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THE ISECG GLOBAL EXPLORATION ROADMAP: STRENGTHENING EXPLORATION THROUGH INCREASED HUMAN ROBOTIC PARTNERSHIP

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An update of the Global Exploration Roadmap (GER) was released in August 2013 by the International Space Exploration Coordination Group (ISECG). The GER builds on the initial efforts by space agencies to prepare for future human exploration of the solar system and reflects the current status of their ongoing road-mapping effort. It reflects the work of space agencies to identify common exploration goals and objectives and look for feasible and sustainable approaches to meeting them. While this work focuses on human space exploration road-mapping, it is recognized that robotic missions are also planned to destinations where humans may someday live and work. Initially, robotic missions will gather high priority science information and contribute to the knowledge base that informs future human missions. Later, they will explore together with humans, taking on roles which increase return on exploration mission investments. This paper will focus on the importance of increasing the natural synergies between human and robotic exploration missions and describe current and potential future initiatives aimed at achieving this goal.

Human exploration of the solar system will proceed in a step-wise manner, extending proven capabilities to achieve more complex goals while enabling new discoveries with each step. Human presence beyond low-Earth orbit enables new opportunities realizing space exploration goals and objectives. New opportunities will be greatly expanded by increasing the coordination with robotic missions, where appropriate. For the most part, robotic missions planned today are primarily science driven missions, however, the information they will collect will help prepare for future human missions. Some agencies are considering missions which are mainly driven by the desire to collect information or reduce risks to future human missions. While these missions have a primary purpose to inform future human missions, they can collect information which is of interest to the science community. Lastly, several privately funded robotic missions are envisioned to help inform future asteroid mining or other human activity in space. Increasing collaboration will be an important contributor to sustainable space exploration.

Since its release in September 2011, the GER has served as a useful tool in many ways. This paper will discuss the recently updated GER and highlight its role in expanding human robotic mission partnership opportunities.

To obtain a copy of the GER or find more information on the ISECG, please consult the ISECG website at www.globalspaceexploration.org or contact the ISECG Secretariat at: isecg@esa.int.

INTRODUCTION

Space exploration, initiated over 50 years ago, has brought new knowledge that has helped us understand the universe in which we live as well as improve our lives here on Earth. Both human and robotic missions have made important contributions. Guided by driving questions and human curiosity, human and robotic explorers have each brought their unique skills to bear in the exploration of space. Looking forward to destinations where humans may someday live and work, namely the Moon, asteroids and Mars, there remains strong scientific interest in each of these destinations. ISECG is working to advance an international long-range human exploration strategy through its human spaceflight road-mapping effort. This work is reflected in The Global Exploration Roadmap (GER), updated in August 2013. Participating agencies have included a focus on identifying and promoting initiatives which build on the natural synergies between human and robotic science missions to enable realization of a greater set of objectives for each community.

Human exploration of the solar system will proceed in a step-wise manner, extending proven capabilities to achieve more complex goals while enabling new discoveries with each step. Human presence beyond low-Earth orbit enables new opportunities realizing space exploration goals and objectives. New opportunities will be greatly expanded by increasing the coordination with robotic missions, where appropriate. For example, samples returned from the Moon by Apollo astronauts continue to provide information to the science community more than 40 years after they were returned. How can this legacy be expanded by future human missions? Planned and future robotic missions can provide information which helps the planning and preparation for human missions. How can these opportunities be realized?

For the most part, robotic missions planned today are primarily science driven missions selected through rigorous and proven processes which address the most important science questions, including community involvement and peer review. These missions are implemented by outstanding science and engineering teams which have demonstrated a thorough knowledge of the extreme environments of space. A new generation of human space exploration capabilities is opening the door to human exploration beyond low-Earth orbit for the first time since Apollo. Sharing knowledge between the human and robotic space exploration communities can create opportunities for increased collaboration. What are the sample selection and handling requirements to maximize science value at a given human destination? What do we know about the natural environments on Mars which can impact crew safety and productivity? What mobility techniques have proven successful in dusty planetary environments?

Privately funded human and robotic initiatives target destinations such as asteroids, the Moon and Mars. These efforts represent significant investments in advancing systems and capabilities which will benefit future human exploration of space, creating partnership opportunities where expertise, resources and ideas can be advanced to mutual benefit. What new partnership models enable leveraging of knowledge and resources to the benefit of privately funded and government initiatives?

