INTERNATIONAL AND INTERDISCIPLINARY WORKSHOP

ON

POLICY AND LAW RELATING TO OUTER SPACE RESOURCES: EXAMPLES OF THE MOON, MARS, AND OTHER CELESTIAL BODIES

Dedicated to Eilene Galloway, who has been advocating and promoting actively international cooperation and peaceful uses of outer space since 1957

WORKSHOP PROCEEDINGS

organized by

Institute of Air and Space Law (IASL), Faculty of Law, McGill University & International Institute of Space Law (IISL)

in cooperation with

the Cologne Institute of Air and Space Law, the Leiden International Institute of Air and Space Law and the University of Mississippi National Remote Sensing and Space Law Centre, and

with the support of

United Nations Office of Outer Space Affairs, Indian Space Research Organization, the Social Sciences and Humanities Research Council of Canada, Nicolas Mateesco Matte Fund for Space Law, MDA Corporation, and OPTECH Corporation

at
Institute of Air & Space Law, Faculty of Law, McGill University
3661 Peel Street, Montreal, Quebec, Canada, June 28-30, 2006.

Published by the
McGill University
Center for Research of Air and Space Law
3661 Peel St.
Montreal, QC
Canada H3A 1X1

ISSN 0701-158-07-02

First published in 2007

TABLE OF CONTENTS

Commentaries:

Commentaries:

PREFACE

Global interest in the exploration of the Moon, the Mars and other celestial bodies is considerable and steadily growing, transcending scientific curiosity. Of particular interest are potential natural resources on these celestial bodies which could help sustain human settlements thereon and manned missions beyond. Furthermore, both the Moon and Mars could in future serve as a springboard for the exploration of more distant planets of our solar system. The primary purpose of this Workshop was to serve as a forum for discussing the commanding ideologies behind the law of outer space and the incentives and growth in interest in the exploration and use of the Moon and other celestial bodies, with special emphasis on the role of private enterprise.

The idea of organizing this workshop was suggested by Dr. Eilene Marie Galloway. It was only natural that we dedicated this Workshop to her, as she celebrated her 100th birthday in May 2006. Eilene is an eminent pioneer and scholar in space law and policy, and has been actively advocating and promoting international cooperation for peaceful uses of outer space since 1957. Eilene's special message to the Workshop was read by her son, Mr. Jonathan F. Galloway, who is a Professor Emeritus at Lake Forest College, Illinois, and a member of the IISL's Board of Directors. All Workshop participants were unanimous in expressing their appreciation for Mrs. Galloway's thoughtful words and in wishing her good health and long life.

The Workshop was co-sponsored by the McGill Institute of Air and Space Law (IASL) and the International Institute of Space Law (IISL). I am especially grateful for the support and guidance provided by Dr. Nandasiri Jasentuliyana, President of the International Institute of Space Law and an alumnus of IASL. I am also deeply indebted to Mrs. Tanja Masson-Zwan, the Secretary of the International Institute of Space Law, who generously put time and effort in organizing this event.

In addition, I would like to thank the Cologne Institute of Air and Space Law, the Leiden International Institute of Air and Space Law, and University of Mississippi National Remote Sensing and Space Law Centre for their co-operation and support in holding this Workshop. Several other institutions also contributed to making this event a great success: the United Nations Office of Outer Space Affairs, the Indian Space Research Organization, the Social Sciences and Humanities Research Council of Canada, Nicolas Mateesco Matte Fund for Space Law, MDA Corporation, and OPTECH Corporation. To all of them, my whole-hearted appreciation!

I am profoundly indebted to Dean Nicholas Kasirer from McGill Faculty of Law and Prof. Paul Dempsey, the Director of the Institute of Air and Space Law, for their continuous encouragement and strong support for holding this Workshop at McGill University.

The final decision to hold this Workshop was taken only a few months ago. I am extremely grateful to all the authors of the discussion papers, Chairpersons, and commentators who responded positively to our requests for participation on a short notice. I am pleased that our goal of making this Workshop a truly international and interdisciplinary gathering was achieved. This success would have not been possible without the tremendous help from Dr. Maria Buzdugan, Maria D'Amico, Susan Trepczynski, Raja Bhattacharya, and Marc Halter. They have worked very hard, often beyond the call of their duties, on all matters related to this event. To them, I simply and sincerely say, thank you.

On the last day of the Workshop, a meeting was organised to further discuss and finalise the recommendations of the Workshop. Mr. Stephen Doyle, Honorary President of the International Institute of Space Law (another alumnus of the IASL), very efficiently chaired this meeting, and we are indebted to him for this.

Ram Jakhu, Workshop Organizer

RATIONALE

Global interest in the exploration of the Moon and Mars is considerable and steadily growing, transcending scientific curiosity. Of particular interest are potential natural resources on these celestial bodies which could help sustain human settlements thereon and manned missions beyond. Furthermore, both the Moon and Mars could in the more distant future serve as a springboard for the exploration of more distant planets of our solar system.

Although the exploration of the Moon is still in its infancy, concentrations of hydrogen have already been found near the lunar poles. Should future missions discover significant deposits of ice, this would become a priceless resource. The prospect of mining precious and rare minerals and generating electricity on the Moon will inevitably create a desire on the part of private enterprise to take an active part in the development and exploitation of those resources. While less is known about the geology of Mars, from what has been discovered so far, this planet may well be much richer in natural resources than the Moon. On the negative side is the great distance of Mars from the Earth.

As our knowledge of outer space, the Moon, Mars and other celestial bodies expands and technology continues to advance, the need to examine whether the current legal regime applicable to space provides appropriate legal clarity and certainty, commercial possibility and stability and technological innovation and adaptability to cope with the future needs became manifest. The Outer Space Treaty of 1967 does not permit national claims and appropriation of territory but is silent with respect to the extraction and appropriation of resources. The 1979 Moon Agreement, on the other hand, has few parties, with the United States and the Russia Federation – the leading space powers – being the most obvious non-participants.

The current state of international space law may be perceived to inhibit capital investments needed to develop new, expensive technologies in order to begin serious exploration and commercial exploitation. Needless to say, any future legal regime providing for the commercial exploitation of outer space resources including those on the Moon and other celestial bodies will have to take into account the potential effect of these activities on the natural environment. In addition, the principle of the "common heritage of mankind", enunciated in the Moon Agreement, will require careful scrutiny in the context of commercial exploitation of spatial resources.

The importance of the issues outlined above and the paucity of fora where leading representatives of the academy, government and private industry can candidly discuss and analyze the future of law and policy in relation to space have given impetus to the McGill Institute of Air and Space Law to take the lead in organizing this Workshop.

OBJECTIVES

This gathering will be a unique opportunity to bring together world-class scholars, scientists, space technology experts, lawyers, academics, government officials, and private sector representatives, who work in various space-related fields and are united in their commitments to promote and advance the cause of sustainable exploration and use of space.

The Workshop will take into account the needs of all States as well as of private commercial enterprises. It will consider the complexities of outer space's topography, the process of public-policy making in this field and the concerns of the investment community. The Workshop will also seek input on the changing role of nation States and international organizations in matters related to outer space and these actors' feedback to the current challenges from the point of view of space technology.

This Workshop will seek to create a forum for critical analysis and cutting-edge commentary on issues at the nexus between law, policy, economics, technology and the environmental sciences. It will discuss the commanding ideologies behind the law of outer space and the incentives and growth in interest in the exploration and use of the Moon and other celestial bodies, with special emphasis on the role of private enterprise. The participants will also critically examine the current challenges to the space regime posed by new commercial entities in their pursuit of space pre-eminence, especially within the framework offered by the 1967 *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies* and the 1979 *Agreement Governing the Activities of States on the Moon and Other Celestial Bodies*.

In line with this, this gathering will allow us to review the political and legal environments that have characterized this field for the last 50 years. This will entail, *inter alia*, identifying the actors in this field, reviewing the changing relationships between governments, non-governmental organizations and the private sector, analyzing their views on issues such as access to its resources, property rights and political sovereignty. This analysis will provide the necessary basis for the drafting of policy recommendations addressing imminent concerns and proposing far-reaching solutions to emerging challenges in the area of space exploration and exploitation.

The Workshop will also include an analysis of the COSPAR Planetary Protection Policy which divides the Moon and Other Celestial Bodies into five mission categories with the purpose to "avoid their harmful contamination and also adverse changes in the environment of the Earth." This policy may constitute a useful example of possible approaches to the use and exploitation of outer space.

In this context, the organizers hope that the Workshop will become an important forum that will provide feasible approaches to addressing the challenges and realities outlined above. It hopes to present thorough, well-articulated analysis and legal and public policy solutions to contemporary conundrums in the exploration and use of outer space resources, including those of the Moon and other celestial bodies.

The Workshop's organizers aim to publish and promote research that is outcome oriented and that will, as such, promote institutional development and impact policy and law making in space matters. The publication to be released will undoubtedly generate transferable results that will provide a forum of ideas, discussion and policy assessment for leading decision makers, impacting the development of uses of the resources of the Moon and other celestial bodies. Consequently, this should help in promoting international cooperation for maintaining outer space, including the Moon and other celestial bodies, for peaceful uses.

Welcome Address

by

Nandi Jasentuliyana
President, International Institute of Space Law (IISL)

I would like to welcome every one to this IASL/IISL workshop on space resources. I am particularly happy to be here today, returning to the place where I first arrived in North America several decades back, and to be here with my Professor of Space Law Dr. Ivan Vlasic and several of my distinguished colleagues from the IASL class of 1963: Dr. Stephen Doyle, Prof. Paul Larsen, Dr. Edmund Fuller as well as several friends and colleagues from that era Prof. Mateesco Matte & Prof. Michael Milde two former Directors of IASL. With the education I had here at the Institute, I had the privilege to go on to the United Nations to be associated with the drafting of the Outer Space Treaty and later all of the other UN Treaties and Declarations of Legal Principles which together forms the basis of space law, and the basis our discussions at this workshop.

Ladies and gentleman, the exploration and use of space resources will become a reality in the near future. It is the inevitability of progress, the march of science and humanity's unquenchable thirst for exploration that will drive the space community onward in this quest.

But, as I am sure of this, I am equally convinced that nations and entities within them, can no longer think only on parochial interests in their space activities. Just as earth is the common heritage of all humanity, so too is outer space and the planets of our solar system. Because of this, international cooperation must be one of primary goals of exploration and use of space resources as was envisaged in the space treaties.

There are many reasons for this. It would seem that development of space resources will be such an enormous undertaking as to make international participation in some form essential. The advanced technology necessary will require an international network of contractors and subcontractors; the capital investment will require tapping of the international capital markets; and the scale of production necessary to justify the investment will require international marketing of products. International cooperation is also necessary to demonstrate the international community's commitment to maintaining space exclusively for peaceful purposes and to ensuring that the benefits of space technology are accessible to all countries and people everywhere.

While all of us gathered here today would like to see exploration of space resources proceed as quickly as technically feasible, we must also temper our expectations against the reality of the world we live in. Those of us active in the field of space cannot ignore what is happening here on Earth and must be cognizant of our responsibility to pursue benefits of space technology so as to elevate the human condition and preserve the quality of our environment.

Indeed, today's economic realities make it even harder to convince governments to loosen the purse strings in order to fund space programs which are viewed by many as extravagant, unnecessary and superfluous to the needs of terrestrial society.

Of course, there would be many benefits of exploration of space resources on the Moon, Mars and other Celestial Bodies. In addition to being a significant scientific accomplishment, by "pushing the envelope," if you will, there would be tangible benefits with a myriad of spin-off benefits of the technology developed specifically for space exploration.

Despite this, a valid argument can be made that no matter how significant these benefits are, there are ultimately more pressing problems that could benefit from large expenditure of financial resources and concentration of scientific talent. The massive environmental problems that face the Earth, the global scourge of AIDS and other diseases and the wide scale starvation and malnutrition in many parts of the world are just some examples of the problems on Earth that require the imminent attention of the scientific community. There are an infinite number of other important causes that are equally important for the survival of humanity on Planet Earth.

We, as a community, must balance these competing priorities in a rational and coherent way in order to extract the utmost benefit for humanity from space activities. There are no easy answers to the question of what our priorities should be. But, discussion and debate such as the one we are going to have here in the next three days will play a vital role in determining the future path of international space efforts.

However, those priorities are set in the future and, though the determination has yet to be made, probably in the next decade or two, as to whether or not Moon and other Celestial Bodies possess resources of value to humanity, and the feasibility of their exploration and use, our most important concern today should be to ensure the peaceful exploration and use of such resources – the first and essential phase that will serve as the foundation of our later efforts.

Without some guiding framework to preserve the necessary stability and make the expectations of the international community predictable, one cannot expect public or private enterprises to provide the enormous investments that are necessary to encourage the timely development of space resources. In considering the elements of such a regulatory framework, we have to ensure in our first steps here that the exploration and use of such resources do not become the basis of national and international conflict. Our efforts here should be designed to encourage resource development in the next decades, by states as well as private enterprises, while discouraging the danger of cartel or monopoly of particular interests. We should ensure that exploitative activities are carried out with due care to maintaining the existing balance of the space environment. Due to the fact that resource development remains far in the future, the regulatory framework we strive for should be flexible to take into account scientific and technological developments which might be beyond any present speculation.

At the present two treaty regimes possess the authority to deal with the exploitability of natural resources of the moon and other celestial bodies. The 1967 Principles Treaty contains the Province of Mankind (res communis) principle. This agreement is binding on 97 countries including all the space faring nations. The 1979 Moon Agreement adopted the Common Heritage of Mankind (modified res communis) principle. It calls for the creation of a formal management entity to manage the resources when it becomes feasible to explore the resources of the moon. It is binding on less than a dozen countries that have ratified it and does not include any space faring nation.

In the meantime, there are proponents of an alternative principle, namely the previously rejected res nullius principle. Its proponents have urged the exclusive property rights in the moon and celestial bodies will facilitate the use of their natural resources and called for formulation of national procedures to achieve such goals. Others have moved to claim property rights to parts of the moon on the flawed premise that the Principles Treaty applies only to states which are prohibited from national appropriation by claims of sovereignty, and therefore, in their view, does not prevent private persons and entities from claiming property rights on the moon.

These proposals, in seeking, seemingly to facilitate exploitative activities, have raised the important issue of property rights respecting acquired tangible natural resources. Practically all of them have been voiced for several years, by the proponents of those proposals; and with considerable vigor, in the meetings of the International Institute of Space Law.

IISL Board of Directors thought it was time to pay attention to this developing debate and two years back established a task force to study the matter. Following the detail work done by that group, the Board was able to agree on a statement that set out the legal status of the issue as provided for in the current treaty law and practice. That statement is posted on the IISL website and I am sure will be referred here in more detail.

Following that effort, our founder Director, Mrs. Eilene Galloway, to whom appropriately this workshop is dedicated, in celebration of her 100th anniversary birthday, proposed that IISL convene an interdisciplinary workshop attended by scientists as well as law and policy experts to consider what steps might be taken to govern space resources, beyond what is provided for in the current legal framework, including public and private sector relationship.

IISL was delighted that our Board Director, Prof. Ram Jakhu, took the initiative to convene this workshop here in Montreal, hosted by the McGill Institute of Air and Space Law. We are also grateful to Prof. Paul Dempsey, Director of IASL who readily supported and encouraged the holding of the workshop.

To Prof. Ram Jakhu, and his team here at the McGill Institute, we are most appreciative of the efforts you have undertaken to make this workshop a reality. We thank all the speakers, commentators, chairpersons, rapporteurs and other participants who accepted the invitation to be here and I am sure you will find the workshop to be a productive experience as we strive here to take the first next steps towards a regulatory framework concerning the exploration of space resources, that will hopefully begin if not in our lifetime, certainly in the lifetime of our children.

Now, to guide you in your work, IISL could do no better than to let a pioneer in space law who wrote the NASA Act, back in the 60s, to give you some pointers as to what our task here entail as compared to the drafters of the space treaties the at the United Nations. I therefore have the pleasure to call on Prof. Jonathan Galloway, distinguished son of Dr. Eilene Galloway, to read her message to this workshop.

Thank you!

Montreal, Canada
28-30 June, 2006.

Remarks by Eilene Galloway at the June 2006 IISL/McGill Workshop on International and Interdisciplinary Factors of Policy and Law for the Moon, Mars, and Other Celestial Bodies

I wish to express my deep appreciation for the honor of receiving the dedication of this Workshop on International and Interdisciplinary Factors of Policy and Law for the Moon, Mars, and Other Celestial Bodies.

