UK in the Aurora Programme

John Bridges surveys the scope of UK planetary science and technology, and the prospects for scientific, technical and commercial gains that could result from our participation in the Aurora Programme.

Abstract

The Aurora Programme uniquely brings together planetary scientists, astronomers, physicists, geologists, space technology engineers and chemists, to study the solar system. It captures the research aspirations of a major part of the UK planetary science and technology community – highlighted at the December 2008 RAS meeting. I describe major topics from the meeting, including the scientific impetus for a Mars sample return mission and that ExoMars and other future Mars missions are likely to be ESA–NASA collaborations. The UK is well placed to take a major part in the scientific discoveries that the Aurora Programme and future international collaborations will generate.

The first "UK in the Aurora Programme" meeting was held on 12 December 2008 at the RAS. The aim of this meeting was to bring together the diverse range of research activities in the planetary science community that are interested in Aurora (described further in the box "The Aurora Programme and ESA–NASA collaboration"). There were 14 talks, 22 poster presentations and a group from the British Geological Survey who showed their new Mars 3-D interactive data products. At the meeting there were scientists and engineers from more than 20 UK institutions and ESA that are involved in ExoMars instruments, Mars Sample Return, missions to the Moon or Mars, and the study of planetary samples and the search for life in the solar system.

At the meeting at least six major areas of active research within the Aurora Programme were evident: scientific instrumentation for the ExoMars and other landers, technology for robotic missions, remote sensing of the Moon and Mars, meteorite and noble-gas analysis, and exobiology. The ExoMars rover mission has stimulated much of this research effort. A new initiative within ExoMars described by **Marcello Coradini** (ESA Solar System Missions Coordinator) was collaboration between ESA and NASA in parts of the mission. This is a response to the escalating cost of ExoMars (€1.2bn). A further change might be altering the landing to a direct hyperbolic approach to Mars rather than delivery from orbit as had previously been planned. This has proved highly successful – the NASA Spirit and Opportunity landers, for example – although there may be compromises in terms of landing ellipse sizes and the ability to delay landing if desired due to atmospheric and dust conditions. Such collaboration between ESA and NASA could well be a blueprint for future large missions to Mars and the Moon.

Science instrumentation for ExoMars

The ExoMars rover mission is a large and complex mission which will use an Ariane 5 or similar-sized launch vehicle. The ongoing great success of the NASA Spirit and Opportunity landers shows that the scientific return from a Mars lander can be immense. For instance, before Opportunity we had no conclusive evidence for sediments on Mars deposited in the presence of water.

The current ExoMars science plan, which will be finalized within the next few years, is for two geophysical packages – Pasteur and Humboldt – and a drill that can extract material from as far as 2 m below the surface. These instruments will involve 30 UK scientists from 21 institutions.

The suite of instruments on Pasteur includes a panoramic camera and X-ray diffraction analysis, and various organic and life-detection instruments such as Urey and the Life Marker Chip. Presentations on all these instruments were given at the Aurora meeting by UK teams from Mullard Space Science Laboratory, Leicester, Open University and Imperial College. An example of the current instrumentation work in the UK is the stereo camera PanCam, led by **Andrew Coates** (MSSL), which has 12 filters to allow the initial characterization of the landing site and planning for the other science activities, and a high-resolution channel allows detailed images of selected areas. The camera can also take solar images for water vapour abundance and dust, optical depth measurements and study the retrieved subsurface samples before analysis by the other Pasteur instruments. A Leicester team (**Richard Ambrosi** and **Graeme Hansford**) are working on the design of the X-ray spectrometer and its potential for mineralogical characterization. **Mark Sephton** (Imperial) leads the UK part of the Urey instrument. This can detect and characterize organic molecules at parts-per-billion level and also measure chirality in molecules – one of the key markers of life processes. **Mark Sims** (Leicester, in collaboration with Cranfield University) talked about the Life Marker Chip, an instrument that uses molecular receptors to measure the parts-per-million to parts-per-billion content of organics in the martian regolith.

