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Radio Detection of UHE Neutrinos with the Antarctic Impulsive Transient Antenna (ANITA) Experiment: Instrumentation

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ANITA is a balloon borne radio telescope designed to detect the interactions of ultra-high energy (UHE) neutrinos (> 3×10^{18} eV) in the Antarctic ice cap. These interactions produce Cherenkov radiation in the form of a distinct broadband radio pulse known as the Askaryan effect. The pure, radio transparent Antarctic ice cap serves as an almost ideal medium for the generation of these pulses and ANITA will have an effective viewing area of one million km^2 at float altitude. A prototype experiment, ANITA-LITE was flown during the 2003/2004 Austral summer from Antarctica to do an impulsive RF background survey. We present a discussion of the instrumentation and technique we will use to utilize the ice cap as a detector to measure the UHE neutrino flux.

1. Introduction

Several experiments have reported measuring cosmic rays with an energy in excess of 10^{20} eV.
There are no known galactic sources of particles at this energy and there is no consensus on possible extra-galactic sources based on current observations [1]. While work continues to measure the UHE cosmic-ray spectrum and look for possible sources, another way to examine the UHE universe exists through the study of neutrinos. Unlike cosmic-ray nuclei, neutrinos are not subject to deflection by magnetic fields and thus should point back to their source. Also neutrinos are not subject to interaction with the cosmic microwave background radiation (CMBR) as nuclei and photons are. This interaction with the CMBR is believed to lead to a cutoff of the cosmic-ray energy spectrum above 10^{20} eV known as the Greisen-Zatsepin-Kuzmin (GZK) cutoff [2]. This cutoff is due to pion photoproduction between UHE cosmic-ray nuclei and the CMBR and is almost certain to produce UHE neutrinos known as GZK neutrinos. In addition there may exist point sources of UHE neutrinos in the universe such as black holes, AGNs or gamma-ray bursters.

Measurements of the neutrino flux can therefore shed light on the UHE universe or, if no UHE neutrinos are detected, reveal violations of the standard models of physics and cosmology governing UHE particles.

Detection of UHE neutrinos is difficult due to their low flux (2 per km^2 per day per steradian for the standard GZK model) and low interaction probability (0.2% per km of water). A detector on the order of a teraton (1000 km^{3}sr) is required to get reasonable rates, far larger than any current neutrino detector [3].

Building and instrumenting a teraton UHE neutrino detector using current techniques, which primarily utilize the optical detection of photons from neutrino interactions, is prohibitive due to the tremendous costs involved. Fortunately there's another approach that can be used, first suggested by Gurgen Askaryan over 40 years ago. Askaryan argued that showers of particles from high-energy interactions in a dielectric medium would develop a charge asymmetry that would yield a strong coherent emission of Cherenkov photons at radio wavelengths [4]. If this interaction occurred in a radio transparent medium – such as salt or cold ice, the resulting radiation could propagate with negligible adsorption from the material and be detected as a coherent, impulsive, broadband radio signal. This effect was observed and verified in a laboratory setting in 2001, opening the way for a new technique to be used in UHE particle detection [5].

2. The ANITA Instrument

ANITA is scheduled to fly on a NASA Long Duration Balloon (LDB) over Antarctica in December 2006. It is a "radio telescope" with 40 antennas oriented to detect Askaryan pulses out to the horizon emanating from within the Antarctic ice sheet. At balloon float altitudes (~37 km), the horizon is about 700 km away allowing a view of more than two million km^3 of ice to a depth of order of one radio attenuation length (~1.2km). The purity of Antarctic ice and the relative radio quietness of the continent provides an almost ideal environment for the detection of Askaryan pulses from UHE neutrinos.

