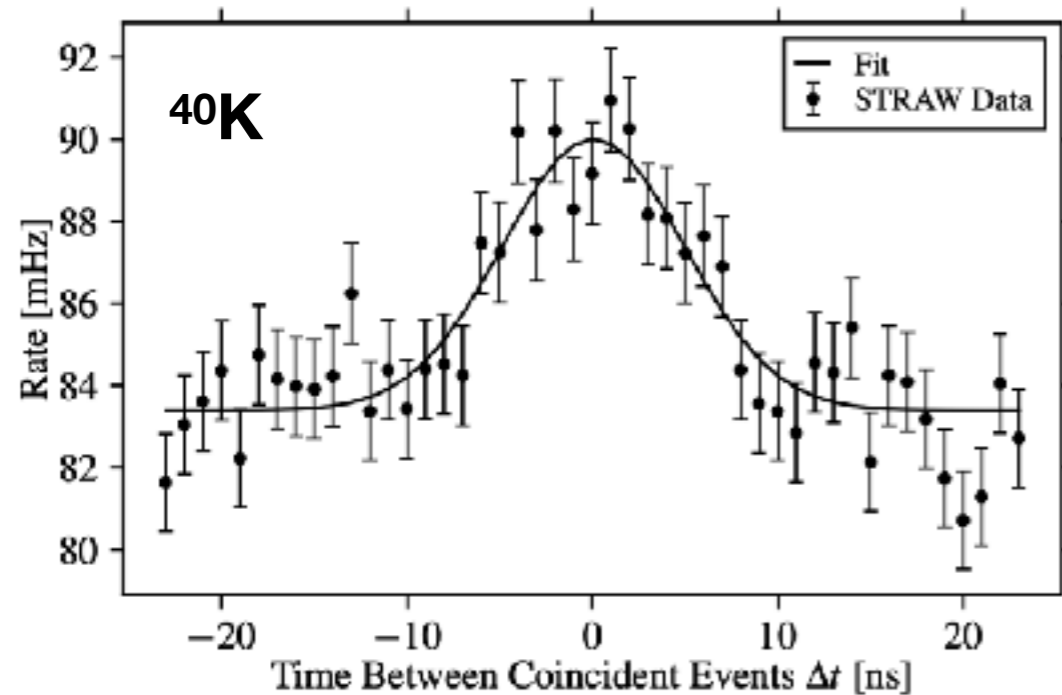
- Strings for Absorption in Water
- Deployed in summer 2018
- All instruments are working
- Absorption and scattering length determined to be similar to other ocean based detector locations