I am reminded of that day on October 4, 1957 when Sputnik was orbited, creating worldwide fear of weapons of mass destruction being dropped on Earth from space. Then scientists and engineers, who were organized for the International Geophysical Year, explained that outer space could be used for many beneficial purposes and changed fear to hope. Governments, the United Nations, and the scientific community united to formulate international space law. The world has subsequently enjoyed 48 years of using outer space for national and international peaceful pursuits.

It is evident that legal solutions developed for solving problems on Earth cannot be expected to work the same way in outer space. Outer space is completely different from the Earth, air and sea from a scientific, technological, and policy standpoint.

The situation has some of the same characteristics as a federation: units with different programs operating under an umbrella of the same basic space laws to which all participants are subject --- such as selection of orbits and landing sites --- and ensuring that the policies on what we hope to achieve are carried out by programs on how to achieve them.

Session 1

State-of-the-Art Technologies, Physical and Geological Composition of the Celestial Bodies and International Cooperation

“Role of the Moon in Reducing Technical and Programmatic Risks for Long-Duration Exploration Missions”

by Carl Walz (NASA, USA)

–

power point presentation

Role of the Moon in Reducing Technical and Programmatic Risks for Long-Duration Exploration Missions

Carl E. Walz
Director
Advanced Capabilities Division
Exploration Systems Mission Directorate
NASA Headquarters

Talk Outline

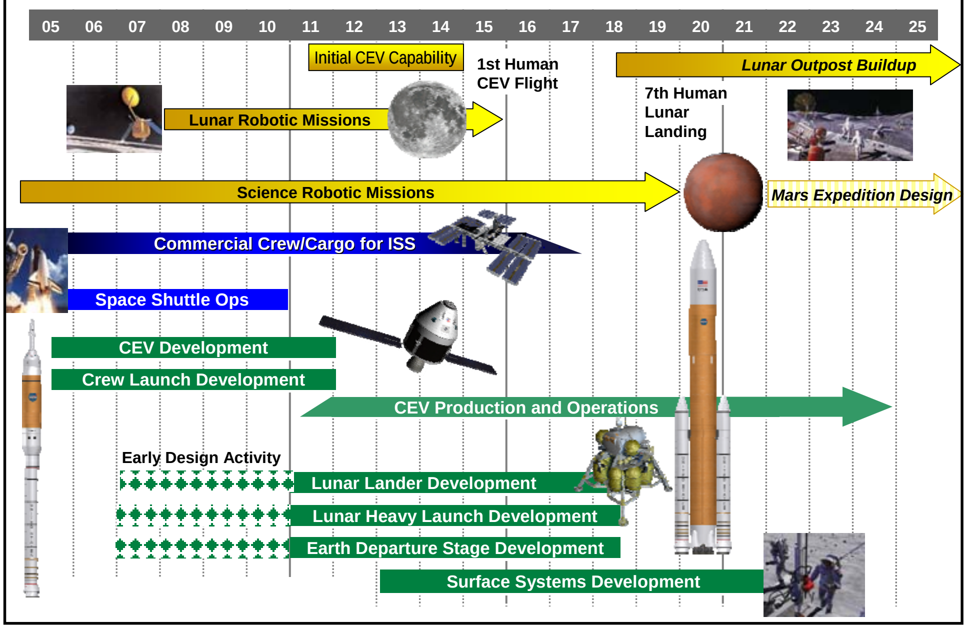
- Why are we going to the Moon?
- How are we getting there?
- What does the Moon offer us?
- What do we do on the Moon to reduce our logistics requirements?

Why are we Going to the Moon?

A Vision for Space Exploration

- Complete the International Space Station
- Safely fly the Space Shuttle until 2010
- Develop and fly the Crew Exploration Vehicle no later than 2014 (goal of 2012)
- Return to the Moon no later than 2020
- Extend human presence across the solar system and beyond
- Implement a sustained and affordable human and robotic program
- Develop supporting innovative technologies, knowledge, and infrastructures
- Promote international and commercial participation in exploration

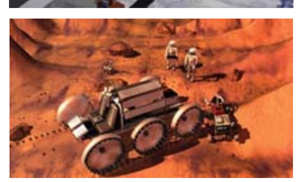
NASA's Exploration Roadmap



The Moon - the 1st Step to Mars and Beyond…

- **Regaining and extending operational experience in a hostile planetary environment**

- **Developing capabilities needed for opening the space frontier**
- **Preparing for human exploration of Mars**

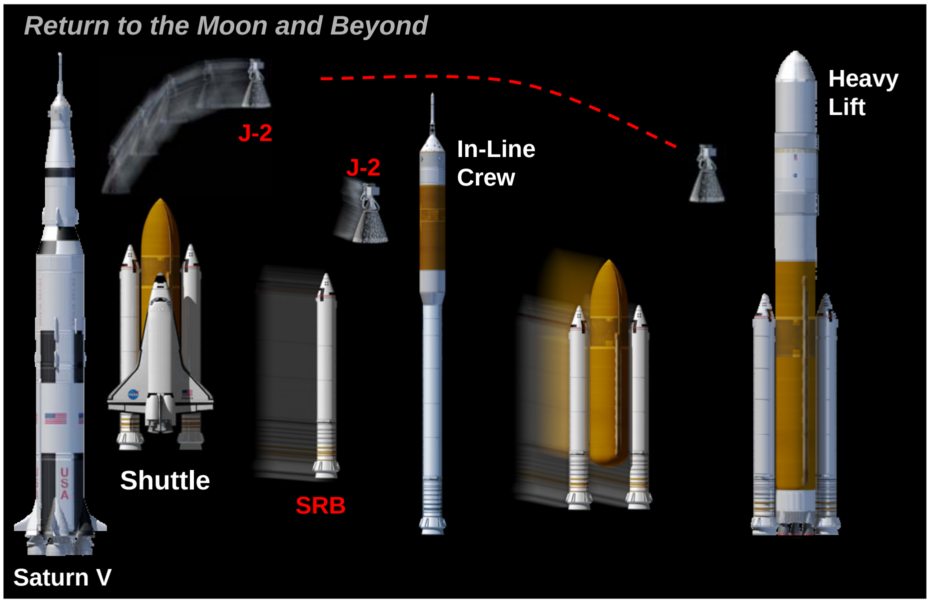


- **Science operations and discovery**
- **Enabling governmental, commercial and scientific goals for the development and use of the Moon**

Next Step in Fulfilling Our Destiny As Explorers

How are we getting there?

Heritage Derived Launch Vehicles



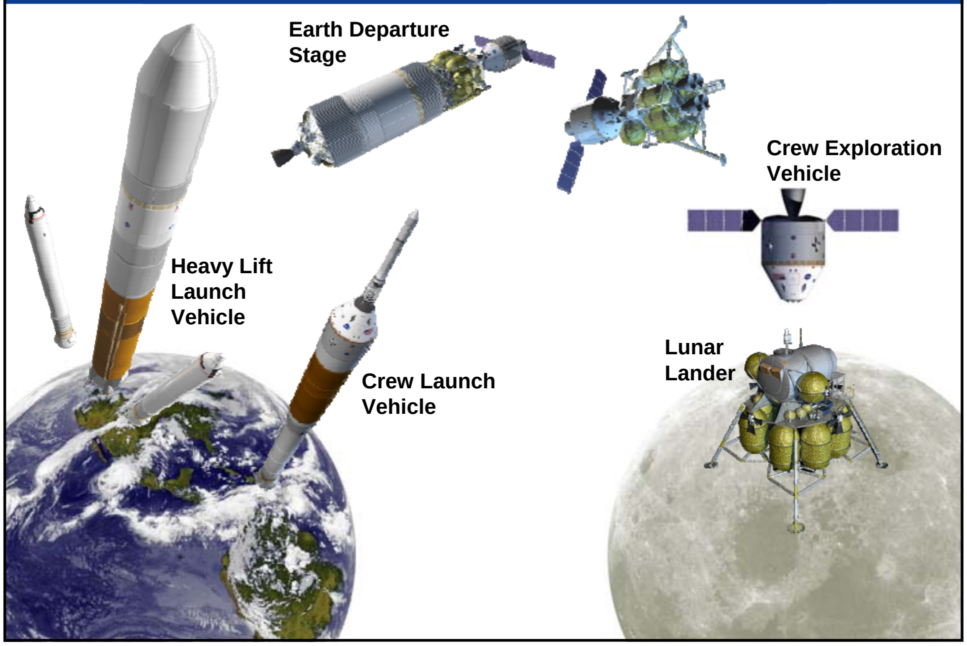
How We Plan to Return to the Moon
Crew Exploration Vehicle:

- **A blunt body capsule is the safest, most affordable and fastest approach**
  - Separate Crew Module and Service Module configuration
  - Vehicle designed for lunar missions with 4 crew. Can accommodate up to 6 crew for Mars and International Space Station missions
  - System also has the potential to deliver pressurized and unpressurized cargo to the International Space Station if needed
- **5 meter diameter capsule scaled from Apollo**
  - Significant increase in internal volume
  - Reduced development time and risk
  - Reduced reentry loads, increased landing stability and better crew visibility

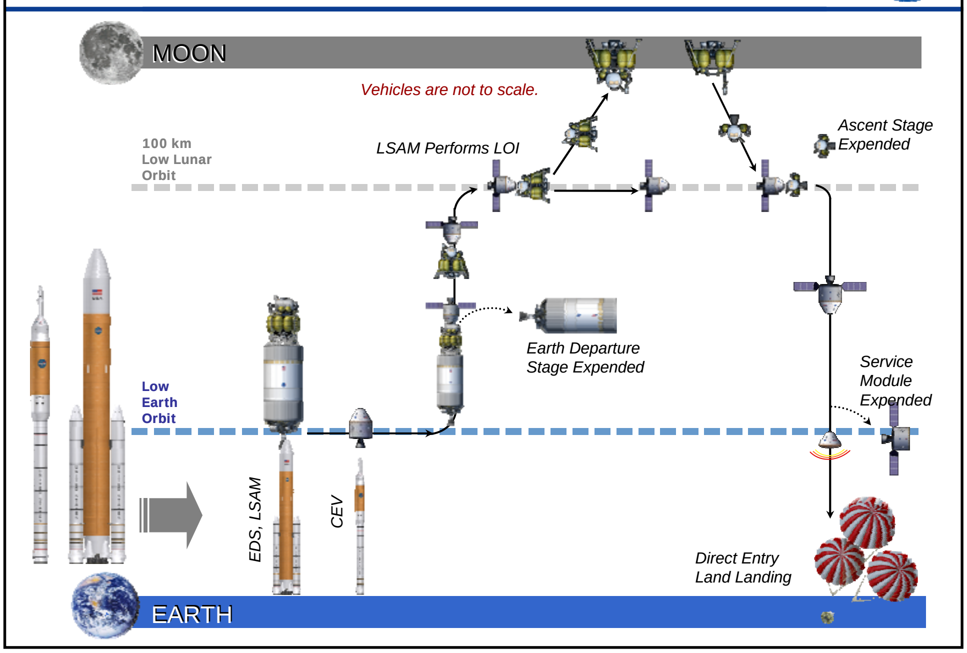
Servicing the International Space Station

- **The CEV will be designed for lunar missions but, if needed, can service the International Space Station. Annually, the CEV has the potential for:**
  - 2 crew flights
  - 3 pressurized cargo flights
- **The CEV will be able to transport crew to and from the International Space Station and remain on-orbit for 6 months**
- **NASA will also invite industry to offer commercial crew and/or cargo delivery service to and from the International Space Station. $500M set aside for milestone payments for selected companies using Space Act agreements**

Components of Program Constellation



Typical Lunar Reference Mission

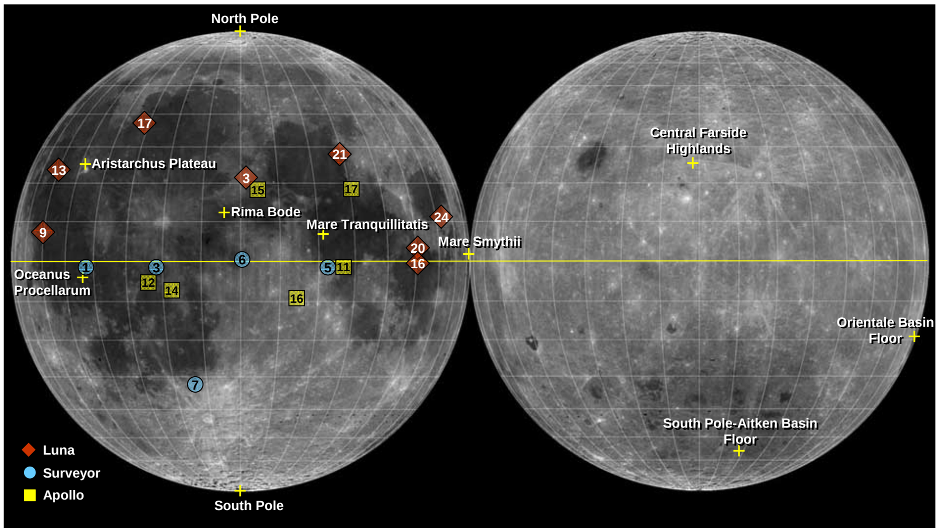


Lunar Lander and Ascent Stage

- **4 crew to and from the surface**
  - Seven days on the surface
  - Lunar outpost crew rotation
- **Global access capability**
- **Anytime return to Earth**
- **Capability to land 21 metric tons of dedicated cargo**
- **Airlock for surface activities**
- **Descent stage:**
  - Liquid oxygen / liquid hydrogen propulsion
- **Ascent stage:**
  - Storable Propellants

What does the Moon offer us?

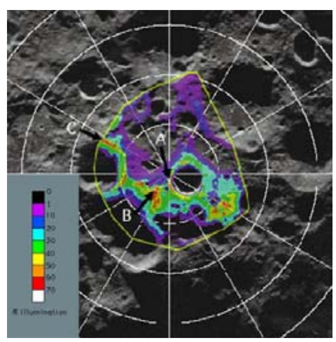
High Priority Lunar Exploration Sites



Near Side *Far Side*

Possible South Pole Outpost

- The lunar South Pole is a likely candidate for outpost site
- Elevated quantities of hydrogen, possibly water ice (e.g., Shackelton Crater)
- Several areas with greater than 80% sunlight and less extreme temperatures
- Incremental deployment of systems – one mission at a time
  - Power system
  - Communications/navigation
  - Habitat
  - Rovers
  - Etc.



What do we do on the Moon to reduce our logistics requirements?

Technology Development Program
ESAS Technology Areas

Structures
- Lightweight cryotanks
- Inflatable space structures

Protection
- Ablative, human-rated TPS

Propulsion
- Non-toxic Propellants
- Deep throttleable engine for LSAM
- Expendable SSMEs

Power
- Fuel cells
- Lithium-ion batteries
- Non-toxic Auxiliary Power Unit for CLV

Thermal Control
- Heat rejection for surface systems

Avionics & Software
- Rad hard & low temperature electronics
- Integrated System Health Management
- Spacecraft autonomy
- Automated Rendezvous & Docking
- Autonomous precision landing
- Reliable software

Environmental Control & Life Support
- Atmospheric management
- Environmental monitoring & control
- Advanced air & water recovery systems

Crew Support & Accommodations
- EVA suit

Mechanisms
- Low temperature mechanisms

***In-Situ* Resource Utilization**
- Regolith excavation & material handling
- Oxygen production from regolith
- Polar volatile collection & separation

Analysis & Integration
- Tool development for architecture & mission analysis
- Technology investment portfolio assessments

Operations
- Supportability
- Human-system interaction
- Surface handling & operations equipment
- Surface mobility

What are Space Resources?

The purpose of *In-Situ* Resource Utilization (ISRU) is to harness & utilize these resources to create products & services which enable and significantly reduce the mass, cost, & risk of near and long-term space exploration

- **Traditional 'Resources':**
  - Water, atmospheric constituents, volatiles, solar wind volatiles, minerals, metals, etc.
- **Energy**
  - Permanent/Near-Permanent Sunlight
    - Stable thermal control & power/energy generation and storage
  - Permanent/Near-Permanent Darkness
    - Thermal cold sink for cryo fluid storage & scientific instruments
- **Environment**
  - Vacuum
  - Micro/Reduced Gravity
  - High Thermal Gradients
- **Location**
  - Stable Locations:
    - Earth viewing, sun viewing, space viewing, staging locations
  - Isolation from Earth
    - Electromagnetic noise, testing & development activities, extraterrestrial sample curation & analysis, storage of vital information, etc.

