Snowmass2021 - Letter of Interest

The Pacific Ocean Neutrino Experiment: a new cabled observatory within Ocean Networks Canada.

NF Topical Groups: (check all that apply ☐/■)

☐ (NF1) Neutrino oscillations
☐ (NF2) Sterile neutrinos
☐ (NF3) Beyond the Standard Model
■ (NF4) Neutrinos from natural sources
☐ (NF5) Neutrino properties
☐ (NF6) Neutrino cross sections
☐ (NF7) Applications
☐ (TF11) Theory of neutrino physics
☐ (NF9) Artificial neutrino sources
■ (NF10) Neutrino detectors
■ (Other): CF1, CF7

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Abstract: The Universe is opaque to very high energy photons, limiting the horizon of γ-ray astronomy above 100 TeV primarily to our Galaxy. Neutrinos, nominally the ideal astrophysical messenger, allow the exploration of the cosmos up to the highest energy frontier. Following the IceCube Neutrino Observatory's discovery of an astrophysical flux of neutrinos in 2013, and the following link between some neutrinos and a γ-ray emitting blazar in 2017, a global effort has mobilized to establish dramatic improvements in the integral exposure to astrophysical neutrinos. Ocean Networks Canada (ONC), a unique oceanographic observatory, offers an emerging opportunity for the construction of a large volume neutrino telescope. Among the various ONC-powered nodes, the Cascadia Basin at a depth of 2660 meters has been selected via long term *in-situ* optical measurements to host the Pacific Ocean Neutrino Experiment (P-ONE). P-ONE will be a new telescope for TeV-PeV neutrinos that will build on a highly modular deployment and maintenance approach[1]. With the construction of P-ONE and coordinated operation of all neutrino telescopes (GVD, KM3NeT, and IceCube) as a distributed network of telescopes, a new cosmic frontier at the highest energies is reachable in the path to reveal the nature of extreme astronomical phenomena.

Ocean Networks Canada offers new opportunities for neutrino astronomy: The era of multi-cubic-kilometre neutrino telescopes is today technologically mature thanks to the experience gained over the last decade in ocean wiring by Ocean Networks Canada (ONC)[1] and in the construction of neutrino telescopes by IceCube[2], Baikal-GVD[3], ANTARES[4], and KM3NeT[5]. With the challenge of a stable system in which construction and operation of deep ocean neutrino telescopes is largely addressable, the next concern is the physical structure of the neutrino telescopes and their associated costs. With a characteristic deep ocean water optical attenuation length of 20-70 m, a uniform infill array, similar to IceCube, would require thousands of instrumented lines distributed over the entire volume. This would pose a daunting challenge that can be overcome by adopting a string configuration optimized for the segmented detection of high energy mouns coming from the horizon (see Fig. 1). The muon induced by a very high-energy neutrino can travel several kilometers in water and ice. The Cherenkov light produced by the propagating muon provides enough information for the reconstruction of the incoming neutrinos with an angular resolution of a fraction of a degree. A segmented sampling approach would retain sufficient information to reconstruct the incoming direction and the energy of the track while significantly reducing the number of mooring lines required to cover the large volumes (see Fig. 1). The P-ONE *Explorer*, corresponding to the first 10-string segment, will be installed in 2023-2024 during a marine operation scheduled to last four weeks. The rest of the telescope will follow in 2028-2030. A total of 20 photo-sensors and at least two calibration modules[6] will be installed in each string of the Explorer. The Explorer will not only pave the way for a successful P-ONE installation, but it will also explore the search for $10-100$ TeV energetic ν_τ of astrophysical origin, probe the production of long-lived exotic particles in the atmosphere, and complete current studies on the systematic uncertainties of cosmic ray interaction patterns[7–10].

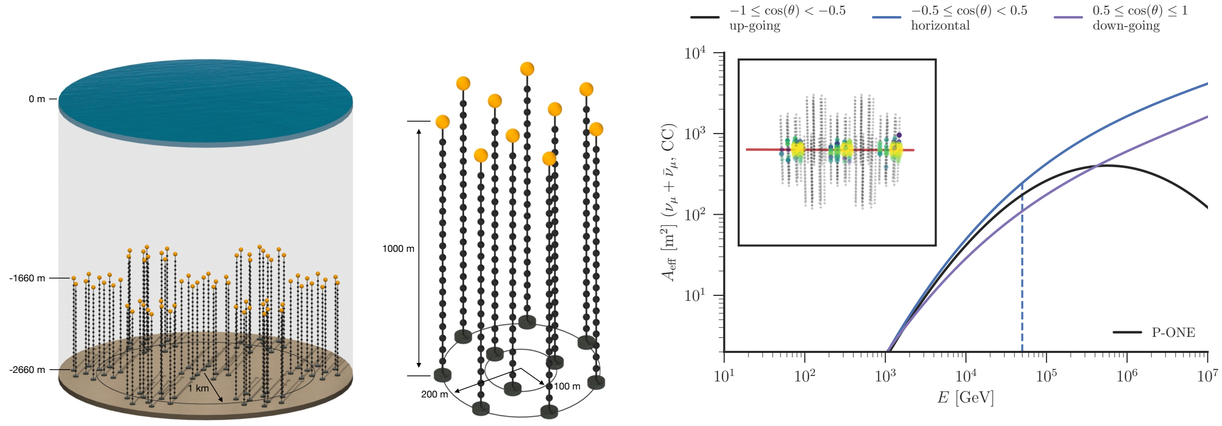

Figure 1: (left) Design of the instrumentation of Pacific Ocean Neutrino Experiment consisting of seven segments optimized for energies 10 TeV-10 PeV and high acceptance, the *Explorer* as individual segment and standalone detector. (right) Neutrino and anti-neutrinos effective area for charged current interaction in P-ONE geometry as reported in Fig. 3. The three different lines represent the effective area in different declination bands. In the box, we show the light pattern for a 50 TeV (dotted line) horizontal muon neutrino in P-ONE. The effective area is calculated by requiring a minimum deposit of 100 GeV of energy, and a minimum track of 100 m in one sector of 10 strings.

