The Global Exploration Strategy

The Framework for Coordination

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Executive Summary

Space exploration enriches and strengthens humanity's future. Searching for answers to fundamental questions such as: 'Where did we come from?' 'What is our place in the universe?' and 'What is our destiny?' can bring nations together in a common cause, reveal new knowledge, inspire young people and stimulate technical and commercial innovation on Earth.

The Global Exploration Strategy is key to delivering these benefits.

One of the most fundamental human characteristics is a relentless curiosity that drives us to investigate the unknown. Throughout our history, we have looked beyond our apparent boundaries to the mysteries that lie beyond.

Compelled to explore, to understand and to use the world in which we find ourselves, we have spread across continents and oceans. We have probed the farthest reaches of the planet—the frozen poles, the deep oceans, the high atmosphere.

With increasing intent and determination, we are resolved to explore our nearest companions—the Moon, Mars and some nearby asteroids. Our goal is not a few quick visits, but rather a sustained and ultimately self-sufficient human presence beyond Earth supported by robotic pathfinders.

Sustainable space exploration is a challenge that no one nation can undertake on its own.

This is why fourteen space agencies[1] have developed the Global Exploration Strategy: The Framework for Coordination, which presents a vision for robotic and human space exploration, focussing on destinations within the solar system where we may one day live and work. It elaborates an action plan to share the strategies and efforts of individual nations so that all can achieve their exploration goals more effectively and safely.

This Framework does not propose a single global programme. Rather, it recommends a voluntary, non-binding forum, the international Coordination Mechanism, through which nations can collaborate to strengthen both individual projects and the collective effort.

Robust science and technology efforts, such as the pursuit of space exploration, help to define nations and their place in the world. The number of countries involved in space exploration is growing steadily and we are entering a new era of historic significance, in which we will extend human presence beyond Earth's orbit, physically and culturally.

The Moon is our nearest and first goal. As a repository of four billion years of solar system history, it has enormous scientific significance. It is also a base from which to

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

study Earth and the universe, and to prepare humans and machines for venturing farther into space.

Mars is also a prime target. With an atmosphere and water, it may hold key secrets to the evolution of life in our solar system. Eventually, we hope to reach other, even more challenging destinations, such as asteroids and the moons of the giant planets.

A partnership between humans and robots is essential to the success of such ventures. Robotic spacecraft are our scouts and proxies, venturing first into hostile environments to gather critical intelligence that makes human exploration feasible. Humans will then bring their ingenuity, creativity and problem-solving skills to these destinations.

This Global Exploration Strategy will bring significant social, intellectual and economic benefits to people on Earth. We will learn about the evolution of the solar system and how to protect against harsh environments. By understanding how planets work, we learn more about our Earth. The technologies created will help build a more sustainable society.

Space exploration also offers significant entrepreneurial opportunities by creating a demand for new technologies and services. These advances will encourage economic expansion and the creation of new businesses.

Finally, this new era of space exploration will strengthen international partnerships through the sharing of challenging and peaceful goals. It will inspire people everywhere, particularly youth. It will steer many students toward careers in science and technology and provide them with challenging jobs that encourage innovation and creativity.

Opportunities such as this come rarely. The human migration into space is still in its infancy. For the most part, we have remained just a few kilometres above the Earth’s surface – not much more than camping out in the backyard.

It is time to take the next step.

Chapter 1

Global Exploration Strategy: The Framework for Coordination

Space exploration is essential to humanity's future. It can help answer fundamental questions such as: 'Where did we come from?' 'What is our place in the universe?' and 'What is our destiny?' It can bring nations together in a common cause, reveal new knowledge, inspire young people and stimulate technical and commercial innovation on Earth. The Global Exploration Strategy is key to unlocking this door to the future.

Human curiosity compels us to *explore*, to *understand* and to *use* the world in which we find ourselves. Voyages of exploration and discovery are a sign of cultural vigour; every vibrant society has looked beyond its horizons to somewhere new.

Scientific evidence suggests that modern humans emerged in ancient Africa and spread across Eurasia, beginning about a million years go. Primitive peoples may have built rafts to sail the oceans.

During the ensuing millennia, humans have migrated throughout all the continents. Explorers and adventurers go first, embracing the risks inherent in pitting themselves against unknown and often hostile environments. Scientists and traders follow and, eventually, ordinary people move in to create permanent settlements.

The human migration into space is the next chapter in this story of exploration and expansion. It is still in its infancy; less than 50 years have passed since the first humans ventured beyond the shores of Earth into the new ocean of space. Nor have we gone far; since Yuri Gagarin's flight in 1961, almost all of the 450 human explorers of space have remained just a few hundred kilometres above the Earth's surface. Only the two dozen Apollo astronauts who visited the Moon between 1968 and 1972 have ventured farther.

Though we have barely begun this new journey of exploration, we have already learnt many of the new skills needed to live and work in space, whether we are physically present ourselves or are sending robotic spacecraft in our stead.[2]

So far, these robotic proxies have been the only ones to explore the most distant and challenging destinations far beyond low Earth orbit. They have given us a tenuous 'virtual presence' throughout the solar system. The most travelled of these probes, Voyager 1, launched in 1977, is only now leaving the solar system forever.

Meanwhile, we have harnessed Earth's orbit to serve society, using satellites to provide global telecommunications, navigation and environmental monitoring, deliver reliable weather forecasts, and aid emergency workers responding to natural disasters.

This document is not concerned with these proven and well-managed uses of space. Instead, the **Global Exploration Strategy** (GES) addresses a new opportunity. It

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[2] Some languages favour "automatic" versus "robotic" but the two should be considered interchangeable.

elaborates a vision for globally coordinated space exploration focussed on solar system destinations where humans will someday live and work.

