Science enabled by the Glo

MEETING REPORT Ian Crawford summarizes an RAS Specialist Discussion Meeting which examined how science stands to benefit from implementation of the Global Exploration Roadmap.

The Global Exploration Strategy (GES) was formulated in 2007 by 14 of the world's space agencies in an attempt to coordinate international activities relating to the robotic and human exploration of the inner solar system (GES 2007). One of its first fruits was the establishment of the International Space Exploration Coordination Group (ISECG) to coordinate inter-agency activities in space exploration; one of ISECG's first deliverables was the creation of a Global Exploration Roadmap (figure 1; ISECG 2011). This roadmap, which was revised in 2013 (ISECG 2013a), illustrates the continuing international effort to define feasible and sustainable exploration pathways to the Moon, near-Earth asteroids and Mars over the next 25 years, with an explicit focus on destinations where humans may one day live and work.

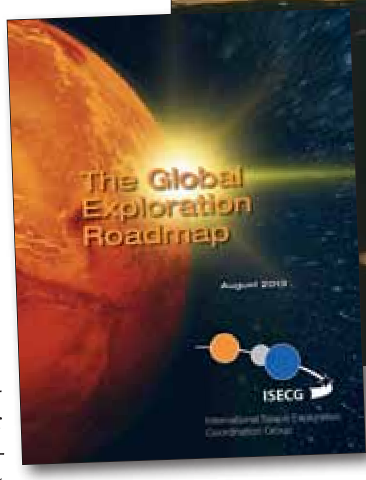
Many diverse areas of science represented by the RAS would benefit from implementation of the Global Exploration Roadmap (GER), including planetary science, astrobiology and aspects of observational astronomy. These potential scientific benefits were the topic of a Specialist Discussion meeting held at Burlington house on 8 November 2013. The meeting began with three scene-setting talks from space agency representatives who have had extensive involvement with ISECG and the development of the GER, before moving on to detailed discussion of the scientific aspects.

Agency talks

The first speaker was NASA's representative to ISECG, **Kathy Laurini**. Kathy introduced the Global Exploration Roadmap and explained NASA's perspective on it. She noted that the second iteration of the GER (ISECG 2013a) represents a major step forward by space agencies in collaboratively planning future space exploration scenarios. While this work focuses mainly on human space exploration, it is recognized that robotic missions will also play a crucial role in exploring solar system destinations where humans may someday live and work. Investigating ways to increase the synergies between human and robotic exploration missions is considered an important element of a sustainable space exploration effort. Although recent US space exploration policy has largely been redirected towards the exploration of near-Earth asteroids, it is recognized that most of the other ISECG partners see the Moon as an important step for human exploration. Because different governments and space agencies are always likely to have a range of ambitions, the GER demonstrates that feasible missions in the next decade can be defined which respond to individual government priorities while advancing the capabilities to meet common long-term goals.

The next speaker was **Jeremy Curtis** (UK Space Agency) who has been the UK representative to ISECG since its inception in 2007. The UKSA is strongly supportive of ISECG and of the GER. Although the UK has to-date stood aside from participation in human space exploration, Jeremy noted that UK policy in this area is changing with the UK's first ESA astronaut, Major Tim Peake, scheduled to begin a long-duration visit to the International Space Station in 2015. There is now a wider recognition in the UK that participation in space exploration can yield both scientific and societal benefits. To illustrate this point, Jeremy drew attention to the conclusions of ISECG's white paper on "Benefits stemming from space exploration" (ISECG 2013b), which identified significant benefits arising from space exploration as a result of contributions to innovation, culture and inspiration, and provision of new means to address global challenges, as well as purely scientific advances.

