IN-ORBIT COINCIDENT LASER SHEET PARTICLE MONITOR

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Coincident Laser Sheet Particle Monitor - COLA

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 an instrument would enhance 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 spacecraft. 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 micro particles, 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 this 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.

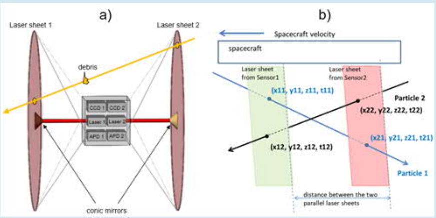

Figure 1. The dual laser sheet concept.

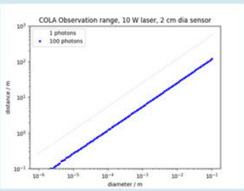

Figure 2. The theoretical range of single laser single sensor concept, for the theoretical minimum of 1 photon and a more productive case of 100 photons.

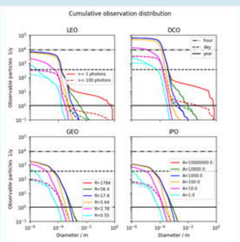

Figure 3. The cumulative distribution of observable particles per year, as a function of particle diameter, 4 orbits, 6 different observation areas (colors), and for single photon (line) and 1000 photon cases (dashes).

It will provide unique means to observe physical properties and velocity distributions of meteoroidal background at 1 AU.

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.

In the MASTER database the debris is divided to 10 subclasses. Part of the objects can be tracked, but below few cm everything is only distributions.

- collision fragments (COLL), result of two satellites or debris colliding
- explosions (EXPL), a satellite explodes alone intentionally or accidentally
- small ejecta (EJEC) by micro particle collision to larger bodies
- multi layer insulation (MLI) fragments
- NaK droplets from Russian ROSAT satellite (NAKD)
- paint flakes (PAFL) peeled off from surfaces
- solid rocket motor flag SRMF
- solid rocket motor dust SRMD
- meteoroidal background (MTBG)
- launch and mission related objects (LMRO)

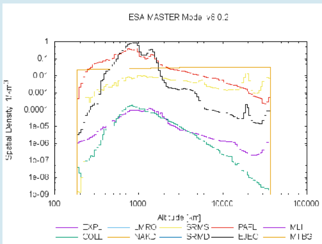

Figure 4. The density of various particles as a function of altitude, at size range of 0.1-1 mm. LEO is dominated by paint flakes (PAFL) and small object collision ejecta (EJEC), other altitudes by meteoroids (MTBG)..

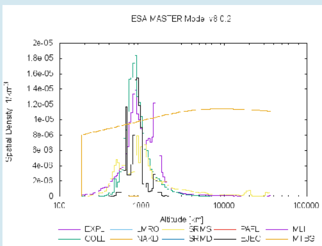

Figure 5. Density of objects in the range 1-10 mm, as a function of altitude. Here, the collision (COLL) and explosion (EXPL) remnants dominate LEO, followed by ejecta (EJEC). In higher and lower orbits, the meteoroids (MTBG) are most important.

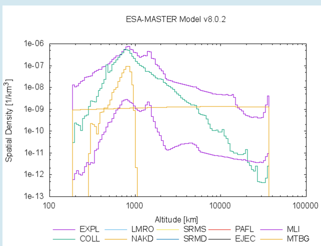

Figure 6. The same for 1-10 cm particles. Explosions (EXPL) and collisions remnants (COLL) are followed by NaK droplets (NAKD) from Russian Rosat, meteoroids (MTBG) and multi layer insulation fragments (MLI).

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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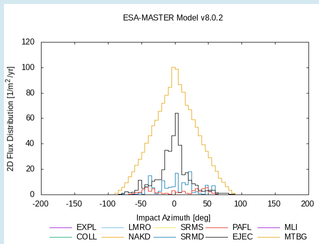

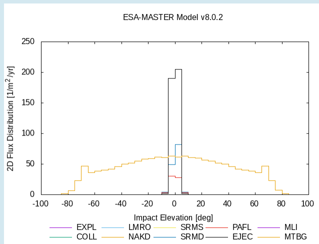

Figure 7. The distribution of impact azimuth and elevation from the MASTER, LEO. Basically, head-on collisions dominate. Meteoroids have widest distribution.

For the natural background (meteoroids) we could divide their compositions into the following categories. Some of these are usually IDPs or small meteoroids (*), other are usually larger bodies (+):

* monomineral fragments (euhedral crystals -> shattered mineral fragments),
* polymineral (=rock) fragments (small particles, not representing full composition of parent body)
* melted glassy material (amorphous or recrystalline material, loose glass chondrules)
* metal particles (small metal particles)
*+ melted material (recrystalline material, loose recrystallined chondrules)
*+ cometary material (icy particles, also larger masses)
*+ carbonaceous material (low albedo, low density, carbonaceous chondrite composition)
+ stony material (stony meteorite compositions)
+ stony-irons (stony-iron meteorite compositions)
+ irons (higher albedo, high density, iron meteorite compositions)

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