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# Overview of the Third Flight of the ANITA Long-duration Balloon Payload

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The third flight of the Antarctic Impulsive Transient Antenna (ANITA) Long Duration Balloon payload was completed in January of this year after 23 days at float. ANITA's goal is the detection of ultra-high energy neutrinos via the Askaryan effect in the Antarctic ice sheets, and utilizes radio-detected ultra-high energy cosmic rays as instrument validation. We discuss instrument performance during the flight, and show examples of some of the data.

*The 34th International Cosmic Ray Conference,*
*30 July- 6 August, 2015*
*The Hague, The Netherlands*

*Speaker.

 

PoS(ICRC2015)1111

The Antarctic Impulsive Transient Antenna (ANITA, Fig. 1) is a suborbital long-duration balloon (LDB) mission with a goal to achieve a definitive measurement of the absolute flux levels and energy spectral characteristics of cosmic ultra-high energy (UHE) neutrinos that have long been predicted to exist and are now within reach of detection [1, 2, 3, 14].

**Figure 1:** *ANITA-III preparing for launch in Dec. 2014, credit C. Miki.*

The flux of extragalactic neutrinos that ANITA seeks to measure peaks in the Exavolt (1 EeV = $10^{18}$ eV) energy range. This flux must be present at a level that is constrained by the known existence, emerging composition, and unknown cosmic evolution of the sources of the ultra-high energy cosmic rays (UHECR) [4, 5, 6, 7, 10]. Recent data from the completed HiRes and ongoing Auger UHECR observatories has provided compelling evidence for the first time of the *GZK* process, first elucidated in the 1960's by Greisen [12] and independently by Zatsepin and Kuzmin [13], by which the UHE cosmogenic neutrinos are generated [8, 9, 10].

This process unfolds as the UHECR, which by all indications are hadronic, propagate through intergalactic space which is filled with the 3K cosmic microwave background radiation. In the center-of-momentum frame of the UHECR on these photon targets, the 3K radiation is boosted to GeV gamma-ray energies, in a momentum region where the cross section for what is now known as photohadronic interactions, is well-studied. If they are light nuclei, the UHECR thus scatter inelastically off the photons, making unstable secondary particles which eventually decay in part to neutrinos at 1-2 orders of magnitude lower energy in the lab frame. This scattering leads to a hard cutoff in the maximum energy of any hadronic UHECR particle as it propagates out from its source, and the scale of the *GZK cutoff*, as it is known, is 50-100 Mpc in the current epoch. If the UHECRs are dominated by iron nuclei, their interactions with the CMB change in details and energy scale, resulting in a reduction of the neutrino flux, though with large uncertainties, since there are no self-consistent scenarios for exclusive acceleration of iron at the expense of light nuclei.

ANITA is the first NASA mission to attempt the observation of cosmogenic neutrinos, and can be characterized as a discovery or 'pathfinder' mission, capable of very high instantaneous sensitivity EeV to ZeV ($10^{18-21}$ eV) energy range of the neutrino spectrum. In addition, ANITA also has made the first observation of UHECR extensive air showers in Antarctica, seen via the a synchrotron-like process whereby the relativistic electron-positron shower emits a beamed radio impulse as a result of Lorentz-force acceleration by the local geomagnetic field. Because of the

