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IAA COSMIC STUDY: DYNAMICS OF SPACE EXPLORATION; A FINAL UPDATE

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The International Academy of Astronautics (IAA) Cosmic Study "Dynamics of Space Exploration and Outlook" aims at presenting a comprehensive space policy report on the domain of space exploration. The proposed vision for space exploration is bold, collective, holistic, paved with attainable milestones shared by the stakeholders and conceived in a sustainable manner. This new challenge relies on a sense of common commitment towards an integrated international effort. Such a shared space vision could be implemented via an International Space Exploration Council acting as an efficient planning and decision-making body. This Council would include high-level government officials, space agencies, space entrepreneurial entities, and representatives of the space industry, the scientific community and the civilian society from all spacefaring countries. Under this scheme, the Council would act as a top-down structure supported by bottom-up activities involving science/technology analysis and space architecture working groups. In this study we identify challenges and opportunities where the different space stakeholders can line up on a national and/or international basis. Particular attention is given to maximize as much as possible an integrated and collective approach, as well as to prevent, through appropriate mechanisms (typically a fail-safe approach), a defaulting partnership that could jeopardize the overall progress of a common undertaking. The role of the considered Council in reconciling the interests of "individual" countries and private pursuits is also discussed A progress report of this Cosmic Study was presented at the Heads of space agencies Summit in Washington DC in January 2014. A preview of the final conclusion and recommendations which incorporate 2014 up to summer 2015 updates on the changing space exploration context, sciences drivers for exploration, dynamics of exploration, legal and policy regime for exploration, and emerging challenges and opportunities is presented in this paper.

I. INTRODUCTION

In recent years an impressive array of space-faring countries have announced space exploration plans[1], be it missions and / or architectures, to explore the Moon, near-Earth asteroids (NEAs) and Mars in coming decades. Despite the recent worldwide economic downturn, these activities have not been yet halted. In addition, ambitious plans of space entrepreneurs have emerged recently to develop new vehicles to access space and resupply the International Space Station (ISS), new ventures to exploit extraterrestrial resources. The increasing interest in both robotic and human missions to various destinations beyond Earth orbit by many countries and stakeholders raises questions on how to prepare, execute and sustain large space endeavours in a coordinated way. This IAA Cosmic Study to be completed this year aims to provide an overview of the changing space exploration context. This paper focuses on some elements of the study that is a preliminary review of international space exploration programmes to shed a relevant light on new projects or approaches where necessary.

II. SPACE EXPLORATION – AN OVERVIEW

For more than 60 years the United States lead in space exploration, and to a lesser extent the Soviet Union, setting the scene for a duopolistic system which progressively moved to a multi-actor activity. From the 1980s onwards successively Europe, Japan, China and India, began to explore the Solar System with their own explorers relying, in many cases, on international cooperation.

Unlike the logic of early space exploration endeavours demonstrating technological superiority and military capability in a race-mode between the United States and the Soviet Union through manned space exploration, space exploration is nowadays no longer a meaningful exercise of power showcase for the these space powers. For China, its manned space programme is not a race but rather a demonstration of its capabilities in space exploration and achievements of national goals. As for India which focused over several decades its space programmes on the utilisation of space technology for economic and social developments, and is giving more recently an increased attention to space exploration with successful missions to the Moon and Mars. For its part, Japan, after a considerable effort on Earth environment and climate missions, has successfully completed lunar orbiter missions and the first sample return mission Hayabusa from an asteroid, which opened up the possibility of considering unmanned asteroid mining and exploitation.

Except at the outset of the 1960s, for France and the UK, Europe has never been directly part of the East-West competition that triggered the space race and its developments regarding space exploration. The European Space Agency (ESA) and its Member States have built for Europe a long-standing tradition of space exploration, providing significant contributions to human and robotic exploration with numerous various international partners. ESA's space exploration plan focuses on several cornerstone missions and activities targeting Low Earth Orbit (LEO) (participation to ISS), Moon (technology and future mission studies) and Mars (ExoMars and technology preparation for future missions).

III. PLANNED EXOLORATION MISSIONS BY DESTINATIONS

Science roadmaps for planetary exploration have been produced and updated by many national and international working groups in the last decade[2] [3]. Several countries are engaged, or are preparing missions that visit the Moon, Mars and the near-Earth asteroids with robots and in the future with humans. These missions should provide answers to the most fundamental questions on the origin and evolution of the solar system, namely: i) improve our understanding of the formation of the solar system, ii) is there or has ever been life beyond Earth, and, iii) what are the environmental conditions of our neighbouring solar system bodies.

- Low Earth Orbit (LEO)

ISS is expected to operate until 2024 with possible extension to 2028. It has now become a large-scale research platform in space where a variety of scientific disciplines such as human physiology, space biology, fundamental physics, chemistry, biology, space science, space weather studies, astrobiology and Earth observation take place. ISS supports also the development and the validation of many of key capabilities needed for future human exploration beyond LEO.

