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The TRISTAN detector. Cosmic ray survey between latitudes 38ºN and 53ºS along the Atlantic Ocean

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TRISTAN (TRasgo para InveSTigaciones ANtarticas) is a cosmic ray detector of the TRASGO family. The detector has been installed at the Spanish Antarctic Base in Livignston Island, as one of the detectors of ORCA (Antarctic Cosmic Ray Observaroty) in December 2019. TRISTAN detector collected data during three journeys crossing the Atlantic Ocean between latitudes 38ºN and 53ºS on board of the Sarmiento de Gamboa and BIO Hesperides oceanographic vessels. The trips took place between November 2018 and December 2019. The main purpose is to evaluate the capability of a TRASGO detector to explore the geomagnetic field variations and the different atmospheric behaviours at both hemispheres and in the Equator region. The main technical aspects of the detector and its performance (efficiency, resolutions, and acceptances) will be discussed and the preliminary results of the last journey will be presented.

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1. Introduction

The discovery of cosmic rays took place after the discovery of natural radioactivity. Cosmic rays are mostly relativistic charged atomic nuclei traveling through the interstellar space at speeds close to light, with energies that are up to around 10^{20} eV, eleven orders of magnitude larger than the energy of the proton at rest. Cosmic rays are a continuous source of penetrating radiation that can be used to perform a "x-ray like" picture of the near Earth space and atmosphere. The first interaction of cosmic rays with a nucleus of the air, typically at an altitude between 10 and 30 km, starts a shower of secondary particles (secondary cosmic rays) called Extensive Air Shower (EAS).

The EAS have three major components; electromagnetic, muonic and hadronic. The decay of neutral pions into two gamma-rays, which may also create a pair electron-positron that can also produce more gamma-rays by bremsstrahlung mechanism, feeds the electromagnetic component. The muonic component is comprised of the muons produced in the decay of charged pions. The hadronic consists of a high energy hadronic core that feeds the electromagnetic and muonic components producing pions. The flux of this secondary particles measure on Earth's surface is affected by different effects [1].

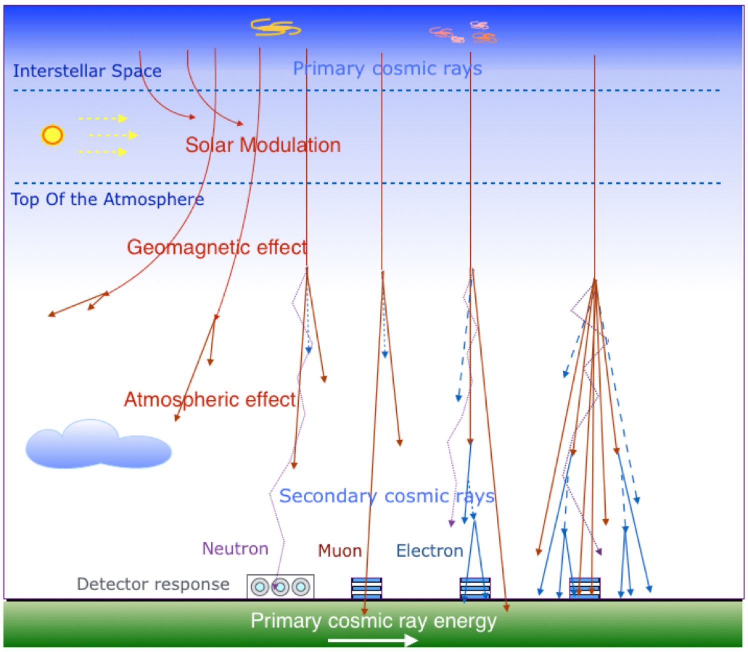


Figure 1: Effects that modulate the flux of cosmic rays measured on the Earth's surface. Curved lines represent the distortion in the trajectory of primary cosmic rays due to the influence of the magnetic fields. Red straight lines correspond to the trajectory of muons of the EAS. Blue dashed lines stand for gamma-rays and the solid ones for electrons and positrons. In purple the trajectory of a neutron.

