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The NUSES space mission

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Summary. — NUSES is a pathfinder project for innovative satellite-borne particle detectors dedicated to the study of cosmic radiation, astrophysical neutrinos, Sun-Earth environment, space weather and magnetosphere-ionosphere-lithosphere coupling. The satellite will host two payloads, named ZIRÉ and TERZINA. The ZIRÉ instrument will measure the fluxes of low-energy cosmic-ray protons, light nuclei, electrons, positrons and gamma rays with energies up to a few hundreds of MeV. TERZINA will test innovative techniques for the detection of astrophysical neutrino signals, looking at the Cherenkov light produced by the extensive air showers generated in the atmosphere. In the following, scientific objectives and features of the NUSES project will be presented.

1. – Introduction

Several new generation space-borne detectors for gamma rays (GR) and cosmic rays (CR) have been proposed in order to improve our understanding of many astrophysical phenomena (a few examples can be found in refs. [1-3]).

NUSES is a joint project between the Gran Sasso Science Institute (GSSI) and Thales Alenia Space Italy (TAS-I), in collaboration with the Italian National Institute of Nuclear Physics (INFN) and several international Universities. The mission is conceived as a technological pathfinder in the study of high and low energy radiations, testing new observation methods and new technological solutions for the satellite platform. The NUSES proposal has been approved by the Italian government as a flagship initiative to relaunch the economy of the L'Aquila area and, recently, by the Italian Space Agency (ASI) as a new space mission.

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TABLE I. – *Mission details.*

Lifetime	3 yr
Orbit	LEO sun-synchronous orbit on the day-night border
Mean altitude	550 km
Inclination	97.6 deg
Local time of the ascending node (LTAN)	18:00:0
Weight	$<$150 kg (total satellite)

The project being a technological pathfinder, the mission scientific goals are multiple. The cosmic radiation will be investigated in different energy ranges, through low-energy cosmic rays (CRs) and gamma rays (GRs), and by studying the showers induced by ultra-high energy (UHE) CRs and neutrinos via the Cherenkov light emission in the atmosphere.

The deep investigation of the space environment should place the NUSES experiment in the network of multi-messenger missions, measuring photons in the 0.1–10 MeV range for transient and steady gamma source, monitoring very low-energy electrons ($<$10 MeV) and protons/nuclei up to hundreds of MeV. In this way, NUSES undertakes the study of space weather, which is fundamental for the effects on manned or unmanned space missions, and contributes to understand the magnetosphere-ionosphere-lithosphere coupling effects induced by natural sources (seismic activities or anthropogenic emitters). In fact, according to the so-called MILC model [4], acoustic gravity waves from an earthquake propagate in the atmosphere, causing a variation of the plasma density in the ionosphere, with consequent electromagnetic emissions towards the lithosphere. As a result, a change in the magnetic field and diffusive motion of particles (precipitation) can occur. The MILC model could provide a possible explanation for those anomalies in the ionosphere (electromagnetic and plasma density perturbations) and the abnormal increase in low-energy electrons (from a few MeV to several tens of MeV) and protons trapped in the Van Allen Belts (VAB), detected by ground observations and Low Earth Orbit (LEO) satellites [5, 6].

2. – The NUSES instruments

The scientific payloads will be hosted onboard the NIMBUS (New Italian Micro BUS) platform, developed by Thales Alenia Space. The NUSES experiment is composed of two main sub-detectors called TERZINA and ZIRÉ (see fig. 1). Details about the orbit are reported in table I.

The design and the scientific goals of the two NUSES payloads will be illustrated in the following sub-sections.

2·1. *TERZINA.* – It is a new concept of optical telescope for the detection of high-energy neutrinos and CRs, which combines space-based atmospheric Cherenkov light