Another pillar is the development by NASA and ESA of the Orion Multipurpose Crew Vehicle (MPCV) manned spacecraft to be launched by the Space Launch System (SLS) currently under development for crewed missions to and beyond LEO. SLS and Orion represent cornerstones of the infrastructure required for the deep space human exploration.

Following the successful series of Shenzhou vehicles, China has been developing the Tiangong modules as part of the Project 921. The Chinese government is investing to operate a permanent space station by 2022 and has already offered to host international astronauts to its LEO infrastructures.

India is also considering developing human space flight capabilities.

- MOON

For the next 15 years, about 15 missions should be carried out, ranging from orbiters to a human lander, through a variety of intermediate mission configurations (Table 1). Key scientific questions for the Moon have been clearly laid out; see for instance[4]. Of particular importance is a renewed focus on the *in situ* Resource Utilisation (ISRU), part of a long-term strategy for lunar exploration.

Future Lunar Missions	***Planned launch Date***	***Main Agency***	***Mission Configuration***
Chang'e-4	2016-2020	CNSA	Lander/mobility
Google Lunar X Prize	2017		lander/mobility
Kaguya-2 (Selene-2)	2017	JAXA	lander/rover/ penetrators?
Lunar Orbiter Pathfinder	2017	KARI	orbiter
Chandrayaan-2	2017-2018	ISRO	orbiter/lander/rover
Chang'e-5	2018	CNSA	sample return
MPCV EM1	2018	NASA/ESA	circumlunar
Luna-Gob 1	2019	Roscosmos	orbiter/lander
Resource Prospector	2020	NASA	lander/ISRU demo
Chang'e-6	2020	CNSA	sample return
Luna-Glob 2	2020	Roscosmos	orbiter
Luna-Resurs 1 Luna 27	2020	Roscosmos	Lander with drill /rover
MPCV EM2	2021	NASA/ESA	crew orbiter /return capsule
Lunar Orbiter/Lander/ Rover	2020-25	KARI	orbiter and lander/ rover
Selene-3	2020+	JAXA	sample return
Selene X	2020+	JAXA	TBD
Luna-Grunt Luna 28	2025+	Roscosmos	lander/rover/sample return
Human Landing	2025-30	CNSA	human lander
Human Circumlunar	2025?	Roscosmos	Human circumlunar flight

Human Moon Landing	2029?	Roscosmos	Human lunar landing

Table1: Planned Future Lunar Missions. All launch dates after 2016 must be regarded as tentative.

- MARS

Understanding whether Mars could have hosted life and did indeed host it is a key driver for past, ongoing and future missions on this planet. Back in 2010, the Mars Exploration Program Analysis Group (MEPAG) identified four main science goals[5] which underpin also the Cosmic Vision Programme of ESA[6]. Table 2 lists the four Mars missions planned for the rest of the decade.

Mission to Mars	***Planned launch date***	***Main Agency***	***Mission Config.***
ExoMars -2016	2016	ESA/ Russia/ NASA	orbiter/ lander
ExoMars -2018	2018	ESA/ Russia	lander/ rover
Insight	2016	NASA/ ESA	lander
Mars mission 2020	2020	NASA	rover/ cache
Al Amal	2021	UAE	orbiter

Table2: Planned Mars Missions up to 2020. All launch dates after 2016 must be regarded as tentative.

Other countries like India, China, and Japan are preparing or developing missions or concepts to explore Mars.

- Near Earth Objects (NEOs)

The physical properties, distribution, formation and evolution of asteroids are fundamental to our understanding of planet formation, and ultimately to why life exists on Earth. Some current exobiological scenarios for the origin of life on Earth invoke an exogenous delivery of organic matter from asteroids (and possibly comets). In addition, Near-Earth-Asteroids (NEA) that come close to the Earth pose a finite hazard on life, a second and more practical reason to study asteroids. The stunning diversity of small bodies and their multidisciplinary attractiveness explain the high international interest in planning and performing new missions (See Table 3).

