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ASTEROID NEXT: A VIEW TO THE ROLE OF ASTEROID MISSIONS IN THE 2ND ITERATION OF THE ISECG GLOBAL EXPLORATION ROADMAP

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The *International Space Exploration Coordination Group* (ISECG) was established in response to *"The Global Exploration Strategy: The Framework for Coordination"* developed by fourteen space agencies[*] and released in May 2007. This GES Framework Document recognizes that preparing for human space exploration is a stepwise process, starting with basic knowledge and culminating in sustained human presence in space.

The first iteration of the *ISECG Global Exploration Roadmap* (GER) has been released in September 2011. Its development focused on identifying the overall framework, consisting of the common goals for exploration, the long-range strategy and associated optional mission scenarios and Design Reference Missions (DRM's) as well as near-term areas for coordination and cooperation. It also provided an opportunity for agencies to share exploration plans and look for synergies. One feasible pathway defined by agencies participating in development of the GER is called "Asteroid Next". By exploring near Earth asteroids, we take significant steps towards preparing the propulsion and habitation technologies and capabilities needed for deep space exploration and ultimate missions to Mars. The second iteration of the GER is planned for late 2012 and interagency work has already been started. Updates of the GER will reflect the ongoing evolution of agency's exploration policies and plans, informed by agency individual and coordinated analysis activities that are relevant to various elements of the GER framework as well as coordinated stakeholder engagement activities.

[*] In alphabetical order: ASI (Italy), BNSC – now UKSA (United Kingdom), CNES (France), CNSA (China), CSA (Canada), CSIRO (Australia), DLR (Germany), ESA (European Space Agency), ISRO (India), JAXA (Japan), KARI (Republic of Korea), NASA (United States of America), NSAU (Ukraine), Roscosmos (Russia). "Space Agencies" refers to government organizations responsible for space activities.

Specific areas which will be further developed in the 2nd iteration include:

- A further refinement and definition of the optional mission scenarios in areas related to near-term DRM's;
- A reflection on the importance of asteroid survey and characterization efforts;
- The identification of agencies plans for technology developments enabling the implementation of the ISECG DRM's; this assessment will identify major gaps, opportunities for cooperation and coordination in developing and demonstrating technologies as well as opportunities for inserting new technology into the mission concepts.
- The definition and prioritization of strategic knowledge gaps which reflect information helpful for preparation of the ISECG DRM's as well as an assessment of the contributions of planned robotic missions in addressing these gaps.

This paper will provide early insight in envisaged updates of the 2nd version of the GER and in particular assess the implications on the "Asteroid Next" mission scenario included in the GER.

INTRODUCTION

With the release of the Global Exploration Roadmap (GER) in September 2011, the agencies participating in the International Space Exploration Coordination Group (ISECG) have taken an important step in preparing for future human space exploration missions. In collaboratively planning for future missions, agencies are assessing priority goals and objectives, and developing mission scenarios which are considered technically feasible and programmatically implementable. They are reviewing many exploration preparatory activities in order to leverage their investments in preparing for the challenges ahead. These are the elements of the effort within ISECG to advance a common exploration roadmap. Agencies have continued their dialog in these areas and expect to provide insight into this work with the 2nd iteration of the GER. The 2nd iteration, planned for release in late 2012 or early 2013, is intended to continue the transparency of agencies participating in ISECG as they collaboratively discuss feasible and sustainable human space exploration missions beyond low Earth orbit (LEO).

Global economic challenges have caused agencies to consider the timing and approach to space exploration. Economic challenges have also highlighted the need for investments in advanced technologies and research. Agencies participating in the International Space Station (ISS) have strengthened their individual and collective plans for using this important platform in LEO for general research activities as well as activities in support of space exploration. In addition, they many agencies have consolidated technology maturation plans, considering their existing competencies and long term interests. The goals, objectives and mission scenarios contained in the GER have been extremely useful in prioritizing these near term investments.

