Particle Radiation Environments and Their Effects at Planetary Surfaces: Lessons Learned at the Moon by LRO/CRaTER and Extension to Other Planetary Objects
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Introduction: Energetic charged particles fill interplanetary space and bathe the environments of planetary objects with a ceaseless source of sometimes powerful but always ever-present ionizing radiation. In turn, these charged particles interact with planetary bodies in various ways, depending upon the properties of the body as well as upon the nature of the charged particles themselves. The Cosmic Ray Telescope for the Effects of Radiation (CRaTER) on the Lunar Reconnaisance Orbiter (LRO), launched in 2009, continues to provide new insights into the ways by which the lunar surface is influenced by these energetic particles. In this presentation, we briefly review some of these mechanisms and how they operate at the Moon, and then explore the importance of these same mechanisms at other planetary objects within our solar system based on the parameters that govern their physical behavior.

Galactic Cosmic Ray Source: Energetic charged particles have multiple sources near planetary bodies. Galactic cosmic rays (GCR) provide an incessant source of extremely energetic particles, emanating from outside our solar system in association with supernova explosions occurring throughout our galaxy. This source of energetic charged particles waxes and wanes slowly (over a solar cycle) and comparatively weakly (well less than a factor of 10) both in space and time throughout the solar system. GCR intensities are largest near the edge of the solar system; the interplanetary magnetic fields and solar wind pose obstacles for GCR entry to the inner solar system which thus creates a radial gradient. Near a planetary body, the intensity of the galactic cosmic rays are further moderated by both any intrinsic planetary magnetic fields and the presence of an atmosphere.

Solar Energetic Particle Source: Energetic charged particles are also produced episodically in association with explosive events on the Sun. Particles are accelerated through the strong electric fields in association with the shock waves produced near the Sun and also further from the Sun as coronal mass ejections (CMEs) are launched from magnetically unstable regions. These impulsive bursts of energetic charged particles stream outward from the Sun, producing many order of magnitude increases in high energy particle fluxes, lasting hours to days. These particles race away from the Sun, with the chance of encountering and interacting with planetary objects in their path. Intensities are strongest closest to the Sun, and fall off in intensity with distance from the Sun as the particle trajectors diverge to fill the increasing volume of interplanetary space.

Magnetospheric Trapped Particle Source: Energetic charged particles can also become efficiently trapped by planetary magnetic fields. In the case of Earth, charged particles can become trapped in Earth's strong dipole field. The component of trapped particles that also have extremely high energies is what we term the Van Allen radiation belts. Other planets with strong intrinsic magnetic fields (e.g., Jupiter) also have powerful radiation belts. These trapped particles vary dynamically, and pose a final source of ionizing radiation for the planetary bodies they surround, both on the planet itself as well as on any moons embedded within it.

The LRO/CRaTER Experiment: The Cosmic Ray Telescope for the Effects of Radiation (CRaTER) [1] has been immersed in the radiation environment of the Moon since its launch on NASA's Lunar Reconnaissance Orbiter (LRO) [2] in June 2009. CRaTER measures the linear energy transfer (LET) of extremely energetic particles traversing the instrument, a quantity that describes the rate at which particles lose kinetic energy as they pass through matter. A significant portion of the kinetic energy converts into deleterious ionizing radiation through interactions with matter, thus posing a radiation risk for human and robotic space explorers subjected to deep space energetic particles. CRaTER employs strategically placed solid-state detectors and tissue equivalent plastic (TEP), a synthetic analog for human tissue, to quantify radiation effects pertinent to astronaut safety.

Though designed to measure principally galactic cosmic rays (GCR) and solar energetic protons coming from zenith and deep space, CRaTER observations can and have been used also to discover an energetic proton albedo coming from the lunar surface [3,4,5]. Ultimately, CRaTER observations have been used to directly measure the collective radiation environment, including all sources. From these primary data, the effects of the particles on the Moon have been explored quantitatively. These include various physical mechanisms, such as the chemical weathering [6,7] of the lunar volatiles in the regolith, as well as the effects of deep dielectric breakdown [8], just to name two. Schwadron et al. [9] provide a summary of these various mechanisms and what we have learned from LRO/CRaTER at Earth's moon.

Extension to Other Planetary Bodies: Based on a deeper understanding of these effects at the Moon, and the parameters that govern the physical interactions, in this presentation we provide a census of other planetary bodies where these same energetic charged particle mechnisms should be operative. We consider both the inner planets (such as Mercury), small bodies (including Mars' moons), larger moons of the Jovian planets, as well as dwarf planets of the outer solar system. Finally, we explore their relative importance of these effect to the best degree possible.

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