PLANETARY INTERIORS, SURFACES AND ATMOSPHERES
NUAP Draft Report.

Summary

This document was drafted following consultation with a small cross-section of members of the community and aims to outline the current UK strengths and international position in the study of planetary interiors, surfaces and atmospheres. Its ultimate purpose is to identify and prioritise the main science questions to be addressed in this area during the next 10 - 15 years and to identify the resources necessary to achieve the identified science goals, future opportunities and the broader benefits to the UK of pursuing research in this area. There is some overlap between this document and some of the other accompanying documents, most notably Space Physics.

Introduction

The planets and minor bodies of the Solar System offer the opportunity for unique insights into solar system formation processes, planetary evolution and how Life developed on Earth. The Solar System contains a bewildering array of different planetary environments – and one of the great challenges ahead of us is understanding what the conditions for Life are, where these conditions may be found in our Solar System (and beyond) and if there is evidence for Life existing on bodies other than Earth.

The many varied planetary environments in our Solar System contain a wealth of information about different aspects of Solar System and planetary formation. However, accessing this information requires developing different approaches, including remote observation, in situ characterisation and laboratory analysis. The UK has a strong track record in all aspects of this work and in recent years has sought to increase its presence in this area, signing up to ESA's Optional robotic exploration program, Aurora. Further evidence of the importance of the exploration of the Solar System is reflected in the development of the Global Exploration Strategy, signed by BNSC on behalf of the Government in 2007.

Knowledge of our own Solar System is important in developing our understanding of planetary systems discovered elsewhere in the Universe.

Goals of the Research

There are two principle goals to research in this area –

1) Solar System & Planetary Formation

- How did the planets evolve – what were the processes and time-scales involved from disk collapse to the present day Sun, planets and minor bodies?
- Is our Solar System typical? What can our Solar System tell us about other planetary systems?
- Can we develop a universal theory of planetary atmospheric structure, circulation and climate? What factors determine the form and character of a planetary atmosphere and its global circulation and climate?

2) Extent of Life in the Solar System

- What makes Earth special? Understanding of similarities and differences between Earth, Mars and Venus, Mercury and the Moon
- Are there places in our Solar System that have conditions that could support life today or may have in the past?
- Can we characterise such places in order to identify similar locations in other

planetary systems?

UK Areas of Excellence

The UK has world leading or world-class expertise and capability in a wide range of areas (in no particular order):

Laboratory Sample Analysis: UK scientists have expertise and a proven track record of excellence in the laboratory analysis of extraterrestrial samples – and continue to play leading roles in the analysis of recent sample return missions (Stardust and Genesis), lunar samples, meteorites, interplanetary and interstellar dust.

In the past 3 years some of the key labs have organised themselves into an integrated network for the development of new analytical technologies for the laboratory analysis of extraterrestrial material - the UK Cosmochemistry Analytical Network (UKCAN), with applications ranging from the physics of stellar nucleosynthesis to the origins of Life.

Over the last 6 years considerable investment has been made both by STFC and the universities to provide state of the art instrumentation for cosmochemistry as part of the on-going research into Solar System & Planetary Formation and some of the aspects of The Extent of Life in the Solar System, and in the build up to forthcoming sample return missions.

Small Planetary Surface Probes: The Beagle2 Mars lander, although unsuccessful, provided exceptional payload capability for a small lander. Penetrator Probes for hard landing of instrumentation onto and into airless planetary surfaces is an area that UK is now leading with development for missions to the Moon (e.g. Moonlite), Europa, Ganymede (e.g. JESM).

Miniaturised in situ Instrumentation: Several UK groups have developed a range of world-leading miniaturised instrumentation for the study of planetary surfaces. Examples include mini mass spectrometers (on Beagle2, Rosetta Lander), x-ray/gamma-ray spectrometers, IR microscope and thermal probes, etc.

Life Detection Instrumentation: Life Marker Experiment is a novel and adaptable instrument developed in the UK that is part of the ExoMars instrument suite. Development of automated sample extraction techniques for the Urey instrument package is also an area of UK leadership.

Planetary Atmospheres: UK groups are leading the design and build of spaceflight instrumentation for remote sensing of planetary atmospheres and surfaces (particularly microwave and infrared), as well as developing models for planetary atmosphere evolution. Instrument leads in ExoMars (Advanced Environmental Package and UV-Vis) and proposed payload for the planetary Cosmic Vision missions as well as significant Co-Is (including hardware delivery) for the Mars Climate Sounder instrument, CIRS and ISS on Cassini, the VIRTIS on Venus Express. Numerous examples of major leadership in theory/modelling – e.g. major role in ESA Mars Climate Database.