One of the UK contributions to the Humboldt science package is the UV-VIS spectrometer (**Manish Patel**, Open University). This is designed to determine for the first time the magnitude of the UV flux reaching the Mars surface in the ranges of UV-C (190–280 nm) and UV-B (280–315 nm). These two spectral ranges are particularly important in breaking down organic compounds. The UVIS experiment can also detect the biologically relevant gas ozone.

It is clear from these examples that the UK is well placed to take a major part in the science discoveries of ExoMars. There are also terrestrial, spin-off applications of the technology. For example, the Life Marker Chip technology is also being developed for health care, defence, forensic science and environmental monitoring.

Technology for space missions

The UK has a major industrial input to the Aurora Programme with the Astrium UK company being prime subcontractor to build the ExoMars rover. Several of the posters discussed its mechanical and electrical architecture. There were also poster presentations giving designs for other space mission technologies, including a Moon NEXT mission rover. New technological developments include radioisotope and nuclear-power systems development. **Rob O'Brien *et al.*** (Leicester) presented the techniques and materials required for the development of safe, low-radiation, radiogenic power sources for space mission and terrestrial applications.

Remote sensing of Mars and the Moon

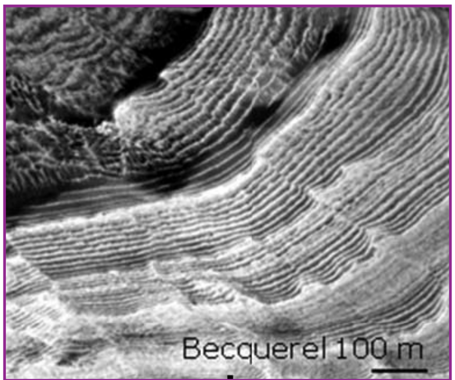
The UK planetary science community has strength in remote sensing of the planets. New stereo, high-resolution coverage of Mars with highly accurate digital elevation models of the surface (**S-Y Lin *et al.*,** MSSL) have enabled a new, better understanding of megafloods during the Hesperian period. For instance, **Sanjeev Gupta** (Imperial College) found evidence that channel erosion around the Chryse Basin was achieved by multiple episodes of flooding, suggesting that release of water from subsurface aquifers occurred at repeated intervals. An important new understanding of Mars that has emerged in recent years as a result of high-resolution imagery and digital elevation models

The Aurora Programme and ESA–NASA collaboration

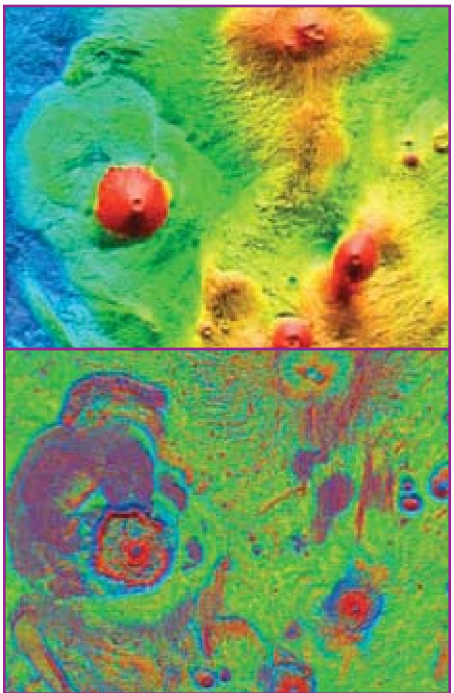
Aurora is an ESA programme to explore the solar system – starting with the Moon and Mars – with robotic spacecraft, eventually leading to manned missions. The cornerstone missions are the ExoMars lander (launch 2016, landing 2017), Mars Sample Return, and their associated technology programmes. The UK has a major stake in the Aurora programme, at the last ESA Council of Ministers increasing its subscription to ExoMars to €165m, for its development and operations to 2017. Also, the UK subscribed to the Mars Robotic Exploration Preparatory Programme (MREP), a technology development programme for Mars missions, at a level of €6.5m. This makes the UK the second largest contributor to ExoMars and the largest contributor to MREP.

