Minutes of Commission III Spring Meeting
6 Rue Galilee
Paris, France
1330-1600
23 March 2015

1. **Agenda:** See Attachment 1
2. **Minute of Silence to Commemorate the Passing of Hans Hoffmann**
3. **Members present:**

Chair: LU Yu (China)
Vice Chair: Ramakrishnan S (India)
Past-Chair: Reibaldi G (Italy)
Secretary: Lenard R (USA)
Member: Kawaguchi J (Japan)
Member: Genta G (Italy)
Member: Yuri Razoumy(Russia)
Members not present:
Korepanov V. (Ukraine)
Saccoccia G (Italy)
FAN Ruxiang (China)

4. **Members removed from active status:**

G. Saccoccia
V. Korepanov

5. **New Leadership:**

Chair: S. Ramakrishnan
Vice-Chair: R. Lenard
Secretary: Giancarlo Genta
The Commission III Leaders requested Mr. Giuseppe to provide continued counsel and advice to Commission III and invited him to be an Ex-Officio functionary of the Commission.

Two new members will be identified to replace those removed during the next month.

6. Status of Study Groups
   a. 3.9 Private Access to Space (Suborbital) – study complete – no status required
   b. 3.14 Private Human Spaceflight Vol. II Presented by Ken Davidian See Attachment 2
   c. 3.15 Long-Term Space Propellant Depot – Presented by Dr. Wang, see attachment 3
   d. 3.16 Global Human Mission to Mars – status verbally briefed by G. Genta, no presentation; short synopsis follows: Mid February, final draft completed, final meeting at Paris Spring

Meeting. Final comments and wrap-up to be completed for submission to Commission III leadership, and then to full Commission for review. Professor Genta hopes to have reviews done and report published prior to Jerusalem conference. Global Mars mission not perceived to be near-term; will need series of stepping stones to complete. The study did not include commercial or private Mars exploration efforts. Follow-on study required?

e. 3.17 Space Mineral Resources. Briefed by Dr. Peter Swan. See Attachment 11. Commission recommends SG 3.17 report be forwarded to SAC pending inclusion of remaining Commission III reviews – deadline 25 March for comments. SG Chair to forward completed report to Secretary 29 March.
f. 3.18 Feasibility Study of Possible International Protocol to Handle Crisis/Emergency to Astronauts in LEO – Presented by S. Ramakrishnan See Attachments 5 and 6.
g. 3.19 Astronaut Standardized Career Dose Limits in LEO and the outlook for BLEO: Biological responses of humans to the impingement of high energy particle radiation. See Attachment 7.
h. 3.20 Impact of Planetary Protection on Human Exploration – This study has been dormant, recommendation: transfer to different commission or terminate study.
i. 3.21 Disposal of Radioactive Waste in Space: Not presented, although presentation available, no presenter see Attachment 8.
j. 3.22 Next-Generation Space System Development Basing on On-Orbit-Servicing Concept-Y. Razoumny, Verbally briefed
k. Human Space Technology Pilot Projects with Developing Countries-Briefed by G. Reibaldi, See attachment 9.
l. 3.24 Road to Space Elevator Era, presented by: A.Tsuchida. See attachment 10.

7. Recommendation for New Study Groups: Proposal for new Study Groups: "The Maintainability and supportability of deep space manned spacecraft" and "Space Detection system based on ultrafast optics". Reported in next commission meeting. S 3.25 "Developing the Interplanetary Econosphere" (follow-on to SMR 3.17).

8. Publications from IAC 2014: Two papers recommended for publication from Session D4. In Acta Astronautica. Status: in draft.

9. Heads of Space Agencies Summit: Follow-on Activities: The primary activities include the presence of space agency representatives at the Torino meeting 7-9 July 2015, and the possibility of a follow-on summit – the latter is TBD.

10. **Symposia Status IAC 2015/2016:** The IAC symposia under the coordination of Commission 3:

a. A5 Symposium on Human Exploration of Solar System
b. D3 Symposium on Building Blocks for future Space Exploration and Development
c. D4 12th IAA Symposium on Visions and Strategies for the Future

11. Future conference proposals: Commission III supports the inclusion of a plenary session on SMR at the Jerusalem conference – SG 3.17 members will check with the Federation

12. Report to the SAC will incorporate subjects contained in these minutes.

Agenda for Spring Commission III
23 March 2015 1330-1600
6 Rue Galilee, 75116 Paris, France

- Introduction
- Action items from Toronto
- Composition of Commission III – actions on truant commission members
- Discussion of Commission III Leadership for 2015-17
- Status of Study Groups
    - Study Group 3.14 Private Human Access to Space (Vol. II)-complete?
    - Study Group 3.15 Long-Term Space Propellant Depot-status
    - Study Group 3.16 Global Human Mission to Mars-status
    - Study Group 3.17 Space Mineral Resources-status of review
    - Study Group 3.18 Feasibility Study of Possible International Protocol to Handle Crisis/Emergency to Astronauts in LEO-status
    - Study Group 3.19 Radiation Hazards-status
    - Study Group 3.20 Impact of Planetary Protection on Human Exploration-status
    - Study Group 3.21 Disposal of Radioactive Waste in Space-status
    - Study Group 3.22 Next-Generation Space System Development Basing on On-Orbit-Servicing Concept
    - Study Group 3.23 Human Space Technology Pilot Projects with Developing Countries
    - Study Group 3.24 Road to Space Elevator Era, TBC by IAA SAC
- Proposal for new Study Groups
- IAA Conferences
    - 07-09 July, 2015, 9th IAA Symposium on The Future of Space Exploration - Towards New Global Programs, Torino, Italy
- Publications
    - Selections from IAC 2014
- Heads of Space Agencies Summit: Follow-on Activities
- IAC 2015, Commission 3 Symposia Status
- IAC 2016, Commission 3, Outlook
- Future Conference Proposals
- Report to the SAC
- Any Other Business

ASSESSMENT OF THE LIKELIHOOD OF US HUMAN ORBITAL MARKETS EMERGENCE

Presentation during the 2015 IAC Planning Meetings
in Paris, France on March 23, 2015

Part of the IAA Commission III Study Group 3.14
"Public/Private Human Access to Space" Vol. 2 - Earth Orbit and Beyond

Presentation Agenda

- Description of Five Analysis Phases
- List of Identified Analyses for Phase 3-5
- Final Report Status by Section

HOM Study Goal & Approach

Goal

- For a given country or region, world-wide, how likely is the emergence of a viable commercial human orbital industry?

Approach

- Multi-disciplinary study methodology
- Five Analysis Phases

1. Identification of Target Markets
2. Conduct Literature Review
3. Assess Socio-economic Factors (e.g., Political, Legal, Capital, Historical, Cultural)
4. Identify HOM Industry Chains, Related and Supporting Industries
5. Assess Probability of HOM Emergence

HOM Study Scope (Level of Analysis)

FIELD	Markets: e.g., Aerospace, etc.
COMMUNITY	Industries: e.g., Military Space, Civil Space, etc.
POPULATION	Industry Segments: e.g., SRMs, LREs, Solid Rocket Propellant, …
ORGANIZATION	Firm, Office: e.g., PW-R, XCOR, SpaceX, etc.
SUB-UNIT	Divisions: e.g.: Management, Structures, Safety, etc.

HOM Study

REFERENCE

- *Autry, Greg. "Exploring New Space: Governmental Roles in the Emergence of New Communities of High-Technology Organizations." University of California, Irvine, 2013.*

Phase 1. Target HOM Results

HOM TARGET MARKETS	ACTIVITIES	
	Near-Term (< 10 Years)	**Far-Term (> 10 and < 50 Years)**
Demonstrated Markets	• LEO Recreation • Gov't ETO Xport	• Not Applicable
Potential Markets	• Commercial R&D • Earth-Moon Recreation • Earth-Moon Gov't Xport • Media / Promotion	• Resource Extraction (from an asteroid) • Solar Energy Platform: Construction • Deep-Space Vehicle: Support Services • Residential Space Station: Construction, Shuttle and Support Services

NOTES
- "Tourism" and "recreation" are terms used interchangeably.
- The upper-right table quadrant is vacant by definition.
- The Earth-Moon system includes cis-lunar and L2.

REFERENCE

- Autry, Greg, and Laura Huang. "An Analysis of the Competitive Advantage of the United States of America in Commercial Human Orbital Spaceflight Markets." New Space 2.2, 2014: 83-110.

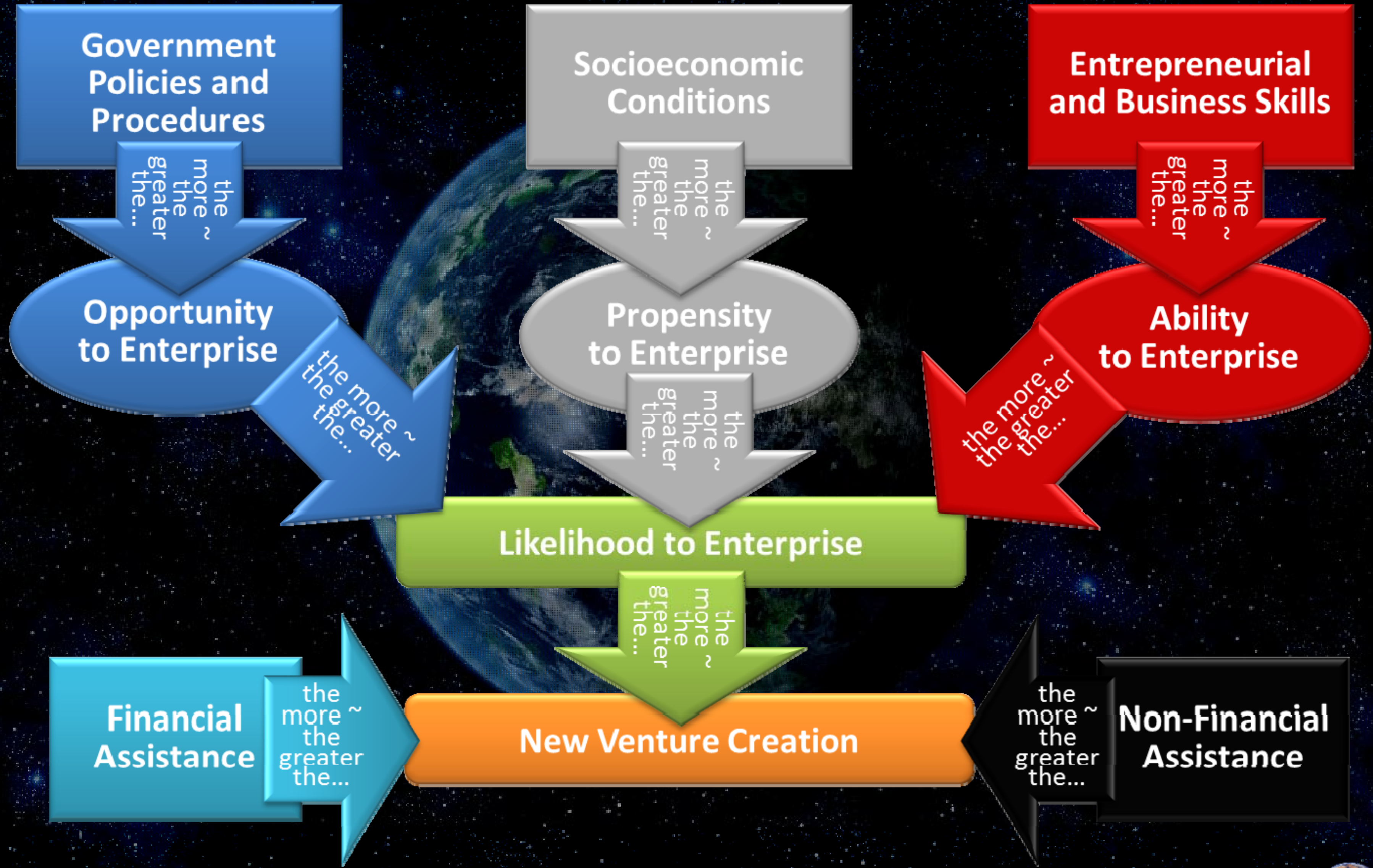
Phase 2. Literature Review Methodology

- Compile publicly available reports that provide data and/or analysis of the space industry for a given country or region (C/Rs).

• Africa (Region)	• Germany	• Portugal
• Australia	• India	• Russia
• Benelux	• Israel	• South Africa
• Canada	• Italy	• Spain
• China	• Japan	• United Kingdom
• Europe (Region)	• Nigeria	• United States
• France	• Norway	• World-wide

- Complete document list for all countries available on IAA HOM web site at…
  - http://iaaorbital.pbworks.com/w/page/63752279/Study%20Matrix

Phase 3. Entrepreneurial Environment Factors



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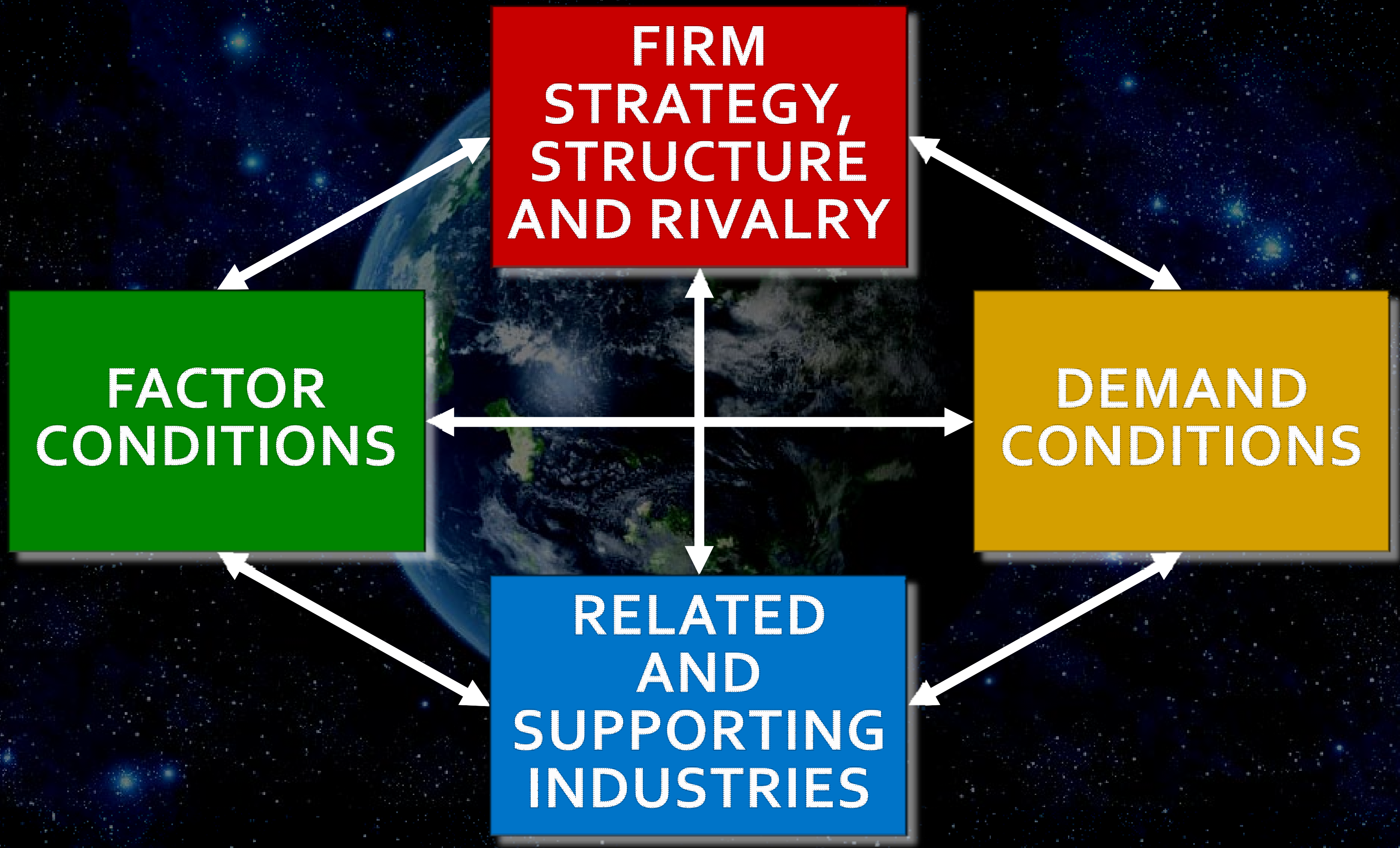
- Gnyawali, DR, and Fogel, DS. “Environments for entrepreneurship development: Key dimensions and research implications.” Entrepreneurship Theory and Practice, 18(4), 1994: 43-63.

Phase 4. HOM Industry Base Evaluation



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- Porter, Michael E. “The Competitive Advantage of Nations: With a New Introduction”. New York: Free, 1998.

Phase 5. Assessment of HOM Emergence

Industry Infrastructure Elements[1,2]	HOM Actors[3,4]			
	Market Actors		Gov't Actors	
PROPRIETARY FUNCTIONS	PROFIT	NON-PROFIT	CIVIL	MILITARY
Proprietary R&D (Invention)				
Production (Innovation)				
Market Creation (Diffusion)				
RESOURCE ENDOWMENTS	PROFIT	NON-PROFIT	CIVIL	MILITARY
Non-Proprietary R&D				
Financing				
Human Resources				
INSTITUTIONAL ARRANGEMENTS	PROFIT	NON-PROFIT	CIVIL	MILITARY
Governance				
Legitimization				
Technical Standards				

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1. Van de Ven, Andrew H. "The Development of an Infrastructure for Entrepreneurship". Journal of Business Venturing 8 (1993), 211-230.
2. Van de Ven, Andrew H. , Running in Packs to Develop Knowledge-Intensive Technologies. MIS Quarterly, Jun 01, 2005; Vol. 29, No. 2, p. 365-377.
3. Pearce, Jone L. "How we can learn how governments matter to management and organization." Journal of Management Inquiry 10.2 (2001): 103-112.
4. Pearce, Jone L. "Organization and management in the embrace of government." Psychology Press, 2001.

HOM Study Group Analyses

Study Phase	3. Socio-Economic	4. Industry Chain	5. Emergence
Australia	• Davis, 2014 • Vaccaro, et al., 2011	• Vaccaro et al., 2011	•
China	• Dong, Liu, & Lan-Juan, 2011 • Dong & Zhifu, 2011 • Wenjie & Donghao, 2014	• Dong & Zhifu, 2011	•
Europe	• Bernede, 2013 • de Hauteclocque, 2012 • Lu, et al., 2013 • Szalai, Detsis, & Peeters, 2012 • Võõras, et al., 2013	• Bernede, 2013 • de Hauteclocque, 2012 • Hempsell, et al., 2014 • Lu et al., 2013	• Hempsell et al., 2014 • Szalai et al., 2012
Europe: Benelux	• Prado, et al., 2014	• Prado et al., 2014	•
Europe: Germany	• Maier, et al., 2014 • Maier, 2013 • Weber-Steinhaus, 2011	• Maier et al., 2014	•
Europe: Italy	• Ainardi, et al., 2012 • Ciccarelli & Pavone, 2013 • Graziola, 2013 • Piperno, et al., 2011 • Sciortino, 2010	• Ainardi et al., 2012 • Ciccarelli & Pavone, 2013 • Graziola, 2013 • Piperno et al., 2011 • Sciortino, 2010	•
Europe: Spain	• Lauer, Harillo, & Onuki, 2013	• Lauer et al., 2013	• Lauer et al., 2013
India	• COMING TO THE IAC 2015	• Khan, 2012 • Khurana, 2014 • Lionnet, Deutscher, & Perrier, 2010 • Murthi & Rao, 2014 • COMING TO THE IAC 2015	• Khan, 2012
Israel	• Tepper, 2013	• Tepper, 2013	•
Japan	• Onuki, Ito, Watanabe, & Lauer, 2009 • Onuki, 2012b • COMING TO THE IAC 2015	• Onuki et al., 2009	• Onuki et al., 2009 • Onuki, 2012a • Onuki, 2012b
Nigeria	• James, Akinyede, & Halilu, 2011	• James et al., 2011	•
Russia	• COMING TO THE IAC 2015	•	•
South Africa	• Guthrie, et al., 2011 • Makapela & Majaja, 2011	• Guthrie et al., 2011 • Makapela & Majaja, 2011	• Guthrie et al., 2011 • Makapela & Majaja, 2011
United States	• Autry & Huang, 2014 • Davidian & Autry, 2014	• Autry & Huang, 2014 • Davidian & Autry, 2014	• Autry & Huang, 2014 • Davidian & Autry, 2014

Conclusion - FINAL REPORT STATUS

- Theoretical Synopses - Complete
- Study Methodology - Complete
- Analysis Results - In Process
  - Phase 1 - Essentially Complete
  - Phase 2 - Essentially Complete
  - Phase 3 - Some Studies Complete, Many Other Found
  - Phase 4 - Some Studies Complete, Many Other Found
  - Phase 5 - Some Studies Complete, Many Other Found
- Discussion - To Be Done
- Conclusions - To Be Done

Need for Extension Probable

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Ainardi, M., Luise, M., & Sabino Titomanlio, I. (2012). *Space Entrepreneurship In Italy: The Role Of Regions*.

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Bernede, N. (2013). *Entrepreneurship And Innovation In The European Space Sector: Overview And Impacts Of European Space Agency And European Union's Initiatives*.

Ciccarelli, S., & Pavone, R. (2013). *New Trends In The Italian Space Industrial Landscape: Smes And Technology Districts As Drivers Of Space Economy*.

Davidian, K., & Autry, G. (2014). *Assessment of the Likelihood of US Human Orbital Markets Emergence*.

Davis, M. (2014). *Australia's Role In The Global Space Industry*. Beijing, China.

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Khurana, S. (2014). *A Historical Overview And Cultural Assessment Of Space Industry Policy And Decision-Making Procedures In India*.

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Murthi, K. R. S., & Rao, M. K. (2014). *India's Space Industry Ecosystem – Challenges Of Innovations And Incentives*.

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IAA SG3.15

Long Term Space Propellant Depot

G.Saccoccia, LU Yu

Paris, France

March 2015

History

2012.08: Study group started.

2012.09: The 1st face-to-face meeting, Naples.

2013.03: The 2nd face-to-face meeting, Paris.

2013.09: The 3rd face-to-face meeting, Beijing.

2014.03: The 4rd face-to-face meeting, Paris.

2014.09: The 5rd face-to-face meeting, Toronto. The 1st draft report discussed.

2015.03:The 6th face-to-face meeting, Paris. (To finalise the draft report)

Study Contents

Introduction

Part 1-Feasibility and Missions

Design reference missions and space transportation systems

Scope and feasibility

Space environment

Part 2-Technologies

Key technologies

Part 3-Programmatic and Implementation

Roadmap for the implementation

Conclusions and Recommendations

The Report

Introduction

a. ***Definition, background and requirements***

b. ***goals of this study***

c. ***Heritage of past experience***

d. ***The basic exploration architecture concept based on depot and the related operational scenarios***

The Report

Introduction

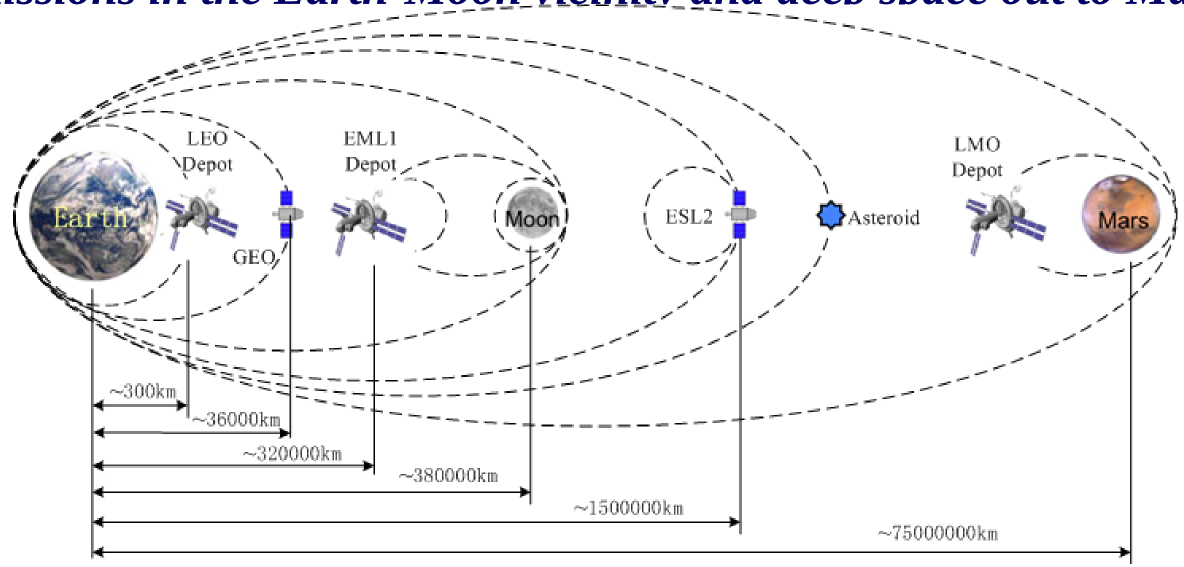
a. Definition, background and requirements

b. goals of this study

c. Heritage of past experience

d. The basic exploration architecture concept based on depot and the related operational scenarios

Three depots in LEO, EML1, and Mars orbit are selected to support all foreseeable missions in the Earth-Moon vicinity and deep space out to Mars.



The Report

Part 1-Feasibility and Missions

Design Reference Missions and Space Transportation Systems

a. *Earth Orbit Mission and Space launch systems (Earth to Orbit)*

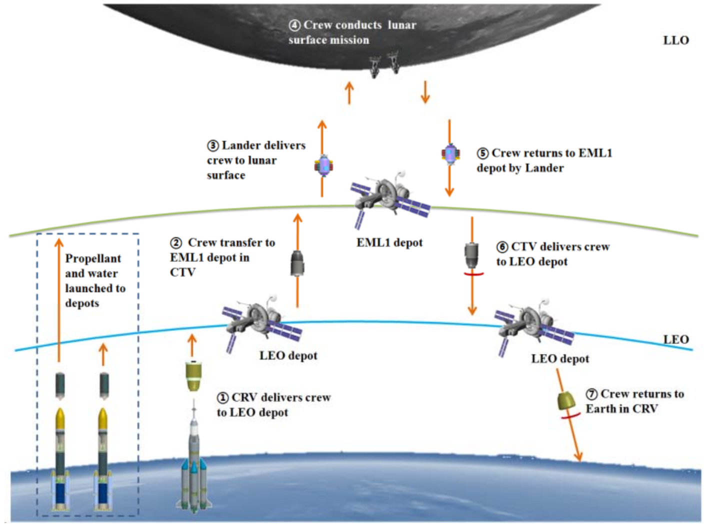
   ① Human GEO Mission

   ② Rabotics GEO Mission

b. *Human Lunar Mission and cislunar space transportation systems*

c. *Asteroid mission and space exploration systems*

d. *Mars Mission and space exploration systems*



The Report

Part 1-Feasibility and Missions (cont.)