As stated in the GER document, by sharing the status of their efforts to define a human space exploration roadmap, agencies hope to generate innovative ideas and solutions to meeting the challenges of complex space exploration missions. With over 80,000 downloads of the GER between September 2011 and February 2012, from the ISECG and participating agency websites, it appears that the GER is gaining the visibility necessary to meet this intended purpose.

As one of two optional pathways in the common exploration strategy (see figure 1), Asteroid Next remains a focus area. Within NASA, efforts to assess asteroid exploration mission architectures continue with high priority. This paper will describe the work within ISECG related to the Asteroid Next mission scenario, with a view towards the 2nd iteration of the GER. A companion paper, GLEX-2012.02.3.4x12556 does the same for ISECG's Moon Next mission scenario.

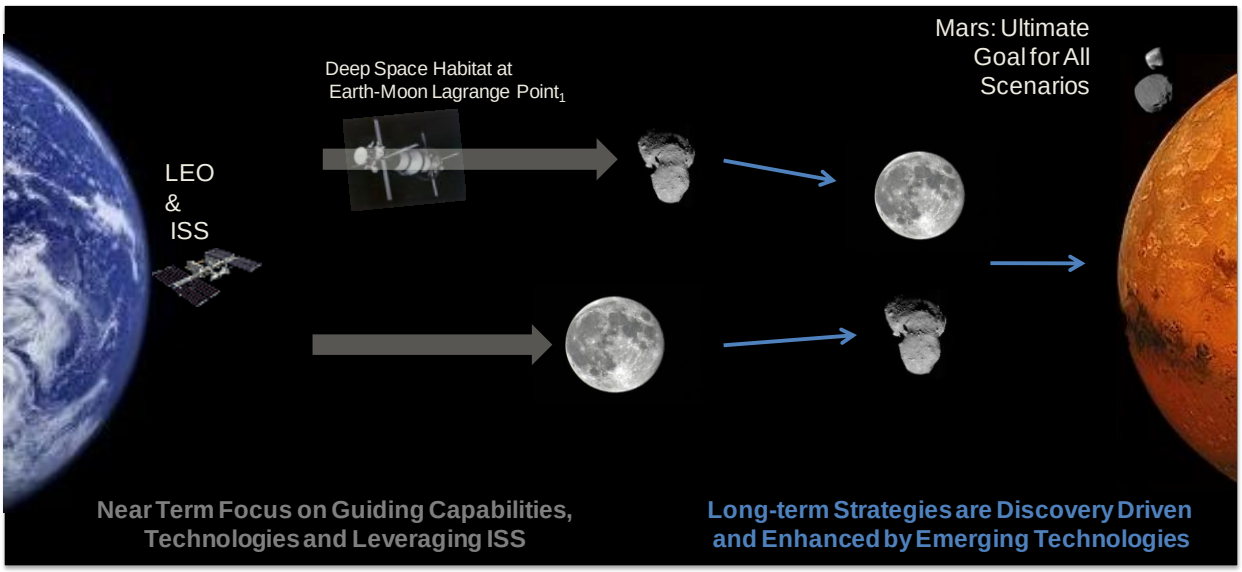

Figure 1: Optional Pathways in a Common Strategy

ASTEROID NEXT: TO MARS WITH AN ASTEROID MISSION AS THE NEXT STEP

This past year has seen several significant developments relating to our understanding of asteroids and interest in them as a future exploration destination. The success of the Japanese Hayabusa mission continues to be highly visible in Japan. Samples returned from S-class asteroid ITOKAWA have been distributed to laboratories in Japan, the USA and other parts of the world. Public excitement for JAXA's heroic efforts to revive the mission from several technical catastrophes has remained high with the release of 3 motion pictures on the mission with different features.

NASA's Dawn mission to the main belt asteroid, Vesta, has already returned a significant amount of information about this asteroid or proto-planet. With a strategy of observing Vesta from increasingly lower orbits, information on the shape and composition of this asteroid has been gained. See figure 2. In mid-2012, Dawn departs for the asteroid Ceres where we hope to obtain data on the role of size and water in planetary evolution. The knowledge we gain from the exploration of Vesta and Ceres will form a bridge between the exploration of the rocky inner solar system and the icy outer solar system.