Figure 1 shows the different phenomena that modulates the flux of secondary cosmic rays measured on the Earth surface, as the interplanetary magnetic field induced by the Sun, the solar wind, the Earth's magnetic field and atmosphere [2]. The first one, solar modulation, explains the temporal variations in cosmic ray intensity. These changes are due to the turbulent solar wind, with an embedded Heliospheric Magnetic Field (HMF), that primary cosmic rays encounter when entering the Heliosphere. The second one, the Earth's geomagnetic field screens from the arrival of primary cosmic rays at a given point in the magnetosphere depending on their energy. The geomagnetic cutoff rigidity (GCR), by definition, is the threshold rigidity below which the particle flux is zero due to geomagnetic shielding. Finally, the atmosphere modulates the production and propagation of secondary cosmic rays. This effect has to be accounted for when studying the variation in the cosmic ray flux [3]. Especially important is the variation of the interaction probability in the atmosphere due to density of nuclei proportional to the atmospheric pressure and temperature.

There are different techniques to detect and measure primary and secondary cosmic rays depending on their energy and kind of particle. The direct detection of primary cosmic rays with energies between 10^3 and 10^{14} eV is done by satellites or detectors placed at the International Space Station [4] or balloons. For energies in the range 10^{14}-10^{20} eV the indirect detection using big arrays of detectors at the Earth's surface is needed and it is based on the observation of EAS.

The TRASGO project aims to develop a new generation of cosmic ray detectors using some of the latest technologies used in High Energy Particle Physics experiments [5] [6]. One of them is the use of Resistive Plate Chambers (RPC) as main detection technique. This technology offers also a broad choice of design possibilities offering either time resolution below 100 ps or sub-millimetric performances [7]. Nowadays, four TRASGO detectors are operative or under development. In this document, some preliminary results of the detector TRISTAN, are presented. The main goal is to study different local effects on the secondary cosmic ray flux measured at Earth's surface. Mostly, effects related to the Earth's atmosphere and magnetic field and also space weather events. For that purpose, TRISTAN detector collected data during three journeys along the Atlantic Ocean between latitudes 38ºN and 53ºS, crossing the region where the South Atlantic Magnetic Anomaly (SAMA) is located. SAMA is a weakness in Earth's magnetic field over South America and the South Atlantic which allows the inner Van Allen radiation belt to dip down closer to the atmosphere. The anomaly has been observed with detectors mounted in satellites [8]. The main purpose is to evaluate the capability of a TRASGO detector to explore the geomagnetic field variations and the different atmospheric behaviours at both hemispheres and in the Equator region. In December 2019, TRISTAN was installed at the Livingston Island, close to the Antarctic Peninsula as a part of the Antarctic Cosmic Ray Observatory (ORCA) [9].

2. Antarctic Cosmic Ray Observatory: ORCA

ORCA consists in a set of detectors with different properties used to measure secondary cosmic rays at the Earth's surface. Two blocks make up the whole observatory. The first one, TRISTAN which is based on RPC technology and built by LIP Coimbra and Hidronav technologies. The second one, is a neutron monitor (NEMO) together with a muon telescope (MITO). ORCA performed one latitudinal scan in late 2018, from latitudes 42ºN (Vigo, Spain) to 53ºS (Punta Arenas, Chile) and NEMO and MITO were installed at the Spanish Antarctic Base in Livingston Island. In addition, TRISTAN measured secondary cosmic rays for another two journeys on board of the Sarmiento de Gamboa (53ºS Punta Arenas to 42ºN Vigo) and BIO Hesperides (38ºN Cartagena, Spain to 53ºS Punta Arenas) oceanographic vessels respectively and from South to North and North to South. The trips took place between November 2018 and December 2019. Multiple ship's instruments provide measurements of outdoor temperature, pressure, position, among many other variables. In December 2019, the last latitudinal scan finished and the detector TRISTAN was installed at the Spanish Antarctic Base in Livingston Island, joining the other detectors of ORCA.

3. TRISTAN Detector

TRISTAN is a detector of the TRASGO family which design is based on RPC technology. Built in Coimbra with the expertise of the mechanical workshop and detector laboratory teams of LIP with the support from HIDRONAV technologies. Three RPC planes of 1.2×1.5 m^2 size define the detector instrumented with the fast FEE electronics [10] [11]. A total of 90 channels, 30 per plane, are read out by the TRB3 readout board via 4 FPGA-based TDCs [12] [13].