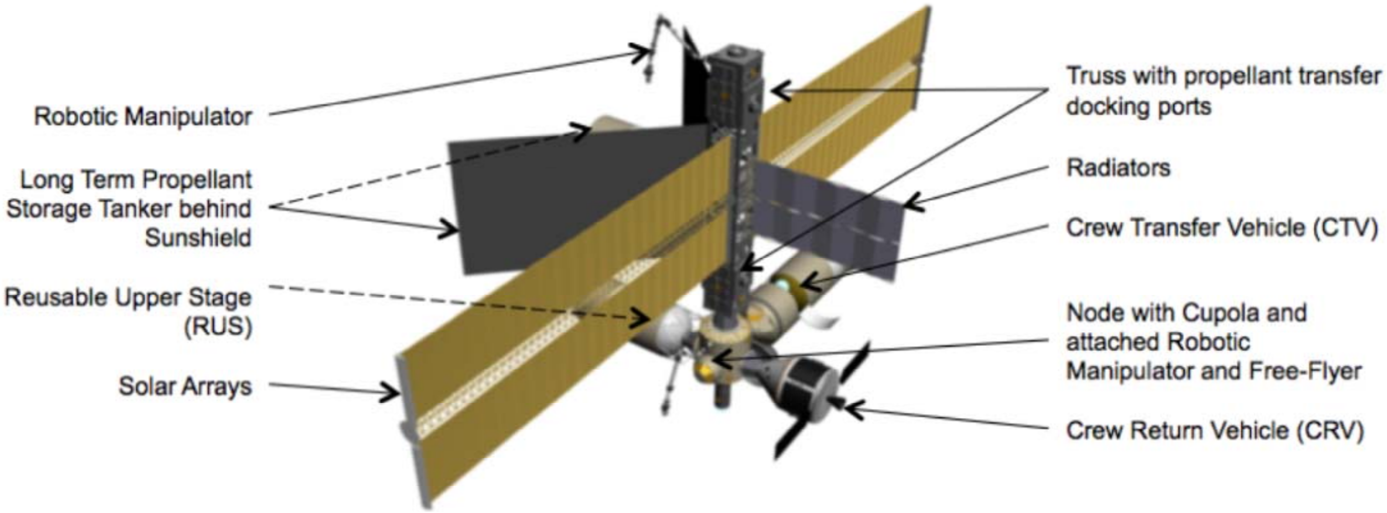
Scope and feasibility

a. The depot concept [1]

b. Propellant Sources

c. Order of Magnitude Scale

d. Costs



[1]. D. Smithermana, G. Woodcockb. Space Transportation Infrastructure Supported By Propellant Depots[C]. AIAA 2011-7160

The Report

Part 1-Feasibility and Missions (cont.)

Scope and feasibility

- *a. The depot concept*
- *b. Propellant Sources*
- *c. Order of Magnitude Scale*
- *d. Costs*

1.Cryogenic propellants launched from the Earth.

2. Electrolyse water or ice from the Earth, Moon, or Asteroids.

Part 1-Feasibility and Missions (cont.)

Scope and feasibility

a. The depot concept

b. Propellant Sources

c. Order of Magnitude Scale

d. Costs

Depot	Mission	Refueling requirement once(t)
LEO	Human GEO mission	53.2
	Robotics GEO launch mission	19.6
	Robotics GEO refueling mission	32.3
	Human lunar mission	21.5
	Human asteroid mission	21.5
	Human Mars mission	21.5
EML1	Human lunar mission	31.9
	Human asteroid mission	13.9
	Human Mars mission	78
MPO	Human Mars mission	88

Part 2-Technologies

Key Technologies

a. List of the key technologies

b. Fundament and Status of key technologies

c. Challenges and Risk assessment

d. Potential solutions

e. Developing schedules

f. Key technology readiness level

Part 2-Technologies

Key Technologies

a. List of the key technologies

1. ***The cryogenic propellant boil-off control***
   a) *Passive insulation*
   b) *Reducing the structure heat load*
   c) *Cryocoolers*
   d) *Para-Ortho Conversion*
   e) *Sun Shield*
   f) *Subcooling propellant*
2. ***Cryogenic propellant transfer***
3. ***Tank pressure control technology***
4. ***Assembly attitude control for propellant refuelling***
5. ***Liquid sloshing and large structure coupled dynamic modeling and control***
6. ***Power supply and management***
7. ***Low acceleration settling***
8. ***Cryogenic propellant gauging***

The Report

Part 3-Programmatic and Implementation

Roadmap for the implementation

a. *International capabilities and possible contributions*

b. *Global set of requirements*

c. *Enabling technologies required with the required time frame*

d. *Programme and operational sustainability*

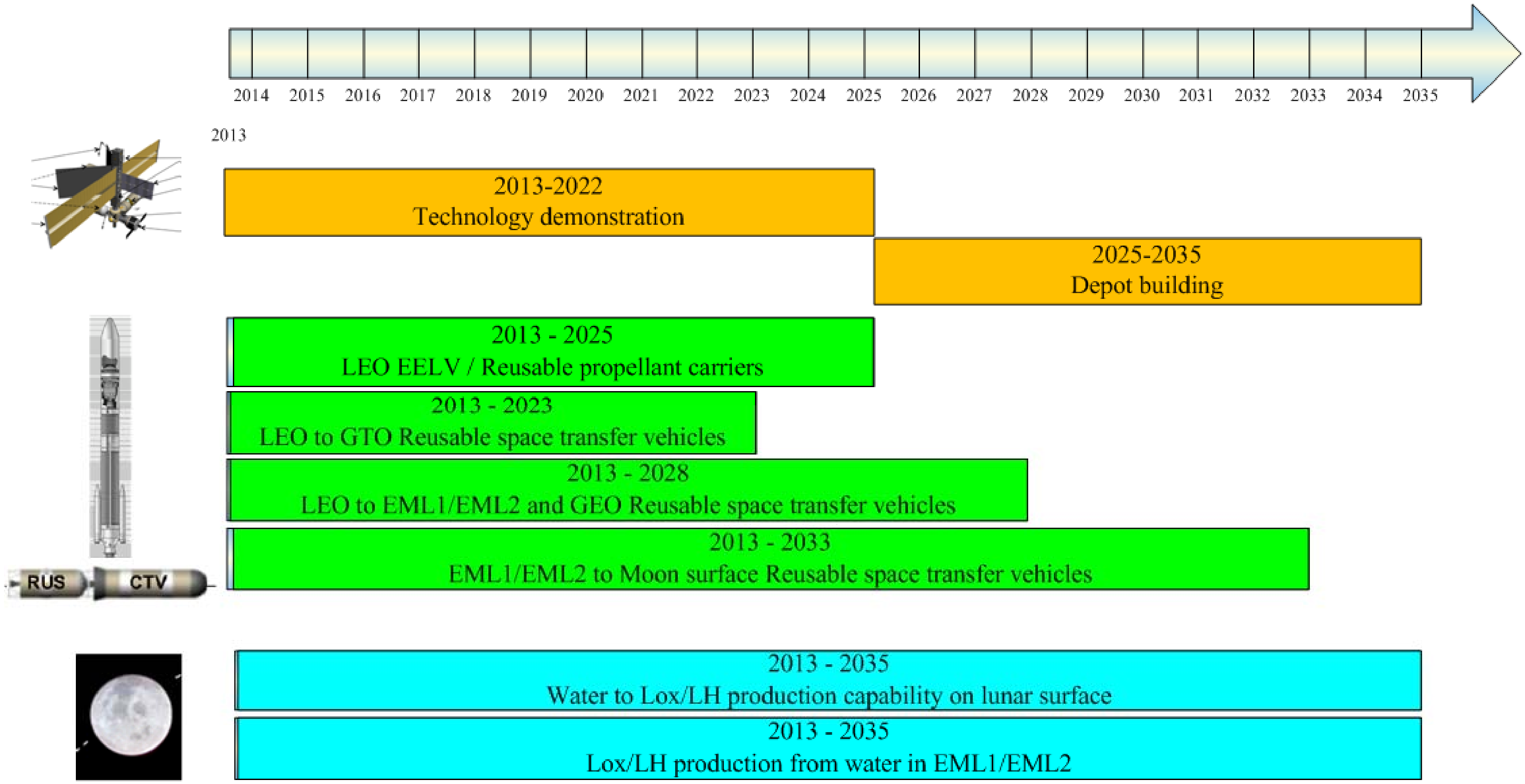
e. *Policy, legal and insurance frameworks*

f. *Outreach aspects*

g. *Cooperative framework*

h. *Decision roadmap*

The Report


2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035
2013
2013-2022
Technology demonstration
2025-2035
Depot building
2013 - 2025
LEO EELV / Reusable propellant carriers
2013 - 2023
LEO to GTO Reusable space transfer vehicles
2013 - 2028
LEO to EML1/EML2 and GEO Reusable space transfer vehicles
2013 - 2033
EML1/EML2 to Moon surface Reusable space transfer vehicles
RUS
CTV
2013 - 2035
Water to Lox/LH production capability on lunar surface
2013 - 2035
Lox/LH production from water in EML1/EML2

Schedule

Mar.-25-2015

Study group meeting in Paris, discuss the draft report before submitting to commission review.

July 2015

Finish the draft report.

Thanks!

Study group 3.18 on

Feasibility Study of Possible Inter-Agency Protocol to handle crisis / emergency to Astronauts in LEO

Status as on 16March 2015

STUDY GROUP MEMBERS

- S Ramakrishnan, VSSC, ISRO, India – Chair
- Bernhard Hufenbach, ESA /ESTEC, The Netherlands
- Mike Hawes, Lockheed Martin, USA
- ZHANG Shu, CALT, China
- Prof . Irmgard Marboe, University of Vienna, Vienna
- Gurric De Crombrugghe De Looringhe, Beligium
- Unnikrishnan Nair S., VSSC/ISRO, India – Secretary

OVERALL GOAL

- The Study will assess the feasibility to establish a protocol, restricted to rescue of crew from LEO, who got marooned or have lost de-orbit burn capability or are left with intolerably damaged thermal protection system and is not considering Moon, trans-lunar, Mars or other interplanetary missions.

- Rescuing from orbit is a critical operation and may not always result in success. It may also subject another set of crew to the uncertainties of rescue operations. Therefore the design of space vehicle shall take care of all conceivable failure modes and make the space vehicle reliable to the extent possible. In the unlikely event of crisis/emergencies, the space vehicle design shall be capable enough to achieve the objective of alleviating the immediate danger to the crew without any external assistance.

- Rescue in the context of this protocol is considered to be those cases where external assistance is mandatory to rescue the lives of the crew.

CONTENTS OF STUDY REPORT

- Executive Summary
- Prologue
- Possible crisis situations/emergency scenario of Crew in LEO and Crew rescue methodologies
- Current International Treaties/Protocol in the area of Outer Space & Space Travel/Space systems and their implementation status
- Impediments in considering an inter-agency protocol to handle crisis/emergency of astronauts in LEO
- Conclusion & way forward
- Annexures:
  - International agreements and other documents
  - References

Preliminary Cosmic Study Report of Study Group prepared and submitted

STATUS OF STUDY GROUP

- Had information exchange through emails
- Preliminary cosmic study report circulated among members for feedback.
- Paper presented at IAA Conference at Washington in January 2014. Feedback and comments awaiting.
- Review article appeared in Aviation Week & Space Technology, February 24, 2014 underscoring the importance of study and was circulated to members
- A new member from Belgium Gurric De Crombrugghe De Looringhe added

ISSUE REQUIRING RESOLUTION

- Members / Participants from other space faring nations like Russia, Japan, are important for wide acceptability of the contents and further refinement of protocol.

IMMEDIATE PLAN

- Plan of action for way forward prepared and sent to all members seeking suggestions.
- Face to face meeting in Paris with available members
- Need to induct more active members from other countries
- Detailing of certain sessions of the preliminary cosmic report based on Telecon

Final Report of Study Group 3.18

Study of possible International Protocol to handle crisis / emergency of astronauts in Low Earth Orbit

STUDY GROUP

S. Ramakrishnan
ISRO, India

Prof.Irmgard Marboe
University of Vienna, Austria

W. Michael Hawes
Lockheed Martin, USA

Bernhard Hufenbach
ESA / ESTEC, The Netherlands

Zhang Shu
CALT, China

Dr. Unnikrishnan Nair S
ISRO, India

OCTOBER 2013

Contents

Executive Summary

Low Earth Orbit (LEO) is the first step in accessing space to perform any Earth bound missions such as building a Space station and also to embark upon voyages to other distant destinations viz. the Moon, Mars etc. As such, human activities in LEO are bound to increase and in-fact, for more than a decade, there is continuous human presence in LEO. Commercial cargo shipment to space by Private agencies is a reality today and it is expected that private human transportation to LEO to service the space station will happen in the near future. While the possibility of Astronauts getting lost in space in a crippled spacecraft has been a subject of concern and discussions, the recent Columbia accident once again brought this subject into focus as a very credible scenario requiring urgent attention. The entry of private operators and advent of space tourism is expected to expose more and more common people to such risks and requirements, methodologies and international protocol for rescue of human life from Low Earth Orbit has become an imperative. While the UN convention for safety of Life at Sea (SOLAS) may serve as a model for such international treaties on rescue from space, there are several complex and unique issues specific to space rescue.

Currently, Article V of UN Outer Space Treaty (OST) incorporates an 'Agreement on the Rescue and Return of Astronauts and the Return of Space Objects' (ARRA), which mainly focuses on events such as emergency/unplanned landing of astronauts occurring within the national territory of a state, there is no explicitly stated obligations for states with respect to rescue operations involving accident/emergency in Low Earth Orbit (LEO). This brings in an urgent need for a protocol to plug this gap in the OST/ARRA regarding the duty of States to rescue Astronauts in distress in LEO.

The possible crisis situations for Astronauts in LEO encompasses a multitude of scenario viz. crippled spacecraft with loss of de-orbit capability, compromised spacecraft integrity, limitations on the resources/life support system to sustain crew on board, crew injury/incapacitation etc. All such contingencies requiring external intervention and assistance for saving the life of crew will be governed by this new protocol. Of course, the variety and complexity of possible contingencies and scenario do pose several challenges in effecting such rescue. The response time to mount a rescue effort, the choice of robotic vs crewed rescue with associated risks etc. are few of the many such daunting issues to be debated and resolved. The key enabling factor to attempt such intervention to a crippled spacecraft is obviously the adaptation of common engineering standards such as docking interfaces and other hardware technical protocol. The Apollo-Soyuz docking experiment and the building up of ISS with multi-national modules provide us with practical models to accomplish this basic compatibility. Having said that, it is the geopolitical consensus on the essentiality of such a rescue mechanism governed by international legal framework which will drive this initiative on crew rescue from LEO.

Formulation of such a rescue protocol will have to address following specific issues:

(i) Definition of situations demanding an international obligation to mount such rescue effort.

(ii) Identification of States having wherewithal to render such assistance and role of other States in this international effort.

(iii) The role, responsibility and liability of State(s) which own the crippled spacecraft, the State which performed the launch and the liability for damages due to an unsuccessful rescue effort.

(iv) The resources required to maintain such international rescue mechanism and the sharing of expenses among member States.

(v) The role of private players and non-governmental space faring entities in implementing this rescue protocol.

(vi) Possible physical and technical limitations in overall rescue efforts.

As a way forward, the immediate action will be the recognition and in-principle acceptance of a need for such a protocol for crew rescue from space by all space faring nations through a declaration/resolution by the Heads of Space Agencies. This should lead to setting up of an international committee, may be under the aegis of UN, to evolve the basic framework for such a rescue mechanism and the governing rules including the funding. On the technical front, the first action will be to develop and define international standards for manned space vehicles specifically addressing the crew safety and survival requirements and mandatory interfaces to enable access and rescue of crew in contingencies. This can be effectively handled by team of technical experts from space faring nations.

In conclusion, with the increase in human presence in space, specifically with the recent spurt in private operators venturing into space transportation as well as growing public response to space tourism opportunities, the spectre of incidents/accidents leading to humans stranded in space in near earth orbit is real. In the current information age, the response of the media and the public at large to such unfortunate happenings is something unfathomable. The public outrage and emotional impact of allowing loss of human life without any positive attempt to rescue them will have a lasting effect on the future of all space endeavours. This makes this whole issue of Astronaut rescue from Space Protocol urgent and imminent.

Chapter 1
Prologue

1.1 Introduction

It is expected that human activities in Low Earth Orbit (LEO) would be on the rise in the future due to missions around the Earth and to other destinations including interplanetary manned missions to Mars, Near Earth Objects, etc. As the potential for more commercial human spaceflight increases in the near future, space missions will no longer be solely government ventures and the applicability of Space treaties and Protocols to such scenarios is under debate. Many of the studies and existing treaties have focused on assisting crew after the landing phase of the mission. Most studies were carried out when only the United States and Russia conducted human launch and re-entry activities. Much has changed in the human spaceflight environment over the past decade. These changing situations include the advent of China as an independent human space-faring nation, the completion of the International Space Station with more than a decade of continuous human presence, the Columbia Shuttle accident and the retirement of the Space Shuttle itself. Individually all these have major influence on the global scope of human spaceflight. Together they present enormous change in the perspective of human spaceflight. In addition, public private partnerships have allowed cargo service flights to be initiated to the ISS. NASA has funded a significant portion of the development cost and is paying for the services of cargo flights, yet has accomplished this in a very different methodology than past space developments. New requirements, methodologies and regulations for crew rescue are therefore likely to become a significant factor in the future, in particular, if one assumes that private operators of crew spacecraft will succeed in developing a market for private human access to space.

With more and more human missions, the probability of crew having significant issues in space increases and there is a strong case for having in place adequate international legal mechanisms to deal with such situations and provide aide to crews, irrespective of their nationality or other geo-political considerations of the disabled craft. In this context, it is imperative to have early consultations among space-faring nations, to identify the issues involved in rescuing a crew in distress from LEO, and if possible, work towards a set of agreements with participation of all nations. This will eventually pave the way to put in place an international mechanism to aide and possibly rescue the crews in distress in LEO.

Rescuing from orbit is a critical operation and may actually subject another set of crew engaged in rescue to operational hazards. Therefore the design of space vehicles must consider conceivable failure modes and make the space vehicle reliable to the extent possible. In the extremely unlikely event of such crisis/emergencies, the space vehicle design should be capable enough to remove the crew from immediate danger without any external assistance. If this is not viable, external assistance to save the lives of stranded crew must be considered.

The Human Spaceflight Coordinating Group (HSFCG) has been established to define and monitor the implementation of the projects related to the priorities in the field of Human Spaceflight, selected by the IAA and the National Space Agencies. This Group is composed of experts from all over the world. The projects, proposed by the HSFCG and approved by the IAA Board of Trustees, shall present summaries of their findings on the occasion of the Head of Space Agency Summit dedicated to Robotics and Human Space Exploration planned in January 2014 at Washington. This report is the outcome of the Study group 3.18 on "Feasibility study of possible international protocol to handle crisis/emergency of astronauts in LEO".

1.2 Scope/Objectives of study

The scope of the study is to support human space exploration in low earth orbit by paving the way for consideration of international design standards and protocols to treat crisis/emergency situations of astronauts in LEO. At this point the scope is limited to address the feasibility of a protocol discussing rescuing crew from LEO and the study is not considering Moon, trans-lunar, Mars or other interplanetary or Near Earth Object missions. Rescue in the context of this study is considered to be those cases where external assistance is mandatory to save the lives of the crew.

The crew in the context of the study is defined as any person who travels to LEO in a space vehicle and belongs to any nation or state inclusive of astronauts, cosmonauts, taikonauts etc

The objectives of the study are outlined below.

- To identify the possible crisis situations/emergency scenario of crew in LEO
- To discuss the various crew rescue methodologies that are available to bring back crew under emergency/crisis
- To study the current international treaties/protocol in the area of outer space & space travel/space systems, their implementation status and limitations
- To bring out the various impediments/hurdles foreseen in evolving an international protocol on crew rescue from space and the approach to overcome them.
- To make recommendations, as outcomes of the study, and propose possible ways forward to evolve such a protocol to handle such crisis/emergency of astronauts

The Study group report has six chapters with the first chapter as a prologue along with the scope and objectives of the study. The possible crisis situations that are likely to encounter in LEO and the possible rescue methodologies are briefed in chapter 2. Chapter 3 discusses the current international treaties/protocols, implementation status along and their limitations. The various impediments or hurdles that can emerge during discussions on an international protocol to handle crisis/emergency along with possible mitigation strategies are discussed in chapter 4. Finally, chapter 5 provides the recommendations of the Study group and chapter 6 discusses the way forward on this very important topic related to future human space missions.

Chapter 2
Possible crisis situations/emergency scenario of Crew in LEO and Crew rescue methodologies

Many studies have considered the potential scenarios and possible issues associated with providing assistance to crew in low Earth Orbit [1,2,3,4].Studies such as Tedeman and Wright 1992 [5] and Bartoe 1989 [6] discuss a variety of scenarios including incapacitation of the crew, failure of the spacecraft de-orbit system and other hardware failures which would compromise the ability of the crew to return safely to the earth.

During the Columbia accident investigation the board tasked a small group of NASA engineers to develop a rescue scenario that might have enabled a transfer of crew from a suspected damaged ship to a new spacecraft. While the scenario developed for the Columbia Accident Investigation Board (CAIB) [7] had to make many large assumptions the exercise served to drive new thinking and perspectives on on-orbit rescue possibilities.

2.1 Possible Failure Scenarios

Failure scenarios such as described by Tedeman and Wright must consider issues of both spacecraft systems and the crew themselves. In the past crew medical emergency cases have been the primary driving requirements for the design of assured crew rescue vehicles [8] and in the development of operational procedures. Much of this discussion has centered on operations of the ISS (International Space Station). Current operational practice is to maintain emergency crew return capability for all crew on board the ISS at all times. The Russian Soyuz vehicles currently provide this function. In fact that emergency return function is one of the limiting factors on crew size. Two Soyuz vehicles allow for a maximum crew of six at any given time in ISS. It is necessary to reduce crew periodically to three as the Soyuz vehicles refresh ISS with new crew. If a crew health emergency occurred it would require that all three crewmembers assigned to that Soyuz vehicle would depart the ISS. As other vehicles are developed to take crew to the ISS the potential exists for the crew size to increase to seven to match the other system design limits.

The ISS can also serve as an emergency safe haven for crews operating in that same orbit. During nearly all the Shuttle missions after the Columbia accident, the ability of the ISS to support a larger crew as part of a safe haven in case of a damaged Shuttle became a mission readiness parameter. In this scenario NASA accepted the risk that the ISS would not maintain emergency return capability for the visiting Shuttle crew that was stranded due to a damaged Orbiter. The Shuttle flights were planned such that the supplies onboard the ISS would meet or exceed the time required for readying and launching a rescue Shuttle.

Many individual system failures can be envisioned which would lead to in space rescue of crew. These possible scenarios highlight the many possible causes and many likely obstacles. The variety of possible failures also presents an almost limitless number of scenarios. By grouping failures into end result scenarios we can identify salient issues and response scenarios as discussed below.

2.1.1 Stable spacecraft but loss of de-orbit capability

In this scenario the crew is healthy, most of the spacecraft systems are healthy and the only significant issue is loss of deorbit capability. On orbit rescues by another spacecraft or use of safe haven capability are the only real approaches that might be considered for this scenario. If another free flying spacecraft could be made available that spacecraft would still have to have several common interfaces to successfully conclude an on orbit rescue. A common docking system would greatly facilitate a rescue operation. The possibility to equalize pressure and share power would also be useful attributes.

The rescue scenario considered by the CAIB was essentially this case. While the use of ISS as a safe haven was the favored response for most missions, the rescue Shuttle was prepared for the Hubble Space Telescope repair mission. In this scenario, the Shuttle could not dock with but utilized the robotic arm to grapple the disabled vehicle. The crew will utilize the limited available spacesuits to transfer to the good Orbiter. This situation was really only possible due to the existence of airlocks on both vehicles so that the crew could transfer and then send spacesuits back to the other crewmembers. Here the limitations on spacewalk capability arise as a very clear obstacle.

2.1.2 Crew is healthy but spacecraft has lost integrity

In this situation, other systems may have failed. This might include slow loss of cabin pressure, loss of communications, degrading control capability, slow loss of propulsion, etc. In this case the crew would face a decision to either reach a safe haven, if possible or conduct an emergency de-orbit into an unplanned landing scenario. This issue has been the subject of past discussion and agreements as countries have agreed to provide assistance to crewmembers of other states.

Moving to the safe haven option presents a number of issues including commonality of docking systems, communications, limited crew supplies, limited crew return capability etc. Currently only the ISS and the Chinese space station, Tiangong, could be considered as safe haven possibilities. Eventually commercial orbital habitats may also provide some capability.

2.1.3 Crew is incapacitated but the spacecraft is functioning well

This scenario presents many of the challenges already described but has the added challenge of dealing with an incapacitated crew. What form of system failure has incapacitated the crew is a critical piece of information. How long can the crew survive in the remaining spacecraft environment? Are the conditions also potentially harmful to any rescuing crewmembers? The techniques described earlier to dock with or grapple a spacecraft are also key aspects of this scenario. The ability to transfer the crippled crew in an environment that they can survive (i.e. avoiding spacewalk) is also critical.

2.1.4 Crew is incapacitated and the spacecraft is not under control

This final scenario is perhaps the most complex and has all the issues of the first three but also adds the challenge of a possible uncooperative object for the rescue spacecraft to approach. Rotation rates, natural venting, rotation axes are now more critical attributes to understand. The docking/berthing and crew transfer issues are very similar to the earlier cases but the rescue crew must now also deal with finding a way to rendezvous with and grapple an uncontrolled spacecraft to access inside to reach and rescue the crew.

2.1.5 Rescue crew or robotic rescue

We also need to consider that an uncrewed vehicle like a space tug could resolve some of these scenarios and could, for example, ensure delivery of a stranded spacecraft to a safe haven. In this type of scenario some issues are simplified while others are dramatically increased.

2.2 Current human launch capability

As of October2013 only two human launch systems are in operation; the Russian Soyuz and the Chinese Shenzhou. Within the next few years additional vehicles are expected both as government developments such as Orion and multiple commercial launch service providers reach maturity. The current limitation makes rescue a very unlikely event. The addition of a number of new human flight systems may enhance the possibility of future rescue.

2.3 Orbital inclination

The most expensive maneuver in terms of energy/propellant requirement is a significant change in the orbital plane or inclination of the spacecraft. At this time, anticipating a rescue spacecraft might be launched into an appropriate inclination but it would be unlikely that any spacecraft already on orbit would have the capacity to significantly change inclination. A robotic tug spacecraft may have more flexibility in a limited set of scenarios.

The role of future man-tended infrastructure being able to act as a safe haven may have a strong influence on the orbital inclination and therefore the overall traffic model for future crewed missions. Pre-deploying safe havens in orbit inclinations of interest may therefore be the most effective means for addressing crew rescue requirements.

2.4 Rendezvous & Docking/berthing systems

The ISS partners have completed the definition of a common docking system that could be applied to future situations [9]. Utilization of a system with common attributes might simplify several of the scenarios that we discussed in this section. The lack of a docking system interface presents extreme difficulties in safely accomplishing crew transfer for rescue.

Several current systems, such as the HTV, Dragon and Cygnus utilize berthing techniques to service the ISS. In this scenario the spacecraft approach the ISS and station keep close enough to be grappled by the robotic Canadarm and then berth to a common berthing mechanism on the ISS. In this case the common berthing mechanism provides that common interface without the more complex docking adapter.

Docking to a target with low inertia, as could be the case in a rescue scenario, poses specific requirements on the docking system and in particular the ability of soft docking. Docking systems in operation today do not have this capability, but developments are underway for soft docking (such as the International Docking and Berthing Mechanism developed by ESA)

Furthermore, crew rescue contingencies will require the ability to rendezvous and dock with varying degree of non-cooperative targets. This capability has only been demonstrated on small robotic missions in limited situations such as the US Air Force XSS-11 mission [10]. Agencies are currently investing in technology associated with rendezvous and docking with uncooperative targets in the context of assessing future options for servicing or actively removing space debris, opening opportunities to exploit them for future development of rescue capabilities.

