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ISSUES IN BRIEF

The Future of Space Exploration: The Next 50 Years

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The Frederick S. Pardee Center for the Study of the Longer-Range Future at Boston University convenes and conducts interdisciplinary, policy-relevant, and future-oriented research that can contribute to long-term improvements in the human condition. Through its programs of research, publications and events, the Center seeks to identify, anticipate, and enhance the long-term potential for human progress, in all its various dimensions.

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Leading visionaries, critical thinkers and entrepreneurs from around the world met at Boston University for three days in Spring 2007 to discuss the future of space exploration. Appropriately, the meeting started on April 12, the anniversary of Yuri Gagarin's history-setting lift-off, and began with an opening address from Dr. A.P.J. Abdul Kalam, then President of India and a leading architect of India's space program.

The participants — historians, theologians, engineers, policy experts, astronauts, students, teachers, businessmen, scientists as well as representatives from government, military and the press — took stock of the fruits of space exploration in the past 50 years and recommended a collective vision for the next 50 years of space activities. This international group gathered to challenge the prevailing wisdom in each of their disciplines and to provide a broad perspective to a simple question framed in the title of the symposium: The Future of Space Exploration: Solutions to Earthly Problems? This paper outlines some of the answers to this question drawing on thoughts exchanged at this seminal meeting.

> "The correct answer to the trick question on the number of known planets is not eight or nine, but rather 300 or more."

Historical Context of Space Exploration

Fifty years ago, space exploration was a race between two superpowers. Today, it is a multi-disciplinary activity of Olympic proportions with representation from many countries. The Ansari X-Prize to successfully launch and return humans in space twice within a span of two weeks by a non-governmental entity, was won in 2004 on the 47th anniversary of the Sputnik-I launch. The fifth tourist in space was circling the globe aboard the Russian space Station Mir during our 2007 conference.

The discovery and exploration of new worlds have made epochs in the history of the human mind and spirit, and we seem to be on the brink of another such epochal moment. The correct answer to the trick question on the number of known planets is not eight or nine, but rather 300 or more. The scientific debate now centers on the uniqueness of our solar system. The technologies that are being developed in the US, Europe and elsewhere promise to produce, within a decade, the first image of a Jupiter-like planet orbiting a Sun-like star in our galactic neighborhood. With these being real possibilities, we can now ask questions such as: Are we and our planet unique? What type of life could exist in environments other than those found in planets? What are the necessary benchmarks describing global processes responsible for life? What are the drivers for habitability? Does space exploration have important implications for humanity and for human development?

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The space industry is now mature enough that private companies are discussing space tourism and other commercial ventures as viable enterprises in the near future. A rocket racing league is set to satiate the ultimate thrill for the double-digit G-force deprived, ground-dwelling denizens. The pervasive presence of mobile phones and images taken by remote sensing satellites have demonstrated the commercial viability of unmanned space business. Now we are ready to ask questions such as, how well do we understand the space weather phenomena that have shown serious detrimental effects on satellites, various communication and navigation systems as well as power grids? How long will it be before we can routinely and accurately forecast space weather, so we may take appropriate precautionary actions?

The success of progress in the scientific exploration of space could be traced to the development of research tools such as spectrometers, radiosondes and cosmic ray detectors as well as innovative materials, electronics and computing technology. New observation platforms like balloons, high altitude aircraft, rockets and satellites and propulsion technology take our novel sensors to reveal phenomena stranger than magical dreams and require frequent rewriting of text books. Our spacef ight instruments have discovered a hole in the ozone layer that has serious consequence for life on Earth; found evidence of running water on Mars; brought back dust scooped up from a comet; and established the age of the universe to one per cent accuracy. The role of space exploration to satisfy our innate scientific curiosity is not a topic for debate any longer.

The progress in space technology since these early days has been explosive; in less than four years after the f ight of Sputnik I, the first human was in space and less than a decade after that monumental achievement, the first human walked on the moon. Today the images captured by our instruments on a dusty, rock-strewn, rust-red planet are available in near-real time from Ankara to Zanzibar. These technological feats make all of us vicarious virtual-travelers to these exotic locations and inspire and unite us as humans. Being in space has opened up breathtaking new vistas — we have seen the Earth for the first time as a glorious but fragile pale blue orb and expanded our vocabulary with acronyms and phrases such as GPS (Global Positioning System) and Space Station. Venturing into space is now routine enough that it is newsworthy only when the results of such attempts are catastrophic. We now ask

The Future of Space Exploration: Solutions to Earthly Problems?

Leading space scientists and experts from around the world met at Boston University in April 2007 to discuss the future of space exploration. The conference marked the 50th anniversary of the launch of Sputnik and the 40th anniversary of the Outer Space Treaty, and was co-organized by the Frederick S. Pardee Center for the Study of the Longer-Range Future, the BU Center for Space Physics, and the Secure World Foundation.