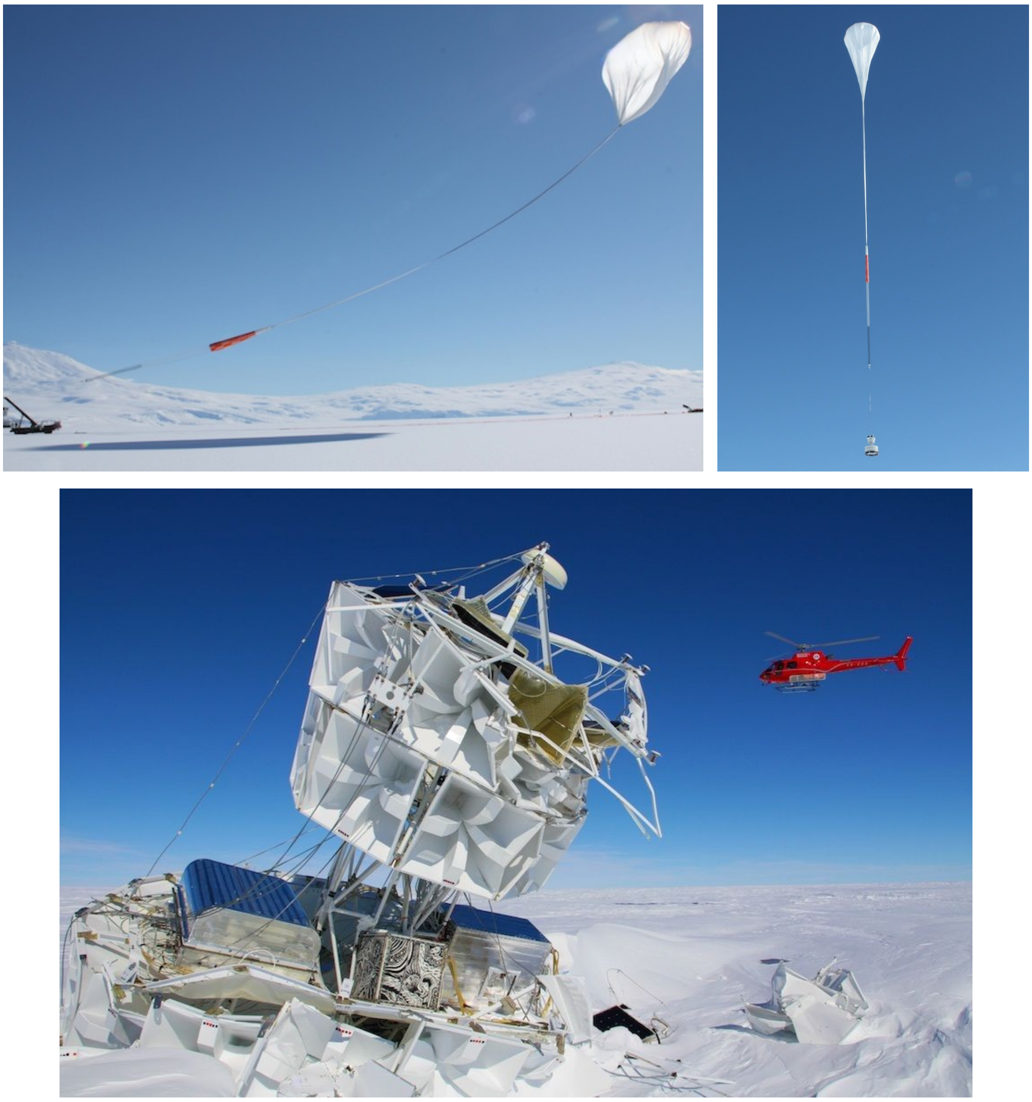

**Figure 2:** *Photographs of the launch and landing of the ANITA-III payload. Credit to C. Miki and the Australian Antarctic program.*



nearly vertical geomagnetic field in Antarctica, these events are almost completely horizontally polarized in their radio signature, and thus are completely separable from the nearly vertically polarized neutrino events. ANITA has detected of order 20 UHECR events, with a mean energy $\sim 10^{19}$ eV, and has established the methodology and basic radio spectrum for suborbital detection of such events, lending veracity to future efforts to pursue characterization of UHECRs via radio methods [16]. In addition, during the ANITA-III flight preparations, the ANITA team performed a beam test, SLAC T-510, which further delineated the behavior of this radio emission process; there are several ICRC contributions on this topic to the current conference.