This paper expands on some of the questions raised above through description of the updated GER, including several innovative new exploration concepts which are considered worth additional study by both the human and robotic exploration communities.

THE GLOBAL EXPLORATION ROADMAP

Consistent with existing policies, programs and plans of participating agencies, the updated GER continues to advance an international long-range strategy for future human exploration missions. This common strategy begins with the International Space Station to prepare for exploration and leads to a sustainable human exploration on the surface Mars. As shown in figure 1, the GER emphasizes the near-term initiatives in implementing the common international strategy, namely: 1) fully utilizing the ISS, 2) continuing efforts to expand on synergies between human and robotic missions, and 3) discovery-driven missions in the lunar vicinity that evolve capabilities and techniques needed for Mars, while enabling discoveries on the Moon and near-Earth asteroids.

Agencies continue to advance exploration scenarios to support future government decisions. As such, the GER reflect the status of interagency work within the originally defined framework of topics necessary to inform future partnerships:

- Common Goals: A thorough assessment of individual agency goals and objectives was conducted during the development of the initial GER. The eight high-level common goals and associated objectives remain unchanged since the initial GER release.

- The Long-Range Strategy: The strategy is elaborated through a conceptual mission scenario which is a sequence of missions over an approximately 25 year period. The strategy reflects a coordinated international effort to advance common goals and objectives while enabling interested agencies to pursue their priorities and prepare for critical contributions to human Mars missions.

- Near-term areas for Coordination and Cooperation: Agencies continue to look for opportunities to leverage their investments in preparatory activities. Preparatory activities in the following areas represent significant investments and initiatives in each area are summarized:

  - Robotic precursor missions;
  - Development of enabling technologies;
  - Use of ISS for preparation of exploration missions beyond low-Earth orbit;
  - Development of new systems and infrastructure;
  - Analogue activities,
  - Human health and performance risk mitigation.

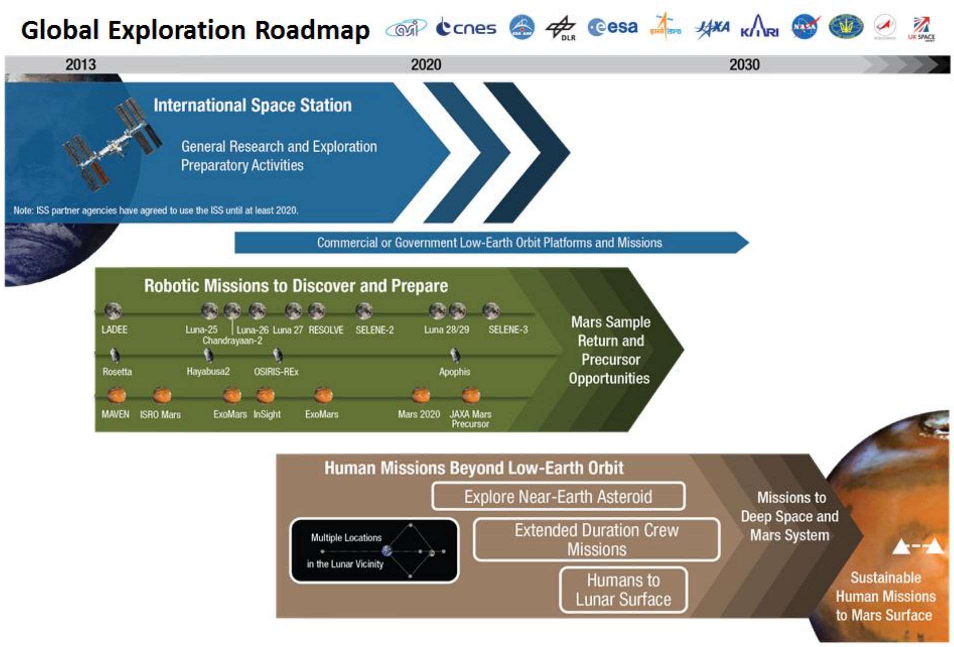

Figure 1: The Global Exploration Roadmap highlights near term exploration priorities

The ISECG Mission Scenario

The conceptual ISECG mission scenario reflects opportunities for pursuing both asteroid and lunar exploration objectives in the lunar vicinity and surface of the Moon as steps toward advancing critical capabilities provided by multiple partners and needed for future missions to the Mars system. It recognizes that missions to Mars will be successful if multiple agencies contribute critical capabilities. The mission scenario (See figure 2) reflects a stepwise development and demonstration of international capabilities necessary for executing increasingly complex missions, while focusing on discoveries at multiple destinations. The focus of the scenario is on conceptual missions, both human and robotic missions. However, ongoing and planned robotic and human missions are critical for preparing for human missions to Mars and they are also shown in the mission scenario.