The ionizing particles that travel throughout the upper and middle planes will encounter a layer of lead of 1 cm thickness before the third plane. This layer has been added to enforce electromagnetic showers associated to gammas and electrons in order to enable a better muon-electron separation. The high voltage power supplies are auto-adjusted to maintain the gain almost constant in each plane independently of pressure and temperature variations [14] [15].

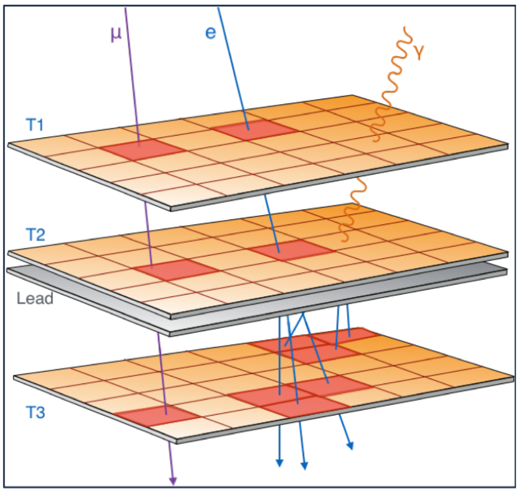


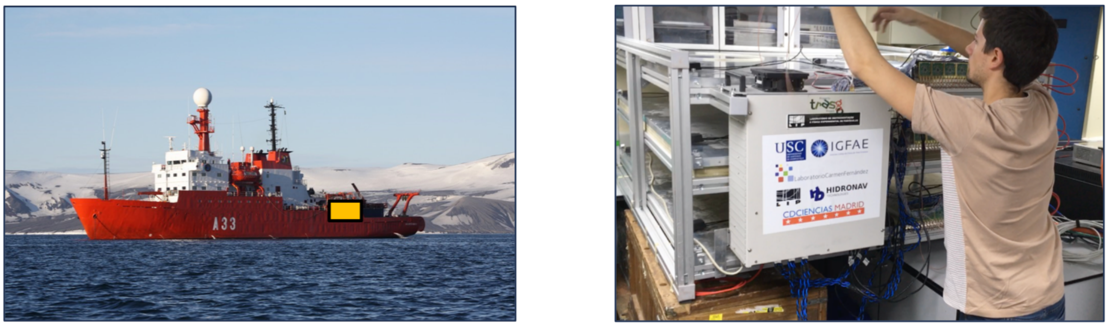
Figure 2: TRISTAN scheme showing the 30 pads per plane in orange, the lead layer between second and third planes in grey and the path that different particles (muons, electrons, gammas) follows across the active size of the detector in red.

TRISTAN main performances for a straight track left by an ionizing particle are a time resolution of 300 ps, the tracking capability and the study of the arrival direction or directionality.

4. TRISTAN: Preliminary Results

TRISTAN collected data during three journeys crossing the Atlantic Ocean between latitudes 38ºN and 53ºS on board of the Sarmiento de Gamboa and BIO Hesperides oceanographic vessels.

The detector took data with coincidence trigger between the upper and middle planes, at a rate of around 10 million of events per day (120 Hz).



(a) (b)

Figure 3: (a) The yellow box drawn on top of the picture indicates the location of TRISTAN in the BIO Hesperides hold and (b) installation of the detector for the last latitudinal survey in late 2019.

The latitudinal surveys provide information about the cosmic ray flux under multiple atmospheric conditions together with variations of the geomagnetic field. Figure 4 shows the cut-off rigidity for the last journey. It has been calculated using a model of the geomagnetic field of 1980 and interpolated to a mesh of 1º×1º [16] [17]. The data taken along the three journeys is of special interest because of the wide range of rigidity values that it covers and the different atmospheric effects to which the detector was exposed.