Proposed Lunar ISRU Approach

Four Phases

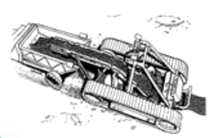
- Robotic Phase**: Robotic precursors to identify resources and validate critical processes *)***
  - Lunar Reconnaissance Orbiter (2008)
  - Future landed missions (to be defined)
- Sortie Phase**: Early human missions (4 to 14 days) to check out systems and operations until long-term Outpost initiated**
  - Demonstrate critical ISRU capabilities at sub-Outpost scale production rates (excavation, oxygen production, water/hydrogen extraction, liquid oxygen storage & transfer)
- Outpost Pre-deploy Phase**: Pre-deploy ISRU assets to be ready at start of crew occupation of Outpost**
  - Surface regolith excavation and manipulation
    - Excavation for volatile extraction and regolith processing
    - Berms and shielding for radiation and plume protection
    - Site/landing pad preparation and road/dust mitigation
  - Extraction & recovery of useful volatiles from surface resources (H_2, CO, N_2, H_2O)
  - Oxygen (O_2) production from regolith processing
  - Production/regeneration of fuel cell reagents
  - Cryogenic storage & transfer

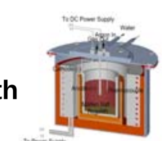
Proposed Lunar ISRU Approach

- Outpost Phase**: Develop infrastructure at one base for Mars mission ‘dress rehearsals’ and sustained human presence in space**
  - Initial Phase ISRU Capabilities:
    - Pilot regolith excavation and oxygen production, storage, & transfer capability sized to support refueling 2 ascent vehicles per year (~3500 kg/vehicle) and habitat & EVA life support needs for 4 crew per year (1500 to 3000 kg)
    - Hydrogen production as fuel dependent on results of LPRP and Sortie missions to lunar poles
    - ISRU produced oxygen ready for 2nd Outpost crew return vehicle
  - Mid-Term ISRU Capabilities
    - *In-Situ* fabrication and repair
    - *In-Situ* power generation
    - Thermal energy storage & use
    - Increased oxygen/fuel production to enable completely reusable landers or surface hoppers
  - Long-Term Lunar Capabilities
    - *In-Situ* manufacturing of complex parts and equipment
    - Habitat and infrastructure construction (surface & subsurface)
    - *In-Situ* life support – bio support (soil, fertilizers, etc.)
    - Helium-3 isotope (^{3}He) mining
- Outcome of ISRU capability for Outpost
  - Enables cost effective lunar surface operations.
  - Enables surface hopping to other locations for short term science mission objectives
  - Will allow us to practice the concept of “living-off the land” and reduce resupply

Current ISRU Technology Development Activities

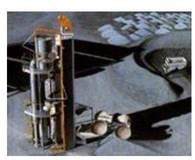
- **Lunar regolith excavation and handling**





- **Oxygen production from lunar regolith**

- **RESOLVE Project - Lunar volatile collection, extraction, and separation**

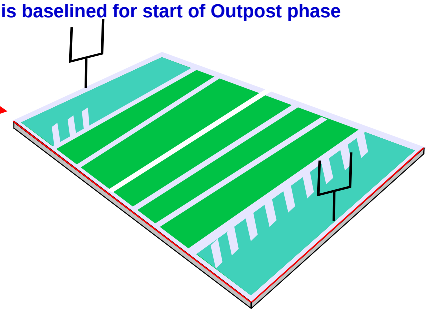


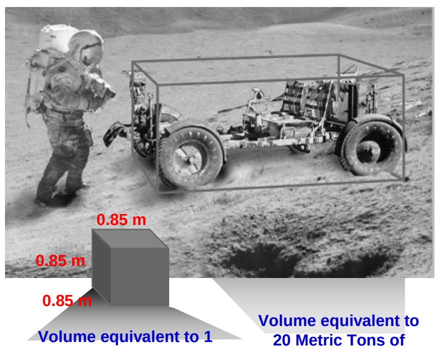
- ***In-Situ* propellant production**

Regolith Excavation Requirements

Oxygen production rate of 8 to 10 MT per year is baselined for start of Outpost phase

8 MT of oxygen per year requires excavation of a football field (with end zones) to a depth of 0.7 to 2 cm. (like cutting the grass)





Volume equivalent to 1 Metric Ton of lunar regolith

Volume equivalent to 20 Metric Tons of lunar regolith

8 MT of oxygen per year requires a regolith excavation rate of **~1 cup per minute.** (5% efficiency - 50% time-14 day lunar day/night)

ISRU Impact on Propulsion

Space Resource Utilization

Mass Reduction

- 3.5:1 to 5:1 mass savings leverage from Moon/Mars surface back to Low Earth Orbit
- Reduces Lunar mission launch mass by 27 to 88% depending on reusability and propellant depot options
- Reduces Earth to orbit mass by 20 to 45% for Mars missions

Cost Reduction

- Reduces number and size of Earth launch vehicles
- Allows reuse of transportation assets

Risk Reduction

- Provides 'safe haven' capabilities if cargo resupply is not possible
- Can reduce number of launches
- Can reduce number of mission operations (i.e. direct return vs rendezvous)
- Radiation and landing/ascent plume shielding

Expands Human Presence

- Increases surface mobility & extends missions
- Habitat & infrastructure construction
- Propellants, life support, power, etc.
- Substitutes propellant & consumable mass for new sustainable infrastructure cargo

Enables Space Commercialization

- Provides infrastructure and market to support space commercialization
- Propellant/consumable depots at Earth-Moon L1 & Surface for Human exploration & commercial activities (ex. LEO to GEO tugs)

Propellant Options from Moon/Mars Resources

- **Oxygen is the simplest oxidizer to produce on the Moon and Mars**
- Hydrogen and methane fuels are the simplest to produce if water (and carbon) is available
- Micro-channel Fischer-Tropsh reactors can produce ‘tailored’ hydrocarbon mixtures to meet desired propellant density, freezing point, and specific impulse
- Difficult or low performing fuels (metals, silane, & carbon monoxide) are possible but highly questionable compared to other options
- Production of nitrogen tetroxide and hydrazine on Mars is theoretically possible but not recommended due to high complexity, high power, toxicity, and processing hazards

Lunar Regolith Excavation Challenge

California Space Authority - $250K Purse in 2006

Summary

- Team that autonomously excavates and delivers the most lunar soil simulant to a collection point within 30 minutes wins
  - Excavated mass must exceed 100kg
- Teams provide excavation hardware
  - Mass limited to <25 kg
  - Power limited to <30 W DC
  - Approximately sized for robotic mission demonstration
- CSA/CSEWI provides
  - 4m x 4m x 50cm “sandbox”
  - 16 metric tons of compacted JSC-1a lunar simulant

Important Capabilities For

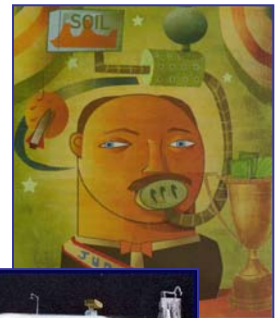
- Lunar *In-Situ* resource utilization
- Lunar radiation shielding
- Lunar site preparation

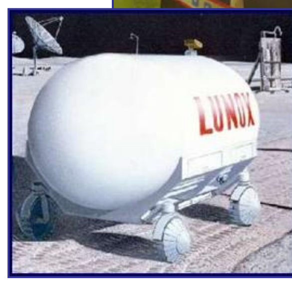
MoonROx Challenge

Florida Space Research Institute - $250K Purse by 2008

♦ Summary

- First team to demonstrate an autonomous system that extracts 5 kilograms of oxygen in under 8 hours from soil (regolith) simulant wins
- Exhaust gas must be < 1% H_2 and breathable
- Teams must deliver MoonROx Hardware
  - mass limited to 25 kg
  - power limited to 3kW and/or solar flux
  - penalties for consumables used in processes
- FSRI to provide
  - regolith simulant (JSC-1) for prize attempt
  - O_2 monitoring and storage equipment
  - $250,000 purse expires June 1, 2008





♦ Important Capabilities For

- *In-Situ* Resource Utilization
- Oxygen extraction from lunar regolith
- Vital technology for long-duration, human exploration

"We leave as we came, and God willing, as we shall return, with peace and hope for all mankind."

— Eugene Cernan, Commander of the last Apollo mission

Acronym List

- CEV: Crew Exploration Vehicle
- LSAM: Lunar surface Access Module
- LOI: Lunar Orbit Insertion
- EDS: Earth Departure Stage
- TPS: Thermal Protection System
- SSMEs: Space Shuttle Main Engines
- CLV: Crew Launch Vehicle
- EVA: Extra Vehicular Activity
- ISRU: *In-Situ* Resource Utilization
- RESOLVE: Regolith & Environment Science and Oxygen & Lunar Volatile Extraction
- CSA/CSEWI: California Space Authority/ California Space Education and Workforce Institute

"Present State of Lunar Exploration & Lunar ISRU Research in Japan"
by Kai Matsui (JAXA Lunar Exploration Technology Office)
-
power point presentation

Present state of Lunar Exploration
&
Lunar ISRU research in Japan

JAXA
Lunar Exploration Technology office

Kai Matsui

Table of contents

1. Present state of Lunar Exploration

JAXA Vision ~2025~

(1) Contribute to building a secure and prosperous society through the utilization of aerospace technologies.

(2) Contribute to the advancement of knowledge and expansion of human frontier by exploring the mysteries and possibilities of the universe.

(3) Establish the capability to independently carry out space activities through the highest-level technologies in the world.

(4) Contribute to the growth of self-sustainable space industry with world-class technological capability.

(5) Contribute to the growth of aviation industry and breakthrough for future air transportation.

http://www.jaxa.jp/2005/index_e.html

1. Present state of Lunar Exploration

JAXA Vision (2) include

"**Moon exploration and possible utilization**"

- Promote studies of the moon and possible utilizations of the moon
- Expand scopes of activities of Japan
- Challenge to develop cutting-edge technologies such as robotics technologies, nanotechnologies and micro machines, power-providing technologies using solar power.
- Prepare for the establishment of a human lunar base
- Develop complementary relationships with other nations for effective explorations

1. Present state of Lunar Exploration

(Within about 10 years）：

Further moon exploration with moon-orbiting satellites (SELENE, etc.)

Studies of possible utilization of the moon and development of innovative future technologies

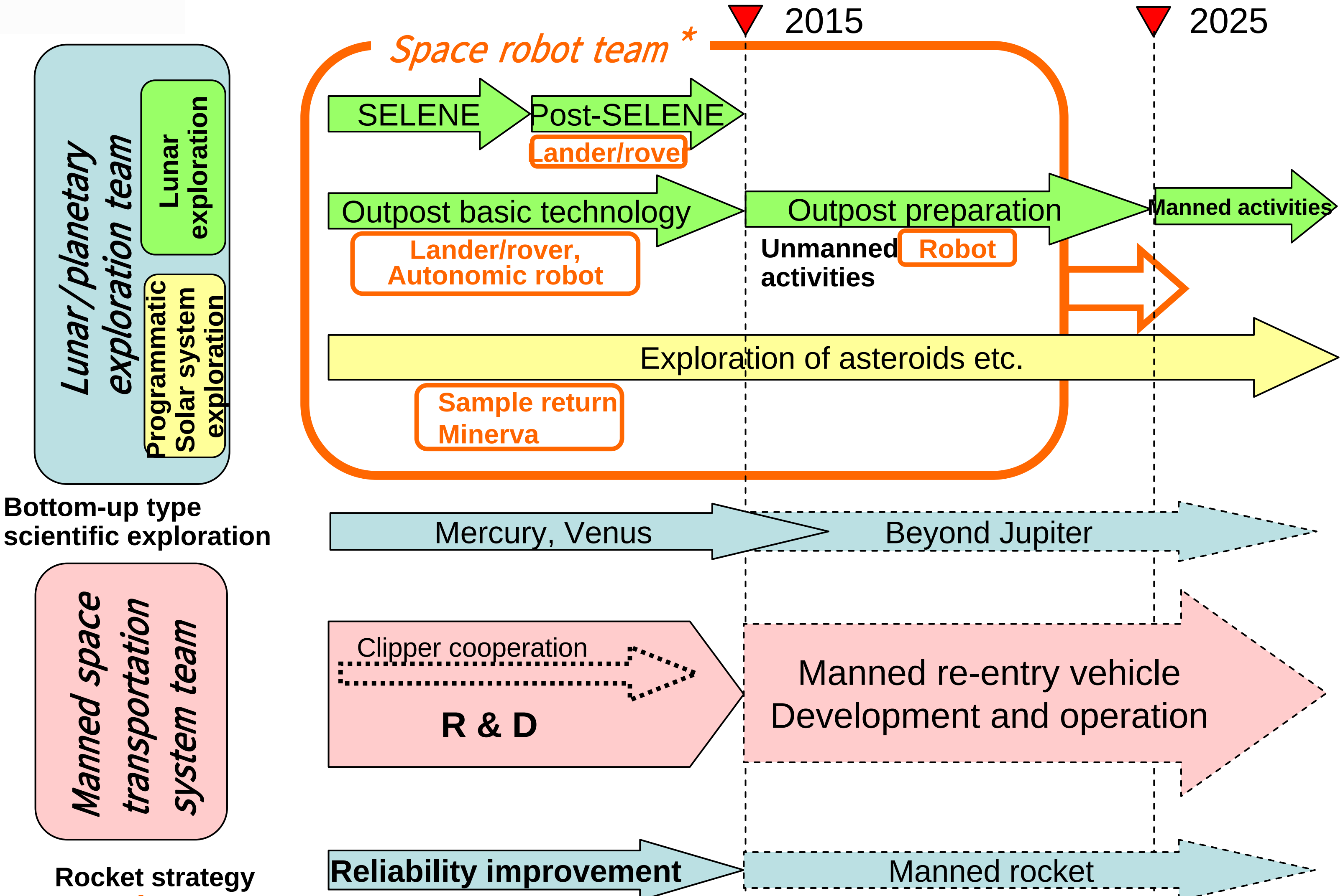
※Within about 10 years, seek for a decision by the government on whether to take significant steps toward the utilization of the Moon.

(Within about 20 years）：

Contributions to the international community by taking roles in the implementation of international lunar initiatives

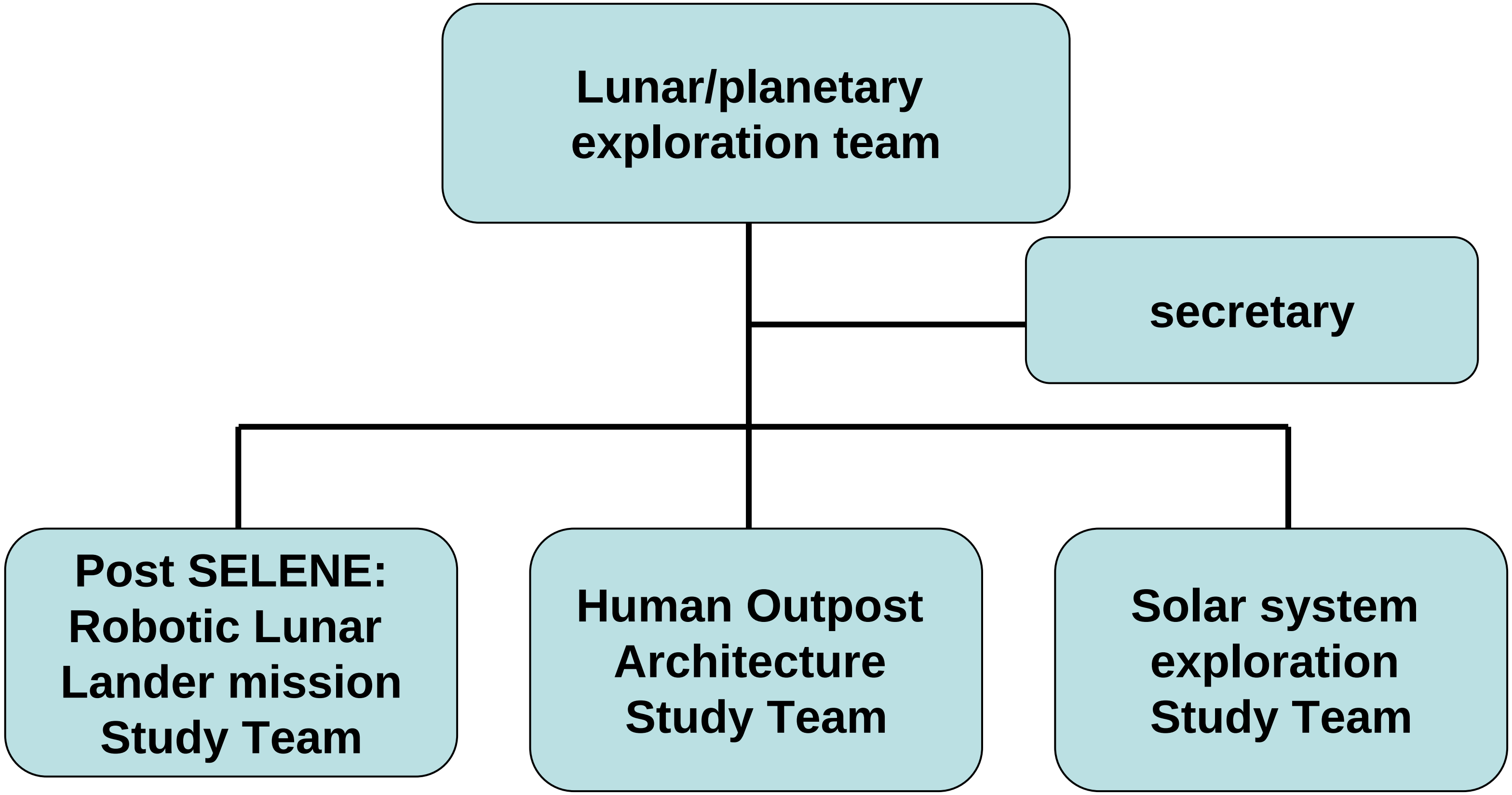
Development of enabling technologies for long-term stay on the Moon

1. Present state of Lunar Exploration



* Space robot team deals with all the robot activities including on-orbit service.

