Solar Wind Proton Interactions with Lunar Magnetic Anomalies and Regolith

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Abstract
The lunar space environment is shaped by the interaction between the Moon and the solar wind. In the present thesis, we investigate two aspects of this interaction, namely the interaction between solar wind protons and lunar crustal magnetic anomalies, and the interaction between solar wind protons and lunar regolith. We use particle sensors that were carried onboard the Chandrayaan-1 lunar orbiter to analyze solar wind protons that reflect from the Moon, including protons that capture an electron from the lunar regolith and reflect as energetic neutral atoms of hydrogen. We also employ computer simulations and use a hybrid plasma solver to expand on the results from the satellite measurements.

The observations from Chandrayaan-1 reveal that the reflection of solar wind protons from magnetic anomalies is a common phenomenon on the Moon, occurring even at relatively small anomalies that have a lateral extent of less than 100 km. At the largest magnetic anomaly cluster (with a diameter of 1000 km), an average of ~10% of the incoming solar wind protons are reflected to space. Our computer simulations show that these reflected proton streams significantly modify the global lunar plasma environment. The reflected protons can enter the lunar wake and impact the lunar nightside surface. They can also reach far upstream of the Moon and disturb the solar wind flow. In the local environment at a 200 km-scale magnetic anomaly, our simulations show a heated and deflected plasma flow and the formation of regions with reduced or increased proton precipitation.

We also observe solar wind protons reflected from the lunar regolith. These proton fluxes are generally lower than those from the magnetic anomalies. We find that the proton reflection efficiency from the regolith varies between ~0.01% and ~1%, in correlation with changes in the solar wind speed. We link this to a velocity dependent charge-exchange process occurring when the particles leave the lunar regolith. Further, we investigate how the properties of the reflected neutral hydrogen atoms depend on the solar wind temperature. We develop a model to describe this dependence, and use this model to study the plasma precipitation on the Moon when it is in the terrestrial magnetosheath. We then use the results from these and other studies, to model solar wind reflection from the surface of the planet Mercury.

KEYWORDS: The Moon, Solar wind, Magnetic anomalies, Regolith, Space physics, Plasma physics, Particle-surface interactions, Mini-magnetospheres, Energetic neutral atoms