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Title: Orbital Debris IC Report

Author(s): Resendiz Lira, Pedro Alberto

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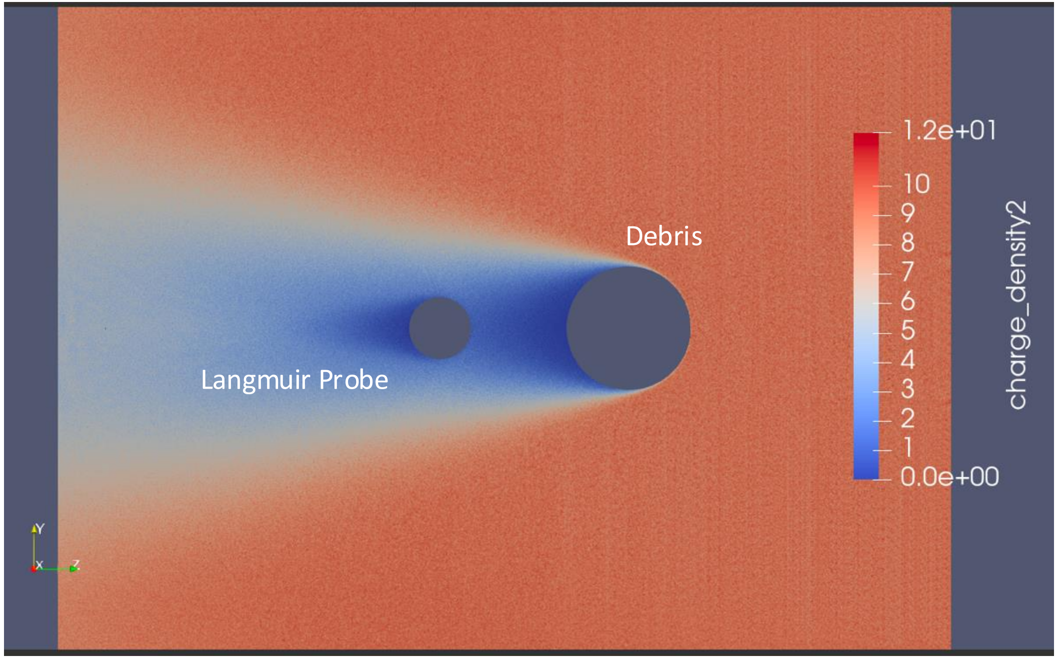
Small Orbital Debris

CPIC Modeling of Plasma Experiment



Cross-section of the ion charge density.

LANL ISR-1 Plasma

FY24 INSTITUTIONAL COMPUTING REPORT
Project: w24_orbital_debris
Title: Plasma Signature of Small Orbital Debris
PI: Pedro Alberto Resendiz Lira (T-5, e-mail: resendiz@lanl.gov, phone: 665-0427)
Co-Investigators: Daniil Svyatsky **(**T-5, dasvyat@lanl.gov**,** 606-2124**)**

LA-UR-25-Pending

We started a simulation campaign in support of our ongoing plasma signatures of small orbital debris project SINTRA program funded by IARPA. This project aims to identify plasma signatures generated by the interaction of small orbital debris (>10cm) with space plasma that can be used for detection, tracking and eventually, develop technologies to remove these small but lethal objects. The small orbital debris problem is increasing exponentially threaten the current and future use of space.

For this purpose, simulations have been performed with a Particle-In-Cell (PIC) code called the Curvilinear PIC (CPIC). The code is formulated in curvilinear geometry and couples the standard PIC algorithm with algorithms for the generation and adaptation of the underlaying computational mesh. It conforms to complex objects like debris with different shapes and it can place more grid points in regions where higher resolution is needed. The code also features a scalable solver based on the multigrid algorithm and it is fully parallelized via domain decomposition and MPI.

We have performed high resolution runs on the IC supercomputers. Our main results are the following:

1. We have performed a parametric study of the plasma response of small debris traveling a supersonic speed. The purpose of this study is to find under which conditions, the small debris generate plasma signature that can be exploited for detection using ground and space assets. Here, we have studied the plasma conditions given by the Earth's ionosphere.
   Our main contribution to this national security problem has been to show, using first-principles modeling, under which plasma conditions the so-called "ion-acoustic precursor solitons" can be generated. These plasma signatures are non-linear waves that can be detected as an ion density enhancement with respect to the background, traveling faster and ahead of the small orbital debris which make it very useful for detection before impact. These results are already published in a peer-review journal.

2. This project has been complemented with an experimental effort in the LANL ISR-1 plasma chamber. Using a controlled environment, lab experiments help to better understand the plasma signatures of the small orbital debris. Simulations have been performed to reproduce laboratory experiments with relatively good success.

List of presentations and publications:
Results from this work have been presented at the following conferences:

1. Resendiz Lira, Pedro Alberto, Gian Luca Delzanno, et al. (2024). "Ion-Acoustic Precursor Soliton Signatures of Orbital Debris in Low Earth Orbit". In: *AIAA Journal of Spacecraft and Rockets*. Accepted on August 13, 2024.

2. "17th Spacecraft Charging and Technology Conference", June 17th – 21th, 2024. Avignon, France. Oral presentation: "Plasma signatures of small orbital debris in LEO"

Funding opportunities:
The simulation campaign performed supports the ongoing SINTRA program funded by IARPA. Simulations results were used in an awarded NASA HSR proposal for small debris remediation. Overall, simulations results are being used to seek funding opportunities at IARPA, NASA as well as LDRD to advance and solve the orbital debris problem recognized by the White House in 2022 as a National Security Problem.