The mission scenario starts with the ISS. The ISS provides the opportunity to conduct research and technology demonstrations along with advancing critical exploration capabilities. The next step for humans would be to explore beyond low-Earth orbit into the lunar vicinity. Missions in the lunar vicinity, such as those to an easily accessible asteroid or an evolvable Deep Space Habitat, could enable discoveries and allow demonstration of the systems on which long-duration missions into deep space must rely. Human missions to the lunar surface could allow demonstrations of planetary exploration capabilities and techniques, while pursuing the highest priority lunar science objectives. Capabilities developed and lessons learned from human exploration of the lunar vicinity could advance the readiness for human Mars missions after 2030.

The scenario reflects NASA's priority for pursuing asteroid missions as a step towards advancing critical capabilities needed for future missions to the Mars system. As an international mission scenario, it recognizes that many space agencies favor the Moon as their next human space exploration destination, and can use these missions to demonstrate critical capabilities needed for future Mars surface missions. Taken together, the missions represent a unified space exploration plan which creates opportunities for partnership in realization of any particular mission theme.

Several new and innovative concepts have been advanced in preparing the updated GER. Each one is considered to have the potential to increase benefits to both the human spaceflight and robotic science mission communities. In particular, human-assisted sample return and tele-presence concepts have been introduced. Mars sample return is a priority for the planetary science community and a sample from Mars will bring insights that aid the preparation for eventual human surface missions. With the ExoMars and Mars 2020 missions, information and samples will be gathered, inviting innovative solutions for mission concepts which enable them to be returned to Earth. The ISECG mission scenario promotes further study on human-assisted mission concept, taking advantage of capabilities and crew presence to return the samples in a manner that reduces complexity of robotic missions.