Efforts to identify and characterize near earth asteroids continue around the globe through ground and space based observations. Not only is this information useful in understanding the potential threat of these bodies, but also informing mission planning and architecture decisions. Objects available in the mid/late 2020 remain few, but a couple of viable targets are under study.

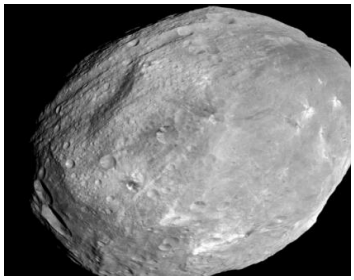

Figure 2: Dawn image of Vesta

The ISECG has identified common space exploration goals and objectives that reflect interests across the range of stakeholder communities and that will guide missions to asteroids. These goals and objectives provide useful direction for the mission scenarios at their current stage of maturity; however it is

recognized that in the future, goals and objectives must be prioritized by participating agencies as they develop specific plans and form partnerships necessary to send humans and robotic precursor missions beyond LEO.

The ISECG Asteroid Next Mission Scenario

As explained in detail in *IAC IAC-11-D3.1.2, ISECG MISSION SCENARIOS AND THEIR ROLE IN INFORMING NEXT STEPS FOR HUMAN EXPLORATION BEYOND LOW EARTH ORBIT, Culbert, C et al*, the ISECG Asteroid Next mission scenario focuses on advancing the capabilities necessary to travel and live in deep space, building on the significant work done on the ISS. It is possible to leverage assets designed for ISS use or previously emplaced on ISS to act as initial capability test beds for emulating future exploration system capabilities. This extension of ISS associated assets would lead to the deployment of a new "deep space habitat", allowing the advancement of habitation systems to be demonstrated in a deep space environment. When the reliability and sustainability of the habitat is demonstrated, deep space exploration missions would begin. At least two NEA missions are envisioned within the 25-year timeframe. This scenario offers the fastest path to a Mars orbital mission with opportunities to explore Phobos and Deimos and tele-operate highly capable Mars surface rovers. A follow-on Mars surface mission would either have to accept greater levels of surface system operations risk or the scenario could later include system testing on the lunar surface before a crewed Mars surface mission was performed. An overview of this mission scenario is shown in Figure 3.