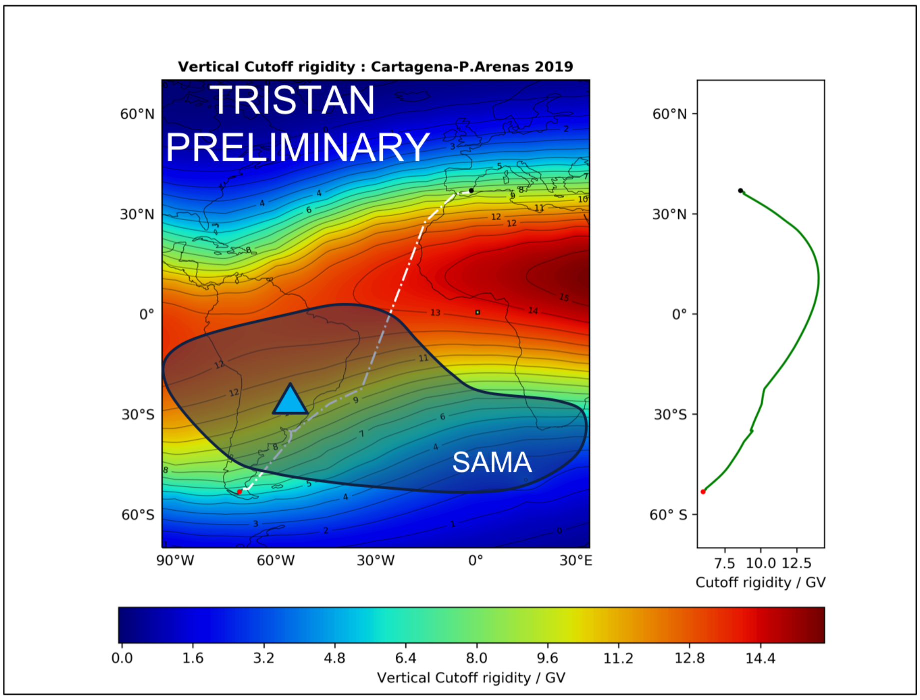


Figure 4: Left) white dashed line shows the trajectory followed by the oceanographic vessel BIO Hesperides for the last journey from 38ºN to 53ºS. SAMA extends from South America to Africa and the region of the minimum of the magnetic field is located over Paraguay. Right) profile of the Vertical Cutoff Rigidity (GV).

The preliminary results of TRISTAN, belong to the last journey from Cartagena, Spain (38ºN) to Punta Arenas, Chile (53ºS), the last one before the installation at the Antarctic Spanish Base in Livingston Island and the longest one with more than 30 days of data. We have chosen only vertical tracks, requesting only one hit, multiplicity M1, in the same column of cells for all planes. Three different methods to obtain the efficiency per plane have been developed in order to produce a sample of data corrected by efficiency. This allowed us to estimate the systematic error of our final sample together with the random coincidences correction.

Figure 5 shows the calibrated rate, uncorrected by temperature and pressure. The rate corresponds to a zenith acceptance of only 15º. Even though there are still minor modulations due to the pressure and temperature conditions that need to be corrected, the rate shows a very good correlation with the cut-off rigidity having a minimum value when the rigidity reached its maximum near Equator.