For its third flight, the ANITA payload's neutrino and UHECR sensitivity was improved in several ways:

- New quad-ridged horns with improved response at 200-300 MHz

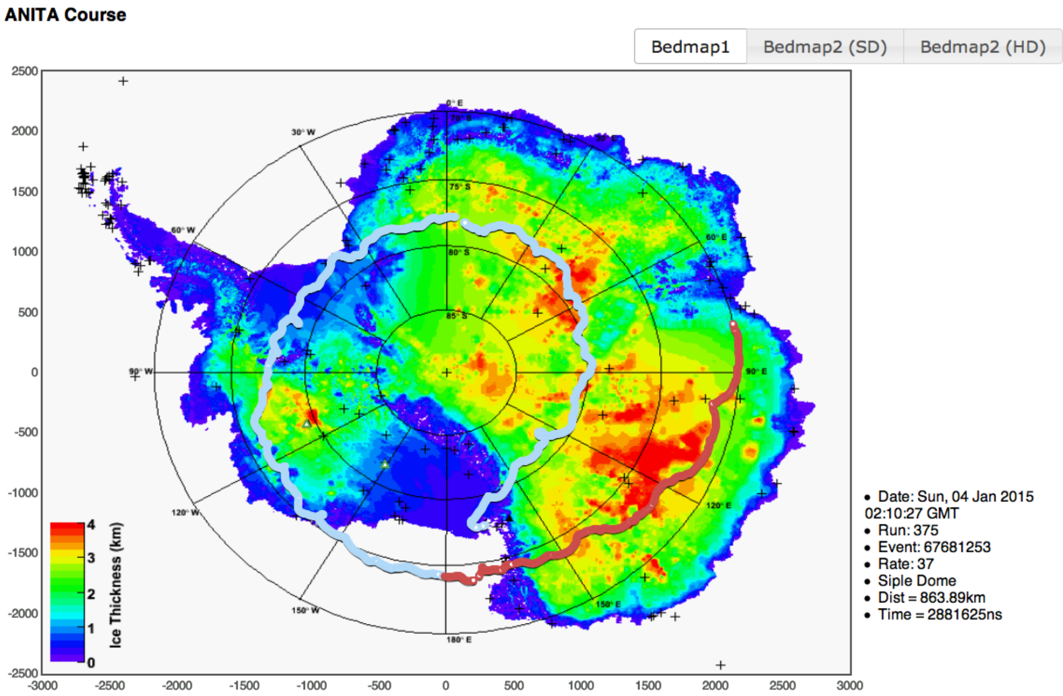


**Figure 3:** *Ice thickness map of the ANITA trajectory (based on Bedmap database).*

- Additional 8 dual polarized horn antennas
- Improved low-noise amplifiers in more than half the channels
- Addition of dedicated H-pol trigger for improved UHECR detection
- increased trigger sensitivity and higher trigger throughput
- Real-time GPU-based event prioritizer and realtime mapper

Simulation results indicate a factor of 2-3 improvement in possible neutrino event rate sensitivity through these augmentations.

The ANITA-III payload was launched on 2014-12-17 at 21:24 UT, and terminated 2015-01-08 at about 23:50 UT after 22 days at float. This is a relatively short flight, the shortest of the three ANITA flights to date; while the payload was performing well and was approved for additional float time, the stratosperic trajectory was spiraling off the Antarctic continent, and because of the danger of loss of the payload, we decided to terminate while near a reasonable recovery site. The final landing place was about 100 nm from Davis Station (AU), on the ice sheet at an elevation of about 2500 m. Fig. 2 shows the launch and the landing site, and Fig. 3 shows a map of the trajectory.

ANITA-III did achieve excellent exposure over deep ice, as Fig. 3 indicates; however, in the several years since our last flight, electromagnetic interference levels from geostationary satellites have increased substantially, and the presence of this unexpected addition noise did reduce the overall efficiency of the exposure, at a level which is still being determined, but could be as high as

40%. Despite this, the payload functioned almost flawlessly, and we recorded approximately 84M triggered events with full bandwidth, full spectrum data taken for all 96 RF channels on each event.