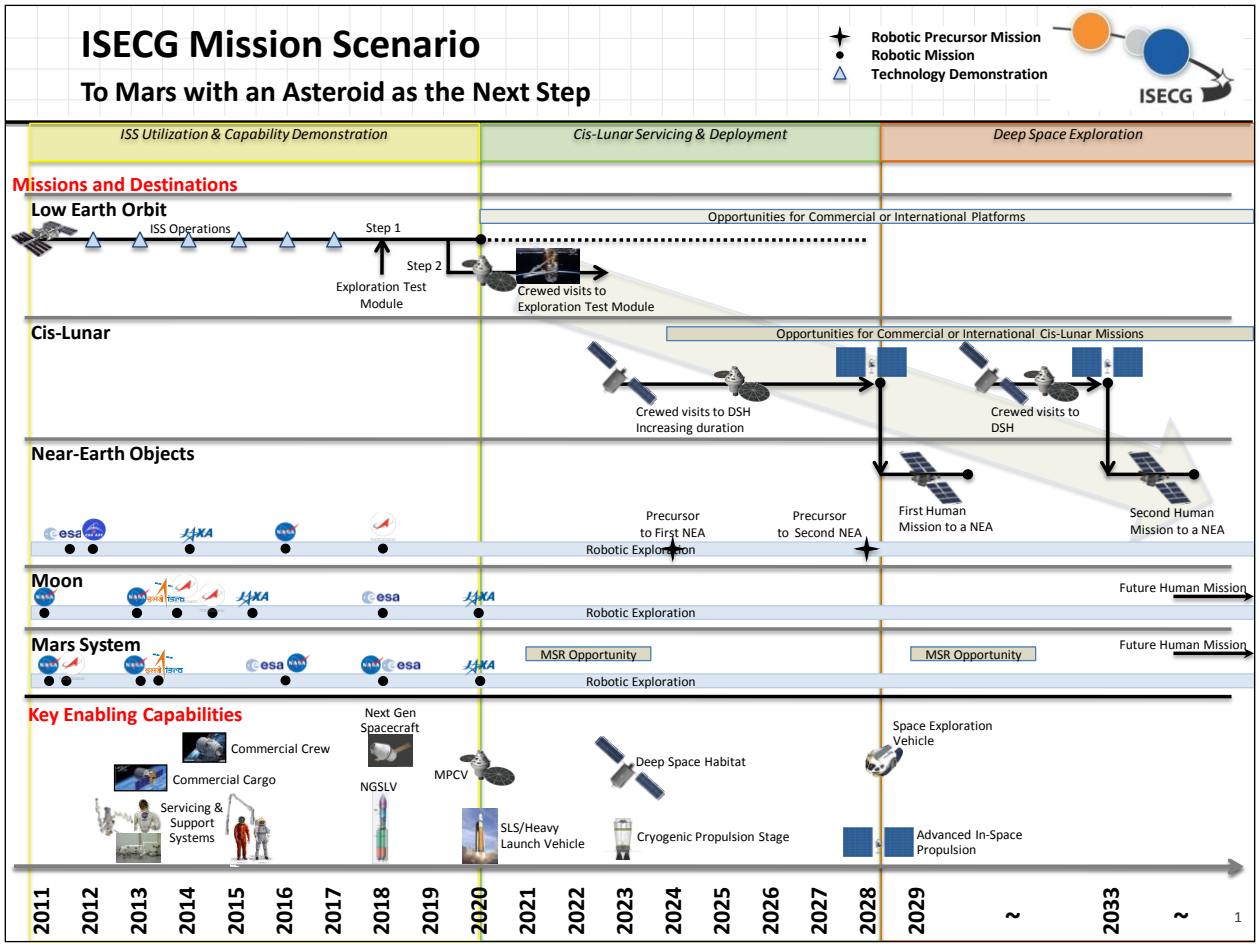

Figure 3: Asteroid Next, the Global Exploration Roadmap, September 2011

Updating the Asteroid Next Mission Scenario

Work over the last year has focused on increasing the definition of the design reference missions (DRMs) in the early phase of the mission scenario in order to reflect the missions possible within the expected performance of the NASA Space Launch System (SLS) and Orion Multi Purpose Crew Vehicle (MPCV). The so-called "early DRM phase" also seeks to align with other relevant plans of ISECG participating agencies, in particular regarding technology demonstrations or robotic precursor missions.

The early DRM phase of this scenario begins in the 2022-2023 timeframe with the deployment of a Deep Space Habitat (DSH) in cis-Lunar space. The first version of the GER, suggested this module be delivered to Earth-Moon Lagrange point 1 (E-M L1). This would allow for demonstration of long duration habitation and other critical systems, and enable a series of progressively longer duration human missions in a deep space environment as reduction on dependence of a regular supply chain from Earth is realized. These early DRMs are conducted until the additional capabilities required to conduct the NEA exploration mission are fully developed and available. This represents a risk reduction approach in Cis-Lunar space before committing humans to long duration missions where limited mission abort capabilities are feasible. In this scenario, abort times to return to Earth are measured in only a few days.

Through the scenario update process, agencies are reevaluating this approach. As capabilities, such as the MPCV and SLS, are better understood, options for the initial deployment location of the DSH and options for supplying systems hardware, supplies, and consumables are being explored. This includes the potential for smaller resupply systems to provide the necessary logistics to enable the crew-tended operations during this phase, increasing mission opportunities for international crew participation in this preparatory time period. The crew time enabled by this strategy will allow risk reduction in the necessary hardware and technologies required for deep space exploration, develop knowledge linked to long duration deep space operations, and provide opportunities for simulation of NEA mission operational concepts. In assessing options, agencies will consider the cost/benefit of different approaches to evaluate the value proposition against the risk reduction benefits.

