ESA'S SMART-1 MISSION AT THE MOON: FIRST RESULTS, STATUS AND NEXT STEPS

B.H. Foing[1], G.D. Racca[2], M. Grande, J. Huovelin, J.-L. Josset, H.U. Keller, A. Nathues, A. Malkki, D. Heather, D. Koschny, M. Almeida, D. Frew, R. Lumb, J.Volp, J. Zender (SMART-1 Science & Technology Working Team), [1]Chief Scientist, ESA, ESTEC/SCI-S, Bernard.Foing@esa.int, [2] SMART-1 Project ESTEC/SCI-PD, postbus 299, 2200 AG Noordwijk, NL, Europe

Introduction: SMART-1 is the first in the programme of ESA's Small Missions for Advanced Research and Technology [1,2,3]. Its first objective has been achieved to demonstrate Solar Electric Primary Propulsion (SEP) for future Cornerstones (such as Bepi-Colombo) and to test new technologies for spacecraft and instruments. The spacecraft has been launched on 27 Sept. 2003, as an Ariane-5 auxiliary passenger and injected in GTO Geostationary Tranfer Orbit. Thanks to the successful electric propulsion navigation, the spacecraft has left the inner radiation belts in early 2004, and reached lunar capture on 17 November 2004. We shall report at LPSC2005 on the first commissioning and results from the spacecraft and the instruments. The SMART-1 mission has spiraled down to reach a lunar orbit 300-3000 km for a nominal science period of six months, with possible extension. The spacecraft is carrying out a complete programme of scientific observations. Some first data and results obtained during the cruise, and during the lunar approach and commissioning will be presented at LPSC.

Overview of SMART-1 payload: SMART-1 science payload, with a total mass of some 19 kg, features many innovative instruments and advanced technologies [1]. A miniaturised high-resolution camera (AMIE) for lunar surface imaging, a near-infrared point-spectrometer (SIR) for lunar mineralogy investigation, and a very compact X-ray spectrometer (D-CIXS) with a new type of detector and micro-collimator which will provide fluorescence spectroscopy and imagery of the Moon's surface elemental composition. The payload also includes an experiment (KaTE) aimed at demonstrating deep-space telemetry and telecommand communications in the X and Ka-bands, a radio-science experiment (RSIS), a deep space optical link (Laser-Link Experiment), using the ESA Optical Ground station in Tenerife, and the validation of a system of autonomous navigation (OBAN) based on image processing.

Electric propulsion and plasma instruments: Being the primary objective of the mission the demonstration of the solar electric propulsion, the monitoring of the spacecraft plasma environment and the contamination produced by the Stationary Plasma thruster has been a key-task, carried out by two experiments: SPEDE (Spacecraft Potential, Electron and Dust Experiment, PI. A. Malkki) and EPDP (Electric propulsion diagnostic Package, PI G. Noci).

SPEDE and EPDP contribute also to the characterisation of the near-Earth and interplanetary plasma environment and to study the solar wind.

SMART-1 remote sensing science: A package of three spectroscopy and imaging instruments has been selected to run technology demonstration of miniaturised compact instrument for planetary remote sensing and for carrying out valuable science at the Moon.

D-CIXS (Demonstration of a Compact Imaging X-ray Spectrometer, PI M. Grande) is based on novel detector and filter/collimator technologies, and will perform the first global mapping of the lunar elemental composition, by looking at X-ray fluorescence in the 0.5–10 keV range [4,5]. It is supported in its operation by XSM (X-ray Solar Monitor) which also monitors coronal X-ray emission and solar flares [6].

Bulk crustal composition has bearing on theories of origin and evolution of the Moon. D-CIXS will produce the first global view of the lunar surface in X-ray fluorescence (XRF), elemental abundances of Mg, Al and Si (and Fe plus others if solar activity permits) across the whole Moon. The South Pole-Aitken Basin (SPA) and large lunar impact basins will be also mapped with D-CIXS. These will be the first XRF measurements of the lunar surface since the Apollo 15 and 16 missions, which covered just 9% of the Moon and were restricted to equatorial regions. D-CIXS will derive absolute elemental abundances, by measuring (with X-ray Solar Monitor XSM) the incident solar spectrum that causes the lunar surface to fluoresce in X-rays.

D-CIXS will provide a global distribution of Mg and permit the production of global magnesium numbers (Mg# = Mg/Mg+Fe). The mapping of Mg# is a key to study the evidence of a primitive source, the relations of Mg-suite rocks vs ferroan anorthosites or KREEP, and the constraints on the magma ocean model/evolution. Although geochemical studies show the Mg-suite appears to have originated from both primitive and evolved sources, recent work suggests that the Mg# is the only attribute to show evidence of a primitive source. All other elements suggest the rocks to have formed from evolved magmas. A number of petrogenetic models that could produce this dichotomy in Mg-suite rocks were presented that range from an impact origin to the remelting of a magma ocean or cumulate pile. A magma ocean model will produce Mg-suite rocks that exhibit specific relations to other rock types, perhaps displaying an association with ferroan anorthosites or KREEP materials. D-CIXS' more comprehensive characterisation of Mg# will aid estimates of bulk crustal composition and theories for the evolution of the lunar crust, to address the thermal and physical evolution of the Moon.