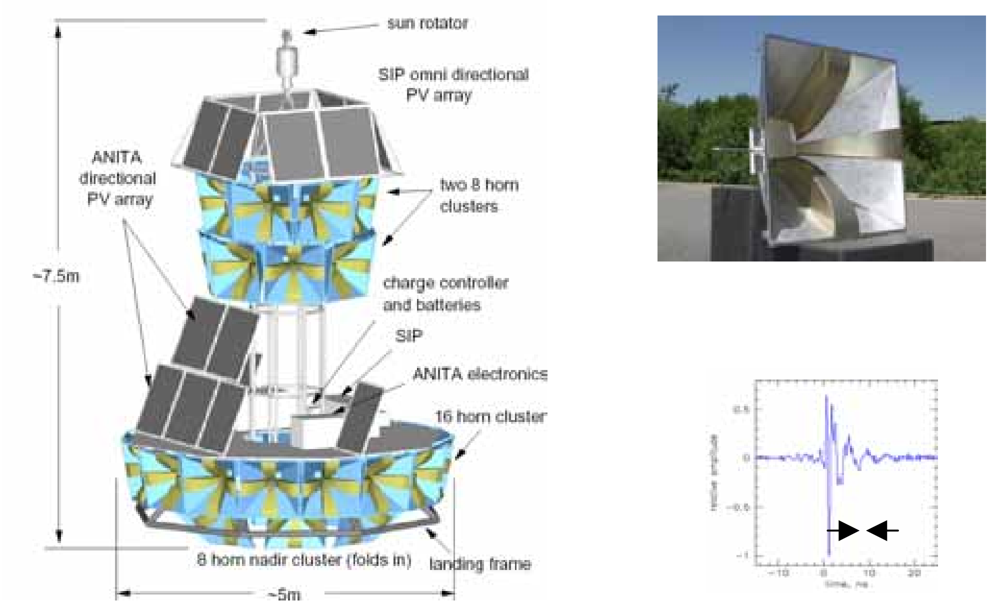

Figure 1. Sketch of the ANITA instrument with major components labeled. To the right is a picture of one of the quad-ridged horn antennas as well as a plot of its RF impulse response.

In Figure 1 we show a diagram of the instrument as well as picture of one of the 40 dual-polarization quad-ridged horn antennas mounted around the gondola. The gondola is built out of tubular aluminum sections held together with socket joints, tongue and clevis joints, and quarter turn cam lock fasteners for easy disassembly in the field. The overall mass of the gondola and scientific instrumentation is expected to be 1770 kg. The quad-ridged horn antennas were chosen since they have an excellent non-dispersive response to impulsive signals as shown in Figure 1. They are sensitive over a frequency range of 200-1200 MHz with a nearly constant effective gain of 9-10 dBi and a beamwidth of ~60°. Near each antenna is a module that provides bandpass filtering to remove signals outside of our frequency range of interest and amplifiers to increase the signal from the antennas by ~70 dB. The antennas are read out using custom digitization boards designed at the University of Hawaii. The board is capable of reading out 8 RF channels, each at a rate of 3 gigasamples/second with a 12 bit dynamic range and an 85 ns sampling window. Triggering is accomplished by both a local and global trigger. A local trigger is formed by looking at the signal in a single antenna. The horizontal and vertical polarized signal from an antenna are divided into four frequency ranges and combined into left and right circular polarizations. This provides eight independent triggering elements per antenna, three of which are required for a positive local trigger. The global trigger is formed by looking at the individual antennas that have triggered locally and requiring them to be localized in the same sector of the instrument. RF waveform data from the digitizer boards is processed and stored via an onboard CPU system to solid state hard drives. A selection of priority data is telemetered down for immediate analysis during flight so that instrument performance can be checked and adjustments can be made to the instrument configuration.

Several subsystems on the instrument provide calibration and orientation information to ensure a full understanding of the RF data collected by ANITA. Each RF channel on ANITA has a noise diode signal that can be coupled into the signal path to provide a relative gain measurement of each channel during flight. In addition, an onboard impulsive RF generation system, consisting of a fast pulse generator and four transmitting antennas, will be integrated into the ANITA instrument to allow for in-flight stimulation and testing of the antennas and trigger system. Information on how the instrument is oriented is provided by a suite of instruments – GPS, accelerometers, magnetometer and a sunsensor. These provide a redundant measure of the attitude and orientation of the instrument while at float. Power to the instrument during the flight is provided via a directional solar array and the instrument is expected to draw ~850 Watts during normal flight operations.

A major challenge that an RF sensitive experiment like ANITA must surmount is overcoming sensitivity to background RF noise. This background can come from a variety of sources such as electronics onboard the ballooncraft and man-made noise from communication and other electronic devices on the ground. To try to gain an understanding of the background ANITA might experience, a prototype experiment ANITA-LITE was flown in 2003/04 over Antarctica [6]. ANITA-LITE demonstrated that the primary RF background for the instrument came from local payload noise, caused by the electronics onboard the ballooncraft. These background signals are distinct from Askaryan pulses and can be recognized and cut from the dataset. We are preparing measures to limit the onboard ballooncraft noise on ANITA, such as the use of shielded cables and Faraday enclosures around all electronics and the use of several RF veto antennas to ensure that any spurious noise from the instrument that might still exist has a limited effect on the livetime of our instrument.