# Results: Attenuation Length & Bioluminescence

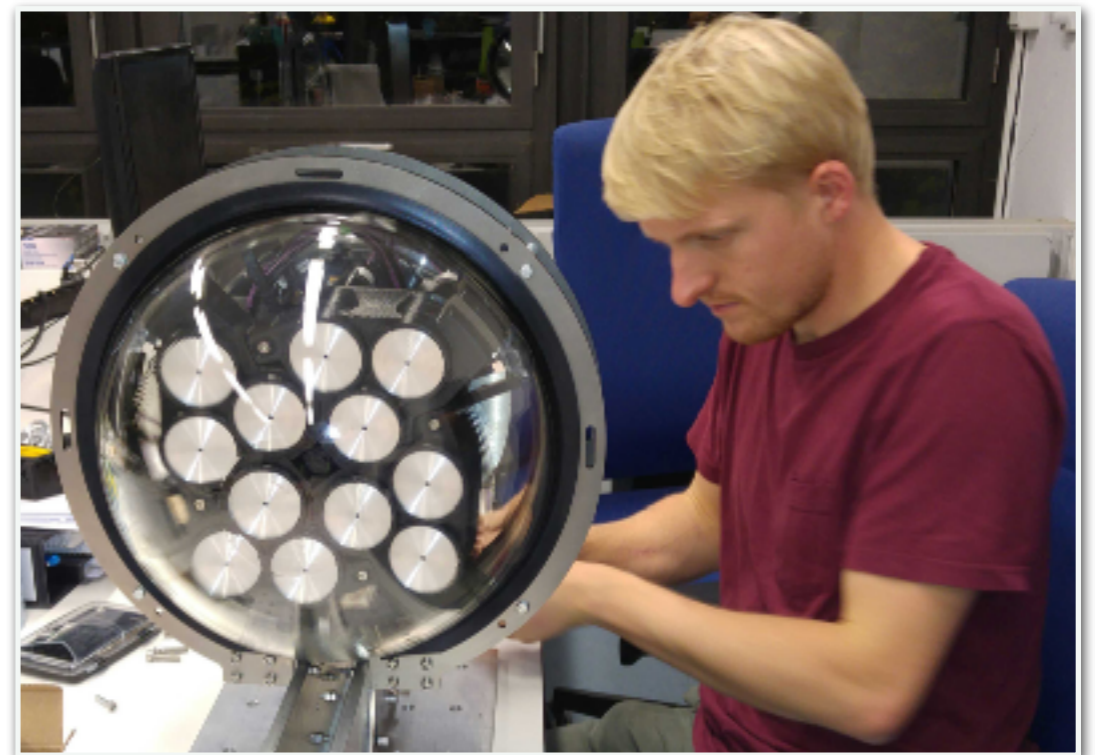
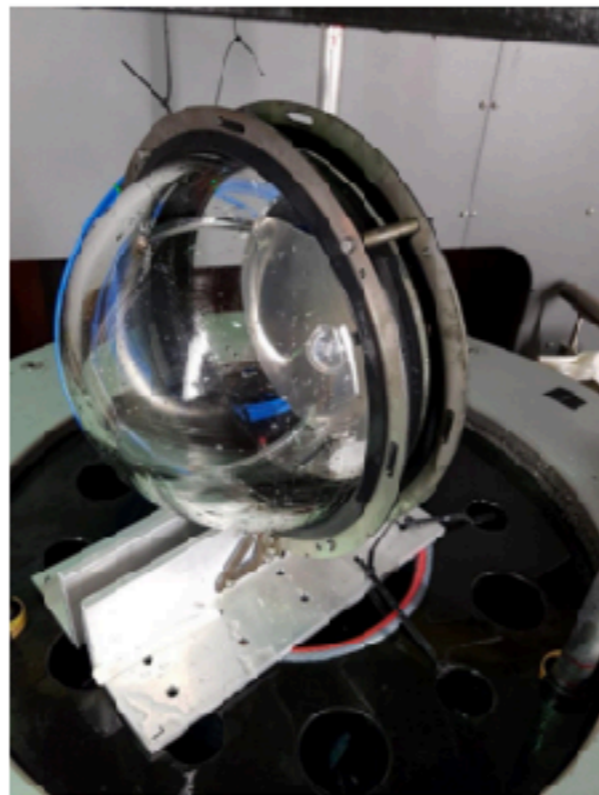
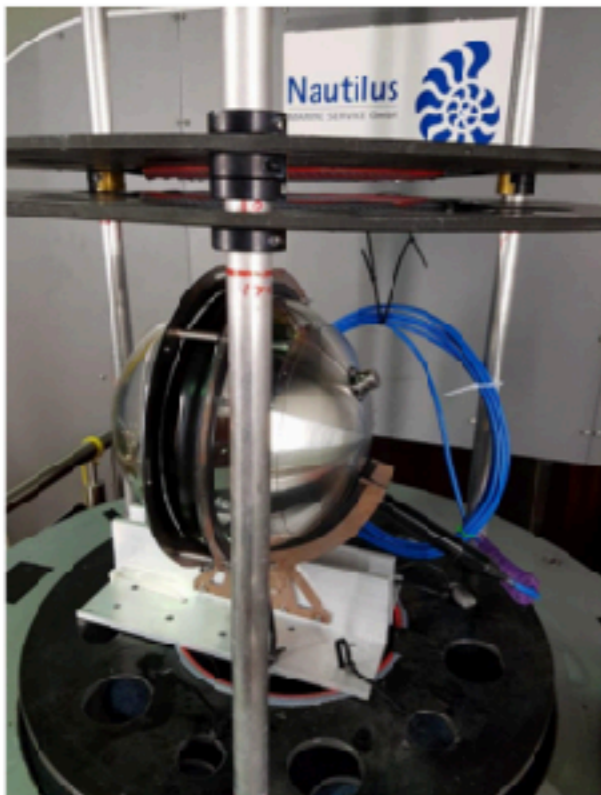