2.5 Internal pressure level

Once docked or berthed the human spacecraft would need to be capable of equalizing the internal pressure to allow for safe crew transfer. Future international standardization efforts should therefore also address this area.

2.6 Communications

Utilization of specific frequencies is closely regulated through the World Radio Conference and various coordination groups. The communications community may need to consider a general emergency frequency that could be easily utilized across different systems.

2.7 Power

Most scenarios would not require a direct transfer of power. It is a certainly a potential resource that requires capability to share.

2.8 Future exploration missions and destinations

The expansion of human spaceflight will present new issues and new opportunities. Missions beyond earth orbit will present new destinations, new challenges and obstacles and new capabilities. The complexity of possible crew rescue will certainly increase dramatically. It is likely that "safe havens in space and on the surface of Moon/ Mars" will play an essential role for expanding human presence into space. The Global Exploration Roadmap developed by the International Space Exploration Coordination (ISECG) suggest e.g. the deployment of a evolvable deep space habitat in cis-lunar space which would not only allow to extended duration missions in cis-lunar space, but also could function as a staging post for human-lunar surface missions at a later stage. One key function of thus evolvable deep space habitat would be to act as a safe haven in case of failure scenarios in cis-lunar space and/ or on the lunar surface.

It is also important to note that space agencies are already discussing the need for standardization to enhance opportunities for international cooperation in advancing common space exploration goals. These standardization efforts will address many of the aspects discussed above. Future space exploration missions may act as a facilitator for enabling future international space rescue operations in Low Earth Orbit.

Chapter 3
Current International Treaties/Protocol in the area of Outer Space & Space Travel/Space systems and their implementation status

The current corpus *iurisspatialis* was elaborated in the 1960s and the 1970s, when spaceflight in general was still in its infancy. The Declaration on Legal Principles of 1963, the Outer Space Treaty (OST) of 1967 and the Agreement on the Rescue and Return of Astronauts and the Return of Space Objects (Rescue and Return Agreement, ARRA)of 1968 were elaborated during the first years following Yuri Gagarin's flight in 1961. It is therefore not surprising that important issues and questions which emerged only in the course of subsequent space flight experience were not sufficiently regulated. In particular, the involvement of private actors, either as participants in space flights or as facilitators/ operators of such activities, has not been envisaged.

The current project aiming at the elaboration of a draft set of principles to handle crisis/emergency of astronauts in Low Earth Orbit (LEO) intends to identify the gaps in the regulation to rescue of crew from LEO. Various emergency scenarios are possible, as elaborated in Chapter 2.They include technical problems of the spacecraft like, for instance, loss of de-orbit capability, integrity or control, as well as other problems endangering the health of the crew, necessitating their rescue.

In the following section, an overview is given on the current legal obligations under international law regarding the rescue of astronauts. As will be shown, the relevant documents concentrate on situations where astronauts have landed on Earth, be it in the territory of a country or in a place outside the jurisdiction of any State. However, several general duties regarding the assistance of astronauts or of humans in general are also relevant and can be used to clarify the role of States in this respect. It has to be remembered that the existing body of space law addresses only the rights and obligations of States and not those of private actors. However, the particularity of space law that States bear international responsibility for national activities in outer space carried out by non-governmental entities (Article VI OST) establishes a link between the activities of private actors and the State. The existing corpus *iurisspatialis* provides a framework that is general enough to avoid that newly developed space activities are taking place in a legal vacuum. Nevertheless, certain aspects with regard to the rescue of astronauts – in particular in LEO – are not regulated and would benefit from a better definition of terms and a clearer formulation of rules.

3.1 Current instruments relevant in the context of space travel

3.1.1 Declaration of Legal Principles Governing the Activities of States in the Exploration of Outer Space

The **"Declaration of Legal Principles Governing the Activities of States in the Exploration and Uses of Outer Space"**(**Declaration of Legal Principles**)was discussed and elaborated in the Legal

Subcommittee during 1962 and 1963.It was then submitted to the General Assembly which incorporated the text in Resolution 1962 (XVIII). The Declaration was approved unanimously on December 13, 1963[11] and is regarded as customary international law today [12]. It consists of nine operative principles. **Principle 9** deals with the assistance to astronauts in distress and provides that

> "States shall regard astronauts as envoys of mankind in outer space, and shall render to them all possible assistance in the event of accident, distress, or emergency landing on the territory of a foreign State or on the high seas".

In this case, astronauts shall be safely and promptly returned to the State of registry of the space object.

3.1.2 Outer Space Treaty

3.1.2.1 The duty to rescue astronauts

Principle 9 of the Declaration of Legal Principles has been confirmed in the **Outer Space Treaty (OST**)[13]. As of 1 January 2013, the OST has 102 State parties and 26 signatories. The main space nations, among them China, India, the Russian Federation and the United States have ratified the treaty.

The presence of humans in outer space is addressed in **Article V OST** which provides:

> "States Parties to the Treaty shall regard astronauts as envoys of mankind in outer space and shall render to them all possible assistance in the event of accident, distress, or emergency landing on the territory of another State Party or on the high seas. When astronauts make such a landing, they shall be safely and promptly returned to the State of registry of their space vehicle.
>
> In carrying on activities in outer space and on celestial bodies, the astronauts of one State Party shall render all possible assistance to the astronauts of other States Parties.
>
> State Parties to the Treaty shall immediately inform the other States Parties to the Treaty or the Secretary-General of the United Nations of any phenomena they discover in outer space, including the Moon and other celestial bodies, which could constitute a danger to the life or health of astronauts".

The OST was the first multilateral treaty that used the term "astronaut" without, however, defining it. It is therefore unclear who exactly falls under this term, in particular, whether private spaceflight participants or private researchers in outer space are included [14].The duty to assist contained in Article V OST is based on the idea that astronauts shall be regarded as "envoys of mankind" deserving a special status and special protection [15].However, in view of the predominant humanitarian motivation reflected in the provision, the special designation of "envoys of mankind" does not have any significant meaning. Today, the prevailing view is not to differentiate between the public or private nature of the space activity and not distinguish personnel and passengers of a spacecraft as regards their rescue and return [16].Article V thus can be seen as a general duty to rescue and assist based on considerations of humanity.

Article V, paragraph 1,reiterates principle 9 of the Declaration on Legal Principle and establishes the obligation to rescue astronauts if they are found in the territory of another State or on the high seas. The obligation to rescue arises in the event of an "accident", "distress" or an "emergency landing"[17].These terms have to be interpreted according to the general rules on treaty interpretation according to which the treaty has to be interpreted "in accordance with the ordinary meaning to be given to the terms of the treaty in their context and in the light of its object and purpose" [18].

The "ordinary meaning" of the word "accident" can be described as an "unfortunate incident that happens unexpectedly and unintentionally, typically resulting in damage or injury" [19].It could cover the situation where there exists a malfunctioning caused by an external factor (e.g. space debris) or by a functional disorder of the spacecraft itself.

"Distress" is a broader term and refers, for example, to "the state of a ship or aircraft when in danger or difficulty and needing help" [20].In the Law of the Sea, "distress" is interpreted as the facing of an imminent danger of losing the vehicle and its cargo, or a threat to the lives of the crew, and can also arise following situations on board, like equipment failure[21].With regard to the object and purpose of the OST, which is amongst others the promotion of international cooperation, the term "distress" has to be interpreted in a broad manner [22].Thus, distress of astronauts should include cases where they, without having suffered yet an accident, are nevertheless in trouble and an accident may be close or at least cannot be excluded [23].

Paragraph 2, in contrast, is not limited to situations of "accident", "distress" or "emergency landing". It demands from astronauts of one State Party, while carrying on activities in outer space or on celestial bodies, to render "all possible assistance" to astronauts of other States Parties [24].This duty refers to situations in which astronauts face danger while in orbit and is therefore of utmost relevance in the context of the present study.

The extent of "all possible assistance" in this provision is unclear. Some authors point out that the duty to assist is supposed to fulfill the underlying humanitarian approach of the Article, namely to ensure assistance to humans in outer space in threatening circumstances [25].Consequently, the obligation has to be regarded as comprehensive demanding to render all possible assistance in any case [26].

Others, however, argue that such an interpretation would stretch the point, as any activity in outer space remains costly and risky and it would be disproportional to require States to render assistance without an emergency situation [27].This critique refers to so-called "trivial" assistance which means assistance in non-threatening situations, for instance helping the personnel of another spacecraft to install a solar panel. In this regard, States should in principle remain free to decide whether to cooperate with others in situation not amounting to distress or emergency. The obligation and standard of care to provide assistance could therefore be interpreted in accordance with general principles of law like liability for failing to rescue in certain cases, the Good Samaritan principle, equity, reciprocity and good faith [28].

In particular, the Good Samaritan principle which is known in several legal systems could provide certain guidance in this context. It addresses the situation in which an individual helps another individual in a situation of danger without being obliged to do so. The main questions discussed in this context are whether a fee or reward should be awarded to the Samaritan and whether the Samaritan himself is liable in the case he causes damage to the aided person [29].The Good Samaritan principle has also been discussed in the Final Report on "Legal Aspects of NEO Threat Response and Related Institutional Issues" [30] in the context of damage caused during response actions against Near Earth Objects, such as asteroids.As regards the costs of the rescue operation, the OST does not provide any regulation. In view of the humanitarian underpinning of the obligation to rescue, the general principle is deemed to prevail according to which the rescuer does not receive any money. This has later been confirmed by the ARRA according to which the costs for the return of a *space object* have to be reimbursed but not those of the rescue and return of an *astronaut*. This similarly applies to the duty of astronauts to help other astronauts. In view of the costs connected to rescue operations, it is advisable for States to establish a mechanism or fund to defray the costs emerging in these situations [28].

3.1.2.2 The international responsibility of States for space activities

According to Article VI OST, States bear international responsibility for activities carried out in outer space, whether such activities are carried out by governmental agencies or non-governmental entities. In the arena of public international law, this creates a rather unusual link between private activities and the State. The State consequently is obliged to authorize and continuously supervise the activities of non-governmental entities in outer space. Usually, this is done through an authorization or licensing procedure. In the conditions of authorization or licensing, a State can establish certain obligations which it otherwise would not have. These may include, for example, the duty to rescue astronauts in distress. In this way, the international obligation of the States may be transformed into a legal obligation of the private operator. Legal regimes governing many aspects of commercial flight have not yet been developed.

3.1.3 Rescue Agreement

Article V OST was the basis for the elaboration of the **Agreement on the Rescue and Return of Astronauts and the Return of Space Objects (Rescue and Return Agreement, ARRA)** [31]. As of 1 January 2013, it has 92 State parties and 24 signatories, the major space faring nations having ratified or acceded to it [32].The preamble states the desire “to develop and give further concrete expression” to the duties already contained in the OST.

The ARRA specifies the range of obligations of State parties concerning assistance to astronauts. Its objective is to set out more clearly who has to do what in cases of accidents involving astronauts and space objects. It reflects one of the basic principles of outer space law, namely, the promotion of international cooperation in the peaceful exploration and use of outer space. As the Preamble states, the Agreement is prompted by sentiments of humanity [61].However, except from the full title and the Preamble of the ARRA, the term “**personnel of a spacecraft**” is used instead of “astronauts”. The term “personnel of a spacecraft” might be regarded as encompassing the whole crew of the spacecraft, i.e. being broader than the term “astronaut” [62]. However, also the opposite conclusion is possible. In air law, the crew – the “personnel” – of the aircraft has other rights and duties than the passengers. It follows that the professional crew of a spacecraft should or could also be distinguished from private spacecraft passengers [33].

Articles 2 and 3 deal with **practical measures** aimed at rescuing and helping the personnel of a spacecraft when they land on the territory of a contracting party or on the high seas or in any other place not under the jurisdiction of any State. Article 2 focuses on events occurring **within the national territory of a State party** and recognises the dominant position of this State. Article 3 applies when astronauts **landed on high sea or any other place not under the jurisdiction of any State**. Only few surfaces on the Earth qualify as places not under the jurisdiction of any State, for example Antarctica [36].The Moon and other celestial bodies can also be regarded as falling within the scope of this provision [37].States that are in a position (from a geographical and technological point of view) to do so **must extend assistance** in search and rescue operations to assure the rescue of the affected personnel, if necessary [38].

As regards the **reimbursement of costs** incurred in the rescue of personnel of a spacecraft, the ARRA is silent. In contrast to the obligation to pay the costs of recovery of a space object the same has not been established with regard to humans being saved. After long discussion in the negotiation process, the view finally prevailed that the duty to rescue is a humanitarian duty and could or should not to be financially rewarded. With regard to space objects, Article in Article 5 (5) provides:

> Expenses incurred in fulfilling obligations to recover and return a space object or its component parts under paragraphs 2 and 3 of this article shall be borne by the launching authority.

This focus on **“emergency landings”** of the Articles of the ARRA mentioned above leads to the conclusion that situations of distress without a “landing” are not covered by its scope of application. This includes, for example, cases of emergency in outer spacewhere the spacecraft is still in flight and the rescue of personnel stranded in orbit or deep space [39].However, based on declaration given by delegates, some authors argue that the gap created by the use of the term “alighted” was not intentional [40].

It is not entirely clear whether in that case the more general obligation contained in Article V OST, paragraph 2, would come in. Generally, according to the *lexspecialis* and *lex posterior* rules, the more specialized prevails over the more general norm and the younger prevails over the older norm. This could mean that the ARRA prevails over the two older and more general instruments and that in case of accidents in LEO, thus not involving a “landing”, there are no obligations for States to rescue. On the other hand, it does not seem to be the purpose of the Rescue and Return Agreement to limit and restrict the duty to rescue astronauts but, on the contrary, to determine the respective obligation of States more clearly. A future protocol or other instrument could try to find a solution to this apparent contradiction of the OST and the ARRA as regards the duty of States to rescue astronauts in distress in LEO.

3.1.4 Relevant provisions in the regime of the Law of the Sea

As the legal regimes of the Law of the Sea and Space law are similar in many respects, principles or rules contained in the former may sometimes serve as a source of inspiration for solving issues not regulated appropriately by the latter. In the following, concepts and provisions of the United Nations Convention on the Law of the Sea (UNCLOS) [41] of 1982, the Convention for the Safety of Life at Sea (SOLAS) [42] of 1974, and the International Convention on Salvage (Salvage Convention) [43] of 1989 will briefly be introduced as a stimulus for the discussion of the duty to rescue of astronauts in LEO.

Article 98 UNCLOS in Part VII (High Seas)deals with the duty to render assistance persons in danger or distress on the high seas, thus in an area outside the jurisdiction of any State as it is the case with Outer Space. Article 98 confirms the general humanitarian duty to rescue persons in distress. More specifically, it obliges the respective State parties to prescribe certain obligations concerning the rendering of assistance to masters of ships under their jurisdiction:

The **SOLAS Convention** of 1974has already regulated earlier the duties of the master of a ship in situations of distress. The main focus of the voluminous **SOLAS Convention** is, however, the prevention of accidents and distress situations. The Convention, in extensive and detailed provisions, deals with the specification of standards for the construction, equipment and operation of ships. The individual chapters of the Convention regulate technical details concerning the construction of ships, including the design of subdivision and stability, machinery, electrical installations, fire protection, lifesaving appliances, radio communications etc. Flag States have to ensure that the vessels flying under their flag comply with the requirements contained in the Convention. According to the Convention’s approach, the standardization of the technical equipment is crucial for the benefit of safety of human life in dangerous environments. The SOLAS Convention thus can serve as a source of inspiration in the endeavor of standardization of outer space technology in the area of manned space flight.

The **Salvage Convention of 1989** aims at determining uniform international rules regarding salvage operations and to ensure that **adequate incentives** are available to those who undertake salvage operations. The duty to render assistance is contained in Article 10 (1) and (2). Article 10 defines the obligation of the master but also the obligation of the State Parties to ensure that this obligation can be effectively enforced. The rescuer must carry out the salvage operations with due care, and the owner of the property in danger must co-operative fully with him. An incentive to undertake salvage operation is the right of the rescuer to obtain a reward as provided in Article 12. However, in the case of salvage of persons, no remuneration shall be paid. This reflects, as in the UN outer space treaties, the humanitarian nature of rescue operations.

The incentive to obtain a reward for salvage operations can be considered as a model for situations in outer space as well. In view of the high risks and costs of rescue operations in outer space, in contrast to the Salvage Convention, the possibility of reimbursement of costs and/or remuneration for the salvage of persons should not be ruled out entirely.

3.1.5 ISS Crew Code of Conduct

The Code of Conduct was agreed upon in 2000 and covers the conduct of astronauts onboard the International Space Station (ISS) [44]. The Code of Conduct is applicable to an astronaut from the time of his or her designation as an ISS expedition crew member until completion of post-flight activities. It also applies to visiting crew members in order to ensure that all persons on board are covered by the same legal prescriptions [45].The Code was accepted by all ISS partners and has to be signed by all ISS crewmembers[46].

It establishes a clear chain of command and relationship between ground and on-orbit management, standards for work and responsibilities, disciplinary regulations and security guidelines, defines the ISS Commander's authority and responsibility **to enforce safety procedures** as well as physical and information security procedures and **crew rescue procedures**. The ISS Code of Conduct could be a useful model for determining the obligations of crew members of spacecraft in situations of distress or emergency occurring in LEO.

Chapter 4
Impediments in considering an international protocol on Crew rescue from space and possible mitigations

The previous chapters have discussed the possible crisis situations/emergency scenario that could happen in LEO manned missions, the current space treaties and its limitations in dealing with present and future rescue situations. Though the concepts of rescuing from space is as old as space age itself, the technical and financial factors of rescue of distressed astronauts in space have prevented a full rescue capability from being developed[7,47]. The existing international legal regime has not kept pace with much of the remarkable technological and commercial progress made in the space arena especially with emerging private space transportation activities [48]. Unlike other similar fields such as civil aviation and commercial shipping, there has been no universal law binding all the parties to certain degrees of observance to enhance crew safety and rescue characteristics. It is imperative to understand the limitations that would impact the spread of technologies that will allow the early integration of different nation's space faring systems. The very fact that there is not a single comprehensive law on crew rescue, even after half a century of manned spaceflight, speaks volumes about the influences of impediments, which make such legislation difficult. The nature and extent of obstacles may be very diverse and include technical, managerial, political and economic issues. Identification of these possible stumbling blocks and addressing them successfully will facilitate the development of a satisfactory and effective international protocol on crew rescue.

4.1 Impediments/hurdles foreseen

Some of the major possible impediments and the approach to overcome them are discussed below.

4.1.1 International Standardization of manned space vehicle systems

Historically, manned spaceflight standards have evolved independently by leading national space agencies. Through the lessons learned and safety analysis conducted, applicable requirements to reduce and control safety risk were derived. In order to successfully establish an international crew rescue capability, common design and operational standards will have to be developed and implemented in each nation's manned space systems. A primary focus maybe on standardisation of systems essential for crew rescue, such as the interfaces for docking/berthing, environmental control and life support systems (ECLSS), interfaces of flight suit/spacesuit, communication systems etc . Capabilities and procedures should be understood and in place so that when the need arises, possible crew rescue can be assessed quickly. This will call for a good understanding of existing human spaceflight systems and related technologies. The countries with human mission capability may not agree to alter their well-proven existing systems. Due to export control limitations countries may not be able to fully share engineering data. Modification of existing systems with enormous flight heritage can also have an adverse impact on overall reliability of the system. Developed countries may be reluctant or prohibited from transferring their technology without adequate financial compensation. The disparity in “the state of the art” of technology among participating nations may also be an impediment. All the above translates into additional cost, time and effort, which can be resented by many of the participants.

Mitigation: The importance of standardization vis-à-vis the usage of existing proven system as well as ‘which’ is the standard to be followed is to be deliberated and agreed upon by the participating countries. The experience of ISS IGAs and MOUs, which took years to develop, may be a good model to consider.

4.1.2 Sharing of cost in rescue mission

A primary issue with space rescue missions is the potential expense and the apportionment associated with it. This question assumes significance, as we consider scenarios with astronauts of different nationalities than the country of launch place or the country providing the rescue capability.

The cost of a typical rescue mission has many elements.

- Cost of development of rescue system
- Launch cost to the LEO or as required by the mission
- Operational cost; which involves :
  - Maintenance of rescue system in orbit
  - Ground support systems like launch/mission control
  - Maintenance of recovery team for rescue vehicle recovery
- Use of space station if it is used as an intermediate safe haven.
- Compensation to various agencies, whose regular activities were affected due to resource diversion to the rescue mission

The factors associated with the spending of funds for rescue is more likely to be heavily influenced by the political relations between countries, frequency with which a nation uses this facility, the formula for apportioning the cost of rescue, existence of available agreements, if any, etc. Obviously the cost of rescue is going to be quite high. Anticipation of cost, estimation based on realistic rescue scenarios and arriving at logical and acceptable mode of cost sharing is going to be a challenge, while discussing any protocol related to space rescue.

Mitigation: A mechanism has to be in place to have a realistic estimate of the actual cost involved on a real-time basis and a proper economic model should be developed. This should take into account the effort and contribution of each agency in a possible rescue operation, and should be flexible enough to accommodate all the possible variations and uncertainties

4.1.3 Rescue scenario and response time

One of the primary choices, within the present constraints of technology, for rescuing a distressed crew in orbit is by sending a rescue spacecraft. This demands an optimal rescue vehicle that can be rapidly prepared for launch.

Due to limitation in launch vehicle payload capacity from a given launch point and constraints with respect to launch stations, rescue spacecraft may not be able to reach the orbit of the stranded vehicle, in all cases. The number of launch opportunities to perform a rescue will be further reduced by orbital mechanics related constraints. All these would severely hamper the rescue attempt. Under such situations, the rescue methodology needs to be expanded by allowing the spacecraft in distress to dock with another vehicle /Space station/crew life stations that can provide ad hoc life support while the main rescue vehicle is on its way.

Mitigation: Every crisis scenario, its consequences and suggested rescue methodology has to be studied well in advance so that in the event of an actual rescue, a clear procedure to be followed and hierarchy of command exist. This will speed up the rescue operation and streamline the co-ordination between the various agencies involved.

4.1.4 Crew Size for future missions

The acceptable crew size for rescue is dictated by the accommodation capacity of the space capsule available at that point of time.

At present, the Russian Soyuz-TMA and Chinese Shenzhou are the only manned spacecraft and can only transport a crew of three. The Russian Soyuz is versatile enough to carry out missions to ISS or perform autonomous missions of its own. The United States is in the process of renewing their human spaceflight capability through new generation modules, viz. Dragon, CST-100, Dreamchaser and Orion for beyond earth orbit.. The Russians have also considered developing bigger modules, which could carry more cosmonauts than Soyuz.

The number of crew to be rescued vis-a-vis the carrying capacity of the rescue vehicle will be serious techno-managerial impediment, which has to be thoroughly debated and resolved. The major points of concern are mission to mission variation of crew size, type of mission; its purpose and orbital parameters, capability of the rescue vehicle with respect to the number of crew, which it can safely evacuate at a time, ; immediate requirement or longer term need and nature of rescue vehicle; Piloted or Autonomous.

The crew rescue options are limited by the current technology and choice of available spacecraft. Depending on the type of crisis and the number of travelers to be rescued, the crew can either be brought back to earth or to the safety of a space station. This is an impediment as most crises scenarios demand the evacuation of larger number of astronauts. In the present scenario, rescue of more than two astronauts, means launch or deployment of multiple rescue spacecraft.

Mitigation: The crew size for any particular mission is driven by the requirements of that specific mission. Crew rescue may be a consideration but will be traded against the design and reliability of the space craft itself.

4.1.5 Limitations on technology transfer

Any crew rescue situation may imply sharing and transferring of technology among the signatories, to successfully address various rescue scenarios. Even if the development of universal safety systems and standards do not intrude on the proprietary or technology transfer realms of the design of space transportation systems, it can still be assumed that objections to technology transfer would be a major deterrent for international cooperation. The concerns include possible dual use of technology, violation of Intellectual Property Rights and disparity in technology readiness or varied maturity level among participating countries. The prevailing socio-political and technology transfer policies of countries, can also act as hindrance to the knowledge sharing.

The Apollo-Soyuz Test Project that materialised (in the 1970s) during the height of the cold war, is often quoted as an example of successful technology transfer between two major space powers. In the years that have followed Apollo-Soyuz, the ISS has demonstrated an ability to share engineering design and technology on a level far greater than past missions. These models should be considered for practical limitations on technology transfer.

Mitigation: The difference of technology maturity level among participating nations should be accepted as a fact and realistic methodology for technology transfer has to be evolved based on past experience like the Apollo-Soyuz test project and the ISS. Focusing design considerations on critical interfaces rather than detailed system knowledge may mitigate much of this concern.

4.1.6 Geopolitical considerations

In the US, emergence of private players in human space flights is being encouraged and private parties have come forward to invest in space. The 21st century witnessed rapid strides made by China in manned space flights and on-orbit construction activities. Their achievements in human spaceflights have triggered many new global partnerships, especially with European countries, resulting in various collaborative ventures. This has greatly altered the dynamics of international space co-operation. Today, what we have is certainly a multi-polar world, as far as space is concerned, with many stake holders in the fray. Obviously, this creates more challenges to arrive at consensual protocols and treaties in space, satisfying the interest of all. It is highly likely that countries might put forward unacceptable conditions for acceding to future treaties and protocols, like lifting of arms/trade embargo, underplaying of human rights violations, encouraging clandestine nuclear activities, interference in regional political skirmishes etc. It may be difficult to insulate space and related ventures from the overtures of geopolitical considerations.

Mitigation: It is quite possible that only a handful of countries will be providing human spaceflight capability, at least, in the foreseeable many years. The success of ISS has demonstrated even larger multinational space operations for many years. Though the geo-political issues are reality, it can be well managed through appropriate consultations at different levels.

4.1.7 Gaps of existing legal framework

Today, there exists no single all-encompassing legal mechanism to deal with or direct the necessary global technological efforts required to tackle the challenges of successful crew rescue. At present, rescue operations or commitments are not mandatory and hence are not governed or regulated by the present treaties. Another inadequacy is that most of the treaties/agreements are between nations or national agencies and they exclude private agencies. This is a serious handicap, in the present scenario, as many private agencies have manned mission capabilities of their own or on the verge of acquiring it. Attempt to forge a single legal framework, which is binding to all space faring nations and capable private parties, can have severe impediments and conflicts with existing national, regional and provisional laws and practices. This can clash with internal goals set by national agencies, national ambitions and agency specific unique technical standards and processes. During evolution of the legal framework, definition of parameters can change and policies that are not made explicit at the beginning of co-operative efforts, can lead to conflicting interpretations, at a later stage. All existing laws are primarily on the use of space for peaceful purposes, on usage of satellite slots and broad guidelines on utilization of resources. They do not address the modalities on policy, management, systems engineering and operation with respect to a realistic crew rescue scenario from Low Earth Orbit.

Mitigation: The nations should not only overcome the gaps in the existing legal framework, but also delineate new ones, wherever necessary, on a priority basis. A clear process should be outlined to make decisions and settle disputes. The line of authority and responsibility should be well defined and the role of each agency should be explicit. The evolved legal framework should also address the funding methodology, resource allocation and the financial commitment needed to undertake the task of crew rescue.

