Exploring the Moon in the 21st century

Ian Crawford and Mahesh Anand report on a wide-ranging RAS Discussion Meeting on the future of lunar exploration, held in the Geological Society Lecture Theatre at Burlington House on Friday 11 November 2005.

1: Is ESA's SMART-1 spacecraft paving the way for a return to the Moon?

Lunar science is undergoing something of a renaissance. The recent success of ESA's SMART-1 mission, a renewed interest in the USA in returning astronauts to the Moon, and the stated long-term aims of new space-faring nations such as China, India and Japan, have put lunar science back into the limelight. The purpose of this RAS meeting was twofold: first, to inform the UK planetary science community about recent developments in lunar science and, secondly, to demonstrate the high level of interest in lunar science in the UK and highlight opportunities for future involvement.

The meeting began with a short introduction by **Ian Crawford** (Birkbeck College) who outlined the scientific importance of the Moon as a recorder of events in the early solar system that may not be preserved anywhere else. He drew attention to possible opportunities for enhanced UK participation in lunar exploration within ESA's Aurora programme – although Aurora is mainly focused on Mars, the Aurora Programme Proposal does make explicit reference to the possibility of lunar missions, and he urged the community to push at what may be a slightly open door. He concluded by referring to the conclusions of the recent *Report of the RAS Commission on the Scientific Case for Human Space Exploration*, which had found that a human return to the Moon would confer many scientific advantages. That said, there is clearly also a lot that can be done by renewed robotic exploration, and we should be aiming for a symbiosis of robotic and human exploration of the Moon.

The first full talk was given by **Jim Head** (Brown University) on "The Moon: a keystone in understanding Earth-like planets". Summarizing the extensive exploration of the Moon conducted by astronauts and automated probes, Prof. Head described the Moon as a natural laboratory for understanding planetary processes. Important comparative planetology issues being addressed by lunar studies include crustal formation and evolution, styles and evolution of magmatism (intrusive and extrusive), impact cratering (both with regard to impact mechanisms themselves and chronologies determined from crater-size frequency distributions), and styles of tectonic activity. In the latter context, the Moon is the type location for tectonics on a planet with a single plate, which can be studied with the help of the extensive lunar data set and then extended to other planetary bodies. Upcoming missions, and a return of astronauts to the Moon, will provide important additional insight into a host of comparative planetological problems. Prof. Head concluded his talk by summarizing the great British contributions to exploration in the past, and expressed the hope that the UK would become more involved in the exciting opportunities for planetary exploration now in prospect. Noting in particular the contributions of the British Antarctic Survey in the exploration of Antarctica, he looked forward to the day when there would be a British Lunar Survey!

The next talk was given by **Alex Halliday** (Oxford University) on the "Origin and differentiation of the Earth–Moon system". He described how the careful measurement of isotope ratios in terrestrial and lunar samples reveals important information about the origin and evolution of the two planets. For example the Hf/W ratio can be used to date lunar core formation, and by inference the origin of the Moon, to 4524 ± 4 Myr ago, some 40 to 50 million years after the canonical date of solar system formation. This delay is consistent with the "giant impact" hypothesis for the Moon's origin. On the other hand, the fact that the oxygen isotope ratios are essentially identical for the Earth and Moon implies either that current impact models are incorrect in predicting that the Moon is mostly composed of debris from the impactor, or that the Earth and the impactor both formed at essentially the same heliocentric distance. Further work on isotope ratios in lunar samples will provide information on the geochemistry of the impactor, and thus open a window on the geological nature of planetesimals in the very early solar system that may not be available in any other way.

After coffee, **Ben Bussey** (Applied Physics Laboratory, Johns Hopkins University) gave a short talk on "The lunar poles: a destination for future lunar exploration". He outlined current plans for returning astronauts to the Moon as part of the US Vision for Space Exploration announced by President Bush in January 2004, and went on to describe work based on observations by the

Clementine spacecraft of illumination conditions at the lunar poles. These are now being complemented by ESA's SMART-1 spacecraft which is obtaining images of the poles at a different season from Clementine. This work aims to identify permanently shadowed areas, where water ice may be located, and permanently illuminated regions, which would permit continuous photovoltaic power generation. These characteristics may make such localities ideal sites for future lunar outposts.

Lunar volcanism

Ben was followed by Mahesh Anand (Open University) who gave a paper on "New views of the Moon: a lunar meteorites perspective", in which he summarized the importance of lunar meteorites in complementing the Apollo and Luna samples for mineralogical and geochemical analysis. To date, more than three dozen lunar meteorites have been discovered, although only six are crystalline mare basalts. In the absence of lunar sample return missions since Apollo and Luna (early to mid-1970s), these meteorites provide invaluable samples from which to derive new information about the origin and evolution of the Moon. Lunar meteorites are likely to have originated from areas that were not visited by the Apollo or Luna missions, and some appear to have been derived from the far side. Some mare meteorites are also younger than the Apollo and Luna basalts. Thus, lunar meteorite studies have improved the temporal and spatial resolution of lunar magmatism. With the recent surge in interest in a return to the Moon, lunar meteorite studies can be combined with remote sensing observations to guide future missions and identify key locations for future sample return missions.

