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Modelling the martian cosmic radiation environment

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Abstract

The martian surface is no longer protected by a global magnetic field or substantial atmosphere and so is essentially unshielded to the flux of cosmic rays. This creates an ionising radiation field on the surface and subsurface that is hazardous to life and the operation of spacecraft instruments. Here we report the modelling approach used to characterise this complex and time-variable radiation environment and discuss the wider applications of the results generated.

Introduction

Beyond the protective environment of Earth's atmosphere and magnetosphere, interplanetary space is pervaded with high-energy ionising radiation particles known as cosmic rays. Solar energetic protons (SEP) are accelerated by flares and coronal mass ejections, and galactic cosmic rays (GCR) are accelerated to much higher energies beyond the solar system, by supernova, but are present at a lower flux than SEP. This flux of ionising radiation is hazardous to the survival of life as well as the continued functioning of spacecraft components [1].

Unlike Earth, Mars no longer possesses a global dipolar magnetic field or substantial atmosphere, and the surface is essentially unshielded from this harmful radiation. Understanding the cosmic radiation environment on the martian surface and near-subsurface is of great importance for human space exploration, astrobiology, and the operation of robotic probes. Particle cascades triggered by the energetic primaries can penetrate metres underground, and so the martian radiation environment is very complex, with the field of different particle types and energies changing as a function of depth underground, as well as being time variable due to the modulation of both SEP and GCR flux by the solar activity cycle. This radiation environment must therefore be studied by computational modelling approaches, as even the radiation assessment detector (RAD) instrument aboard NASA's Curiosity rover gives information on only its local environment. The surface flux of albedo neutrons, for example, is of particular concern for human missions operating over ice-containing regolith.

Here we report the modelling approach taken to characterise the cosmic ray ionising radiation environment on both the martian surface and in the top few metres of subsurface, as well as applications that these results are relevant to.

Modelling approach

The Geant4 particle physics toolkit was used to create a modular model of the martian atmosphere and surface and simulate the propagation of high energy particles through the shielding material. The particle physics lists are similar to those employed by the PLANETOCOSMICS application.

The model is composed of an atmospheric column atop a block of surface material, with an angular distribution of primary particles generated above. The atmosphere is built-up of stacked layers so that density, temperature and gaseous composition profiles can be accurately reproduced. The planetary surface is by default an homogenous slab with user-defined composition and density, which can be specified to represent dry martian regolith, pure ice (such as polar deposits), or to model a heterogenous composition of regolith bearing subsurface ice. Figure 1 displays a visualisation of the model set-up, with the secondary cascade produced by an energetic primary particle shown.

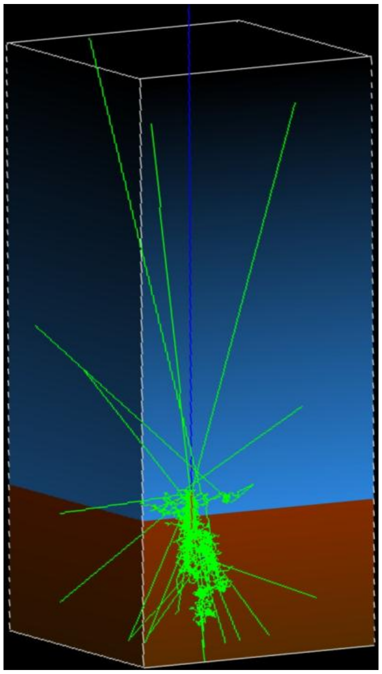

Figure 1. Visualisation of the model output. A high energy GCR proton (shown in blue, originating at the top) passes through the thin martian atmosphere to strike the surface, triggering an extensive cascade of secondary particles (shown in green and red) that penetrates metres underground, and also produces albedo particles that propagate back upwards to increase the surface radiation environment.

Certain volumes are specified as sensitive detectors to record information on particle fluxes, energy spectra, and ionisation distributions, all as a function of depth.

We present results of the dose-depth profile in the Martian subsurface for various scenarios: variations of surface composition (dry regolith, ice, layered permafrost), solar minimum and maximum conditions, locations of different elevation (Olympus Mons, Hellas basin, datum altitude), and increasing atmospheric thickness over geological history. We also model the changing composition of the subsurface radiation field with depth compared between Martian locations with different shielding material, determine the relative dose contributions from primaries of different energies, and discuss particle deflection by the crustal magnetic fields. [2,3]

Applications of the results

Astrobiology - The unshielded flux of cosmic rays is one of the major hazards to biology on the martian surface. This is a principle concern for both human space exploration, and the likely radiation environment encountered by astronauts during a Mars mission and devising the best strategies for mitigating the risks, as well as the survival of any microbial life that may exist on Mars [2,3].

Instrumentation - The ionising radiation field is also deleterious to the functionality of many types of sensitive equipment launched aboard Mars probes. In particular, instruments designed to search for organic molecules with an immunoassay-type approach using antibodies may be vulnerable. Modelling of the radiation environment likely to be encountered, coupled with experimental irradiations, is crucial for space-qualifying such hardware [4].

Geology - Optically-Stimulated Luminescence (OSL) is a technique able to date the period since sediments were last exposed to sunlight (i.e. their time of deposition), and so could provide important insight into aeolian processes on Mars. It relies on knowledge of the rate of accumulation of radiation dose in suitable minerals such as feldspar, and thus for martian applications requires modelling of cosmic rays [5].

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