The meeting brought together some of the leading thinkers on space exploration. It began with a keynote address (via satellite) from the then President of India, Dr. A.P.J. Abdul Kalam, and participants included such luminaries as Lord Martin Rees, Royal Astronomer and President of the Royal Society; leading authorities including Roald Sagdeev and Freeman Dyson; Nobel-winning astrophysicist John C. Mather; former astronauts Harrison Schmitt, Jean-Jaques Favier and Russell L. Schweickart; and those who have seen and studied the history of space exploration at close quarters, including Steven Dick, NASA's Chief Historian, and Susan Eisenhower and Sergei Khrushchev.

Through exciting discussions and debate, participants took stock of space exploration in the past 50 years and crafted a conference 'declaration' that recommends a collective vision based on the following priorities for space exploration in the next half century:

1. SPACE GOVERNANCE. A system of laws, regulations and agreements are needed that include: (1) prohibiting space weapons; (2) managing traffic of space vehicles to avoid collisions and ensure uninterrupted satellite services; (3) managing the global environment and security; and (4) enabling and encouraging private and national space utilization.

2. PUBLIC PARTICIPATION. To ensure the long-term sustainability of human endeavors in space, the public can be, and should be, directly integrated with space missions.

3. RESOURCES AND ENERGY. Material resources, energy sources and other sources of economic value in space need to be developed for their potential to improve the quality of life on Earth.

4. BIOTECHNOLOGY. Developments in biotech may allow humans to live in space without harmful effects of space radiation or bone degradation. This will have profound effects on the limits of human experience and our presence in the solar system.

5. STRATEGY. A 50-year global vision should be developed that can provide guidance for the future of human endeavors in space, concurrently with a 10-year horizon rolling plan, considering the needs of all peoples.

questions like: what is in store for science from space? What is the appropriate mix of medium to large programs and high-risk with high-return small programs that will maintain the vitality of space science and technology? How do we leverage the best science by creating the right environment that makes space science missions international? Is there an optimal mix of Earth-based versus space-based science for disciplines that use both? How do we prepare our next generation of space explorers? The answer to these types of questions will determine what kind of science-savvy society we will have in the next 50 years.

Historically, the development of space technology has progressed hand-in-hand with the need for security. However, at the height of cold war, we saw the Apollo-Soyuz Test Project, an outstanding example of scientific and technical cooperation in space. But in recent years the continued peaceful use of space has come into question. Even conventional warfare is heavily dependent on space-based assets, which are extremely vulnerable. Over the next 50 years this already acute problem may loom larger. We will need to determine the appropriate framework for sustainable international collaborations in space science. Our answers to questions such as what options we have for global cooperation in space and what decisions will have to be made will set the agenda for future discussions and provide a durable guide, touchstone, and reference for policymakers for the next half-century and beyond.

The next decades will bring revolution in our exploration of space fueled by the expected convergence of technological developments in all of the related fields. Now, we stand at a critical junction. The tremendous potential offered by access to space can be used to solve many of the important human issues — scientific and technological as well as societal. How we approach these in the geopolitical context will determine our future landscape.

An Exercise to Chart a Course for The Next 50 Years

One of the primary objectives of the April 2007 assembly was to chart a course of action that would ensure the long-term vitality of the space program. An equally important consideration was to identify a path to a future that would explicitly consider the solution to critical human needs to benefit the global society. The conference participants evaluated the contribution space exploration made in different arenas and the many different routes it has taken in different countries to identify key focus areas for global attention. In the end, five areas were identified as being of particular importance:

- First, there is an urgent need to establish clear guidelines for activities in space that would allow this vision to succeed.
- Second, harnessing material resources and energy to address pressing present global needs could benefit from space-based solutions.
- Third, it is clear that there will be expanding and extended human presence in space in the foreseeable and longer-range future and we need to be prepared for this.
- Fourth, incorporation of the latest developments in biotechnology in future human exploration of space would improve the quality of life on earth.
- Finally, international mechanisms need to be in place to ensure that the future of space exploration is truly global in its implementation and its benefits.

The Need for a Clear and Enforceable Code of Conduct

When there were only two space-faring nations, many of the rules of the road could have been implemented with a ceremonial handshake. With many countries and many private industries actively pursuing space exploration, that may require an awkward group hug. The disparate cultures and interests of governments and private enterprises demand that it would be in the best interest of all to avoid the reenactment of scenes from Star Wars involving any combination of humans and robots played out in a sky near us. Every "crazy" action in space may have serious consequence; while throwing a soda bottle out the rear window of a car may not cause significant damage, similar action in space results in catastrophic consequences. With multiple countries pursuing trips to the Moon, Mars and beyond, and private entrepreneurs salivating over mineral or other property rights on heavenly bodies, it is essential that a range of comprehensive guidelines in the form of agreement to laws are carefully drafted.

