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Development of CubeSat-based Payload for Space Weather Monitoring Missions

Nikolai Ivanov*

Department of Physics and Astronomy, University of Glasgow, Glasgow G12 8QQ, UK

Introduction

Space weather—driven primarily by solar activity such as flares, Coronal Mass Ejections (CMEs), and high-energy particle streams—has profound effects on space-borne and terrestrial systems, including satellite operations, navigation systems, communication networks, and power grids. Continuous and real-time monitoring of space weather is therefore critical for both scientific understanding and operational forecasting. Traditional space weather missions, such as SOHO and ACE, have provided invaluable data, but their high cost and limited accessibility prompt the need for more agile, affordable solutions. In this context, CubeSats—miniaturized satellites in standardized Units (U)—have emerged as promising platforms for targeted, low-cost missions. This paper presents an in-depth overview of the development of a CubeSat-based payload specifically designed for space weather monitoring, instrumentation, subsystem integration, and mission architecture [1].

Description

The primary scientific objective of the CubeSat payload is to monitor Solar Energetic Particles (SEPs), variations in the Earth's magnetosphere, and changes in ionospheric parameters that are influenced by space weather events. These measurements can be achieved by incorporating miniaturized sensors capable of detecting charged particles, magnetometer readings, and plasma densities. For this mission, the payload configuration includes a solid-state energetic particle detector, a triaxial fluxgate magnetometer, and a Langmuir probe, all optimized for CubeSat constraints in terms of Size, Weight, and Power (SWaP). Designing instruments for a CubeSat demands trade-offs between sensitivity and form factor. The energetic particle detector utilizes silicon PIN diodes and thin scintillator crystals coupled with avalanche photodiodes, allowing for the discrimination of particle energies and species. The fluxgate magnetometer, mounted on an extendable boom to reduce magnetic interference from the satellite's own electronics, provides vector magnetic field data at high cadence. The Langmuir probe enables real-time measurements of electron density and temperature in the ionosphere, which are critical for detecting space weather-induced disturbances. These instruments collectively provide a comprehensive picture of the near-Earth space environment during both quiet and stormy conditions.

Subsystem integration is a core challenge in CubeSat development. The payload must be tightly integrated with the satellite bus, which includes power systems (solar panels, batteries), an Onboard Computer (OBC), communication systems (UHF/VHF or X-band), and Attitude Determination and Control Systems (ADCS). A 3U CubeSat configuration (10 × 10 × 30 cm) is selected to accommodate all systems while maintaining adequate payload volume. Power budgeting ensures the payload can operate continuously during data acquisition windows, with instrument duty cycling and power conditioning circuits implemented to manage consumption. Data storage and telemetry scheduling are designed to prioritize high-resolution data during geomagnetic storm events, enabling efficient downlink to ground stations.

The mission design incorporates a LOW EARTH ORBIT (LEO) at an altitude of ~500–600 km, ideally in a Sun-Synchronous Orbit (SSO) for consistent illumination and thermal conditions. This orbit allows frequent revisit times over specific regions and maximizes opportunities for observing space weather variations across latitudes. Ground segment planning includes a network of ground stations or use of the Global Educational Network for Satellite Operations (GENSO) to enable reliable data downlink and command uplink. A modular software architecture running on the OBC enables real-time data compression, anomaly detection, and autonomous decision-making, such as switching to high-cadence sampling during SEP events [2].

Conclusion

The development of a CubeSat-based payload for space weather monitoring represents a significant step toward democratizing access to space-based environmental data. By leveraging miniaturized sensors and innovative integration techniques, CubeSats can deliver valuable scientific insights at a fraction of the cost and development time of traditional missions. The proposed mission architecture not only addresses the fundamental challenges of CubeSat design but also positions the platform as a viable tool for space weather forecasting and space science. As the impact of space weather on modern technology continues to grow, such agile and scalable systems are essential for building global resilience and advancing our understanding of heliophysical processes.

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Conflict of Interest

None.

***Address for correspondence:** Nikolai Ivanov, Department of Physics and Astronomy, University of Glasgow, Glasgow G12 8QQ, UK E-mail: nikolai@ivanov.uk*

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