4.1.8 Satisfying diverse interest of stake holders/consensus among member countries

The achievements of pioneering nations in human spaceflight arena are acquired through significant economic commitments and technological development. There can be varying priorities about sharing such achievements with agencies, which are not state backed, as it could be utilized for their respective commercial interests. Arriving at a global consensus on any treaty could well be thwarted by regional challenges which depend on the geographic setting and mutually shared economic and political interests. A powerful regional space faring nation could seek to dictate supplementary objectives of their choice in addition to co-operative space rescue, in a regional space co-operation organization. This advantage, in addition to consolidating that country's position in space, can also result in gains in other commercial space ventures, over its regional partners. In such cases, those countries, which do not have a strong political/economic stature in the region, could lose out on opportunities to establish themselves as future leaders on space activities. Therefore, if issues related to space rescue are discussed at a regional level, stake holders should take into account the existence of multiple regional space bodies and its influence.

Mitigation: The success of ISS can be cited as an example in bringing together many nations for a common cause. Emphasis should be given in promoting mutual commercial and technological interests in the region and provision for international consensus on various aspects of space rescue should be inscribed in the protocol. At the same time ISS has allowed for individual agency priorities to also be included.

4.1.9 Technology obsolescence

Obsolescence is a significant cost driver and can have impact at all stages of the development and operational phases. Components, methodologies as well as approaches have to be selected keeping this in mind. Thorough and periodic reviews have to be carried out to avoid systems becoming unacceptably outmoded, which is difficult from a technical management point of view. A robust obsolescence management strategy has to be considered involving all the concerned parties and manufacturers to ensure uninterrupted supply. Although electronics are most likely to be affected by the onslaught of new technology, obsolescence of non-electronic and commercial off-the-shelf (COTS) items also poses a problem in the long run.

Mitigation: A clear obsolescence management strategy, which is both practical and effective, should be considered in the development of the protocol. The strategy should address the concerns of participating countries and should encompass all aspects including advances in technology, costs involved and support from participating countries. Useful guidelines shall be evolved with mutual consent of all the agencies involved.

Chapter 5
Considerations towards evolving a protocol to handle crisis/emergency of astronauts in LEO

As the current legal framework of activities in outer space, most prominently the Declaration of Legal Principles Governing the Activities of States in the Exploration of Outer Space (Declaration of Legal Principles), the Outer Space Treaty (OST) and the Agreement on Rescue and Return of Astronauts (ARRA), do not specifically address crisis or emergency situations of astronauts in LEO, there is a need for clarification and further development of the existing international rules. Some general principles are applicable and give some guidance but several questions remain open. The open questions concern, in particular,(1) the definition of situations which would trigger the obligations to rescue, (2) the identification of who would be obliged to render assistance and/or carry out salvage operations, and (3) what kind of assistance and/or salvage operations would be required. In addition, (4) matters of liability and (5) cost bearing should be addressed.

The following considerations need to be taken into account in the development of a future consensus protocol to put in place an international mechanism to aide and possibly rescue the crews in distress.

5.1 Situations that trigger an obligation to assistance and/or rescue

Different scenarios are possible which could lead to an emergency situation in LEO. As shown in Chapter 2, these can be technical problems of the spacecraft or further problems endangering the health of the crew. All of these situations become life-threatening at one point, either in orbit or when the spacecraft tries to re-enter the Earth atmosphere.

The current legal framework already stipulates obligations of States in respect of assistance and rescue of astronauts. Principle 9 of the Declaration of Legal Principles and Article V (1) OST establishes that States “shall regard astronauts as envoys of mankind in outer space and shall render to them all possible assistance”. However, the language of the provision appears to limit the scope of this obligation to events of “accident, distress or an emergency landing on the territory of another State Party or on the high seas.” Yet, it is generally accepted that this obligation has a predominantly humanitarian underpinning. It should thus be interpreted in a way that includes events of “accident, distress or emergency” occurring in outer space. A “landing” on a territory or on the high seas should not be required to trigger the obligation to assist.

This would fill the gap between Article V (1) in relation to (2) which already establishes the duty of astronauts to assist astronauts of other States when carrying on activities **in outer space.**

Such an interpretation would also confirm the general principle that anyone in a position to do so must help other persons in an emergency situation. Even if the extent of the duty to assist or rescue varies from country to country, it exists in numerous national jurisdictions. This duty may therefore be regarded as a general principle of law which is also binding upon States. It is generally limited by the helper's capabilities and by the exclusion that he or she must not endanger his or her own life or that of others while conducting the rescue.

Similar obligations are already well established in the Law of the Sea (see Article 98 UNCLOS, Regulation 10 of Chapter V of the SOLAS Convention 1974, and Article 10 of the Salvage Convention 1989 (as quoted above).

It may be concluded that situations triggering the obligation of States "to render all possible assistance to astronauts" should be "accident, distress or emergency situations occurring in LEO." The term "astronaut" in this context should also encompass private spaceflight participants and private researchers.

5.2 Obligation to provide assistance and rescue

Principle 9 and Article V OST simply refer to "States" being obliged to provide assistance. However, a differentiation may be appropriate depending on the capability of the State and its involvement in the concrete mission. Only relatively few States are actually carrying out space activities and have the necessary infrastructure. Their duties must be different from those which do not have any space faring capability.

With respect to the issue of astronauts in emergency situations in LEO, it appears to be appropriate to differentiate between three different types of States: (1) States which are involved in the mission, either as a launching State or as a responsible State; (2) States which have space faring capabilities, in particular with respect to manned space flight; and (3) all other States.

Group (1) may have the most far-reaching obligations in the case of emergency in LEO as they have the relevant know-how concerning the planning and procedure of the mission.

Other space faring nations not involved in the respective mission (Group 2) may also have certain duties with respect to astronauts in distress in LEO. The reason is that they potentially have the capability to conduct rescue missions. In this respect, Article 3 of the ARRA provides some guidance. It provides that States which are in a position to do so from a geographical and technological point of view are obliged to extend assistance in rescue operations. The obligations of States not having space faring capabilities at all (3) will be more limited due to the lack of technologies. However, due to humanitarian considerations, all States have general obligations to assist them in case of necessity. Article V paragraph 3 OST already requires State parties to provide information on any phenomena they discover in outer space that could constitute a danger to the life or health of astronauts to other State parties or the UN Secretary General.

Astronauts themselves are obliged to provide assistance to other astronauts while in orbit according to Article V paragraph 2 OST. A similar obligation is also known in the Law of the Sea. Various conventions (UNCLOS, SOLAS, Salvage Convention) provide for the duty of the master of a ship to render assistance and to rescue persons in distress at sea.

5.3 Providing assistance and rescue

Principle 9 of the Declaration of Principles and Article V OST do not set parameters for required assistance other than it being "possible". In general, the extent of obligation to assist or rescue depends on the concrete circumstances of both the crew/ spacecraft in danger and the rescuing crew.

In the Law of the Sea it is accepted that "all possible assistance" does not place an unlimited duty to provide assistance on the assistor, but is guided by the technological or financial capability and a general geographical proximity. In outer space, the situation is even more sensible as any activity, including rescue activity, is hazardous, putting into risk also the rescuing crew. Also in other highly dangerous environments, such as Antarctica or extreme sports adventures, there exists a legal obligation to help and assist only in situations which are life threatening to other participants and only if the rescue does not entail a large risk for the rescuer himself.

The type of measures constituting "possible assistance" in outer space depends on the capabilities of the rescuing crew and the concrete circumstances of the emergency situation. Most importantly, the safety of the rescuing crew should always be crucial in the evaluation of measures to be taken.

Several measures aiming at assisting and rescuing astronauts in LEO can be distinguished:

- Measures to prevent emergency situations from occurring (*a priori*, long before the respective mission is launched)

- Measures to assist astronauts in distress (assist phase). This includes both ground based and in-space components of assistance. For example, providing emergency communication

- Measures to rescue astronauts in distress (evacuation phase)

Measures to prevent emergency situations have to begin well in advance and may include standardization procedures of manned space vehicle systems. In this respect, reference can be made to the SOLAS Convention of 1974 which specifies minimum safety standards in construction, equipment and operation of ships in order to ensure their safety.

Measures to assist are measures aimed at helping the crew in distress to manage the crisis by itself until its members are rescued or can return to safe haven. Such measures could include allowing the crew in danger dock at a space station in order to get oxygen or other supplies needed.

The evacuation phase includes evacuation and transport of the crew to a safe place in orbit or on the Earth.

When deciding which measures should be taken in the concrete case, the limitations attached to the duty to rescue as a general principle of law could provide guidance. In a number of jurisdictions due care is required from the rescuer, which is established according to his personal skills and knowledge. Due care is also relevant in the context of the Good Samaritan principle and is reflected in Article 8 of the Salvage Convention of 1989.

5.4 Liability for damages occurring during the rescue operation

An issue to be addressed is whether liability could be triggered for damage occurring during rescue operations, such as damage on the spacecraft in emergency, the rescue space vehicle, death or injury of persons, damage to the environment (like, for instance, emergence of space debris).

The current legal regime for outer space establishes State liability for damages caused by space objects under the OST as well as the Liability Convention. A waiver of liability should be considered for damage caused by, or in the course of an effort to rescue astronauts. In this context general principles of law could provide useful guidance and the Good Samaritan principle, the liability of the rescuer in emergency situations is more limited than usual.

As long as the rescuer acts with due care in a reasonable manner, he/she should not be liable for the failure of the rescue attempt or for damages that might arise as a consequence. The liability in this case should be limited to grossly negligent or reckless behavior. In addition, there should be no liability for contributory negligence, if he or she acted reasonably.

The necessity of due care is also reflected in Article 8 of the Salvage Convention and could be applied for situations of rescue attempts in orbit.

The Good Samaritan principle was included in the Recommendations enshrined in the Final Report on "Legal Aspects of NEO Threat Response and Related Institutional Issues", According to Recommendation No 3, if damage occurs "(…) as a consequence of such mission being not (completely) successful, the state(s) responsible for such mission should not be held liable for such damage as long as the mission was undertaken within the parameters set by a proper mandate by the international community".

5.5 Bearing the costs of rescue mission

Assistance and rescue operations in orbit involve very high costs. It is therefore of utmost importance to define how the costs for such operations should be born. In view of humanitarian considerations upon which Principle 9 of the Declaration of Legal Principles and Article V OST are based, costs of measures taken to save human life should not be reimbursed. This contrasts with the costs for the return of a space object and its regulation in the ARRA (Article 5 (5) ARRA). The same distinction between objects and human life is made in the Law of the Sea (Article 12, 13 and 16 of the Salvage Convention of 1989).

However, in view of the costs of rescue operations in outer space which are not comparable to costs emerging in similar legal regimes, it seems to be unfair to ask the "capable" States with all the financial burden of rescue operations.

In order to create an incentive for developing and employing rescue operations and measures, re-imbursement or remuneration mechanisms could be introduced. These could be financed by an international fund. In addition, launch providers could ask for appropriate insurance to cover such costs.

Chapter 6
Conclusions and Way forward

1. Summary of Study

1. The ability to provide assistance in on-orbit scenarios is fundamentally driven by the physical parameters of the spacecraft position in space and the state of the spacecraft and the crew. While many systems failures can be envisioned to cause situations leading to distress events those situations can be organized into a smaller set of scenario outcomes. Several of the scenarios highlight the desirability of common standards and interface definition.

2. The current legal framework was elaborated in a period when space activities were conducted only by States, were reflecting the technological capabilities of the time and were conducted in front of a particular political background. Thus, in addition to humanitarian considerations, the duties of States to rescue and return astronauts were very much drafted to safeguard the interests of the then space faring nations. The current legal frame work does not cover all types of space activities carried out by a number of different space actors, including emerging space faring nations and private operators. The obligations of States in cases of distress or emergency situations occurring in LEO are not clear. The respective provisions on the rescue of astronauts have a slightly different scope in the Principles Declaration, the OST and the ARRA. A protocol or another instrument for interpretation could be beneficial for the clarification of the outstanding questions.

3. The various impediments that can come up in formulating an internationally acceptable protocol on crew rescue from LEO are identified along with the approaches to overcome them. There are technical as well as geopolitical issues that need to be tackled.

4. A set of discussion points, as given below, have been identified by the study group addressing questions related to the development of a possible consensus protocol to handle crisis/emergency of crew in LEO.

    1. Defining the situations that trigger an obligation to assist and/or rescue and the persons who should benefit.

    2. Identifying the States which should have a duty to render assistance to astronauts in outer space, depending on their respective capabilities, particularly in the area of manned space flight and other space activities.

    3. Describing the extent of the duty to render assistance, possibly distinguishing between measures aiming at assisting and rescuing astronauts which consist of measures to prevent,

measures to assist, and measures to rescue. Measures to assist and rescue astronauts shall be carried out with due care. Considering that, when the circumstances so require, assistance from other States and non-governmental entities should/could be sought.

4. Defining the extent of liability for damages caused by an assistance or rescue operation. Such liability could be limited to cases of gross negligence, intention or recklessness.

5. Considering the establishment of an international fund for the coverage of the costs for assistance and rescue operations for astronauts in distress or emergency situations in outer space.

6. Considering whether non-governmental entities carrying out space activities should be encouraged to take out insurance to cover the costs for assistance and rescue operations for astronauts in distress or emergency situations in outer space.

7. Paying due regard to the ISS International Docking System Standard as a great start in the development of compatible interface systems for human spaceflight, several other systems can be considered for studies leading to similar standards.

8. Developing a list of primary systems to be considered for definition of standards. That list could then be shared and considered in international for a. Synergies with international coordination efforts driven by the intent of space agencies to cooperate for advancing common space exploration goals could be identified and exploited. Space agencies could also give due considerations to crew rescue requirements as they plan future human spaceflight missions and define the associated architecture, infrastructure and Design Reference Missions.

9. Acknowledging the physical limitations of various orbital scenarios in the legal considerations for assistance.

10. Considering an international crew rescue organization, in line with the International Maritime Organisation (IMO), with participation from many countries, possibly under the aegis of the United Nations, to formulate, oversee and implement the standardization process.

2. Recommendations of SG3.18 for immediate consideration

From above, the following recommendations are put forward for immediate consideration while discussing the feasibility study of possible international protocol to handle crisis or emergency of astronauts in LEO.

2.1 **Need for protocol:** Considering the gaps in the existing space laws and the changed scenario of human spaceflight world-wide, there is a need to bring out a protocol on crew rescue in low earth orbit missions. The various impediments that are likely to crop up while discussing a consensual protocol are brought out along with the mitigation plan. Space faring nations with human spaceflight capability may take the initiative in arriving at a consensual protocol on this.

2.2 **Developing international standards in vehicle systems:** Developing a list of primary systems to be considered for definition of standards. Synergies with international coordination efforts driven by the intent of space agencies to cooperate for advancing common space exploration goals could be identified and exploited. Space agencies could also give due considerations to crew rescue requirements as they plan future human spaceflight missions and define the associated architecture, infrastructure and Design Reference Missions. Paying due regard to the ISS International Docking System Standard as a great start in the development of compatible interface systems for human spaceflight, several other systems can be considered for studies leading to similar standards.

2.3 **Defining preferred orbital corridors for manned flights:** Acknowledging the physical limitations of rescue of crew in danger from various orbital scenarios, the feasibility of defining few orbital corridors with defined orbital inclinations may be considered for human spaceflight activities and construction of space stations.

2.4 **Setting up of an international mechanism:** Considering setting up an international body, preferably under the aegis of the United Nations, in line with the International Maritime Organisation (IMO), to formulate, oversee and implement crew rescue from LEO along with addressing associated issues like cost sharing.

Annexure
International Agreements and other documents

Treaties

1. The Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies of 27 January 1967
2. The Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space of 22 April 1968
3. The Convention on International Liability for Damage Caused by Space Objects of 29 March 1972
4. Vienna Convention on the Law of Treaties of 23 May1969
5. International Convention on Maritime Search and Rescue, of 27 April 1979
6. United Nations Convention on the Law of the Sea of 10 December 1982, see http://www.un.org/depts/los/convention_agreements/texts/unclos/closindx.htm
7. International Convention for the Safety of Life at Sea 1 November1974, see http://treaties.un.org/doc/Publication/UNTS/Volume%201184/volume-1184-I-18961-English.pdf
8. International Convention On Salvage of 28 April 1989
9. Intergovernmental Agreement on the International Space Station of 29 January 1998

Non-binding international instruments

1. The Declaration of Legal Principles Governing the Activities of States in the Exploration and Uses of Outer Space (General Assembly resolution 1962 (XVIII) of 13 December 1963);
2. The Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interest of All States, Taking into Particular Account the Needs of Developing Countries (resolution 51/122 of 13 December 1996)
3. Memoranda of Understandings (MOUs) between NASA and each of the four cooperating agencies of Russian Federation, Canada, Europe, and Japan, signed on 29 January 1998 (and 24 February 1998 for Japan)
4. Code of Conduct for the International Space Station Crew, 14 CFR 1214.403, last update of 1 January 2012

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Status Report to Commission III on Feasibility Study of Astronaut Standardized Career Dose Limits in LEO and the outlook for BLEO: Biological responses of humans to the impingement of high energy particle radiation

Susan McKenna-Lawlor

Space Technology Ireland,

Maynooth, County Kildare, Ireland

The topic:

Feasibility Study of Astronaut Standardized Career Dose Limits in LEO and the outlook for BLEO

was approved by the Board of Trustees in February, 2013 as a Cosmic Study and assigned jointly to Commissions III and I of the Academy under the designation SG 3.19/1.10. It has since been titled SG 3.19 and consigned completely to Commission III.

In March 2013 the HSFCG recommended that the study be extended to consider the biological responses of humans to the impingement of high energy particle radiation

Team Membership in 2013

Space Technology (Ireland) Ltd.

Representatives of ten countries (Canada, China, Germany, India, Ireland, Japan, Malaysia, Poland, Russia and the United States of America) made up the Team in 2013 and their individual skills are multi-disciplinary (the membership includes: physicists, biologists, modellers, theoreticians, a flight surgeon and an astronaut).

Further members joined in 2014, including members from the Czech Republic, Italy and Sweden (total: 13 countries).

Status Report

Space Technology (Ireland) Ltd.

The status of the study was presented at an IAA Symposium in Torino (July 2013) and at a United Nations Workshop in Beijing (September 2013).

A 30-page report was delivered to the HSFCG (25 October, 2013) containing the results obtained up to that time by the study. These results were incorporated in recommendations made by the Academy to the Heads of Space Agencies in advance of their summit meeting in Washington (January, 2014).

Publications

A paper entitled:

Recommendations arising from a feasibility study of (a) astronaut standardized career dose limits in LEO and the outlook for BLEO; (b) the biological response of humans to energetic particle radiation under microgravity conditions

S. M. P. McKenna-Lawlor and the SG 3.19 team

was published by Acta Astronautica during September 2014.

A further paper:

Strategies to mitigate against human health risks incurred due to energetic particle irradiation Beyond Low Earth Orbit/BLEO

based on a key note talk presented by SMcKL at an IAA Symposium on *Space Flight Safety* (held at St. Petersburg State Polytechnical University, 28 July 2014) was published in Acta Astronautica in early 2015.

Phase 2 : Study Target for 2015

The team has been requested by the HSFCG to incorporate in Phase 2 the following topic which they anticipate would be of special (and immediate) interest to the Space Agencies:

"Development of a methodology to derive a common radiation standard for future human missions that will orbit around the Moon as well as land on the Moon".

Future Plan

1. **Delivery of an SG - 3.19 draft status report in mid-May 2015, to the HSFCG Co-Chairs.**
2. **This report will be forwarded, following a short review by the HSFCG, to the ISECG Chair by the end of May with the understanding that it can be distributed to ISECG Space Agency participants.**
3. **On the occasion of the IAA Turin Conference (7-9 July 2015) the IAA will organize mini-workshop sessions for selected SGs. The Mini-workshops will offer the possibility for members of the SG teams to interact with other technical experts, including space agencies, and collect feedback on the draft reports.**

Future Plan contd.

4. **The IAA will finalize the SG activities, taking into account (according to best effort) comments raised at the mini-workshop sessions mentioned above, and present key findings of selected studies to interested ISECG participating individuals in the 4th quarter of 2015.**

5. **Initiation of an IAA Peer Review Process will occur by the end of 2015 (with Space Agencies directly engaged) with the goal of publication of the reports by early 2016.**

spais teicneolaíocht éire teoranta
Space Technology (Ireland) Ltd.

Go raibh maith agaibh go léir

International Academy of Astronautics

SPACE DISPOSAL OF RADIOACTIVE WASTE

Study Group 3.21

REPORT ON STUDY PROGRESS

March 2015

SG 3.21 MEMBERS

On March 2015 members of the Study Group 3.21 “Space Disposal of Radioactive Waste” are:

Baranov Eugeniy		Ukraine
Degtyarev Olexandr	M	Ukraine, Chair
Genta Giancarlo	M	Italy
Kostenko Victor		Ukraine
Kushnaryov Olexandr	CM	Ukraine
Pastor Vinader Miquel		France
Pyshnev Vladimir		Ukraine
Ramusat Guy	CM	France
Slyunyayev Mykola	M	Ukraine
Takahashi Sakurako		Japan
Ventskovsky Oleg	M	Ukraine
Antoni Ntorina		Greece

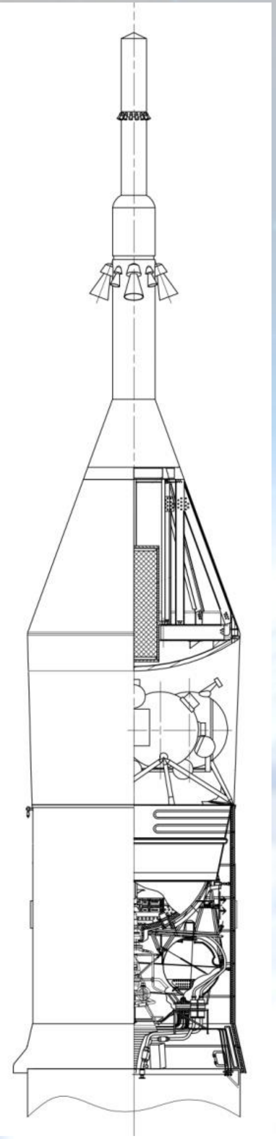
A number of specialists (who are not formally the Study Group members) will take part in preparation of separate sections of Final Report.

PROGRESS IN PAST SIX MONTHS:

Preparation of Draft Final Report materials is completed in general. Particularly:

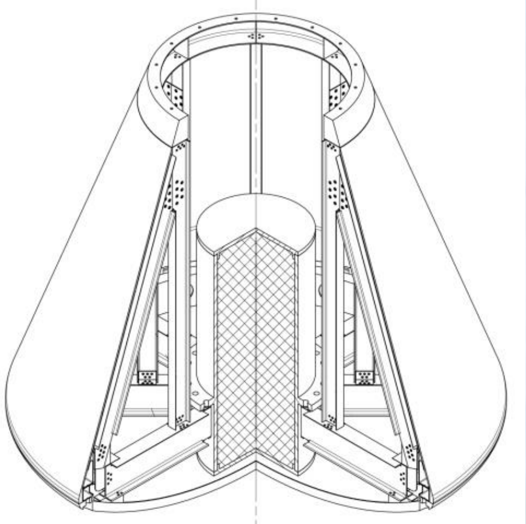
- **The approaches to selection of the target isotopes, subjected to the space disposal as well as capabilities of their conditioning and immobilization have been defined;**
- **Safety requirements at all phases of RW handling have been defined;**
- **The possible places for RW space disposal as well as possible methods of RW delivery into disposal places using the traditional launch vehicles (LV) or alternative methods have been considered;**

PROGRESS IN PAST SIX MONTHS:



- Technical layout of Space Launch System for RW space disposal using the traditional launch vehicles has been defined;

- It is shown that the technical issues related to creation of Space Launch System and RW safe delivery to the target orbits can be resolved, despite the necessity of extensive complex of R&D works;



PROGRESS IN PAST SIX MONTHS:

- **The risks associated with the RW space disposal have been defined; their technical composition has been estimated;**
- **The “Design Accident” concept for this project has been defined;**
- **It is shown that the RW space disposal safe technology can be used to delete any hazardous materials from the biosphere (biological, chemical etc.);**
- **A list of scientific and technical issues to be resolved for the project successful implementation has been defined;**
- **The volume of legal issues to be fixed in order to authenticate the RW space disposal conception is being defined.**

PROGRESS IN PAST SIX MONTHS:

- **It is shown that RW space disposal using the traditional LV is economically disadvantageous at the present moment. It has been determined the cost limit of a unit of the RW to be injected at the intermediate Earth orbit, lower which the cost of the RW space disposal becomes comparable with the cost of RW deep geological disposal;**
- **Possible scientific-industrial cooperation necessary for RW space disposal project successful implementation is being defined.**

Draft Report will be sent round the study group participants after completion its translation.

PROGRESS IN PAST SIX MONTHS:

- Ms. Ntorina Antoni joint as a member of the Study Group responsible for legal issues study;
- In-person meeting with study group 3.24 “Road to Space Elevator Era”, discussion of opportunity to use space elevator for RW space disposal took place at October 2nd, 2014 in the frame of IAC-2014 in Toronto, Canada.

Space for Humanity

International Academy of Astronautics

SG3.23
HUMAN SPACE TECHNOLOGY PILOT PROJECTS WITH EMERGING SPACEFARING COUNTRIES

Paris, 23 March 2015

By

Dr. Giuseppe Reibaldi, Prof. Fengyan Zhuang

International Academy of Astronautics

Human Space Technology Pilot Projects with Emerging Spacefaring Countries

- **Leadeship**: Co-Chairs; G.Reibaldi (Italy), Z.Fengyuan (China), Secretary: Dr.Nair Unnikrishnan (India)
- **Members:** 32 from 12 countries: India, China, Austria, Germany, Singapore, Japan, Malaysia, Italy, Russia, Thailand,Korea, Pakistan
- **Goals:** Define Emerging Spacefaring Countries Challenges and Opportunities in exploiting HSF technologies in Life Science and Education

- Identify available Infrastructures, Ground and In-orbit, for implementing projects
- Confirm need of Call for Proposal for Pilot Project
- Pilot Projects selection, definition, implementation
- Decision Road map in cooperation with UNOOSA
- **Status:** Preliminary Content List defined
- Contributions to be confirmed
- First Draft available by end 2015

E-30M Activity Report: SG3.24 “Road to Space Elevator Era”

As a preparation of Space Elevator Permanent Committee creation in IAA

Akira Tsuchida,
Chair, IAA Study Group 3.24 “Road to Space Elevator Era”

SG3.24 "Road to Space Elevator Era" - 1. Status Report Overview

2014/9	2015/3	2015/9	2016/3	2016/9	2017/3	2017/9
Toronto	Paris	Jerusalem	Paris	Guadalajara	Paris	Adelaide
						E-0
Start "Final products" review of SG3.24					E-6	
Reviewing the advancement of critical technologies required to implement the Space Elevator using SEMDD and SESRD				E-12		
			E-18	SEMDD and SESRD Development		
		E-24	SEMDD and SESRD Development			
We are here!	E-30	Start drafting Space Elevator Mission Definition Document (SEMDD)/System Requirements Documents (SESRD)				
E-36	Established SG3.24, 1st meeting, formed 5 sub-groups					
IAC2014		IAC2015		IAC2016		IAC2017
Work with Symposium of IAC D4-3, Technology Assessment and Space Elevators Components, to get inputs of this study group						

SG3.24 "Road to Space Elevator Era"
- 2. Final Products and Intermediate Goals

- New IAA Study Group "Road to Space Elevator Era" provides the following results as **intermediate goals**:
  - Review the advancement of critical technologies required to implement the Space Elevator. This will include carbon nano-tubes, control dynamics, etc.
  - Define the Space Elevator Prediction Feasibility Index (SEPFI) based upon the critical technologies identified
  - Publish the yearly Space Elevator Feasibility Status Assessment
  - Conduct IAA sponsored SPace Elevator Challenge (SPEC) and conference in the world
  - Making presentations in countries and organizations throughout the world, especially in developing countries and countries just beginning their involvement in space activities.
  - Making space elevator infrastructure concepts an integral part of university science and engineering curricula.