It also sets the stage for the discussions and hard work that will turn the vision into reality. It includes an action plan for coordinating strategies to help national space agencies[3] reach their space exploration goals more effectively and safely.

The number of countries involved in space exploration is growing steadily. Building on what has already been learnt, our overall ability to accomplish scientific, technological and human goals has never been greater.

We are now entering a new wave of space exploration, one of historic significance. The United States has developed its Vision for Space Exploration; the European Space Agency has its Aurora space exploration programme. China, India, Japan and Russia have ambitious national projects to explore the Moon or Mars, while future national missions are being discussed in Canada, Germany, Italy, Republic of Korea and the United Kingdom.

The public has marvelled as astronauts from several countries build the International Space Station, perhaps the most ambitious science and technology project ever undertaken. They have witnessed China become the third country to launch their own astronauts.

On the robotic front, the Huygens probe revealed a new world of river valleys and mountains beneath the dense haze of Saturn's moon, Titan. The Hayabusa spacecraft landed on the asteroid Itokawa to pick up samples for return to Earth, heralding a new era of round-trip exploration in interplanetary space.

Bilateral and multilateral cooperation among space-faring nations has enabled much of what has been achieved so far, and this will continue in the future. But there's never been a single, comprehensive strategy for space exploration that allows existing plans to be coordinated and new ones to be developed.

This GES **Framework for Coordination**, developed by 14 space agencies, therefore represents a new beginning. International discussions during 2006 produced a common set of space exploration themes, as elaborated in this document. The Framework makes the case for a voluntary, non-binding forum (the **Coordination Mechanism**) where nations can share plans for space exploration and collaborate to strengthen both individual projects and the collective effort.

As a voluntary mechanism, the international coordination process is open to new participants. Each will bring their own perspectives and skills and, in return, will gain access to the common knowledge and experience.

This Framework is *not* a proposal for a single programme, but recognizes that individual space exploration activities can achieve more through coordination and cooperation. Nations have varying scientific, technological and societal objectives for their space activities, and – inevitably – some can afford to do more than others.

For the foreseeable future, the Moon, Mars and near-Earth asteroids are the primary targets for human space exploration. We do not yet have the practical knowledge or

[3] "Space agencies" refers to government representatives that include space agencies, science organizations and groups of space agencies that have been designated by their government to represent them.

skills to send humans to other exciting but more distant destinations such as Jupiter's moon Europa, or Titan and Enceladus, which orbit Saturn.

But exploring even the first group of feasible destinations will require both robotic and human missions of all sizes and complexity. A coordinated strategy will help individual nations with shared objectives to engage in joint projects that will maximise their return on investment. The scientific and technical successes – and even the failures – of each project can be used to improve the ones that follow.

The Framework calls for the development of an international exploration coordination tool to enhance mutual understanding among partners and to identify areas for potential cooperation. By jointly creating a common language of exploration building blocks, planners and engineers will be able to agree how practical features such as communications, control, life support and docking systems could be made to work together. Such 'interoperability' between space vehicles will lower the risks of space exploration and could assure crew safety in case of life-threatening emergencies.

Although government agencies have led the creation of the GES, the Framework also recognises that industry will have an increasingly important role in turning the new frontiers of space to economic opportunity. It is hoped that entrepreneurs will create businesses to exploit resources or provide commercial services such as cargo transport and telecommunications. Thus, space exploration will become more sustainable and government resources may be released to push further the bounds of human knowledge.

The successful exploitation of Earth's orbit over the past 30 years suggests that this is likely. In time, issues of property rights and protection of sites of interest may arise and the GES Coordination Mechanism will help address such new challenges.

The following chapters present the rationale for space exploration, organized under specific themes that highlight its benefits to society. This Framework outlines the steps humanity must take to embark on this new journey, focussing on the complementary roles of human and robotic missions.

It argues for a return to the Moon, a target of intrinsic value and an essential stepping stone to the exploration of Mars and beyond. It concludes that improved coordination of national and international efforts can make space exploration more robust and more affordable for all.

Chapter 2

Space Exploration in Service of Society

Global-scale space exploration represents the sum of many projects undertaken nationally and internationally. But it also signifies a collective will to find answers to profound scientific questions, to create new economic opportunity and to expand the boundaries of human life beyond Earth. These goals of space exploration in the service of society are embodied in the recurring themes of the Global Exploration Strategy.

Globally, humankind is facing many pressing social, political and environmental challenges. In this context, the relevance of space exploration to society is sometimes not well understood. So, why does it matter? How can space exploration contribute to our common future?

Space exploration is today's expression of a fundamental human characteristic: our deep curiosity and a resulting imperative to explore the unknown.

This is how we gain new knowledge and skills that become part of our collective ability to solve human problems and support commercial activities in useful and unpredictable ways. The very difficulty of space exploration is what triggers human inspiration and innovation.

The first 50 years of spaceflight provide many notable examples. Satellites have revolutionized global communications and navigation, and have provided critical data on climate change. Robotic and imaging technologies and other tools developed for the demanding space environment have found important applications on Earth, such as airport security scanners and medical diagnostic instruments.

In the future, a sustained but affordable agenda of globally coordinated space exploration can serve society through:

- securing new knowledge and solving global challenges in space and on Earth through innovative technology;
- permanently extending human presence into space, physically and culturally;
- enabling economic expansion and new business opportunities;
- creating global partnerships by sharing challenging and peaceful goals; and
- inspiring society through collective effort and personal endeavour.