3. Instrument Performance

The ANITA antennas are arranged to function as a radio interferometer. There are four rings of antennas stacked on the ANITA instrument. The antennas in the two upper and the large lower ring are separated by a distance of 3.3m and are all canted at 10° below the horizon. The rings in the lowest ring, the nadir ring, are canted at 55°. The two upper and nadir rings with 8 antennas each have a 45° azimuthal offset between

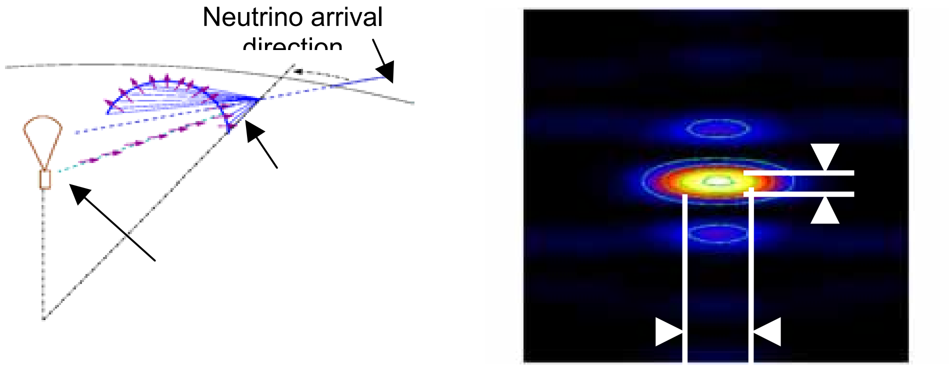

Figure 2: The direction and polarization (represented by the small arrows) of the Askaryan radiation allow the reconstruction of the Chrenkov cone created by an interacting neutrino in the ice as shown in the left sketch. By determining the Chrenkov cone we can constrain the arrival direction of the neutrino as shown in the right diagram.

adjacent antennas while the lower large ring with 16 antennas has a 22.5° offset. The antennas are arranged in the horizontal plane such that there is about a 1.2m distance between antenna centers, which ensures that the beams of nearest neighbors overlap. Therefore, an Askaryan pulse produced by an interacting neutrino will be seen in multiple antennas in the same ring. If the pulse originates further than about 40 km from the instrument, it should be seen by antennas in both the upper and lower rings. The ability to measure an Askaryan pulse in multiple antennas allows us to perform pulse-phase interferometry and determine the origin of the pulse. Based on timing calibration data from the ANITA-LITE experiment, improvements in timing with new custom built digitizers and an increased number of antennas we expect to achieve a timing resolution of ~0.1 ns with ANITA [6]. Using the timing resolution and antenna geometry we can calculate the expected overall intrinsic resolution of the instrument to be 0.5° in elevation and 1.5° in azimuth for the arrival direction of the radio pulse. From this and measurements of the polarization angle of the radio pulse we can determine the arrival direction of the neutrino from modeling the orientation of the cone of Cherenkov radiation produced by the neutrino interaction. With this approach we will constrain the neutrino arrival direction to ~2° in elevation and ~5° in azimuth as illustrated in Figure 2. Discussion of constraints ANITA can make to the UHE neutrino flux and possible sources detection is presented elsewhere [7].

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References

[1] Teshima, M. et al., 28th ICRC, Tskuba (2003)
Abbasi, R.U. et al., Astro-ph/0501317 (2005)
[2] Greisen, K., Phys. Rev. Lett. 16, 748 (1966)
Zatsepin, G. T. and Kuzmin V.A., JETP. Lett. 4, 78 (1966)
[3] Lehtinen N.G. et al., Phys. Rev. D., 69, id 013008 (2004).
[4] Askaryan, G.A., JETP, 14, 441 (1962)
Askaryan, G.A., JETP, 14, 658 (1965)
[5] Saltzberg, D. et. al., Phys. Rev. Lett, 86, 2802 (2001)
[6] Miocinovic, P. et. al., 22nd Texas Symposium on Relative Astrophysics, Stanford (2004).
[7] Duvernois, M. et. Al. 29th ICRC, Pune (2005)