Lunar/planetary exploration team



International corporation policy stance

- **On going planning works to make realize JAXA Vision**
- **International corporation policy to be examined**

Baseline is the follows:

"JAXA shares the spirit and principle of human space exploration pursued by Europe and the United States that "the ultimate goal of our space activities should be to take the human beings on a continuous journey into the cosmos."

(excerpt from JAXA Vision summary)

Lunar Resources Utilization Study Group Objectives:

1. Exchange opinions and information among experts in various ISRU related fields.

2. Identify technologies necessary for ISRU, and evaluate the technological readiness.

3. Schedule research and development for each of identified technological issues and prepare a technology development roadmap for future ISRU missions.

4. Confirm the consistence between the technology development roadmap and JAXA's mid-/long-term vision.

2. ISRU research

Lunar Resources Utilization Workshop

Lunar Resources Utilization Workshop was held on July 2005.

More than 60 experts gathered from academia, commercial and JAXA.

Following topics were discussed.

- Remote and *In-situ* sensing
- Geotechnical measurements and regolith handling
- Resource Processing

Workshop report has been completed as "Lunar Resources Utilization Workshop - Technological Feasibility and Maturity- (March 2006)".

Lunar Resource Utilization Study Group Leading Members (May 2005)

Agenda	Leader Name	Member		JAXA Secretariat
Sensing (remote)	Takeda (Chiba Institute of Technology)	Nakamura (AIST) Kobayashi (JAXA)	[Kobayashi (Kyushu Univ.)] Okada (JAXA)	Matsui Otake
Sensing (in-situ)		Hasebe (Waseda Univ.)	Haruyama (JAXA)	
Robotics	Ueno (JAXA)	Hokamoto (Kyushu Univ.)	Endo (JAXA)	
Resources sampling	Takahashi (Tohoku Univ.)	Kobayashi (Kyushu Univ.) Nakashima (Kyoto Univ.) [Hokamoto (Kyushu Univ.)]	Fukagawa (Ritsumeikan Univ.) Tateyama (Ritsumeikan Univ.)	Aoki
Processing	Watanabe (Tokyo Institute of Technology)	Susa (Tokyo Institute of Technology) Kanamori (Shimizu Co) Yamada(JAXA)	[Takeda (Chiba Institute of Technology)] Saeki (Osaka Univ.) Komatsuzaki (Tokyo Institute of Technology)	
Energy supply	Naito (JAXA)	[Yamada(JAXA)]		Miyahara
Logistics				
Economical potential				
Space law				

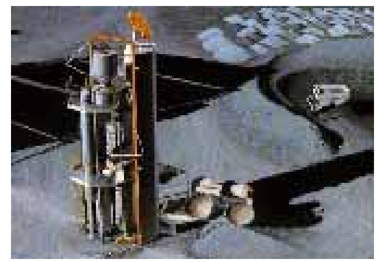
Proposed Lunar ISRU Roadmap

Remote Sensing → In-situ Sensing → ISRU Demonstration → System Integration → Lunar Outpost

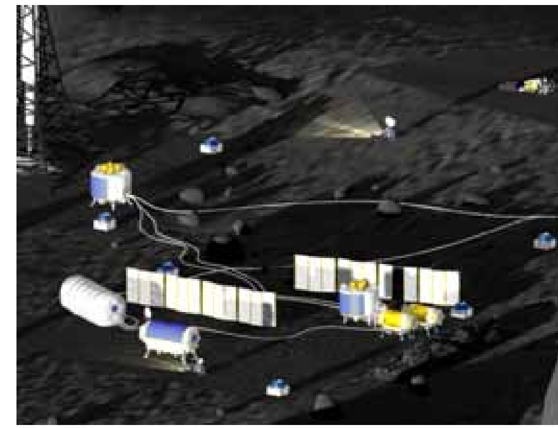
Global mapping
&
Local mapping

- Mineralogy
- Geography
- Topography
- Environment
- Insolation

- Ground truth
- Geotechnical properties
- Volatiles
- Local Topography
- Earth visibility



- ISRU Technology Demonstration



- Outpost infrastructure

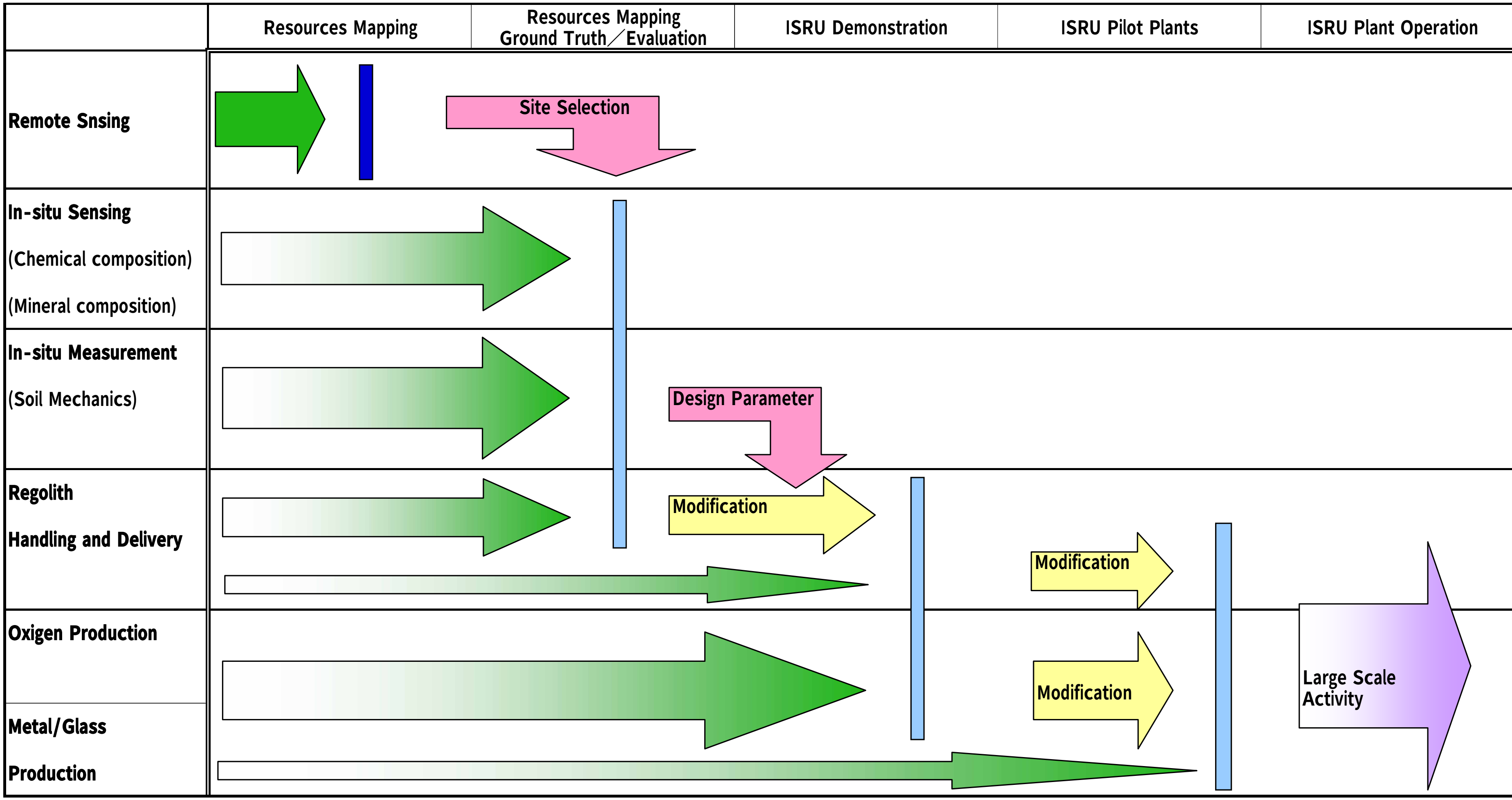
- System Integration

Site selection

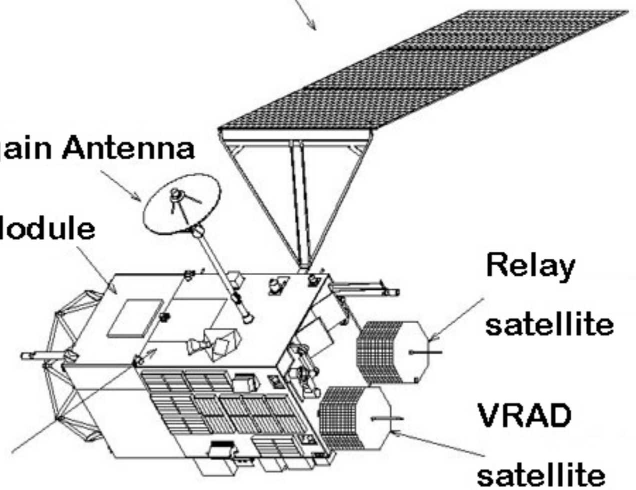
System parameter

2. ISRU research

Proposed Lunar ISRU Technology Roadmap



SELENE mission outline



Launch Vehicle : H-IIA 2022
Launch Year : 2007 summer

SELENE specification :

Orbit	inclination 90 [deg],100 x 100 [km]
Mass	2885[kg] (at launch) (mission payload : ~300kg)
Size	2.1 x 2.1 x 4.8 [m]
Attitude Control	3 axis controlled
Power	3.5kW [Max]
Mission Period	1 year (nominal)

3. Recent project

SELENE mission outline

	Observation	Instrument
Main Orbiter	**Chemical elements distribution**	**X-Ray Spectrometer (XRS)**
		Gamma-Ray Spectrometer (GRS)
	Mineralogical distribution	**Spectral Profiler (SP) / LISM (Lunar Imager / SpectroMeter)**
		Multi-band Imager (MI) / LISM
	Surface structure	**Terrain Camera (TC) / LISM**
		Lunar Radar Sounder (LRS)
		Laser Altimeter (LALT)
	Surface & Space environment	**Lunar Magnetometer (LMAG)**
		Plasma Imager (UPI)
		Charged Particle Spectrometer (CPS)
		Plasma Analyzer (PACE)
	Imaging	**High Definition Television camera (HDTV)**

	Observation	Instrument
Rstar	Gravitational field distribution	**Relay Satellite transponder (RSAT)**
		VLBI Radio-source (VRAD) on Rstar
Vstar	Gravitational field distribution	**VLBI Radio-source (VRAD) on Vstar**
	Environment	**Radio Science (RS)**

3. Recent project

SELENE mission outline

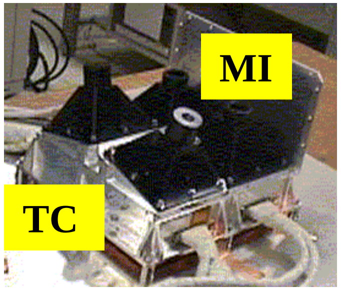
•SELENE data are used for studying the lunar origin and evolution, and future utilization of the Moon.

•The following maps which may be used for especially future lunar In-situ Resource Utilization (ISRU) can be produced from SELENE Data Products.

(1) **Maps of water ice** 【GRS、SP】

(2) **Maps of permanent polar shadow/sunshine areas, polar DEM** 【SP、LALT】

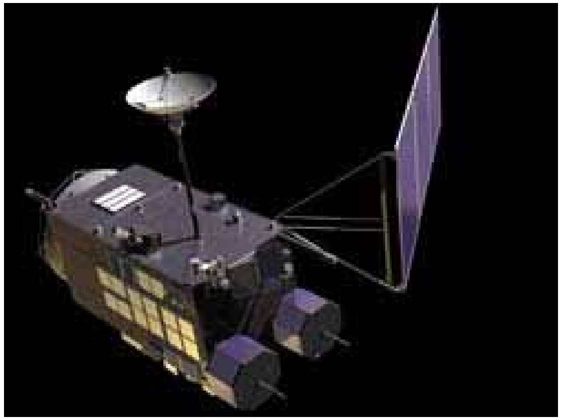
(3) **Maps of surface composition** (ex. ilmenite-rich region) 【MI,SP,XRS,GRS】



3. Recent project

Robotic Lunar exploration plan

Remote sensing	Landing mission	Mission on the Moon
SELENE(2007)	SELENE-2(2012)	SELENE-3(2015)



Under consideration

Remote sensing
- Chemical distribution
- Mineralogical distribution
- Surface Structure
- Gravitational field distribution

In-situ sensing
- Validation data
- Resource

Technology demo
- Power subsystem for long-term stay demo
- Survival technology during the moon night demo

To be prioritized

- Lunar resource extraction demo

or

- Sample return

Chandrayaan-1 and Future Planetary Exploration Missions of India: Contributions to International Cooperation

By

K.R. Sridhara Murthi•

Although Indian Space Programme is essentially applications driven, it placed emphasis on space science as an integral component for reasons of strong heritage in science and instrumentation, primarily in the related areas of cosmic rays, astronomy and atmospheric sciences. Since the early 1960's, several groups in India have been carrying out research in planetary sciences using telescopes and laboratory simulations. Study of cosmic ray effects on meteorites was pioneered by scientists at Physical Research Laboratory at Ahmedabad. With the arrival of lunar samples from Apollo and LUNA missions, the early investigations at the Tata Institute of Fundamental Research (TIFR) in Mumbai were extended to the rocks and dust from the Moon during 1972-81. With the backdrop of this heritage, a detailed process of analysis and consultations with scientists, academics and other stake holders has led to embarking on two major space missions in astronomy and planetary exploration by the Indian Space Research Organisation, namely Astrosat and Chandrayaan-1 space missions. In 2004, Indian Academy of Sciences brought out a well analyzed and researched publication, "Astronomy and Astrophysics – A Decadal Vision Document".[1] The Advisory Committee for Space Science (ADCOS), which is national level apex body for Space Sciences under the chairmanship of Prof U.R.Rao, has recently reviewed and recommended India's future program directions for planetary exploration over next five years. The present paper high lights these trends, bringing elements of international cooperation associated with India's planetary exploration efforts.

1. ASTROSAT MISSION

ASTROSAT is an Indian multiwavelength Astronomy Satellite, which has been conceived to meet the long felt need for a mission, which will greatly facilitate understanding of the energetic processes and the mechanism of the radiation in different bands enabled by simultaneous observations of various types of sources. Unlike any other previous astronomy mission, the uniqueness of ASTROSAT lies

---

• Executive Director, Antrix Corporation Limited and Director (Technology Transfer & Industry Cooperation), ISRO Headquarters, Bangalore. The views expressed in this article are of the author and not attributable to the organisation with which he is affiliated.

[1] Published by Indian Academy of Sciences, C.V. Raman Avenue, Sadashivnagar Post, Bangalore 560 080, 2004.

in its wide spectral coverage extending over visible, ultraviolet, soft x-ray and hard x-ray regions. It will provide an opportunity for the Indian astronomers to carry out cutting edge research in the frontier areas of X-ray astronomy and ultraviolet astronomy and allow them to address some of the outstanding problems in the high-energy astrophysics.