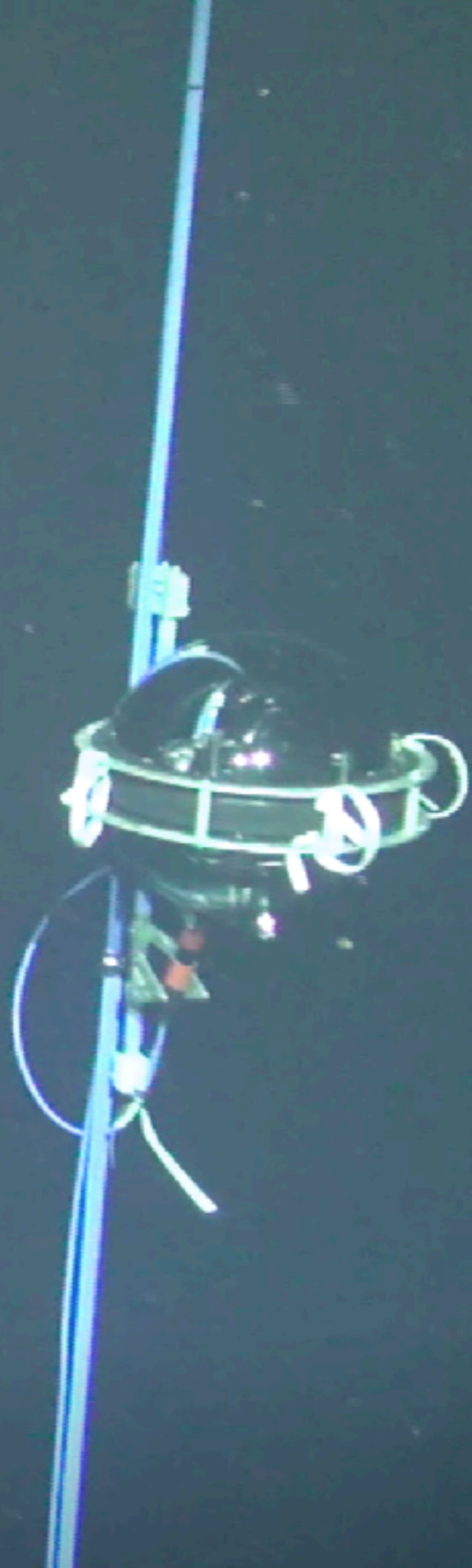
- Full publication with optical parameters:
- Bioluminescence is modulated with the tides
- $^{40}\text{K}$  Rate is consistent with ONC salinity measurements and expectations
- Attenuation length is good enough for a large scale neutrino telescope



# STRAW-b

- Longer string with new, systematically independent measurements: LIDAR, spectrometer
- Modules were developed at TUM, Munich and shipped to Canada for deployment
- Complete qualification of the deep site.
- Test longer mooring line (500m) and specialized devices.





# Status

- Both STRAW and STRAW-b are operational and deliver high quality data
- We have published first data from the prototype setups and are preparing more data for publication
- STRAW and STRAW-b will be retrieved in the coming two weeks to make room for the first full size components of P-ONE
- We are preparing for the deployment of the first “real” P-ONE line in 2024














# Activities In Canada

- Testing of Straw-B modules before deployment
- Biofouling studies and remedies (See talk by B. Veenstra, Wednesday)
- Leadership in the STRAW data taking and analysis to extract optical properties and performance data
- Reconstruction algorithm development
- Development of a new algorithm for tau event identification
- Background simulation ( $^{40}\text{K}$  and others)
- Trigger algorithm development and implementation
- Hardware development, flasher system, acoustic calibration and positioning system, electronics, calibration systems
- Final assembly and testing at TRIUMF for P-ONE.1, the first string
- Development of an internal muon tracker for reconstruction accuracy calibration
- DAQ development