> "Availability of funding for science and technology is often a political decision, made on the basis of an established (or perceived) social contract between the people, political leadership, and the scientific community."

Since these guidelines will have a wide-ranging impact, any such plan should involve the largest possible number of stakeholders. These initiatives, whatever they might be, would require international cooperation and joint decision-making that would consider and respect collective interests. For their successful implementation, it may be necessary to bolster goodwill and appeal to the best of human spirits by an appropriate and collaborative enforcement program.

The 1967 Outer Space Treaty provides a very important step towards this goal, even though some of its shortcomings have been exposed by clever enterprising minds such as the one who claimed ownership of the Moon as an individual and then proceeded to sell acres of it at a time. One of the first items the treaty addressed was the free exploration of celestial bodies exclusively for peaceful purposes. Even though there is no consensus on the definition of "space weapon," it can be argued that weaponization of space has already begun. Satellites for military reconnaissance are sometimes called *gun sights in space* — a not-so-subtle signal of their potential usage. Modern warfare depends critically on space assets to identify and transmit information on targets to the appropriate subsystem, track targets and to follow up on the result. There are scenarios in ballistic missile defense systems that could arguably be considered weapons in space. We have seen demonstration of anti-satellite missile tests; furthermore, many countries already possess the necessary technologies to jam or interfere with communication using lasers or other means that do not necessarily require overt demonstration in space. In an environment like this, to instill confidence in the partner nations and indeed in non-government entities, who are guided by different political, economic and other motivations, a set of principles that prohibit weaponization in space would foster the spirit of cooperation that the Outer Space Treaty started.

"The possibility of harvesting helium-3 from the Moon to use in the production of energy through fusion is another attractive option."

As society depends increasingly on modern creature comforts provided by space-based systems, even space feels crowded with the large number of satellites placed by various countries and companies, with more vying to place theirs. This is especially true in geosynchronous orbits (GEO) favored by communication satellites huddled in a sliver of prime real estate above the Earth's equator. Navigational systems such as US GPS, Russian Global Navigation Satellite System (GLONASS) and European Space Agency's (ESA) Galileo do not use the GEO. For uninterrupted operation and to avoid interference from neighboring satellites, we currently have guidelines that dictate the spacing between the satellites. The demand for increased communication bandwidth will undoubtedly strain the presently adopted limits in the upcoming decades and will require more sophisticated station keeping and frequency rationing than presently available. Simple missteps or accidents in a crowded and highly charged political atmosphere could be misinterpreted as a deliberate security threat, even though there is no precedence of such occurrence.

While the majority of the efforts in space exploration revolve around increasing performances, the currently available capabilities will become increasingly affordable and attractive, whatever the objective might be. Even with a myopic imagination it is not difficult to extrapolate to a future where individuals or groups with nefarious mindset could create terrifying scenarios involving anti-satellite activities. Additionally, the threat posed by the increased availability of long-range ballistic missiles adds color to possible horrible plots. A universally acceptable and enforceable code of conduct would allay these concerns.

The damage caused to the home planet by impact of asteroids is understood enough to have its own Torino Impact Hazard scale — a logarithmic scale that describes the nature of the encounter between near-Earth objects and the Earth and their consequences. A process is underway to develop a protocol under the auspices of the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) to develop a decision-making strategy. The mitigation of this planet-scale cosmic environmental disaster would require collaboration from all space-faring nations.

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The complex issue of space governance continues to intrigue the youth and veteran space professionals alike. The student representatives at the conference reported their desire to see an update of the Outer Space Treaty. They noted their concern about activities in space that could have long-lasting negative impact on the Earth and human activities. A full 70 percent of the respondents to a survey they conducted advocated the formation of a new space governance body. It appears that the time is ripe for the development of a comprehensive set of guidelines describing acceptable activities in space.

It is possible to articulate a global vision for the future of space exploration. However, we cannot ignore the geopolitical and economic reality or the demonstrated failure of key developments that are responsible for the current extensive presence in space. It would therefore be prudent to periodically review the plans. In the US, the National Academies have produced Decadal Plans in many of the science disciplines. Our vision for the next 50 years needs to consider incorporating the progress in technology and other relevant fields with a 10-year periodicity to fine-tune the short-term goals as necessary.

Use of Resources and Energy Harnessed through Space Exploration

Minerals that could be harnessed from asteroids or the Moon have long lured entrepreneurs. For example, the relative abundance of iron, calcium, manganese and titanium are significantly higher on the Moon than they are on the Earth. Engineering feasibility studies have suggested that there are commercially viable means to use these minerals on the Earth.