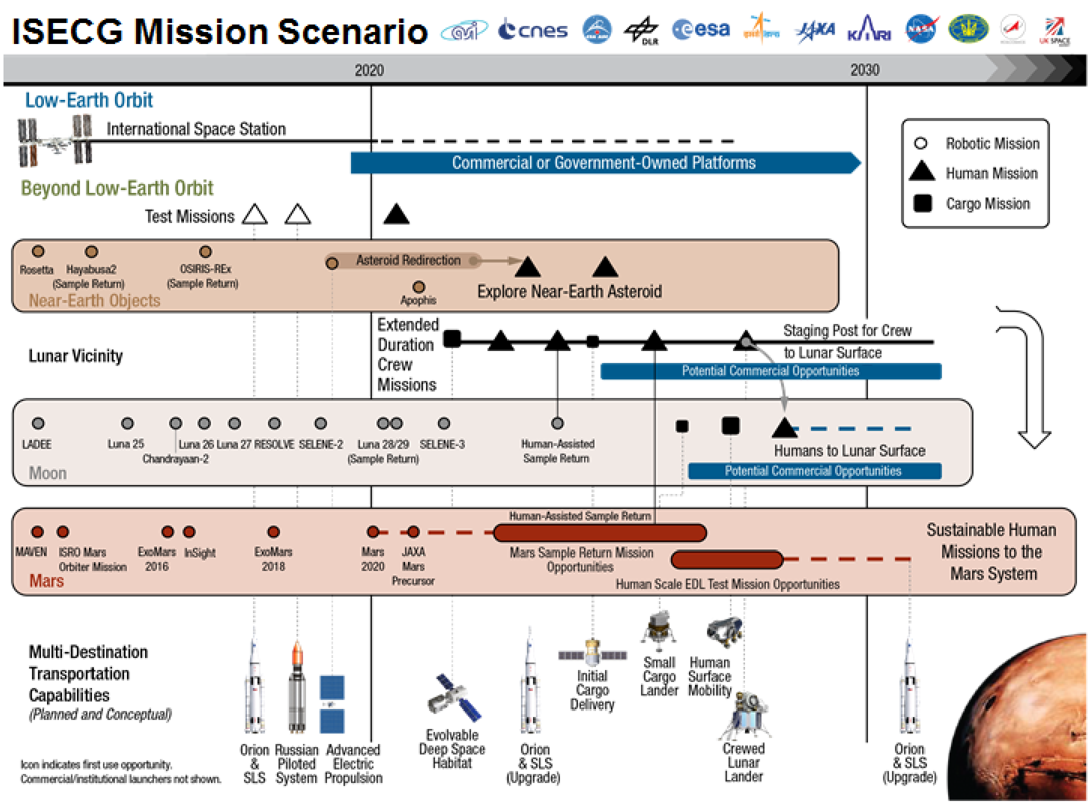

Figure 2: Global Exploration Roadmap Conceptual Mission Scenario

ISECG OBJECTIVES RELATED TO EXPANDING THE HUMAN ROBOTIC MISSION PARTNERSHIP

Agencies participating in ISECG have defined strategic shared principles which are intended to inform mission scenario development. Each of the driving principles, shown in Figure 3, are considered important to participating agencies and capture the characteristics of a sustainable (one that can be supported by politicians over a long period of time) human exploration effort. The interdependent nature of the driving principles demonstrates how efforts to increase synergies between human and robotic science exploration missions are so important. Global affordability constraints dictate that the value delivered by each exploration mission be significant and as far reaching as possible. And, by defining human exploration activities to include integrated scenarios where both humans and robots are simultaneously exploring a destination, an opportunity is created for nations with robotic mission capabilities who are interested in significant contributions to human exploration.

Principles Driving the Mission Scenario:

Affordability – Take into account budget constraints

Affordability of a complex exploration programme must be maintained over extended periods of time. Cost must be a consideration when formulating programmes and throughout programme execution. Innovations and integration of advanced technologies must be driven by the goal to reduce costs. Each agency's planned contributions must accommodate realistic expectations regarding cost and the future availability of funding.

Exploration Value – Generate public benefits and meet exploration objective

Sustainable human space exploration must respond to exploration goals and objectives and deliver value to the public as well as to participating stakeholder communities, beginning early in the process and continuing throughout the journey.

International Partnerships – Provide early and sustained opportunities for diverse partners

Broad international cooperation is not only critical for enabling increasingly complex exploration missions, but also an important contributor to achieving exploration value. Mission scenarios must build on the competencies and long-term interests of each agency, large or small, allowing each to sustain and grow its aspirations for space exploration. Collaborations will be established at all levels (missions, capabilities, technologies), with various levels of interdependency among the partners. These collaborations should be set up to ensure resiliency of the programme against failures, delays or programmatic issues. In addition, opportunities for new partners should be available to strengthen robustness of the overall partnership.

Capability Evolution – Execute missions of increasing complexity based on the stepwise development of capabilities

Sustainable human exploration beyond low-Earth orbit, toward the long-term goal of human missions to Mars, requires building upon existing capabilities and competencies, increasing performance with each step. New technologies should be pursued and applied to address challenges. Exploration mission challenges necessitate advancing and demonstrating critical capabilities to manage risk.

Human/Robotic Partnership – Maximize synergy between human and robotic missions

Combine the unique and complementary capabilities of humans and robotic systems, enabling a greater set of goals to be met effectively, cost-efficiently and safely. Robotic precursor missions will prepare for human missions by acquiring strategic knowledge about future destinations and demonstrating critical technologies. Use of robots to assist and complement crew activities will also enhance the productivity and benefits of eventual human exploration missions to any given destination.

Robustness – Provide for resilience to programmatic and technical challenges

A robust human space exploration programme will have sufficient flexibility to cope with unplanned changes or crisis situations, whether they are due to catastrophic events, changes in the partnership structure, adjustments in available funding or evolution of the exploration goals and objectives. To achieve robustness, dissimilar redundancies of critical functions should be applied early, where practicable.

Figure 3: Principles driving the ISECG Conceptual Mission Scenario

Agency participants in ISECG are predominantly representatives of the human spaceflight community, yet the global science community is also represented. This diversity ensures that ISECG is careful to respect the considerations of each community while looking for initiatives which have the potential of creating a meaningful step in expanding the human robotic mission partnership. This was the spirit in which the concept of human exploration "strategic knowledge gaps" was created. Establishing a set of human exploration knowledge gaps, reviewed by human spaceflight and science communities globally was the goal of ISECG. By making these gaps available, it is hoped that opportunities for addressing them with missions in formulation will be realized by nations around the world.