Planetary Protection: UK Scientists and Industry lead European activities in this critical area of Solar System exploration – in terms of preventing false positives in life-detection experiments, protecting alien environments from terrestrial contamination, as well as ensuring that returned samples cannot contaminate Earth, and in the secure curation of samples returned from astrobiologically-significant sources.

Imaging Systems: UK has excellent capability with high-resolution colour and wide angle multispectral stereoscopic panoramic imaging systems – e.g. Leadership of PanCam for ExoMars rover.

System Manufacture & Development: The UK has a number of industrial companies with strong academic links, leading the development and construction of systems/sub-systems for spacecraft and related activities. In terms of the largest, most important aspect of robotic exploration in the ESA plan is the ExoMars rover for which the UK is prime contractor.

<u>Future Requirements</u> Again – in no particular order….

Sample Analysis: A wide range of approaches address many of the key areas of the two principle science goals – Solar System and Planetary Formation and The Extent of Life in the Solar System. Key questions relating to the processes and timescales of Solar System formation and accretion and evolution of the planets can only be achieved through detailed investigation of samples of primitive asteroidal and cometary materials with laboratory instrumentation. Similarly, martian meteorites currently offer our only detailed insight into process in the martian crust and mantle.
There is a wealth of samples, continually expanding with fresh meteorite falls, from which important information can be teased –samples of primitive asteroids, comets, differentiated asteroids, martian meteorites, the Moon (meteorites and returned samples), interplanetary dust particles, interstellar grains (modern and ancient) and the solar photosphere. The continued development of analytical instrumentation, with many examples having been driven by the cosmochemistry community, also offers the opportunity for major progress to be made in our understanding of Solar System processes.

Continued development of the instrument base and pool of expertise is critical to maintaining the position of UK in this area. Sample return missions (e.g. MSR, Marco Polo, Hayabusa, Phobos Grunt, lunar samples) will be a key aspect of future planetary missions and in order to have access to these precious samples, and for the UK to take a leading role in such missions it is essential that the expertise and instrumentation is continually developed.

Larger analytical instruments are beyond the cost of the grants line and therefore a long term investment mechanism is required to support such a programme, through the development of the UK Cosmochemical Analysis Network (UKCAN). Support through the grant line remains critical for smaller equipment development and for staff time and technical support.

Hardware Development Programme: The planetary bodies that will be explored in the forthcoming decade or so present a wide variety of environments, requiring study by a wide range of instruments. Within the study of planetary interiors, surfaces and atmospheres, there are generic themes in which the UK has significant leadership and that offer great scientific return. Development of instruments, or major sub-systems, to address future scientific questions, requires continued funding in order to ensure that the UK's instrumentation base is technically competitive and meets the specific requirements of forthcoming missions.

<u>Instruments</u>**:** Some of the principle small instrument types currently developed for investigation of planetary interiors, surfaces and atmospheres within the UK include:

Imaging Systems: UK has expertise in small camera systems, such as sample imagers, panoramic cameras, decent cameras, etc – widespread application to surface missions – including Moon, Mars, Europa, Ganymede, NEO.

Mini Mass Spectrometers: Powerful geo-analytical tools with widespread application to planetary landers and orbital spacecraft developed for Rosetta and Beagle2. Such instruments can be readily tailored to a broad range of applications for missions to the Moon, Mars, Europa, and Ganymede.

Life Detection Systems: Life Marker Experiment is a novel instrument drawing upon the biotechnology field for the detection of specific molecules that would be indicative of the presence of Life. This small, readily adaptable instrument is being developed as part of the ExoMars programs and can be tailored for all missions with an astrobiological component.

Microseismometers: For small landers/surface probes to investigate sub-surface/interior structure of bodies for missions to the Moon, Mars, Europa, and Ganymede.

Environmental Monitors: Drawing on expertise from Beagle2 and Huygens landers, these small instruments have the potential to contribute detailed knowledge about local environments in a wide range of alien environments.

Spectrometer Imaging Systems: - UK has leading expertise across a range of wavelengths for spectrometers and imaging spectrometers to measure spectral properties of atmospheres and surfaces remotely and *in situ*, including UV-Vis, Near IR, Thermal IR, sub-mm. As one of the principle means of obtaining compositional information remotely such instruments are applicable to missions to every planetary body.

