IN-ORBIT COINCIDENT LASERSHEET PARTICLE MONITOR

J. Peltoniemi[1], M. Gritsevich[1, 2], J. Moilanen[1], V. Mitev[3], J.-C. Roulet[3] and M. Millinger[4], [1]Finnish Geospatial Research Institute (FGI), Geodeetinrinne 2, 02430 Masala, Finland (jouni.peltoniemi@nls.fi, maria.gritsevich@nls.fi) [2]Institute of Physics and Technology, Ural Federal University, Ekaterinburg, Russia, [3]Centre Suisse d'Électronique et de Microtechnique (CSEM), Switzerland, [4]European Space Agency (ESA), Email: mark.millinger@esa.int.

Introduction: Interplanetary dust particles and meteoroids (including the small dust particles called micrometeoroids) are the most populous objects in the solar system. Improving the knowledge on their spatial density and velocity distribution is important to support and optimize human-initiated activities in space. In this study we exploit the potential of state-of-the-art laser sheets and fast detectors to detect and identify in situ the trajectory of particles in the mm-cm size range. Such instrument would enchance the safety of the near-Earth environment by allowing to monitor the evolution of small space debris in orbit and contribute to the safety of satellites and spacecrafts. It will also provide unique means to observe physical properties and velocity distributions of meteoroidal background at 1 AU.

Methods: We review the state of the art in microparticles detection and imaging, with an emphasis on the applicability to meteoroids and space debris with sizes below 1 cm. A special emphasis is made on the fidelity of light-particle interaction modelling and on the characterization of particle samples, which play a major role on the event simulator performances and results reliability. This allows us to design an end-to-end event simulator for particles detection, coded in Python. The model makes use of Monte Carlo (MC) methods to determine the probability to detect certain microparticles, depending on their nature, the instrument design, and its position with respect to other celestial objects. The choice of MC methods is motivated by the fact that several parameters in the system can vary with a certain randomness (e.g., particle orientation, reflectivity, scattering directions, detector noise and quantum efficiency) and we assume the outcome to be deterministic. Solving the problem with a random sampling to obtain a probability distribution is clearly more versatile and adaptive for evaluating and comparing different system architectures as well. It offers flexibility to modify individual component's characteristics or add complexity to a specific phenomenon.

Results: We implement the 3D visualizer aimed to display in an interactive manner particle orbit as well as location and orbit of the envisaged instrument. Additional information of interest to evaluate the instrument performances are provided in a separate frame of the simulator. For example, it concerns the particle size (actual and estimated), the particle material, the signal-to-noise ratio, and the detection efficiency.

Conclusions: The cumulated expertise of our consortium allows proposing system concepts and evaluating their feasibility for the in-orbit detection and monitoring of interplanetary dust particles, meteoroids, and space debris. A key milestone is the development and validation of an event simulator that serves as a basis for concepts feasibility assessment. In order to comply with real-world operating conditions, considerations based on previous experiences available within our consortium were the key for the conceptual trade-off and flight model development plan.

As a practical development, we propose an advanced scheme for in situ observations of particles by combining the laser sheet concept with an additional fast single-pixel photodetector to precisely monitor the timestamp of each event. This way, submillimeter and millimeter size debris can be detected with good performances in a short range, together with the complete information on their orbit. To disclose the orbital information (i.e. position and velocity), the principle relies on the use of at least two separate laser sheets. Additionally a miniaturized flash imaging LiDAR can be used to provide essential information on the particle. This allows assessing the particle coordinates at two different time steps, in two different planes. The dual laser sheet concept is demonstrated in Fig. 1ab.

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