Initial Results from the ANITA 2006-2007 Balloon Flight

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Abstract. We report initial results of the Antarctic Impulsive Transient Antenna (ANITA) 2006-2007 Long Duration Balloon flight, which searched for evidence of the flux of cosmogenic neutrinos. ANITA flew for 35 days looking for radio impulses that might be due to the Askaryan effect in neutrino-induced electromagnetic showers within the Antarctic ice sheets. In our initial high-threshold robust analysis, no neutrino candidates are seen, with no physics background. In a non-signal horizontal-polarization channel, we do detect 6 events consistent with radio impulses from extensive air showers, which helps to validate the effectiveness of our method. Upper limits derived from our analysis now begin to eliminate the highest cosmogenic neutrino models.

1. Introduction

In all standard models for ultra-high energy cosmic ray (UHECR) propagation, their range is ultimately limited by the opacity of the universe due to the density of cosmic microwave background radiation (CMBR). The UHECR energy above which this opacity becomes significant is about 6×10^{19} eV in the current epoch, and this opacity limits their travel to distances of order 50 Mpc or so, as first noted by Greisen [1], and Zatsepin and Kuzmin [2] (GZK). As a result of this absorption, the UHECR energy above this GZK cutoff is ultimately converted to photons and neutrinos. The resulting neutrinos were first described by Berezinsky and Zatsepin [3], and in standard UHECR source models, the BZ neutrino fluxes peak at energies about 2 orders of magnitude below the GZK energy. Thus a "guaranteed" flux of neutrinos at energies of order 10^{17-19} eV exists and its detection is one of the cleanest ways to establish the nature and cosmic distribution of the UHECR sources, which is one of the longest-standing problems in modern high energy astrophysics.

The ANITA Long Duration Balloon (LDB) experiment was designed specifically to search for this cosmogenic BZ neutrino flux by exploiting the Askaryan effect, in which strong coherent radio emission arises from electromagnetic showers in any dielectric medium [4],. The effect was first observed in 2000 [5], and has now been clearly confirmed and characterized for ice as the medium, as part of the pre-flight calibration of the ANITA LDB payload [6]. A prior flight of a prototype payload, called ANITA-lite, in 2005 led to validation of the technique and initial neutrino flux limits that effectively ruled out several models [7].

2. Flight Details

The full ANITA payload launched from Williams Field, Antarctica, on the Ross Ice Shelf near McMurdo station on Ross Island, on December 15, 2007, and executed more than 3 circuits of the South Pole before being terminated on the Antarctic Plateau abut 300 nautical miles from Amundsen-Scott station, after 35 days aloft. Anomalous stratospheric conditions led to a significant misalignment of the polar vortex for the 2006-2007 season, and as a result the ANITA polar circuits spent an unusually large fraction of the time over West Antarctica where the ice sheet is smaller and shallower. In addition, the payload field-of-view to the horizon (at a distance of about 650 km at typical altitudes of 33-35 km above the ice), often included the two largest occupied stations in Antarctica, McMurdo and Amundsen-Scott, and thus was subject to higher-than-normal levels of anthropogenic electromagnetic interference (EMI). Despite these effects, the payload accumulated a net exposure livetime of 18 days with a mean depth-of-ice in the field of view of 1.2 km, comparable to the attenuation length of the ice at radio frequencies [8]. The instantaneous volume of ice to which ANITA was thus sensitive is of order 1.6M km^3, and the effective acceptance to an isotropic source, accounting for the small solid angle of acceptance for any given volume element, is several hundred km^3 steradians at a neutrino energy of 10^{19} eV. While it was aloft, ANITA had by far the largest acceptance for BZ neutrinos of any neutrino experiment ever deployed.

Figure 1. The ANITA payload just prior to launch in late 2006.

A photograph of the ANITA payload shortly before launch is shown in Fig. 1. The primary radio sensors are 32 ultra-broadband, dual-linear-polarization, quad-ridged horn antennas with a field of view

which averages about 50° over their 200-1200 MHz working bandwidth. The antennas are arranged in an upper and lower cluster, each with 16 antennas at azimuthal intervals of 22.5°; all antennas point at 10° below the horizontal, to maximize sensitivity to the largest portion of the volume near the horizon at 6° below the horizontal. Apparent radio impulses that exceed the ambient thermal noise by about 5σ in at least four of the antennas in adjacent azimuths produce a trigger, and the entire antenna set of waveforms are then digitized and stored for later analysis. Thermal noise fluctuations themselves are allowed to produce triggers at a rate of about 4-5 Hz to provide a continuous monitor of instrument health, but these events are incoherent in phase and produce a completely negligible background to actual coherent radio impulses.