Ensuring the sustainability of space exploration is the overwhelming driver to pursuing initiatives which expand the human robotic exploration partnership. The strategic knowledge gap database also captures the contribution of each on-going and future mission to generating information which informs future human exploration. In this way, each mission, whether an agency is a participant or not, carries the opportunity to share the excitement and interest in space exploration, inspiring and generating knowledge which brings benefits to people around the world.

CURRENT INITIATIVES

Efforts have been made to further identify concrete opportunities for coordination of human and robotic missions. Work within the ISECG focused on two aspects: 1) the definition of strategic knowledge gaps and 2) identification of new exploration approaches which use the unique skills of humans and robots to advance a larger set of exploration goals. The work of ISECG has been concentrated on expanding synergies between human missions and agency-funded robotic missions. Increasingly, there are robotic exploration missions which are privately funded. These may also provide opportunities for collaboration which benefit both communities.

Strategic Knowledge Gaps

Many robotic missions are planned to destinations where humans may someday live and work. These are shown in Figure 4. Some of these missions will be launched in the next year; others are early in the mission formulation process. The identification of Strategic Knowledge Gaps (SKGs) was an initiative worked by ISECG together with several science community groups and representatives. The inputs from these groups and individuals were invaluable and not only promoted a wider understanding of information of interest to both the science and human exploration communities, but also established a common terminology which is certain to facilitate communication going forward. The basic ideas is to identify specific knowledge which can help human mission planners understand exploration destinations, thereby increasing the safety, efficiency and effectiveness of future human missions. By making this information available to robotic mission planners around the world, opportunities are created to enhance the specific knowledge about exploration destination required by human mission planners. By mapping the SKGs to planned missions or ground based activities, it also helps to communicate the benefits of each mission and promote overall sustainability of space exploration.

