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A SPACE EXPLORATION INDUSTRY AGENDA FOR INDIA

by Chaitanya Giri,
Fellow, Space & Oceans Studies Programme

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List of Abbreviations

AI	*Artificial Intelligence*
ASCL	*Advanced Space Concepts Laboratories*
BMDO	*Ballistic Missile Defense Organization*
BBIL	*Bharat Broadband Internet Limited*
CII	*Confederation of Indian Industry*
CLEP	*Chinese Lunar Exploration Programme*
CRIS	*Centre for Railway Information Systems*
CSIR	*Council of Scientific and Industrial Research*
DAE	*Department of Atomic Energy*
DOD	*Department of Defense*
DoS	*Department of Space*
DSIR	*Department of Scientific and Industrial Research*
DSN	*Deep Space Network*
DRDO	*Defence Research and Development Organisation*
ESA	*European Space Agency*
GGAN	*GPS-Aided Geo Augmented Navigation*
GDP	*Gross Domestic Product*
GSAT	*Geostationary Satellite*
GSI	*Geological Survey of India*
IHSFP	*Indian Human Spaceflight Programme*
IIT	*Indian Institute of Technology*
IP	*Intellectual Property*
ISECG	*International Space Exploration Cooperation Group*
JAXA	*Japan Aerospace Exploration Agency*
MoES	*Ministry of Earth Sciences*
MSME	*Micro, Small and Medium Enterprises*
NASA	*National Aeronautics and Space Administration*
NHAI	*National Highways Authority of India*
NSIL	*New Space India Limited*
NZSA	*New Zealand Space Agency*
OECD	*Organisation for Economic Cooperation & Development*
PMO	*Prime Minister's Office*
R&D	*Research and Development*
RDTE	*Research, Development, Testing & Evaluation*
RESPOND	*Sponsored Research*
TTC	*Telemetry Tracking and Command*
UAESA	*United Arab Emirates Space Agency*

Introduction

In 2022, India will celebrate the 50th anniversary of the establishment of the Department of Space (DoS), the lead administrator of its space programme. A diamond jubilee is a good time to review India's space aspirations and consider whether they need to be revised.

DoS, which began as a unit of the Department of Atomic Energy (DAE),[1] has built a vast repertoire of space technologies, forged strategic international space cooperative relations, managed superpower economic conflicts that threatened to interfere with its acquisition of essential materials and technologies, and led India to touch the south pole of the moon (2019). India's prolific civilian space programme helped nurture the technologies of the first space age – Space 1.0. It used these technologies to fulfil a mandate to address socio-economic concerns. It broke new grounds in satellite-based agriculture support, distance education, long-range communications, multimedia and weather-forecasting.[2]

The socio-economic goals that the DoS vowed to address in the 20th century have been met. India today is a much more advanced country, with an economy now ranking 5th in the world.[3] But times have changed, and India's space programme must change with them. Just as the First Space Age (Space 1.0) was closely linked to the rise of semiconductors, plastics and composites, which defined what is known as the Third Industrial Age (Industry 3.0), a new, Second Space Age (Space 2.0) is emerging as the Fourth Industrial Age (Industry 4.0), based on the merger of cyber and physical systems.[4]

But achieving a marriage of space technology and industrial development today will require different approaches than those pursued during the Space 1.0. Space 2.0 is witnessing a heightened interest in space exploration based on the canon of commercialisation-industrialisation-democratisation. For the first time countries are extensively commercialising their space programme. As part of that effort, they are formulating new space policies and visions designed to stimulate the development, scale-up, and market permeation of new technologies by Micro, Small and Medium Enterprises (MSMEs) and large industrial corporations as well as public and private institutions that engage in research, development, testing and evaluation (RDTE).

This transformation is occurring at a time when space programmes and associated economic developments are becoming democratised; countries that previously lacked space agencies or formal structures for space exploration are seizing opportunities to participate in the new space age. They are shunning the old Space 1.0 models. They are merging cutting-edge cyber and physical technologies, including ones built in non-space technology ecosystems, to meet current and future needs of space exploration and the economic and social needs of the immediate future.

Recognising the link between space programmes and new-age technologies, most of India's Space 1.0 contemporaries – Russia, U.S., Japan and China – already are commercialising and industrialising their space sectors, and in the process moving beyond strict national space programme silos and in favour of public-private collaboration that spans across domestic and global realms. But India's space programme remains driven by a single government agency, the Indian Space Research Organisation (ISRO). Held back by nostalgia for past achievements that have come painstakingly, India's civilian space programme is reluctant to move beyond the Space 1.0 era ethos, practices and skills.