Gamma/XRS: Considerable expertise in X-ray spectroscopy has already been exploited for the development of compact X-ray and gamma-ray sensors for in situ chemical characterisation of small samples. As such this is a powerful geo-analytical tool important to the characterisation of samples for planetary landers to the Moon, Mars, Europa, Ganymede and NEOs.

<u>Systems</u>**:** UK industry already has strong links with academia for the development of novel spaceflight hardware and systems. This needs to be developed further, and should be built upon in the following areas that are already developed/developing and which are important to future planetary interior, surface and atmospheric missions:

Penetrator Probes: These probes offer a simple means to delivery suites of instruments into the surface planetary bodies – for the investigation of geophysical and geochemical studies. There is a UK-led consortium developing a generic probe that can be deployed to many different mission scenarios.

Rovers: The success of the NASA MERs in the past 5 years has highlighted the importance of the ability to travel across planetary surfaces in order to explore different terrains and environments. UK industry is the lead contractor for the development of the ExoMars Rover. Continued development of this technology will be of great importance to future exploration of Mars, including collection of samples for MSR.

Sampling Devices: UK has been developing expertise which should be developed further for a range of forthcoming missions, as collection of samples is a fundamental aspect of in situ and sample return missions and therefore will have widespread application in future missions.

Future Missions: There are a number of missions currently operational, planned, under study or proposed which are of high importance to addressing the key questions of Solar System & Planetary Formation and Extent of Life in the Solar System. Resources are required to ensure that UK science can participate in these mission opportunities – in having competitive instrumentation at appropriate levels of flight readiness and an underpinning active science theory and data exploitation community. These missions include:

Mars: The European Space Agency's Aurora program seeks to explore the Solar System, starting with the Moon and Mars. ExoMars, the first mission in this program, will explore Mars with the aim of finding evidence of life. A longer term objective is to return a sample(s) of Mars to Earth for detailed investigation. Sites of instruments will be required for ExoMars and MSR for which the UK is well placed to deliver high quality instrumentation for which resources are required for their development. It is expected that post-ExoMars there will also be opportunities to participate in one or more missions to develop relevant technology important to UK interests in MSR – such as Rover development – but which will also provide new opportunities to investigate the surface environment of the planet.

Moon: Lunar exploration is now a major objective of many space agencies. UK scientists require continued funding for staff for exploitation of involvement in on-going missions LRO and Chandrayaan-1. Expertise from these and other missions and instruments should be developed to ensure that the UK can provide leadership in the scientific investigation of the Moon. The UK-led Moonlite mission (launch 2014-16) will deploy a network of penetrator probes for geophysical and geochemical investigation of the Moon surface and interior. Moonlite is likely to be a key programme in building up UK lunar science capabilities for a range of future missions – International Lunar Network, MoonNEXT.

Mercury: Bepi Colombo offers the opportunity to investigate this rocky body, to understand differences in planetary formation at different parts of the accretion disk as well as aspects about the history of Mercury and the inner Solar System recrded on the planets surface. UK scientists require support for their lead on the X-Ray Imaging Spectrometer which will map chemical variation across Mercury’s surface.

Minor Bodies: Primitive asteroids and comets are the remnants of Solar System formation, and contain the most pristine materials from processes occurring during the birth of the Solar System 4.56 Ga, particularly the astrobiologically important organic- and volatile-rich components. These bodies also present a major risk to Earth if one were to impact.

NEOs: UK has major leadership in the Cosmic Vision NEO sample return mission Marco Polo – in the sample science, instrumentation and systems hardware. Instrument leads, for which continued/further funding is required:

– Infra-red mapping spectrometer – for understanding of regolith properties
– Microscope system for sub-surface mineralogy and thermal properties
– X-Ray spectrometer for regolith composition.

UK industry has expertise in sampling methods for such extreme environments – which will require further development for this and future related missions.

Comets: The Rosetta mission is due to rendezvous with comet 67P/Churyumov-Gerasimenko in mid 2014 (for over 1 year). UK scientists are involved with thermal sensors, and mass spectroscopic analysis of the nucleus. Need staff for science exploitation phase, including sufficient ramp up time after long cruise phase.

Comets are expected to provide pristine materials from the birth of the Solar System. Return of a large sample of cometary nucleus material is the ultimate goal for the study of primitive materials in the solar system – and development of necessary instruments and sub-systems (e.g. micro-gravity sampling device) is required.

