Geophysical Research Abstracts
Vol. 19, EGU2017-10243, 2017
EGU General Assembly 2017

The Moon observed in Energetic Neutral Atoms: Review of the Scientific Findings from SARA/CENA on board Chandrayaan-1

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The Sub-keV Atom Reflecting Analyzer (SARA) instrument on board Chandrayaan-1 was exceptionally successful. The instrument not only achieved all its set science goals but also revealed several hitherto unknown and unexpected properties of the solar wind interaction with the lunar surface.

SARA's scientific findings can be divided into two groups based on the nature of the particles detected: The first group contains findings gained from ion measurements (from SWIM, SARA's ion sensor) whereas the second group contains findings gained from energetic neutral atom (ENA) measurements (from CENA, SARA's ENA sensor). Here, we present a review of all scientific findings based on ENA measurements.

Since the Moon is constantly bombarded by solar wind ions. Until recently, it was tacitly assumed that the ions that impinge onto the lunar surface are almost completely absorbed, with less than 1% reflection, (e.g. Crider and Vondrak, Adv. Space Res., 2002; Feldman et al., JGR, 2000). However, recent observations conducted showed that on average 16% of the impinging solar wind ions are reflected as ENAs (e.g. McComas et al., GRL, 2009; Wieser et al., PSS, 2009; Vorburger et al., JGR, 2013). The energy spectrum of the reflected ENAs is broader than the spectrum of the incident solar wind protons (Futaana et al., JGR, 2012; Harada et al., JGR, 2014), and the characteristic energy is $< 50\%$ of the incident solar wind characteristic energy. This hints at multiple scattering processes taking place on the lunar surface. Determination of the ENA angular backscatter function showed that, contrary to expectations, as the solar zenith angle (SZA) increases, particles scatter more toward the sunward direction than in the anti-sunward direction (Vorburger et al., GRL, 2011; Lue et al., JGR, 2016).

The ENA reflection ratio is rather featureless over the lunar surface (Vorburger et al., JGR., 2013), showing only strong variations at local crustal magnetic fields due to the interaction of the plasma with so-called mini-magnetospheres (e.g., Wieser et al., GRL, 2010; Vorburger et al., JGR, 2012; Vorburger et al., JGR, 2013). CENA measurements were also used to derive the electric potential above a lunar magnetic anomaly (Futaana et al., GRL, 2012, Järvinen et al. GRL, 2014). Electrical potentials are of scientific interest because they can influence the local plasma and dust environment near the magnetic anomaly.

CENA also presented the first-ever measurements of sputtered lunar oxygen (Vorburger et al., JGR., 2012) as well as the first-ever observations of backscattered solar wind helium (Vorburger et al., JGR., 2012). With the backscattered proton signal being unexpectedly large, these signals are small in comparison, but persistent nevertheless.

Finally, recent CENA data analyses showed that a significant fraction of the solar wind plasma is able to reach far into the lunar nightside surface: CENA measured a 30 deg broad ENA ring parallel to the terminator, with a total flux equal to $\sim$1.5% of the total dayside flux (Vorburger et al., GR., 2016). These measurements shed light onto the expansion of plasma into voids as they occur in planetary wakes.