PARTICLE RADIATION ENVIRONMENTS AND THEIR EFFECTS AT PLANETARY SURFACES OF AIRLESS BODIES: REMOTE SENSING LESSONS LEARNED AT THE MOON BY LRO/CRaTER AND EXTENSION TO OTHER PLANETARY OBJECTS. H. E. Spence¹, N. A. Schwadron², J. K. Wilson¹, A. P. Jordan³, R. Winslow³, C. Joyce³, M. D. Looper², A. W. Case³,⁴, T. J. Stubbs⁵, C. Zeitlin⁶, J. B. Blake⁶, J. Kasper³,⁶,⁸, J.E. Mazur³, S. S. Smith⁷, and L. W. Townsend⁷, ¹Space Science Center, University of New Hampshire, Durham, NH (harlan.spence@unh.edu), ²The Aerospace Corporation, Los Angeles, CA, ³High Energy Astrophysics Division, Harvard CFA, Cambridge, MA, ⁴Goddard Space Flight Center, Greenbelt, MD, ⁵Southwest Research Institute, Boulder, CO, ⁶AOSS, College of Engineering, University of Michigan, Ann Arbor, MI, ⁷Dept. of Nuclear Engineering, Univ. of Tennessee, Knoxville, TN, ⁸NASA Lunar Science Institute.

Energetic Particle - Planetary Surface Interactions: We focus on the interaction of energetic particles with the surfaces of planets that are surrounded by extremely tenuous atmospheres and weak intrinsic planetary-scale magnetic fields. For this study, we define energetic charged particles as those with sufficient energy to penetrate significantly (at least 100 milimeters and up to several meters) into the planet’s regolith. For practical purposes, the energetic particles of interest herein are those with energies greater than ~1 MeV. At sufficiently high energies (>500 MeV protons, for instance), this population not only penetrates substantially into a planet’s regolith in an energy-dependent manner, but they also lose energy through nuclear interactions, in turn producing secondary nuclear by-products, including those that can be sensed remotely by orbiting spacecraft.

Energetic Particle Sources – GCR and SEP: Such highly energetic charged particles have two primary sources near planetary bodies – galactic cosmic rays (GCR) and solar energetic particles (SEP). GCR provide an incessant source of extremely energetic particles, emanating from outside our solar system and produced in association with processes occurring at supernova explosions throughout our galaxy. This source of energetic charged particles waxes and wanes slowly (over the ~11 year solar cycle) and comparatively weakly (well less than a factor of 10) both in space and time throughout the solar system.

Energetic charged particles are also produced episodically in association with explosive events on the Sun. These impulsive bursts of energetic charged particles, called solar energetic particles (SEP), stream outward from the Sun, producing many order of magnitude increases in high energy particle fluxes, lasting hours to days. SEPs race away from the Sun through interplanetary space, with the chance of encountering and interacting with planetary objects in their path.

Science Goal and Approach: Our focused goal is to provide a comparison of how GCR and SEP intensities vary throughout the solar system, and how they interact directly with the surfaces of similar atmosphereless planetary objects. In this study, we use Earth’s Moon as the most well-studied object, enabled by the extensive radiation measurements obtained by NASA’s Lunar Reconnaissance Orbiter (LRO).

Lessons Learned from LRO/CRaTER: 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 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.

Though designed to measure principally GCR and SEPs coming from zenith and deep space, CRaTER observations can and have been used also to remotely sense the energetic particle albedo coming from the lunar surface [3,4,5]. CRaTER observations have been used to quantify the collective radiation environment, including all sources, as well as the effects of the particles on the Moon’s surface. These include various physical mechanisms, such as chemical weathering [6,7] of regolith lunar volatiles, as well as the effects of deep dielectric breakdown [8], just to name two.

Summary: We summarize the physics of GCR and SEP interactions with the Moon and how these processes depend also on the physical properties of the lunar surface (e.g., bulk composition, meteoritic gardening rates, temperature, etc.). Based on this core knowledge, we then quantify how these same processes operate at similar airless objects throughout the solar system, including at Mercury, in the Mars system, at Ceres as a core asteroid belt representative, and at the Pluto system.