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Measurement of the cosmic ray flux with the ANITA experiment

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Abstract. The ANITA experiment consists on an aerostatic balloon flying over Antarctica and carrying a payload with antennas. Although ANITA was designed to detect the electric field of netrino-induced showers in the ice cap, it has also detected 16 radio pulses coming from extensive air showers, and the ANITA collaboration has used these data to produce the first cosmic ray flux measurement obtained by employing radio as a stand-alone technique. We review the experimental results and its interpretation. We also focus on the simulations and the method used for obtaining the cosmic ray flux.

1 Introduction

The ANITA experiment [1], originally conceived for the detection of the radio emission coming from neutrino-induced showers, detected 16 pulses emitted by cosmic ray showers. Out of those 16 radio pulses, 14 were reflected on the polar ice cap [2].

The arrival times of the pulses coming from different parts of the shower differ, due to reflection, from those an antenna located on the ground would see, and a realistic treatment of this process is key to the understanding of the received electric field.

In this work we discuss the calculation of the electric field via the ZHAireS code [3] and review the experimental results obtained by ANITA.

2 The experiment

The ANtarctic Impulse Transient Antenna (ANITA) (see Fig. 1) is an experiment composed of a balloon with antennas flying over Antarctica at an altitude of $\sim$ 36 km and with a receiving band streching from 200 MHz to 1200 MHz. The choice of a balloon allows to cover a wide fiducial area and helps to reduce the anthropogenic noise. There have been three different ANITA flights (I, II and III) [4], with the fourth scheduled for December 2016.

ANITA I found that the measured electric field for certain events was polarised perpendicularly to both the shower axis and the geomagnetic field, suggesting that the electric field had been created by means of the geomagnetic effect, and therefore its origin was a cosmic ray shower. The radiation

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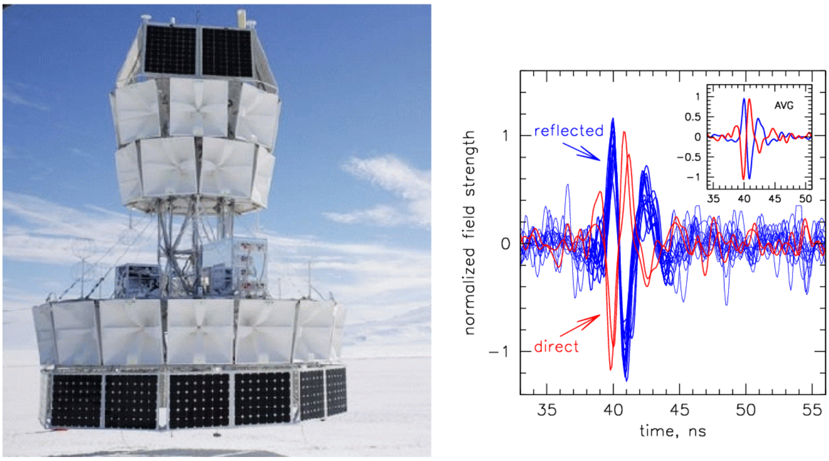

Figure 1. Left: Picture of the ANITA payload. Taken from [1]. Right: voltage as a function of time for the 16 cosmic ray events detected by ANITA. The reflected events possess an opposite polarisation to that of the direct events. Taken from [2].

of 14 of these events came from the ground and had a polarisation opposed to that of the 2 events that came from avobe the horizon, implying a reflection on the ground [2]. The electric field induced by the shower illuminates the ground, gets reflected and propagates through the atmosphere until it arrives at the payload.

3 Simulations

The reflection and the propagation in the atmosphere change the arrival times of the radiation. For these reflected events, it is important to model the atmosphere properly (its sphericity), calculate the arrival times according to the altitude-dependent refractive index and treat the reflection on the ground.

In order to do so, we used the ZHAireS code [5], a combination of the Aires Monte Carlo for particle showers [6] with the ZHS algorithm for the calculation of the electric field [7]. We upgraded the code to a new version called ZHAireS-Reflex [3] which embeds the treatment of the reflection. Our main assumptions were the reflection on a flat surface, the application of the Fresnel coefficients at the interface and the rectilinear propagation of the electric field. A ray-tracing model showed that this rectilinear propagation is valid for the ANITA configuration up to 85° zenith angle showers.

Simulations with ZHAireS-Reflex show the existence of a region where the field is coherent even at 1.4 GHz and that the Cherenkov cone is preserved upon reflection (see Fig. 2, left). The spectrum falls exponentially as a function of the frequency (see Fig. 2, right). Besides, the slope of the spectrum falls is dependent on the off-axis angle, defined as the angle between the observer and the shower axis. Another important result is that the flux of the electric field scales quadratically with the energy of the primary particle. This scaling is a general feature of the electric field produced by air showers that is preserved after reflection.

This suggests a method for measuring the energy of cosmic rays: the slope of the spectrum tells us the off-axis angle, which allows us to estimate the electric field flux at the Cherenkov angle. This is then used for calculating the energy of the cosmic ray.

