

Space Environmental Effects Situational Awareness for Human Exploration to Mars. L. Habash Krause¹, R. D. Loper¹, H. Haviland¹, D. Kocevski¹, O. Leon², D. Miles³, V. M. Tennishev¹, J. R. Wood¹, and L. Zhou²
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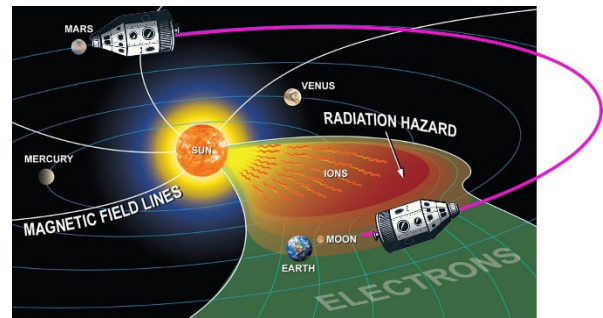
Introduction and Purpose: The Space Environmental Effects Situational Awareness (SEESAW) operational system is conceived as a proof-of-concept payload that integrates remote solar monitoring, in situ radiation, plasma, field, and charging sensors, onboard processing, and AI/ML-assisted decision logic to generate real-time, Earth-independent space-weather alarm states for crewed Moon-to-Mars missions. Discrete space weather hazard states form an operational warning ladder, progressing from nominal conditions to elevated monitoring, to a developing hazard, and finally for protective action when a hazard is imminent. The alarm state is generated by fusing solar, plasma, field, radiation, and charging measurements into a simple crew- and spacecraft-facing warning product.

Payload and System Concept: SEESAW is envisioned to incorporate a graduated approach to Earth-independent space weather operations for human Mars transit. The onboard AI/ML alerting system would be trained pre-flight using historical, simulated, and multi-point heliospheric observations, then validated during early cruise through comparison of SEESAW's in situ sensor measurements with Earth-confirmed space weather analyses. This Earth-confirmed phase would fine-tune sensor performance, event classification accuracy, alert thresholds, and confidence metrics. As communication latency increases and Earth-based observations become less representative of the spacecraft's local environment, SEESAW would transition toward greater onboard authority, enabling real-time, crew-relevant alerts based increasingly on local measurements and onboard data fusion.

Mission Concept: SEESAW can be integrated into a crewed space vehicle or proximately flown on a free-flyer, such as the conceived Physics and Local Analysis of Dynamic Interplanetary Environments (PALADIN) escort satellite. Upon arrival at Mars, PALADIN would enter a halo orbit about the Sun-Mars L1 point to continue space weather forecasting for astronauts on the Martian surface or in orbit about the red planet.

Measurements and function: Solar flare and irradiance precursor measurements, acquired with X-ray and EUV photometers, provide early indication of flare activity that may precede SEP acceleration and evolving radiation risk. Solar radio activity measurements, collected by a solar radio-burst monitor, detect burst signatures associated with particle acceleration, shock formation, and the onset of geoeffective solar eruptive activity. Ionizing radiation measurements quantify the local crew and system hazard through dose-rate trends,

accumulated exposure, and warning-threshold crossings. Vector electric field and charging measurements identify surface charging conditions relevant to electrostatic discharge. Vector magnetic field measurements provide context for SEP anisotropy, magnetic connectivity, plasma disturbances, and the local field geometry through which energetic particles propagate. Solar wind plasma measurements, collected by ion and electron plasma spectrometers, characterize shocks, streams, turbulence, and changing solar-wind conditions that can affect spacecraft systems, communications, and environmental hazard interpretation. Solar magnetograms, produced by an onboard photospheric vector magnetographic imager, add source-region magnetic context by tracking solar active-region magnetic field complexity commonly used in flare forecasting. Alarm states output from the AI/ML models driven by these data are then telemetered to crew in real-time.



The R2O2R Challenge: SEESAW directly addresses the R2O2R challenge by treating AI/ML not as a replacement for mission rules, but as a means of improving the early recognition of complex, multivariate space environment conditions that cannot be robustly reduced to single-parameter thresholds. Its decision architecture is designed to generate confidence-tagged, physically traceable alarm states while preserving the underlying measurements, model inputs, uncertainty estimates, and feature drivers that produced each warning. In this framework, onboard autonomy remains anchored to configuration-controlled operational rules, while AI/ML provides the data-fusion, pattern-recognition, and forecast capability needed for increasingly Earth-independent crewed exploration. SEESAW would therefore serve not only as an operational warning system for Mars transit, but also as a research-to-operations-to-research testbed in which validated flight experience informs future space weather models, mission rules, and crew-safety practices.