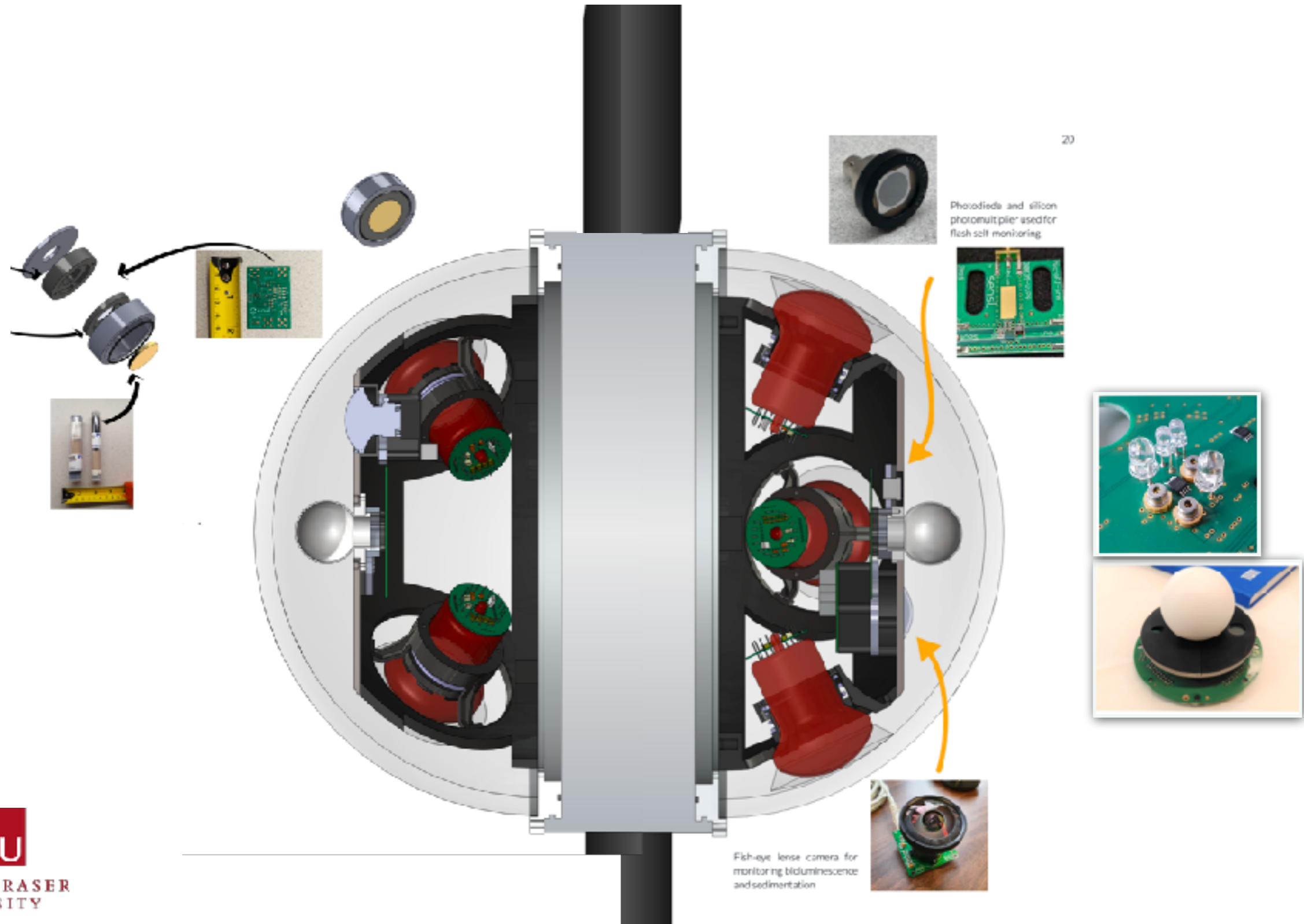


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-  • Testing of Straw-B modules before deployment
-  • Biofouling studies and remedies (See talk by B. Veenstra, Wednesday)
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-  • Development of a new algorithm for tau event identification
-  • Background simulation ( $^{40}\text{K}$  and others)
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-  • DAQ development