Current status of P-ONE: P-ONE[2], a new initiative for a large-scale neutrino telescopes in a deep ocean environment, will be installed and operated within one of the world's largest and most advanced cabled ocean observatories, ONC. ONC is composed of many infrastructures, the largest being the North East Pa-

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[1] `https://www.oceannetworks.ca`

[2] `http://www.pacific-neutrino.org`

cific Time-series Underwater Networked Experiment (NEPTUNE) and the Victoria Experimental Network Under the Sea (VENUS) coastal network. The NEPTUNE cabled ocean observatory[11], completed in 2009, comprises an 800 km loop of telecommunication fibre-optic cables to power and transfer data to a variety of sensors. It has been designed for long-lived, highly reliable underwater operations. The high-speed data link (up to 4 Gb/s per node) and high power (of the order of 8 kW/node) is available at 5 nodes across the Juan de Fuca tectonic plate (200,000 square kilometers) approximately 200 km off the coast of British Columbia, Canada. Each node acts as a local hub for core observations and experiments. A total of 17 primary junction boxes are cabled to the nodes and used to connect hundreds of instruments that report data in real time at high time resolution. The installation of the scientific instrumentation is effectively *plug and play*, allowing a highly modular deployment and maintenance. The connections rely on underwater-mateble connectors with field proven reliability (failure <2% in deployed connector pairs over a period of 10 years). The node deployed in 2009 at Cascadia Basin at a depth of 2660 m has been selected to host the P-ONE detector array. The wide and flat sediment surface provides ideal conditions to host a neutrino observatory, namely a large abyssal plain with temperature below 2°C. The Cascadia Basin is home to an assortment of well-adapted organisms, so if which emit bioluminescence light that is a source of background for a neutrino telescope. The local sea currents, under constant monitoring by ONC, are relatively strong (average high of 10 cm/s). This helps reduce the local sedimentation on the deployed instruments. To fully qualify Cascadia Basin as a site to host a multi-cubic- kilometer-scale neutrino telescope, a two-lines calibration setup - the STRings for Absorption length in Water (STRAW)[12;13] - was deployed in Spring 2018 and connected to the existing NEPTUNE node of Cascadia Basin. STRAW has been constantly monitoring the deep Pacific Ocean conditions in nearly real-time with a duty cycle of 98% since completion of the commissioning phase in January 2019. This pathfinder deployment has allowed a first *in-situ* measure of the effective attenuation length – at a wavelength of 465 nm – of 35 ± 5 m, as well as the monitoring of the bioluminescence activity over a period of more than 12 months. The level of irradiance observed locally in the deep ocean is in the range of $10^{-11} - 10^{-9}$ W/m^2. A second pathfinder mission named STRAW-b is presently under construction and will be deployed in 2020 to continue the optical qualification of the underwater site. In parallel to the pathfinder missions, the P-ONE collaboration has finalized the design of the *Explorer*, the first phase of P-ONE.

A distributed planetary network of telescopes: From the first indicative neutrino associations with blazars[14], it is evident that neutrino astronomy finds itself at the tipping point. As recently verified[15;16], the cross section for the neutrino–nucleon interaction increases with increasing neutrino energy, making the Earth significantly less transparent to neutrinos with energies above 50 TeV[3]. Neutrino telescopes are therefore effectively *blind* to very high energy neutrinos crossing the Earth. In order to obtain an all-sky neutrino exposure, it will be essential to be able to combine data from all the telescopes (see Fig. 2), including IceCube-Gen2[17]. Each telescope will be able to send alerts to the whole astronomy community, as well as to other neutrino telescopes, that will be able to follow in real-time the temporal evolution of a transient event emitting in the PeV energy region (e.g. GRBs).

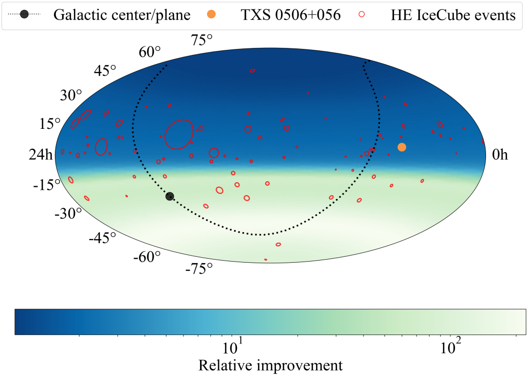

Figure 2: Map of the relative gain in neutrino acceptance with respect to IceCube. Combination of four IceCube equivalent telescopes placed in Siberia, Sicily, British Columbia, and South Pole.

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[3] less than 20% (5%) of the neutrinos with energy of 100 TeV (1 PeV) can cross the Earth at vertical zenith angle cos(θ) = -0.8.

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