These benefits are encompassed in five exploration themes (no prioritization is implied):

Theme 1: New Knowledge in Science and Technology

At its core, exploration is about taking manageable risks to discover what is unknown. Significantly, much of what it reveals is unknowable in advance. This presents challenges for those wanting to weigh the risks against the returns from new investments.

This problem is as old as innovation itself; when Heinrich Hertz developed the first apparatus to transmit and receive electromagnetic waves in 1887, he hardly envisaged the vast global telecommunications networks of today, or the economic activity they sustain.

Space exploration generates new knowledge that helps us understand the solar system in relation to both the biosphere of Earth and to the vast universe beyond. Though many mysteries remain, we have made a good start with robotic spacecraft, brief human missions to the Moon and human activity in low Earth orbit.

The scientific exploration of the solar system began in the earliest days of the space age. First we sent robotic probes to the nearest planetary bodies, the Moon, Venus and Mars. We also investigated the local space environment and learnt how the Earth's magnetic field protects us from the Sun's lethal radiation and continuous bombardment by material it casts off.

These early missions significantly enriched our knowledge about each celestial body. Today, more sophisticated missions are starting to unravel the inner workings of the solar system since it formed some 4.5 billion years ago.

Systematic, science-driven space exploration reveals fundamental truths about the history of the solar system and the origin and nature of life. Both robotic and human exploration are necessary to answer the key questions.

Much of the current research focusses on two big questions: how did the solar system evolve and is there life beyond Earth? These questions are profoundly important, scientifically and philosophically. The quest to answer these questions took us first to our nearest neighbours in the solar system.

Though often called Earth's twin because of its similar size, Venus could hardly be more hostile to life as we know it. Planetary probes found hellish conditions; runaway global warming has produced a dense atmosphere of choking sulphuric acid and temperatures hot enough to melt lead. We will continue to study Venus, but it is unlikely to be a destination for human exploration.

The story on Mars is different. Although its surface today is cold and barren, evidence suggests it was once warm and wet; it also seems to have many of the raw materials for life, including the key one – water. Robotic missions have found signs of recent hydrological activity and some scientists believe there is evidence of frozen oceans.

Today, we simply do not know whether life could, did or even still does exist on Mars. But, despite the undeniable hazards of its inhospitable surface, it is, unlike Venus, a place we can contemplate visiting to look for answers.

Of necessity, the most detailed investigations will occur in locations accessible to humans, where they can undertake long-term research. However, robotic proxies will allow us to reach farther afield. Already, they have found simple carbon molecules that could be precursors to the complex chemistry of life in such diverse places as comets and the thick atmosphere of Titan, a huge moon orbiting Saturn.

Why is our chemical make-up more akin to both the Sun and the giant planets, such as Saturn and Jupiter, than it is to the rocky planet on which we live? The answers are unclear and will only be found by mapping the distribution of these 'pre-biotic' chemicals throughout the solar system, as well as in the planets forming around distant stars.

Another enduring question that space exploration seeks to answer is: how did our solar system come to be? The Moon has been described as a potentially unique museum of the history of the solar system and it may play a key role in unravelling this story.

Furthermore, if – as is currently thought – the Moon was formed by a cataclysmic collision between a Mars-sized object and the early Earth, some clues about the earliest conditions on Earth may be uniquely preserved in the Moon. The Earth's surface records little of the solar system's origins or history; its face has been remade many times by geological processes such as earthquakes, volcanic eruptions and erosion.

Global scale space exploration is an engine of scientific and technical progress. Problem-solving drives innovation and the bigger the problem, the greater the innovation.

Exploring this 'planetary museum' will likely require the ability to roam over the lunar surface and to dig several hundred meters down. Both tasks will require humans and robots working in partnership, and similar techniques will be needed on Mars. Taking ice core samples, just as we do in Greenland and the Antarctic, will provide an historical record of the planet's climate. Subsurface bodies of water, if they exist, may yield life forms protected from radiation and the cold of the surface.

We have also started to investigate the leftover materials from which the solar system was built: asteroids and comets. Our interest in these bodies is scientific, economic and practical. We are interested in exploring their role in distributing pre-biotic chemicals and water through the early solar system. In addition, there are some who believe there is a realistic prospect of mapping and even exploiting these objects for their mineral resources.

More significantly, we know these objects can and do strike Earth and likely have caused several mass extinctions in the past. It could happen again. So far, humanity has been lucky, but one day our luck may run out.

Studies are underway to develop the first spacecraft capable of deflecting an Earth-crossing asteroid. A healthy space exploration programme will generate the knowledge needed to give us this ultimate insurance policy. As space scientist Carl Sagan once observed, the dinosaurs died out because they did not have a space programme.

Theme 2: A Sustained Presence - Extending Human Frontiers

Since humans first emerged in ancient Africa, we have populated the most hot, cold, humid and dry regions of Earth. Our first tentative steps in space exploration have already expanded humanity's reach to the hostile environment of Earth's orbit and the Moon's surface, while robotic probes have reached out even farther.

The brief sorties by the Apollo astronauts required the ability to sustain humans for only a few days on the lunar surface; there was no attempt to establish a long-term presence or exploit local resources. Space stations like Mir and the International Space Station have extended our staying power to months and years, albeit in a manner that requires constant support from Earth.

Going farther afield and establishing long-term, self-sufficient outposts will require a significant commitment of human, scientific, technical and economic resources.

But why send humans into space at all? Why not let robots do it all? Humans have unique decision-making capabilities that allow them to respond to new situations based on previous experience and knowledge. Sending humans to live and work in space takes full advantage of the intellectual capital and real-time reasoning that only they can provide. A human can quickly find and tighten a loose bolt on a core-sample drilling rig, whereas it might take hours to programme a robot to do so, even if it had the means to sense the problem. We are a long way from having robots that can match humans, even in the lab.