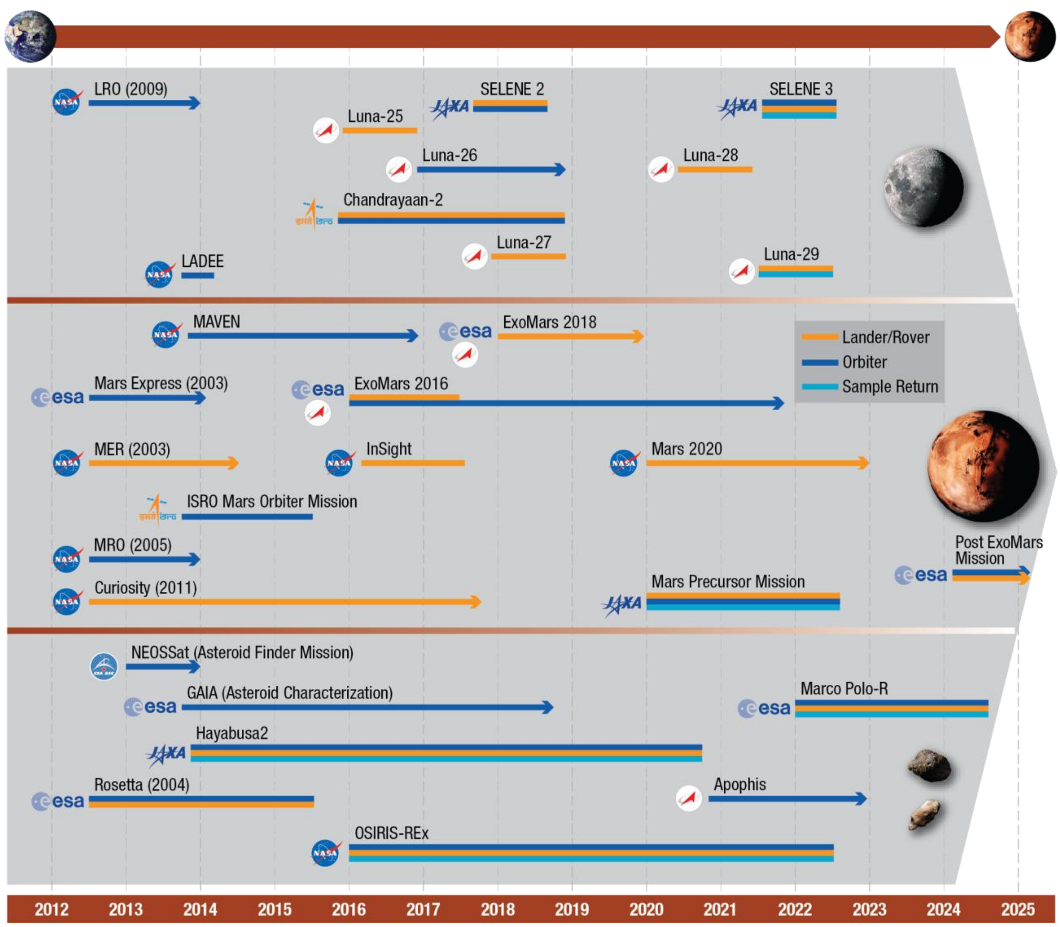

Figure 4: Robotic missions: The figure indicates on-going and planned mission with the respective lead agency. Most of these missions feature international partnerships and have significant technical and scientific contributions from other agencies.

A detailed list of SKGs has been defined and then prioritized on the basis of crew/mission risks, relevance to the ISECG mission scenario, and applicability to more than one destination. The list identifies specific measurements which would contribute to filling the gaps. It also gives insights into how recent and planned robotic missions and ground-based activities will contribute information related to the gaps and where additional measurements will be useful to fill the gaps. Figure 5 shows an excerpt of the list. The full list can be downloaded at the ISECG website.

Destination	Knowledge Domain	Strategic Knowledge Gap: Description and Priority	Target Measurement	Mission or Ground Based Activity Addressing the SKG	Additional Measurements: R = Robotic Mission SR = Sample Return G = Ground Based Activities
Moon	**Resource Potential**	**Lunar Cold Trap Volatiles:** Composition/quantity/distribution/form of water/H species and other volatiles associated with lunar cold traps.	In-situ measurement of volatile characteristics and distribution within permanently shadowed lunar craters or other sites identified using remote sensing data (e.g., from LRO)	Roscosmos Luna-25/ Luna-27/Luna-28 and 29 NASA-CSA RESOLVE	R, SR
Near-Earth Objects (NEO)	**Human Mission Target**	**NEO Composition/Physical Characteristics:** Rotation State	Light curve and radar observations from different ground (Earth based telescopes) and space based assets.	e.g.: Goldstone Observatory (US); Bisei Spaceguard Center (Japan), Observatoire du Pic du Midi (France)	G, R
Mars	**Atmosphere**	**Atmospheric Modeling:** The atmospheric models for Mars have not been well validated due to a lack of sufficient observational data, and thus confidence in them is limited.	Density, pressure, temperature, and wind data, trajectory performance information	NASA Viking, Pathfinder, MGS, MERs, Phoenix, MRO, MSL ESA Mars Express ESA-Roscosmos ExoMars 2016, 2018	G, R

Figure 5: Example strategic knowledge gaps

As mentioned above, establishing and communicating a coordinated list of SKGs is intended to inform the definition of objectives for future robotic missions and ground-based activities and it is hoped that availability of this information will contribute to further strengthen coordination between the communities planning robotic and human missions and thereby increase the value of space exploration investments to our global stakeholder community.

<u>New Exploration Approaches</u>

Several innovative mission concepts are included in the GER: tele-presence and human-assisted sample return. Each of these exploration concepts attempts to use the unique skills of humans and robots to achieve exploration objectives which might otherwise not be achievable in the timeframe or given affordability constraints. The concept of low-latency, high bandwidth tele-presence was promoted in several stakeholder consultation efforts associated with the initial GER. In preparing the updated GER, ISECG has supported discussions within the broader community on each of these concepts.

In addition, the importance of using local resources has been discussed and a coordinated approach has been advanced. By using robotic missions to assess the availability and usability of resources it is possible to gain information which advances future human exploration architectures. Robotic resource prospecting missions also address high priority science goals.

