Status of the ANITA experiment

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Abstract. The ANtarctic Impulsive Transient Antenna (ANITA) is a NASA-sponsored long-duration balloon experiment designed to detect radio Cherenkov pulses from particle showers initiated by UHE neutrinos in the Antarctic ice. ANITA is scheduled to fly during this Austral summer (Dec 2006 – Jan 2007). We present an overview of the ANITA experiment and its goals. We will also give an update on the experiment’s current status. Milestones in the past year include an engineering flight in August 2005 and a beamtest using an ice target at SLAC in June 2006.

1. The purpose of ANITA
ANITA is a discovery experiment, intended to detect ultrahigh-energy (UHE) neutrinos\footnote{In this paper, “ultrahigh-energy” refers to energies greater than $10^{18}$ eV.} created in the Greisen-Zatsepin-Kuz'min (GZK) process. The study of UHE neutrinos would provide a new window both on the universe at cosmological scales and on particle physics beyond energies reachable by current generation accelerators.

1.1. Ultrahigh-energy cosmic rays
Ultrahigh-energy cosmic rays pose one of the great mysteries of astrophysics. Many cosmic ray particles with energies above the ~ $10^{19.5}$ eV GZK limit \cite{1} have been observed hitting the Earth’s atmosphere. The sources of these particles remain unknown, and at these energies, the GZK process limits their mean free path to cosmologically short distance scales. This means that experiments designed to observe UHE cosmic rays directly can only detect sources relatively close to Earth. As a result of interactions in the GZK process, however, the energy of the cosmic rays is transferred to numerous daughter particles, including neutrinos. These GZK neutrinos can provide otherwise unobtainable information about the source and spectrum of the universe’s highest energy particles \cite{2}.

1.2. Ultrahigh-energy neutrinos
The GZK effect is the process by which ultrahigh-energy cosmic-ray particles\footnote{Protons or heavier nuclei. Neutrons could potentially participate in this process, but even at ultrahigh energies, most neutrons decay before interacting.} interact inelastically with the cosmic microwave background. The end products of these interactions often include neutrinos. Because neutrinos interact only weakly, they can travel cosmologically large...
distances. These GZK neutrinos will therefore point back to their sources (which means pointing near the sources of their progenitor cosmic rays), even over cosmologically large distances.

There is also the possibility that UHE neutrinos are emitted directly from astrophysical sources. Furthermore, UHE neutrinos interact on Earth at center-of-mass energies that cannot be duplicated in the laboratory, and that will remain unavailable to colliders for the foreseeable future. Detection of the interactions of naturally produced ultrahigh-energy neutrinos can provide information in previously untested regimes, and provide a probe of the Standard Model at extreme energies.

2. Detection of ultra-high energy neutrinos

ANITA will be taking advantage of the Askaryan effect to detect interactions of UHE neutrinos. The Askaryan effect is the process by which a particle shower developing in matter will develop a negative charge excess and emit radio Cherenkov radiation [3]. Furthermore, since the bulk of the shower electrons are within a \( \sim 10 \) cm radius, this radio Cherenkov radiation will be coherent through frequencies of \( \sim 1 \) GHz.

The Askaryan effect has been observed in the lab [4], and several experiments to date have looked for UHE neutrino-induced particle showers by searching for this signature Askaryan pulse. Experiments utilizing the Askaryan effect include RICE, FORTE, and ANITA-lite in ice, and GLUE in the Lunar regolith. (See Fig. 1 for experimental limits compared to theoretical predictions.) No experiment has yet detected UHE neutrinos, but the region of parameter space that they have excluded is not yet into the region where theoretical models say the GZK neutrino flux is most likely to reside.

2.1. Detector volume

The flux of UHE neutrinos from the GZK effect is tied to the flux of UHE cosmic rays, and theoretical models predict a similarly small flux. In fact, the flux of UHE GZK neutrinos is expected to be \( < 1 \) neutrino / km\(^2\) / year / sr [5]. A rough idea of the detector volume required to detect this flux can be found with the following order of magnitude estimate.

The interaction length of a neutrino at energies of \( E_\nu = 10^{19} \) eV is \( \sim 500 \) km in ice. Such a neutrino then has only a \( \sim 0.002 \) probability of interacting after traversing 1 km of ice. Because upcoming neutrinos are stopped by the Earth before reaching our detector, we can observe at most half of the sky or, being generous, on the order of \( \sim 10 \) sr. So our detector can see at most \( \sim 0.02 \) neutrinos / km\(^3\) / year. We would need on the order of 50 km\(^3\) of ice to see 1 event per year.