E-36
Through
E-12

- **Final Products**:
  - IAA Report on the Road to Space Elevator Era
    - ✓ Space Elevator Prediction Feasibility Index (SEPFI)
    - ✓ Pilot project proposal with first level system engineering details

E-6: Start
E-0: Conclude

SG3.24 "Road to Space Elevator Era" - 3. SG Structure

Chair

Chair: Akira Tsuchida (CM2)
Co-chair: Peter Swan, Ph.D. (M4)
David Raitt, Ph.D. (M4)

Secretary

Sakurako Takahashi

Sub-Group 1

Space Elevator Overall System, Tether systems, Dynamics

Brij N. Agrawai, Ph.D. (CM 2),
Vladimir Aslanov, Ph.D.,
Stephen Cohen,
Hironori Fujii, Ph.D.,
Arun Misra, Ph.D. (M 2),
Yoshiki Yamagiwa, Ph.D.

Sub-Group 2

System of Systems

Yoshio Aoki, Ph.D.,
Yevgeny Baranov,
John Knapman, Ph.D.,
Olexandr Kushnar`ov,
Shen Lin,
Minoru Sato,
Gennadiy Osinovyy

Sub-Group 3

International Policy and Laws

Setsuko Aoki (CM 4),
Sunao Kai, Ph.D.

Sub-Group 4

Outreach activities

Shuichi Ohno,
Cathy Swan, Ph.D.
(M4 - emeritus)

Sub-Group 5

System Operations and Integration

Yoji Ishikawa, Ph.D.,
Robert "Skip" Penny

Total 23 specialists from around the world: Japan [10], with Canada [2], China [1], Finland [1], Russia [1], UK [2], Ukraine [3], and USA [3]

SG3.24 "Road to Space Elevator Era" - 3. Specific Activities in past 6 month

- Sub-Group 5 System Operations and Integration
  - Chairman and secretary start working with Dr. Yoji Ishikawa to draft Space Elevator Mission Definition document and Space Elevator System Requirements document.
  - These draft documents will be used as a baseline document of Space Elevator Development as IAA Study. Especially Space Elevator System Requirements document will be structured based on MIL-STD-961E DEFENSE AND PROGRAM-UNIQUE SPECIFICATIONS FORMAT AND CONTENT.
  - This will be more practical and efficient approach to find out critical technologies required to implement the Space Elevator, one of our intermediate goal.

SG3.24 “Road to Space Elevator Era”
- 3. Specific Activities in past 6 month (Continued)

- Sub-Group 5 System Operations and Integration (Continued)
  - Space Elevator System Requirements Draft Table of Contents

Para	Contents (Requirements)	Para	Contents (Verification and validation)	Critical Tech/TRL
3	System Requirements	4	Quality Assurance Provisions	–
3.1	System Definition	4.3.1	Analysis of Segment Results	
3.2	Characteristics	4.3.2	Characteristics	
3.3	Design and construction	4.3.3	Design and Construction	
3.5	Logistics (and Maintenance)	4.3.5	Logistics (and Maintenance)	Tether durability
3.6	Personnel and Training	4.3.6	Personnel and Training	
3.7	Characteristics of Major Functional Elements	4.3.7	Characteristics of Major Functional Elements	
3.7.1	GEO Node	4.3.7.1	GEO Node	
3.7.2	Tether	4.3.7.2	Tether	(1) Deployment, (2) Dynamics

SG3.24 "Road to Space Elevator Era" - 3. Specific Activities in past 6 month (Continued)

Sub-Group 4 Outreach activities

- SG3.24 member Dr. Yoji Ishikawa and Mr. Akira Tsuchida visited National Museum of Natural Science in Taiwan and had a chance to talk to Wei-Hsin Sun Ph.D, Director General. Both agreed to discuss preparation of Space Elevator event in Taiwan.

(from the left) Ishikawa, Tsuchida, Sun, Cheng

SG3.24 “Road to Space Elevator Era” - 4. Next 6 months plan

- Sub-Group 5 System Operations and Integration
  - Continue to make draft version of Space Elevator Mission Definition Document (SEMDD) and Space Elevator System Requirement Document (SESRD) so that other sub-group can join to develop these documents.
  - Explanation to reviewer (other members) for these documents drafted above at <u>Space Elevator Conference in USA in Aug, 2015</u>
  - Start developing “Define the Space Elevator Prediction Feasibility Index (SEPFI)”
- Sub-Group 1 Space Elevator Overall System, Tether systems, Dynamics
  - Start reviewing Sub-Group 5 products (SEMDD/SESRD) for critical technologies
  - Identifying issued paper in the past which can be linked these documents
  - report advancement of critical technologies
  - Status report of Cubesat Tether deployment experience using ISS as a part of pilot project proposal
- Sub-Group 2 System of Systems, 3 International Policy and Laws
  - Same as Sub-Group 1 above related System, International Policy and laws
- Sub-Group 4 Outreach activities
  - Continue develop new area to spread Space Elevator concept.

Appendix-1

- Proposal presentation in Toronto (Sep. 2014)

New IAA SG 3.24 “Road to Space Elevator Era” Background

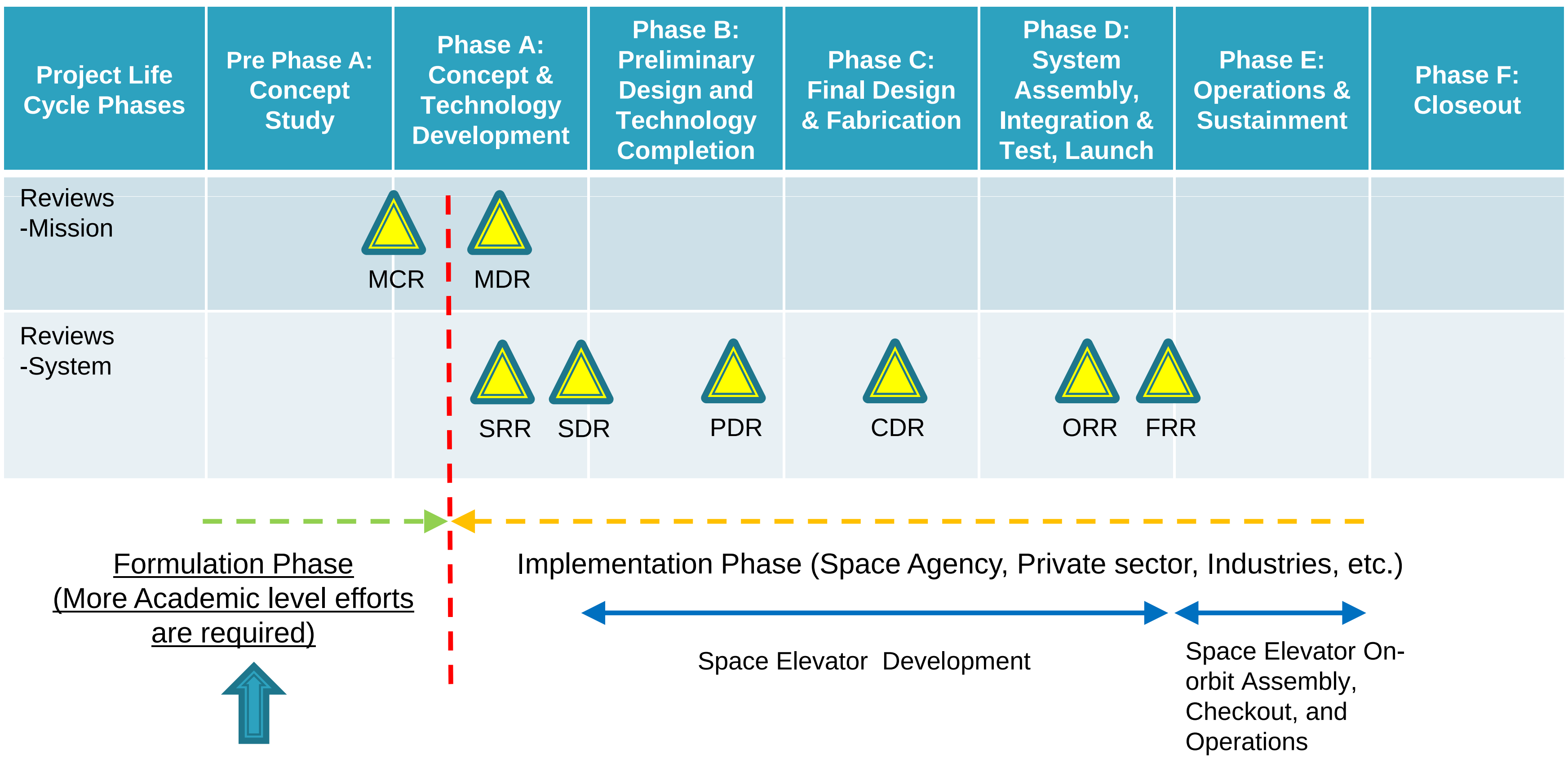
- Background
  - ✓ After successful completion of IAA Study Group 3-13 “Assessment of the Technological Feasibility and Challenges of the Space Elevator Concept” activity, we originally wanted to create Permanent Committee (SEPC) in IAA.
  - ✓ Proposer and co-authors determined that it is more practical to suggest to create new study group for now so that IAA can be ready to create SEPC in the future.

New IAA SG3.24 "Road to Space Elevator Era"
Table of contents

	Title
1	Where are we?
2	Primary Mission
3	Participants
4	Things to be researched
5	Conclusion
Backup	Several on-going projects in the world

New IAA SG3.24 “Road to Space Elevator Era” - 1. Where are we?

Typical Project Life Cycle Phases



We are still here.

<Notes>
MCR: Mission Concept Review, MDR: Mission Definition Review, SRR: System Requirements Review, SDR: System Definition Review, PDR: Preliminary Design Review, CDR: Critical Design Review, ORR: Operational Readiness Review, FRR: Flight Readiness Review
(Ref: NPR7123.1A NASA Systems Engineering Processes and Requirements w/Change 1 (11/04/09))

SG3.24 "Road to Space Elevator Era" - 2. Primary Mission

2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020

IAA Study Group 3.13
(2010/4-2013/3)
"Assessment of the Technological Feasibility and Challenges of the Space Elevator Concept"

Primary Mission:
Technical Feasibility Assessment

IAA Study Group 3.24
(2014/10-2017/9)
"Road to Space Elevator Era"

Primary Mission:
1. Review the advancement of critical technologies required to implement the Space Elevator
2. Define the Space Elevator Prediction Feasibility Index (SEPFI) including pilot project proposal (on-orbit demo) with first level system engineering details
3. Progress consideration of non-technological area such as international policy and law.
4. Increase more involvement from non-space area, developing countries

IAA Permanent Committee?
(2018/3-)
"Space Elevator (TBD)"

Primary Mission:
1. (IAA leads to) show options of the next generation transport infrastructure in space.

2. (IAA) creates recommended Mission Definition and/or System Requirement of the Space Elevator.

SG3.24 “Road to Space Elevator Era” - 3. SG Structure

Chair

Chair: Akira Tsuchida (CM2)
Co-chair: Peter Swan, Ph.D. (M4)
David Raitt, Ph.D. (M4)

Secretary

Sakurako Takahashi

Sub-Group 1
Space Elevator Overall System, Tether systems, Dynamics

Brij N. Agrawai, Ph.D. (CM 2),
Vladimir Aslanov, Ph.D.,
Stephen Cohen, Hironori Fujii, Ph.D.,
Arun Misra, Ph.D. (M 2),
Yoshiki Yamagiwa, Ph.D.

Sub-Group 2
System of Systems

Yoshio Aoki, Ph.D.,
Yevgeny Baranov,
John Knapman, Ph.D.,
Olexandr Kushnar`ov,
Shen Lin,
Minoru Sato,
Gennadiy Osinovyy

Sub-Group 3
International Policy and Laws

Setsuko Aoki (CM 4),
Sunao Kai, Ph.D.

Sub-Group 4
Outreach activities

Shuichi Ohno,
Cathy Swan, Ph.D.
(M4 - emeritus)

Sub-Group 5
System Operations and Integration

Yoji Ishikawa, Ph.D.,
Robert ”Skip” Penny

Total 23 specialists from around the world: Japan [10], with Canada [2], China [1], Finland [1], Russia [1], UK [2], Ukraine [3], and USA [3]

SG3.24 “Road to Space Elevator Era”
- 4. Things to be researched

- There are several topics (Candidates) to be researched:

Primary Mission	Things	Pre-cursor missions as a preparation of Space Elevator achievement	Primary group in this Study Group	Related Study Group (SG), Permanent Committee (PC) of IAA
1. Review the advancement of critical technologies required to implement the Space Elevator	Tether Dynamics	1. Simulation 2. On orbit verification of Dynamics of Flexible Space Tether	Group 1	2. Small Satellite PC
	Tether materials development, testing and manufacture	1. Material exposure experiment in space	Group 1, 5	
	Hazards to the tether and to tether climbers	1.Space Debris 2. Rates of wear and erosion	Group 1, 2	1. Space Debris PC
	Hazards caused by the space elevator	1. Risks to other spacecraft of collision with high-strength tether 2. Laser interference with existing operational satellites	Secretary, Group 2, 3, 5	
	Marine Node, High Stage one	System requirements development in addition to existing Marine launch system	Group 2	
	Tether Climber Design	1. Heat Management 2. Light weight structure 3. Energy transmission 4. Radiation Protection	Group 2, 5	

<Notes> These candidates are mainly suggested by ISEC, Space Elevator’s research topics.

SG3.24 "Road to Space Elevator Era"
- 4. Things to be researched

- There are several topics (Candidates) to be researched: (Continued)

Primary Mission	Things	Pre-cursor missions	Primary group	Related Study Group (SG), Permanent Committee (PC) of IAA
2. Define the Space Elevator Prediction Feasibility Index (SEPFI)	Maintain Developmental Roadmaps of Space Elevator and TRL (Technology Readiness Level)	N/A	Secretary, Group5	
3. Progress consideration of non-technological area such as international policy and law.	1.Evaluate the issues to be addressed at the international level. 2. Develop concept of legal approach to the entities responsible for Terrestrial [both land and sea], Aeronautical, and Space Laws.	N/A	Group 3	
4. Increase more involvement from non-space area, developing countries	1. Making presentations in countries and organizations throughout the world, especially in developing countries and countries just beginning their involvement in space activities. 2. Demonstrated event such as Space Elevator Challenge in developing countries	N/A	Group 4	SG5-11 Comparative Assessment of Regional Cooperation in Space: Policies, Governance and Legal Tools. SG1-14 Promoting Global Space Knowledge and Expertise in Developing Countries
	Disposal of Radiation Waste	N/A	Group 2	SG3-21 Space Disposal of Radioactive Waste

<Notes> These candidates are mainly suggested by ISEC, Space Elevator's research topics.

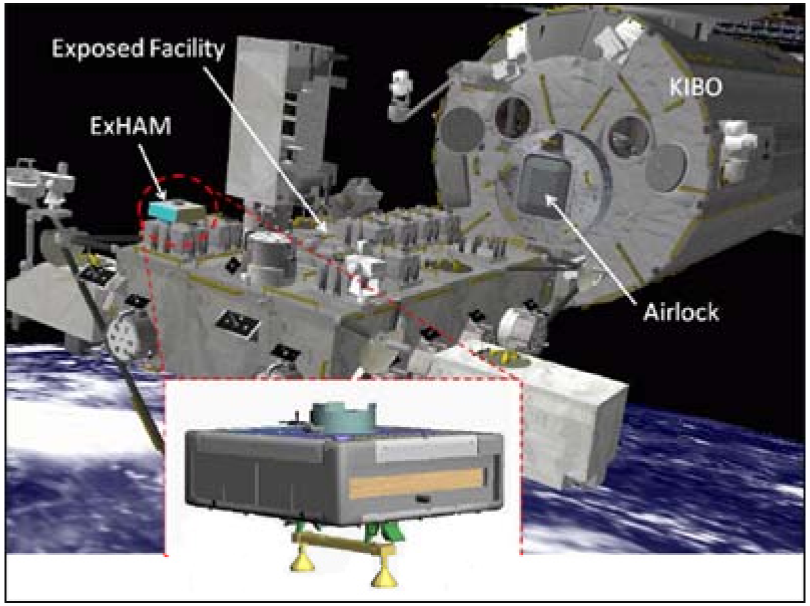
SG3.24 "Road to Space Elevator Era" - 5. Conclusion

- New IAA Study Group "Road to Space Elevator Era" provides the following results as intermediate goals:
  - Review the advancement of critical technologies required to implement the Space Elevator. This will include carbon nano-tubes, control dynamics, etc.
  - Define the Space Elevator Prediction Feasibility Index (SEPFI) based upon the critical technologies identified
  - Publish the yearly Space Elevator Feasibility Status Assessment
  - Conduct IAA sponsored SPace Elevator Challenge (SPEC) and conference in the world
  - Making presentations in countries and organizations throughout the world, especially in developing countries and countries just beginning their involvement in space activities.
  - Making space elevator infrastructure concepts an integral part of university science and engineering curricula.
- Final Products:
  - IAA Report on the Road to Space Elevator Era
    - ✓ Space Elevator Prediction Feasibility Index (SEPFI)
    - ✓ Pilot project proposal with first level system engineering details

SG3.24 "Road to Space Elevator Era"

- Back-up chart, several on-going projects in the world

- Japan Society for Aeronautical and Space Science made committee for SE feasibility study.
- "Science Council of Japan" defined Space Elevator project as one of master plan for large research projects - 2014. It is the first step of starting very small research but recognized Space Elevator as "National Project".
- JAXA started ExHAM, material exposure experiment in space service using Japanese experiment module of the International Space Station.



<Credit> JAXA (http://iss.jaxa.jp/en/kiboexp/ef/exham/)

SG3.24 “Road to Space Elevator Era”

- Back-up chart, several on-going projects in the world

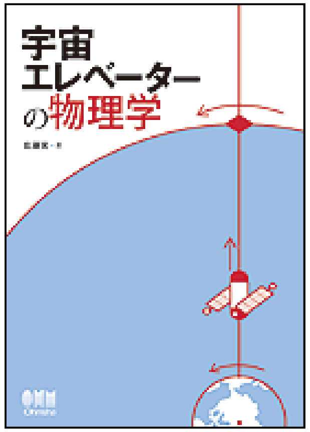
- Encouraging young student, future engineers and scientists are the most important things. Space Elevator Challenges are now held in worldwide. (US, Japan, Europe, and Israel).

SPEC in Japan
Aug 2014
(Alt 1200m)
(45 sec video is available.)

SG3.24 “Road to Space Elevator Era”
- Back-up chart, several on-going projects in the world

Robo Climb: a robotic climber competition between student teams around the region of Seattle, USA. Aug, 2014

- “Physics of Space Elevator” is published in Japan. This book is actually a textbook to learn physics for high school student level.



Physics of Space Elevator

Commission III Study Group 3-17
Space Mineral Resources:
Challenges, Approaches, and Opportunities

Co-Chairs

Arthur Dula — Member, International Academy of Astronautics

Zhang Zhenjun — Member, IAA

Editors

Peter A. Swan, Ph.D. — Member, IAA, Study Group Member

Roger X. Lenard — Member, IAA – Commission III Secretary

Cathy Swan, Ph.D. — Member, IAA, Study Group Member

Note: many images from Heinlein Prize Trust and Excalibur Exploration

03/23/2015

Image from IAA Study

Today's Topics

- Topic Introduction
- IAA Study Approach
- Who are the New Players
- Asteroid Characteristics
- Roadmaps
- Conclusions & Questions

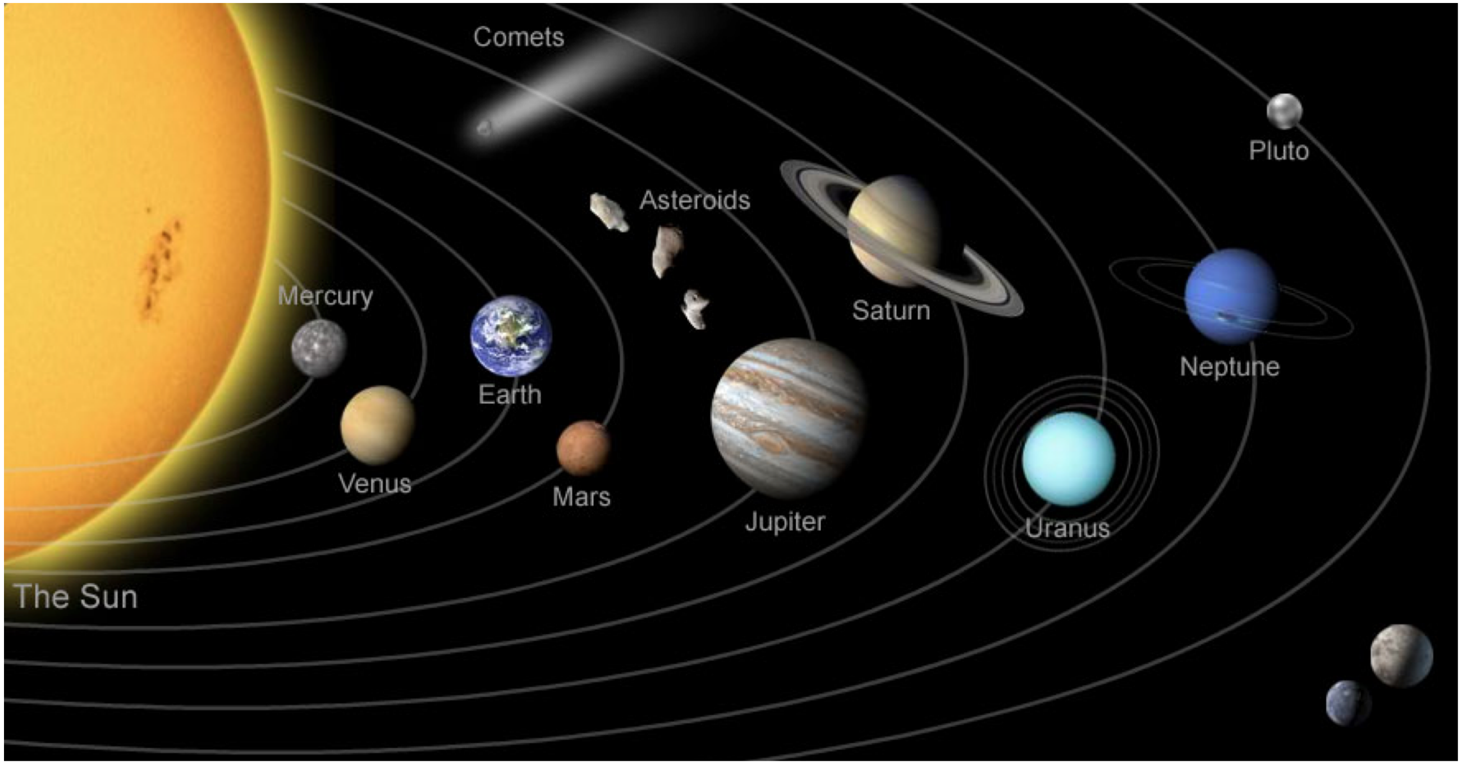
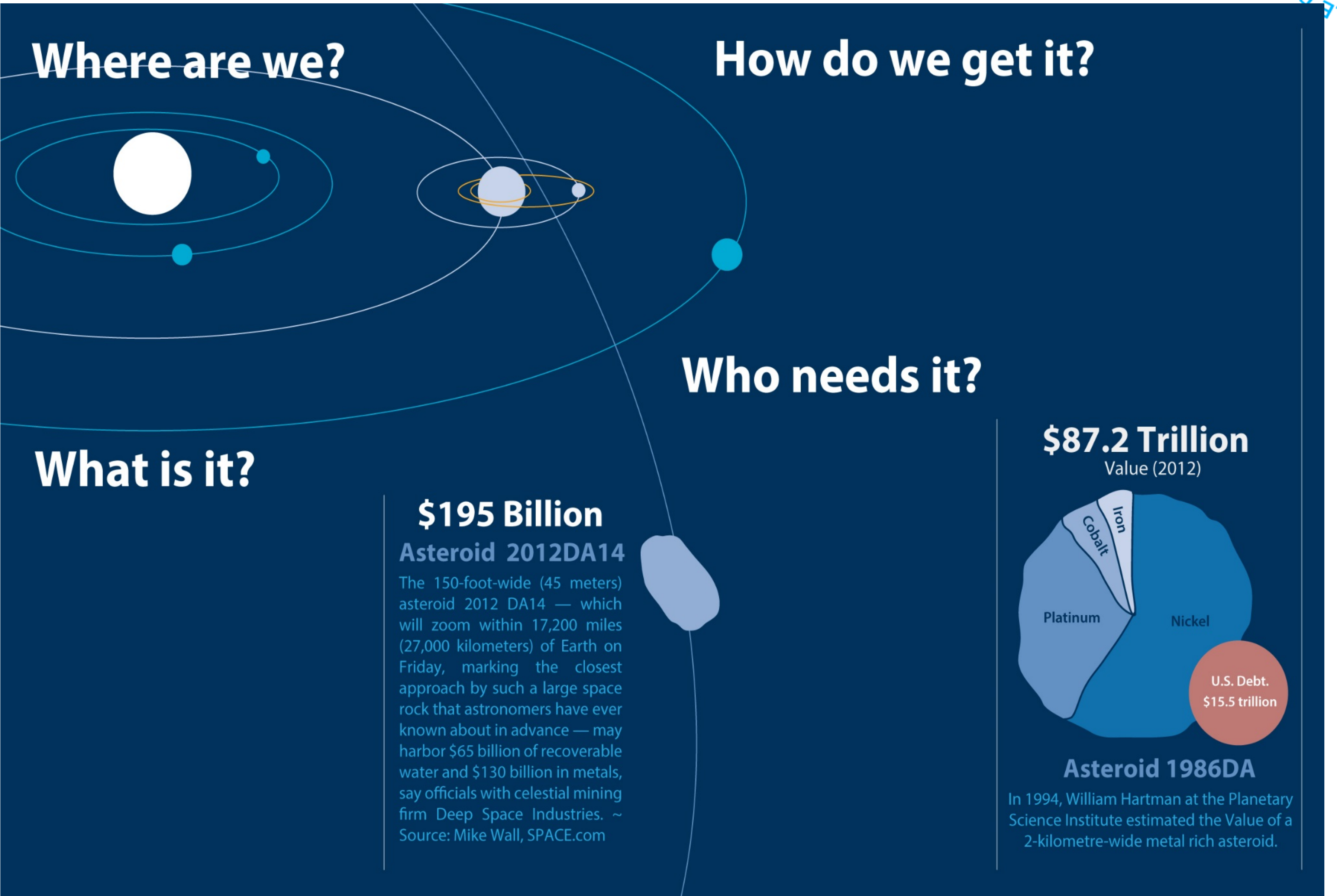