The last of the three space agency representatives to speak was **Sylvie Espinasse** (ESA) who discussed synergies between science-driven missions and the preparation for human exploration. In order to prepare for safe and efficient human exploration beyond low Earth orbit (LEO), mission planners will need access to data that characterizes the boundary conditions of exploration destination environments, identifies hazards and assesses resources. Such data can be obtained in space through robotic missions and/or on Earth. The ISECG Strategic Knowledge Gap (SKG) Assessment Team developed an internationally integrated and prioritized set of SKGs to inform planning of robotic precursor exploration of human exploration destinations (Wargo *et al.* 2013). The effort also mapped SKGs to planned robotic missions that will contribute to filling those gaps and identified high-priority SKGs not currently addressed. This assessment showed how robotic science missions are invaluable for obtaining the data needed to prepare for human exploration beyond LEO, and that data sets obtained from these missions support both the advancement of science and the preparation for later human exploration. Sylvie also made the important observation that, even if science isn't



1: The Global Exploration Roadmap.

bal Exploration Roadmap

2: Artist's conception of NASA's Orion Multi-Purpose Crew Vehicle, supported by an ESA Service Module, being tested in Earth orbit. This is exactly the kind of international cooperation that will be facilitated by the roadmap. Deployment of Orion to the Earth–Moon L2 point in the early 2020s will facilitate a number of lunar exploration objectives (e.g. Burns *et al.* 2013) while also testing technologies for the human exploration of Mars and near-Earth asteroids. (ESA)

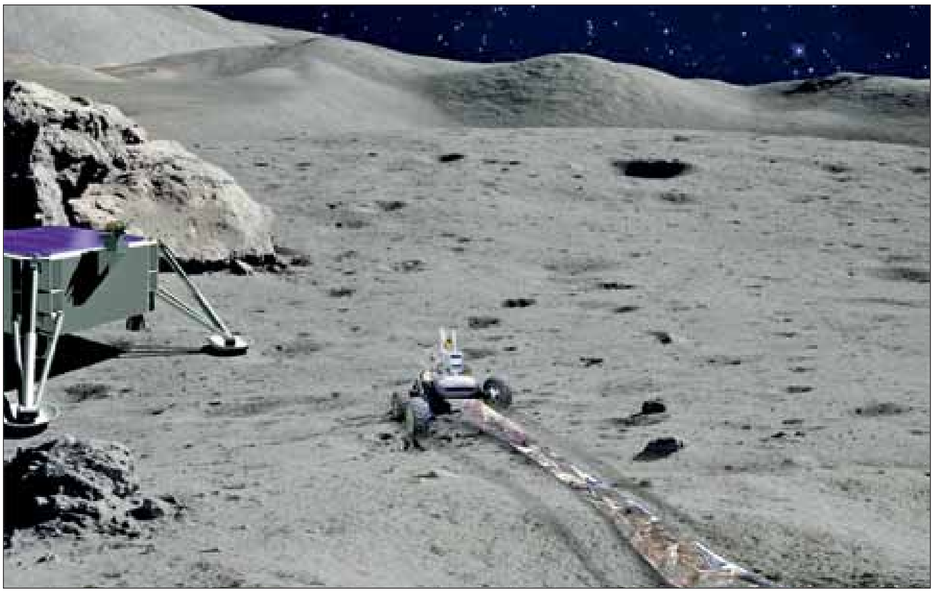
always the main driver for space exploration, it is very often one of the major beneficiaries. This may either be because of overlapping objectives between science and exploration, or because exploration infrastructures and a human presence can enable science experiments that would not be possible otherwise (e.g. the HST servicing missions, and the installation of the Alpha Magnetic Spectrometer on the ISS).

Science talks

Following these three agency presentations, the first science talk was by **Helen Fraser** (Open University), who discussed the relevance of the research opportunities offered by the European Programme for Life and Physical Sciences in Space (ELIPS) for space exploration as envisaged by the GER. In the field of astrochemistry, fundamental questions include "How does life originate?" and "Is life a natural by-product of the processes of star and planet formation?" On the one hand such research requires observational and laboratory understanding of the chemical evolution of the universe, while on the other hand it is reliant on evidence and data collected from our nearby laboratory – the solar system. With Mars, the Moon and near-Earth asteroids featuring as key exploratory elements in the GER, Helen argued that it is important to understand and interpret data from such exploration. From the perspective of the physical sciences, such preparatory activities will be strongly rooted in utilizing ELIPS microgravity facilities, particularly drop-tower experiments, parabolic flights (replicating microgravity, lunar, martian and asteroid gravitational conditions), as well as ISS experimental facilities. Helen also showed how science can benefit from human spaceflight capabilities; for example, experiments with colliding icy grains in microgravity are providing insights relevant to understanding the accretion of dust grains to form planets.