SIR (PI H.U. Keller) is a miniature near-infrared spectrometer operating in the 0.9-2.6 μm wavelength range and will carry out mineralogical survey of the lunar crust in a previously uncovered bandwidth.

SIR will have high enough spectral resolution to separate the pyroxene and olivine signatures in lunar soils. This is a key in our understanding of the evolution of crustal materials, as the distribution of olivine is poorly constrained in current models. Olivine is considered by many to be a common mineral in the lunar mantle, so its distribution throughout the lunar crust and across the lunar surface is of critical importance to models of crustal differentiation and evolution. A key target for observations using the SIR instrument will be the 2,500 km diameter South Pole-Aitken Basin (SPA), which may have dug through to expose materials from the lunar mantle. This is strongly debated, however, and many consider the anomalously mafic units in the region to represent lower crustal materials rather than lunar mantle units. If measurements of the olivine and pyroxene distribution throughout the SPA can be made, the results would have a strong bearing on this contentious issue and would allow for improved models of crustal differentiation and thermal evolutionary models. SIR will help to further this study.

SIR data will help to refine compositional analyses from Clementine/ Lunar Prospector data. IR spectrometry, with spatial resolution as good as 300 m will permit to distinguish units on central peaks, walls, rims and ejecta blankets of large impact craters, allowing for stratigraphic studies of the lunar crust.

AMIE (Advanced-Moon micro-Imager Experiment, PI J.L. Josset) is a miniature high resolution (30 m pixel at 300 km perilune height) camera, equipped with a fixed panchromatic and 3-colour filter, for Moon topography and imaging support to other experiments [7]. The micro camera AMIE will provide high-resolution CCD images of selected lunar areas. It includes filters deposited on the CCD in white light + three filters for colour analyses, with bands at 750 nm, 900 nm and 950 nm. These will provide data on the 1 μm absorption of pyroxene and olivine. AMIE images will provide a geological context for SIR and D-CIXS data, and colour or multi-phase angle complement. Lunar south pole repeated and deep high resolution images will be obtained. This will allow the identification of shadowed or double-shadowed areas, the search for potential 'water ice traps' or 'cold traps'. Also, SMART-1 will map potential sites of 'eternal light' and 'eternal shadow', or sites relevant for future lunar exploration (lunar bases, power supplies).

SMART-1 overall planetary science: SMART-1 science investigations include studies of the chemical composition of the Moon, of geophysical processes (volcanism, tectonics, cratering, erosion, deposition of ices and volatiles) for comparative planetology, and high resolution studies in preparation for future steps of lunar exploration. The mission could address several topics such as the accretional processes that led to the formation of rocky planets, and the origin and evolution of the Earth-Moon system [8].

SMART-1 operations and coordination: The Experiments are run during distinct phases of the SMART-1 mission: 1) the 17-months long Earth escape phase when the spacecraft spiralled out from Earth to perform a weak capture of the Moon on 17 November 2004; 2) a spiral down towards the Moon until end of January (but allowing some lunar observations); 3) a nominal science phase of 6-months (+ possible extension) in elliptical Moon orbit (starting at 300-3000 km) with peri-centre near the south pole. The planning and co-ordination of the Technology and science experiments operations is carried out at ESA/ESTEC (SMART-1 STOC). The SMART-1 STOC supports also the mission data archiving based on the PDS (Planetary Data System) Standard.

The SMART-1 observations will be coordinated with upcoming missions. SMART-1 will be useful in the preparation of Lunar-A, Selene, the Indian lunar mission Chandrayaan-1, Chinese Chang'E , the US Lunar Reconnaissance Orbiter, and South Pole Aitken Basin Sample Return Moonrise.

SMART-1 can also contribute to prepare the next steps for exploration: survey of resources, search for ice, monitoring polar illumination, and mapping of sites for potential landings, international robotic villages and for future human activities and lunar bases.

References: [1] Foing, B. et al (2001) Earth Moon Planets, 85, 523 . [2] Racca, G.D. et al. (2002) Earth Moon Planets, 85, 379. [3] Racca, G.D. et al. (2002) P&SS, 50, 1323. [4] Grande, M. et al. (2003) P&SS, 51, 427. [5] Dunkin, S. et al. (2003) P&SS, 51, 435. [6] Huovelin, J. et al. (2002) P&SS, 50, 1345. [7] Shkuratov, Y. et al (2003) JGRE 108, E4, 1. [8] Foing, B.H. et al (2003) AdSpR, 31, 2323.

Links: http://sci.esa.int/smart-1/, http://sci.esa.int/ilewg/