PHOTO-ELECTRON EMISSION FROM MULTIPLE REFLECTIONS

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ABSTRACT

Particle in Cell (PIC) simulations are made to study the impact of multiple UV reflections on the Solar Orbiter spacecraft, and their effect on the electron distribution functions near the Solar Wind Analyzer (SWA) instrument. The simulations are carried out with PTetra, in which the simulation domain is discretised with an unstructured tetrahedral mesh1. The model accounts for surface charging from plasma particle collection, for photo-electron and secondary electron emission. The use of an unstructured adaptive tetrahedral mesh enables simulations with a realistic satellite geometry in which the main satellite components and the particle sensor of interest can be accounted for accurately. Our study focuses on the SWA particle sensor which will be used to measure thermal electron distribution functions in the solar wind. This instrument is to be located at the end of a boom in the wake of the satellite, where it will be affected by the surrounding wake potential, by the spacecraft potential, as well as by secondary electron emission, and photo-electrons emitted by satellite components exposed to UV radiation. In most if not all calculations of satellite photo-electron emission effects made so far, only direct solar UV illumination is taken into account. Yet, given the high albedo of UV on most materials, reflected radiation should enhance illumination of areas directly exposed to solar light, or lead to illumination and emission of photo-electrons from surfaces otherwise in the shade. The result must then be an increase in the amount of photo-electrons emitted, and a modified distribution of these electrons around the satellite. Comparisons are made between electron distribution functions near SWA computed with direct illumination only, and with multiple reflections. Multiple reflections are calculated assuming purely specular, purely diffusive reflections, and a combination of the two. Particle distribution functions at precise locations around the SWA particle sensor are computed with a back-tracking test-kinetic based on Liouville's theorem for the one-particle particle distribution function2. Particle distribution functions are computed for the total electron distribution, as well as for those originating from photo-electron emission.

Key words: LaTeX; ESA; macros.

1. INTRODUCTION

Photoelectron emission from satellite components exposed to solar radiation is an important factor in determining spacecraft floating potentials, and general space environmental conditions. In computer simulations, photoelectron emission is usually calculated from direct solar illumination. Owing to the high UV albedo on most materials at the surface of satellites, however, it is important to account for solar illumination which results from multiple reflections, in addition to that associated with direct solar exposure. In this work we use a model developed by one of us (SG) to calculate solar illumination on a satellite of arbitrary shape, while accounting for multiple reflections, and use the result in a simulation of a spacecraft with space environment in the solar wind. Specifically, simulation results are presented for Solar Orbiter (SO) near perihelion assuming an error in the satellite attitude of order 5°. A particular attention is given to the vicinity of the Solar Wind Analyzer (SWA) located in the wake of the satellite, and designed to measure solar wind thermal electron distribution functions. For the conditions considered, the electron distribution function is found to be strongly affected by photoelectrons emitted direct solar radiation as well as resulting from multiple reflections.

2. NUMERICAL APPROACH

The numerical approach used in the calculation of satellite illumination resulting from multiple reflections is described in detail in another contribution (S. Grey, Tuesday, 10:00-10:20). In summary, in addition to multiple reflections, the code used to calculate multiple reflections, also accounts for the sun angular width and for a combination of specular and diffuse reflections. PTetra, the simulation tool used in this study has been described in detail previously [Mar12]. Its main features are that it is based on the Particle In Cell (PIC) formalism and is therefore fully kinetic, it uses an unstructured tetrahedral mesh. It includes many physical processes of importance in satellite interaction with space environment, such as photoelectron and secondary electron emission, background and first order perturbed magnetic fields, and the possibility of biasing satellite components with respect to one another. PTetra can be run on a single processor or for larger simulations, on several hundreds of processors. In addition to PIC simulations, we also use a backtracking test-particle approach to calculate the particle distribution functions as precise locations in space [Mar11]. This approach makes use of Liouville's theorem for the one-particle distribution, which applicable when plasma is collisionless. It has the advantage of producing distribution functions without having to resort to counting particles in configuration or velocity bins, and it therefore produces distributions with practically no statistical errors.

3. GEOMETRY AND SIMULATION DOMAIN

The satellite geometry and simulation mesh were generated with the open source mesh generator gmsh [GR09]. An illustration of the meshed surface of the satellite is shown in Fig. 1. The simulation mesh had a total volume of approximately $10^4 \mathrm{m}^3$ and more than one million tetrahedra. In the simulations, the number of particles per cells (ions and electrons) was approximately 400. Each simulation took from two to three days to run on one hundred processors.

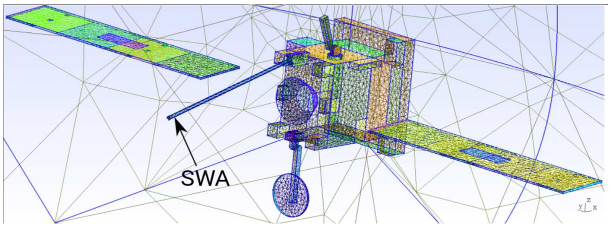

Figure 1. Illustration of the Solar Orbiter meshed surface, as used in the simulations. Parts of the outer boundary mesh are also visible. The latter has been considerably coarsened in order to make the satellite more visible.