Outer Planets: Cassini mission is now extended until 2017 to explore seasonal effects on Saturn and Titan – UK involvement in a number of instruments – e.g. CIRS, ISS, CDA, etc – will require further funding for ongoing ops and new data exploitation.

EJSM is now the favoured outer planet mission scenario of Cosmic Vision – studying Jupiter and its satellites – principally Europa and Ganymede in order to investigate the emergence of habitable worlds around gas giants and to study the sub-surface oceans present on these two moons of Jupiter. UK has the opportunity to provide a number of instruments for this mission(s) as well as penetrator probes for deployment on Europa and Ganymede. Development of the instruments is required, a number of spectral imagers and the penetrator probes including a complete set of miniturised, impact toughened instruments.

Observing Requirements: Telescope observation of planetary bodies is an important aspect to some of the strands of research into planetary bodies.

In the case of minor bodies, improved access to telescopes with low resolution optical and infra-red spectroscopy capability for the detection and characterisation of minor bodies is required.

Continued funding and development of the Desert Fireball Network - providing orbital information for specific meteorites. Spectral characterization of NEOs in similar orbits will provide a means to much better determine the nature of the asteroids and the distribution of this material – invaluable information in developing a picture of Solar System structure at the time of its formation.

Mission Exploitation: It is critical that funds are available to support staff for the exploitation phase of each of these missions. Appropriate post-launch support is of course essential. But it is equally important that there is sufficient resource (staff, pdra, tech, HPC) to maximise UK exploitation of the results from these missions and to participate in the science exploitation of missions by other agencies or to which UK does not have direct input, but for which UK does have world-leading expertise in the analysis of those new datasets. The exploitation will include analysis of the returned data but may also include use of simulation experiments, complementary sample analysis, remote sensing, modelling and theory which need to be funded as appropriate, primarily through the grant line.

Supporting Infrastructure: Supporting the development of the missions and instruments identified above (as well as other mission areas listed in accompanying documents) a number of new facilities are required, as part of the new ESA Centre planned for the Harwell campus. This will include the Exploration Centre and the Robotics Facility. Key aspects of these facilities important to the development of UK involvement in Planetary Interiors, Surfaces and Atmospheres are:

Sample Curation: There is no centralised facility in Europe for the curation of samples returned from a space mission, required for the preliminary identification and characterisation of samples, documentation, sample preparation for distribution, storage and archiving. Sample suites in the foreseeable future include sample return from asteroids, the Moon and Mars as well as particularly precious samples of meteorites (e.g. falls of primitive/martian/lunar samples) and interplanetary dust collected in various localities including spacecraft hardware/collection surfaces.

Planetary Protection: This is an integral part of the technology development for missions and science of high astrobiological significance. This will include training of instrument-build staff in PP techniques and requirements, and analysis of contamination transport and input into the development of contamination free hardware/instrumentation. Requirements for this facility will include staff, suites of clean rooms, computing and environmental simulation chambers.

Robotics Facility: Intelligent, autonomous instrumentation (and systems) will be an important part of ever increasingly sophisticated spaceflight instrumentation, particularly for surface landers which have experiments attempting to emulate complex analyses and sample handling normally performed in the laboratory. Concurrent Design Facility (CDF) and prototyping capabilities will be key requirements for the UK to better develop leading instrumentation and sub-systems for future missions.

Wider Benefits

Planetary science, particularly the Solar System exploration aspects, has always been a great tool for public outreach and an inspiration for the next generation of scientists and engineers. The multidisciplinary science and technically challenging missions provide an attraction across a broad scientific spectrum. The development of a scientifically- and technologically-aware, highly-skilled workforce is one of the Governments key aims, and planetary science is an area which can be used to attract, and then train, young people.

Development of increasing autonomous robotic planetary missions and instruments is of particular interest to UK industry, where the expertise developed for spaceflight has potential application in the rapidly expanding, and huge robotic market for terrestrial applications (e.g., the food preparation market, nuclear industry decommissioning, etc).

There have already been several areas where instrumentation built for planetary exploration has been developed for wider application beyond the planetary sciences (e.g., CCD cameras used in medical imaging, etc). Miniaturised suites of instruments, and the technology behind such miniaturisation, has application in many areas, and the potential to deliver economic benefit to the UK.

Knowledge of planetary systems will help develop our understanding of the terrestrial system.