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SMART-1 Results and Lessons for Future Exploration

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Abstract: We summarise SMART-1 lunar highlights relevant for future lunar exploration. SMART-1 has been useful in the preparation of Selene Kaguya, the Indian lunar mission Chandrayaan-1, Chinese Chang'E 1 , the US Lunar Reconnaissance Orbiter, LCROSS, and subsequent lunar landers (Google Lunar X-prize, International Lunar Network, Moon-NEXT, cargo and manned 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.

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 Transfer Orbit. The SMART-1 spacecraft reached on 15 March 2005 a lunar orbit 400-3000 km for a nominal science period of six months, with 1 year extension until impact on 3 September 2006. SMART-1 science payload, with a total mass of some 19 kg, featured many innovative instruments and advanced technologies [1], with 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) [4-6] for fluorescence spectroscopy and imagery of the Moon's sur-face elemental composition. The payload also included two plasma experiments: SPEDE (Spacecraft Potential, Electron and Dust Experiment) and EPDP (Electric propulsion diagnostic Package), 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 and exploration results: A package of three multiband mapping instruments has performed science and exploration at the Moon.

AMIE (Advanced-Moon micro-Imager Experiment). AMIE is a miniature high 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 has provided high-resolution CCD images of selected lunar areas. It included 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 absorption of pyroxene and olivine).
Lunar North polar maps and South pole repeated high resolution images have been obtained, giving a monitoring of illumination to map potential sites relevant for future exploration .

AMIE images provided a geological context for SIR and D-CIXS data, and colour or multi-phase angle complement. AMIE has been used to map sites of interest in the South Pole –Aitken basin relevant to the study of cataclysm bombardment, and to preview future sites for sampling return. SMART-1 studied also volcanic processes, and the coupling between impacts and volcanism.

D-CIXS (Demonstration of a Compact Imaging X-ray Spectrometer). DCIXS is based on novel detector and filter/collimator technologies, and has performing the first lunar X-ray fluorescence global mapping in the 0.5–10 keV range [4,5,9], in order to map the lunar elemental composition. It was supported in its operation by

XSM (X-ray Solar Monitor) which also moni-tored coronal X-ray emission and solar flares [6]. For instance, D-CIXS measurements of Si, Mg, Al, Si, Ca & Fe lines at 1.25, 1.49, 1.74, 3.7 & 6.4 keV, were made over North of Mare Crisium during the 15 Jan 2005 solar flare, permitting the first detection of Calcium from lunar orbit [9].
Bulk crustal composition has bearing on theories of origin and evolution of the Moon. D-CIXS produced the first global measurements of the lunar surface in X-ray fluorescence (XRF), elemental abundances of Mg, Al and Si (and Fe when solar activity permitted) across the whole Moon. The South Pole-Aitken Basin (SPA) and large lunar impact basins have been also measured with D-CIXS. D-CIXS has been improved for the C1XS instrument adapted to ISRO Chandrayaan-1.
SIR (Smart-1 Infra-Red Spectrometer). SIR has been operating in the 0.9-2.6 µm wavelength range and carrying out mineralogical survey of the lunar crust. SIR had high enough spectral resolution to separate the pyroxene and olivine signatures in lunar soils. SIR data with spatial resolution as good as 400 m permitted to distinguish units on central peaks, walls, rims and ejecta blankets of large impact craters, allowing for stratigraphic studies of the lunar crust. SIR has been improved for the Chandrayaan-1 SIR2 instrument.

SMART-1 overall planetary science: SMART-1 science investigations included 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 addressed 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 have been run according to illumination and altitude conditions during the nominal science phase of 6-months and 1 yr extension, in elliptical Moon orbit. The planning and co-ordination of the Technology and science experiments operations was carried out at ESA/ESTEC (SMART-1 STOC). The data archiving is based on the PDS (Planetary Data System) Standard.
The SMART-1 observations have been coordinated with follow-up missions.

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