Its reticence is nothing new. India avoided space exploration for the first four decades of the civilian space programme, viewing it as a fantastic pursuit limited to the most economically advanced nations. [5] Now, despite its moments of glory in recent years, the Chandrayaan series of lunar missions (2008 and 2019), the Mars Orbiter Mission (Mangalyaan, 2013), and the ongoing Indian Human Space Flight Programme (IHSFP) or Gaganyaan, have yet to result in large-scale economic liberalisation that will put India's space exploration sector among leaders in space and industry.

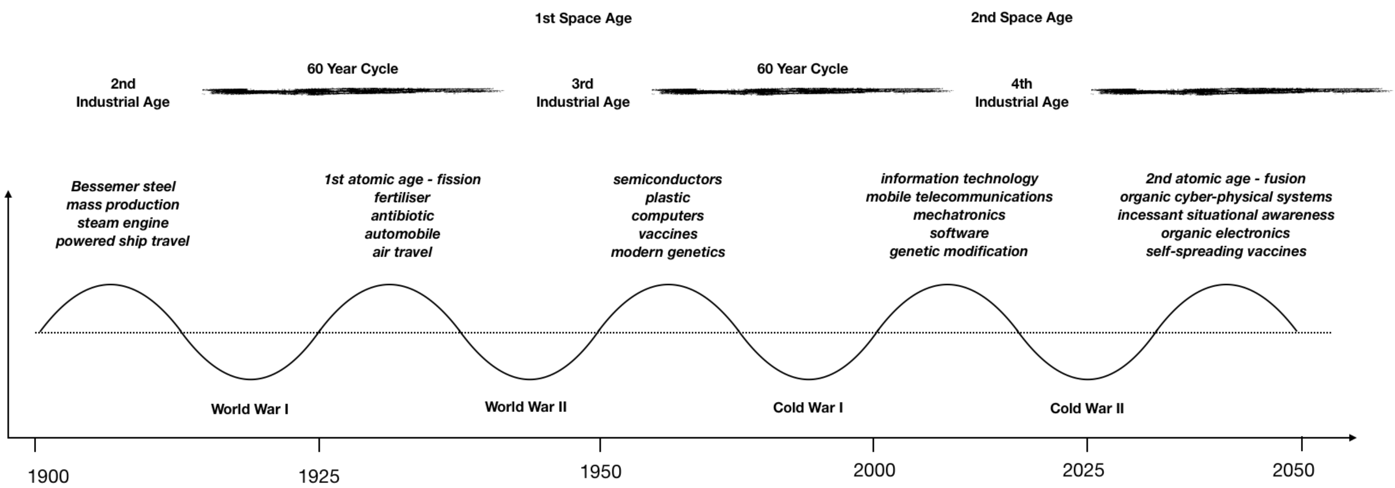
India's civilian space programme must let go of the past and start preparing for Space 2.0. It must foster indigenous technologies and ensure synergies with the Indian private sector, including start-ups and large private companies. Failure to act – to exploit fully the economic opportunities that could result from a robust national public-private space exploration programme – would mean more than lost opportunities in space. India could miss chances to spur its economic growth on Earth.

1. An Opportune Moment For Global Industry 4.0 In Space

The end of the Second World War led to an accelerated technological evolution that ushered the world into Industry 3.0.[6] The U.S., Russia, France, Germany, UK, and Japan pioneered research that led to revolutionary changes in aeronautics, polymers, semiconductors, computation, information technology and electronics. Not surprisingly, the same countries dominated the First Space Age (Space 1.0), reaping the economic and strategic benefits of being first movers in nurturing diversified innovation and vibrant industrial ecosystems. Their efforts showed that any nation that can function at the frontiers of scientific research and development can be a leader in outer space too.

The world is now experiencing a new wave of technological innovation (Figure 1). Industry 4.0 will offer advanced and emerging economies a rare chance to compete on a level playing field. But this window of opportunity is narrow; only countries that can develop and take Industry 4.0 technologies from R&D through commercialisation and secure market niches will rise technologically and, hence, politically.

