Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008
Vol. 5 (HE part 2), pages 1601–1604

30TH INTERNATIONAL COSMIC RAY CONFERENCE

ARIANNA: A New Concept for UHE Neutrino Detection

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Abstract: The ARIANNA concept utilizes the Ross Ice Shelf near the coast of Antarctica to increase the sensitivity to cosmogenic neutrinos by roughly an order of magnitude when compared to the sensitivity of existing detectors and those under construction. Therefore, ARIANNA can test a wide variety of scenarios for GZK neutrino production, and probe for physics beyond the standard model by measuring the neutrino cross-section at center of mass energies near 100 TeV. ARIANNA capitalizes on several remarkable properties of the Ross Ice Shelf: shelf ice is relatively transparent to electromagnetic radiation at radio frequencies and the water-ice boundary below the shelf creates a good mirror to reflect radio signals from interactions by neutrinos traveling downward. The high sensitivity results from nearly six months (or more) of continuous operation, low energy threshold (~3×10^{17} eV), and more than 2π of sky coverage. The baseline concept for ARIANNA consists of moderately high gain antenna stations arranged on a 100 x 100 square grid, separated by about 300m. Each station consists of eight linearly polarized antennas residing just beneath the snow surface, facing downwards. They communicate with each other and with a central control hub by wireless links to generate global triggers. This paper describes the ARIANNA concept, science goals, and recent progress in the development of the detector.

Introduction

During the past decade, Antarctica has emerged as one of the preferred locations to construct and operate high energy neutrino telescopes. Neutrinos interact so infrequently that a realistic detector must encompass or survey an enormous number of target nuclei, and the target medium must be transparent to the electromagnetic signals generated by the interaction. Several large projects (AMANDA[1], ANITA[2], IceCube[3], and RICE[4]) exploit the fact that Antarctic ice is transparent to radio and optical emission. With the recent successful flight of ANITA in December 2006, we may soon know much more about the ultrahigh energy neutrino flux.

The ARIANNA (Antarctic Ross Iceshelf ANtenna Neutrino Array) concept[5] utilizes the Ross Ice Shelf near the coast of Antarctica to increase the sensitivity to ultrahigh energy cosmogenic neutrinos by roughly an order of magnitude when compared to the sensitivity of existing detectors and those under construction. Therefore, ARIANNA can test a wide variety of scenarios for neutrino production, and probe for physics beyond the standard model [6] by measuring the neutrino cross-section at center of mass energies near 100 TeV. The idea of using a surface array of radio receivers to search for astrophysical sources of neutrinos has a long history[7]. ARIANNA capitalizes on several remarkable properties of the Ross Ice Shelf: shelf ice is now measured to be relatively transparent to electromagnetic radiation at the radio frequencies of interest and the water-ice boundary below the shelf behaves like a mirror that can reflect radio signals from downgoing neutrinos back up to the surface antennas. The high sensitivity of ARIANNA results from nearly six months of continuous operation, low energy threshold (~3×10^{17} eV), and more than 2π of sky coverage. The baseline concept for ARIANNA consists of moderately high gain antenna stations arranged on a 100 x 100 square grid, separated by about 300m. Each station consists of 8 linearly-polarized log-periodic dipole antennas (LPDA) to detect the radio signals generated by the neutrino interactions. The antennas are deployed just beneath the snow surface and point downwards to detect the conical radio emission from neutrino interactions. They surround a solar panel tower in an octagonal geometry with a diameter of ~6m. The stations communicate with each other and a central control hub by standard wireless technology to generate global triggers. The long-term environmental impact of the project is mitigated by the fact that the station components are deployed on or near the surface, and therefore readily retrieved.

ARIANNA benefits from recent developments in distributed detector technology. The Pierre Auger ultra-high energy cosmic ray observatory[8], has 1600 independent solar-powered surface detector stations linked by a wireless network to function as a single detector. ARIANNA combines the radio detection technology developed for neutrino detection in Antarctic ice with the technology required to deploy this technique economically over a large area.