We know it is possible to establish a more sustained human presence on the Moon and that it may well be possible to extract resources that will reduce dependence on Earth. Many more resources certainly exist on Mars, but the much longer travelling time makes the technical requirements more demanding and increases the risks, especially from radiation.

In the long run, having a sustained and self-sufficient presence in space will also allow humanity to maintain off-world repositories of knowledge and history.

It will almost certainly redefine our relationship with Earth in profound ways, and increase our appreciation of the rare bounty we have here. One of the great legacies of the space programme is the psychological impact of the image taken by Apollo astronauts of a vibrant Earth floating above the lifeless plains of the Moon, fragile and isolated in the emptiness of space.

Theme 3: Economic Expansion

The first stages of space activity were driven by national space agencies, but business has gradually come to play a larger role. Today, a multi-billion dollar industry uses privately-owned satellites to provide voice telephone service, mobile Internet access, and high quality television broadcasting to subscribers around the world.

In the past century, governments have nurtured major industries, either through investment in infrastructure, such as railways, highways and the Internet, or by becoming the first customer for services like air delivery of the mail. These investments now yield large tax returns to national treasuries. Space-based services are following the same model.

More recently, commercial Earth observation satellites have been launched. At first, governments were their key customers, but their client base expanded rapidly. Countless users now have satellite-based navigation equipment in their private cars and anyone can access geographical data through software tools such as Internet-based Google™ Earth.

Already, far-sighted entrepreneurs are thinking about further commercial expansion into space. As space exploration extends to the Moon and Mars, there will be potential opportunities for companies to provide crew and cargo transportation services, telecommunications and navigation systems, and space-based resource extraction and processing capabilities.

For example, Moon rocks are rich in oxygen that might be exploited to provide life support systems for lunar operations. Liquid oxygen can also be used as a rocket propellant – and it might be more economical to manufacture it in space than to lift it off the Earth.

Mining the Moon might also yield titanium – a strong but light metal favoured for high-end aerospace applications. Finally, the Moon's known abundance of Helium-3 could prove valuable if fusion reactors ever become feasible in the future.

There are also potential opportunities in commercial space tourism, both real and virtual. New telecommunications and robotic innovations create the prospect of offering customers on Earth a 'virtual presence' on the Moon or Mars. For those who yearn to experience the real thing, sub-orbital spaceflight is on the verge of becoming reality. The future may also hold Earth-orbiting space hotels and excursions to the Moon.

Much of the technology for space exploration will be created by business, and business will find unexpected ways of exploiting this know-how in the wider economy. Governments can assist by stimulating links between the public and private sectors in innovative ways – prize funds are one example.

The challenges and constraints of doing things in space stimulate creative minds. Many of the capabilities and technologies developed for the space programme probably would not have appeared in its absence, even with the same level of investment.

For business to be confident about investing, it needs the certainty of a long-term commitment to space exploration, the opportunity to introduce its ideas into government thinking, and the rule of law. This means common understanding on such difficult issues as property rights and technology transfer. The Coordination Mechanism foreseen as part of the Global Exploration Strategy will provide a forum to discuss these important issues.

Space exploration brings together diverse expertise, creating opportunities for innovative ways of working. Skills required for space exploration, such as the ability to engineer very complex systems and design highly reliable mechanisms and software, are now used in the wider economy.

Some of the challenging technologies for the new era of space exploration include:

- efficient power generation and energy storage;
- space and surface transportation;
- communications and navigation;
- health care for human explorers, including tele-medicine;
- autonomous operation and smart decision-making for robotic explorers;
- planetary resource extraction and utilisation;
- on-orbit spacecraft servicing;
- human-robot cooperation; and
- safe habitats with efficient life support and environmental control.

Development of these technologies will be driven by the constraints of space exploration, such as minimising mass and designing for reliable operation in a high radiation environment. Such attributes often lend themselves to terrestrial products and services. For example, robotic instrumentation developed to search for life on Mars is now being turned into a portable tuberculosis diagnostic machine for use in the developing world.

We will need to support human and biological life far from Earth by conserving resources and recycling as much as possible. Meeting these challenges will foster spin-off opportunities in fields such as medicine, agriculture and environmental management, and help achieve sustainable development on Earth.

In the past, human explorers have overcome complexities and uncertainties that demanded the utmost intelligence, ingenuity and innovation. Space exploration in the future will be no different. New technologies and an effective partnership between humans and machines will be key requirements in exploring and exploiting planetary surfaces to support human operations in remote locations.

Theme 4: A Global Partnership

Space is an unforgiving environment and no nation has the resources to take on all of its challenges at once. So space-faring nations have worked together from the earliest days in bilateral or multilateral partnerships.

The shared challenges of space exploration and the common motivation to answer fundamental scientific questions encourage nations of all sizes to work together in a spirit of friendship and cooperation.

The Apollo-Soyuz project in the 1970s was a striking example not just of technical cooperation, but also of political détente at the height of the Cold War. The 17- nation European Space Agency has its origin in the wish to build scientific links across the whole continent. Today, ESA's programme – which includes exploring Mars and building launchers and meteorological satellites – is far beyond the capabilities of any one European country.

The International Space Station program, arguably the largest project of its type ever undertaken, has clearly demonstrated the value of a partnership approach. The U.S., Canada, Europe, Japan, and Russia have achieved together what no one nation could have accomplished alone – and, in the process, have forged strong ties, including cultural and political understanding.

