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MINIATURE MEMS-BASED MASS SPECTROMETER FOR SPACE WEATHER MONITORING IN LOW EARTH ORBIT

Abstract

Miniaturization of satellites for various applications is a prevailing trend in all aspects of space exploration and utilization. This trend is particularly evident in Near-Earth Space Weather monitoring, where the demand for micro- and nanosatellite platforms is increasing to enable continuous observation of various space weather phenomena. The urgency of this trend has been further underscored by recent incidents involving the unplanned deorbiting of satellites [1], highlighting significant gaps in our understanding of orbital environmental dynamics and their impact on the sustainability of space utilization.

Numerous space weather aspects can be monitored, including magnetic, radiation, plasma and microparticle environment, or electron density, neutral density (i.e., atmospheric pressure), and its composition. Long-term monitoring is particularly valuable, as it reveals variations due to seasonal cycles, natural phenomena, and anthropogenic influences. One of the most critical aspects affecting the long-term utilization of near-Earth space, particularly Low Earth Orbit, is the density and composition of neutral atmospheric molecules, which contribute to aerodynamic drag on high-velocity satellites. While multiple techniques exist for such measurements, mass spectrometry remains the most powerful and reliable method, despite its traditional drawbacks, namely large size and high power consumption. Fortunately, the requirements for mass range and resolution in LEO neutral and ion composition analysis are less stringent than in other applications, opening the way of the development new-class of miniaturized solutions.

In this work, we leverage chip-scale MEMS-based technology to develop the smallest mass spectrometer for in-situ monitoring of neutral density and atomic oxygen concentration in LEO. The instrument, named ANDREW (Atomic and Neutral Density Analysis in Space Weather), builds upon the advancements made during the ESA-funded "MEMS-based Mass Spectrometry" project and is further adapted for space weather monitoring under the ESA "Space Weather Nanosatellites System Enhancement Phase 0/A" initiative. A key advantage of this approach is the exceptional miniaturization of the instrument while maintaining sufficiently high analytical performance. The core instrument size is only 0.04U, with a resolution of 80 and a mass range of 1–60 u, making it the smallest mass spectrometer of its kind while achieving adequate performance for the intended application. The complete instrument is designed to fit within a volume of less than 1U and operate with a power consumption of less than 10 W, making it possible to use it even in the smallest satellite platforms.

[1] Reznychenko, et al., Geophysical Research Letters (2025), 52, e2024GL112620.
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