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SOLSAT: A LOW-COST 3-U CUBESAT SYSTEM FOR SPACE WEATHER APPLICATIONS

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Abstract

Space weather is becoming as important as Earth weather, and the main driver for both is our star, the Sun. Electronics systems are subject to electrical faults due to some extreme solar activities. For this reason, it is important to study the behavior of Earth's ionosphere when solar storms occur. Solar eruptions are intense source of radiation as EUV emissions, which can modify the ionospheric ionization and thus the properties of this layer. Furthermore such energetic events produces electrons, protons and ions which interact with atmospheric elements before even reaching the ground. The most energetic Solar Energetic Events can even reach the polar ionosphere which can couple to the outer magnetosphere.These ionospheric perturbations can then engender internet connections and communication losses in various frequencies impacting space-ground or ground-ground telecommunications, LEO satellites, and the stock market's fall. Financial damages could run into trillions of dollars. This is why developing a low-cost 3U CubeSat system to monitor the ionosphere's daily behavior due to the Sun's activities is a" must-do" to predict such catastrophes before they happen. These SolSats systems will collect valuable data on conditions of the upper ionosphere at the LEO level. The main scientific goal is to learn how the 11- year solar cycle affects the charged particles density of the upper ionosphere. This will help better space weather models to prevent catastrophic events that may have disastrous consequences on our technological world. The payload is the main element of a SolSat 3U CubeSat, besides the supporting subsystems (ADCS, EPS, OBDH, etc.). It will consist of two sub-payloads. The first one consists of a board equipped with an array of off-the-shelf sensors: a temperature sensor, a light sensor, a magnetometer, a microprocessor, and an accelerometer. The second payload will be a sensor to measure the charge particles' density of electrons, protons, and ions in the energy range of 0.1 - 1 MeV, the expected energies of these particles at the LEO level. This sensor will have enough high temporal, energetic, and mass resolutions. The main goal is to monitor the upper ionosphere charge particles density as the Sun becomes more active in the present 25th solar cycle. The operational duration of such a SolSat system in Space is expected to be 30 months. The paper will present the possible payloads that may fit in a 3U CubeSat along with operational principles and supporting CubeSat bus.

Keywords:

CubeSats, Space Systems, Space Weather, X-ray Detectors, Space Situational Awareness

1. Introduction

The Sharjah Academy for Astronomy, Space Sciences, and Technology (SAASST) has recently achieved a milestone with the successful launch of its first CubeSat mission, named Sharjah-Sat-1. This 3U CubeSat comes equipped with an improved X-Ray detector payload. As part of its CubeSat missions program, SAASST aims to launch SolSat, a small satellite focused on monitoring the Earth's Ionosphere. This mission will contribute to space weather research by providing data obtained from the Solar Particle Detector (SPD) payload onboard. This payload is novel in that it covers a range from 0.1-100 MeV and will fit into the proposed 6U structure, which has not been covered by previous satellites of its scale.

Space Weather is a natural hazard that originates mainly from the Sun and, to a lesser extent, from galactic cosmic rays. It has been known to cause significant impacts on Earth's technology, as evidenced by major events such as the Carrington event in 1859 and the Quebec power grid blackout in 1989. During the Halloween event of 2003, extreme radiation impacted the terrestrial environment, leading to satellite TV and radio services disruptions, the destruction of NASA's MARIE experiment, and satellite operations loss over high-interest regions. The adverse effects of space weather on various systems, including global navigation satellite systems, aviation radars, and power grids, can cause worldwide economic losses and prolonged recovery times.

The effects of space weather on spacecraft in low Earth orbit (LEO) can also be disastrous. In February 2022, SpaceX lost 38 out of 49 satellites it had just launched to LEO, which was attributed to two geomagnetic storms. The storms added energy in the form of heat, increasing the density and distribution of the upper atmosphere, which resulted in an extra drag on LEO satellites, leading to their burn-up during re-entry. This incident highlights the vulnerability of our increasing dependence on technology and the potential for significant financial losses.

2. Motivation:

The motivation behind Sharjah-Sat-3 (SolSat) CubeSat mission is to establish a platform to study space weather and its effects on us, Space has its own weather, which is affected by radiation. Studying and monitoring space weather is essential because it primarily affects our way of life in three ways. Firstly, Radio blackout storms are electromagnetic storms that mainly occur following a solar flare. Electromagnetic energy released in flares disrupts Earth's upper atmosphere, the region where satellite communication signals travel to planet earth, and can cause signal blackouts and data losses. The second-way space weather affects us is through a solar radiation storm, where a wave of highly charged particles from the Sun's radiation permeates through the magnetosphere at an accelerated speed, endangering astronauts' health onboard space stations. Lastly and most importantly, severe space weather can cause Geomagnetic storms which occur one to three days after a solar eruption, where giant clouds of plasma can reach the Earth's orbit, compressing the magnetosphere. The influx of such charged particles and electromagnetic fields bouncing through Earth's magnetosphere can induce currents in many critical electrical systems and infrastructure on the Earth's surface, including power grids, causing blackouts [1].