Helen was followed by **Simon Evetts** (UK Space Biomedicine Consortium), who spoke on space biomedicine research opportunities likely to result from implementing the GER. To fully explore our solar system we will require humans to spend long periods of time in an extreme environment which in many ways adversely affects the human body when Earth standards are retained as "normal". The physical deconditioning (muscle, bone, neuromotor control) seen after six months on the ISS indicates that longer deep-space missions will pose a challenge. Science will need to make advances in fields such as biomedicine, telemedicine and radiation protection to prevent unacceptable detriments to astronauts over the two to three years that some exploration missions may take (e.g. Clément 2005). Importantly, however, Simon noted that because the effects of long-term space travel can be likened to accelerated ageing, the search for solutions to space exploration needs will lead to a concomitant increase in our understanding and ability to prevent and treat terrestrial health issues related to ageing (Vernikos and Schneider 2010). The prevention of the deleterious effects of space exploration, and an augmented ability for autonomous diagnosis and treatment, will therefore also offer advances in healthcare solutions on Earth.

The final talk of the morning session was given by **Heino Falcke** (Radboud University) on potential astronomical benefits arising out of the GER. Heino pointed out that astronomers have often sought the most remote and isolated sites in order to access the best observing conditions, and that the exploration of other planets, as envisaged by the GER, may provide additional opportunities in this regard. Especially for radio astronomy, lunar exploration offers a completely new window to the universe. The far side of the Moon is acknowledged to be a unique location for a low-frequency radio telescope that would provide scientific data at wavelengths that cannot be observed from the Earth (figure 3). Scientific areas that would benefit include cosmology, solar-system studies, exoplanet detection, and astroparticle physics (Jester and Falcke 2009). Moreover, Heino argued that it would be interesting to revisit the possibility of installing telescopes operating at other wavelengths on the lunar surface, such as optical, near-infrared or even X-ray telescopes, which would benefit from both a large stable space platform (i.e. the Moon) and an infrastructure able to provide access to it. In addition, Heino noted that, as current space telescopes keep growing in size, even large free-flying space observatories could benefit from the heavy-lift and in-orbit assembly opportunities developed as part of the GER.



3: Artist's concept of a robotically deployed antenna on the lunar surface forming part of a low-frequency array to observe the early universe. (Joe Lazio/JPL/NASA)

Moon exploration

The first talk after lunch was given by **David Kring** (Lunar and Planetary Institute) on the case for an integrated robotic and human exploration of the Moon within the context of the GER. David argued that the Moon is the most accessible target for space exploration beyond LEO, and provides technical challenges that will sharpen our ability to explore more distant targets. Moreover, the Moon is a destination worthy of exploration: we have never been to the Moon's far side, western limb, or the polar regions – most of the Moon, in fact. The Moon is also an important scientific destination: it is the best target to evaluate the origin and evolution of the entire solar system, including the earliest evolutionary phase of our own planet, a period of geologic activity that has since been erased from Earth's rock record. In addition, the Moon contains evidence of planetary accretion, the production of magma oceans and planetary differentiation, and the collisional processes that shape planetary surfaces. The latter aspect of the lunar geological record is essential to our evaluation of environmental and biologic consequences of impact cratering events, both on Earth and other potentially habitable worlds like Mars (e.g. Kring 2003). David also pointed out that recent work suggests there is a variety of volatile deposits on the Moon which can both be used to further explore the collisional evolution of the Earth–Moon system, and provide *in situ* resources which may ease the economic hurdles of exploration beyond the Moon as envisaged by the GER.