ANITA's current instrument records about 100 ns of time-series for 48 dual-polarization antennas (96 channels total) over a passband from 180-1200 MHz, which covers most of the region where ice is highly radio transparent. The instrument is triggered anytime an impulsive radio signal arrives in more than about three antennas above a level of about three times the thermal noise, corresponding to typically around 30 pW at the antenna terminals. At this signal-to-noise ratio, the inter-antenna timing is $\sim 65$ ps, and improves to $\sim 25$ ps at higher SNR. Based on prior flights, we expect an angular resolution of $\sim 0.2^\circ$ in elevation and $\sim 0.7^\circ$ in azimuth for mapping of received impulses. ANITA uses this angular resolution to ensure that events cannot be associated with known anthropogenic sources in Antarctica, nor can they be associated with each other – "repeating" locations are excluded for neutrino or cosmic ray candidate selection.

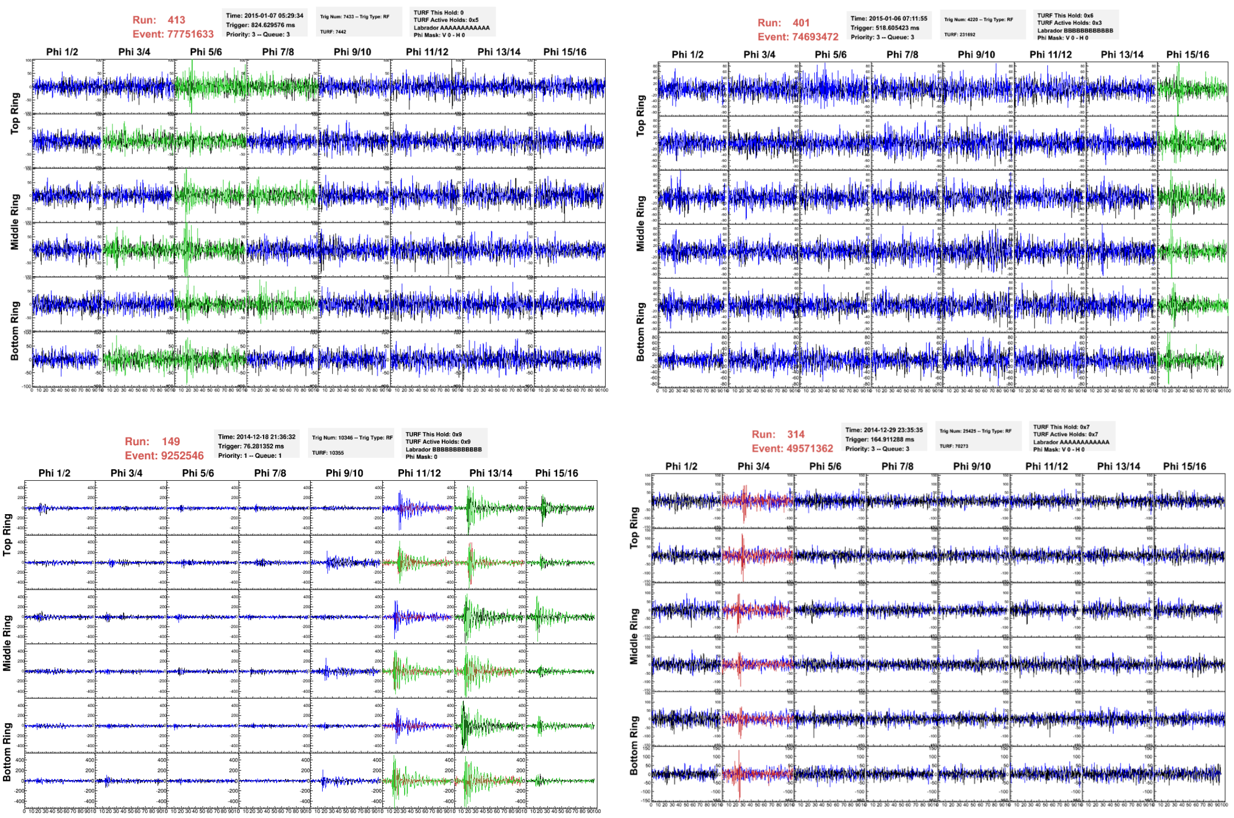


**Figure 4:** *Detected ANITA-III impulsive events. Upper left and upper right: Primary HiCal Hpol impulses, seen when the payload separation was about 600 km. Lower left: a strong ground-pulser event observed near McMurdo station. Lower right: anthropogenic signal seen in the Mt. Vinson region in West Antarctica.*

Our data analysis is done using blinding techniques, and for these data, which were only recovered in early May of this year, analysis is in a very early stage. The vast majority of triggered events are just due to thermal noise fluctuations, since the trigger is operated very close to the thermal noise level. However, such events are quickly eliminated from analysis since they do not have the coherent wavefront characteristics associated with an actual arriving plane wave impulse.

The vast majority of reconstructable plane-wave impulses are due to anthropogenic sources, either terrestrial or from satellites in Earth orbit. Most of these trigger due to upward fluctuations in a broadly modulated noise background, but a small subset of anthropogenic signals are impulsive and could provide a background to actual candidate events. We also use ground-truth radio pulsers at several stations to provide angular resolution and trigger efficiency measurements; in addition, for this flight, we launched a follow-on pulser payload, called HiCal, which was intended to provide both direct and reflected Hpol events to be used to calibrate ice surface reflectivity. We show several examples of detected impulses here.

Fig. 4 shows two events from the HiCal balloon pulser, these are not reflections, but observed directly between the two payloads when they were at separations of order 600 km. Fig. 4, lower left shows a strong signal seen from one of our ground pulsers, and the lower right signal is a strong and very coherent impulse from some anthropogenic activity near Mt. Vinson in West Antarctica.