The event analysis is conceptually simple, but requires detailed calibration of the instrument to achieve good precision. In the results reported here, we took only events having at least six total azimuthally adjacent antennas with detectable signals. This constraint leads to a somewhat higher neutrino energy threshold (and thus a somewhat lower sensitivity), but it provides a result that is robust to any systematic effects. The six antenna signals are then analyzed using a method of pulse-phase interferometry to determine the best arrival direction of the radio impulse plane wave, and this direction and its associated uncertainty is then mapped onto the Antarctic ice by reference to onboard payload navigation instruments.

To ensure that any analysis bias would be minimized, the analysis cuts were tuned on a 10% randomized sample of the entire data set, and the remaining 90% was blinded from the analysts until the cuts were fixed. The cuts proceed as follows:

(i) Events that do not reconstruct to a coherent plane wave in arrival direction are rejected as random thermal noise or other unrelated triggers.

(ii) Events that reconstruct but have non-impulsive waveforms from relatively narrow-band sources are rejected.

(iii) Events that coincide (or cluster) in source location to within reconstruction errors projected onto the ice, or 50 km radius, whichever is greater, are rejected as being from a possibly repetitive non-neutrino-like source. True source candidates must be single, isolated events. Note that this cut, and the “camp cut” that follows it, are largely but not completely redundant.

(iv) Events that coincide in source location with any known active or inactive. station, camp, aircraft flight path, or traverse path, to within reconstruction errors projected onto the ice, or 50 km radius, whichever is greater are rejected as being associated with anthropogenic activity. Even inactive camps or those long-abandoned are considered a risk, since left-over equipment might nucleate charge deposition and associated electromagnetic discharges which could be mistaken for signals.

(v) Events whose radio waveforms are not predominantly vertically polarized are rejected because, from considerations of the Askaryan impulse generation process, and the Fresnel transmission through the ice surface, they cannot be of particle shower origin. Conversely, strongly horizontally polarized events are likely to originate from above the ice from similar considerations.

Table 1 shows the results of the total event sample after unblinding (the 10% initial sample is included in the totals). Note that the isolation (or “cluster”) cut is the single most stringent criterion in rejecting impulsive events, and this shows that the overwhelming majority of impulsive events detected are not single, isolated events. Inversion of the order of the camp and isolation cuts showed very similar results, indicating that these events are dominated by anthropogenic interference. In addition here we have included all effects of livetime and analysis efficiency. The former is included when estimating the 18 day exposure, and the latter averaged about 80%.

In Figure 2 we show the before-and-after maps of reconstructed ANITA-1 events superposed on the Antarctic continent. The strong correlation to a small number of stations is evident. The 6 surviving H-pol events are by contrast widely distributed across the continent. Our simulations of the high-frequency tail of impulsive geo-synchrotron radio emission [9, 10] from ultra-high energy cosmic ray extensive air showers (UHECR EAS) suggests that these events are consistent with expectations for our sensitivity

Table 1. Results from unblinded ANITA-1 data set.

Cut	total	Hpol	Vpol
Hardware-Triggered	$\sim$ 8.2M	...	...
Not thermal noise	32308	15997	16311
Impulsive	19695	10095	9600
Isolated from other events	9	8	1
Isolated from camps	6	6	0
Vpol dominant	0	0	0

to such events seen in reflection off the ice surface. Such events are expected to be predominantly H-pol because of the strong Fresnel reflectivity in the region near Brewster's angle, and the overall initial preference for H-pol because of the more vertical polar magnetic fields. Our simulations predicted a total of 4.5 such events for our flight, all of which arise from UHECR EAS with energies above 10^{19} eV. While these events do not constitute a background for our neutrino search because of their incorrect polarization, they are a potentially interesting signal in their own right, and if confirmed they lend additional validation to ANITA's signal sensitivity.