Mission to NEOs	Launch	***Main Agency***	***Mission Configuration***
OSIRIS-REx	2016	NASA	sample return mission
ARM	TBD	NASA	Asteroid Retrieval Mission

Table 3: Planned NEOs Missions up to 2020. All launch dates after 2016 must be regarded as tentative

In support of these science driven programmes, progress has to be made in the following areas:

- Robotics: further miniaturization, power and thermal control at large heliocentric distances as well as during Lunar and Martian nights, effective propulsion to allow high delta-v and to reduce mission duration, autonomy for surface and landing operations, and high data rate communications;

- Human spaceflight: Improving technology foundations for a series of key capabilities to enable a sustainable strategy (entry, descent, landing, propulsion, energy management, habitation, closed-loop life support, health management, radiation protection, and servicing). Also of major importance is the development by NASA and ESA of the Orion Multipurpose Crew Vehicle (MPCV) manned spacecraft to be launched by the Space Launch System (SLS) aforementioned;

- Technology Roadmaps: Major space agencies have initiated or updated this essential tool to guide the procurement of the needed technologies as well as to coordinate the resources and know-how available in such a way to accelerate Technology Readiness Level (TRL) advancement and mission readiness;

- Access to space: New developments are underway in several countries that will benefit to transportation for space exploration, and summarized as follows

: United States (SpaceX and Boeing developing Crew systems for the ISS, Orion MPCV and evolvable heavy-lift launch SLS), Russia (Angara launchers family under development), China (Development of Long March 5,6 and 7, concept studies of a super heavy lift launcher Long March 9), Europe (development of Ariane 6), Japan (development of H-3,), India (development and qualification of the heavy lift launcher GSLV Mark III)

IV. THE CHANGING SPACE EXPLORATION CONTEXT

With this diversity of missions addressing a wide range of targets throughout the Solar System, the nature of the actors and their mode of involvement as space actors have diversified in a visible way. Initially, States through their space agencies had the central role for the programmes' management, contracting with industry, companies being essentially asked to deliver requested products or services. Starting in the United States, this standard scheme has progressively undergone some changes, with industry developing new and competitive means applicable to the field of exploration. Just to pick three significant examples: i) SpaceX, reducing significantly the launchers costs, developing new manned access to the ISS and building its own views on Mars exploration, ii) Bigelow Aerospace having in 2016 an Expandable Activity Module (BEAM) attached to the ISS, and developing flexible and configurable space habitats usable in space as well as on the surface of celestial bodies, and iii) Planetary Resources dedicated to affordable asteroid mining to ship back to Earth high-value metals, or park in space asteroid resources to be used by explorers into their mission.

Although space agencies will remain naturally in their central role of supporting and organising space exploration missions, industry is also playing more strongly its part. Scenarios involving governmental agencies and private companies in a co-entrepreneurship of some sort will continue to be on the rise.

Moreover, following the initiation by Europe of high-level conferences for space exploration, at Ministerial level that was held in Prague in 2009, followed by Brussels in 2010, Lucca in 2011, the United States organized in Washington DC in January 2014 the first International Space Exploration Forum (ISEF) attended by institution representatives from all over the world. Japan will host the next ISEF to develop further the framework of international space exploration including the potential role of non-governmental actors.

V. PROPOSING A WAY FORWARD

When looking back at what has been achieved in the domain of space exploration in the last 60 years, exciting and "easy" endeavours are behind us. We now have to gear up for more complex missions requiring extra preparatory work, international cooperation, and very likely higher costs. Under today's constrained financial environment, international cooperation is a must and technical plans should not be defined in isolation from overall public policy guidelines. Indeed, expensive high-energy physics facilities, large ground-based astronomy instruments and, more recently, large fusion energy installations are accepted today because their management and funding underwent profound changes a few decades back.

To move forward, the contributors of this IAA Study Group on Exploration of the solar system recommend to develop a new **vision for space exploration to be bold, collective, holistic, paved with realistic milestones shared by the stakeholders and conceived in a sustainable manner.** For this, an International Space Exploration Council could be effective in designing and implementing an innovative long-term roadmap that will allow new countries and stakeholders to join and engage in an overall effort and exploit tangible and intangible resources for a sustainable global space exploration programme.

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[1] Space exploration is an open-ended project relying on both human and robotic activities to extend access to unknown terrains and environments by means of direct (humans) and/or indirect (automated missions and robots) presence. Through a systematic approach, including preparatory activities, space exploration opens up new frontiers for the progress and acquisition of new knowledge and presents options to extend the range of human actions and inspire future generations.

[2] COSPAR Report 2012, P. Ehrenfreund et al (2012)"Toward a Global Space Exploration Program: A Stepping Stone Approach", Advances in Space Research 49 (2012) 2-48

[3] The Global Exploration Roadmap, International Space Exploration Coordinating Group (ISECG),August 2013 http://globalspaceexploration.org

[4] The lunar Exploration Group: LEAG and the Vision for Space Exploration, Clive R. Neal, August 2008 http://www.nasa.gov/pdf/456673main_PIF_1_neal_leag.pdf ;
LEAG Home Page: http://lpi.usra.edu/leag/roadmap/

[5] MEPAG (2010), Mars Scientific Goals, Objectives, Investigations, and Priorities, J. R. Robinson et al. http://mepag.jpl.nasa.gov/reports/index.html

[6] ESA BR-247: Cosmic Vision-Space Science for Europe 2015-2025