Scientific Rationale

The scientific promise of high energy neutrino astronomy remains as compelling and elusive as ever. Although powerful neutrino telescopes such as AMANDA-II [1] and NT-200 in Lake Baikal [9] have uncovered no evidence for astrophysical neutrino sources, these first-generation detectors, optimized to detect neutrinos with energies between 10^{12}-10^{15} eV, have paved the way for more capable telescopes with instrumented volumes as large as one cubic kilometer. At yet higher neutrino energies, new techniques were developed that utilize *coherent* Cherenkov emission at *radio* wavelengths[10]. The balloon-borne ANITA-lite payload [2] and the South Pole based RICE array have exploited this effect to produce important constraints on the extraterrestrial neutrino flux[4]. Recently, the fully-instrumented ANITA payload was launched and remained aloft for about 35 days[11]. Since the power of coherent radio emission grows as the square of the shower energy (and therefore neutrino energy), the balloon-borne detectors tend to yield interesting apertures above 10^{18} eV. Therefore, a gap exists in the energy coverage of current-generation high energy neutrino detectors, as shown in Fig. 1. ARIANNA is designed to bridge this gap in sensitivity.

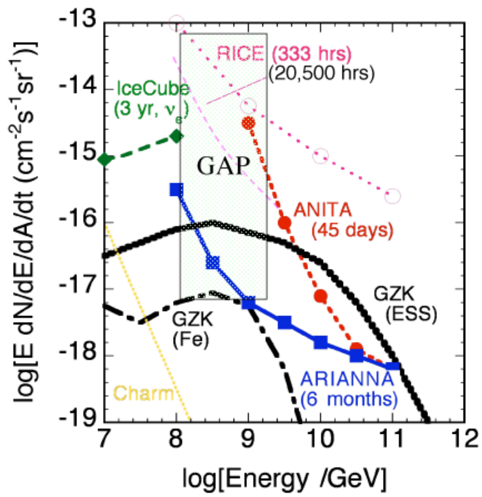

Figure 1: Representative survey of experimental flux limits, anticipated sensitivity of current generation instruments, and theoretical predictions for neutrino energies in excess of 10^{15} eV. Note the gap in instrumental sensitivity between 10^{17} eV and ~$3x10^{18}$ eV. ARIANNA is designed to provide sufficient sensitivity to bridge the energy gap.

Neutrinos spanning the energy interval 10^{17-20} eV are produced as a direct by-product the GZK mechanism [12], and therefore known as GZK or cosmogenic neutrinos. Since the GZK mechanism is based on widely accepted tenets and measurements, the predictions for the neutrino flux is perhaps the most secure of any in high energy neutrino astronomy. Moreover, the neutrino energy spectrum helps to break the degeneracy in models of the cosmic rays between source distribution and evolution (ie, time dependent variation in the rate of cosmic ray production)[13]. GZK neutrinos collide with matter on earth with center of mass energies at ~100 TeV, and thereby provide an opportunity to study physics at energies above that which is available at current or planned accelerator facilities. The powerful ARIANNA neutrino telescope creates an unprecedented opportunity to probe the energy frontier of particle physics with a "beam" that interacts solely by the weak force. ARIANNA has sufficient collecting power to ensure adequate statistics to determine the cross-section from the zenith angle dependence of the measured flux[5].The scientific advantages of ARIANNA are summarized as follows:

(1) ARIANNA increases the sensitivity for the detection of GZK neutrinos by an order of magnitude over state-of-the-art detectors currently under construction, such as ANITA. Simulations indicate that ARIANNA can observe ~40 events per 6 months of operation based on the widely-used predictions for the GZK neutrino flux by Engel, Seckel and Stanev (ESS) [14].

(2) The “low” energy threshold of ARIANNA, combined with high statistics and good energy resolution, provides an unparalleled opportunity to measure the flux over a broad interval of the GZK neutrino energy spectrum.

(3) ARIANNA can test alternative scenarios for GZK neutrino production such as models that assume that the extragalactic cosmic rays are mixed elemental composition or injected with soft spectra.

(4) ARIANNA can survey the southern half the sky for point sources of high-energy neutrinos with unprecedented sensitivity. Preliminary reconstruction studies show that ARIANNA can achieve angular resolution of 1.1 degrees[5].

(5) ARIANNA can probe for physics beyond the standard model by measuring the neutrino cross-section at center of mass energies of 100 TeV, a factor 10 larger than available at the LHC. Preliminary studies indicate that the cross-section can be measured with a precision of 25%, benefiting from the large statistical sample of 400 events spanning 2π solid angle.