Human-Assisted Sample Return

The concept of human-assisted sample return is based on the assumption that human missions in the lunar vicinity will take place for advancing broader exploration goals and taking the first steps toward enabling human missions to the Moon, deep space and Mars. A robotic mission will be sent to the destination of interest, collect samples, and deliver them to a location in space which can be accessed by the crew in the 2021-2028 timeframe. The crew can collect the samples and return them back to Earth for analysis. This concept can enhance the value of sample return missions in various ways:

- Increased science return with a larger and more diverse set of samples;

- Reduced complexity of robotic mission, transferring sample handling responsibilities to the crew and Earth re-entry capabilities to the crew system;
- Improved mission robustness and reliability due to having a human in the loop;
- Better opportunities for public engagement due to astronaut involvement;
- Broader opportunities for international cooperation.

This concept provides opportunities to revisit the approach for sample return missions targeting asteroids, Moon and Mars. The human mission to an asteroid which has been redirected to a stable orbit in the lunar vicinity offers the opportunity to collect samples from the asteroid. The asteroid mission is intended to collect a larger (and hopefully more diverse) sample set than planned robotic missions. Collecting, handling and securing the samples for safe return to Earth will expand the technology currently available for planetary sample collection. These advances can be put to use for acquisition of lunar and Martian samples.

In advancing concepts for human-assisted sample return, it is advisable to demonstrate the added value provided by such an approach over a purely robotic sample return mission. An example could be reducing the complexity of the robotic mission or increasing the sample size and diversity. In the case of Mars sample return, reducing the required number of missions could be studied. For example, can the "Mars ascent vehicle" be simplified if it does not have to rendezvous with the return vehicle in the Martian vicinity but rather puts the sample on a slow trajectory back to the Earth-Moon system? Such a proposal may, in fact, complicate the design of the ascent vehicle, but this will not be clear until a study of the conceptual architecture is performed.

Tele-presence

Tele-presence can be defined as tele-operation of a robotic asset on a planetary surface by a person who is relatively close to the planetary surface, perhaps orbiting in a spacecraft or positioned at a suitable Lagrange point. Tele-presence is a capability which could promote humans and robotic exploration where the specific exploration tasks would benefit from this capability. Potential tasks include those characterized by high-speed mobility, short mission durations, focused or dexterous tasks with short-time decision-making, reduced autonomy or redundancy on the surface asset as well as contingency modes/failure analysis through crew interaction. The concept of tele-presence is currently under evaluation through several on-going and planned ISS activities. Examples include delay tolerant networking and haptic and immersive technologies for remote robotic operations, leading ultimately to simulating operations of robots on planetary surfaces from space.

In assessing the needed capabilities and driving risks associated with future Mars missions, ISECG has also reviewed work done by NASA on missions to the Martian vicinity. Conceptual Mars vicinity missions, where the crew does not land on the surface of Mars but remains in Martian orbit or the vicinity of Phobos or Diemos, do not require surface access capabilities. While ISECG has not reviewed mission concepts in great detail, it is recognized that these missions offer the opportunity for crew to control robotic assets on the Martian surface potentially expanding the set of achievable mission objectives.

Tele-presence has been proposed as an exploration paradigm which eliminates the need to ever send humans to a planetary surface as a way of reducing the costs of exploration. Such a proposal, while innovative, would put an additional and significant burden on the cost/benefit analysis associated with human space exploration. A human space exploration value proposition is traditionally difficult to establish, primarily due to the long-term nature of benefit delivery and the intangible effects of human spaceflight on global innovation. Realizing certain tangible and intangible benefits may be difficult without sending the crew to a planetary surface. Lastly, it is widely believed that the presence of crew on the surface will significantly increase science return.

In-Situ Resource Utilization

Maintaining human presence beyond low-Earth orbit would benefit significantly from use of local resources. Use of local resources would limit the cost and complexity of bringing all the needed supplies from Earth, at the cost of systems to extract and manage these resources at the destination. The most promising uses for local resource utilization are in life support systems or as propellants. The technology and capabilities needed to do this cost effectively and safely have progressed from paper concepts to systems developed and tested at analogue sites, but more work is required. The ISECG mission scenario recognizes the early robotic missions taking the first steps to assess usability of lunar (or asteroid) resources in a cost-effective and safe manner will bring important information to both the human spaceflight and science communities and is a great symbol of the potential benefits of expanding the human robotic partnership.