Figure 1: The Cycle of War and Technological Revolution. The world is currently at the onset of the Second Cold War – between U.S. and China – and the onset of the Fourth Industrial Age



Source: Gateway House Research

As in the past, countries that lead in developing Industry 4.0 science and technology – such as personalised medicine, small satellites, artificial intelligence, additive manufacturing, clean and regenerative fuels, enhanced long-range communication systems driven by hyper-connectivity tools, and self-healing and radiation-resistant materials – stand a better chance of augmenting global space exploration capabilities, and thus surely earning socio-economic dividends from Space 2.0.

Important Industry 4.0 technologies and their applications in Space 2.0

Personalised medicine	Vital for astronauts during long-duration space travel
Small satellites	Expendable, low-cost, low-mass and miniaturised material consumption as against conventional satellites
Additive manufacturing	In-orbit and extra-terrestrial printing of satellites, spacecraft and human habitats
Clean and regenerative fuel	Cost-effective, low-mass, long-lasting fuels for in-space and extra-terrestrial robotic and human-rated missions
Enhanced long-range communications systems	Low-latency cis-lunar (Earth-Moon) and interplanetary internet and telecommunications network
Self-healing and radiation resistant materials	Self-healing materials for repairing the mechanical and structural damages incurred by satellites and spacecraft through impact events, caused by debris or natural meteoroids. Radiation-resistant materials to protect sensitive electronics and equipment and for human-rated space missions

Industry 4.0 technologies are not the exclusive domain of established space-faring countries. Many technologically advanced nations which, for a variety of reasons, did not pursue national space programmes during Space 1.0 – Australia, New Zealand, Luxembourg, Czech Republic and South Korea, for instance – have top-class competencies in niche Industry 4.0 technologies. These could make them indispensable in new global space-technology supply chains in the near-future.

India has had a robotic space exploration programme for 20 years. With successful missions to the Moon (Chandrayaan series) and Mars (Mangalyaan series), it has demonstrated its ability to undertake complex interplanetary missions. But these have been achieved with Industry 3.0-era technologies that are fast facing commercial obsolescence.

To thrive in the Space 2.0 era profuse with the newest Industry 4.0 technologies, India's space exploration efforts need vision and patronage from the highest level – the Prime Minister who oversees the Space Commission, the Indian government's outer-space policy-making body.[7] Until the Prime Minister's Office puts forth a multi-decade national space-exploration vision, India's space exploration missions will remain laggard and dependent on the limited resources available within ISRO. And unless the national space-exploration vision includes a major role for India's private sector start-ups and corporations, the country faces an uphill struggle to compete as a provider of Industry 4.0 technologies that will drive space exploration and economic growth in the years ahead.

2. New Spacefaring Nations Focus On Integrating Industry 4.0 And Space Exploration

A new and more competitive era of space exploration is upon us. The U.S. is in the lead. The world's leading superpower, it dominated the Space 1.0 landscape. During the shift from Space 1.0 to Space 2.0, the U.S. approach has undergone a significant change.

U.S. space exploration missions of Space 1.0 were conceived not only by its civilian space agency – National Aeronautics and Space Administration (NASA) – but also by the U.S. Department of Defense (DoD). DoD's interest in celestial bodies can be gauged by its decision to give the Ballistic Missile Defence Organization (subsequently renamed the Missile Defense Agency) a central role in the 1994 Clementine mission to the Moon.[8]

Both DoD and NASA benefited initially from a small, but effective, U.S. private space-technology ecosystem that provided spacecraft, space-probes and payloads to both the military and civilian agencies. It eventually became clear that this limited set of government-run agencies, working with a select few space and defence contractors, could not fulfil all the needs of the U.S. national space programme. This deficiency became apparent after the U.S. retired its Space Shuttle in 2011, leaving it with no alternative heavy-lift launch capacities, forcing the U.S. to rely on Russian heavy-lift rockets to carry its logistics and crews to the International Space Station. Even the workhorse U.S. heavy-lift Atlas V rocket* began extensively using the RD-180 rocket engine, manufactured by the Russian manufacturer, NPO Energomash [9].