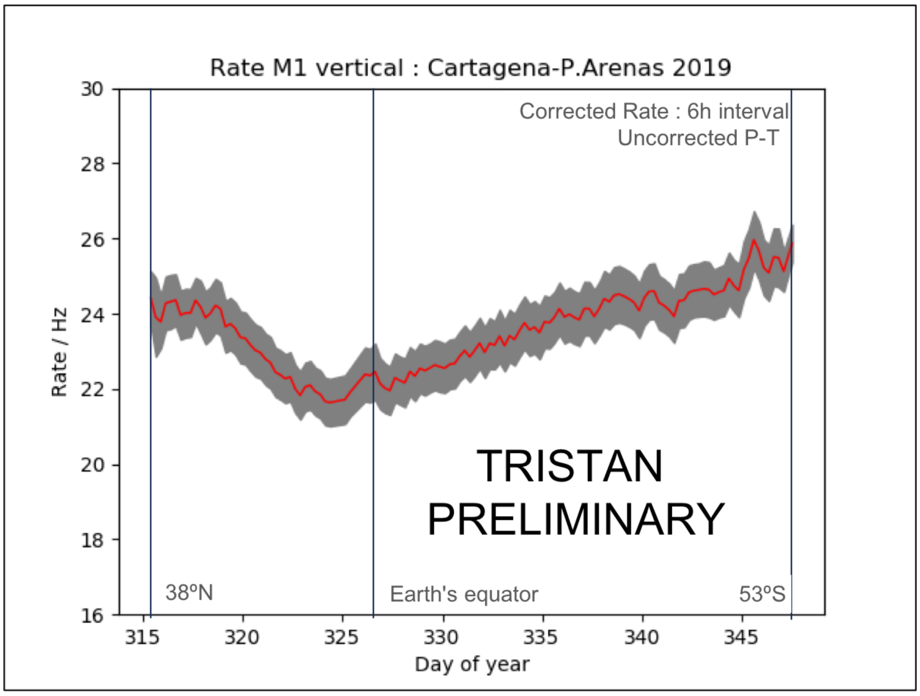


Figure 5: Rate of multiplicity M1, corrected by efficiency and random coincidences, as a function of the day of the year for the third latitudinal survey and uncorrected by pressure and temperature.

The addition of the GCR as a new dimension to the previous figure, gives Figure 6, that shows the time evolution of the rate as a function of the vertical cut-off rigidity. The expected linear correlation between the rate and the rigidity can be seen looking at the projection of the 3D plot. There are many effects for example, the knee in the rigidity, that is a long stop of three days in Montevideo, Uruguay. Also, the minimum of the rate is at the same time the rigidity reaches its maximum during the journey.

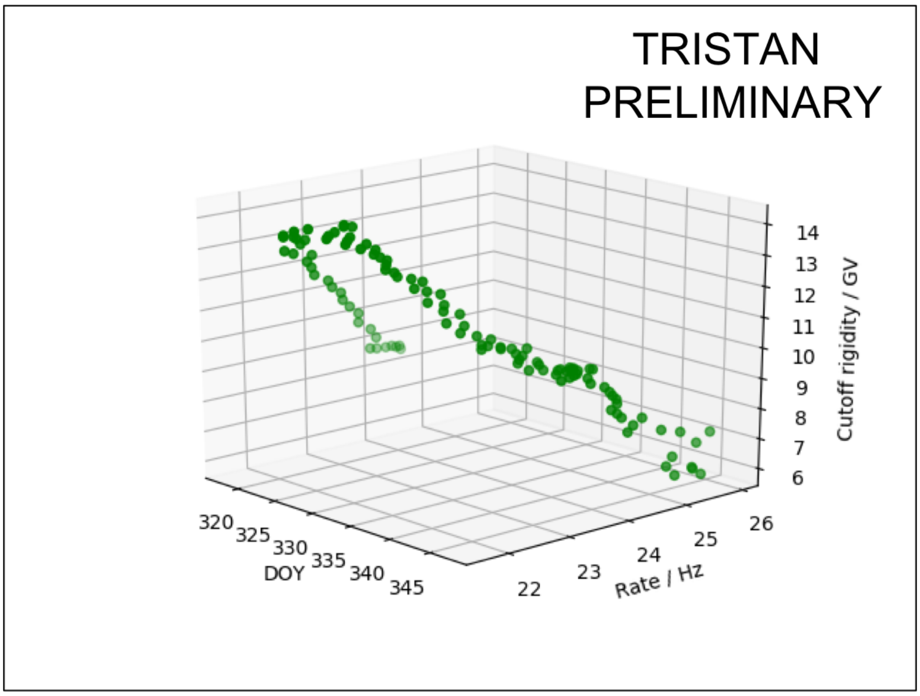


Figure 6: 3D plot that shows the evolution and correlation between the different variables : rate of multiplicity M1, corrected by efficiency and random coincidences, and rigidity as a function of the day of the year.

5. Conclusions

TRISTAN detector has performed three latitudinal surveys from 38ºN to 53ºS before being placed at the Spanish Antarctic Base, Juan Carlos I, in Livingston Island. The main purpose of the multiple journeys crossing the Atlantic Ocean is the study of geomagnetic and atmospheric effects on the rate of cosmic rays measured at the Earth's surface.

Preliminary results of the last journey are presented in this work. Data of multiplicity M1 with a maximum zenith acceptance of 15º have been selected for this preliminary study. The detector's efficiency correction has been performed using multiple methods to obtain the efficiency of the RPC planes and a correction for random coincidences. Calibrated data shows a linear correlation with the rigidity as expected.

The detector has been installed in December 2019 at the Spanish Antarctic Base in Livingston Island and has been taking data in early 2020.

Acknowledgments

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