Image from 100 YSS

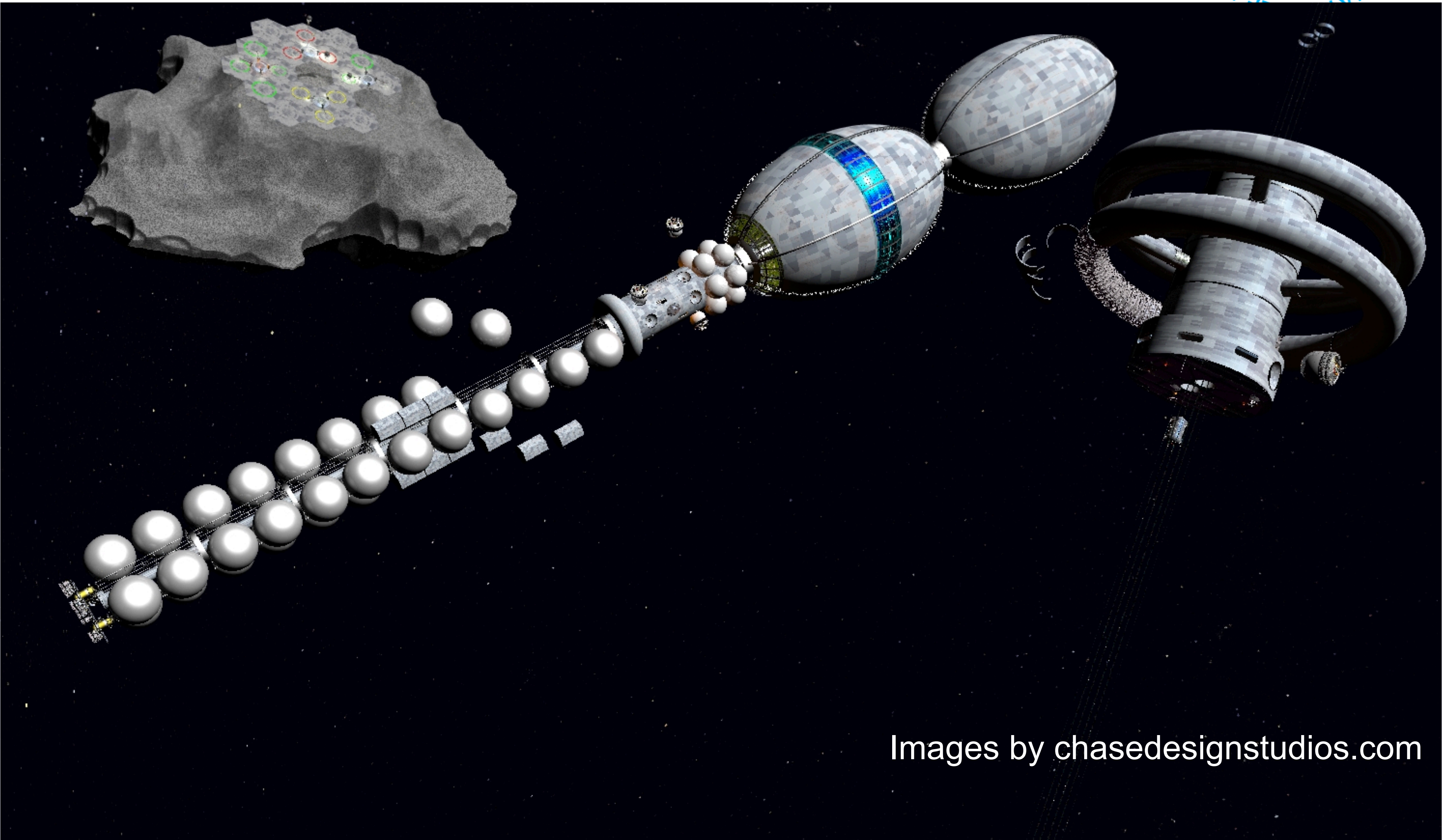
Vision -- ***Leverage the phenomenal resources available in our solar system.***



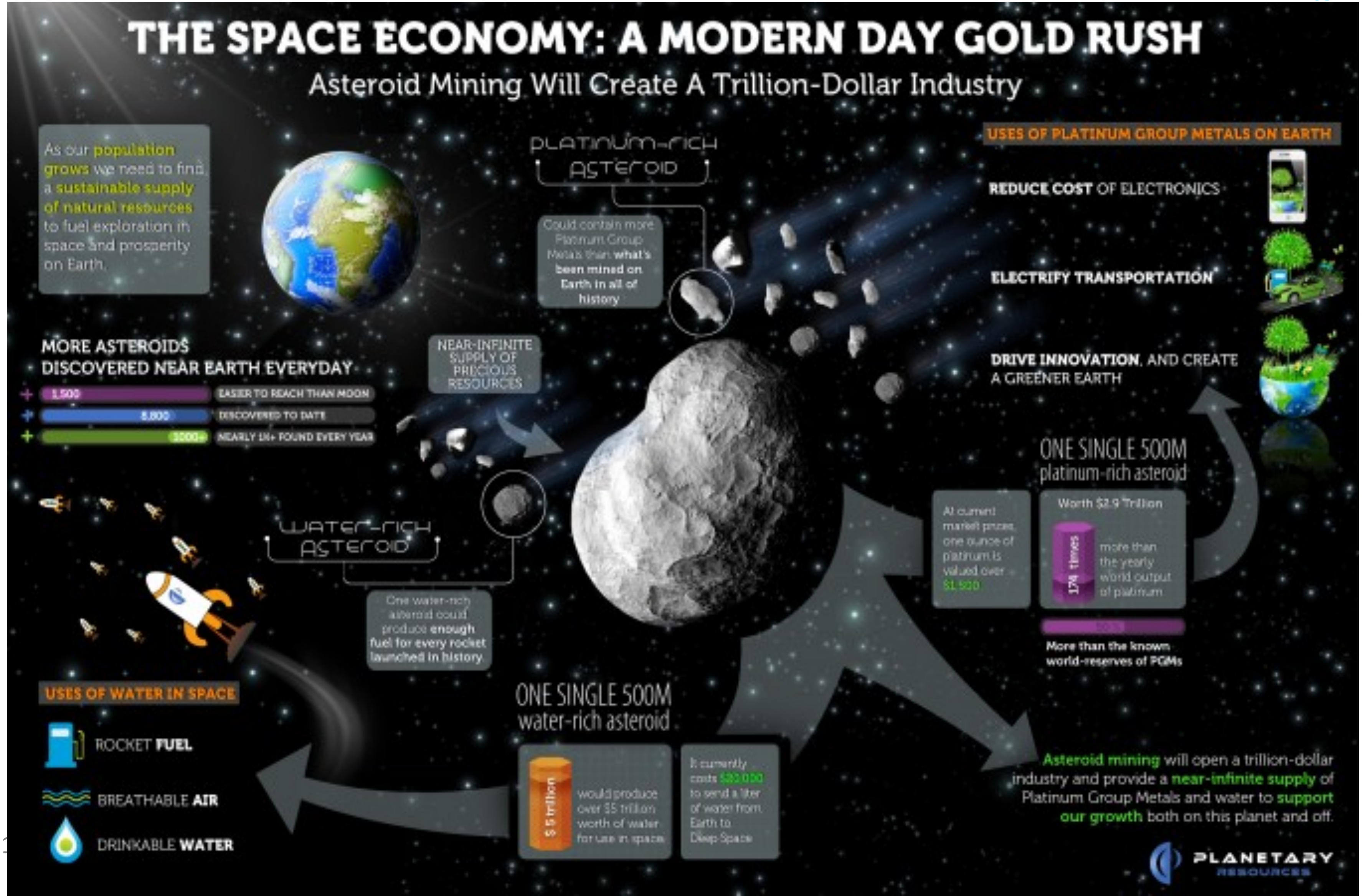
Essence of SMR

- Enhance the human condition on Earth
  - Provide Jobs
  - Re-invigorate education in science, technology, engineering, and mathematics [STEM]
  - Stimulate innovation
  - Provide a vision for return on investment [ROI] from space
  - Stimulate commercial investors for space activities
  - Provide avenues for commercial expansion into our solar system
- Initiate Commercial Movement into the Solar System
  - Provide a vision for movement off-planet
  - Provide profit motive for movement into space
  - Provide commercial products to national space exploration programs
  - Enable space exploration
  - Enable space colonization
  - Enable solar power satellites

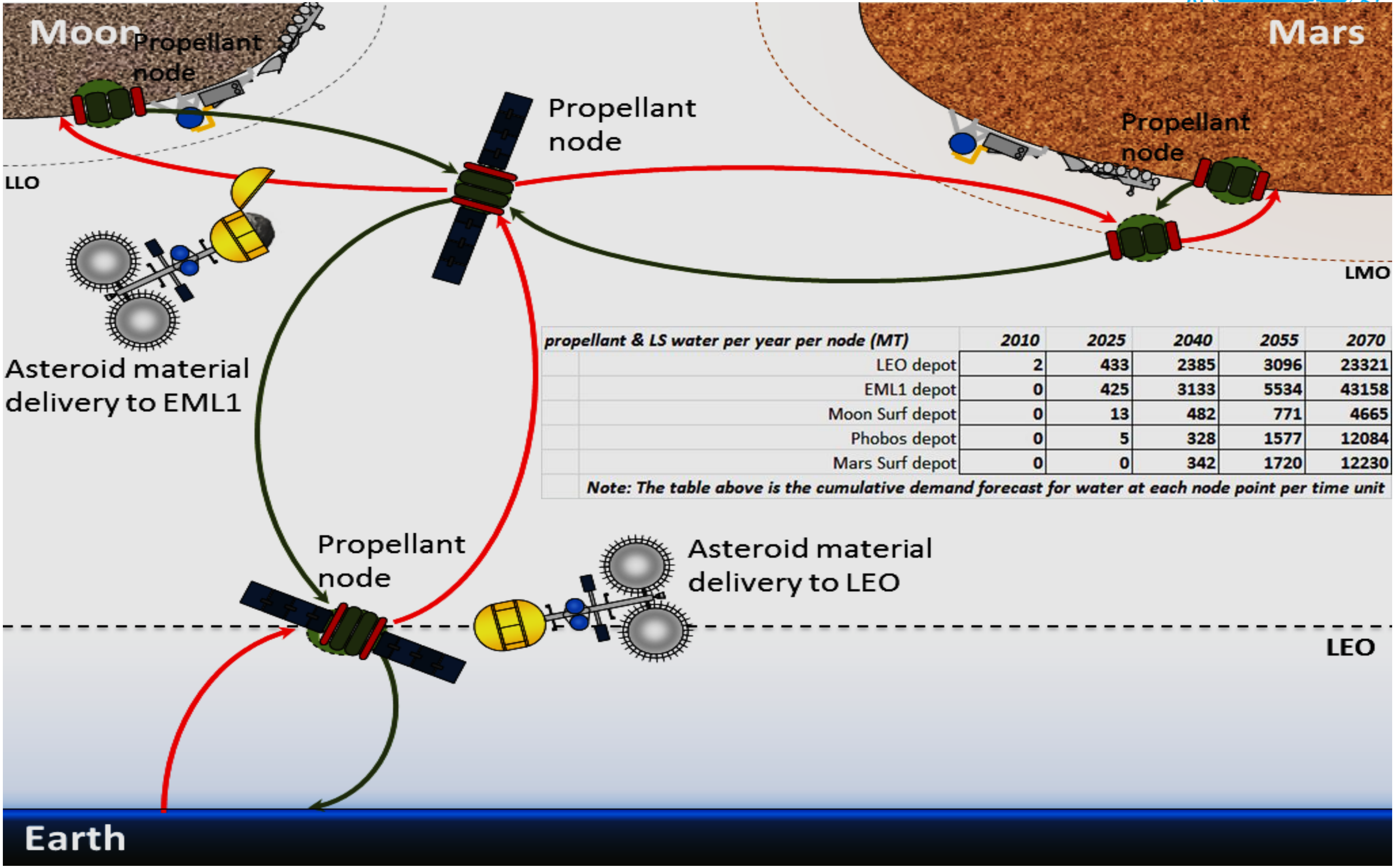
Opening Solar System Starts at Earth Moon L-1 – A Vision



Looking to the Future



Propellant Flow (quantity)



propellant & LS water per year per node (MT)	2010	2025	2040	2055	2070
LEO depot	2	433	2385	3096	23321
EML1 depot	0	425	3133	5534	43158
Moon Surf depot	0	13	482	771	4665
Phobos depot	0	5	328	1577	12084
Mars Surf depot	0	0	342	1720	12230

Note: The table above is the cumulative demand forecast for water at each node point per time unit

Today's Topics

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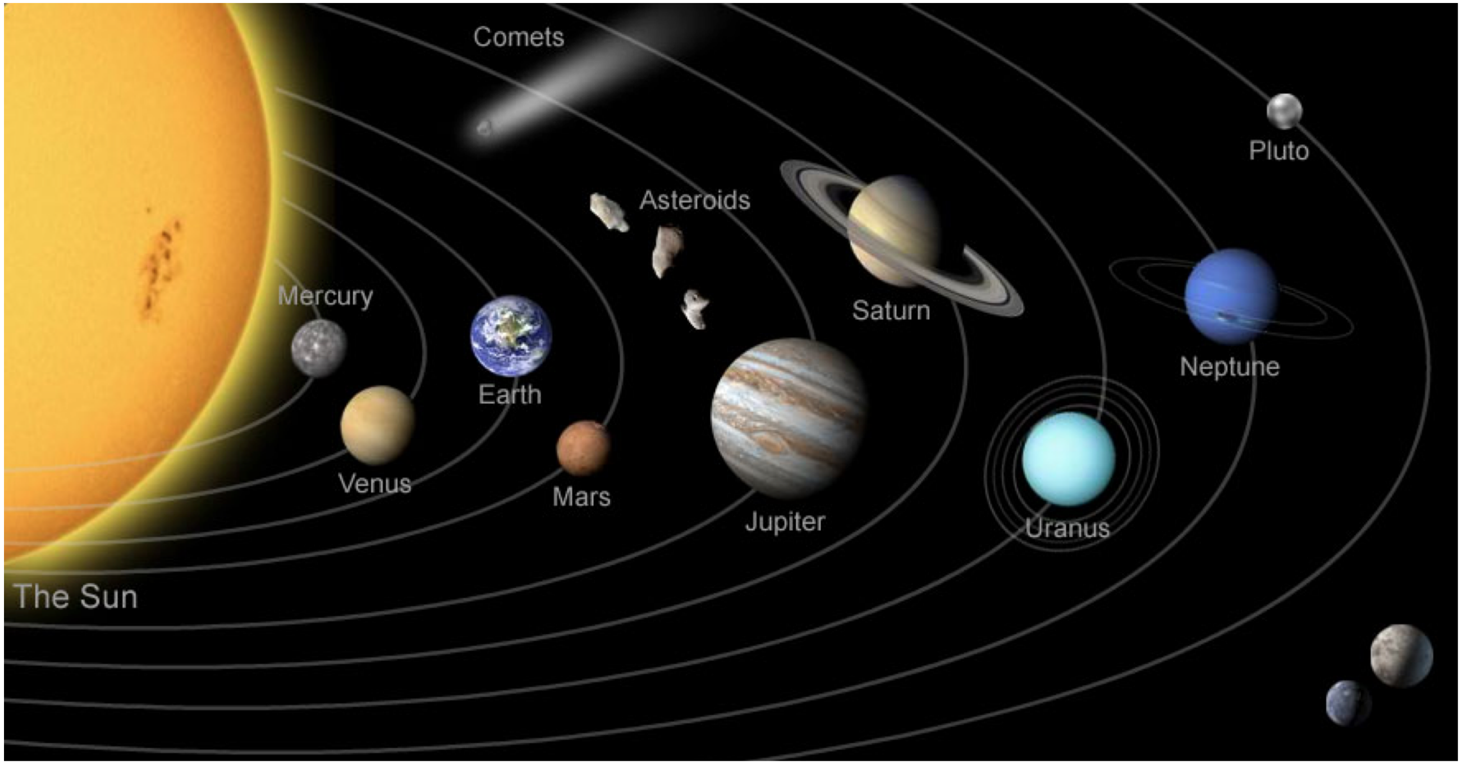

Image from 100 YSS

Study 3-17 Charter

To provide a logical, systematic and practical road map to promote and encourage near term evaluation, development and use of space mineral resources (SMR)

- Broad areas outline of the proposed study:
  - Type, location and extent of SMR; Lunar, Asteroid, Mars, others.
  - Current technical state of the art in the identification, recovery and use of SRM in space and on the Earth that identifies all required technical processes and systems, and that makes recommendations for specific technology developments that should be addressed near term at the system and subsystem level to make possible prospecting, mineral extraction, beneficiation, transport, delivery and use of SMR. Particular attention will be dedicated to study the transportation and retrieval options available for SRM .
  - Analysis of the legal, regulatory and policy issues that control, limit, promote and are related to the development and use of SMR in space and on the Earth including right to use SMR under current international and national laws, with identification of unresolved legal and regulatory issues and recommendations for action to resolved potential roadblocks.
  - Analysis of business and business issues related to development and use of SMR in space and on the Earth with pro forma case studies. Particular attention will be paid in evaluating the economical aspects related to the SRM. A broad spectrum of potential stakeholders, including international mining and resource development firms, banking and capital market will be identified
  - Development of several specific technical, legal and economic "road maps" for SMR development and use in space and on the Earth.
  - Conclusions and recommendations.

Members of Study 3-17

Co-Chairs - Arthur M. Dula & Zhang Zhenjun

Oleg Alifanov,	Russia
Haithem Altwaijry,	Saudi Arabia
Bohdan I. Bejmuk,	Ukarine
Prof. Giovanni F Bignami,	Italy
Andrea Boyd (YP),	Australia
Christopher Bonnal,	France
Franklin Chang-Diaz,	Costa Rica
Catharine Conley,	United States
Arthur M. Dula,	United States
Russell Dula (YP),	United States
Anat Friedman (YP),	United States
Li Furong,	China
Jose Gavira,	Spain
Fernando G. Gonzalez (YP),	Spain
Yang Junhua,	China
Shirazi Jaleel-Khan (YP),	Sri Lanka
Roger Lenard,	United States
Chris Lewicki,	United States
John Mankins,	United States
Susan McKenna-Lawlor,	Ireland
Jacques Masson,	France
George C. Nield,	United States
Vladislav Shevchenko,	Russia
Andrea Sommariva,	Italy
Christopher Stott,	Isle of Man
Cathy Swan,	United States
Peter Swan,	United States
Tai Sik Lee,	Korea
Rick Tumlinson,	United States
Hiroshi Yoshida,	Japan
Zhang Zhenjun,	China

Cosmic Study Outline

"To provide a logical, systematic and practical road map to promote and encourage near term evaluation, development and use of space mineral resources (SMR)"

Executive Summary

1 Introduction

2 Mining of Space Resources

3 Market Approach

4 SMR Roadmaps

5 Analysis of Systems

6 Modeling and Analysis

7 Policy and Legal

8 Findings, Conclusions & Recom's

9 Concept for the Future

Executive Summary

"Don't undertake a project unless it is manifestly important and nearly impossible." Edwin Land, quoted in the Coral Reef Alliance letter, March 30, 2011. www.coral.org

Executive Summary:

- The exploitation of space mineral resources is becoming a commercial space endeavor for the benefit of humanity and profit
- The question on the table is not "how" to leverage space minerals resources; but, "how best" to leverage them
- Preliminary economic conclusions include (1) architectures based upon returning precious metals to terrestrial markets alone appears to be a non-starter, (2) the existence of in-space customers for propellants, consumables, structural materials, and shielding could make asteroid mining economically feasible, and (3) longer-term hybrid architectures with both terrestrial and in-space customers could become feasible as costs drop and market size increases.

Major Conclusion & Finding

Major Conclusion: The process of mining water from asteroids, the Moon or Mars will ensure that the key elements are available at the spaceports of the future. Water will ensure that human exploration will expand beyond low Earth orbit with the profit motive driving the exploitation of resources.

Principle Finding: SMR ventures cannot wait for government programs to lower technological and programmatic risks. Commercial ventures must determine the optimum path for commercial success and aggressively lead the way beyond LEO. During the first half of the 21st century, space leadership will come from commercial enterprises and not depend upon government space programs.

Study Group Next Steps

- Study Completed [Sept 2014] at IAC 2014 - accomplished
- Commission III review [Sept 14 – Mar 15] - accomplished
- Commission III Approve Study Report
  - This afternoon approve at SAC
- Academy Peer Review [Dr. Hans-Peter Roeser]
  - April 1 – 15, 2015
- Publish Book [Virginia Edition Publishing Co.] [15 May]
- Report Distribution to IAA Symposium Turin - July]
- Start Study #2 on Space Mineral Resources
  - Proposal submitted to Commission III

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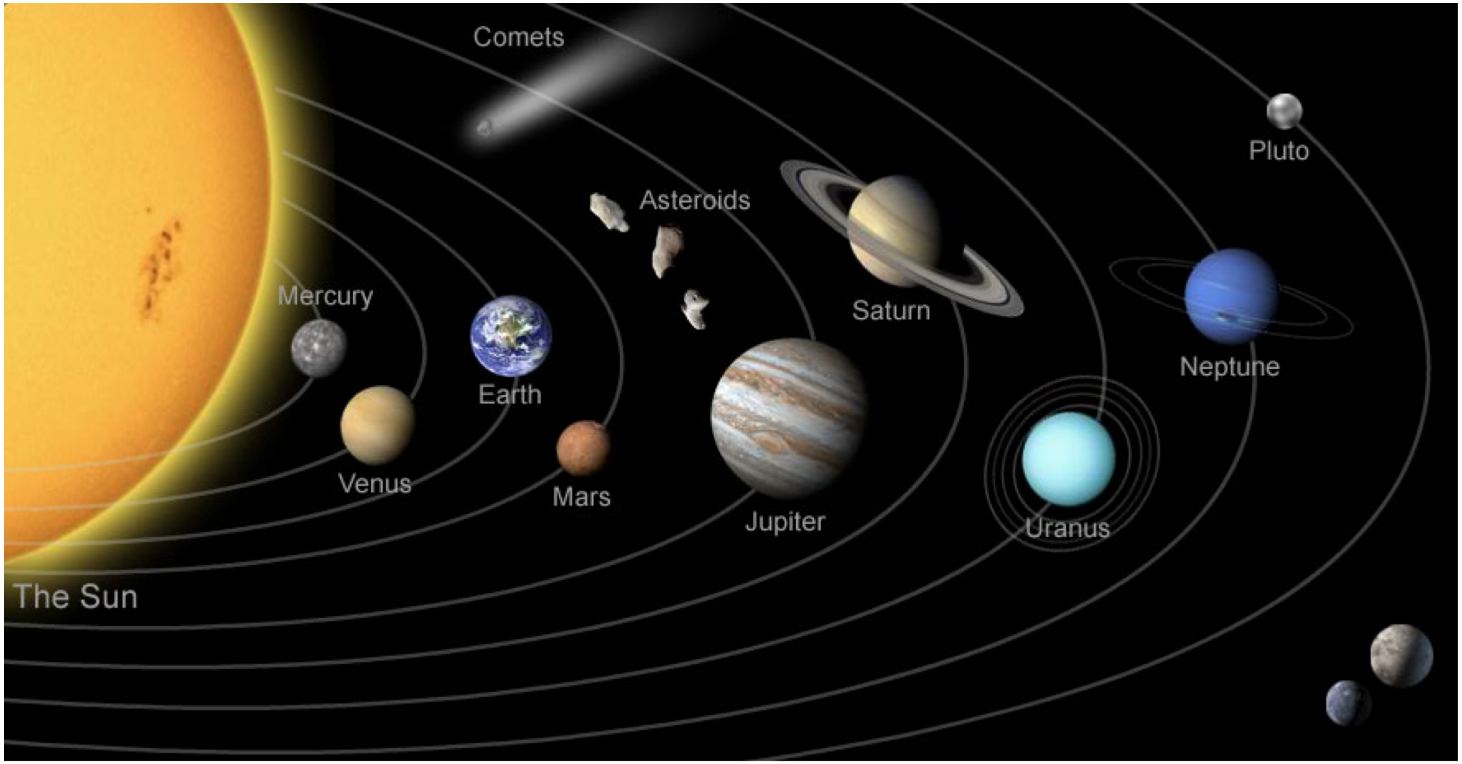


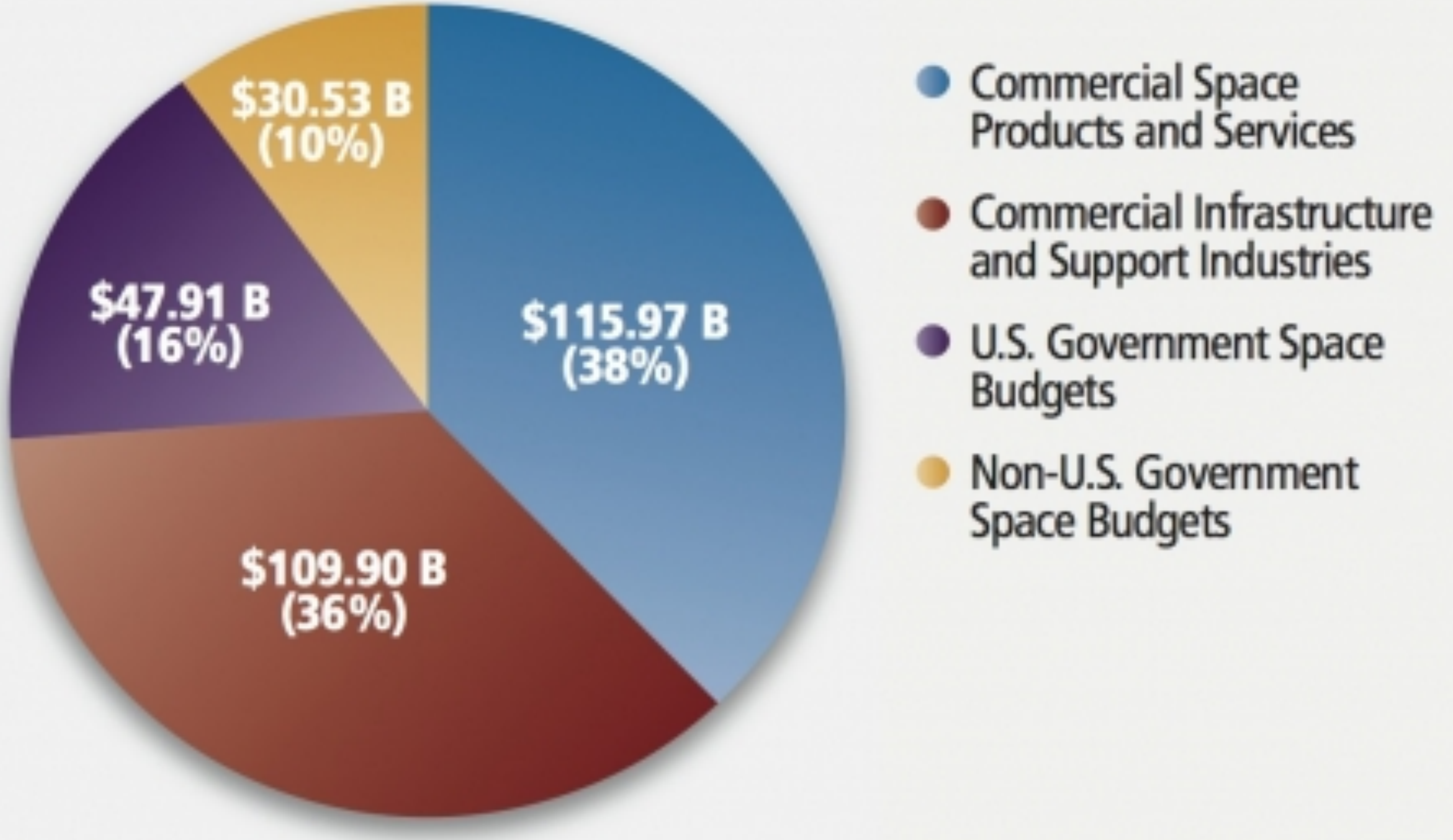
Image from 100 YSS

Why – Mining in Space?