Another part of the UK Aurora programme is the STFC fellowship scheme: four of the Aurora fellows gave presentations at the RAS meeting. A series of workshops for the Aurora community are also being organized; one of the first will be on Habitability and Landing Sites. The range of presentations at the RAS meeting demonstrated the UK's strength in planetary materials analysis, which together with planetary protection expertise (e.g. heritage from Beagle 2 preparation) mean that the UK planetary science community is hoping to gain the ESA sample receiving facility for sample return missions.

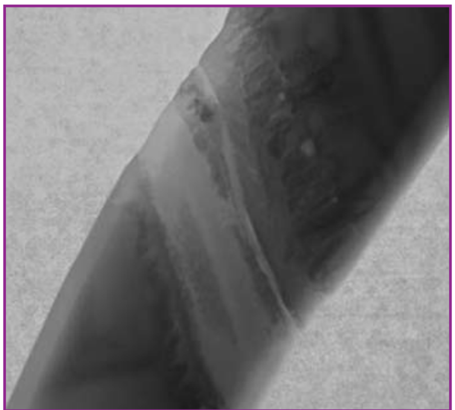
http://www.esa.int/SPECIALS/Aurora



1: Cyclic sediments within Becquerel Crater, Mars. The light–dark layering shows a cyclicity – 10 dark layers within each cycle – which corresponds to the current obliquity cyclicity on Mars. (Bridges *et al.*)



2: Examples of new remote-sensing processing techniques for remote data from Mars. These are maps of the Tharsis volcanic region with (top) an elevation map and (bottom) a slope map derived from it. These have been prepared from MOLA data using geophysical filtering techniques by a British Geological Survey team. (Tragheim *et al.*)



3: Wafer (~1.75 μm across) extracted across hydrothermal vein from a martian (Nakhlite) meteorite. This is a bright-field transmission electron microscope image. This type of microscopic-scale characterization revealing different constituent minerals precipitated from a carbonate-rich brine will be central to studying samples from Mars Sample Return and other missions.

is that there have been periods of climate change including equatorial glaciations or periglacial activity in the recent past. **John Bridges** (Leicester) showed that layered sediments within the interior of large craters of the equatorial regions of Mars preserve a pattern of light–dark layering similar to that predicted from orbital forcing (figure 1). The sediments formed by varying dust deposition rates in an analogous way to the current polar layer deposits. **Matt Balme** (Open University) described periglacial landforms in equatorial latitudes that include sorted stone circles formed through progressive movement of the ground surface during freeze–thaw cycles.

The Aurora Programme has also helped stimulate new interdisciplinary work. The British Geological Survey (**Doug Tragheim *et al.***) demonstrated their new 3-D Mars data products (figure 2), which use a series of data filtering techniques to produce detailed elevation, slope and roughness maps of the martian surface.

Aurora also includes exploring the Moon, and **Katie Joy** (UCL) discussed UK involvement in the Europe (SMART-1), India (Chandrayaan-1), China (Chang'e-1) and Japan (Kaguya) missions. The recent increase in interest in new landing missions to the Moon has renewed interest in the 40-year-old Apollo results. **Axel Hagermann** (Open University) discussed seismic and heat-flow experiments from those landings and argued that there was potentially new valuable data about the lunar structure to be gained from more geophysical experiments such as those proposed for the UK-led Moonlite Penetrator mission.

Meteorite and noble-gas analysis

A major part of the impetus behind the UK's interest in Aurora and sample return missions is our long heritage in meteorite analyses and geochemical techniques. For instance, Manchester was the first laboratory to date meteorites using the $^{40}Ar/^{39}Ar$ technique, allowing the identification of impact-induced shock ages in samples from Mars, the Moon and asteroids. **Jamie Gilmour** (Manchester) discussed how noble gases from 1 mm^3 of the atmosphere collected within a Mars sample return mission could provide enough molecules to help constrain the processes associated with the fractionation of the martian atmosphere, crust and mantle, distinguishing between solar and radiogenic compositional reservoirs (figure 3).