Other examples of partnership abound:

- The Japan Aerospace Exploration Agency (JAXA) and NASA worked together to land the Hayabusa probe on the asteroid Itokawa. It is expected to return the first samples from the asteroid to Earth in 2010.
- Novel U.S. and European scientific instruments will soon orbit the Moon aboard an Indian spacecraft.
- The Chinese Double Star spacecraft are probing the relationship between the Earth's magnetic field and the solar wind with the help of instruments built in Europe.

- China and Russia are planning a joint mission to one of Mars' moons.
- Japan and Europe are cooperating on a mission to the innermost planet, Mercury.

These successes suggest that much more can be achieved with a global strategy for space exploration. Partnerships will enable nations to develop a common understanding of their respective interests, to share lessons learnt and thus avoid costly mistakes, and to discuss scientific results that will help in planning for the future.

Most importantly, we need a forum to discuss the essential building blocks of space exploration and practical issues such as interoperability – ensuring that different systems can work together. Internationally-agreed standards that allow a mobile phone bought in China to work in Canada or a car made in Germany to meet U.S. safety laws are critical to the global economy; they will be just as important when human activities extend beyond Earth. Complex issues such as the protection of areas of scientific importance may arise and can be discussed before they block progress.

By developing a common language of space exploration, nations can more readily share their specific objectives and enhance opportunities for joint projects. Leveraging national funds and coordinating mission objectives will enable them to build upon, strengthen, and expand existing global partnerships through space exploration.

This spirit of partnership will indirectly enhance global security by providing a challenging and peaceful activity that unites nations in the pursuit of common objectives. It is inclusive; the goal is to expand the opportunity for participation in space exploration to all nations and their citizens.

Theme 5: Inspiration and Education

Space exploration catches our attention in a special way. It excites and inspires us to think about the wonders of the universe in which we live. People all over the world experience a sense of pride in unique achievements and the pain of failure when missions go awry.

In the future, new virtual reality technologies will enable them to share the excitement and wonder of exploration and discovery more viscerally than ever before. In a very real sense, they can 'be there' when humans land on Mars or robots land on Europa.

One of the greatest legacies of space exploration is the role it plays in inspiring young people to think about what they want to achieve in their lives and to reach beyond the obvious. An interest in space steers many of them toward careers in science and technology and prompts them to make educational choices that will get them there. Space exploration programmes also provide a wealth of new information for educators in all disciplines, making lessons more exciting and intriguing for their students.

Space exploration creates jobs with limitless possibilities for creativity, challenge and motivation. This is a powerful magnet to attract and sustain new generations of scientists and engineers, most of whom will find careers in the wider economy.

Many countries are concerned about a decline in their scientific and technical talent. A vibrant space exploration programme can help turn this trend around.

Chapter 3

Mapping the Space Exploration Journey

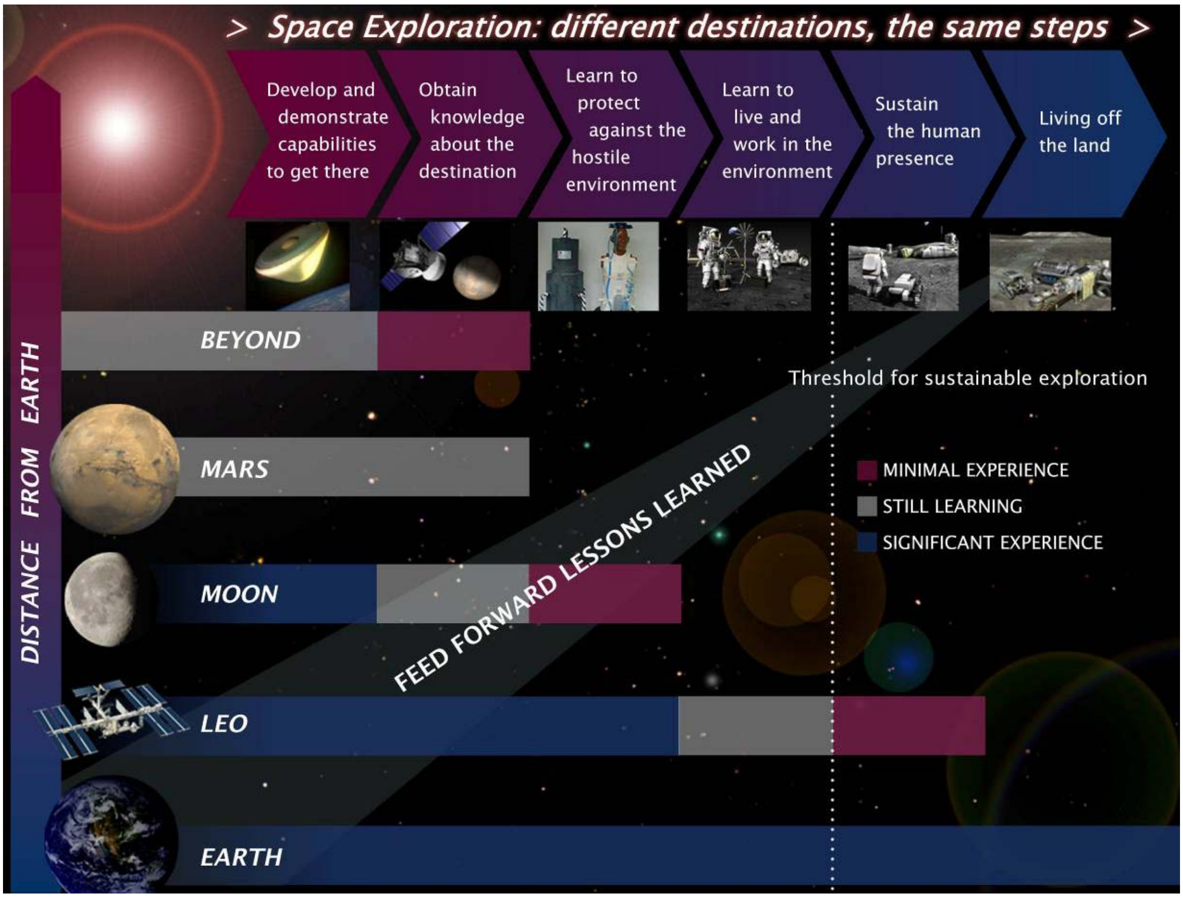
Space exploration follows a logical set of steps, starting with basic knowledge and culminating, it is hoped, in a sustained human presence in space. This journey requires a variety of both robotic and human missions. The Global Exploration Strategy provides a framework to coordinate the efforts and contributions of all nations so that all may participate in the expansion into space and benefit from it.