4. SIMULATION CONDITIONS AND RESULTS

The conditions assumed in the simulations correspond to SO at its perihelion, that is, at approximately 0.28 astronomical units. At that distance, solar radiation will be ~ 13 times more intense than at Earth orbit. The sun will also appear as a significantly wider disk, resulting in illumination of side faces which would not be exposed to solar UVs if the sun appeared as a point source. The solar wind parameters assumed in the simulations are summarised in Table 1. Simulations were made with direct illumination only, as well as with multiple reflections. In both cases an error of five degrees was assumed in the satellite attitude so that the satellite shield would not be exactly facing the sun. The relative illumination resulting from multiple reflection is illustrated in Fig. 2, where illumination on the back face of the shield is clearly visible. Without multiple reflections, this face would be totally dark, and in turn it would emit no photoelectrons.

Table 1. Solar wind parameters assumed in the simulations

$n_e = n_i$	$1.19 \times 10^8\ \mathrm{m}^{-3}$
$T_e = T_i$	$10eV$
ion species	$100\% H^+$
solar wind speed	$4.1 \times 10^5 m/s$
magnetic flux density	5 nT

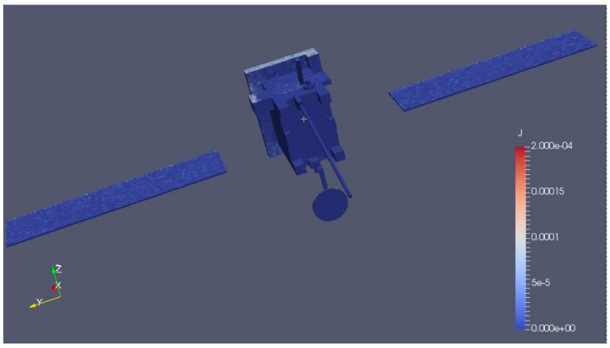

Figure 2. Illustration of solar illumination on the back side of the solar shield resulting from multiple reflection.

5. ELECTRON DISTRIBUTION

Our goal in this study is to better understand the effect of the wake and of photoelectron emission on the electron population which will be measured by the Solar Wind Analyzer (SWA). This is done by comparing electron distribution functions near the end of the boom in the wake region, where SWA is to be located. A comparison between distribution functions computed with and without multiple reflections is shown in Figs. 3 Photoelectron emission computed with multiple reflection is seen to produce fine structures in the electron distribution in which the numerical value of the distribution is significantly larger, if less extended, than that of the background plasma.

6. SUMMARY

Photoelectron emission will be particularly important in determining the environmental conditions of satellites close to the sun, including their floating potential, and the distribution of particles surrounding them. We studied the effect of multiple reflection on the electron distribution function near the Solar Orbiter Solar Wind Analyzer (SWA) and found that the inclusion of multiple reflections leads to fine but intense structures in the distribution functions. These structures in turn are likely to affect measurements made with this instrument, and should be accounted for in order to get the highest scientific value of the resulting in situ measurements.

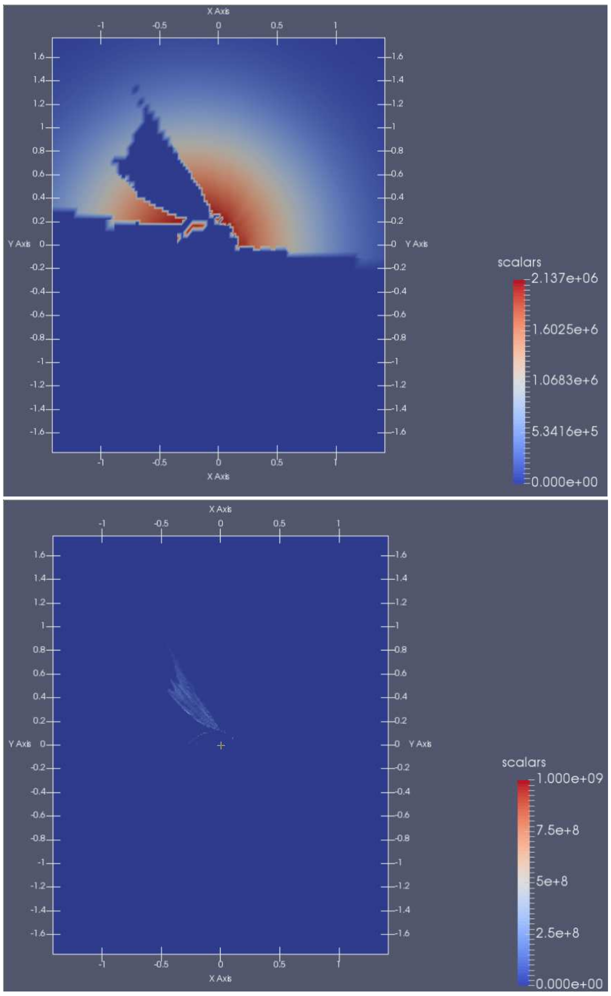

Figure 3. Computed electron distribution functions computed near the tip of the boom without (top) and with (bottom) multiple reflections in the calculation of photo-electron emission.

ACKNOWLEDGMENTS

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REFERENCES

[GR09] Christophe Geuzaine and Jean-Francois Remacle. *Int. J. Numer. Meth. Eng.*, 79(11):1309, 2009.

[Mar11] R. Marchand. *Commun. Comput. Phys.*, 8:471–483, 2011.

[Mar12] R. Marchand. Ptetra, a tool to simulate low orbit satellite-plasma interaction. *IEEE Trans. Plasma Sci. (USA)*, 40(2):217 – 29, 2012.