ASTEROID NEXT PREPARATORY ACTIVITIES

As previously stated, one important goal of agencies participating in the ISECG GER effort is to leverage investments in exploration preparatory activities. No one nation can robustly invest in maturing all the advanced technologies or acquiring strategic knowledge considered important in enabling affordable and sustainable human exploration missions of the future. By sharing their priorities, it is intended that agencies can make individual decisions regarding directing their investments in areas which are consistent with their capabilities, and long-term strategic interests. By using the GER mission scenarios as a reference, agencies can maximize the coordination of today's expenditures to the extend they find useful.

Two key areas have maintained a significant amount of coordination work within ISECG over the past year: advanced technologies and strategic knowledge gaps. By examining the benefits of advanced technologies in either enabling or enhancing the Asteroid Next mission scenario, a clearer picture is emerging regarding the global effort. Strategic knowledge gaps represent opportunities for preparing human exploration missions, either by gaining a better understanding of risks to human explorers posed by the environment around asteroids, or by better understanding the population so as to enable identification of an asteroid exploration strategy. An overview of the objectives of ongoing work is described below.

Technology Investments

Technology assessment in the context of the GER will help to facilitate leveraging investments in technology development efforts of individual ISECG agencies. While preparing the GER agencies have already begun sharing information on their technology development investment areas and priorities. The GER

already features in its current version a high-level categorization of the technology development input of participating agencies, providing a general overview of the applicable challenges.

As the ISECG exploration scenarios mature, work is underway to prepare additional levels of analysis for the next release of the GER. The goal for this next step is improving the coherence and level of detail of the collected inputs by adding high-level performance characteristics and identifying the applicability to exploration scenarios. This is achieved through a mapping process of the individual technology development activities to the specific elements and capabilities of the ISECG design reference missions.

It is important to note that individual technology development activity inputs of the participating ISECG space agencies to this *GER Technology Development Map* (GTDM) are guided by varying constraints and assumptions. While one agency might have identified a technology development activity in great detail, others might not yet have broken down their entries to the same level. To allow for a high-level analysis, the various agencies technology development inputs have been categorized based on the Technology Areas developed by NASA's Office of the Chief Technologist.

As a result, individual agencies can identify gaps as well as overlapping areas that could spur innovative competition and yield a more robust architecture. Joint activities, on the other hand, can create partnership opportunities not only related to technology demonstration missions or platforms but also to the usage of unique ground facilities or capabilities. The overall goal is to create opportunities for cooperation while recognizing agency autonomy in investment decisions and for allowing each agency to find promising technologies in the global exploration effort.

The NRC[2] defines three Technology Objectives. Two of them are closely tight to the GER, namely

- Technology Objective A: *Extend and sustain human activities beyond low Earth orbit.* Technologies to enable humans to survive long voyages throughout the solar system, get to their chosen destination, work effectively, and return safely; and
- Technology Objective B: *Explore the evolution of the solar system and the potential for life elsewhere.* Technologies that enable humans and robots to perform in-situ measurements on Earth (astrobiology) and on other planetary bodies.

That report identifies a number of priority technologies for each of those objectives. The mapping of the technology development activities of the individual participating agencies identified in the GTDM against those "Final Prioritization of Top Priority Technologies" for Objectives A and B shows that all those top technology have associated development activities identified by multiple agencies. For instance three to five out of the six currently agencies participating in the GTDM have identified technology development activities in the area of Radiation Mitigation for Human Spaceflight, Long-Duration Crew Health, ECLSS, GN&C, Solar Power Generation, Electric Propulsion, and In-Situ Instruments and Sensor.