Site Studies At Moore’s Bay

The ARIANNA site is located about 68 miles south of the McMurdo station, Antarctica, and centered at 78.75 S, 165.0 E. Minna Bluff, a narrow ridge of land extending into the Ross Ice Shelf, protects the site from radio interference generated by transmitters on Black Island and in the vicinity of McMurdo. Visual inspection revealed no obvious crevasse fields near the center of the site, and the surface snow was hard and smooth with a surface density of 0.3 g/cm^3.

Previous radar studies of the Ross Ice Shelf indicated that the one-way power attenuation length ranges between 18-21 dB/km [15] at 60 MHz, a value compatible with measurements performed at the South Pole [16] when corrected for warmer temperatures of the shelf ice. The ARIANNA site on the Ross Ice Shelf was selected according to the following criteria:

Good specular reflection from the water-ice boundary: Neal [17] shows that the reflection loss is typically less than -3dB over a majority of the Ross Ice Shelf. Neal also argues that large values for reflection efficiency are correlated with a relatively small amount of surface roughness at the saltwater-ice interface, and he shows that the variation in depth from a smooth surface is 0.03m in a region of the Ross Ice Shelf that exhibits low reflection losses.

Geographical proximity to logistical support: McMurdo, the largest US research station in Antarctica is only 68 miles from the site.

Minna Bluff shields the site from nearby anthropogenic sources of radio noise.

In early November 2006, the radio properties of *in situ* ice at center of the ARIANNA site were evaluated[18]. The attenuation length and reflected power from the bottom of the Ross Ice Shelf were measured between 50 –1000 MHz, the frequencies most relevant to ARIANNA. The studies were conducted using a linearly polarized TV antenna (Grove) and Quad Ridge Horn (Seavey). Impulse waveforms were transmitted through the air over short distances and compared to the radio pulses that were reflected from the bottom of the Ross Ice Shelf (see Fig. 2). The excellent fidelity of the reflected pulse and the absence of significant scattered power suggest a very smooth surface, consistent with previous measurements of the Ross and Fimbul Ice Shelves. The time domain pulses were transformed into the frequency domain, and the power corrected for distance to determine the frequency dependence of the one-way field attenuation.

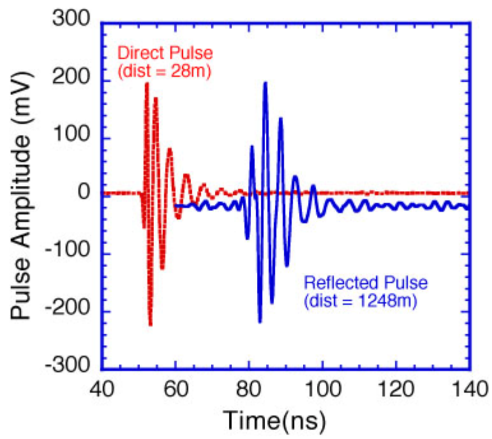

Figure 2: Comparison of radio pulses in the time domain. "Direct" pulse (left) propagated 28m through the air between transmitter and receiver. The right pulse was reflected from the bottom ice-water boundary. The time delay and amplitude is arbitrary.

To summarize the preliminary results from the *in situ* study of ARIANNA site: The one-way field attenuation length exceeds 350m between 100 MHz and 1 GHz. The water-ice interface at the bottom behaves like a nearly flawless reflector. Ambient noise levels were modest – below thermal backgrounds except for a few narrow frequency bands, the strongest at 44 MHz. Impulsive noise was infrequently observed at a rate of 1/minute, and its structure in the time domain was dissimilar to that expected from neutrino interactions. We conclude that the observed impulsive noise at the ARIANNA site can be identified and rejected by straightforward techniques.

The science goals of ARIANNA are compelling – collect enough neutrino events to probe for non-standard physics mechanisms at extraordinary energies. A site was selected and shown to have suitable properties at radio wavelengths. Because the site is relatively close to McMurdo Station, the central hub of US Antarctic operations, there are several options for logistical support. A prototype station, deployed on the Ross Ice Shelf last December provided valuable guidance on a number of technical choices. Relatively mature simulation and reconstruction programs were used to demonstrate required performance characteristics[19].

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