At a time when strategic dependencies began hurting U.S. astropolitical heft, the U.S. sought to nurture a new set of space and defence contractors to work closely with NASA and DoD. New space contractors like Blue Origin and SpaceX have been at the forefront of developing heavy-lift launch capabilities for the U.S.[9] This has not only enhanced the robustness of U.S. innovation ecosystems but also made space exploration pursuits commercial and thus contribute to the wider U.S. economy.[10]

In reforming its national space programme, the U.S. embraced the canon of commercialisation-industrialisation-democratisation.[11] The Commercial Space Launch Competitiveness Act (2015) helped previously-unsolicited commercial contractors and start-ups – some independent and some under the wing of established contractors and U.S. government agencies – to gain a foothold in the U.S. (as well as the global) space launch industry.[12]

The U.S. has demonstrated its intent to expand commercialisation of the space industry from space launch to space resource utilisation. In 2015, the Space Resource Exploration and Utilization Bill was introduced in the 114th U.S. Congress. Had it been enacted, the legislation would have facilitated U.S.-origin commercial enterprises to explore, extract, utilise, sell and transfer natural space resources.[13] The bill did not become a law, but an amended version that supports non-U.S. origin companies has come up in the form of the U.S. Presidential Executive Order on Encouraging International Support for the Recovery and Use of Space Resources. Such a globally inclusive order could increase the prospects of the U.S. becoming a leader in asteroid and lunar mining. The U.S. realises that many countries now have the means to extract resources from outer space, but it can rally them since it continues to be the leader in space exploration.

** The Atlas rockets are built by the United Launch Alliance – a collaboration between Lockheed Martin Space Systems and Boeing Defense, Space & Security.*

The U.S. has plenty of company in Space 2.0. Since the turn of the 21st century, as many as 22 emerging and advanced economies have established space agencies (Table 1). These countries are not competing directly with the established spacefaring nations, especially not in sectors where the latter already have strong competencies. Instead, they are shaping their space programmes around their own niche Industry 4.0 technological capacities.

Table 1: New space agencies established since 2000

COUNTRY	ECONOMY CATEGORY	AGENCY	YEAR EST.
Australia	Advanced	Australian Space Agency	2018
Algeria	Emerging	Algerian Space Agency	2002
Belarus	Emerging	Belarus Space Agency	2009
Bahrain	Emerging	National Space Science Agency	2014
Bolivia	Emerging	Bolivian Space Agency	2012
Czech Republic	Advanced	Czech Space Office	2003
Colombia	Emerging	Colombian Space Commission	2006
Poland	Emerging	Polish Space Agency	2014
Thailand	Emerging	Geo-informatics and Space Technology Development Agency	2002
Iran	Emerging	Iranian Space Agency	2003
New Zealand	Advanced	New Zealand Space Agency	2016
North Korea	-	Korean Committee of Space Technology	2013
Lithuania	Advanced	Lithuanian Space Association	2007
Malaysia	Emerging	Malaysian National Space Agency	2002
Paraguay	Emerging	Paraguayan Space Agency	2014
Philippines	Emerging	Philippine Space Agency	2019
Uzbekistan	Emerging	Uzbek State Space Research Agency	2001
Portugal	Advanced	Portugal Space	2019
South Africa	Emerging	South African National Space Agency	2010
Saudi Arabia	Emerging	Saudi Space Commission	2018
United Arab Emirates	Emerging	United Arab Emirates Space Agency	2014
Turkmenistan	Emerging	Turkmenistan National Space Agency	2011

Source: Gateway House Research

The competition is healthy for everyone. In fact, the U.S. is engaging in space diplomacy by supporting countries which, while being comparative greenhorns with respect to space technology, are well-equipped with space-capable Industry 4.0 technologies. The U.S. clearly sees self-interest in helping other countries establish space credentials and in keeping them intimately linked to a global space-technology value chain in which it plays a central role.

The following case studies show how the United Arab Emirates (U.A.E.), Luxembourg and New Zealand are finding an important role for themselves in space – and discovering that the U.S. is not an obstacle but, in fact, can be supportive.

2.1. United Arab Emirates – Building a Martian City with 3D-Printing Technology

The U.A.E. has one of the strongest space-cooperation agreements with the U.S. among West Asian countries. The U.A.E.-U.S. Space Implementation Agreement, signed in 2018, identifies lunar and Martian robotic exploration, human spaceflight, and missions to the International Space Station as key areas for bilateral cooperation.[14] The U.A.E. has nascent, but strong and unique, space capabilities that helped it gain this powerful position.