More details on the technology assessment activity and a preliminary analysis can be found in GLEX-2012.09.3.1x12269.

Strategic Knowledge Gaps

In order to prepare for safe, effective, and efficient human exploration beyond Low Earth Orbit (LEO), system and mission planners will

[2] The Steering Committee for NASA Technology Roadmaps; National Research Council of the National Academies identifies in its report entitled NASA Space Technology Roadmaps and Priorities: Restoring NASA's Technological Edge and Paving the Way for a New Era in Space, 2012 (www)

need access to data that characterizes the engineering boundary conditions of representative exploration environments, identifies hazards, and assesses resources. The knowledge developed from this data will inform the selection of future destinations, support the development of exploration systems, and reduce the risk associated with human exploration. Such data can be obtained on Earth, in space, by analog, experimentation, or direct measurement by remote sensing or in situ. In order to accomplish this, it is necessary to identify the Strategic Knowledge Gaps (SKGs) associated with potential destinations for human exploration, what measurements or data are needed to fill those gaps, how the knowledge is best obtained, and when the knowledge is needed.

A Strategic Knowledge Gap (SKG) Assessment Team has been formed and charged with developing an internationally integrated set of SKGs to inform our joint efforts at planning human and robotic precursor exploration of asteroids, the Moon, and Mars and its moons. The effort also includes articulating how currently planned robotic missions will contribute to filling the SKGs and elucidation of potential future precursor robotic missions that complement those currently planned and could provide robust opportunities for international cooperation. Some examples of destination specific SKGs are listed below:

- Asteroid: Near-Surface Mechanical Stability, Surface Morphology & Compaction

  This knowledge is needed to inform effective anchoring to and safe interaction with the body during a human exploration mission.

- Moon: Detailed Characterization of Polar Cold Traps and Nearby Sunlit Areas

  This knowledge is needed to inform the identification of potential landing sites at the lunar poles that take best advantage of local resources (e.g. near-continuous sunlight) and are scientifically compelling (e.g. lunar polar volatiles).

- Mars: Atmospheric Aspects (Characteristics) that Affect Aerocapture, EDL and Launch from the Mars Surface

  These observations/measurements directly support engineering design and also assist in numerical model validation.

The SKG Assessment Team has developed a comprehensive set of knowledge gaps and is in the process of consulting with international experts in order to establish the priority gaps. It is the intention of ISECG to document the internationally integrated set of priority gaps, as well as information on how planned robotic mission fulfill these gaps, in the second iteration of the GER.

CONCLUSION

Agencies intend the GER to be updated regularly to enable it to serve as a relatively timely view of ongoing work to prepare for future human exploration missions. The second iteration of the GER will reflect the work since release of the initial GER in September 2011. For ISECG work to continue to inform agency and political decision makers, it must remain focused on highly meritorious goals and objectives as well as mission scenarios which are technically feasible and programmatically implementable. With these elements, agencies can continue to look for opportunities to leverage the investments they are making in preparatory activities such as technologies and robotic precursor missions.

Space exploration is about progress, knowledge, and understanding humankind's place in the universe. Agencies invest in these challenging missions in order to advance, in order to bring tangible and intangible benefits to their citizens. Striving for solutions to the challenges of exploring asteroids or other destinations, much can be accomplished to benefit people on earth. Whether it is new scientific and medical knowledge, advanced technologies, clues to

tapping valuable space resources or strategies for protecting planet Earth, the discoveries resulting from space exploration enable substantial improvements to the quality of life on earth.

Asteroid Next remains an optional pathway under consideration by ISECG agencies. These missions represent huge challenges because of the nature of deep space travel. Longer missions, farther away from planet earth, drive advancements in our current capabilities and knowledge. Human exploration missions enable significant advancement in our three main objectives for studying asteroids; unlocking their secrets, testing capabilities needed for Mars and better understanding and mitigating collision threats. As more information characterizing the availability and characteristics of these primordial bodies becomes available, ISECG will continue to advance approaches which enable future missions as part of a sustainable human exploration effort.