Since the first satellite was launched in 1957, space exploration has evolved in a characteristic way, progressing steadily from short term, very focussed missions to longer and more comprehensive ones.

During the Apollo programme in the 1960s and 1970s, humans visited the Moon for fewer than three days on each mission. With space stations such as Salyut, Skylab, Mir and the International Space Station, we learned how to live for months in space. Russian cosmonaut Valeri Polyakov holds the record with 14 months onboard Mir.

By building upon these experiences, we are now preparing to establish a sustained human presence on the Moon and, eventually, in other parts of the solar system. The long term space exploration envisioned in this document is very different from the International Space Station. It is not a single space project but instead will comprise multiple missions and projects, large and small, to several destinations. Nations not involved in the ISS can and are making valuable contributions to space exploration.

Individual projects may emphasise certain goals more than others – for example, focussing on robotic science on Mars or testing technology needed for resource utilisation on the Moon. Each project will support the overall goal of extending the human frontier, step by step.



This diagram[4] shows how far we have progressed toward continuous living and working at key destinations. The central vertical bar in the diagram shows the threshold that must be crossed to achieve sustainable space exploration. This means not just simply tackling a new environment for a brief time, but actually living there and using local resources, with little or no support from Earth.

We have not yet reached this level of autonomy for either robotic or human missions. Our activities in low Earth orbit approach the threshold of sustainability but crossing it remains an enormous challenge, even for robotic missions. For example, in principle, we have the technology to refuel communications satellites but we lack the infrastructure to make this a reality.

Robotic exploration is a key first step in expanding human presence into the solar system. Several generations of robotic exploration may be required to gain basic knowledge about a target destination before human exploration is useful or justified.

First, we send orbiters to remotely sense the surface and identify safe locations for landing. They are followed by landers that investigate the surface directly and then by robotic sample-return missions that carry material back to be examined in terrestrial labs.

[4] "LEO" in the diagram refers to Low Earth Orbit, the location of the International Space Station.

Today, we have a limited amount of material on Earth that has been returned from outer space. Within the next decade, this knowledge will be increased by robotic missions returning material from certain asteroids and one of the moons of Mars.

The first robotic sample-return mission from the surface of Mars will likely occur around the same time that humans return to the Moon – an indication of just how large a technical challenge it represents.

Robotic probes that have explored the major bodies in the solar system have generated much valuable data but, for the more distant destinations (’Beyond’, in the terms of the diagram), the knowledge accumulated so far has been limited by the constraints of our space technology.

We have glimpsed a riverbed and rocks of ice on Titan, but we do not know the composition of the ice, or if rivers still flow there. We believe the ice of Europa covers a liquid ocean, but we do not know whether it might contain life.

We have accomplished only the first tentative steps towards understanding these destinations; we cannot speculate if and when humans will reach them or what technology we will use.

This schematic picture of exploration shows that experience gained at each step of the journey enables the next one. Equally important, parallel progress toward several destinations may well generate valuable experience that is useful for all. Progress along the pathway to each destination will be assisted by increased coordination between projects.

Chapter 4

The Moon: A Second Home in the Solar System

The Moon will be the first place where humans learn to live on another celestial body. Just three days from Earth, the Moon has low gravity and natural resources that make it an ideal location to prepare people and machines for venturing farther into space. As a repository of four billion years of solar system history and as a place to observe the Earth and the universe, it has great scientific potential. Exploration of the Moon will also reveal whether the resources available in space will allow humans to live off the land.

In the 1960s, robotic spacecraft from the United States and the Soviet Union began exploring the Moon. The first soft landing was made in 1966 by the Soviet spacecraft Luna-9. It was followed by several more Soviet and U.S. lunar missions, including orbiters, sample-return missions, and rovers.

During this period, six Apollo crews also landed on the Moon and returned samples to Earth.

Thanks to these dramatic successes, lunar material could be examined in laboratories on Earth. The oldest material proved to be nearly a billion years older than the oldest known terrestrial rocks. Samples from the Moon still provide the best measurement of the age of any planetary surface.

Sustained human exploration will start on the Moon. That is where we will learn to live and work without immediate support from Earth and where we can test technologies needed for human missions to Mars and beyond.

Lunar scientific exploration will involve three types of investigations: science 'of the Moon', science 'from the Moon', and science 'on the Moon'. Science 'of the Moon,' which involves lunar geology, geochemistry and geophysics, will help us understand the history of the Moon. Current theories suggest the Moon was created when a body the size of Mars struck the young Earth, throwing vaporized rock into Earth's orbit. This material later coalesced into the Moon.