The possibility of harvesting helium-3 from the Moon to use in the production of energy through fusion is another attractive option. In spite of the significant risk and expense for these ventures, the potential for the rights to these properties might be a key impetus for private investors. The availability of additional sources of clean energy could solve many of the problems society is expected to experience in the coming decades. Use of other material from the lunar regolith, or surface rock layer, in combination with solar power has also been proposed as a means for generation and storage of power to support the exploration efforts on the Moon.

The possibility of using water from the permanently shadowed interiors of craters near the polar region of the Moon has received considerable attention, viewed as a pathway for sustainable long-term human presence on the Moon. Such a presence could open up new commercial opportunities. There will be other benefits of a permanent human presence on the Moon. For example, a scenario of the human exploration of Mars uses a lunar base as a staging ground. Also, astronomers have argued in favor of deploying telescopes on the far side, which would be free from earthly interferences.

There might be other ways to mine the riches of resources accessible in space that we have not considered here. Many of these activities could directly benefit life on Earth. Some may be technically feasible now, and need political will and public support. Others may require demonstration of their potential benefit either through computer simulations, or by analogy or actual demonstration that is scalable. Use of space resources that would allow further exploration and improve life on Earth will be one of the global grand challenges for the upcoming decades.

Incorporation of Just-In-Time Technology

Space business is conservative. It is naturally risk averse and demands the use of proven technology. For example, the space shuttle f ies with five general purpose computers that control most of the essential functions. They were originally developed in the 1970s and upgraded in the early 1990s with a lighter (29 kg) and less power-hungry (550 watts) version. The primary motivation of using this older technology is safety. For example, five computers provide redundancy. They are also designed to work under extreme conditions involving vibration, shock (launch and landing), temperature extremes and radiation exposure (lack of protection from the atmosphere). It can also be argued that modern cars have a lot more computing power and they also must work properly even after being subjected to prolonged vibration and some moderate temperature excursions. Incorporating technology developed elsewhere can have many beneficial effects on the space program. One vivid example was the use of airbags for landing a spacecraft on Mars.

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The biotechnology revolution has already produced drug delivery and health monitoring systems that were the topics of science fiction not so long ago. After several surgeries in Antarctica, telemedicine in space should not be any riskier than in some other remote corner of the Earth. These spectacular advances and the many more to come will change the health and survival capabilities of the humans in space. As we gain more confidence in biotechnology, incorporating biotechnologies to ameliorate the harmful effects of space radiation or bone degradation would not be considered heroic acts. As we domesticate biotechnology and nanotechnology along with the information technology, the future in space exploration could indeed be unimaginably bright.

A Strong Public Support is Essential

The long-term vitality of space exploration relies upon the enthusiastic support of tax payers from many countries. The market for privately financed trips to the Mir space station as well as suborbital trips has been well-established. An extrapolation from this to the Moon or at some future time to Mars is not completely ludicrous. While the era of private space tourism has begun, it will remain inaccessible to the vast majority of the world population for the next few decades. However, public participation is essential to develop the necessary tools that will lead us to that day.

There are several hurdles we have to overcome. First, the risk of human space programs in western society is on display when the public reaction to the terrible accidents of the space shuttle program is often the only reminder of an on-going space mission. This aversion to risk is also prevalent in the robotic exploration, which may be viewed as lacking the pioneering spirit. Furthermore, it is difficult to excite the majority of the present generation, who

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sometimes wait days in line to get their hands on the latest in mobile telephone technology, by a static image of a collection of dots (data) along a beautifully smooth line that shows the theoretical prediction of the Big Bang, even if that won Dr. John Mather a trip to Stockholm to collect a Nobel prize in December 2006.

One cannot ignore the political environment in any decision involving two or more nations. Fortunately, we have seen successful bilateral collaboration between the US and Russia that brought significant political, technological and economic benefits for both partners. It should not be difficult to demonstrate that the opportunity costs for similar effort involving all space faring nations is minimal and the return is priceless.

"To ensure the long-term sustainability of human endeavors in space, the public can be, and indeed must be, directly engaged with space missions."

This ever-widening chasm between what can be done technically and what there is motivation to do must be bridged by emphasizing the many benefits of space exploration to the human race and indeed its long term vitality and survival. The overnight explosion of awareness and popularity of the environmental movement gives a lot of hope that it would not be such a long row to hoe. To ensure the long-term sustainability of human endeavors in space, the public can be, and indeed must be, directly engaged with space missions. We need clear communication of the benefits of space exploration to society, emphasizing that our survival is the foremost incentive — in terms of space providing knowledge of our environment and space systems providing warnings of natural and cosmic disasters, use of resources in space to generate clean energy and, someday, through the potential of self-sustaining settlements off our home planet.

One of the young participants at the conference articulated this scenario in the most hopeful language: young people see the connection between space exploration and the survival of the human species, and would like to see the technology and knowledge gained from space exploration being used for the survival of the human race. It is time that the rest of us learn to speak their language.

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