The U.A.E.'s space programme began in the late 1990s when its state-owned Mubadala Investment Company, which owns the Al Yah Satellite Communications and Thuraya mobile-telephone satellite service companies, began operating communication satellites. In its early years, they were built by the European Aeronautics Defence and Space Company (now Airbus Defence and Space), Thales Alenia (France) and Boeing (U.S.A.). The Emirates' recent foray into Earth-observation satellites – the Khalifasat series – was assisted by the South Korean satellite manufacturer, Satrec Initiative.[15]

In 2014, the U.A.E. established the United Arab Emirates Space Agency (UAESA) to initiate development of indigenous capacities in satellite and spacecraft construction and subsequent downstream operations. To take this indigenisation drive ahead, the U.A.E. Prime Minister's Office in 2015 announced a National Innovation Strategy, which emphasises promoting space innovation through exploration of celestial bodies via space telescopes and spacecraft.[15] Subsequently, in 2019, the U.A.E. government announced its National Space Strategy 2030, which prioritised space exploration as a national undertaking.[16]

UAESA is building a spacecraft to orbit Mars in 2021 on a scientific space mission it calls Hope*. The Hope spacecraft is one of several global scientific efforts to learn about the Martian climate, weather patterns and atmosphere-escape phenomena resulting from the planet's weak magnetic field [17]. Hope will be the first building block in a long-term U.A.E. plan to build a habitable city on Mars by the year 2071, the country's centennial year.[18] A greater understanding of Martian climate will be imperative to create a Martian city, which is likely to be built by an international consortium.

To simulate construction of the Martian city, the U.A.E. is building a 1.9-million square feet, enclosed habitat – Mars Science City – near Dubai. This simulation city, worth $136 million, will be built with materials made through additive manufacturing (3D printing).[19] This is part of the U.A.E.'s national strategy to become a global hub for additive manufacturing and 3D-printed urban infrastructure.[20] The U.A.E. intends to employ the expertise thus garnered to manage construction of the city on Mars by meticulously employing 3D printing as well as utilising construction materials available on Mars.**

** The Hope mission is happening only eight years after India's Mars Orbiter Mission, indicating how quickly spacefaring countries are catching up with ones that have been engaged in space exploration for some time.*
*** maximally utilising natural materials and resources already existing on Mars for the construction of the city.*

2.2. Luxembourg – Enabling Asteroid Mining with Blockchain Technology

Near-Earth asteroids possess vast and diverse reserves of minerals, metals and materials that are critical to electronics and high-technology industry on Earth. In 2018, Luxembourg became the first nation in the world to pass national legislation, granting private companies the legal framework to extract resources from near-Earth asteroids and other celestial bodies.[21] This legislation - Law of July 20th 2017 on the Exploration and Use of Space Resources - applies to overseas companies that have registered in Luxembourg or are bound by European company laws; whereas the similar U.S. Space Resource Exploration and Utilization Bill of 2015 was strictly limited to U.S.-origin companies. The liberal approach of the Grand Duchy's legislation has brought Luxembourg to the centre stage of global extra-terrestrial resource management and governance.

Luxembourg demonstrated strategic foresight in capitalising on its existing strengths in the finance and financial technology sectors to position itself as a player in extra-terrestrial mining and real estate. The Grand Duchy also has shown interest in nurturing innovative blockchain-based tokenisation of property sales on asteroids.

Luxembourg's competence in blockchain, an Industry 4.0 technology, along with its legislation that enables its extra-terrestrial resource utilisation, has led it to build bridges to U.S.-based private space-technology companies. Planetary Resources, one such company whose European base also is in Luxembourg, was recently purchased by the U.S.-based blockchain company, Consensys.[22] Its success in attracting companies like Consensys shows that Luxembourg clearly comprehends the importance of specialised finance to facilitate the commercialisation of space exploration – and of staying ahead of the space exploration game.[23]

2.3. New Zealand: Low-Earth Orbit Launchpad of the Global South

Small satellites (weighing less than 500 kg) are becoming functionally efficient and equivalent to larger conventional satellites (weighing greater than 1,000 kg) due to unprecedented progress in miniaturisation of actuators, sensors and electronics – a prominent attribute of Industry 4.0.[24] This is creating vast downstream and upstream markets for satellite manufacturing and services sought by a wide range of civilian end-users. The Earth-oriented space industry, which deals with remote sensing and communications, is seeking shorter supply responses to demand for satellite services, creating vast potential for manufacturers of small satellite-launch systems.

Located in the South Pacific, New Zealand is remote from much global aviation traffic, making it an ideal location to launch satellites on demand and at shorter intervals, a growing need of the satellite industry.