The Moon is an invaluable witness to much of solar system history. It has recorded this history more completely and more clearly than any other planetary body. For example, did the comets and meteorites that bombarded the Earth and the Moon in their early history contain the building blocks of life? The answer may be preserved on the pristine surface of the Moon. To make sense of the data encoded in the Moon, we may need both extensive robotic exploration and sophisticated surveying by humans at sites of high scientific interest.

Science 'from the Moon' will take advantage of the Moon's lack of atmosphere and its 'radio quiet' environment to provide a stable platform for observing the universe. For example, astronomers are interested in constructing a lunar-based low-frequency radio telescope to 'see' signals emanating from the formation of the first stars, billions of years ago.

Science ‘on the Moon’ will investigate the effects of the lunar environment on robotic instruments, equipment and humans. Exposure on the lunar surface to low gravity, radiation, dust, micrometeorites and wide variations in temperature will pose numerous challenges. Understanding these effects will enable engineers to develop materials and design systems for long-term use by humans in this hostile environment.

To sustain human presence beyond Earth, we must learn from science ‘on the Moon’ how to live and work on other celestial bodies. A critical step will be to determine whether we can use the Moon’s resources. For example, the ability to extract oxygen from the lunar soil might provide not only breathable air for the crew’s life support system but also perhaps fuel for spacecraft.

Another priority will be to build on our experience with the International Space Station to develop efficient recycling techniques that will reduce the use of consumables such as air, power and water. This work may also teach us how to manage precious resources on Earth.

Finally, it is incumbent upon us to consider that the lunar environment is both fragile and special; we must protect and preserve it even as we explore it.

The Moon, as our closest ‘natural space station,’ is the ideal place for humanity to develop the capability to journey to Mars and beyond. The Moon is only three days travelling time from Earth, compared with a minimum six months for Mars, and the communications delay is only one and a half seconds instead of tens of minutes.

The development of transportation, life support and habitation systems, and advanced robots, can all be attempted in a challenging environment on the Moon, before they are used farther away. Human explorers will also use the Moon to develop their skills and learn how to prepare their bodies and minds for the long journey ahead.

The Moon has a strong place in the culture of many peoples and it instinctively appeals to the human imagination. It is the only celestial body that is familiar to all humanity as a ‘place’ and not just a point of light. It is a place, moreover, that many more humans can aspire to visit in the future.

Just as the first lunar landings nearly 40 years ago enthralled an earlier generation, lunar exploration in the years to come will continue to inspire enthusiasm and creativity among future generations around the world.

Compared with the early days of lunar exploration, the more sophisticated media of today will create novel means to relate the space exploration journey to all people. Anyone may be able to participate personally in lunar robotic and human missions through virtual-presence technologies. In particular, children can be involved and will be inspired to become the explorers of the future – as scientists, engineers, teachers and entrepreneurs.

Chapter 5

To Mars and Beyond

Mars is a key focus for space exploration because it has both an atmosphere and water. Increasingly complex robotic missions are already being mounted to study its geology and to search for the presence of ancient and maybe even existing life forms. As robotic capabilities reach their limits, humans will step in to unlock further secrets. Other destinations such as asteroids, comets and the moons of the giant planets are also important targets of human curiosity.

Mars engages the public's imagination as much as the Moon – perhaps even more. Millions avidly follow the adventures of little rovers that explore the Martian surface. Human exploration, when it happens, will be even more exciting.

The possibility of humans visiting, exploring and living on Mars may be the most challenging but also the most rewarding objective of space exploration in this century. Although many approaches to such a mission have been studied, its technical and financial feasibility is not yet certain and much more preparation is needed.

At present, Mars is being explored by robotic orbiters, landers and rovers. In the longer term, there are plans for ambitious robotic missions to return samples from the Martian surface.

A better knowledge of Mars would help us better understand Earth's history and evolution. Evidence suggests that Mars and the Earth were, long ago, even more similar than they are today. The reasons for their subsequent divergent evolution are still poorly understood. Questions remain as to whether life could have appeared on Mars or could even still exist today.

A close-up study may yield important clues about how the planet evolved from one capable of sustaining life to the barren world we see now. By studying Martian geology, weather and climate and other natural phenomena, researchers will learn not only more about Mars but also gain insight into how Earth's environment has evolved and how it may change in the future.

At present, the focus is on robotic reconnaissance and surface exploration. Drilling to collect samples will help further unravel the history of the planet and the possible evidence of life. For example, reaching under the Martian surface may reveal life forms protected from the harsh cold and radiation above.

Robotic exploration is ultimately limited, though. More effective exploration can be achieved by leveraging the insight and ingenuity of human explorers sent to Mars.

Because of its similarity to Earth, Mars is the place in the solar system where human life could most likely be sustained in the future. There are many significant technological challenges that must be overcome, but Mars also gives us something to work with. It has a thin atmosphere that partially shields the surface from radiation. Surface temperatures at low latitudes are quite harsh but not unmanageable. And it has a day-length only 37 minutes longer than Earth's, which makes the production of electricity from solar cells feasible. This could sustain humans and their machines until more advanced power sources are available.

The potential presence of water ice and maybe liquid water under the surface might make sustained human habitation more practical and self-supporting. It may also be possible to synthesise methane and oxygen rocket propellants from the carbon dioxide in the atmosphere and hydrogen from water ice.

When they go, humans will be able to advance the exploration of Mars in ways not possible with robots alone.

Several nations can afford to send their own robotic exploration missions to Mars but there are significant benefits in coordinating these national efforts and future human exploration missions. Groups like the International Mars Exploration Working Group are already making this happen for scientific missions. Given the enormous challenges, human exploration of Mars may only be achievable through sustained international cooperation.