# Calibration Module

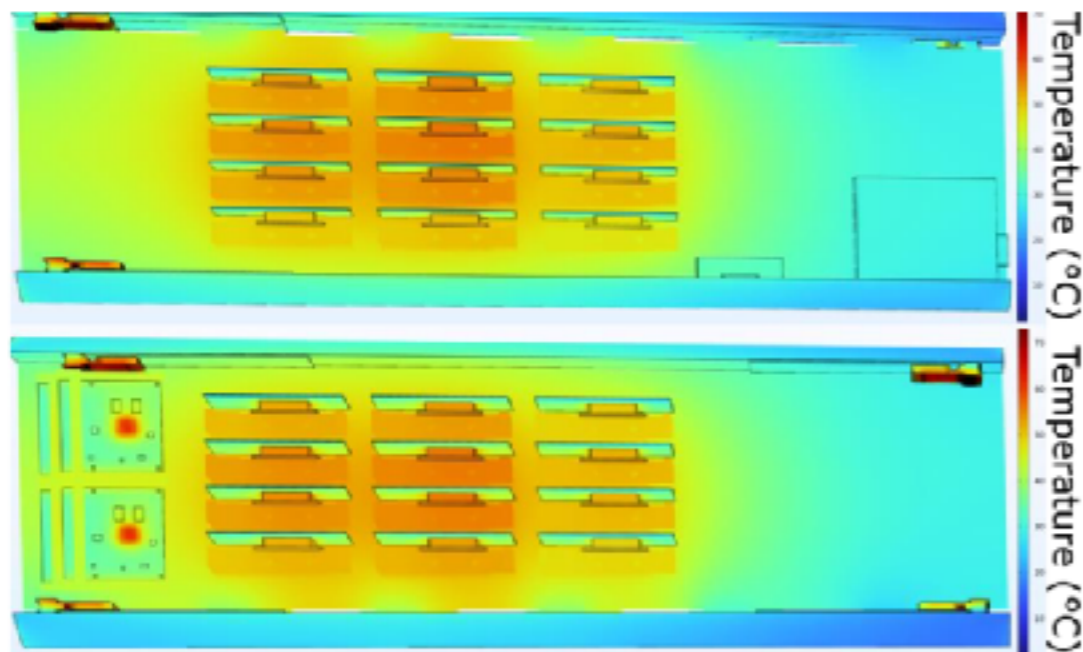


20

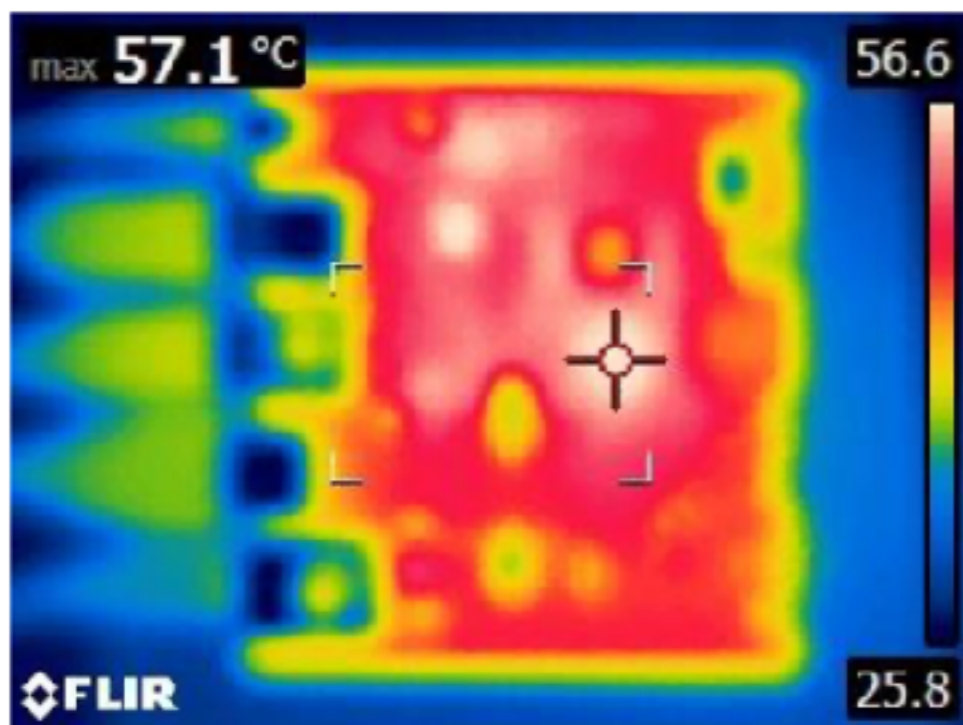
Photodiode and silicon photomultiplier used for flash self monitoring