The newly established New Zealand Space Agency (NZSA, 2016) has enabled the country's private space companies to develop capabilities to launch small satellites into low-Earth orbit. Rocket Labs, a commercial small-satellite launch company, is making the most of this geographical advantage. Established with funds from New Zealand's state-owned company, Callaghan Innovation, Rocket Labs is now a U.S.-based company that is able to utilise launch facilities, based in both the United States (particularly the Wallops Space Launch Facility in Virginia) and in New Zealand (it has built a facility on the Mahia Peninsula there).[25] Since the U.S. is perhaps the largest small-satellite market in the world, registering as a U.S.-based company made it easier for Rocket Labs to avail itself of the obvious business opportunities in North America.

New Zealand wants to put its strategic location to good use and take the lead in space situational awareness – the ability to monitor and track all types of satellites, spacecraft, debris and other objects in the Earth's orbit – by developing ground-based satellite and debris-monitoring stations. In the coming years, space debris mitigation, management, and removal will become a lucrative business opportunity since companies or entities will be liable for damages generated by the objects they make.

The NZSA has entered into an agreement with a U.S.-based start-up, LeoLabs, which works with the California-based not-for-profit science institute, SRI International, to build a global network of phased-array radars to monitor satellites in low-Earth orbit and ensure that all satellites launched from New Zealand comply with their licenses and do not contribute to space debris. The NZSA has agreed to establish the first of these radars in the Southern Hemisphere within its sovereign territory, bringing it closer to its goal of leading in outer-space monitoring.[25]

2.4. Benefits of Leveraging Industry 4.0-Space 2.0 Interfaces

New Zealand, Luxembourg, and U.A.E are prime examples of countries that are not attempting to shape their space programmes in the fashion space players did in the middle of the 20th century. Their strategies are based on meeting the future demands of the global space economy through the early adoption of Industry 4.0 technologies.

These countries will not get into a proverbial space race with the established space players, since that would run the risk of failure for their nascent commercial space industries. Rather, they are filling needs that established space players have missed for a very long time. Since these new players in space exploration are undertaking innovative projects, they are being pursued by countries from a range of geopolitical blocs. For instance, while Luxembourg's asteroid mining aspirations are closely linked to those of the U.S., this has not deterred Russia from showing interest in making similar links to it.[26] Luxembourg has shown a proclivity to collaborate with other countries as well.

The early lead taken by these countries in Industry 4.0 technologies like blockchain, 3D printing, and space situational awareness potentially will earn them a high rank in global space-competitiveness indices. This shows that, while absolute government dominance over space activities was unavoidable during Space 1.0 because the economic potential was highly uncertain and the private sector lacked intellectual property and investment gumption, the limitless commercial possibilities of Industry 4.0 make a decentralised approach, based on private-sector involvement, favourable for fostering industrial innovation in space exploration.

India's Space Commission must analyse the space aspirations and strategies of the new space-age countries and look for ways it too can carve out important, but as yet unfilled, niches in space exploration. The opportunities are enormous. Space economy activities that seem fantastic and unrealistic today are likely to become major enterprises in the not-too-distant future.

3. India's Technological Deficiencies At The Onset Of Second Space Age

The global space economy, which was estimated to total $350 billion in 2018, is expected to triple in size to reach $3.3 trillion by 2040.[27] But India's share in the space economy is small even though its space programme is six decades old. The country's annual sales of products and services in the satellite and non-satellite industries total $945 million, with most of the investment being top-down infusions from the government to DoS-governed laboratories.[28]

The problem, in part, is that India's space policymakers have been slow to establish a strong space exploration vision for India. They did not initiate a space-exploration programme for its initial four decades, 40 years after the establishment of ISRO. The agonising delay reflected political inertia and lack of foresight. India's Space Commission eventually overcame those impediments, but the legacy of delay set India behind in fostering public-private cooperation and market-oriented planning that are becoming increasingly important to space exploration. Even today, despite India's successful string of space-exploration missions – Chandrayaan (2008; 2019), Mangalyaan (2013) and the in-progress Gaganyaan (2022) – its space-exploration programme continues to be almost entirely non-commercial, operating within the confines of DoS. Policy makers still do not view space exploration as an economy-boosting enterprise.