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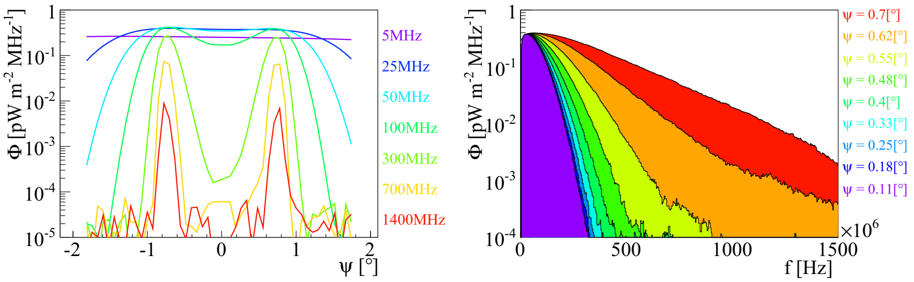

Figure 2. Left: electric field flux as a function of the off-axis angle for several frequencies. Right: electric field flux as a function of the observation frequency for several off-axis angles. See text and [3] for details.

4 Data analysis

The detailed analysis can be found in [8]. When treating the data for the cosmic ray events that ANITA found, the exponential fall-off of the spectrum with frequency was observed. Fits obtained from simulations help us to obtain the electric field at the Cherenkov angle using the amplitude of the measured spectrum at 300 MHz and the constant for the exponential fall-off of the spectrum. Afterwards, the energy of the primary is calculated.

The analysis included a treatment of the defocusing of the electric field due to the curvature of the Earth, and also the loss of coherence due to the roughness of the Antarctic ice. These are also a sort of systematic uncertainties, along with the uncertainties on the shower maximum, the atmospheric refractive index, *etc*, included in the analysis.

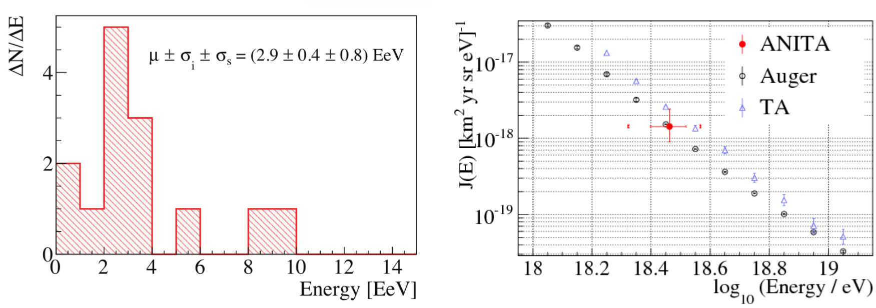

Figure 3. Left: energy distribution of the cosmic ray events detected by ANITA, with the mean energy depicted. Right: flux for the cosmic ray events measured by ANITA and its comparison with the spectra obtained by the Pierre Auger Observatory and Telescope Array. See text and [8] for details.

The energy distribution of the reflected events was obtained, with its mean being $\mu \pm \sigma_i \pm \sigma_s =$ $(2.9 \pm 0.4 \pm 0.8)$ EeV. σ_i corresponds to the statistical uncertainty and σ_s corresponds to the energy scale uncertainty due to the systematic errors of the method and the measurements.

After a calculation of the acceptance of the detector, a point for the cosmic ray flux spectrum was calculated. The result is in agreement within uncertainties with the spectra measured by Pierre

Auger and Telescope Array and it constitutes the first cosmic ray flux measurement using radio as a stand-alone technique.

5 Conclusions

The ZHAireS-Reflex code has been shown to reproduce some of the important features of the cosmic ray events observed by ANITA, such as the spectrum of the electric field and the coherence up to the GHz frequency. As evidenced by the data, a single payload is enough to measure the radio spectrum. The simulations obtained with the ZHAireS-Reflex code were used, together with the ANITA data, for measuring the energy of the primary cosmic rays and the primary cosmic ray spectrum. This is the first analysis that has produced a cosmic ray spectrum using the radio technique exclusively.

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References

[1] P.W. Gorham, *et al.*, Astroparticle Physics **32**, 10 (2009)

[2] S. Hoover, *et al.*, Physical Review Letters **105** (2010)

[3] J. Alvarez-Muñiz, W. Carvalho, D. García-Fernández, H. Schoorlemmer, E. Zas, Astroparticle Physics **66**, 31 (2015)

[4] P. Gorham, *Overview of the Third Flight of the ANITA Long-duration Balloon Payload*, in *Proceedings of the 34th International Cosmic Ray Conference (ICRC)* (2015), 1111

[5] J. Alvarez-Muñiz, W.R.C. Jr., E. Zas, Astroparticle Physics **35**, 325 (2012)

[6] S. Sciutto, <http://www.fisica.unlp.edu.ar/auger/aires/>

[7] D. García-Fernández, J. Alvarez-Muñiz, W.R.C. Jr., A. Romero-Wolf, E. Zas, Physical Review D **87** (2013)

[8] H. Schoorlemmer, *et al.*, *Energy and flux measurements of ultra-high energy cosmic rays observed during the first ANITA flight* (2016)