Hitesh Changela *et al.* (Leicester) used new transmission electron microscopy studies of martian meteorites to show the fine detail of how some crustal rocks had been altered through evaporation of a heated brine (figure 4). These and other techniques – isotopic, geochemical, spectroscopic – will be a central part of the scientific work on samples returned to Earth from sample return missions.

Lunar meteorites are also a major area of international and UK study. **Joshua Snape *et al.*** (UCL/Birkbeck) showed how studying the geochemistry of lunar meteorite Northeast Africa 001 could be used to constrain a likely far-side origin for the meteorite's parent rock close to a region of very low-titanium mare basalt.

Exobiology

A stimulus for Aurora is the search for life. To this end UK researchers are attempting to identify mineralogical terrains and landscapes where traces of life may have been preserved. These results show that impacted sulphate terrains are susceptible to colonization by sulphur/iron-metabolizing microbes. **John Parnell** (Aberdeen) used terrestrial analogues to argue that martian sulphates, including jarosite, should be a priority target for analysis of organics *in situ* and for Mars Sample Return. **Charles Cockell** (Open University) used analogue terrain studies in Iceland to suggest that the best materials to preserve a microbial rock weathering signature are subglacial basaltic glasses. Other studies by **Cousins** and **Grindrod** (UCL) showed the way terrestrial analogue studies can help in the search for biosignatures and understanding the origin of hydrated minerals on Mars. A workshop in 2009 on Habitability and Landing Sites is planned, to bring together exobiologists and remote-sensing scientists to determine the best and most practical regions to aim the Aurora missions on Mars in the search for life.

Next in Aurora – Mars Sample Return?

The scientific case for Mars Sample Return (MSR) principally arises because definitive answers about life, climate and geology require diverse and complex labs on Earth that can replicate analyses and check or enhance data returned from *in situ* missions such as ExoMars (figure 5). For instance, *in situ* atmospheric analyses are unlikely to be able to achieve the precision of terrestrial labs. Meteorites now known to originate from Mars have been studied for a century, including, for example, the Nakhla meteorite that fell near Alexandria in 1911. Successive, more up-to-date techniques have been applied to the samples, leading to new research discoveries to this day. It can be assumed that samples returned from Mars would stimulate a similarly long programme of research.

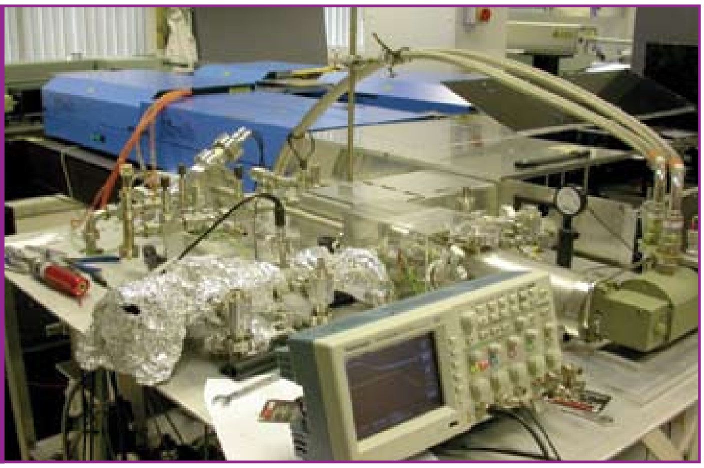
It is important that the samples are brought back in carefully selected suites from geologically characterized sites. Much has been learnt from martian meteorites, but they do not provide a selection from all the terrains of the martian crust. For instance, we hold no sedimentary deposits comparable to those identified by the Opportunity lander. Objectives in the study of Mars that require a sample return mission include assessing the evidence for life by characterizing organic molecules, biominerals and isotopic compositions. Another example is that the palaeoenvironments and history of near-surface water on Mars could be characterized in detail from the clastic and chemical history of sedimentary and hydrothermal sample suites.