Mars resource utilization has primarily focused on providing oxygen and possibly fuel for ascent propellant from the Mars surface to orbit, by processing carbon dioxide collected from the Mars atmosphere. While the Moon does not have an atmosphere, the lunar regolith is known to contain oxygen. Techniques for its extraction have been proposed and demonstrated in the laboratory and in the field. Existing data indicate higher levels of hydrogen in the polar region, however, neither the exact concentration of the volatiles in the regolith, nor the precise distribution is known. To gain an understanding of whether lunar volatiles could be used in a cost effective and safe manner, it is necessary to understand more about the nature and distribution of the volatiles and whether they could be processed cost effectively. Several of the planned robotic missions are attempting this lunar resource prospecting. Information from these missions will inform prospecting techniques on Mars.

OPPORTUNITIES TO FURTHER INTEGRATE HUMAN AND ROBOTIC MISSIONS

Efforts to further build on synergies between human and robotic missions can be expected to bring significant benefits to each community. Identifying opportunities which have a good chance of success has been the priority of ISECG. Robotic missions are currently executed by many agencies, while human missions remain largely in the planning stage. This reality creates reluctance in both communities to actively pursue specific investments or spend a lot of time advancing particular concepts. This is understandable. However, it is important to increase appreciation of possible positive outcomes over the long term through advancement of specific initiatives where the investment of time is commensurate with potential future benefits.

When human presence is extended to the Moon and Mars, it is likely that first missions will be in the vicinity of these destinations rather than on the surface. Missions to the surface will follow. Whether humans are exploring the Moon, asteroids or Mars they can be assisted by robots, with each taking on roles which are best suited for their unique capabilities. Planning cost effective exploration approaches which are built around these unique skill sets promises to drive innovations in ways which further expand the benefits generated when humans do arrive on the scene.

The authors suggest several opportunities to further promote human robotic synergies and suggest they be explored within ISECG. They are briefly described below:

1. Deliberately include opportunities for addressing SKGs in the robotic mission formulation phase

When identifying the payload complement for any robotic mission, limits on mass and volume are driving factors. Technology readiness and cost are also major considerations. Nonetheless, dedicating resources for payloads which address or close human knowledge gaps should be considered. NASA is attempting to do just that with formulation of its Mars 2020 mission. Lessons learned from this selection should be shared, perhaps creating the opportunity to implement this approach on mission formulated by any nation or agency.

2. Establish figures of merit related to human exploration

What kind of incentives can be imagined to facilitate proposals for measurements which address high priority human strategic knowledge gaps? The breadth of human exploration strategic knowledge gaps demonstrates that much of the information needed to address a gap is also of interest to the science community. It could be interesting to develop an additional set of 'figures of merit' related specifically to the human knowledge gap. These figures of merit could be used in selecting possible robotic mission payloads by judging not only scientific priority, but also ability to fill human exploration strategic knowledge gaps.

3. Ensure that the presence of astronauts at each destination brings the highest return to the science community

Scientific priorities associated with human destinations are well established and these certainly should inform human mission planning. What are the scientific questions or priorities which would most benefit from human presence? This information would be useful in guiding human mission planning and capability development and should be given strong emphasis by human mission planners.

4. Expand on efforts to share knowledge, expertise between members of the community

Within the exploration community, there are efforts to share knowledge and lessons learned. For example, NASA science advisory groups are active in information exchange related to priorities and challenges associated with destinations within their scope (e.g. the Moon, small bodies, etc). These efforts are absolutely needed and more work could be done to ensure human mission planners can benefit from the knowledge and expertise gained through executing human missions. Are there improvements possible which could make science data which addresses a human exploration gap readily available to the international human spaceflight community?

5. Expand partnerships with privately funded initiatives

Several privately funded robotic missions are envisioned to promote asteroid mining, tourism or other human activity in space. These initiatives are exciting people around the world in ways which expand the human desire to explore. Are there new partnership models which benefit innovative new initiatives, while driving technologies and capabilities for future exploration scenarios? Examining this question, together with external stakeholders, could be interesting.

CONCLUSION

The updated Global Exploration Roadmap demonstrates agencies are still working to lay the ground work for future human exploration missions. Agencies remain interested in finding meaningful and effective approaches to increasing the synergy between human and robotic missions. The updated roadmap makes it clear that innovative ideas which expand this partnership are sought. This paper presents some ideas for expanding on the partnership, creating new opportunities for dialog. It is hoped that they trigger new ideas and approaches which contribute to enhancing the sustainability of human and robotic space exploration for the centuries to come.