One direct result of the institutional reluctance at DoS is low intellectual property (IP) generation. A 2018 study by the India's Office of the Controller General of Patents, Designs, Trademarks and Geographical Indications noted space-related patents represent a small share of India's total patents (Figure 2). None of the country's three big clusters of space R&D institutions rank high in the generation of space-related patents (Figure 2).[29] Of the 47,854 patents filed in 2017-2018 in India, only 14 came from the ISRO. The patent productivity of DoS institutions is lower than that of other Indian R&D entities like the Indian Institutes of Technology (IITs), the Council of Scientific and Industrial Research (CSIR) and the Defence Research Development Organisation (DRDO) (Table 2).[30]

Table 2: Number of patent applications filed by major Indian research institutions and organisations for the year 2017-2018.[30]

Scientific Research Institutions and Organisations	Patent applications filed
Indian Institutes of Technology (cumulatively)	540
Council of Scientific and Industrial Research	176
Defence Research Development Organisation	126
Indian Council of Agricultural Research	37
Indian Space Research Organisation	14

DoS has a few strong supply-chain linkages with the domestic private sector, mostly a handful of solicited contractors. Of late, the agency has been reaching out to new MSMEs that can purchase its indigenous technology spin-offs and commercialise them. But these relationships, while successful, are insufficient for the country to increase its stake in Space 2.0.

3.1. Space-Exploration Missions are not Generating Economic Innovation

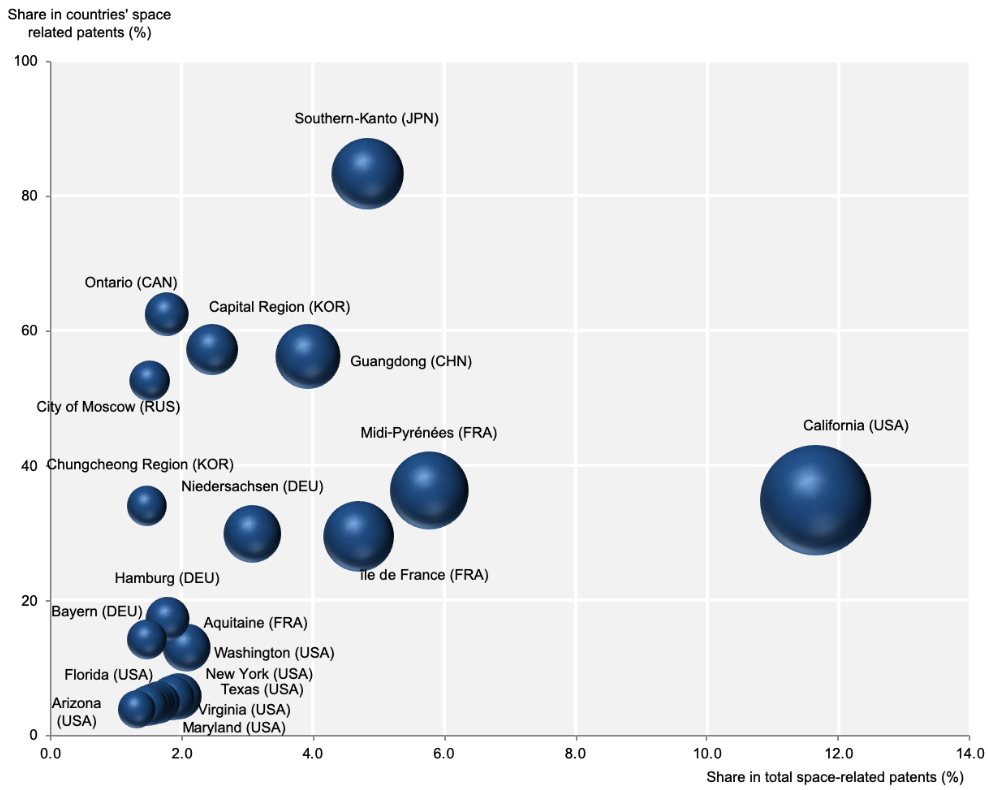
The lop-sided dependence of India's space programme on government funds and mandates, and the resulting deficiencies in space innovation and development of industrial ecosystems, severely restrict the creation of quality Space 2.0 and Industry 4.0 intellectual property in India.

Most technology transfers from DoS institutions to the private sector occur so slowly that by the time Indian companies are ready to begin commercial activities based on new technology, competitors in other countries already dominate the market. Indian automotive and energy storage manufacturers, for instance, are losing substantial domestic market share due to the long drawn out transfer of lithium ion battery technology from ISRO. Most Indian urban transport companies have already begun procuring low-floor electric buses from more market-ready Chinese automobile manufacturers, representing the loss of a massive opportunity for India to lead a global industry.[31]

The few existing public-private partnerships in the sector are not generating innovation either. The DoS does business with several private, medium-sized enterprises based in Mumbai, Bengaluru, Hyderabad, Chennai and elsewhere in India. However, the role of these companies is limited to supplying components to DoS' space projects, particularly construction of launch vehicles, satellites and spacecraft. Because they are empanelled and embedded in the system, there is little incentive for them to innovate beyond existing requirements. The sooner the Space Commission addresses these issues, the greater will the chances be of unclogging India's obstructed space economy.