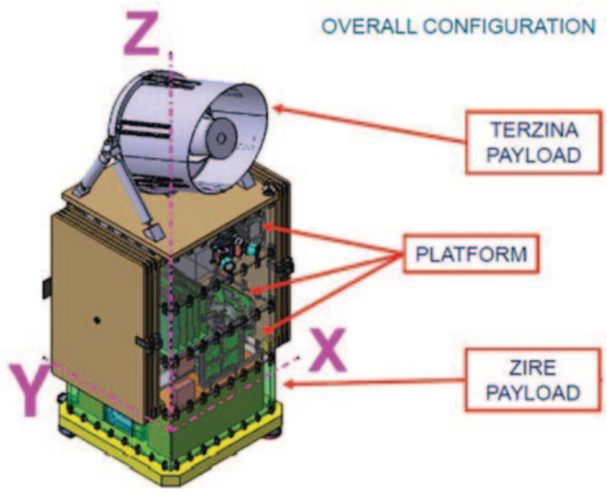

Fig. 1. – Satellite configuration at the launch showing the location of the scientific payloads and service modules. After the launch, the satellite will be rotated upside-down so to have TERZINA pointing to the Earth limb, and the solar panels (shown in brown) will be opened.

detection and SiPM (Silicon Photomultiplier) technology. It will point to the dark side of the Earth's limb, looking for Cherenkov light emissions from UHE CRs or neutrinos. TERZINA will be the precursor of upcoming missions equipped with imaging atmospheric Cherenkov telescopes, such as POEMMA [3].

The preliminary design (see fig. 2, left) consists of a double mirror optics with an oblate spheroidal geometry, focusing the collected light on a multi-pixel focal surface detector based on the SiPM technology. Rate studies are underway to optimize the number of pixels and the field of view of the detector.

2˙2. *ZIRÈ*. – It is dedicated to the measurement of the fluxes of cosmic electrons, protons and light nuclei with energies up to hundreds of MeV, but also operates as a

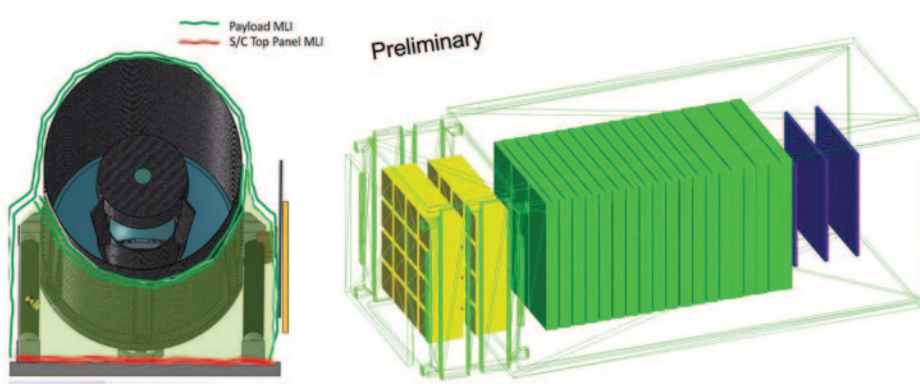

Fig. 2. – Left: the preliminary TERZINA optical design. Right: the preliminary ZIRÈ design: fiber tracker in blue, plastic scintillator tracker in green and calorimeter in yellow. External anticoincidence system in green lines.

GR telescope in the MeV energy range. Further objectives include the study of space weather and the search for possible correlations of the electron and proton fluxes with seismic activities through MILC phenomena.

The preliminary design (see fig. 2, right) consists of a system of several sub-detectors: external scintillator tiles for the anticoincidence system (VETO); a compact calorimeter of LYSO cubes as gamma detector (CALOg); a tracker of plastic scintillator bars (PST) and a new optimized tracker (FTK), using the scintillating fiber technology, as the CR detector. The main innovative technological proposal includes a whole readout system based on SiPM sensors.

Finally, a compact detector, called Low Energy Module (LEM), specifically designed to detect electrons down to hundreds keV, will be placed next to ZIRÈ. Its preliminary design consists of a shielding of aluminium; a plastic scintillator as an active collimator; a layer of silicon detectors as Particle Identification detectors and additional plastic scintillators both to extend to higher energy and as veto. Its modular geometry will allow covering a large field of view, increasing the ability to detect very low energy electrons (<5 MeV) from the zenith.

3. – Conclusions

The NUSES space mission is a technological pathfinder in the exploration of low and high energy radiation, for future satellite-borne particle detectors, and a demonstrator of atmospheric Cherenkov light detection. New sensors, front-end electronics and data acquisition system, based on the SiPM technology, and new methods of observing Cherenkov light from the space will result in a precursor project for next generation space missions.

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