The historic decision to start the human journey to Mars is still several years away. However, two important first steps are being taken: first, the engagement of more nations in space exploration; and second, the start of global coordination, as foreseen in this Framework document.

As with the Moon, the Martian environment is both fragile and special and we must protect and preserve it, even as we explore it.

Asteroids and comets left over from the formation of the solar system have high scientific interest. Robotic spacecraft have already started to explore these relics of the early solar system, which contain water and organic compounds. The first material to be returned from a comet's tail is already yielding unexpected results. Future discoveries are certain when pristine material from a comet's nucleus, and from an asteroid, can be brought to Earth.

In parallel with the sustained human exploration of the Moon, the robotic exploration of Mars, asteroids, and other destinations offers nations the chance to develop important skills that may later be used when humans start to explore Mars and beyond.

The first sample-return mission to an asteroid is already on its way back to Earth and an attempt to land a probe on the surface of a comet is underway. Such missions could also give us a better understanding of the risk presented by a few asteroids with orbits that could cause them to hit Earth.

More distant destinations, such the moons of the giant planets Jupiter and Saturn, are extremely important scientifically. For example, Europa likely has liquid water beneath its ice crust and Titan's cold, dense atmosphere contains carbon-based molecules. These are not realistic targets for human exploration in the coming decades, but they will become more accessible as space exploration technologies improve.

Chapter 6

Implementing the Global Exploration Strategy

International cooperation expands the breadth of what any one nation can do on its own, reduces risks and increases the potential for success of robotic or human space exploration initiatives. It is important to establish and sustain practical mechanisms to support exploration if humanity is to succeed in implementing long-term space exploration on a global scale.

In early 2006, 14 space agencies began discussing their common interests in space exploration. With different backgrounds, interests and capabilities, the agencies have started to develop a mutual understanding of, and language, for space exploration.

The success of the preliminary discussions suggests that the future establishment of a formal, though non-binding and voluntary, coordination mechanism among interested space agencies could assist the development and implementation of the **Global Exploration Strategy**.

Such a mechanism could help coordinate global space exploration by:

- providing a forum for participants to discuss their interests, objectives and plans in space exploration; and
- promoting interest and engagement in space exploration activities throughout society;

for purposes of:

- making use of all available resources, knowledge and technological capabilities;
- leveraging each agency's individual investments;
- identifying gaps in national programs and overlaps between them;
- sharing 'lessons learnt' from national and international missions;
- improving the safety of humans in space – for example, through interoperability of life support systems; and
- enhancing the overall robustness of global space exploration.

Principles of International Coordination

The table below outlines key principles for international coordination for sustainable space exploration and examples of resulting requirements for the mechanism.

Principles	Resulting Requirements
Open and Inclusive	• receives inputs from all interested agency participants that invest in and perform activities related to space exploration • provides for consultations among all interested agencies with a vested interest in space exploration, and also space agencies or national government agencies without specific related capabilities

Flexible and Evolutionary	• takes into account and may integrate existing consultation and coordination mechanisms • allows consultation and coordination structures and mechanism(s) to gradually build and evolve as requirements for these activities grow • allows for entry of assigned representatives of governments with a vested interest and clear stake in space exploration • provides for different levels of consultation and coordination
Effective	• encourages participating agencies to accept the role of the coordination process and act upon the anticipated results of the coordination mechanism
Mutual Interest	• contributes to common peaceful goals and benefits all participants • respects the national prerogatives of participating agencies • allows for optional participation based on the level of each agency's interest

The Way Forward

Using the principles elaborated above, the 14 space agencies have agreed to pursue the establishment of a formal **Coordination Mechanism** for the coordination of the Global Exploration Strategy. The specific terms of reference for such a mechanism are being defined and will be described in a separate document.

Although potential areas and activities that could benefit from coordination may change over time, areas for initial consideration include:

- identification of standards to promote interoperability;
- methods for sharing scientific data and related analyses;
- identification of common services, allowing for the development of shared infrastructures;
- mechanism(s) to allow the provision of payload opportunities;
- ways and means to include broader future participation in the planning and coordination process; and
- an assessment of the requirement for any relevant international legal agreements.

The 14 participating agencies have recognized that the development of a common international exploration coordination tool will enhance the implementation of the coordination process. This coordination tool is being defined and will be described in another document.

The Coordination Mechanism will be a voluntary partnership. It will not diminish each agency's right of autonomous decision-making. However, all participants hope that sharing knowledge, ideas and plans will help to optimize agency decisions.

Chapter 7

A Window to Tomorrow: Why We Explore

Space exploration is a global partnership in service of society. It will require both human endeavour and technological innovation and it will deliver new knowledge and commercial opportunity.

Space exploration is driven by:

- **human civilization**: extending human presence to other planets to enable eventual settlement;
- **scientific knowledge**: pursuing scientific activities that address fundamental questions about the history of Earth, the solar system, and the universe – and about our place in them;
- **global partnerships**: providing a challenging, shared, and peaceful activity that unites nations in pursuit of common objectives;
- **economic expansion**: expanding Earth's economic sphere and conducting space activities that benefit life on the home planet; and
- **public engagement**: using a vibrant space exploration programme to engage the public, encourage students and help develop the high-tech workforce required to address the challenges of tomorrow.

This Framework for Coordination of the Global Exploration Strategy presents a vision of tomorrow in which the human frontiers are permanently expanded into the solar system, inspiring generations of humanity to come. It foresees how the robotic and human space exploration efforts undertaken by many nations, working individually and in partnership, could be coordinated to maximise the long-term benefits for all humanity.

Each agency that has contributed to this document shares this vision and invites other agencies or institutional bodies around the world to join them in translating the vision into reality.