The next talk was given by **James Carpenter** (ESA) who pointed out that the sequence of missions outlined in the GER would provide an unprecedented opportunity for scientific research. He highlighted especially the scientific opportunities that implementation of the GER would offer by providing renewed access to the lunar surface and the return of lunar samples. Recent data from orbiting missions and new analysis of existing lunar samples has led to a new focus on the value of the Moon for a broad range of scientific disciplines. Regolith serves as a recorder of the early history of the Earth and Moon and the inner solar system. Ices at the lunar poles may contain complex organics and information of the sources of volatiles and prebiotic chemistry on Earth. Samples from impact basins provide ages for the epoch of the basin-forming events while dating of the surface generally provides a reference for the impact chronology for the entire inner solar system. In addition, the Moon serves as a reference point for planetary formation and evolution processes in general. New lunar samples could therefore be used to address scientific questions relating not just to the Moon itself, but also to areas as diverse as the emergence of life, the history of the inner solar system and the passage of the solar system through the galaxy. There are numerous other potential science questions that can be addressed through utilization of lunar surface access, for fundamental physics, space science, astronomy and life sciences (e.g. Crawford *et al.* 2012). Through the GER the Moon could therefore become a place both to research in its own right, and a platform for research in other areas. An opportunity to advance lunar exploration within the context of the GER may come in the 2020s from operation of NASA's Orion Multi-Purpose Crew Vehicle, incorporating an ESA-supplied service module (figure 1) at the Earth–Moon L2 point to support robotic operations on the lunar far side (Burns *et al.* 2013).

Mars exploration

Moving beyond the Moon, the next talk was given by **Monica Grady** (Open University) on opportunities for Mars exploration within the context of the GER. Monica pointed out that Mars has long exerted a fascination on humans in terms of its potential for exploration because it is relatively nearby and because of its potential for hosting life. Human Mars exploration is the ultimate goal of the GER, although robotic exploration will be required beforehand. Indeed, we have learned a lot about Mars from the various robotic missions that have visited the Red Planet in the five decades since space exploration began. We can also learn about Mars from analysis of martian meteorites. But Monica argued that there is more that we need to know and understand before we can send humans to Mars and bring them back again safely. At the very least, we need to bring rock and soil samples back from the surface of Mars so that they can be analysed in laboratories on Earth. Analysis of such material would directly address some of the strategic knowledge gaps related to Mars exploration (e.g. the possible biological and/or chemical hazards of martian dust) that Sylvie addressed in her talk earlier in the day. Monica outlined one possible robotic Mars sample return mission scenario that could be a valuable and important step in the progress towards the human exploration of Mars (Grady *et al.* 2013). In the longer term, the in-depth study of Mars, the search for past or present life, is likely to benefit from such human exploration.

The next talk was given by **Mark Sephton** (Imperial College London) on astrobiology research opportunities arising from the GER. The GER prescribes a stepwise development of exploration into the solar system, with the medium-term goal of human missions to Mars. The necessary development of technologies and investigation of planetary environments will provide numerous astrobiological research opportunities. In the search for life, geological and biological assessment of solar system targets such as the asteroids, Moon and Mars can all act as indicators of how planet formation

4: An artist's conception of NASA's Orion Multi-Purpose Crew Vehicle operating on the surface of a near-Earth asteroid. As for Moon and Mars exploration, human missions to asteroids, as envisaged by the GER, would add scientific value by enhancing mission flexibility and sample-return capacity compared to what can be achieved robotically. (NASA)

can evolve to produce habitable environments. The detection of organic remains elsewhere in the solar system is another high priority activity (Sephton 2013), and various biosignatures can be sought with a focus on both how they may be produced and how they may be preserved (Sephton *et al.* 2013). Echoing comments made by Jeremy Curtis on the societal benefits of space exploration, Mark reiterated that many space-based astrobiological objectives can have terrestrial applications in the form of educational stimuli, public engagement, and medical and industrial innovations.

