ESA'S SMART-1 MISSION: LUNAR SCIENCE RESULTS AFTER ONE YEAR

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Introduction: Thanks to the successful electric propulsion navigation, the SMART-1 spacecraft reached lunar capture on 17 November 2004, and has spiraled down to reach on 15 March 2005 a lunar is to orbit the Moon 300-3000 km for a nominal science period of six months, with 1 year science extension. We shall report at LPSC2006 on one year of lunar science results, and describe the plan for operations until end of mission impact in August 2006.

Overview of SMART-1 mission and payload: 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 SMART-1 spacecraft has been launched on 27 Sept. 2003, as an Ariane-5 auxiliary passenger and injected in GTO Geostationary Tranfer Orbit. 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) for fluorescence spectroscopy and imagery of the Moon's surface elemental composition. The payload also includes two plasma experiments: SPEDE (Spacecraft Potential, Electron and Dust Experiment, PI. A. Malkki) and EPDP (Electric propulsion diagnostic Package, PI G. Noci), an experiment (KaTE) that demonstrated 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.

SMART-1 lunar science results: A package of three spectroscopy and imaging instruments has perfomed 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 is performing the first global mapping of the lunar elemental composition (Fig. 1), by looking at X-ray fluorescence in the 0.5–10 keV range [4,5,9]. It is supported in its operation by XSM (X-ray Solar Monitor) which also monitors coronal X-ray emission and solar flares [6].

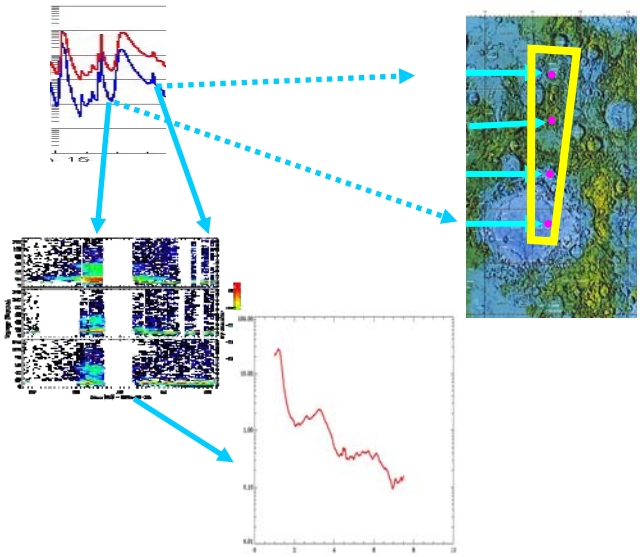

Fig 1. D-CIXS detection of Si, Mg, Al, Si, Ca & Fe lines at 1.25, 1.49, 1.74, 3.7 & 6.4 keV, over north of Mare Crisium during the 15 Jan 2005 solar flare [9].

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 have been also mapped with D-CIXS. D-CIXS is deriving 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.

SIR (Smart-1 Infra-Red Spectrometer, PI H. Keller) is operating in the 0.9-2.6 μm wavelength range and is carrying out mineralogical survey of the lunar crust. SIR has high enough spectral resolution to separate the pyroxene and olivine signatures in lunar soils.
SIR data 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 (Advancedsteroid-Moon micro-Imager Experiment, PI J.L. Josset) is a miniature high medium-resolution (35 m pixel at 350 km perilune height) camera, equipped with a fixed panchromatic and 3-colour filter, for Moon topography and imaging support to other experiments [7,10, 11]. The micro camera AMIE is providing 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 (measuring the 1 μm absorption of pyroxene and olivine). The camera will have an average resolution of 80 m/pixel, and 40 m/pixel near a 300 km perilune. AMIE images provide a geological context for SIR and D-CIXS data, and colour or multi-phase angle complement. Lunar North (Fig 2) and South pole repeated high resolution images have been obtained, giving a monitoring of illumination to map potential sites of 'eternal light' and 'eternal shadow', or sites relevant for future exploration .

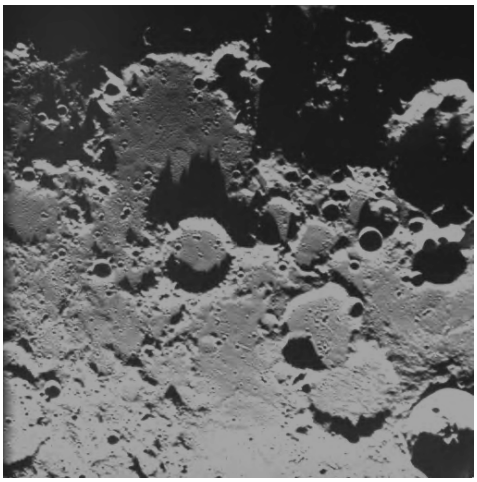

Fig.2: Polar view near polar Byrd crater (FOV 200 km)

Dedicated fixed polar pointings with long explosures will search for shadowed or double-shadowed areas, and for potential 'water ice traps' or 'cold traps'.

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 can 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].

A wide Lunar coverage was obtained with the AMIE camera in synoptic survey mode. A specific push broom mode in Oct-Dec 05 and April-May 06 has been used for high resolution colour targeted imaging.

SMART-1 operations and coordination: The Experiments are run according to illumination and altitude conditions during the nominal science phase of 6-months (see Fig 3) and 1 yr extension, in elliptical Moon orbit. The planning and co-ordination of the Technology and science experiments operations is carried out at ESA/ESTEC (SMART-1 STOC). The data archiving is based on the PDS (Planetary Data System) Standard.
The SMART-1 observations are coordinated with upcoming missions. SMART-1 is useful in the preparation of and Selene, the Indian lunar mission Chandrayaan-1, Chinese Chang'E , and of the US Lunar Reconnaissance Orbiter, Lunar-A, and subsequent lunar landers. SMART-1 is contributing 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.

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