Multiple space missions have been launched to study space weather through measuring X-ray and high energy particles, such as GOES, Proba-2 missions which utilize larger satellite platforms, the scope of this paper focuses on smaller satellite platforms specifically CubeSats, multiple CubeSat missions have the primary objective of studying space weather such as NinjaSat which is a 6-unit (10x20x30 cm) CubeSat conducting X-ray observations. The primary X-ray detector onboard NinjaSat is a system of two identical non-imaging Gas Multiplier Counters (GMCs) measuring X-rays with a range of 2 to 50 keV. The detector is collimated with a passive collimator made from iron^55 having a full width at half maximum (FWHM) field of view of 2.1° [2]. Another CubeSat studying X-ray is called MeVCube which is a CubeSat with a mission to detect energy ranges from 200 KeV up to 4 MeV, utilizing a 2x2x1.5 cm CdZnTe crystal detector as an active sensing element, with a mean FWHM resolution of >3% [3]. BeEagleSAT is a 2-unit (10x10x20 Cm) CubeSat from the QB-50 multi-CubeSat mission which utilizes a 2 x 2 x 0.3 cm CdZnTe crystal as an active sensing element measuring X-ray energies with a range of 20 to 150 KeV [4]. BeEagleSAT was used as the foundation in designing the Improved X-ray Detector (IXRD) on board the Sharjah-Sat-1 3-unit (10x10x30 cm) CubeSat which also utilizes a 2.54 x 2.54 x 0.3 Cm CdZnTe crystal but with a higher range of detection at 20-200 KeV with a resolution of 6 KeV at 60 KeV, Sharjah-Sat-1 was launched in January of 2023 [5].

Another CubeSat mission, Colorado Student Space Weather Experiment (CSSWE), was launched by the University of Colorado in 2012. This 3U CubeSat housed the Relativistic Electron and Proton Telescope (REPTile) instrument, which performed directional differential flux measurements of electrons ranging from 0.5 to >3.3 MeV and protons from 9 to 40 MeV. CSSWE was launched into an elliptical orbit (478km × 786km) with an inclination of 64.7° [6]. The University of Colorado has planned a consecutive mission, Colorado Inner Radiation Belt Experiment (CIRBE), set to launch in early 2023. This 3U CubeSat will have a Relativistic Electron Proton Telescope (REPTile-2) onboard to measure incident electron and proton energies. The payload targets the range of 0.3-3.5 MeV for electrons and 6-35 MeV for protons and is planned for a highly inclined Low Earth Orbit [7].

3. Sharjah-Sat-3 (SolSat)

3.1 General Mission Objectives

The primary goals of Sharjah-Sat-3 are to introduce the UAE to the research field of space weather, help establish the policy towards the adverse effects of space weather and advise the UAE aviation authority on space weather hazards. The data provided by the mission will also assist in setting up early warning systems to prevent electrical power grids and radio and GPS blackouts due to solar storm effects. Ultimately, this will enable the UAE to contribute to international efforts to mitigate the impact of space weather on our human civilization.

Those goals will be achieved through the understanding of the Sun's solar cycle and the solar flares activities using the proposed payload. The solar energetic particle events (SEP) that occur during the regular 11 years solar cycle, if directed towards Earth, can produce the mentioned damaging effects on the different Earth systems. And the relation between solar flares and SEP is intended to be investigated with the CubeSat in order to mitigate them.

3.2 General Detector Specifications

Sharjah-Sat-3's main payload is a novel Solar Particle Detector (SPD) intended to detect electrons, protons, and ions in the Low Earth Orbit (LEO) in the energy range 0.1- 100 MeV, housed in a 6U structure. This range of energy was previously only achieved with larger satellites because of the challenges of miniaturizing the technology to fit in a CubeSat form.

The SPD relies on the well-known dE/E measurement technique in high-energy experimental physics to detect incident particles, mainly trapped electrons, protons, solar protons, and the galactic cosmic (heavier ions from Z=2 to Z=26), in addition to gamma rays. This is the first attempt to measure the energy spectrum of these particles in a CubeSat and using a Silicon Photomultiplier (SIPM) as the active detector.

A Geant4 simulation was conducted of a possible payload geometry composed of thin (100 µm), and thick (10 mm) scintillator layers placed thin on top (dE) of the thick one (E). It was found that the protons with energies 0.1 MeV to about 5 MeV stop in a thin scintillator layer. Over this energy, the release is linearly in the thick up to about 60 MeV. In this project, the thickness of the thick scintillator will be increased to extend the linearity up to 100 MeV. The simulation also shows that the electrons release their energy in thin and thick scintillators giving a clear signature. On the contrary, the gamma particles pass through the thin layer and release the total or partial energy only in the thick scintillator, providing a clear signature for identification in the targeted energy region.

Four SIPMs, each of the size 3mm × 3mm, will be utilized to collect the data from the thick scintillator. And the thin scintillator will be placed into a light guide to drive the light collected toward two/four scintillators coupled to the light guide exits. Each of the two layers will have independent triggering mechanisms to perform measurements separately or in coincidence.

Conclusion

To conclude, it can be observed in the motivation section of this paper, the Sharjah-Sat-3 (SolSat) mission has an advanced energy detector capable of detecting high energy particles in the range of 0.1 to 100 MeV. The team in the Sharjah Academy for Astronomy, Space Sciences & Technology and our technological partners are optimistic in the success of the mission, the detector is still currently under further design verification and testing.

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