Fish-eye lens camera for monitoring bioluminescence and sedimentation

# MiniJunction Box - trigger and mooring line power & data distribution

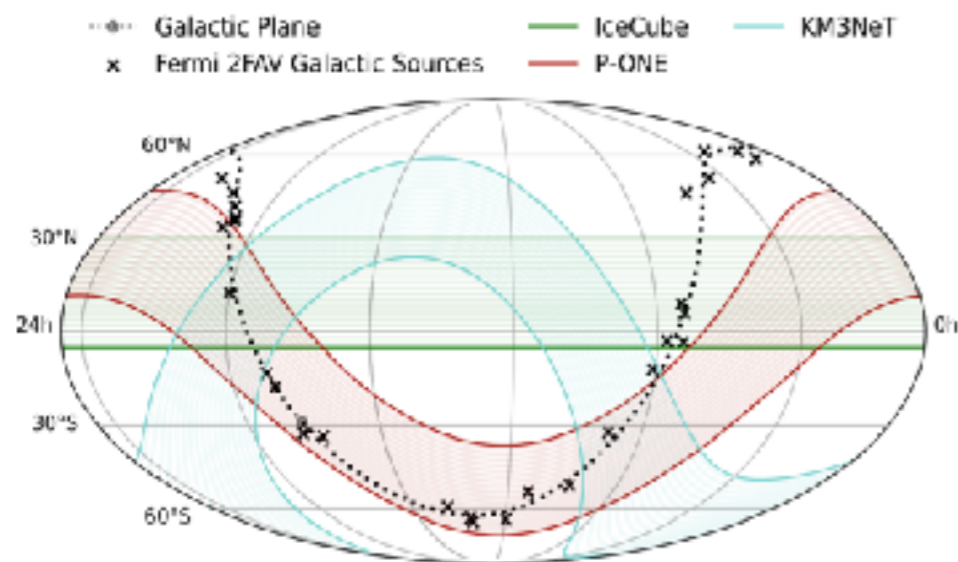


Simulated temperature on surface of solids in module



- The MiniJunction Box is the primary data and power system hub for each mooring line
- All systems are contained in a titanium pressure housing
- Thermal measurement and FEA simulations have shown that the current design is meeting requirements well

# P-ONE Goals - Demonstrator



COMMISSIONING! PROOF OF CONCEPT,  
SUCCESSFUL OPERATION 100% DUTY CYCLE



CALIBRATION! IN-SITU BACKGROUNDS,  
DETECTORS, ATMOSPHERIC BACKGROUNDS



PHYSICS GOALS:

- FIRST NEUTRINOS IN PACIFIC OCEAN
- IMPLEMENTATION OF MULTI MESSENGER PROTOCOL
- DEVELOPMENT OF  $\nu$ -FLAVOUR PARTICLE ID



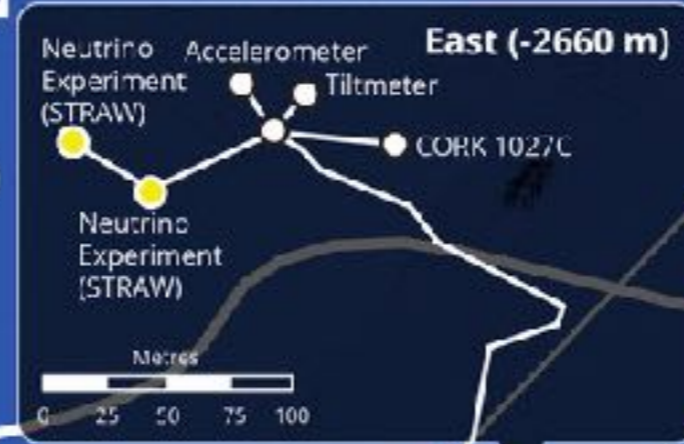
TRIGGER AN INTERNATIONAL EFFORT (P-ONE)  
SYNERGETIC OPERATION  $\nu$ -TELESCOPES