The principal scientific objectives of ASTROSAT are the following:

1. Understand the production processes that lead to the broadband x-ray emission spectrum in cosmic sources.

2. Study correlated intensity variations over time in the visible, UV, soft and hard X-ray bands to address the origin of radiation in the different wave bands

3. Search for black hole sources by limited surveys in the galactic plane.]

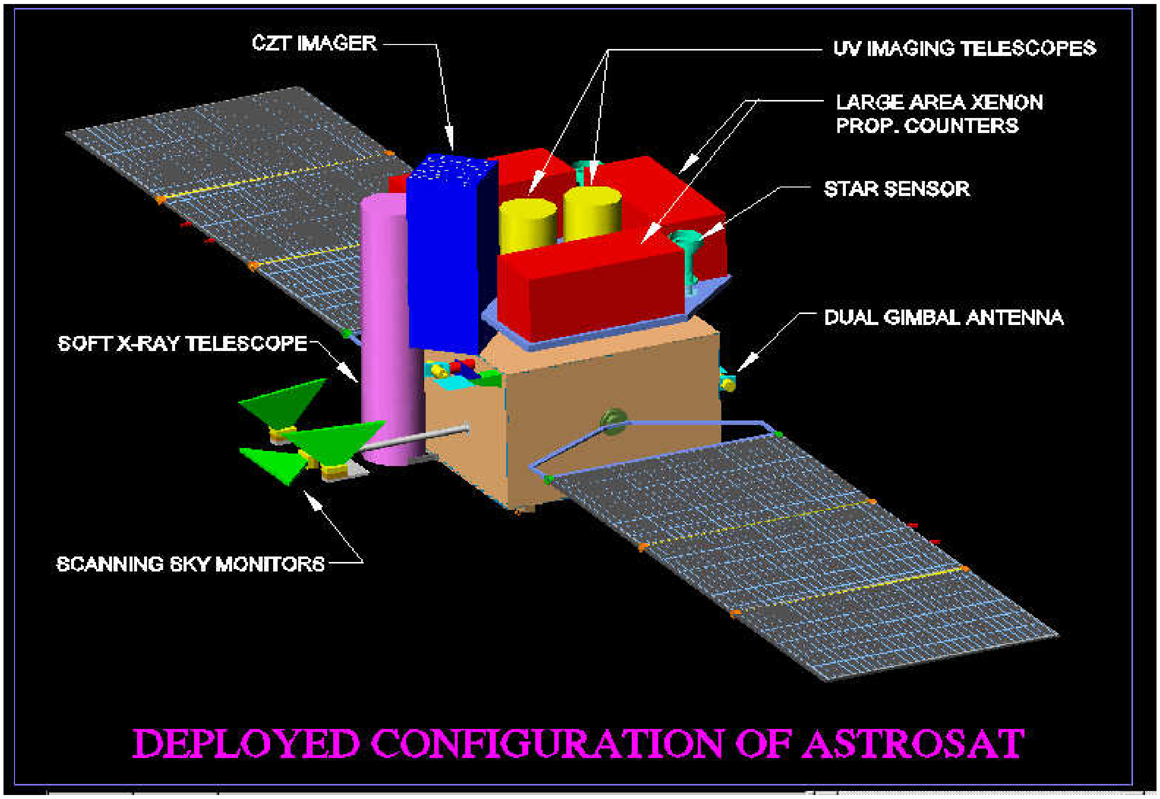
4. Measure magnetic fields of neutron stars by detection and studies of cyclotron lines in the X-ray spectra of X-ray pulsars.

5. Detect and locate new transient X-ray sources.

6. Multi-band survey covering Ultra-violet band from 130-300 nm and X-ray band from 0.3 - 100 keV.

7. Deep surveys of selected regions of the sky to detect faint quasars to study their clustering and large-scale structures, and obtain UV fluxes from very distant galaxies.

Based on these scientific objectives, instrument configuration will include four types of X-ray detectors, an ultraviolet telescope and an optical telescope (Vide following illustration).



ASTROSAT mission has been funded by the Government of India, and the various instruments are being developed at several collaborating institutions in India. It is noteworthy that the photon counting detectors for the Ultraviolet Telescope are being developed by the Canadian Space Agency, in collaboration with Canadian astronomers.

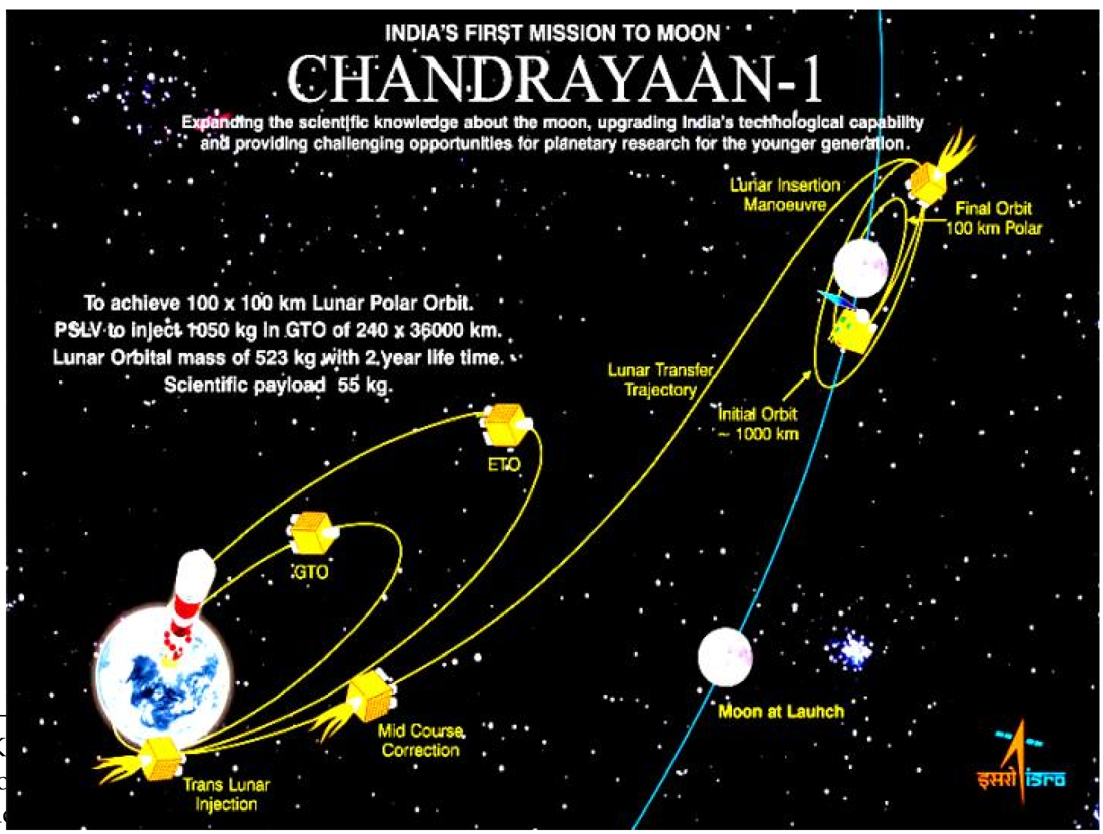
Chandrayaan-1 (First Indian Mission to Moon)

Chandrayaan in the ancient Indian language Sanskrit means journey to the Moon. There are several basic considerations that influenced the decision for a Mission to Moon by India**:**

> First and foremost, there is a great deal of interest in understanding the origin and the evolution of the Moon. Many aspects of associated events and processes remain unclear. For example, the size and composition of the lunar core and the bulk and internal composition of the Moon are not accurately known. Even in the most widely accepted "Giant Impact theory" of Moon's origin, some isotopic data are not consistent with the values

expected in high temperature fractionation expected due to the giant impact. The depth to which Moon melted during magma ocean formation, the rates of cooling and the mechanism of Late Heavy Bombardment (LHB) are open questions. Existence of ice in the permanently shadowed lunar Polar Regions is another subject of intense interest. It is in this context that there is renewed interest in the astronomical, physical, chemical, isotopic, geological and geochronological aspects of lunar exploration. **CHANDRAYAAN-1** will address some of these questions. Secondly, a small nucleus of active scientists currently engaged in planetary research would receive a new impetus with a committed long term program. Of equal significance is the fact that the mission is expected to provide unique opportunities to upgrade several areas of technology. Examples include dealing with a challenging mission scenario, higher levels of refinement in the trajectory computation and orbital maneuvers, newer strategies for guidance and navigation, and deep space communications. Another important consideration is India's objective to participate in international planetary missions in the future. The creation of a cadre of young scientists, and demonstration of the various relevant technologies and techniques, are critical to achieve this goal.[2]

Description of the Mission
How do we reach there?



[2] Dr.K
Memo
Relati

The choice of the trajectory to achieve the desired lunar orbit optimally is an important aspect of mission planning. India's Polar Satellite Launch Vehicle has been chosen to place spacecraft initially elliptic parking orbit as illustrated in the figure. *The Spacecraft could have a mass of 523 kg in lunar orbit*. The actual mission sequence is envisaged as follows:

- After separation from the launch vehicle, the spacecraft in the Geo Transfer Orbit (GTO) is injected into Lunar Transfer Trajectory (LTT) and will coast for about 5 days.
- A lunar capture maneuver will place the spacecraft in a 1000km lunar polar orbit. After "health checks" the solar panel will be deployed.
- Then, the altitude will be lowered to a 200km near circular orbit.
- After studying the orbit perturbations for a week or two, the target altitude of 100 km circular polar orbit will be achieved.

The Instruments on board

Once in the 100 km x 100 km lunar polar orbit, the complement of payloads will enable simultaneous photo geological, mineralogical and chemical mapping of the lunar surface. The table summarizes the scientific instruments that will be on **CHANDRAYAAN-1** and their characteristics.

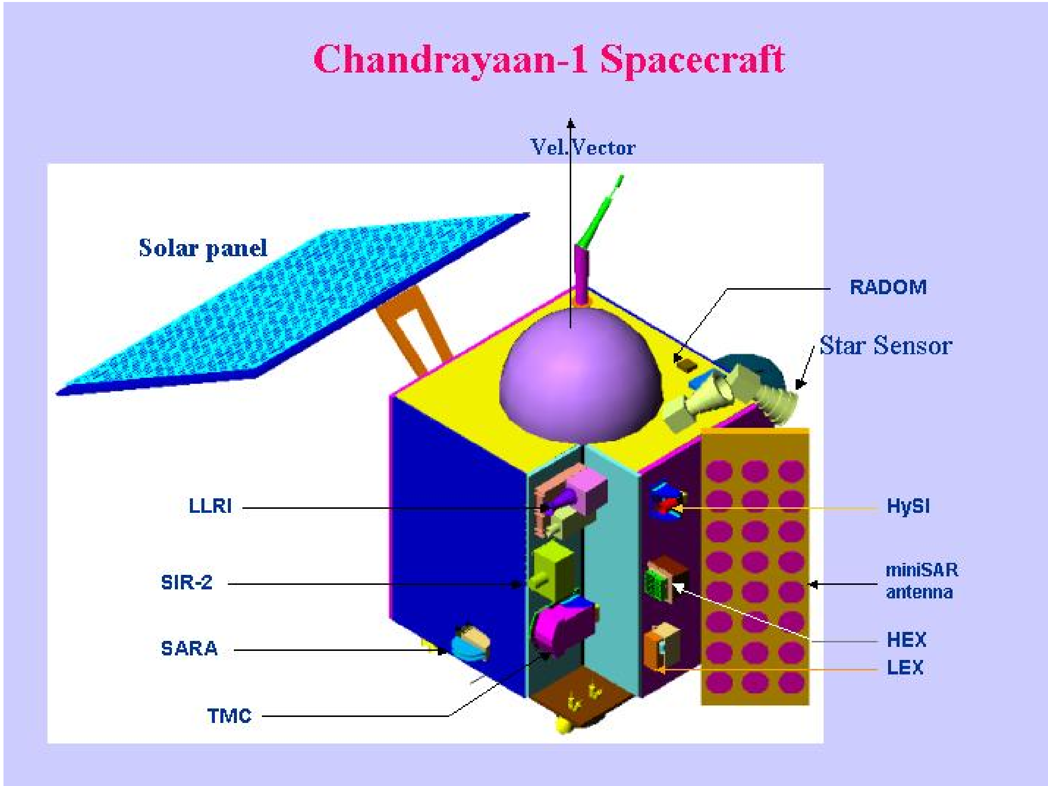
Payload	Function	Spectral band	Capabilities	Country
Terrain Mapping Camera (TMC)	High-resolution imaging	optical	5m resolution; 40 km swath; Active Pixel Sensor	India
Hyper spectral Imager (HySI)	Imaging spectrometer	0.4 – 0.9 microns (32 channels)	15 nm spectral resolution; 80 m spatial resolution; 40 km swath	India
Lunar Laser Ranging Instrument (LLRI)	Topography mapping	1064 nm laser-based altimetry	10 m vertical height resolution; 1 Hz repetition rate; Nd-YAG laser	India
Low-energy X-ray Spectrometer (CIXS)	moderate resolution spectrometer	Soft x-rays (0.5 – 10 keV)	Energy resolution = 3% @ 6 keV ; 20 km swath (FOV); swept-charge detector	UK (ESA)
High-energy X-ray Spectrometer (HEX)	moderate resolution spectrometer	Hard x-rays (20 – 250 keV)	Energy Resolution = 7% @ 60 keV ; 40 km swath (FOV)	India

MiniSAR	Detection of water-ice at poles	2.5 GHz radar	Can detect water-ice to a depth of a few meters using ratio of right to left circular polarisation in the reflected signal.	USA
Radiation Environment Monitoring (RADOM)	Spectrometer - dosimeter	20 keV – 20 MeV	Measures particle flux, spectrum and dose; silicon detector	Bulgaria
Sub-keV Atom Reflecting Analyser (SARA)	Electrostatic charged particle deflector	10 eV to 2 keV	Images surface magnetic anomalies; spatial resolution = 50 km	Sweden (ESA)
IR Spectrometer (SIR-2)	Grating IR spectrometer	0.93 – 2.4 micrometer	Spectral resolution = 6 nm; FOV = few mrad	Germany (ESA)
Moon Mineralogy Mapper	Push broom Imaging Spectrometer	0.7-3 micrometer	FOV=30 Km, 10nm. sampling at 70m pixel	USA
Solar X-ray Monitor	Monitors SolarX-ray activities		Uses Si-PIN-diode	India
Collimated Low Energy X-ray Spectrometer	measuring fluorescence X-ray from lunar surface	1-10keV	Users CCDs and the footprint of about 20 km.	India

As regards scientific objectives, **CHANDRAYAAN-1 (Figure-2)** will provide new information about several processes on the Moon like the ***impact rate of meteoroids, chemical evolution of the lunar surface, mineral composition, and transport of volatiles***. These would provide improved inputs to modeling the formation and early evolution of the Moon, as well as processes operating on the lunar surface. Another aspect to which we attach considerable significance is ***the search for water frozen on the permanently shadowed polar regions of the Moon***.

The Indian Moon Mission is designed to have an operational life of two years in a 100 km circular polar orbit (i=90 deg).

.



2. POSSIBLE FUTURE MISSIONS IN PLANETARY EXPLORATION

The Advisory Committee on Space Sciences in India has set up mechanisms to define the future programs for space sciences. As a result of their recent review, the following programmes in planetary exploration are proposed for further approvals and funding decisions.

Following the launch of Chandrayaan-1, the planetary exploration group has proposed Chandrayaan-2 and a special mission to Mars. The expertise developed for Chandrayaan-1, should come in very handy for developing advanced instruments for both the above missions.

A. Chandrayaan-2 (Exploration of the Moon as a Follow-up of Chandrayaan-1, during 2009-2011):

Chandrayaan-2 will carry out further studies of lunar origin and evolution with improved version of Chandrayaan-1 instruments for imaging, mineralogy and chemistry, using alpha and neutron spectrometers. Studies of lunar radiation environment including solar wind-magneto tail interactions are also envisaged. With the addition of lander, robotics and rover, it may be possible to carry out in-situ analysis of lunar samples through alpha/neutron/x-ray florescence spectroscopy and also study lunar regolith. In order to achieve these objectives, it is necessary to develop x-ray, gamma-ray, alpha, and neutron spectrometers and special detectors to measure radiation, magnetic field and energetic particles in addition to mass spectrometers.

B. Mars Orbiter (2010-2012):

The main aim of this mission would be, understanding Martian atmospheric processes; day and night time Martian ionosphere, effect of solar wind, local magnetic fields and dust storms, remote sensing of Martian surface for investigating its mineralogy, chemistry, water and other resources. This would require:

(i) Placing of the spacecraft in low altitude orbit around Mars.
(ii) Development of command, communication, navigation and control.
(iii) Development of state-of-the-art instruments to monitor radiation, electric and magnetic fields (tens of nanotesla) and energetic particles in Martian space.

