# Snowmass2021 - Letter of Interest

# *ARIANNA-200: High Energy Neutrino Telescope*

**Thematic Areas:** (check all that apply □/■)

□ (CF1) Dark Matter: Particle Like
□ (CF2) Dark Matter: Wavelike
□ (CF3) Dark Matter: Cosmic Probes
□ (CF4) Dark Energy and Cosmic Acceleration: The Modern Universe
□ (CF5) Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before
□ (CF6) Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities
■ (CF7) Cosmic Probes of Fundamental Physics
■ (Other) Relevant also for *NF04, NF10*

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**Abstract:**
The proposed ARIANNA-200 neutrino detector, located at sea-level on the Ross Ice Shelf, Antarctica, consists of 200 autonomous and independent detector stations separated by 1 kilometer in a uniform triangular mesh, and serves to inform the planning of the future IceCube-Gen2 project. The primary science mission of ARIANNA-200 is to search for sources of neutrinos with energies greater than $10^{17}$ eV, complementing the reach of IceCube. An ARIANNA observation of a neutrino source would provide strong insight into the enigmatic sources of cosmic rays. ARIANNA observes the radio emission from high energy neutrino interactions in the Antarctic ice. Among radio based concepts under current investigation, ARIANNA-200 would uniquely survey the vast majority of the southern sky at any instant in time, and an important region of the northern sky, by virtue of its location on the surface of the Ross Ice Shelf in Antarctica. The broad sky coverage is specific to the Moore's Bay site, and makes ARIANNA-200 ideally suited to contribute to the multi-messenger thrust by the US National Science Foundation, Windows on the Universe – Multi-Messenger Astrophysics, providing capabilities to observe explosive sources from unknown directions. The ARIANNA architecture is designed to measure the angular direction to within 3° for every neutrino candidate, which too plays an important role in the pursuit of multi-messenger observations of astrophysical sources.

## Science enabled by ARIANNA-200

The ARIANNA-200 neutrino detector[1], located at sea-level on the Ross Ice Shelf, Antarctica, consists of 200 autonomous and independent detector stations separated by 1 kilometer in a uniform triangular mesh. As a consequence of the reflection properties at the ice-water interface at the bottom of the Ross Ice Shelf, ARIANNA-200 views almost the entire southern sky, including the galactic center, with nearly uniform exposure. ARIANNA-200 (Figure 1, left) exceeds the instantaneous sky coverage of all other radio-based neutrino detectors being studied. It's broad sky coverage is ideally suited to contribute to multi-messenger campaigns initiated by gravitational-wave detectors, gamma-ray telescopes, cosmic ray observatories, and neutrino telescopes targeting lower energies such as IceCube[2] in the Southern hemisphere, and KM3NeT[3] and Baikal-GVD[4] in the Northern hemisphere.

The sky coverage of ARIANNA-200 augments the point source capabilities of IceCube. At high neutrino energies ($E_\nu > \sim 10^{14}$ eV), the Earth becomes opaque. Thus, at higher energies, both IceCube and ARIANNA-200 observe mostly the Southern sky, leading to a substantial overlap in sky coverage. ARIANNA-200 will observe about one event for every three sources of the highest energy cosmic rays observed by IceCube, assuming neutrino production above $10^{15}$ eV with an unbroken power law up to $10^{20}$ eV proportional to $E_\nu^{-2}$. A spatially and temporally coincident detection of the same source would establish a hard spectrum up to an energy of $10^{18}$ eV or greater, and provide a direct link to an accelerator of the very highest energy cosmic rays. The model parameter-space for neutrino fluxes of sources is large. Some models suggest that the flux from some neutrino sources may be enhanced at energies close to maximum sensitivity of ARIANNA-200, for example[5–7], while others predict no observable emission. It is quite possible that new experimental results will be able to guide theory in this respect.

The simultaneous observation of a point source by IceCube and ARIANNA-200 in different energy ranges would create transformational progress in understanding the half-century old mystery of cosmic rays. Cosmic rays possess extraordinary high energy, but we do not know the sources of their power, nor the physics responsible for their acceleration. The ARIANNA architecture is designed to measure the angular direction to within 3° or better for every neutrino candidate, which too plays an important role in the pursuit of multi-messenger observations of astrophysical sources. Perhaps as few as one neutrino detected by ARIANNA-200, correlated in time and direction with an explosive event observed by IceCube or in some other messenger channel, would provide conclusive steps forward in field of cosmic ray astrophysics.

Apart from the astrophysical neutrinos produced directly at the sources of cosmic rays, cosmogenic neutrinos are produced by the interaction of UHECR protons and cosmic microwave photons[8–11]. These interactions typically still happen close to the source, and the neutrino preserves the cosmic-ray direction. Thus, also cosmogenic neutrinos can reveal the sources of cosmic rays. They have not been detected so far. In 10 years of operation, ARIANNA-200 will be sensitive to cosmogenic fluxes at a level of $E_\nu^2 \Phi \leq 4 \times 10^{-9}\,\mathrm{GeV cm^{-2} s^{-1} sr^{-1}}$, corresponding to $\sim$10% of the current limits for neutrino energies above $10^{18}$ eV. The observation or upper limit from ARIANNA-200 will constrain model parameters, such as source evolution, energy cutoff and cosmic ray composition.