# CASCADIA BASIN

NEPTUNE Observatory  
 Ocean Networks Canada  
 Pacific Ocean Neutrino Explorer (P-ONE)



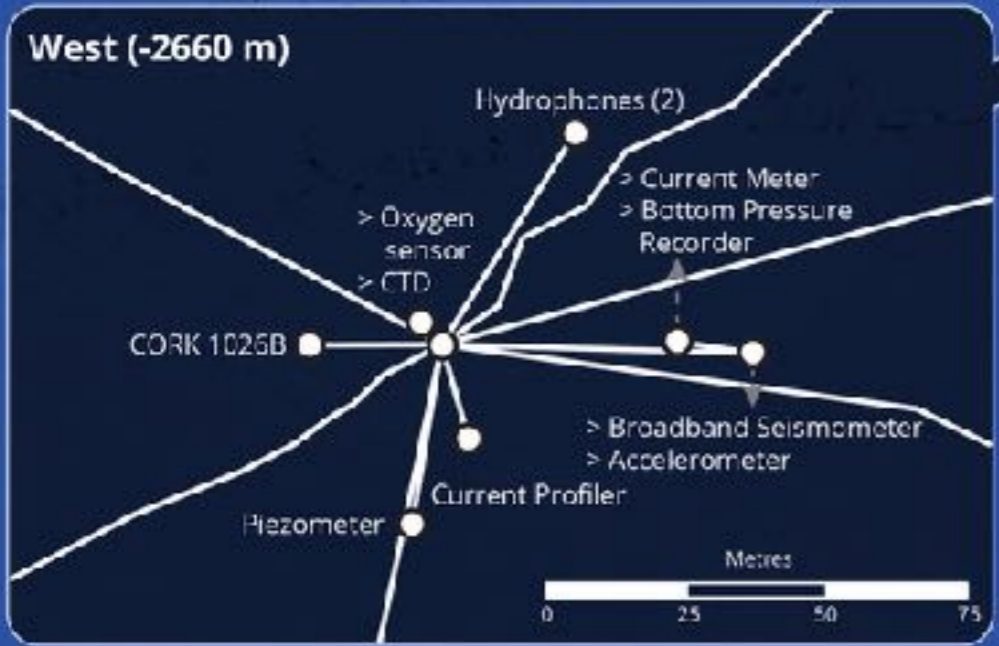
NE Bottom Pressure Recorder (-2640 m)

Papa Bare Seamount

Baby Bare Seamount

P-ONE

W Bottom Pressure Recorder (-2639 m)



SE Bottom Pressure Recorder (-2633 m) (Autonomous)

**Legend:**

- Node
- Instrument Platform
- Mooring
- Fibre-optic Cable (Active)
- Fibre-optic Cable (Planned)

**Bathymetry:** -2650 m to -2700 m

**Scale:** 10 km

**AN INITIATIVE OF** **University of Victoria**

**Description:** This map illustrates the planned location of the Pacific Ocean Neutrino Explorer (P-ONE) at Cascadia Basin. P-ONE is a new initiative which aims to redevelop ocean-based neutrino telescopes by harnessing Ocean Networks Canada infrastructure.

**Data Sources:** University of Alberta, University of Bremen, USOS Cascadia, McDonald Institute, Queens University

**Last Updated:** 7 Jan July 2021



# Summary



- Neutrino Astronomy will allow new and exciting studies for particle physics - The only thing keeping us from breakthrough discoveries is the small size of the current detectors
- The northern Pacific Ocean is ideally located and already instrumented by ONC for a new observatory to achieve full sky coverage
- Canadian groups haven taken on major responsibilities for the initial string and are leading calibration systems, trigger systems and final assembly planning efforts towards the P-ONE demonstrator