We need a large detector (> 1000 km\(^3\) sr!) to obtain reasonable event rates. Ice was chosen as a medium in the previous calculation for two reasons: first, that it is reasonably transparent to radio\(^3\) and second, that large volumes of pure ice are naturally present on the continent of Antarctica. For these reasons, Antarctica presents itself as a natural option for an UHE neutrino detector. Figure 2 is a map of ice depths over the Antarctic continent. Note how deep ice is widespread on the continent. Another detection medium, salt, is also both radio transparent and naturally present in large, pure volumes. Potential for the use of this option is discussed elsewhere in these proceedings.

2.2. The ANITA mission plan

In order to observe the maximum amount of ice for the minimum amount of budget, ANITA has been designed as a balloon payload. The National Aeronautics and Space Administration (NASA) runs the Antarctic long-duration balloon program from McMurdo base, Antarctica. During the Antarctic summer, circular wind currents are set up around the continent. Balloons

\(^3\) Antarctic polar ice has been measured to have a radio attenuation length of \( \sim 1 \) km [13].
Figure 1. Present experimental 90% confidence level limits on UHE neutrino flux compared to theoretical predictions of the flux. Grey stars: AMANDA limits [6]. Blue triangles: RICE limits [7]. Pink circles: ANITA-lite limits [8] Light blue squared: GLUE limits [9]. Gray inverted triangles: FORTE limits [10]. Grey circles on dotted line: projected ANITA limits. Red solid line: flux predictions from a top-down theoretical model [11]. Blue solid line: flux predictions from a standard GZK model, assuming UHE cosmic rays are all protons [5]. Green solid line: flux predictions from a standard GZK model, assuming UHE cosmic rays are all iron [12].

are launched to take advantage of these winds, flying at altitudes of 37 km and remaining aloft over Antarctica for upward of 15 days. Flights end when the balloon begins to drift too close to the edge of the continent, and have lasted up to 42 days in the past. Most projects use balloon platforms to lift upward-looking astronomical instruments above the bulk of the Earth’s atmosphere, but the ANITA project will be making use of the fact that the altitude of the balloon allows us to observe $\sim 1.5$ million km$^2$ of ice simultaneously. See Figure 3 for a diagram of how ANITA would detect a neutrino interaction.

3. The ANITA instrument
The heart of ANITA is 32 quad-ridge horn antennas. These antennas are sensitive from 200 – 1200 MHz, have a beam pattern with FWHM of $\sim 50^\circ$, and are pointed $10^\circ$ below the horizon in order to observe distant ice. ANITA also includes 8 bicone and discone antennas, which will be used both to monitor the local radio environment for any payload-generated noise, and to transmit test pulses for use in verifying instrument health. Power comes from an omnidirectional array of photovoltaic cells, which are sufficient for all power needs in the 24-hour sunlight present during the experiment.

As the experiment is a payload on a very high altitude balloon, it shares many of the same hardware constraints as a space mission. For example, the payload weight is limited to be under
4000 pounds. Power consumption is restricted to what can be generated by the on-board solar cells. Heat dissipation is also an important concern – as there is almost no air, all cooling must be done by radiation. Finally, the payload’s structure must be sturdy enough to survive the ~10 g acceleration on launch, as well as the duration of the flight. Surviving the (crash) landing is also a nice bonus.

Because ANITA is >100 km from the events that it is looking for, a sound trigger system is essential for picking Askaryan signals out of the background thermal noise. The trigger pathway is divided into three levels. At the first level, because the Askaryan pulse is broadband, the signal received at each antenna is split into four frequency bands (200 – 330 MHz, 355 – 515 MHz, 525 – 775 MHz, and 795 – 1165 MHz). The vertical and horizontal polarizations in each frequency band are then converted to LCP and RCP signals, giving us eight trigger bands per antenna. If 3 out of these 8 bands exceed threshold, a level 1 trigger is issued for that antenna. Next, we divide the payload into 16 phi trigger sectors, each with three antennas in the upper rings and three antennas in the lower ring\(^4\). If 2 of the 3 antennas in a phi sector issue a level 1 trigger, that phi sector issues a level 2 trigger. Finally, if both the upper cluster of 3 antennas and the lower cluster of 3 antennas issue a level 2 trigger, the payload records a level 3, or global trigger, and writes the data to the hard drive.