For many years there has been a strong call within the international and UK planetary science community for a Mars sample return mission. In June 2008 a joint NASA, ESA and national delegate preliminary plan for an MSR mission was published by iMARS (International Mars Architecture for the Return of Samples) (iMARS 2008) and prior to this an extensive consideration of the case for such a mission was published by the Next Decade Science Analysis Group (MEPAG 2008). Mars Sample Return is the next logical step in the exploration of Mars, following on from the successful landing and orbital missions by NASA and ESA.

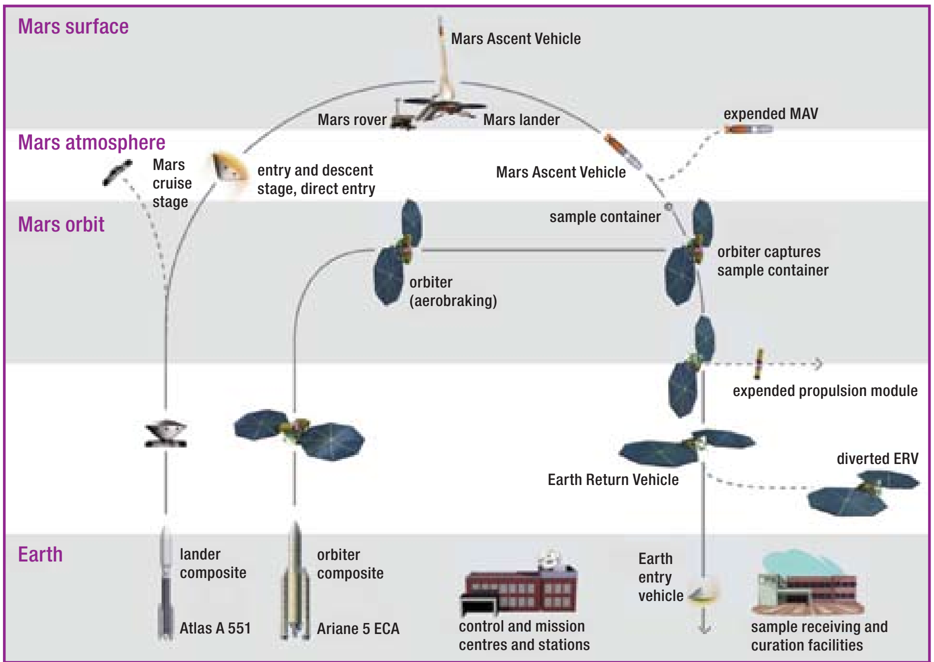
The MSR mission envisaged by iMARS could bring back 500 g consisting of twenty rock, three regolith, one dust and two atmospheric samples (iMARS 2008). Some of these samples could have been cached by ExoMars or the NASA Mars Science Laboratory in 2012. But there is a general assumption that a sample return mission will need enough science instruments to select the most valuable samples for return.

Planetary protection – sample return is a restricted (category V) mission in order to avoid Earth being contaminated by martian microbes – and initial sample characterization requires at least one international sample returning facility for quarantine and a curation facility.

Current mission plans for MSR within a 2018–2024 timescale involve a lander spacecraft (with rover and Mars Ascent Vehicle) and an orbiter spacecraft to bring the samples back to Earth within five years of the initial launch. Figure 5 shows the current mission architecture planned by the iMARS team. ●



4: Mass spectrometer designed for noble gas (Xe and Kr) isotopic analyses with a detection limit of ~1000 atoms (Gilmour *et al.*, Manchester). It is the precision of this type of technique in terrestrial labs that is hardest to replicate with *in situ* analyses on Mars and shows the potential of Mars Sample Return.



5: Summary of the Mars Sample Return mission for launch opportunities 2018–2022. (iMARS 2008)

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