EPSC Abstracts
Vol. 5, EPSC2010-808, 2010
European Planetary Science Congress 2010

Application of PLANETOCOSMICS to Simulate the Radiation Environment at the Galilean Moons

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Abstract

The PLANETOCOSMICS radiation simulation code has been extended to simulate the radiation environment in the vicinity of the Galilean moons. The software model treats the detailed nuclear and electromagnetic interactions of particles with the surface of the moon (including the secondary particle production) and also tracks charged particles in the Jovian and moon internal magnetic fields. Treatment of these complex processes will allow more accurate prediction of the radiation environment for future missions to these moons.

1. Introduction

The Jupiter radiation environment presents spacecraft engineers with unique challenges when designing equipment for the Jovian system due to the intensity and high energy of the trapped electron and proton populations which induces effects much more severe than encountered in the near-Earth environment. The effects which are of particular concern for a Jupiter mission are total ionising dose, displacement damage and internal charging.

The Europa Jupiter System Mission (EJSM or "Laplace") is a joint NASA/ESA mission which will focus on the Jovian moons, in particular Ganymede and Europa. Ganymede has a radius in excess of that of the planet Mercury, and also has an intrinsic magnetic field which exceeds the local Jovian field. As a result there is evidence of closed field-lines which influence the accessibility of equatorial regions of the moon's surface by trapped particles from the Jovian magnetosphere [1]. In contrast, magnetometer measurements from the Galileo mission did not reveal any intrinsic field in the vicinity of Europa, but did indicate a weak induced field hypothesized as the result of a sub-surface ocean [2]. However, the relative motion of the trapped electrons around Jupiter with respect to Europa results in depletion of the electron population through collisions in the trailing surface of the moon, and therefore much lower particle fluxes at the leading surface. Under the ESA JORE^{2}M^2 Project, a consortium comprising QinetiQ, ONERA and DH Consultancy is developing radiation/plasma environment and effects models in order to support the analysis of these effects for future missions to the Jovian system. As well as introducing a new model for the trapped proton and electron belts (the Jovian Specification Environment or JOSE model), enhancements have been made to the Geant4-based PLANETOCOSMICS code to allow 3D tracking of particles within the local environment of the Galilean moons. This paper will examine the basis of the PLANETOCOSMICS model and the first results from the simulation of Europa and Ganymede.

2. PLANETOCOSMICS

Desorgher initially developed the Geant4-based MAGNETOCOSMICS and ATMOSCOSMICS codes analyse particle propagation in a detailed magnetic field model of the Earth, and propagation within the Earth's atmosphere of cosmic rays and solar energetic particles. This was later extended by Desorgher to PLANETOCOSMICS, which treats the propagation of particles in the planetary magnetic fields, atmospheres and surfaces of the Earth, Mars, and Mercury [3][4]. Being based on Geant4 [5], the software performs a full 3D Monte Carlo simulation of particle transport taking into consideration nuclear and electromagnetic interactions for almost any particle from TeV energies down to ~100eV (and to thermal energies for neutrons). Full simulation of particle cascades can be performed, *i.e.* tracking all secondary, tertiary, *etc* particles. The tracking and particle tallying functions in the code permit a range of analyses to be performed within a simulation, and the main applications of the code are:

- Calculation of flux of particles as a function of depth resulting from the interaction of cosmic rays.
- Calculation of energy deposited by showers.
- Determination of the magnetic shielding of a planet's magnetic field.

3. PLANETOCOSMICS-J

The updated PLANETOCOSMICS software allows simulation of all four of the Galilean moons, taking into consideration (see Figure 1):

- The Jovian internal magnetic field determined using a range of possible models (selectable by the user) such as the O6 model of Connerney, the O4 model of Acuna and Ness, the VIP4 of Connerney *et al*, *etc.*
- The Jovian external magnetic fields – user-selectable models based on the work of Khurana (1997 & 2003).
- The intrinsic field of Ganymede (Kivelson, Khurana and Volwerk).
- Induced fields, based on the model of Zimmer, Khurana and Kivelson. The field can be tuned by the user to simulate different conductivity and ocean-depth/thickness conditions.

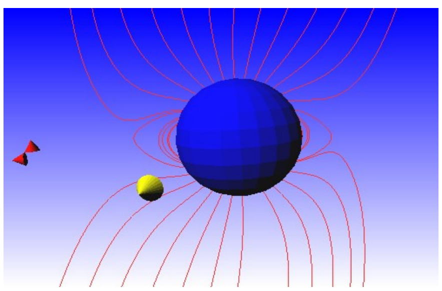

Figure 1: Figure from PLANETOCOSMICS-J showing field lines for Ganymede, including Jupiter internal and external field, and Kivelson *et al* intrinsic moon field. Arrows point to Sun (yellow) and Jupiter (red-left) and north spin axis (red-up).

In addition to standard $v \times B$ forces, processes are included to simulate particle mirroring within Jupiter's magnetosphere as well as particle azimuthal drift without having to include the Jovian magntosphere within the geometry of the moon (making for a more efficient simulation) – see Figure 2. Particle losses for primaries or secondary particles which fall within the loss cone are also treated. The moon surface composition can also be user-defined to examine effects on sensitivity on the local radiation environment.

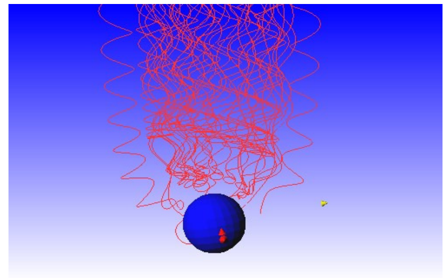

Figure 2: Simulation of one 50MeV trapped electron in vicinity of Ganymede, including magnetic mirroring in Ganymede intrinsic field and mirroring and drift in Jovian field. Particle starts near equator to the right, propagating north.

6. Summary

At the time of writing, PLANETOCOSMICS-J is just completing testing, and the final paper will include the first results of simulations of the Ganymede and Europa radiation environment. Overall this Geant4-based software is expected to provide Laplace mission engineers with a valuable tool for the comprehensive assessment of the radiation environment in the vicinity of the Galilean moons.

Acknowledgements

This work was supported by ESA under Contract number 21290/08/NL/JK.

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