- ***When I awoke this morning, I looked around and saw nature in crises***
- If I expand this perception from my small community to the global population, predictions from the Club of Rome seem real.*
- Opening the resources of space will not only change our lives; it will change our destiny. The question is not what can I do about it; but, what can we all do about the multitude of problems that seem to be overwhelming our world. The answers seem simple:
  - Change the equation.
  - Change the assumptions.
  - Increase the resources and produce innovation, jobs and wealth along the way

*Donella H. Meadows, Dennis L. Meadows, Jørgen Randers, and William W. Behrens III, "Limits to Growth," 1972.

EXHIBIT 1. Global Space Activity, 2012



Total: $304.31 Billion

Billionaire Space Investors

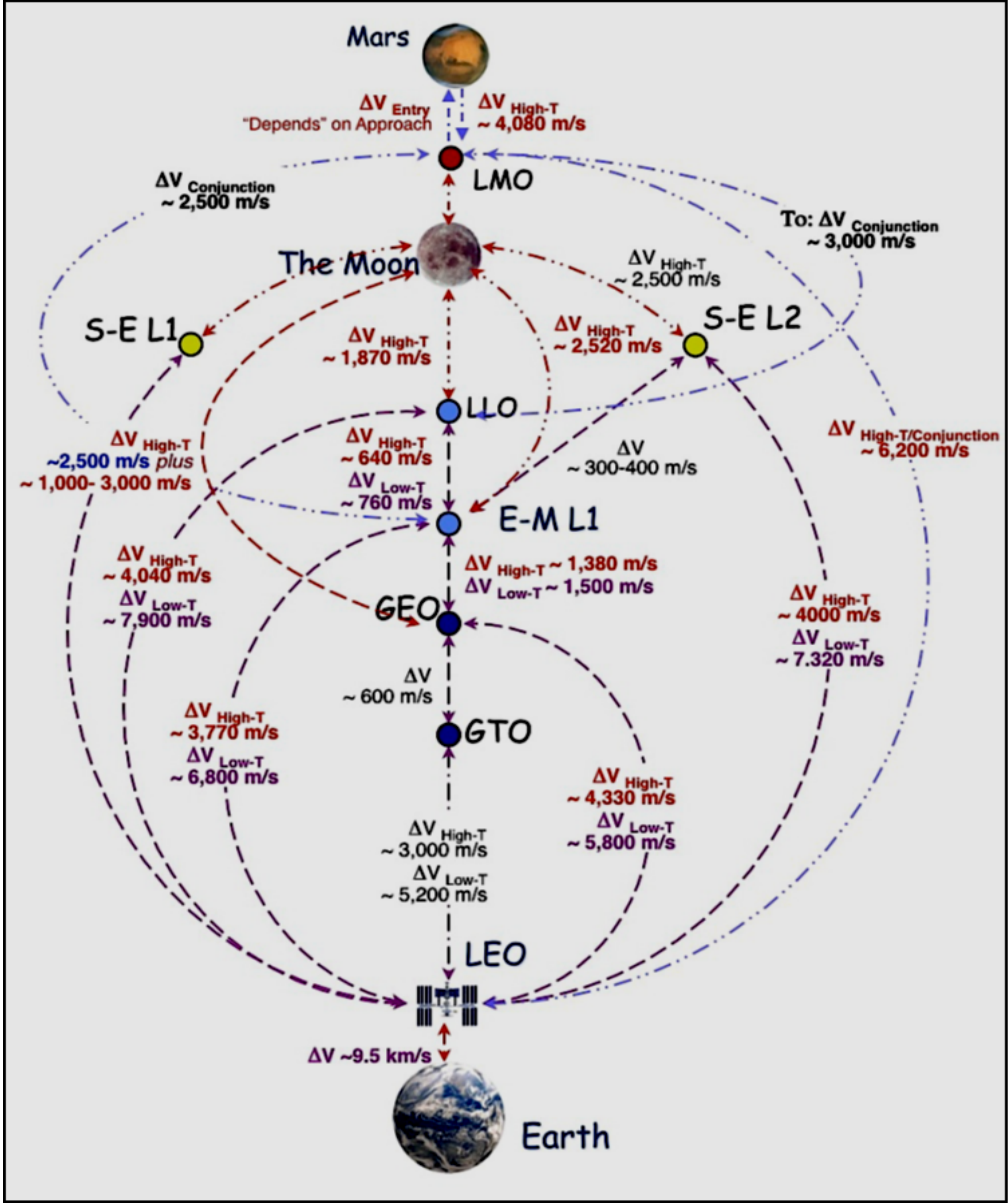
rank	name	age	net worth	source	space investment
19	Jeff Bezos	49	$25.20	Amazon	Blue Origin
21	Sergey Brin	40	$22.80	Google	Google Lunar X Prize
20	Larry Page	40	$23.00	Google	Google Lunar X Prize, Planetary Resources
53	Paul Allen	60	$15.00	Microsoft	SpaceShipOne, SETI telescope array
138	Eric Schmidt	58	$8.20	Google	Planetary Resources
272	Sir Richard Branson	63	$4.60	Virgin Group	Virgin Galactic
527	Elon Musk	42	$2.70	PayPal, Tesla Motors	SpaceX
831	Guy Laliberte	53	$1.80	Cirque du Soleil	Visitor to ISS
922	K Ram Shriram	56	$1.65	Google	Planetary Resources
1031	Ross Perot, Jr.	54	$1.40	Oil & Gas	Planetary Resources
			$106.35	**Total Net Worth**	

Commercial Space Companies

Lunar Developmenmt	***Asteroid Development***	***Mars Development***	***Space Tethers and Elevators***
Golden Spike	Planetary Resources	SpaceX	Tethers Unlimited
Shackleton Energy, Co.	Deep Space Industries	Inspiration Mars	Liftport
Moon Express	Excalibur Exploration	Mars One	International Space Elevator Consortium
Excalibur Almaz			Japanese Space Elevator Association
Bigelow Aerospace			

Earth Moon Infrastructure Velocity Requirements:

Delta-Vs in Earth's Neighborhood [Mankins, 2012].



Bummer – approximately 10,000 kilometers per second of energy required to get to LEO

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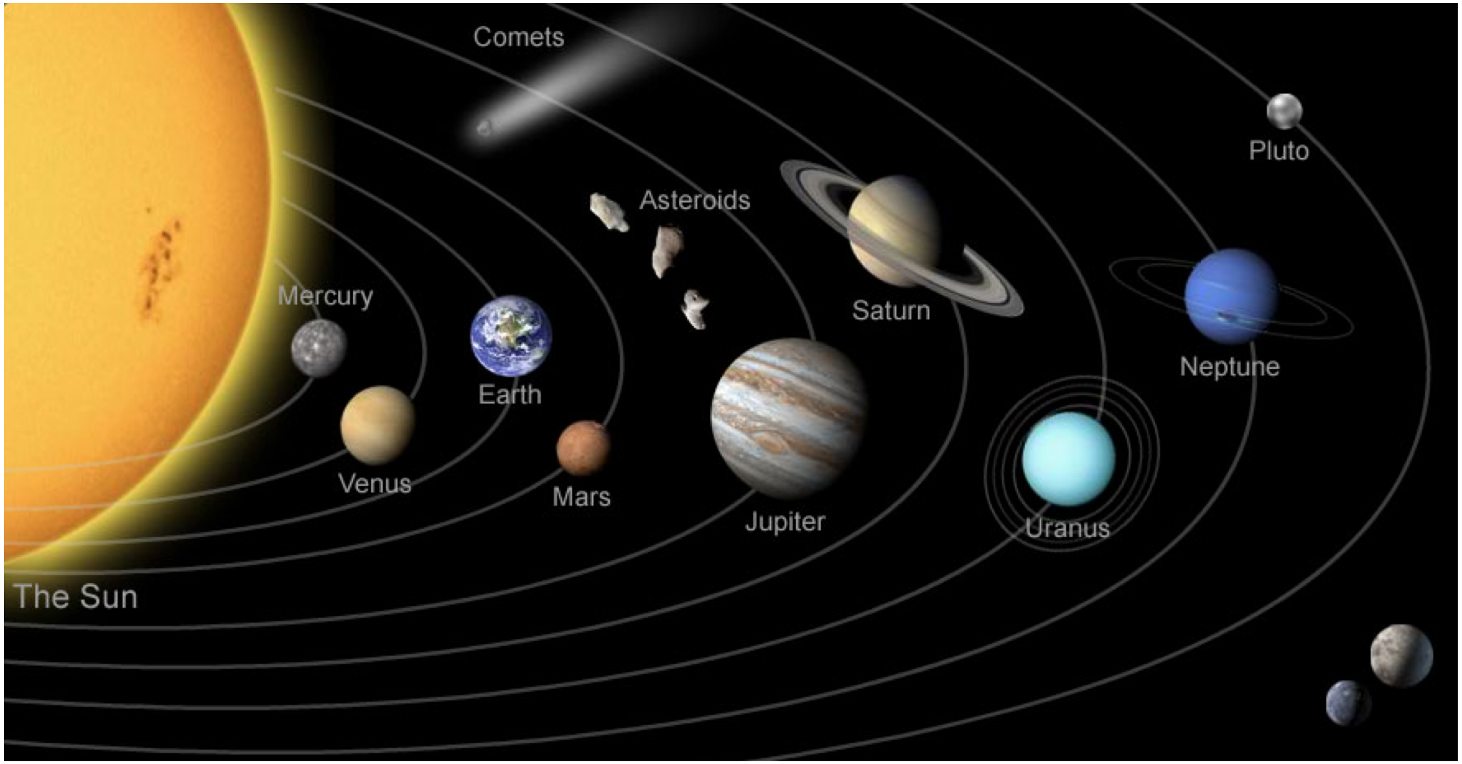
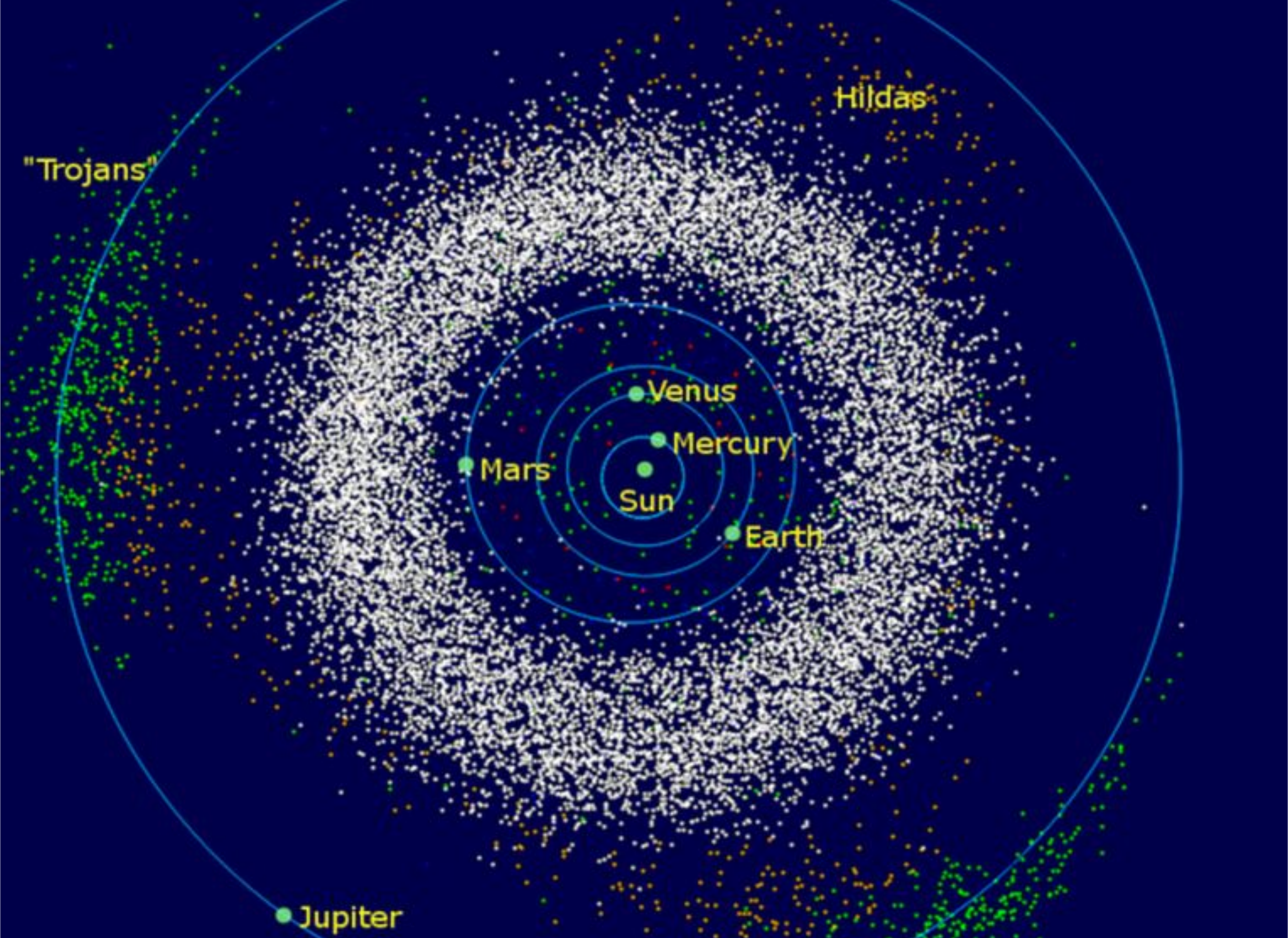
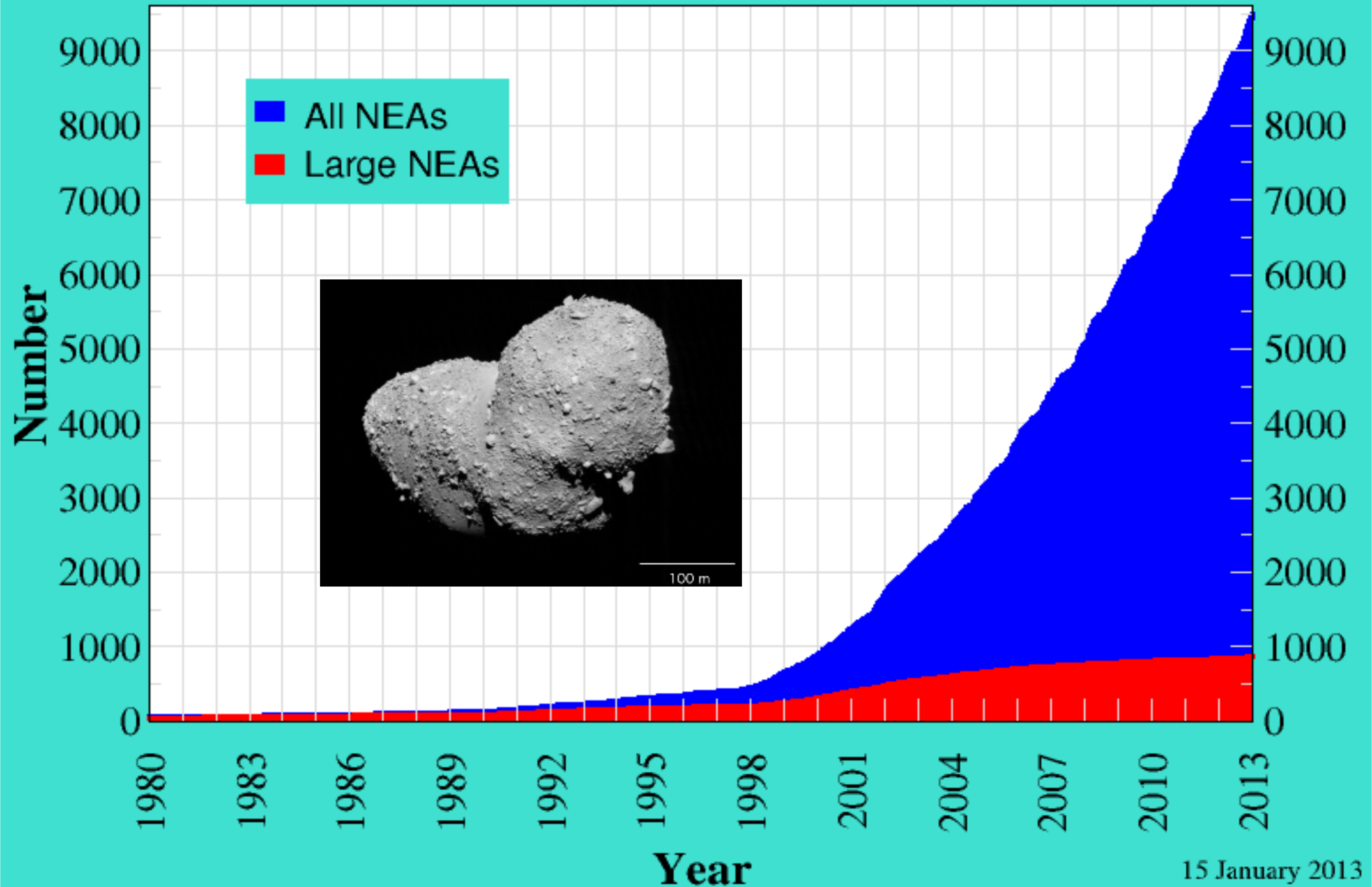


Image from 100 YSS



Hildas
"Trojans"
Venus
Mercury
Mars
Sun
Earth
Jupiter

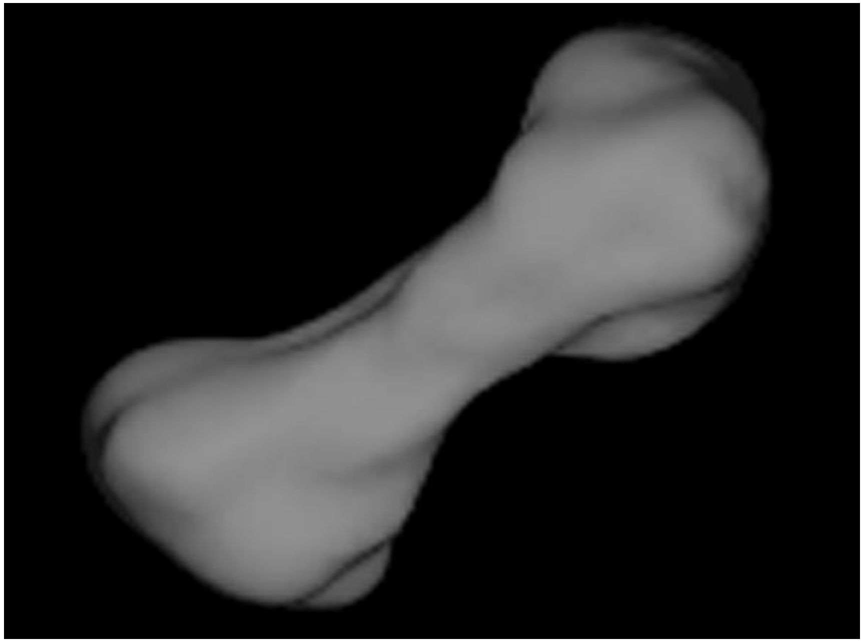
Known Near-Earth Asteroids
1980-Jan through 2012-Dec



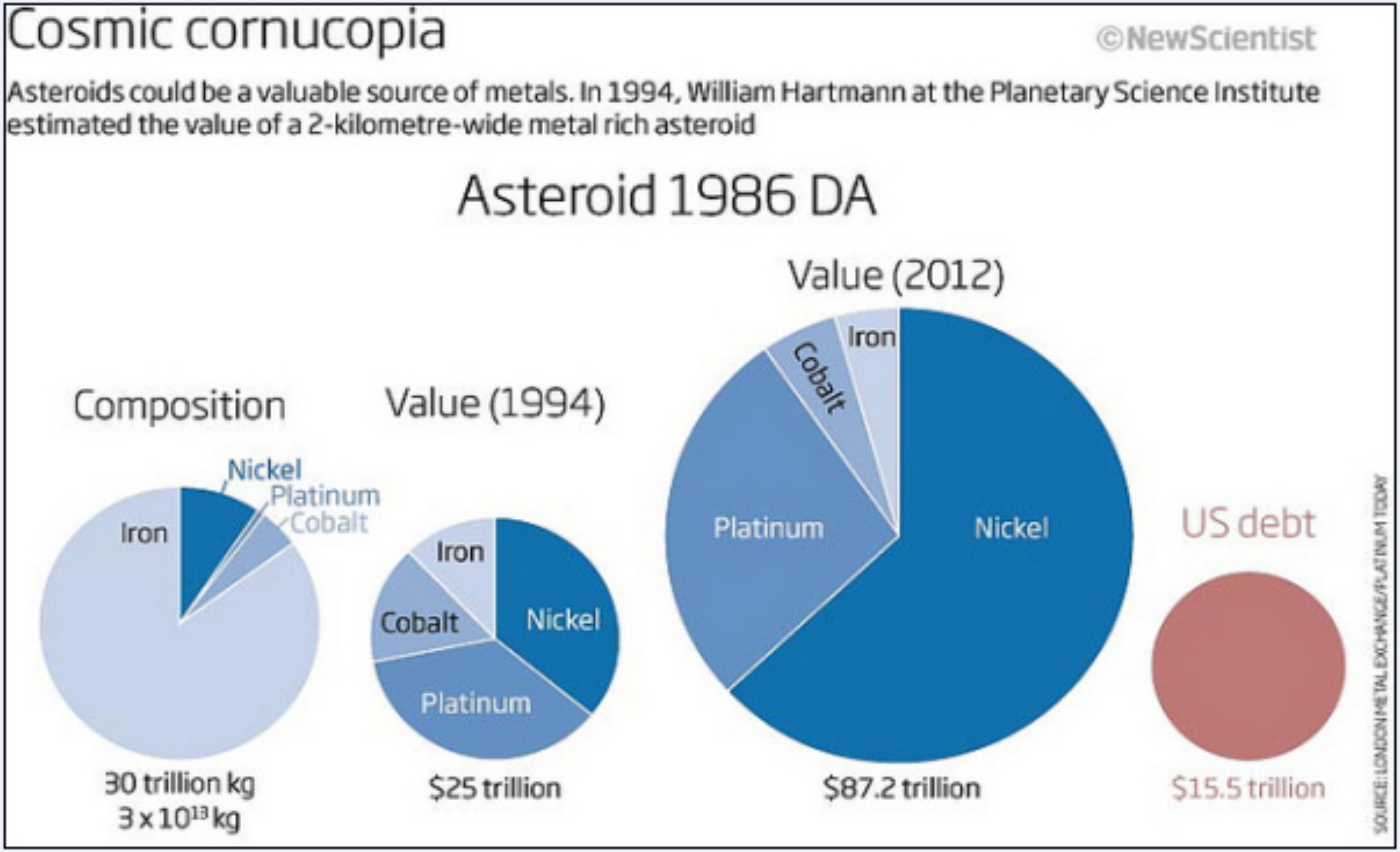
15 January 2013
Alan B. Chamberlin (JPL)

Asteroid 216 Kleopatra

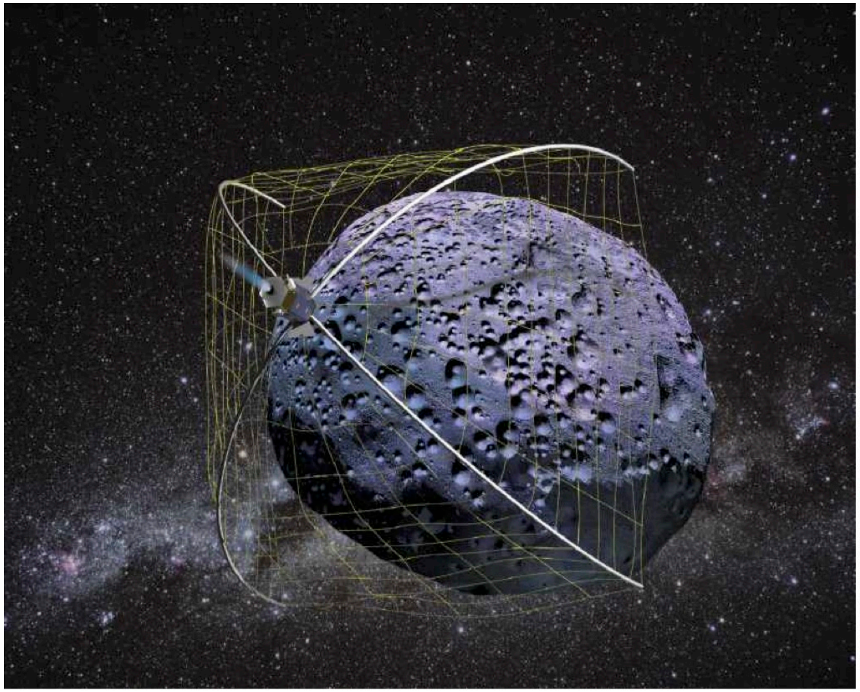
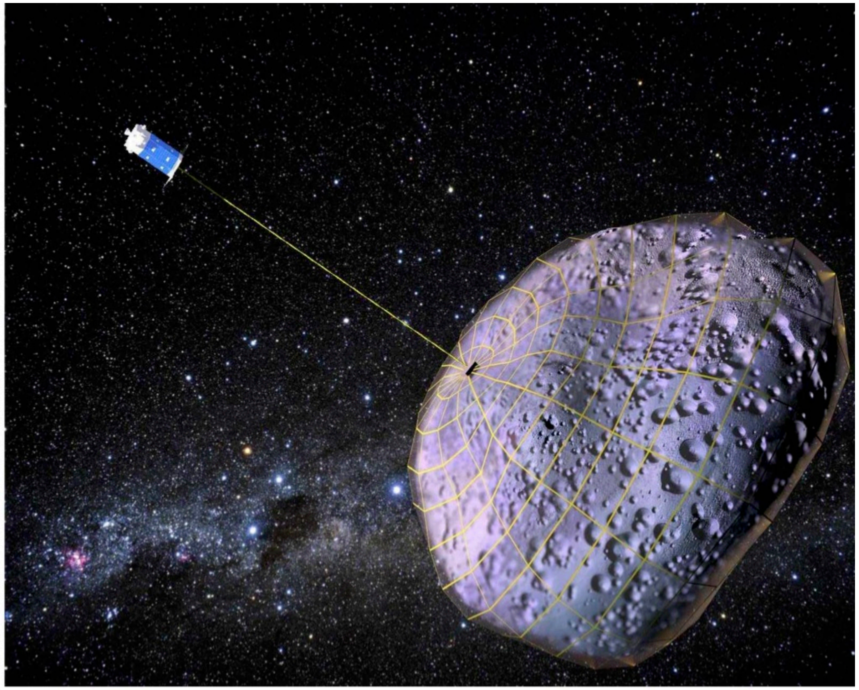
An asteroid roughly the size of New Jersey (135 x 58 miles) located between Mars and Jupiter.