C. Asteroid Orbiter & Comet Flyby: (2010-2015):

On a slightly larger time scale, the planetary group proposes the launch of Asteroid orbiter and Comet Flyby (AOCF) to study early evolution of planetesimals, meteorite-asteroid connection, physical and chemical composition and evaluation of asteroids and comets. The remote sensing instruments for imaging, mineralogy and chemistry of surface as well as sub-surface developed for earlier missions need to be suitably modified in addition to inclusion of sensors for the measurement of energetic particles, radiation and fields in interplanetary space. Technology challenges involved in this mission are:

(i) Orbiting around small (low gravity) objects.
(ii) Achieving high impulse (>5km/s) needed for reaching main belt asteroid.
(iii) Command, communication, navigation and control.

3. INTERNATIONAL COOPERATION

International co-operation has always been an integral part of Indian space programme. Over the years, as ISRO has matured in experience and 'technological capabilities, international co-operation has also grown. The international cooperation strategy aims at achieving synergy of efforts through bilateral and multilateral tie ups in a mutually beneficial manner, working with international bodies to bring space benefits for welfare of all and working with international community for developing legal measures and guide lines in the best interest of all nations and sharing Indian expertise and experience in applications.

In the field of exploration and peaceful uses of outer space, India has bilateral cooperative arrangements with Australia, Brazil, Brunei Darussalam, Canada, China, France, Germany, Hungary, Indonesia, Israel, Italy, Japan, Mauritius, Mongolia, the Netherlands, Norway, Peru, Russia, Sweden, Taiwan, UK, Ukraine, USA and Venezuela. Such agreements are also in place with multilateral agencies such as the European Space Agency (ESA) and Eumetsat. Cooperation pursued by Indian Space Research Organisation currently is multidimensional and include conduct of joint missions such as Megha tropics, which is an Indo-French joint satellite mission to study climate and water cycle in tropical regions, or offering opportunity for flight of instruments such as MEOSS (Germany), ROSA (Italy), and Altica (France) on Indian satellites and exchange of meteorological data between Indian and US Satellites. Perhaps more significant step is sharing of experience in space with other developing countries under SHARES program initiated in early 1980's. ISRO extended fellowships for scientists from other developing countries to get training in its laboratories on various aspects of space science and applications. A decade ago, a Center for Space Science Technology and Education for Asia and Pacific, affiliated to the UN was established in India with the support of Government of India. The Center has been extending excellent educational programs at postgraduate level in the fields of satellite meteorology, remote sensing and geographic information systems, satellite communications and space sciences with emphasis on practical training. Indian scientists have been actively supporting efforts of multilateral fora such as the Committee on Earth Observation Satellite (CEOS), the Inter Agency Debris Coordination Committee (IADC) and so on. As a party to the international charter of space and major disasters, ISRO provides services of its space assets for meeting the needs of emergency assistance. On space science endeavors too, cooperation is extended to agencies in other countries to fly their instruments on Indian spacecraft, for example, an ultraviolet telescope called TAUVEX from Israel will be flown on ISRO's Geostationary satellite GEOSAT-4 and mention is already made on the six scientific instruments from the USA and Europe to be flown on board the first Indian lunar mission, Chandrayaan-1.

3.1 International Cooperation Promoted by Chandrayaan:

Chandrayaan-1 will be a forerunner for forging a strong international cooperation in the planetary exploration missions participated by India. Two of the above payloads will be provided by Institutions in the USA namely Mini Synthetic Aperture Radar from Applied Physics Laboratory and the Moon Mineralogy Mapper from JPL, NASA. The Low energy X-ray Spectrometer (CIXS) will be provided by Rutherford Appleton Laboratory, UK, the Near Infrared Spectrometer by Max Planck Institute of Aeronomie, Germany and Sub keV Atom Reflecting Analyser by Swedish Institute of Space Physics. The last three payloads have been accommodated under the aegis of cooperative agreements with ESA. In addition to the above three, one more payload from Europe will fly on Chandrayaan namely Radiation Dose Monitor from the Bulgarian Space Laboratory.

The agreements for cooperation have been evolved by ISRO with NASA and ESA for the above. While the launch and flight opportunity is provided by ISRO on cooperative basis, the institutions associated with the guest instruments will have responsibilities for delivering the instruments in time for the flight and provide necessary support for effective interfacing with the spacecraft and its mission. The principle investigators from all the participating institutions will have immediate access free of charge to scientific data obtained by their respective instruments. Also, scientific data obtained by Chandrayaan mission will be released to the international scientific community after a period that shall not exceed one year. The ISRO and other participating agencies and their principle investigators could also freely exchange data for collaborative studies. The agreement also crafted necessary provisions for transfer of technical data and goods which are necessary to fulfill respective responsibilities of parties. In summary, the agreements reflect the spirit of international cooperation enshrined in the Space Treaties evolved by the UN and serve as a good model for future endeavours in this field.

4. COMMENTS AND CONCLUDING REMARKS

Planetary exploration and probing beyond solar system will be the next major endeavour of space by International community. These endeavours by different nations have several common objectives and goals indeed, to be pursued with a long-term perspective, having regard to the common destiny of human beings. Also, realizing these dreams require a large amount of resources, which are beyond the capacity of any single nation. Hence International cooperation is *sine qua non* for making reasonable pace of progress and also for ensuring broader ethics of sharing a common resource from Outer space in a sustainable way. Further, it has to be achieved at cost which is reasonable having regard to the priorities of human development on planet earth itself. An important aspect is also to involve all stakeholders, minimize risks and ensure orderly development of activities through further development of International Space Law. However, the progress of law making in this field is still fraught with many controversial positions. Therefore the first step for the international community is to recognise and agree on a common strategy for further development of international space law. In the near earth environment, a number of activities have been enabled and promoted notwithstanding the special status of space as provided by the international law, as the common territory for exploration and use and as a territory beyond national appropriation. Since a significant part of resources in the foreseeable future has to come from public investments particularly to develop our permanent activities on moon and for in-situ resources utilization, a clear cut legally unforceable role for private sector has to be considered, without changing the fundamental tenets of Outer Space Treaty. It is noteworthy that as of 1st January 2006, only 16 states have either signed and/or ratified the Moon Treaty, it is clear that the prohibition on national appropriation of Outerspace including Moon and other celestial bodies is probably seen as insurmountable deterrent for private sector initiatives. Further, the exploitation of resources which is provided in the Moon agreement is to be mandatorily carried out under the framework of an international regime. Since states will be responsible for activities in space of private entities under their jurisdiction, a broader consensus by the states on the rules for exploitation of resources is the need of the hour. The bid by private individuals to own or sell real estate on moon is obviously not in harmony with the existing international law and concerned states should act upon such initiatives, which may undermine the environment for further orderly development of international space law.

It is increasingly apparent that apart from the scientific interest, the moon and other celestial bodies will have economic contributions to mankind. The abundant resources of Oxygen, Hydrogen and other solar wind gasses trapped in its regolith could be exploited, subject to further developments in technology. There have also been assessments on the possibilities of the use of helium-3 embedded in the surface of the moon for energy generation. Perhaps the most significant step of humanity will be creation of human outpost on the Moon which can facilitate in-situ resources utilization and provide for an intermediate base for missions to other planets as well as earth bound missions, thus reducing costs and risks of space exploration. Viewing from these perspectives, the paper presented by Mr. Carl E. Watz on “Role of Moon in Reducing Technical and Programmatic Risks for Long-Duration Exploration Missions” is an excellent contribution, which can be basis for exploring and forging new cooperative relationships at international level.

“ISAS/JAXA’s Perspective on the Exploration and Utilization of the Moon” by Hitoshi Mizutani (Institute of Space and Astronautical Science, JAXA)

–

power point presentation

ISAS / JAXA's Perspective on the Exploration and Utilization of the Moon

Hitoshi Mizutani

Emeritus Professor

Institute of Space and Astronautical Science,
Japan Aerospace Exploration Agency

JAXA Activity of Lunar Exploration

Past

- 1990 /1/ 24 Launch (M3S-II Rocket)
- Orbit Maneuver by Lunar/Solar Gravity Assist Technology
- Technology of Orbit Determination
- 1993 /4/ 11 Impact on Lunar Surface

Current

Future

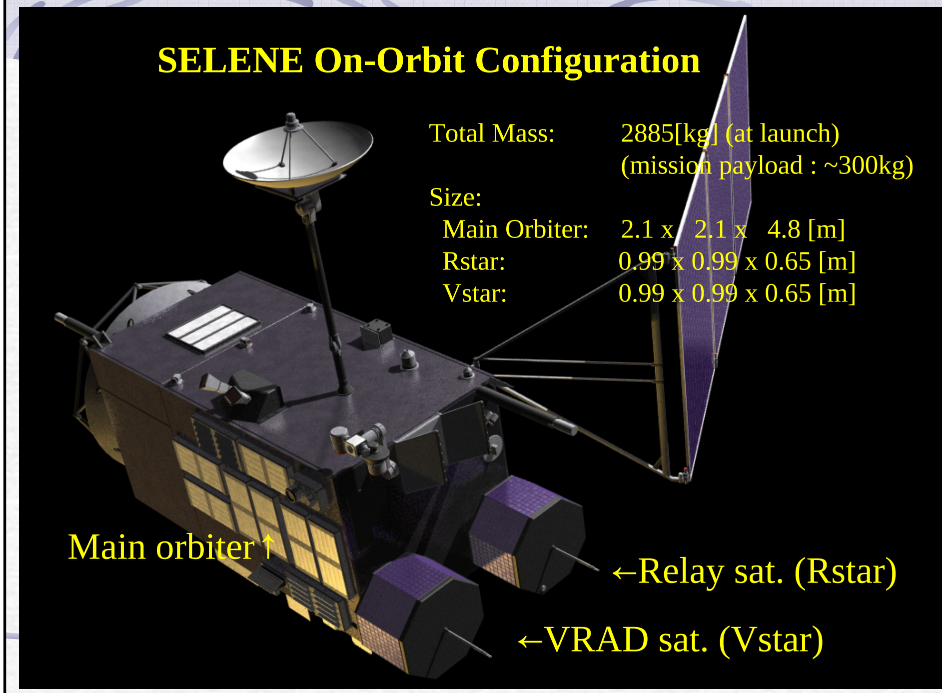
Soft Landing
for
in-situ
Observation

Outline of Selene Mission

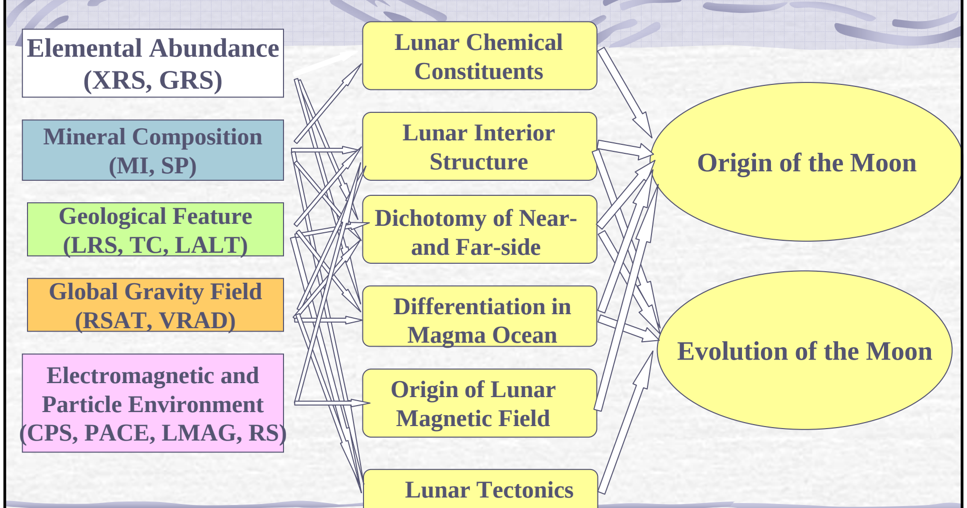
- Launch Date: 2007 summer by H-IIA rocket
- Spacecraft configuration:
  Main Orbiter, Relay, and VRAD Sub-satellites
- Mission period : 1 year nominal; possible extension
- Orbits : Polar Orbit i= 90 [deg]
  Main Orbiter : 100 km x 100 km
  Vstar : 100 km x 800 km
  Rstar : 100 km x 2400 km
- Mass: Total 2885 kg,
  Science Instruments: ca. 300 kg
- 12 Science Instruments on board

Instruments of Selene Mission

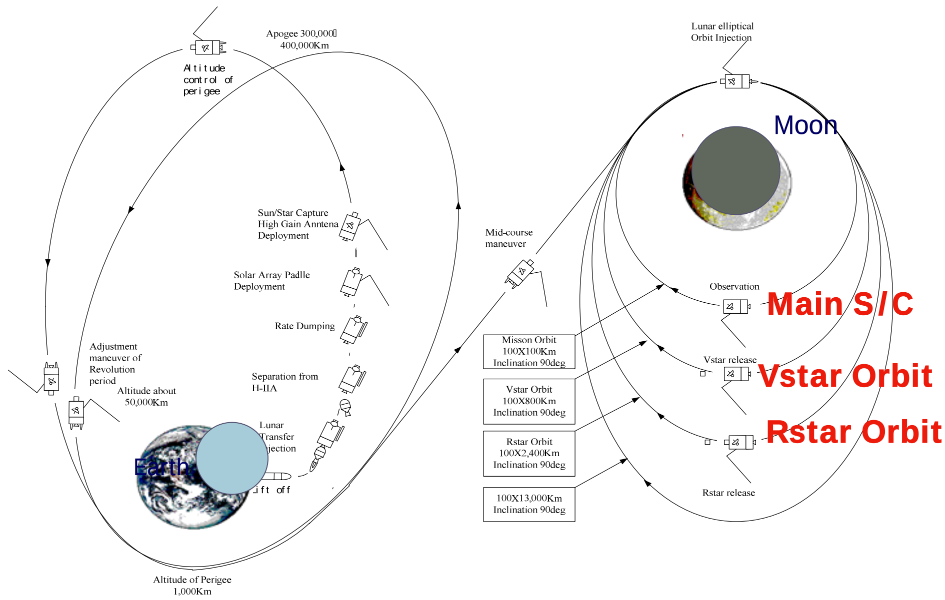
Subsystems	Abbreviation	Mass, kg
X-ray Spectrometer	XRS	21.87
Gamma-ray Spectrometer/ Charged Particle Spectrometer	GRS/CPS	52.48
Lunar Imager/ Spectrometer	LISM	54.00
Lunar Radar Sounder	LRS	22.80
Laser Altimeter	LALT	20.00
Magnetic Field and Plasma Measurements	MAP	38.34
Upper-atmosphere and Plasma Imager	UPI	42.00
Transponder Opposed to Rstar	RSAT-2	3.86
High Definition Television	HDTV	16.50
Relay-satellite Transponder	RSAT-1	12.84
Differential VLBI Radio Source	VRAD-1	2.20
Differential VLBI Radio Source	VRAD-2	10.21
Science Mission Total		297.07



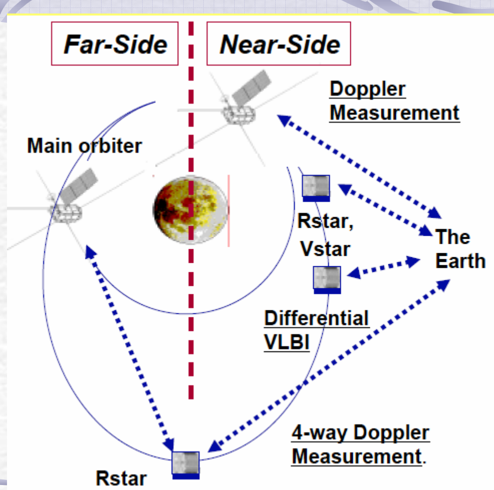
Science of Selene Mission



Orbits of Selene Spacecrafts



Precise Determination of Lunar Gravity Field



Far-side gravity field

4-way Doppler measurement between Main orbiter and UDSC station via Rstar.

