Geophysical Research Abstracts,
Vol. 11, EGU2009-6748-1, 2009
EGU General Assembly 2009

Multi-angular regolith effects on planetary soft X-ray fluorescence spectroscopy

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Fluorescent X-rays from the surfaces of airless planetary bodies in the inner solar system have been measured by instruments on several spacecraft. MESSENGER carries an X-ray spectrometer (XRS) on-board and has already attempted to obtain fluorescent X-rays from the Hermean surface. BepiColombo will later on carry an X-ray telescope (MIXS-T) along with a more conventional collimating detector (MIXS-C) to the Hermean orbit, supported by a next-generation X-ray solar monitor (SIXS). These instruments will provide unprecedented knowledge about the geochemical properties of the Hermean regolith.

X-ray emission from planetary surfaces follows photoionisation by incident solar X-rays and charged particles and reveals information about the elemental composition of the surface. Analyses of X-ray spectra, obtained by orbiting spacecraft, use both the relative intensities of elemental emission lines (e.g., Ca/Si, Fe/Si) and absolute abundancies of the elements to determine the geochemistry of the target body. Historically, the analysis of X-ray spectra has largely assumed that surfaces can be considered as homogeneous plane-parallel media. It has been shown, however, that fluorescent line intensities are affected by the physical properties of the target surface (e.g., surface roughness of the regolith) as a function of the viewing and illumination geometry of observations in a way that cannot be explained by the traditional models.

We describe experimental investigations where we simulated the effects of regolith properties on the fluorescent lines measured by an orbiting instrument, with a large variety of illumination and viewing angles. The planetary regolith analogue used in these experiments was a terrestrial, olivine rich basalt, which has been used by previous authors as an analogue to the lunar maria. The basalt samples were ground to powder and sieved to discriminate particles in the ranges, <75 micrometers, 75-250 micrometers, and 250-500 micrometers. These separate powders were then pressed into solid pellets. The separation of particles with different sizes allows some determination of the effects due to changes in, e.g., surface roughness. The pellets were imaged with a CT scanner to obtain the physical parameters of the samples. All measurements were made at near-vacuum pressures to prevent absorption of fluorescent X-rays in air. The relative fluorescent line ratios of several major rock-forming elements (e.g., Si, K, Ca, Ti, Fe) were measured.

In addition to experimental studies we have simulated the X-ray emission from a regolith using a numerical Monte-Carlo ray-tracing model. This model simulates a regolith of spherical particles, with defined physical properties (particle size distribution, packing density, etc.) and with a realistic macro-scale surface roughness characteristics generated by constraining the surface with a fractional-Brownian-motion surface model.

A comparison is made between the modelling and experimental results to validate the modelling. A good agreement between the results is found. We find that both the measured and the simulated spectra become increasingly hard as the phase angle increases (i.e., X-ray lines at higher energies are enhanced relative to those at lower energies). Some hardening of spectra is predicted by the fundamental parameters equation (FPE) of X-ray fluorescence, which assumes a smooth, flat, and homogeneous surface, but we observe further spectral hardening that is in excess to that predicted by the FPE and that this excess hardening is also a function of the surface roughness. We propose to use modelling similar to ours for the data analysis of soft X-ray fluorescence spectra to take the multi-angular effects related to the physical properties of the regolith into account.