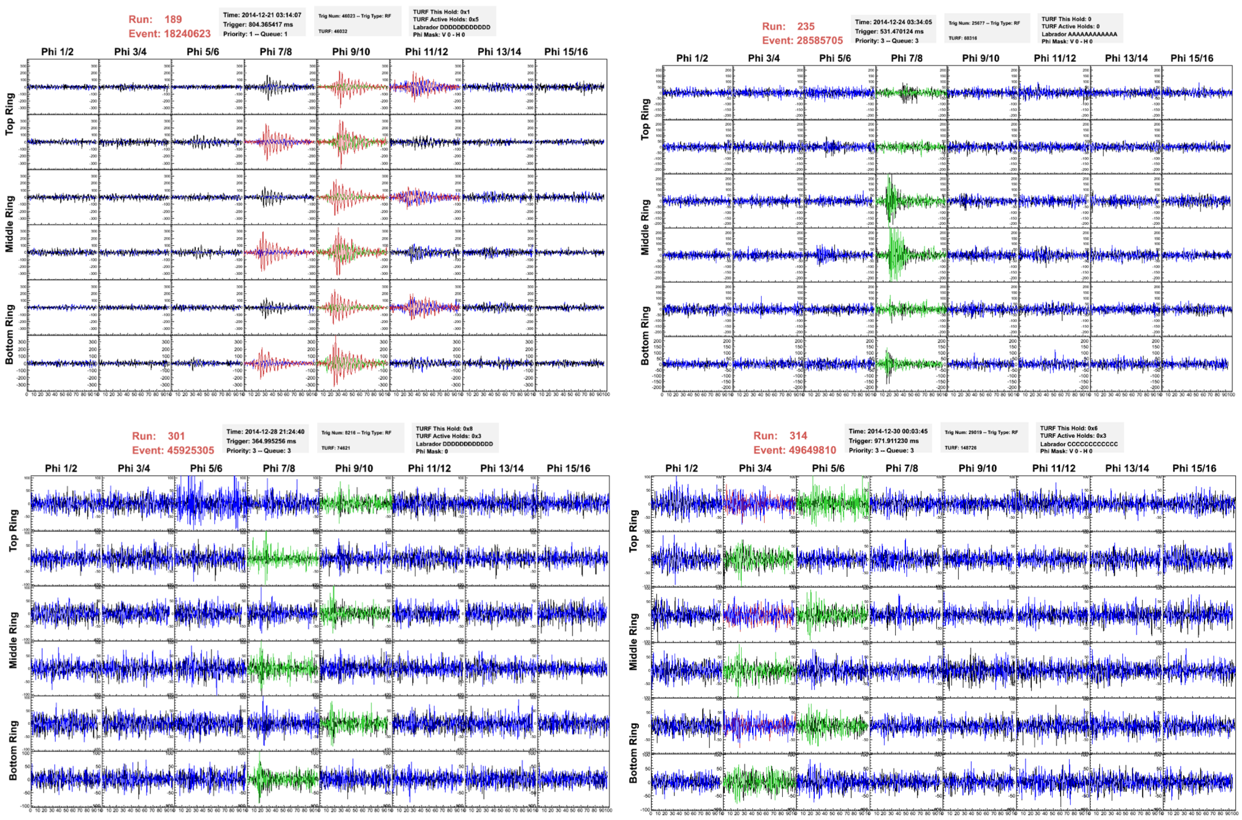


**Figure 5:** *Possible ANITA-III UHECR candidate events at various signal-to-noise levels. All show predominant horizontal polarization. The largest event is probably partly saturated, and the weakest event is close to the baseline trigger level. No further analysis has yet been performed.*

Fig. 5 show four preliminary UHECR candidate events, selected because of their strong Hpol signature, and the lack of obvious correlation with Antarctic camps or other sites, or with other similar events at the same locations or times. These events range from very strong, possibly saturating the digitizer, to one very weak even, close to thermal noise. The autoscaling display of these events accentuates the thermal noise level for the weaker events.

The total UHECR sample in the ANITA-III data could be of order a hundred events or more, depending on somewhat uncertain details of the energy threshold and exposure; the event sample will help to improve models for cosmic ray radio emission in the UHF radio regime. For neutrinos, current limits probably allow no more than a handful of detectable events if the limits are saturated, but the totals could be larger if the cosmogenic spectrum is unusually steep.

The ANITA-III instrument also flew very sensitive total power radiometer receivers for each antenna channel; these are sensitive to millisecond time-scale transients in the entire ANITA field of view, and a search for exotic dark matter candidates and related phenomena is also part of the current ANITA-III analysis (see the poster by B. Rotter).

ANITA-IV is now approved for a flight in December 2016, and several significant improvements are expected:

- Low-noise amplifiers & receivers with 30-40K improvement in noise figure (20% in energy threshold);
- A real-time 3-bit signal correlator is expected to lower the trigger threshold by another 15-20%;
- Programmable notch filters will allow much better response time and control of radio-frequency interference, giving perhaps a 30% improvement in exposure;
- Improvements in our GPU-based trigger processor will yield higher sustainable raw trigger rates and corresponding improvements of 10-15% in threshold.

Realizing all of these efforts will lead to a 50-60% improvement in energy threshold, the most important figure of merit for ANITA, since the peak of the cosmogenic neutrino spectrum is still below our primary energy range. While the ANITA-III flight was shortened due to anomalous vortex conditions, flights of more than twice as long are now not uncommon. In total, ANITA-IV has some chance of achieving as much as a factor of four improvement over ANITA-III.

We thank the NASA Columbia Scientific Balloon Facility for their excellent support of the ANITA-III mission, the NASA Particle Astrophysics program and the High Energy Physics Division of the US Department of Energy for their generous support and encouragement.

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