With a combined fit to the energy spectrum and $X_{\max}$ distribution (an estimator of the cosmic-ray mass) of UHECR data, the parameters of cosmic-ray sources are estimated from which the cosmogenic neutrino flux can be predicted. However, the analysis is based on a number of simplified assumptions (e.g. a continuous distribution of identical sources and rigidity dependent maximum energies) and the results possess large uncertainties. For example, analysis of the data of the Pierre

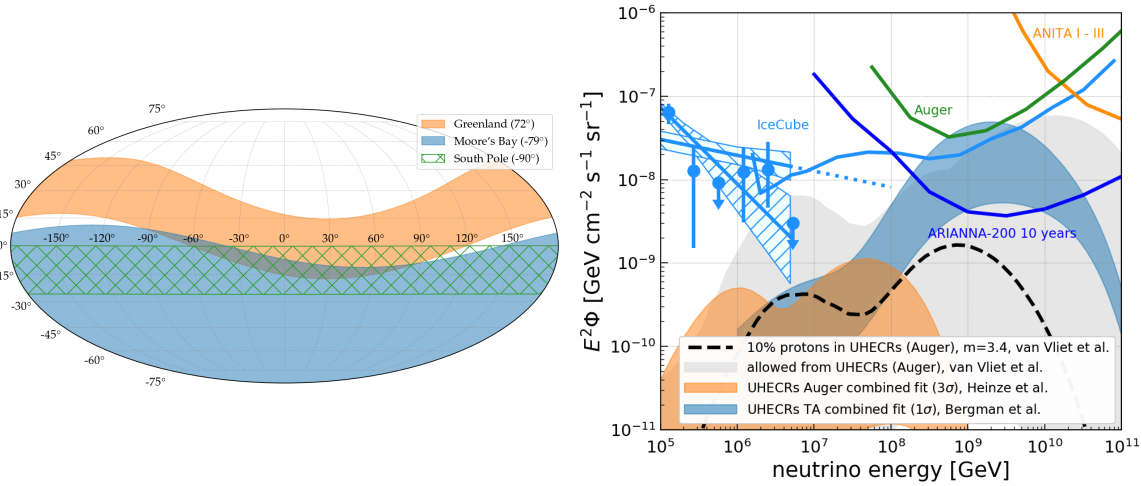


Figure 1: **Left:** Instantaneous sky coverage of ARIANNA-200 at Moore's Bay, Antarctica (Blue), plotted in Right Ascension (RA) and Declination (Dec) at one particular time of the day. For comparison, the sky coverage is shown for radio-based neutrino detectors located at Summit Station in Greenland (gold) and South Pole, Antarctica (green hatch). **Right:** Expected sensitivity of the ARIANNA-200 detector in one-decade energy bins calculated using NuRadioMC[16] for 10 years of operation assuming a uptime of 100%. Also shown is the measured astrophysical neutrino flux from IceCube using the high-energy starting event (HESE) selection[17] and using a muon neutrino sample[18], limits from existing experiments (IceCube[19], Auger[20] and Anita[21]). The color shaded bands show predictions using a simple astrophysical model with commonly discussed source evolution parameters based on cosmic ray data of the Telescope Array (blue)[14;22] and the Pierre Auger Observatory (orange)[23]. The dashed line shows a slightly more complex model with an additional small proton component[15]. The gray band indicates the range of theoretical uncertainties on model parameters[15].

Auger Observatory located in Argentina[12;13] results in substantial differences to an analysis of the data of the Telescope Array (TA) located in Utah[14]. The former favors a heavy composition with a low rigidity cutoff at the source resulting in a small cosmogenic neutrino flux, whereas the former favors a high rigidity cutoff and a slightly lighter source composition resulting in a much higher neutrino flux. Furthermore, data of the Pierre Auger Observatory is compatible with an additional proton contribution resulting in substantial increase in the expected neutrino flux[15].

We summarize the different predictions of cosmogenic neutrinos as well as the predicted ARIANNA-200 sensitivity, and results from existing experiments in Fig. 1, (right). The prediction from TA data is well within the reach of ARIANNA-200. For the more pessimistic source parameters derived from Auger data, ARIANNA-200 may observe cosmogenic neutrinos if the proton fraction is larger than 20% of the total particle number. Thus, ARIANNA-200 will provide new insights into the properties of cosmic-ray sources.

The ARIANNA-200 approach provides a wide $2\pi$ field of view of mostly the Southern Sky, and the largest overlap with IceCube-Gen2[24] of any location discussed by the community. The autonomous architecture employed by ARIANNA-200 has successfully operated at the South Pole, and is a viable technological option for devices located at other locations in polar regions, such as Greenland.

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