4. The ANITA Monte Carlo
The experiment’s Monte Carlo simulation is vital to the interpretation of data. The Monte Carlo simulates our experiment, from the interaction of neutrinos in the Antarctic ice sheet, through the propagation of the resulting Askaryan pulse, and ending at the payload. This

\(^4\) The talk given at the ARENA conference stated that there were 5 upper and 5 lower antennas in a phi trigger sector. This has since been changed to 3 antennas to reduce the noise trigger rate, thereby allowing a reduction in trigger thresholds.
simulation allows us to determine ANITA’s sensitivity using statistical methods, a calculation
that will allow conversion of the ANITA data into a physical flux. Two independent Monte
Carlos are being maintained, allowing cross-verification of their outputs. The Monte Carlos
currently include models of the radio Cherenkov emission from UHE neutrino-induced particle
showers, the Antarctic ice sheet, surface roughness, the structure of the Earth, the antenna
response, and the trigger system. The projected ANITA limits shown in Figure 1 were found
with our Monte Carlo simulations.

5. ANITA-lite
A prototype of the ANITA experiment, named “ANITA-lite”, flew in the 2003–2004 season. The
payload was piggybacked on the TIGER experiment, and tested many of the systems planned for
the full version of ANITA. ANITA-lite carried two antennas on an 18.4 day flight. Data collected
from ANITA-lite contained numerous impulsive noise events, but no events were consistent with
the expected Askaryan pulse from an UHE neutrino-induced shower. The noise events recorded
appear to have been generated on the payload itself. (The full ANITA, of course, has RF-shielded
electronics to eliminate this source of noise.) Having detected no neutrino events, ANITA-lite
set a flux limit on UHE neutrinos [8]. This limit, and now also the 7-year RICE results [7]
exclude the Z-burst models for production of the UHE cosmic rays.

6. Ft. Sumner engineering flight
The first full-scale test of ANITA took place in Ft. Sumner, New Mexico, in August 2005.
The payload was assembled and flown on a several hour long flight in order to demonstrate
the structure’s flight-worthiness. Most instrument systems were also represented, to test the
electronics under flight conditions. Two live antennas were also included, and we made an effort
to detect signals from the ground calibration system.

The Ft. Sumner engineering flight was a success. The structure held together through the
launch and during flight. The installed electronics also functioned during the flight and recorded
data from the antennas. Unfortunately, the skies over New Mexico contain a great deal of RF
noise\(^5\), and we were unable to detect our signals transmitted from the ground.

Two signals were detected during the Ft. Sumner engineering flight. First, we were able to
detect signals from onboard antennas, although we required heavy averaging to pick the signal
out of the background. Second, we detected the nearby city of Clovis, NM and the neighboring
US Air Force base by noting the increase in RF background when the antennas were pointing
in their direction.

7. SLAC beam test
In June 2006, ANITA was put through a mockup of its Antarctic neutrino search. We were
able to produce a particle shower which mimicked a UHE neutrino-induced shower by using an
electron beam from the Stanford Linear Accelerator Center (SLAC) accelerator. A beam with
\(\sim 10^9 \) 28.5 GeV electrons (for a total energy per pulse of \(10^{19} \text{ eV} \) to \(10^{20} \text{ eV}\)) hit a 10 ton ice
target to produce a particle shower with associated Askaryan pulse. We recorded data from one
week of beam time.

The results of the SLAC test are good. The full instrument functioned as it should, self-
triggering on the Askaryan pulses from the ice. Having tested the instrument with signals like
those we’re searching for, we gain confidence in our ability to perform in Antarctica. We have
also gained large amounts of data on our instrument which will be useful in the analysis of flight
data.

\(^{5}\) Noise being defined as radiation we aren’t interested in. I’m sure that someone finds what we saw useful.
8. Conclusions and the future

ANITA has come a long way in only a few years. The full instrument has now been tested on real Askaryan pulses, and stands ready to detect signals from particle showers started by ultrahigh-energy neutrinos. As of September 2006, much of ANITA is already in transit to McMurdo base, Antarctica, and the electronics are undergoing final tests and adjustments. On-ice assembly of ANITA is scheduled to begin in late October to early November 2006. The payload itself will launch in December 2006, and the flight may continue into January 2007. Our Monte Carlos predict that ANITA will see from 2 to 20 events from GZK neutrinos, with the large spread coming from uncertainty in the theoretical models themselves. See Figure 1 for a comparison of projected ANITA sensitivities with theoretical models and past experimental limits.

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