- **Composed mostly of nickel (10%) and iron (88%)**
- **Kleopatra is not completely solid - its surface is about one meter of metal dust and loosely consolidated rubble, although its core may contain large (cubic miles) solid-metal nodes.**
- **2003 world steel production was 854.1 million metric tons. At the world market price of $482/ton this is $320 billion.**
- **At this rate, 10% of Kleopatra would be worth over $200 trillion.**
- **Kleopatra alone has more material wealth than all of humanity has produced on Earth.**


Cosmic cornucopia
©NewScientist
Asteroids could be a valuable source of metals. In 1994, William Hartmann at the Planetary Science Institute estimated the value of a 2-kilometre-wide metal rich asteroid
Asteroid 1986 DA
Composition
Nickel
Platinum
Cobalt
Iron
30 trillion kg
3 x 10¹³ kg
Value (1994)
Iron
Cobalt
Nickel
Platinum
$25 trillion
Value (2012)
Iron
Cobalt
Platinum
Nickel
$87.2 trillion
US debt
$15.5 trillion
SOURCE: LONDON METAL EXCHANGE/PLATINUM TODAY

Capture and Move Resources

WRANGLER system - Asteroid Capture [Tethers Unlimited]

Sell Water at Spaceports

	Mass kg	Payload [water] Mass kg	Price per kg	Price per metric ton
On–Pad	1,462,836			
In LEO	53,000	13,250	$7,547	$ 7.5 million
At GEO	21,000	5,300	$ 18,868	$ 18.9 million
At Earth-Moon EML-1	20,000	5,000	$ 20,000	$ 20.0 million
On Asteroid surface*	14,000	3,500	$ 28,571	$ 28.6 million
On Lunar Surface**	7,314	1,828	$ 54,705	$ 54.7 million
On Mars Surface***	13,200 (Insertion)	1,320 [surface]	$ 75,757	$ 75.8 million

"Water will be the Currency of Space!"

Footnotes for the Price of Water

- Price: $77-135 Million [choose $100 Million as standard]
- Mass at Pad: 1,462,836 kg
- Water % Mass at Location: 25% of payload reaching LEO, GEO, Asteroid, EML-1
- Water % Mass at Location: 10% of payload reaching Mars [25% transfer orbit, 40% to move to surface]
- Moon Surface used Apollo numbers [Lunar Lander on surface vs Saturn V Mass]

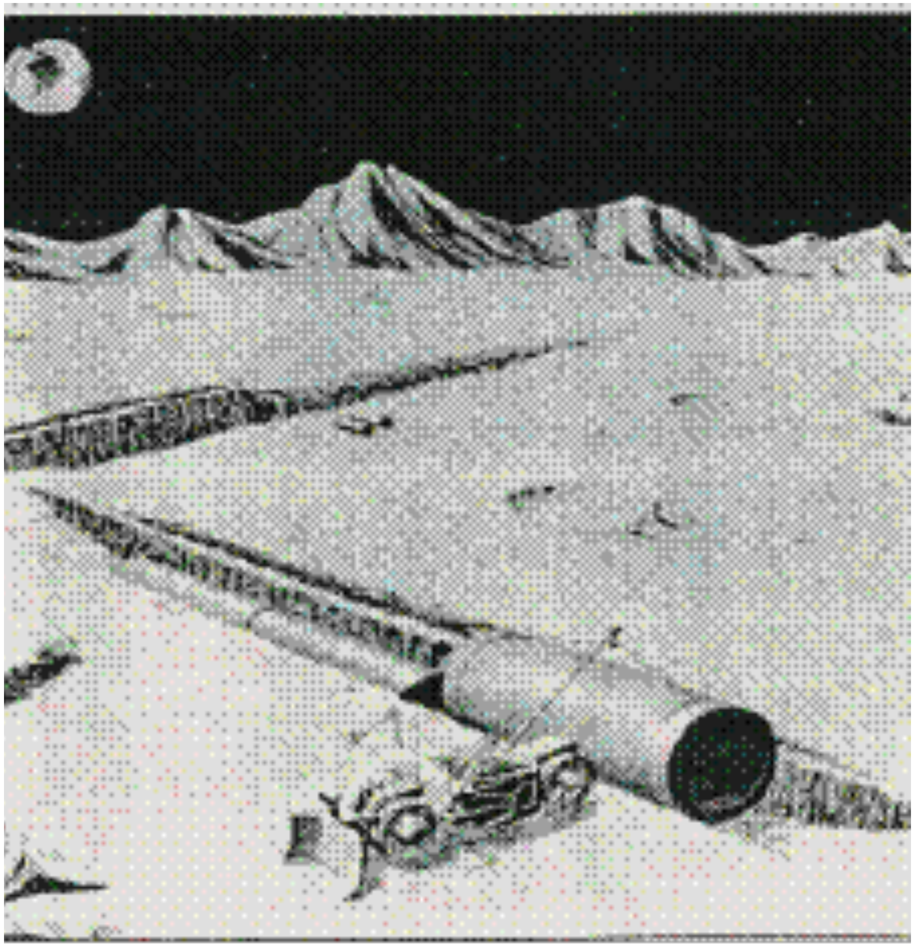
*L-1 and Asteriod estimates based upon delta V comparisons

**used Apollo ratio of mass of Lunar Lander to Mass of Saturn V

***from Mars insertion mass to surface required reduction to 10%

The basic assumptions are derived from the web page of the Falcon Heavy vehicle [projecting best prices and capabilities, yet to be proven].

Lunar & Mars Resources



From Project Horizon Study, US Army, 1959]

- Resources are boundless on the Moon and Mars
- Lower gravity enables movement by multiple methods
- One key development will be processing of in-situ resources for power on site.
- A key resource is Lunar water for living and fuel.
- A key resource on Mars is the low-pressure atmosphere

Today's Topics

- Topic Introduction
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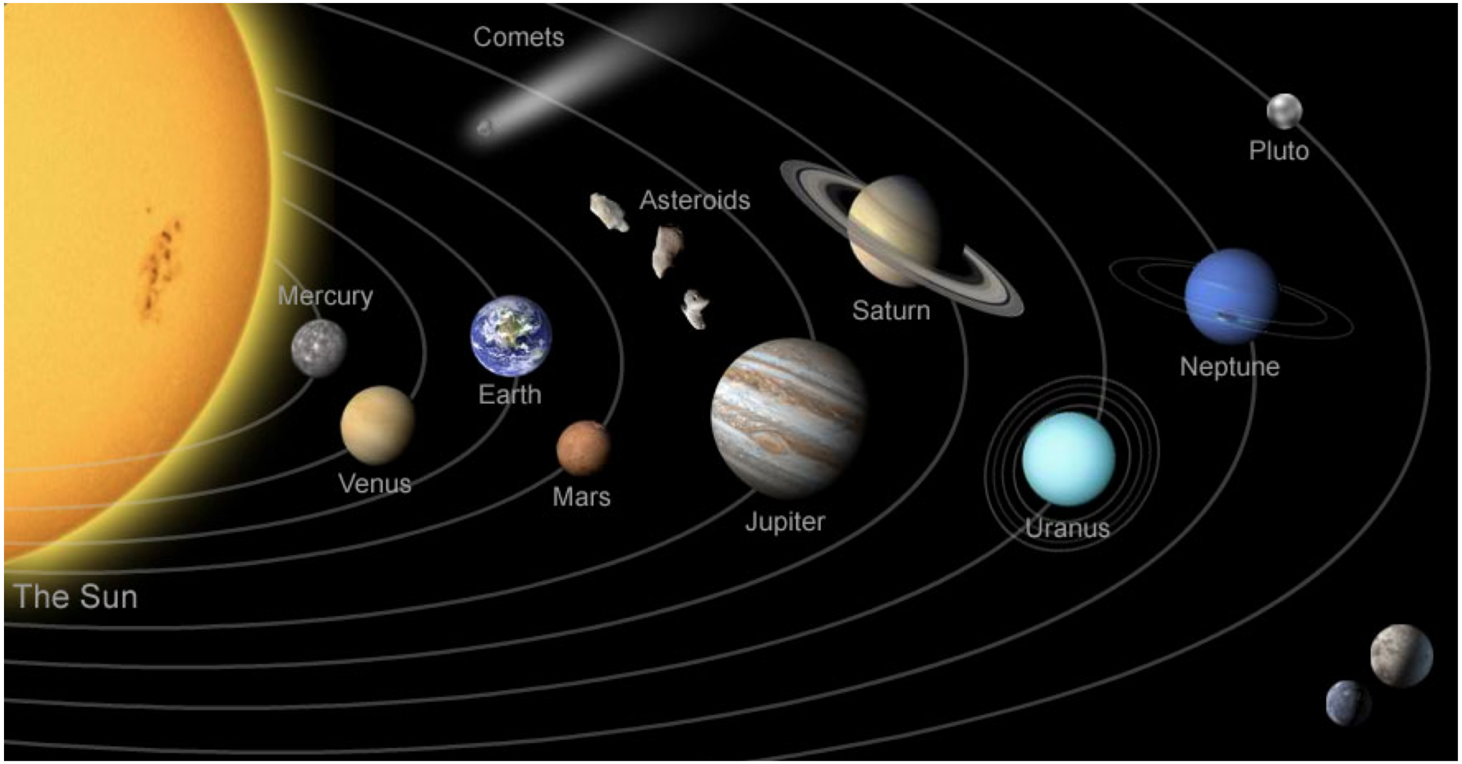


Image from 100 YSS

International Space Exploration Coordination Group (ISECG)

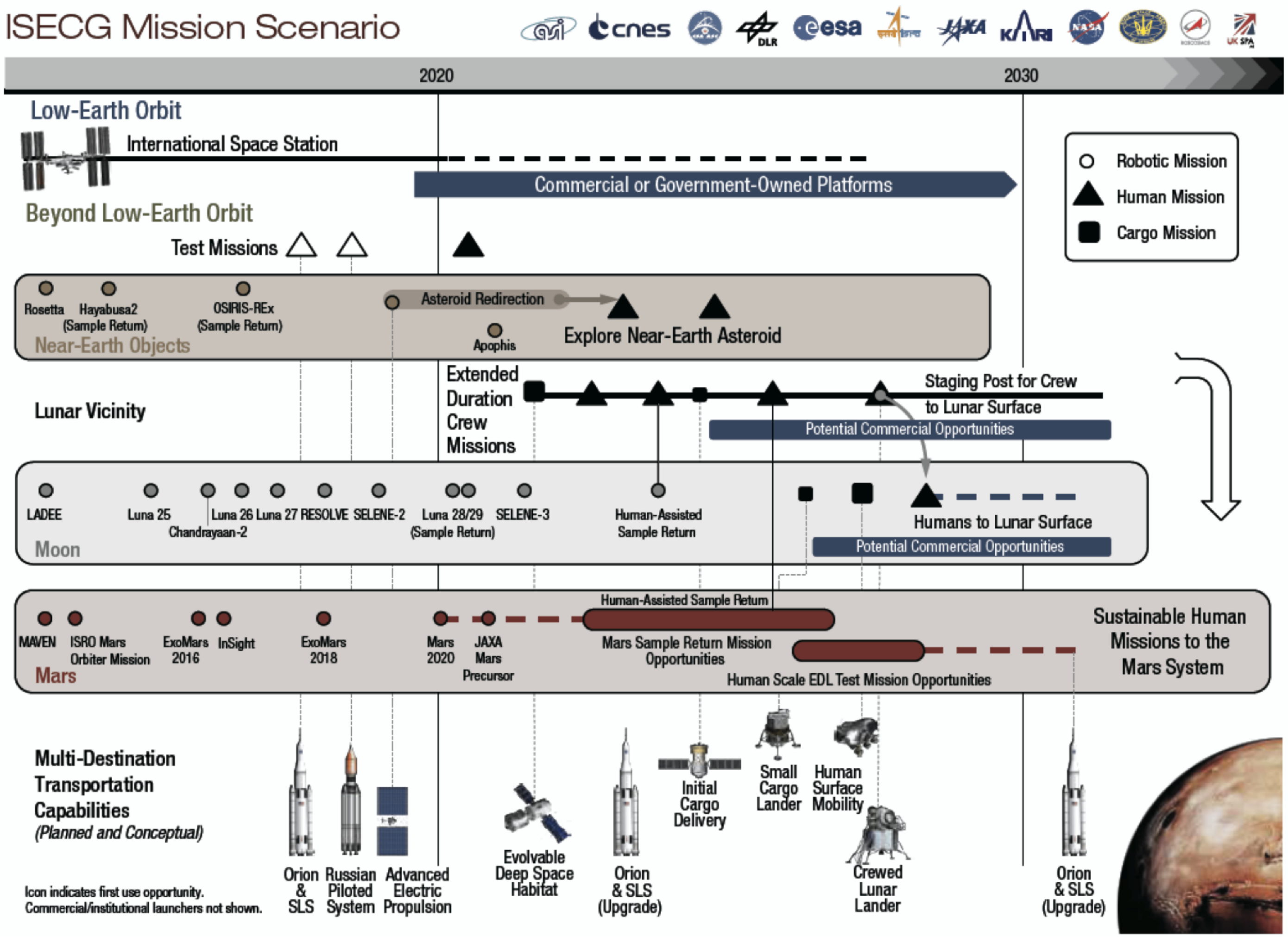
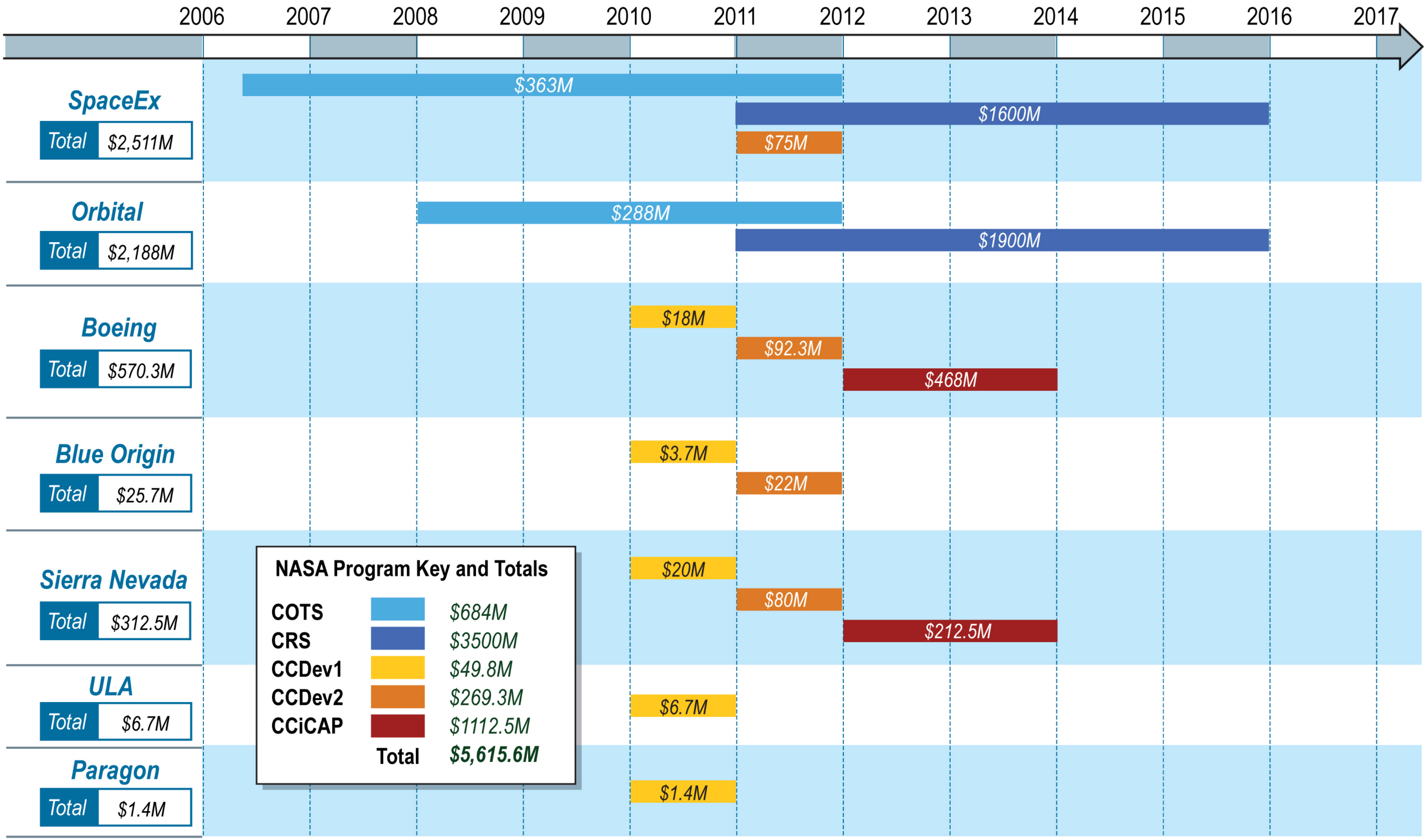


Figure 4-1. Roadmap Scenarios– Moon, Mars and Asteroid[ISECG, 2013].

NASA Funding Timeline



Deep Space Industries Roadmap

Situation Awareness: The most valuable near Earth asteroids (NEAs) are those whose orbits closely mimic that of Earth, so that minimal energy is required to reach them and return. More than two million are estimated to exist, yet only 11,300 have been charted.

- Deep Space Industries prospecting agendas begin with one-way FireFly spacecraft FireFlies are launched as secondary payloads into GTO or GEO orbits,
- and then use their own ion propulsion to depart for their targets.
- FireFlies utilize the six-unit (6U) CubeSat form factor

Prospecting: Because only 11,300 of the estimated more than two million NEAs have had their trajectories charted, an important element of prospecting will be the identification of the as-yet-unseen millions of potentially valuable objects.

- Other Deep Space prospecting craft include the DragonFly for returning 5 to 15 kg of samples from an asteroid,
- and the Mothership of Asteroid CubeSats.

Material Acquisition: Space miners can acquire asteroid ore and process it on site and shipping out only the refined components; or, they can transport raw or beneficiated ore to stable locations near or on Earth for processing. Both approaches may make sense for particular applications in various situations. On-site processing saves transportation costs by shipping only the valuable portion of the NEA.

- Mothership service includes delivery of nanosats built by a variety of researchers, communications relay to Earth, and video of the asteroid surface and surrounding area. This service allows researchers to house their instruments in a low-cost nanosat body

Processing: The two primary materials of value expected from asteroids are volatiles and nickel-iron mixtures. Volatiles will be comprised of many elements and compounds (water, ammonia, carbon monoxide and kerogen are expected to be abundant). In addition to nickel-iron (natural stainless steel), much smaller amounts of precious metals are expected.

International Space Exploration Coordination Group (ISECG) with Commercial Efforts

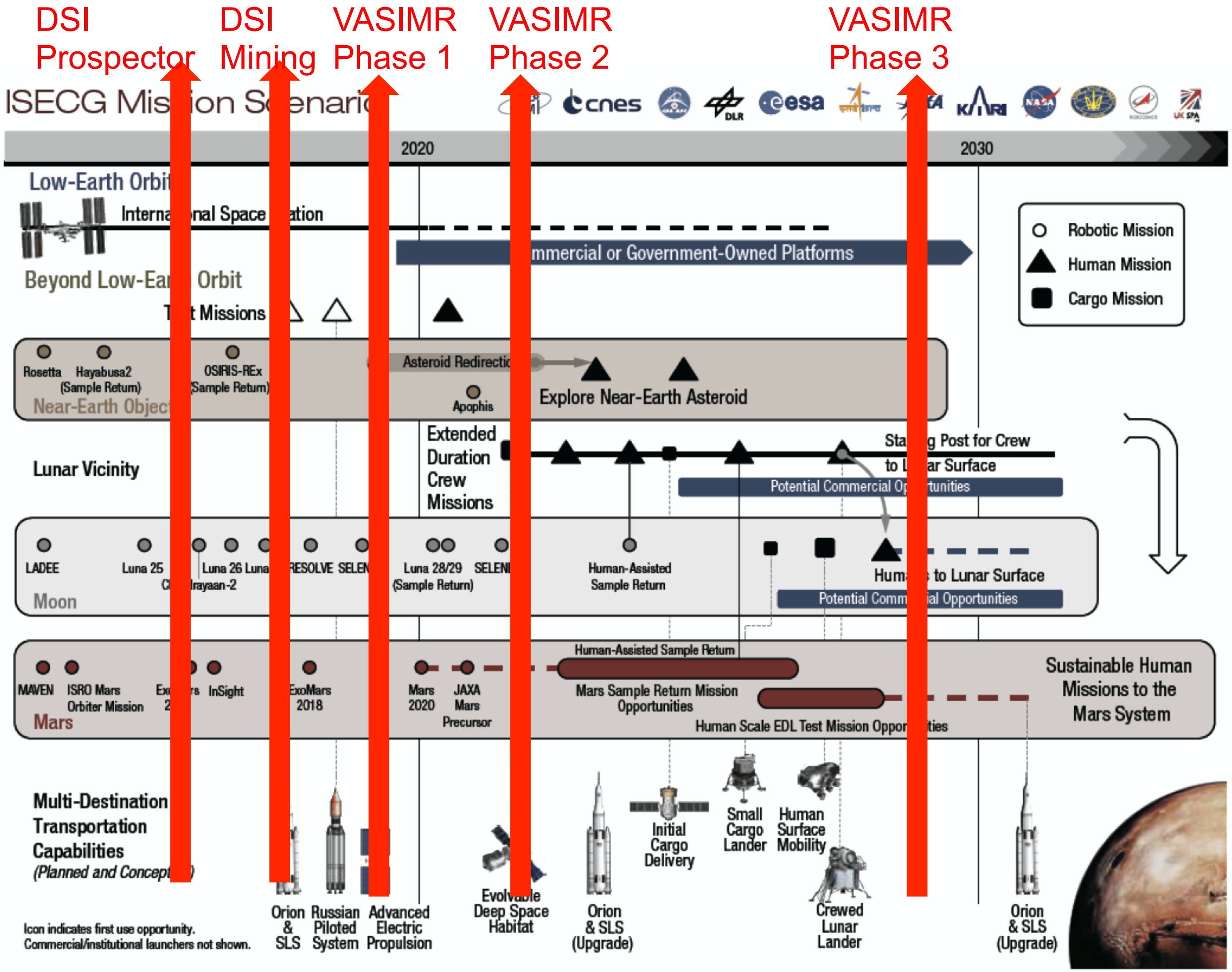


Figure 4-1. Roadmap Scenarios– Moon, Mars and Asteroid[ISECG, 2013].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Today's Topics

- Topic Introduction
- IAA Study Approach
- Who are the Players
- Commercial Ventures
- Asteroid Characteristics
- Roadmaps
- Conclusions & Questions

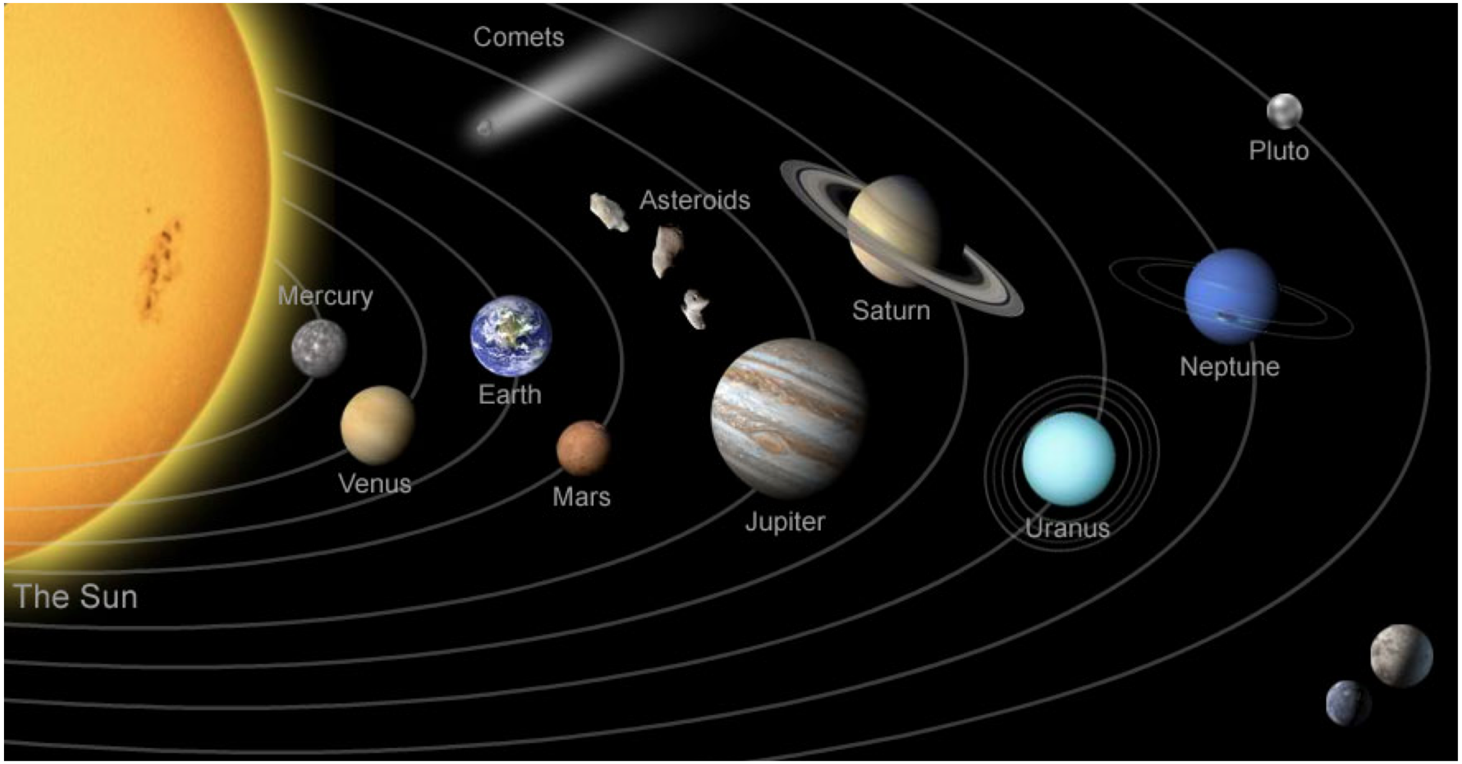

Image from 100 YSS

What will we use Space for in the future?

- **A positive vision of the future for our children.**
- **A physical, economic and spiritual frontier to enrich all people.**
- **A new place for us to live and work**
  - Space stations, settlements, colonies, independent states
  - A place rich in valuable minerals and energy
  - Solar electric power use in space and on the Earth
  - Basic metals and other raw materials
- **The Space Option concept is an evolutionary plan to meet the basic and anticipated needs of humanity through the utilization of near Earth resources - especially that of energy from space.**

The “Space Option”

The ability to fulfill the Space Option will lead to:

- Developed by two Academy Members – Arthur Woods & Marco C. Bernasconi
- Defines the positive future of Humanity
- Rapid technological growth to be leveraged by space faring companies and nations as well as stimulating technological leaps in efficient manufacturing and recycling on-planet.
- Remarkable leveraging of space mineral resources for growth off-planet; and, as necessary, bring back rare resources for consumption on Earth.
- Experiences in asteroid rendezvous and mining will result in a tremendous capability to design, track and/or divert threatening space objects
- A recharging of Earth’s learning environment will be stimulated because of the vast demands for higher education/training to enter or support these off-planet roles.
- A recharging of Earth’s economy will result from the vast investments and resources needed to support off-planet activities. New businesses must be creative and aggressive ensuring they are able to support these highly complex activities, both on and off planet.
- Re-energizing the human spirit as the understanding emerges that humanity has a future off-planet.
- Re-kindle the concept of Manifest Destiny: “Go up young person.”

Our Future?

Science-fiction author Arthur C. Clarke could not have been more perceptive in 1968 when he wrote:

*The challenge of the great spaces between the worlds is a stupendous one, but if we fail to meet it, the story of our race will be drawing to a close. Humanity will have turned its back upon the still untrodden heights and will be descending again the long slope that stretches, across a thousand million years of time, down to the shores of the primeval sea. [*Arthur C. Clarke, *The Promise of Space* (London: Penguin Books, 1968).]