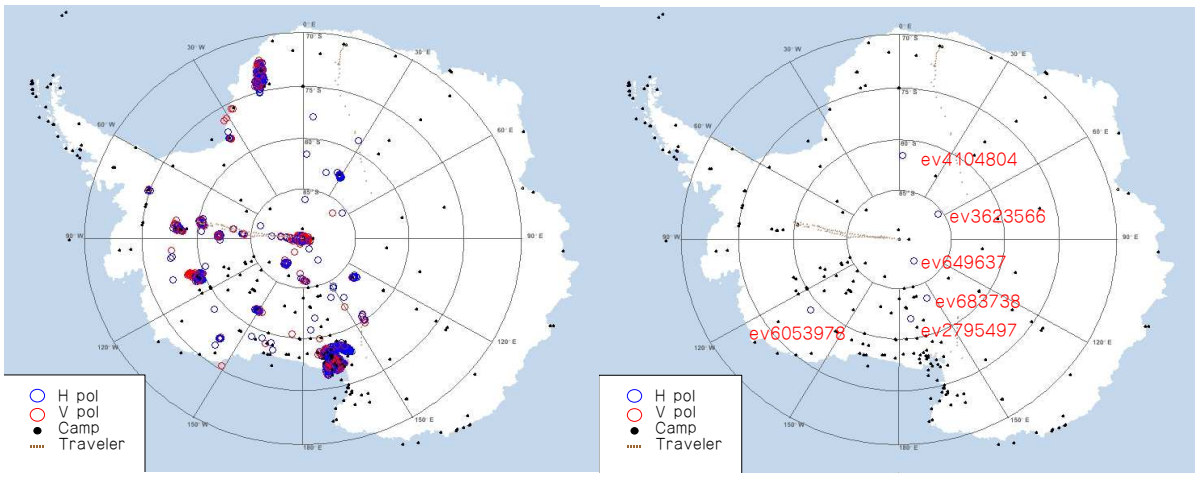

Figure 2. Left: Plot of all reconstructed events, in both horizontal and vertical polarization. Right: events remaining after cuts to remove anthropogenic noise. 6 events remain in the horizontally polarized group, but these are non-candidates for neutrino events.

Preliminary limits at the 90% confidence level on neutrino fluxes, based on no surviving candidates, are shown in Fig. 3. We plot only an approximate set of bands for the BZ neutrino models, which are too numerous to individually identify here. ANITA-1 strongly constrains the very highest of these, and is approaching the central region of preferred model space, although these are not constrained significantly yet. These limits correspond approximately to a smooth neutrino flux which would give 2.3 events if it matched the limit curve for approximately one decade of energy.

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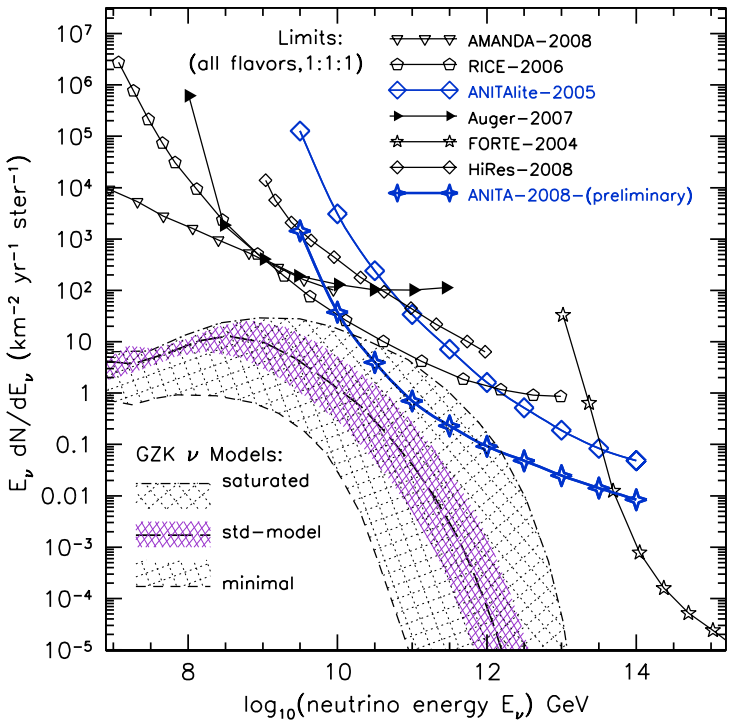

Figure 3. ANITA-1 limits based on no surviving candidates for 18 days of livetime. Other limits are from AMANDA [11], RICE [12], ANITA-lite [7], Auger [13], HiRes [15], FORTE [14]. References the BZ (GZK) neutrino model range is determined by a variety of models, with some characteristic ones here [16, 17, 18, 19, 20, 21, 22].

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