Asteroid exploration

Mark Burchell (University of Kent) then discussed asteroid science opportunities resulting from the GER. Mark pointed out that the human and robotic exploration of space are often discussed separately, with apparently independent aims. Part of this is because there has been little human exploration in space since the Apollo era; although astronauts now conduct research on the ISS, no-one has ventured beyond low Earth orbit since the last Apollo mission in 1972. The development of a new human deep-space capability as envisaged by the GER may offer the opportunity to remedy this. It is therefore timely to integrate scientific goals into mission objectives as early as possible. Over the last few years the topic of an asteroid mission by NASA astronauts has arisen. Mark reviewed the importance of asteroid studies (see also Burchell *et al.* 2013) and the role human spaceflight can play in best achieving and extending asteroidal research objectives (figure 4). Mark stressed that humans *in situ* at the exploration target will add scientific value by enhancing mission flexibility, and drew particular attention to the likely need for a human presence to facilitate deep drilling operations into the interiors of asteroids. Similar arguments also apply to the scientific investigation of larger bodies such as the Moon and Mars.

The final talk was given by **Ian Crawford** (Birkbeck) on the GER as a step towards an integrated scientific and societal case for global space exploration. He argued that an ambitious programme of robotic and human space exploration, such as envisaged by the GER, will add greatly to human knowledge in multiple areas. Human exploration of the Moon and Mars will increase our knowledge of the history and evolution of the solar system beyond what can plausibly be achieved by robotic exploration alone (Crawford 2012), while also facilitating scientific advances in astronomy, fundamental physics, and human physiology and medicine. Consideration of the scientific arguments for space exploration must therefore take a holistic view, and integrate the potential benefits over the entire spectrum of human knowledge. Moreover, science is only one thread in a much larger overall case for space exploration, which also includes economic, industrial, educational, geopolitical and cultural benefits (Crawford 2005, ISECG 2013b). Any responsibly formulated public space policy must weigh all of these factors before deciding if an investment in space exploration is scientifically and socially desirable. The development of the Global Exploration Strategy, and the resulting roadmap, is a significant positive step in this direction. Ian also pointed out that the GER is fully consistent with the important principle enunciated by Hartmann (1985) that "space exploration and development should be done in such a way so as to reduce, not aggravate, tensions on Earth".

Posters

In addition to the talks, three posters were presented at the meeting. **Abigail Calzada-Diaz** and **Jane MacArthur** (Birkbeck/UCL) presented a poster on the perspectives of students and young space professionals on the GER. They presented the results of a survey which indicated that most of the more than 50 respondents are supportive of the GER and the need for inter-agency collaboration in space exploration. Respondents widely agreed that China should be participating in the GER, which echoed similar comments made during the day at the meeting.

Ashley Dale (University of Bristol) and colleagues presented a poster on a simulated martian expedition at the Mars Desert Research Station in Utah, where a six-person crew of scientists and engineers will conduct research and fieldwork in a simulated Mars environment; training in such analogue environments is a valuable means of preparing for human space exploration.

Setnam Shemar (National Physical Laboratory), **John Pye** (University of Leicester) and colleagues presented a poster on the feasibility of using X-ray timing observations of pulsars for deep-space navigation (XNAV). The XNAV technique could allow increased spacecraft autonomy, improved position accuracies, and lower mission operating costs compared to existing systems; potential instrumentation has been designed in the context of the Mercury Imaging X-ray Spectrometer for ESA's BepiColombo mission to Mercury.

Overall, the meeting, which was attended by 69 participants, demonstrated considerable interest in the GER among the scientific communities represented by the RAS. Although science is only one thread in the totality of the case for greater international cooperation in space exploration, with equally important threads covering economic, political and societal aspects, it seems clear that science would be a major beneficiary of implementing an ambitious global space exploration programme such as envisaged by the Global Exploration Roadmap. ●

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Acknowledgments. I thank the RAS for supporting this meeting, and my fellow organizers for their help: Jeremy Curtis, Jill Stuart and John Zarnecki. Most of all I thank the speakers for their contributions which resulted in such an interesting meeting. The summaries of talks here are based on the abstracts provided by each named speaker, supplemented by my own notes. It is intended that more detailed versions of some of the above contributions will appear in a forthcoming issue of the international peer-reviewed journal Space Policy.

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