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Interaction between solar wind and non-magnetized solar system objects

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Interaction between the solar wind and a solar system object varies largely according to the object 's properties, such as the existence of a global intrinsic magnetic field and/or thick atmosphere. The Moon's case is characterized by the absence of both of them. Until recently, understanding of the lunar plasma environment has suffered from a lack of in situ measurements of low energy ions. MAP-PACE (MAgnetic field and Plasma experiment - Plasma energy Angle and Composition Experiment) on Kaguya (SELENE) completed its 1.5-year observation of low energy charged particles around the Moon. After the successful launch on 14 September 2007 by H2A launch vehicle, Kaguya was inserted into a circular lunar polar orbit of 100km altitude and continued observation till it impacted the Moon on 10 June 2009. During the last 5 months, the orbit was lowered to 50km-altitude between January 2009 and April 2009, and some orbits had further lower perilune altitude of 10km after April 2009. MAP-PACE consisted of 4 sensors: ESA (Electron Spectrum Analyzer)-S1, ESA-S2, IMA (Ion Mass Analyzer), and IEA (Ion Energy Analyzer). ESA-S1 and S2 measured the distribution function of low energy electrons in the energy range 6eV - 9keV and 9eV - 16keV, respectively. IMA and IEA measured the distribution function of low energy ions in the energy range 7eV/q - 28keV/q and 7eV/q - 29keV/q. These four sensors could cover the full 3-dimensional phase space of low energy electrons and ions. One of the ion sensors IMA was an energy mass spectrometer. IMA measured mass specific ion energy spectra that had never been obtained at 100km altitude polar orbit around the Moon.
The newly observed data showed characteristic ion populations around the Moon. Besides the solar wind, MAP-PACE-IMA found four clearly distinguishable ion populations on the dayside of the Moon. 1) Solar wind protons backscattered at the lunar surface: The flux of the solar wind ions scattered at the lunar surface was less than about 1% of the incident solar wind ions. Though solar wind consists of alpha particles as a second major component, the scattered ions consisted of almost no alpha particles. 2) Solar wind protons reflected by magnetic anomalies on the lunar surface: When Kaguya flew over strong magnetic anomalies, solar wind ions reflected by magnetic anomalies were observed. Comparing with the ions scattered at the lunar surface, these reflected ions had much higher flux. 3) Reflected / backscattered protons picked-up by the solar wind: The reflected/scattered ions were picked up by the solar wind convection electric field and they were accelerated viewed from the Moon reference frame. Since these ions had initial velocity that was as fast as the incident solar wind ions, the maximum possible acceleration was three times the solar wind velocity. 4) Ions originating from the lunar surface / lunar exosphere: The ions generated on the lunar surface / lunar exosphere were accelerated by the solar wind convection electric field and detected by MAP-PACE-IMA. The mass profiles of these ions show heavy ions including C+, O+, Na+, K+ and Ar+. These heavy ions were also observed when the Moon was in the Earth's magnetotail where no solar wind ions impinged on the lunar surface.
In the lunar wake region, MAP-PACE also found new phenomena in terms of the ion entry into the lunar wake. 1) Type-1 entry: Solar wind protons enter into the lunar wake at 100 km altitude in the direction perpendicular to the magnetic field, as they gain kinetic energy in one hemisphere while lose in the other hemisphere. 2) Type 2 entry: Solar wind protons can enter into the deepest lunar wake (anti-subsolar region at 100 km altitude), and that the entry made strong asymmetry

of the near-Moon wake environment. The newly obtained knowledge about the lunar plasma environment by Kaguya must be useful in understanding the plasma environment around non-magnetized solar system objects.

Keywords: moon, plasma, magnetic anomaly, alkali atmosphere, magnetosphere, solar wind