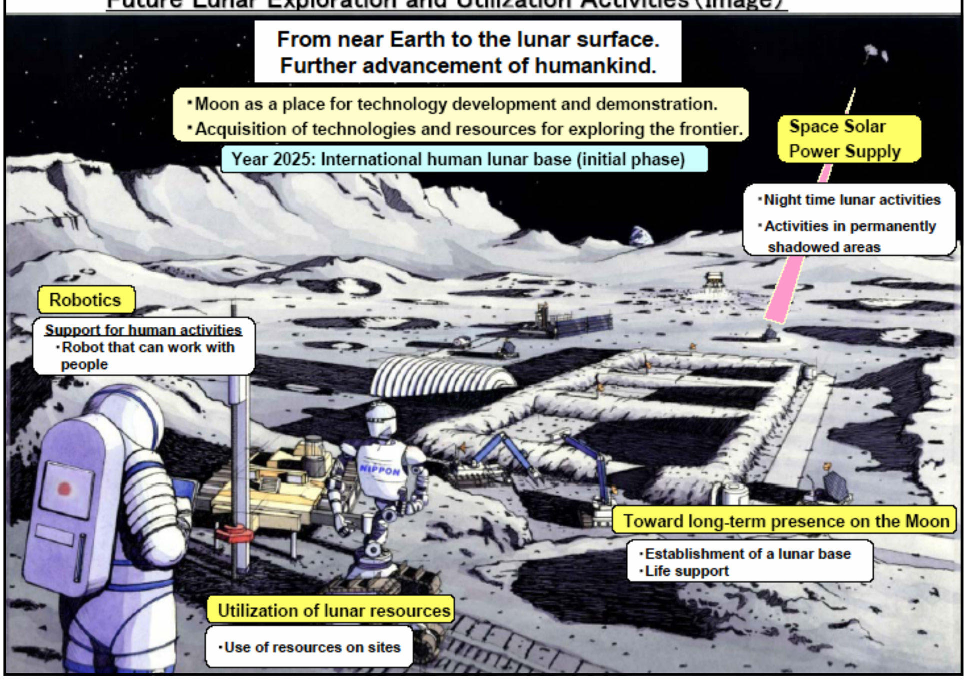
Current Status of Development

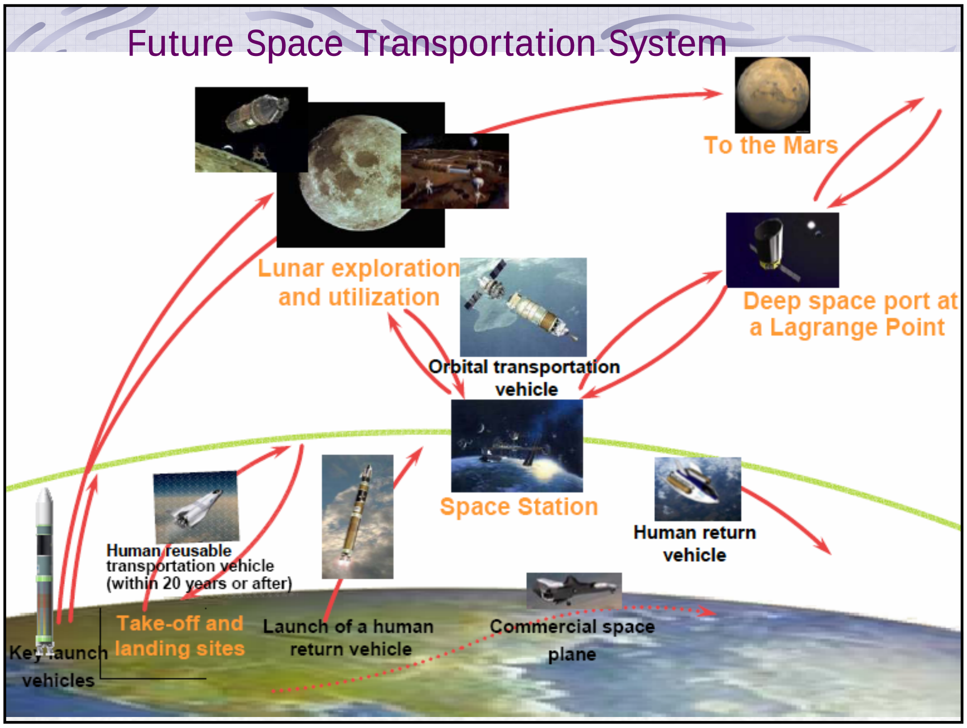
Tasks of this year

- PFM integration test
- SOAC data center
- Framework of international collaboration

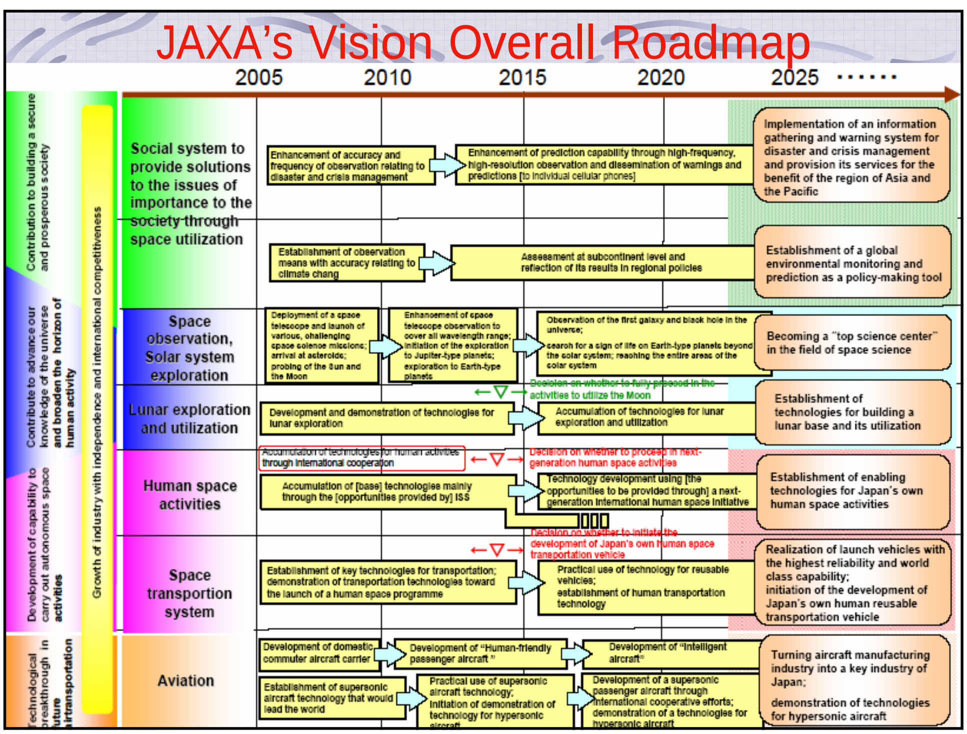
FM Interface Test, 2003 –2004

Future Lunar Exploration and Utilization Activities (Image)





Future Space Transportation System
To the Mars
Lunar exploration and utilization
Deep space port at a Lagrange Point
Orbital transportation vehicle
Space Station
Human return vehicle
Human reusable transportation vehicle (within 20 years or after)
Take-off and landing sites
Launch of a human return vehicle
Commercial space plane
Key launch vehicles



JAXA's Vision Overall Roadmap
2005
2010
2015
2020
2025 ……
Contribution to building a secure and prosperous society
Contribute to advance our knowledge of the universe and broaden the horizon of human activity
Development of capability to carry out autonomous space activities
Technological breakthrough in future airtransportation
Growth of industry with independence and international competitiveness
Social system to provide solutions to the issues of importance to the society through space utilization
Enhancement of accuracy and frequency of observation relating to disaster and crisis management
Enhancement of prediction capability through high-frequency, high-resolution observation and dissemination of warnings and predictions [to individual cellular phones]
Implementation of an information gathering and warning system for disaster and crisis management and provision its services for the benefit of the region of Asia and the Pacific
Establishment of observation means with accuracy relating to climate chang
Assessment at subcontinent level and reflection of its results in regional policies
Establishment of a global environmental monitoring and prediction as a policy-making tool
Space observation, Solar system exploration
Deployment of a space telescope and launch of various, challenging space science missions; arrival at asteroids; probing of the Sun and the Moon
Enhancement of space telescope observation to cover all wavelength range; initiation of the exploration to Jupiter-type planets; exploration to Earth-type planets
Observation of the first galaxy and black hole in the universe;
search for a sign of life on Earth-type planets beyond the solar system; reaching the entire areas of the solar system
Becoming a "top science center" in the field of space science
Decision on whether to fully proceed in the activities to utilize the Moon
Lunar exploration and utilization
Development and demonstration of technologies for lunar exploration
Accumulation of technologies for lunar exploration and utilization
Establishment of technologies for building a lunar base and its utilization
Accumulation of technologies for human activities through international cooperation
Decision on whether to proceed in next-generation human space activities
Human space activities
Accumulation of [base] technologies mainly through the [opportunities provided by] ISS
Technology development using [the opportunities to be provided through] a next-generation international human space initiative
Establishment of enabling technologies for Japan's own human space activities
Decision on whether to initiate the development of Japan's own human space transportation vehicle
Space transportion system
Establishment of key technologies for transportation; demonstration of transportation technologies toward the launch of a human space programme
Practical use of technology for reusable vehicles;
establishment of human transportation technology
Realization of launch vehicles with the highest reliability and world class capability;
initiation of the development of Japan's own human reusable transportation vehicle
Aviation
Development of domestic commuter aircraft carrier
Development of "Human-friendly passenger aircraft"
Development of "Intelligent aircraft"
Establishment of supersonic aircraft technology that would lead the world
Practical use of supersonic aircraft technology; Initiation of demonstration of technology for hypersonic aircraft
Development of a supersonic passenger aircraft through international cooperative efforts; demonstration of a technologies for hypersonic aircraft
Turning aircraft manufacturing industry into a key industry of Japan;
demonstration of technologies for hypersonic aircraft

Problems of Space Resource Exploitation in Japan

Premise

0. Human Being Needs Space Resources in Future

Problems

1. Extensive Technological Development Required
2. Program of Space Resource Exploitation should live together with Space Science Programs.
3. Can Japanese Government afford steady and secure funding for Space Resource Exploitation Program ?

Problems of Space Resource Exploitation in Japan (2)

Solution

- ✓ Exploitation and utilization of space resource must be undertaken with international collaboration.
- ✓ We need a new framework for the international collaboration on this enterprise.

“The U.S. Approach to International Participation in the Vision for Space Exploration”
by Jennifer L. Troxell (NASA, USA)
–
power point presentation

The U.S. Approach to International Participation in the Vision for Space Exploration

Jennifer L. Troxell
International Programs Specialist
NASA Headquarters, Washington, DC

The Goals of the Vision for Space Exploration

"We'll invite other nations to share the challenges and opportunities of this new era of discovery. The vision I outline today is a journey, not a race, and I call on other nations to join us on this journey, in a spirit of cooperation and friendship."

President George W. Bush
January 14, 2004

NASA's Architecture—the International Component

- **NASA Administrator Mike Griffin on November 1, 2005:**

"We intend to engage other nations on a bilateral and multilateral basis in more serious discussions as to how we can form productive partnerships to advance the objectives of the Vision. Exploratory discussions so far have been very promising…"

"We seek to collaborate, not to prescribe. In these ways we hope to promote common space exploration objectives and cooperative or complementary space exploration missions, along with the development of breakthrough technologies that will open up many opportunities for exploration and discovery."

How NASA Cooperates Internationally

- **Traditional NASA guidelines for international cooperation**
  - Mutually beneficial programmatic goals
  - "No exchange of funds" as a general, but not absolute, rule
  - Partners are generally government agencies
  - Consistent with export control laws, regulations, and foreign policy objectives of each partner
- **Other characteristics**
  - Avoid unique development costs, where technology and/or infrastructure already exist
  - Maximize advanced technology and development programs
  - Pool international technical capabilities for optimal innovation and science
  - Establish clearly defined interfaces

New International Opportunities

- **The initial focus of the U.S. Exploration Architecture is on U.S. transportation systems for crew and cargo**
- **There are a variety of opportunities to cooperate in areas other than core transportation, such as surface infrastructure:**
  - Habitats
  - Rovers
  - Power and logistics
  - Science and in-situ resource utilization equipment
  - Communications
- **Robust capabilities and redundant systems are key factors in a successful exploration program**

Commercial Opportunities

- **“**Pursue commercial opportunities for **providing transportation and other services supporting the international space station and** exploration missions beyond low earth orbit**.”**
  -The Vision for Space Exploration
- **Recommendation 5-2:**

  “The Commission recommends that Congress increase the potential for commercial opportunities related to the national space exploration vision by . . . assuring appropriate property rights for those who seek to develop space resources and infrastructure.”

  -Report of the President’s Commission on Implementation of United States Space Exploration Policy: A Journey to Inspire, Innovate, and Discover, June 2004

Linking International Space Station – Moon – Mars Architectures

The US is developing new transportation systems to the Moon and Beyond

The US has and will cooperate internationally in LEO, on the lunar surface and beyond

Closing Thoughts

- **International cooperation is a part of the Vision for Space Exploration and will be a key component of our exploration plans**
- **The US plans to return humans to the Moon by providing the core transportation system**
- **No one nation can afford such an exploration program alone**
- **The efforts of any one nation are not as effective as the coordinated efforts of many nations in exploring space**
  - Robotic precursors
  - Technologies and concepts for operations on the Moon
  - Lunar infrastructure
  - Commitment to sustained human presence
- **Exploration must be a shared goal — and a shared commitment**

RAPORTEUR’S NOTES

SESSION 1

State-of-the-Art Technologies, Physical and Geological Composition of the Celestial Bodies and International Cooperation

This session was chaired by Hugues Gilbert of the Canadian Space Agency. The rapporteur was Peter Martinez of the South African National Research Foundation.

This session provided the scientific and technical foundation for the policy and legal discussions in this workshop. Representatives of leading space agencies presented their agencies’ visions for the exploration of the Moon and other celestial bodies. The golden thread that emerged from all the presentations was that space exploration is inherently costly and expensive, and is best accomplished as a collaborative endeavour.

The Role of the Moon in Reducing Technical and Programmatic Risks for Long-Duration Exploration Missions

The first speaker was Mr. Carl Walz, an astronaut with spaceflight experience on four flights totalling 231 days in space and current Director of the Advanced Capabilities Division within the Exploration Systems Mission Directorate at NASA Headquarters. He began by presenting the United States’ vision for space exploration. This comprises the following near-term steps:

- Complete the International Space Station;
- Fly the Space Shuttle safely until 2010 and then retire this vehicle;
- Develop and fly the successor to the Space Shuttle, the Crew Exploration Vehicle no later than 2014 (goal of 2012);
- Return to the Moon by 2020;
- Implement a sustained and affordable human and robotic presence on the Moon;
- Build on experience of space transportation systems developed for lunar exploration and use the operational experience gained from a lunar outpost to develop a human mission to Mars some time in the second quarter of this century.

This exploration roadmap envisages broad international participation and a role for participation by commercial entities in exploration activities.

NASA is developing the space transportation system to allow a human return to the Moon. This is based on a combination of heritage hardware concepts from the Apollo and Space Shuttle programmes. The new Crew Exploration Vehicle will be based on the Apollo era capsule design. The vehicle is being designed to accommodate four crew for lunar missions and up to six crew for Mars and ISS missions.

A lunar reference mission was presented to illustrate the various phases and programme segments of a human return to the Moon. Unlike the Apollo era Moon landings, which were confined to the near side of the Moon, the new lunar lander would be able to land on the far side of the Moon and at the lunar poles, which are high-priority lunar exploration sites. The south pole of the Moon is a candidate outpost site because it has areas with extended periods of illumination or shade, elevated quantities of hydrogen and possibly also water ice.

Any sustained human or robotic presence on the Moon would require the capacity to harness *in situ* resources. A comprehensive programme is under way to develop technologies that will allow us to harness and utilise resources on the Moon to create products and services that reduce the cost, mass and risk of near and long term lunar and space exploration. The development of the necessary technologies and infrastructure is proposed to take place in four phases:

- Robotic Phase – robotic precursors identify resources and validate critical processes for *in situ* resource utilisation;
- Sortie Phase – short duration human missions to validate systems and operations;
- Outpost Preparation Phase – assets for *in situ* resource utilisation deployed prior to crew occupation of an outpost;
- Outpost Phase – develop infrastructure to sustain a human presence on the Moon and to develop experience for eventual human landings on Mars.

Work is already under way to develop technologies for lunar regolith excavation and handling, for oxygen production from regolith, for collection, extraction and separation of volatiles and for propellant production. The latter especially will have a major impact in terms of mass, cost and risk reduction for lunar and planetary missions and will enable an expanded human presence (and commerce) in the solar system. In order to stimulate the development of these technologies, a number of challenges have been funded. The Lunar Regolith Excavation Challenge has as its goal the development of autonomous excavation technology with tight mass, power and dimensional constraints. The MoonROX Challenge has as its objective the development of an autonomous system to extract 5 kg of oxygen from regolith in under 8 hours to produce breathable gas under constraints of mass, power and consumables.