The next talk was given by **Vera Fernandes** (University of Coimbra) on "Lunar volcanism: what have we learned and what we still need to learn". She discussed the importance of studying the geochemistry of mare basalt samples as a guide to understanding the structure and mineralogy of the lunar mantle. However, the very limited sampling from the Apollo and Luna missions means that compositional variations within the lunar mantle remain poorly understood. Remote-sensing data indicate that the Apollo and Luna samples do not represent the full geochemical diversity of lunar basalts, and there is a pressing need for additional samples for detailed geochemical analysis and radiometric age determinations.

Exploring from orbit

The following talk came from **Urs Mall** (Max Planck Institute) on "Near-infrared observations of the Moon", in which he summarized the objectives of the near-infrared spectrometer on ESA's SMART-1 spacecraft. Near-infrared spectroscopy is a powerful tool for determining the mineralogy of the lunar surface, and is particularly useful for complementing the UV–visible multispectral data obtained by Clementine. For example, near-infrared spectra are better able to determine the relative proportions of mafic minerals (e.g. orthopyroxene, clinopyroxene and olivine) in lunar soils, which in turn provide a guide to the geological evolution of different regions.

The final talk before lunch was given by **Bernard Foing** (ESA) on "Europe to the Moon: SMART-1 and future exploration". SMART-1 is ESA's first mission to the Moon and is designed to test new technologies for spacecraft and instruments. The payload includes a miniaturized high-resolution camera for lunar surface imaging, a near-infrared spectrometer for mineralogy investigations, and a compact X-ray spectrometer for geochemical analyses. SMART-1 lunar science investigations thus include studies of the chemical composition of the Moon, of geophysical processes, and studies preparatory to future exploration. ESA is developing a strategy for future lunar exploration that will address the possibility of landers/sample return missions, synergies with Mars exploration, and in-situ resource utilization relevant to future human exploration.

The lunch break provided an opportunity for participants to view the poster papers that had been contributed to the meeting, covering topics as diverse as: UK participation in the US Lunar Reconnaissance Orbiter (**Neil Bowles *et al.***, Oxford University); characterizing the lunar environment as an aid to future exploration (**Barry Kellett *et al.***, Rutherford Appleton Laboratory); in-situ measurements of space weathering (**Mark Bentley *et al.***, Open University); studies of basaltic lunar meteorites (**Katie Joy**, UCL); theoretical models of impact crater formation (**Emily Baldwin**, UCL); the case for renewed human exploration of the Moon (**Ian Crawford**, Birkbeck); and how Virgin Galactic might contribute to future lunar exploration (**Stephen Ashworth**).

After lunch, **Manuel Grande** (RAL) spoke on "Lunar X-ray science with D-CIXS and Chandrayaan-1", in which he summarized the recent results from the D-CIXS X-ray spectrometer on SMART-1. These include detection of a fluorescent argon line in the Earth's atmosphere during the cruise phase to the Moon, and detection of Mg, Al, Si, Ca and Fe in the lunar surface from observations over Mare Crisium and the adjoining highlands. These initial observations have demonstrated the ability of D-CIXS to make geochemically valuable measurements of the lunar surface. Having thus demonstrated the basic soundness of the instrument design, it is hoped to build a similar instrument for the forthcoming Indian Chandrayaan-1 mission. This will have a lower orbit than SMART-1 (giving better spatial resolution), and will fly at a more active phase of the solar cycle (yielding higher X-ray fluxes), and our participation will consolidate experience gained with D-CIXS and further stimulate the development of lunar science in the UK.

Next, **Dean Talboys** (University of Leicester) discussed "Instrument development applicable to lunar research", focusing on current topics at the Space Research Centre of Leicester University. These include imaging X-ray fluorescence spectroscopy, sampling and in-situ measurements of subsurface materials, and radiation and particle environment monitoring systems suitable for deployment on planetary surfaces. The group is involved in a programme of research and development to provide a suite of instruments and tools for planetary surface and orbital missions, and Dean outlined a specific mission opportunity involving a collaboration with Peking University (Beijing) to develop instrumentation for the Chang'e II lunar rover.

Moon rock? Yes please!

The next talk was by **Alex Ellery** (Surrey Space Centre) on "Low-cost robotic missions to the Moon: a UK perspective". Alex began by asking those present whether there was any scientific interest in retrieving samples from the Moon, given that the Apollo and Luna missions had already done so? There was near unanimity that such samples would be desirable, from a large number of suggested targets. He then went on to outline a low-cost sample-return mission concept being investigated by Surrey Space Centre, which would aim to retrieve a sample having a mass of a few tens of grams. There was general agreement that such a mission would be scientifically very valuable.

The final talk of the day was given by **Mark Sims** (University of Leicester) on "ESA's Aurora Programme". Mark chairs the UK Aurora Advisory Committee (AurAC), and he outlined ESA's plans for Aurora and the UK's position within it. At present Aurora is dominated by Mars exploration, but Mark acknowledged that room for lunar exploration has been left in the programme, and intimated that AurAC would start to examine the possibilities for UK involvement in lunar missions following the ESA Ministerial Council meeting in December 2005. The UK lunar science community will await the outcome of these discussions with interest.

In conclusion, the meeting clearly succeeded in demonstrating the high level of interest in lunar science in the UK, with more than 50 members of the planetary science community in attendance. There was a broad consensus that the UK is well placed to benefit from, and contribute to, the exciting developments in lunar exploration that are in prospect. What we need now is for the relevant agencies, especially PPARC through its Solar System Advisory Panel (SSAP), to sit up and take notice. ●

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