Questions and Discussion
The speaker was asked whether NASA had considered the space elevator concept during the development of its space transportation architecture. In his reply, Mr. Walz emphasized that NASA is currently concentrating on the development of near-term capabilities that make use of adaptations of heritage hardware. This does not exclude the exploration of some new ideas, as is evidenced in the technology development challenges, like the Power Beam Challenge. However, there is currently no significant commitment of resources to the investigation of very long-term technologies such as the space elevator.

A question about the extent of bilateral discussions regarding international cooperation in space exploration was raised. Mr. Walz indicated that NASA is engaging in a significant way with the international community. A number of international workshops have been organised to get broad input. NASA's approach to international collaboration would be addressed in Jennifer Troxell's presentation later in this session.

A question about the timetable for the proposed lunar landing was raised. When the Presidential Vision was first announced, the President proposed returning to the Moon as early as 2015, but no later than 2020 [A Renewed Spirit of Discovery: The President's Vision for U.S. Space Exploration, <http://www.whitehouse.gov/space /renewed_spirit.html>. Mr. Walz indicated that a return to the Moon would likely be closer to 2020 in light of budgetary realities and NASA's existing commitments to complete the ISS by 2016 and to develop a successor for the Space Shuttle, which is scheduled for retirement in 2010.

The Present State of Lunar Exploration and Lunar ISRU Research in Japan

The second speaker for the session was Mr Kai Matsui of the Lunar Exploration Technology Office of JAXA. He reviewed the present state of lunar exploration and *in situ* resource utilisation research in Japan. Japan's space exploration activities are underpinned by the JAXA Vision which includes *inter alia* the stated objectives of *(i)* contributing to the advancement of knowledge and expansion of the human frontier by exploring the universe and *(ii)* the establishment of independent capability to carry out space activities at the highest level. Within this framework Japan is working towards the development of technologies to support the exploration of the Moon and other celestial bodies. Japan is seeking to develop complementary relationships with other nations for effective lunar exploration. The JAXA Vision summary states that "JAXA shares the spirit and principle of human space exploration pursued by Europe and the United States that the ultimate goal of our space activities should be to take human beings on a continuous journey into the cosmos."

Japan already has an active lunar exploration programme under way in the framework of the SELENE and LUNAR-A projects. It is expected that on the time scale of approximately 10 years Japan will decide whether to take significant steps towards the utilisation of the Moon's mineral and other resources and whether to participate in international human lunar exploration activities. On a time scale of 20 years Japan expects to make its contribution to the international exploration initiative by taking certain roles in the implementation of international lunar initiatives. On a similar time scale technologies will be developed to enable a sustained robotic (or human) presence on the Moon.

The basic roadmap is to start with lunar orbital missions (like SELENE), and then to move to landers/rovers on the lunar surface. These will be followed by robotic precursors and robotic outpost preparation for an eventual human landing, possibly in the timeframe of 2025. Japan's exploration roadmap includes research and development work on a crew transportation and re-entry vehicle. The lunar exploration plans are part of a broader exploration roadmap that includes planetary exploration and exploration of asteroids with sample return.

Study teams have been established to conduct studies of robotic lunar landers and supporting technologies for *in situ* resource utilisation (ISRU). A lunar resources utilisation workshop was held in July 2005 to address issues of resource identification, sampling, extraction and processing. The proposed ISRU roadmap identifies the following progression of activities: remote sensing; *in-situ* sensing; ISRU demonstrations; system integration and an eventual lunar outpost. In order to support the development of such technologies JAXA has developed a lunar regolith simulant "FJS-1".

A status update on the SELENE mission was presented. The SELENE mission comprises a main orbiter equipped with a number of instruments for spectroscopy, imaging, laser altimetry, magnetometry and charged particle/plasma studies. Two smaller satellites Rstar and Vstar (also part of the SELENE mission) will study the gravitational potential field of the Moon. This mission will address questions of the origin and evolution of the Moon and will produce data that will inform decisions about future ISRU potentials on the Moon, such as maps of water ice and maps of permanent shadow/light areas. A future SELENE 2 mission, which is not yet approved, is envisaged to comprise a lander that will validate technologies for long-term operation on the lunar surface. Even further into the future, a possible SELENE 3 mission comprising a lunar resource extraction demonstration and a sample return is envisaged.

Questions and Discussion
A question was asked concerning Japan's international cooperation stance and

whether there is any cooperation with Russia in Japan's space exploration activities. Mr Matsui replied that to the best of his knowledge he was not aware of any collaborations with Russia in the context of lunar and planetary exploration.

Chanrayaan-1 and Future Planetary Exploration Missions of India: Contributions to International Collaboration

The third speaker was Mr K. R. Sridhara Murthi, Executive Director of Antrix Corporation and Director (Technology Transfer & Industry Cooperation), ISRO Headquarters. He presented a status update on India's current lunar and planetary exploration programmes.

The ASTROSAT mission is a multi-wavelength astronomical satellite with very wide spectral coverage extending over the visible, ultraviolet, soft and hard X-ray domains. The mission will address problems in high-energy astrophysics, such as accretion processes in compact objects, detection of new and transient X-ray sources, and deep surveys of the sky to detect faint quasars. The instruments on ASTROSAT have been contributed by various institutes in India. The photon counting detectors for the UV telescope have been developed by the Canadian Space Agency.

Chandrayaan-1, India's first mission to the Moon, will be its contribution to studies of the origin and evolution of the Moon. At the same time, the technological challenges posed by this mission will provide India with operational experience in the planning and conduct of deep space missions. This is a necessary precursor to support India's long-term objective to participate in international planetary missions in the future. Chandrayaan-1 is equipped with 12 scientific payloads that will permit simultaneous photogeological, mineralogical and chemical mapping of the lunar surface from a 100 km x 100 km lunar polar orbit. The instrument complement of Chandrayaan-1 has been developed in collaboration with scientists from Bulgaria, Germany, Sweden, the UK, and the USA. Chandrayaan-1 is scheduled to launch in 2008.

Following the launch of Chandrayaan-1, the Advisory Committee on Space Sciences in India has proposed a second lunar mission Chandrayaan-2 in the timeframe 2009-2011 to carry out further studies of lunar origin and evolution with improved instruments. Such a mission could also possibly incorporate a lander or rover to carry out *in situ* analysis of samples on the lunar surface.

India's space exploration vision is not only confined to its lunar programme. Building on the Chandrayaan-1 experience, India is also considering the possibility of a Mars orbiter in the time frame of 2010-2012. The main aim of this mission would be to understand Martian atmospheric processes and remote sensing of the Martian surface for investigating its mineralogy, chemistry, water and other resources. On the time frame of 2010-2015 India is also considering an asteroid orbiter and comet fly-by mission. This will pose new technical challenges relating to achieving high impulse to reach main belt asteroids, as well as challenges for command, communications, navigation and control.

All of the abovementioned exploration programmes are planned and executed in the context of India's international cooperation strategy, which aims at achieving synergy of efforts through bilateral and multilateral ties in a mutually beneficial manner. ISRO has bilateral cooperative arrangements with 24 countries, as well as multilateral agreements with agencies such as ESA and Eumetsat and other multilateral fora such as the Committee on Earth Observation Satellites (CEOS) and the Inter-Agency Debris Coordination Committee (IADC). India also hosts the United Nations Regional Centre for Space Science and Technology Education for the Asia-Pacific Region. This Centre is widely acknowledged to be the most successful of five such centres worldwide.

India believes that the exploration endeavours of several nations have common objectives and goals and are underpinned by a common vision regarding humanity's destiny in space. India also believes that the risk, cost and complexity of these endeavours require international cooperation in order to make progress at a reasonable pace. It is becoming increasingly clear that, apart from scientific interest, the Moon and other celestial bodies will provide the material means to sustain a human presence in space and will therefore also have economic and commercial significance. Therefore, undertaking the initial exploratory activities in the context of broad international cooperation also ensures the development of an appropriate ethics and legal regime to explore outer space in a peaceful and sustainable manner.

Questions and Discussion

The speaker was asked to describe the current status of space legislation in India. Mr Murthi remarked that India does not, as yet, have national space legislation. In his view, part of the reason for this is that there are many different actors in the Indian space arena and that this is retarding the development of space law in India.

The speaker was asked if he could comment on whether India has any plans to develop its own human space exploration programme. He replied that as yet there is no consensus on whether India should develop a transportation system to support its own human spaceflight programme. There is, however, a strong consensus to develop technologies to participate in manned missions, perhaps to access international facilities, such as the ISS.

A question was raised concerning the impact of regulatory export control barriers, such as ITAR, on international cooperation with the Indian space exploration programme. The speaker replied that cooperation with India is governed by ITAR rules. While the ITAR rules constrain cooperation possibilities, the more serious problems for cooperation arise when there is uncertainty about whether ITAR issues apply in a particular instance, or not.

The speaker was asked about ISRO's plans for the Chandrayaan-1 spacecraft at the end of its mission. The speaker replied that at the end of its expected mission lifetime the spacecraft will be at an altitude of about 540 km and that without propulsion its orbit will decay and it will eventually crash on the Moon.

China's Space Exploration Programme

The fourth speaker was Li Zhaojie, professor of international law at Tsinghua University School of Law in Beijing. Professor Zhaojie provided a brief overview of the current status of China's space programme. China launched its first satellite in 1970, and by the year 2000, some 40 satellites had been launched. The development of the Long March rocket series has provided China with independent access to low Earth orbit and to geostationary orbit. China has the capability to loft 9000 kg satellites to LEO and 5100 kg satellites to GSO transfer orbit. Launch operations are supported by a series of ground stations and ships that may be deployed around the world to support a particular launch.

In 2000 China issued a White Paper on space exploration outlining the nation's long-term goals for space exploration. The White Paper identified several policy thrusts for China's space programme. The White Paper views the development of space technology as a means to support the country's modernisation drive. In the context of space exploration the White Paper recommends the selection of a limited number of key targets and making key breakthroughs in the selected areas. The White Paper recognises the important role of international cooperation in reducing the cost and risk of space exploration. China seeks to pursue international cooperation in space exploration on the basis of mutual benefits and in keeping with the UN principles and treaties on outer space to utilise space for the benefit of mankind. Cooperation is pursued on the basis of equality, mutual benefit and complementarity. In this regard China appreciates the important role of regional cooperation and is a founder of the Asia-Pacific Space Cooperation Organisation (APSCO), an inter-governmental organization to promote multilateral cooperation in space science and technology and its applications to regional economic and social development in Asia-Pacific nations.

Member states include China, Bangladesh, Indonesia, Iran, Mongolia, Pakistan, Peru, Thailand and Turkey. China is the hosting country of APSCO and the headquarters are in Beijing.

China's human spaceflight programme commenced in 1992. China's human space flight roadmap comprises three broad stages: *(i)* Loft humans to low Earth orbit; *(ii)* dock two spacecraft to form a small orbiting habitat and laboratory; *(iii)* build and utilize a larger space station. The first stage is well under way. In 1999 an unmanned Shenzhou vehicle was launched. In 2003 the first Chinese astronaut entered Earth orbit aboard Shenzhou 5 and in 2005 two astronauts conducted a 5-day space flight aboard Shenzhou 6. The Chinese government has invested approximately US$2 billion in Shenzhou 1-5 and a further US$110 million on Shenzhou 6. The first space walk is planned for 2007 and the first rendezvous and docking for 2009.

China is contributing towards global lunar exploration efforts with its Chang'e mission, due to launch in late 2006. This lunar orbiter will map the Moon in 3D to identify potential future landing sites. Chang'e will also study the Moon's composition and radiation environment. On a longer time-scale consideration is being given to an unmanned lander/rover in the timeframe of 2010/2012 for *in situ* analysis and small-scale excursions, and a lunar sample return mission in the time frame of 2015. So far, no plans for potential manned lunar or planetary exploration missions have been announced.

Questions and Discussion

A reference for China's White Paper was requested. Professor Zhaojie indicated that this document is available on the internet at www.spacechina.gov.cn. [Rapporteur's note: At the time of writing, this URL was not accessible, but a copy of the text of White Paper was located at <http://www.spaceref.com/china/china.white.paper.nov.22.2000.html>. The speaker was asked about the launch date for Chang'e. He replied that this is due to launch in late 2006.

ISAS/JAXA's Perspective on the Exploration and Utilisation of the Moon

The fifth speaker was Hitoshi Mizutani, emeritus professor of the Institute of Space and Astronautical Science of JAXA. Professor Mizutani commenced his presentation with an overview of JAXA's current activities and future plans for lunar exploration. Current missions include the SELENE orbiter for lunar global mapping and the LUNAR-A mission, which will conduct studies of the deep interior of the Moon with seismometers and penetrators. The instrument complement on the SELENE mission has been selected to address questions of the origin and evolution of the Moon by providing data on elemental abundances, mineral composition, geological features, global gravity field and the electromagnetic and particle environment in lunar orbit. Future plans for follow-up studies after SELENE include a possible SELENE-2 mission which will comprise a lander and rover for *in situ* investigations of the lunar surface.

JAXA's long term exploration vision for the time frame leading to 2025 and beyond includes the accumulation of technologies for human space exploration through opportunities provided by the ISS, the development of a space transportation system for humans, and the development of technologies for the establishment and utilisation of a lunar base.

Japan believes that in future the demand for space resources by humans will grow. However, a number of challenges will have to be met. Extensive technological development will be required in order to utilise space resources. This development will have to be accommodated in some way within the current space science programmes. This may prove a challenging combination to realise in practice as the objectives are very different. The high cost of conducting a lunar exploration and space resource exploitation programme poses a challenge to continuity of government funding for such activities. Prof. Mizutani suggested that the solution to these challenges is to pursue the exploration and utilisation of space resources in the context of a new framework for international collaboration on this enterprise.

Questions and Discussion

A question was raised concerning the wisdom of combining scientific and resource utilisation goals in the same mission since the objectives of these activities are quite different. Prof. Mizutani remarked that he shares this concern but that the pressure to combine multiple objectives into a single mission is usually related to funding constraints.

A comment was made that, in regard to the new framework for collaboration suggested by the speaker in his closing remarks, perhaps the ISS could provide such a model. Professor Mizutani replied that in his view a larger and much more comprehensive framework would be required than is the case with the ISS. In particular, the framework must address the economic impact (benefit) for all participating countries.

The U.S. Approach to International Participation in the Vision for Space Exploration

The sixth and final speaker of the session was Ms. Jennifer Troxell, International

Programs Specialist at NASA Headquarters. Ms. Troxell presented the United States' approach to international participation in the Vision for Space Exploration. She began by referring to President George W. Bush's announcement of the Vision, delivered on January 14, 2004, in which he highlighted the international nature of the Vision – *"...a journey, not a race..."*. NASA has accordingly engaged other nations on a bilateral and multilateral basis to form partnerships to advance the objectives of the Vision. In this way NASA seeks to promote common space exploration objectives through cooperative or complementary missions.

NASA has a number of traditional guidelines for international cooperation. Firstly, there should be mutually beneficial programmatic goals. Cooperation is carried out on a "no exchange of funds" basis, although exchanges in kind are possible. NASA's international partners are usually government agencies, and any international cooperative activities must comply with U.S. export control regulations and U.S. foreign policy objectives. In order to contain schedule, cost and development risks, NASA generally avoids having international partners on the critical path of a project, if possible.

In the context of the Vision for Exploration, the initial focus of the U.S. Exploration Architecture is on the development of U.S. crew and cargo transportation systems. NASA has identified opportunities for international collaboration in areas other than transportation, such as habitats, rovers, power, logistics, *in-situ* resource utilisation, and communications.

The Vision for Space Exploration anticipates the commercial opportunities to flow from exploration programmes. The Report of the President's Commission on the Implementation of United States Space Exploration Policy recommends that "Congress increase the potential for commercial opportunities related to the national space exploration vision." The Report also recommends that property rights should be assured for those who seek to develop space resources and infrastructure.

In closing, the speaker reiterated the U.S. position that no single nation can afford such an exploration programme alone. The U.S. will provide the core transportation system to return humans and cargo to the Moon, and is open to cooperation in a number of other areas with countries that share the same goals and commitment.

Questions and Discussion

The speaker was asked whether, in seeking international cooperation possibilities, NASA was engaging with only the space faring nations, or with all other nations, and in particular with the developing nations to create opportunities for them to participate in the Vision for Space Exploration. Ms. Troxell responded by indicating that NASA had organised a number of international workshops to discuss the exploration vision. Dr. Doyle remarked that developing countries should declare their interest to participate in a global space exploration effort and should indicate the potential role that they could play in such an effort.

A remark was made that property rights and the definition of different forms of property rights needs to be carefully considered in developing international cooperative arrangements for the exploration of the Moon and other celestial bodies and the utilisation of resources thereon.