Figure 2: Patent productivity of various space-technology ecosystems around the world. Conspicuous absence of India's three major space ecosystems in Ahmedabad, Bengaluru, and Thiruvananthapuram

Source: Space Economy at Glance, OECD, 2014[29]



3.2. The absence of space-technology ecosystems causes low space-related patent productivity

Perhaps the biggest impediment is the Indian technology policymakers inability to comprehend the need to establish Special Economic Zones or ecosystems for the space RDTE sector, as the government has done for the information technology, biotechnology, aerospace and automotive sectors. Even the three major DoS clusters in Thiruvananthapuram, Ahmedabad and Bengaluru have not built extensive private sector ecosystems around them. The current DoS-governed institutions carry the full burden of achieving India's space goals with limited funds and resources; their emphasis on in-house RDTE leaves little scope for spawning new space-technology ecosystems consisting of start-ups, public sector laboratories and private sector R&D contractors across other parts of the country. The U.S., China, Russia, France, and Germany, by contrast, have created numerous space-research RDTE ecosystems, most outside the ambit of the countries' respective space agencies. India should follow suit.

India's lack of preparedness for the Space 2.0 era, in short, arises from a confluence of several factors:

- myopic space policymaking
- its small space-technology IP repertoire
- weak IP-generating mechanisms
- lack of spin-off and spin-in technology-generating capacities in its private sector
- over-reliance on existing DoS institutions
- and disregard for market forces.

4. Industrialising India's Space Exploration Pursuits

India cannot develop a robust space economy if it depends solely on the space agency. Because the government's resources and ISRO's competencies are not unlimited, the tremendous potential in the private sector must be tapped. That does not mean the private sector, however pivotal to Space 2.0, can be a substitute for governmental space agencies or can stray too far from serving governmental goals. Many of the goals of space exploration have metastrategic implications that require commitments that must continue for multiple decades.

Clearly, a close association between the public and private sectors is required. The private sector's untapped potential must be unleashed, but government supervision, guidance and incentive creation are absolutely necessary. The Space Commission must scout and nurture novel technologies at all levels of readiness (Figure 3), and create synergies across both sectors.

Figure 3: The entire spectrum of Technology Readiness Level (TRL). The Indian Space Commission should support private entities that can contribute to technology research, development, testing and evaluation at all TRLs.

Source: Gateway House Research

4.1. Recommendation 1: Commercialise Spacecraft Payload Technologies for Import Substitution

Precision scientific instruments are the backbone of most space-exploration payloads, which involve experimental and test-driven investigations. It is no coincidence that countries proficient in precision-instrument development and sales also have strong competencies in building scientific payloads for space exploration.

India's public and private sectors currently import more than 80% of their precision scientific instruments.[32]** Because of this import dependency, Indian civilian and defence R&D laboratories could come to a disastrous halt if exporting nations decide to increase their prices or impose export sanctions or if there are supply chain disruptions caused by wars and pandemics. To avoid this potential national security threat and fulfil the DoS mandate to provide for India's socio-economic well-being, the space agency should encourage indigenous commercialisation of precision instruments used in building payloads for space missions.

Table 3: India's imports of high-precision instruments. Space payloads can be vital for stimulating commercialisation of high-precision instruments[33]

HS 9027 Imports from Countries	2018-19 (US$)	2017-18 (US$)
Singapore	257.03	166.38
United States	206.50	288.61
Germany	204.29	190.09
Japan	85.64	147.50
France	58.71	44.50
United Kingdom	55.97	56.81
People's Republic of China	52.86	63.78
Switzerland	41.70	62.34
Austria	34.08	26.39
Total Imports of HS 9027	1182.28	1217.42
India's Total Imports	4,69,631.44	4,65,580.99
% Share	0.2517	0.2615

Given India's low-cost space missions, it can be estimated that the innovation and construction costs of Indian space payloads could be kept low compared to similar payloads developed by the European Space Agency (ESA) and NASA. These can be redesigned innovatively for use in various medical, biological, chemical, physical, electronics, heavy-engineering, agricultural and vehicle RDTE laboratories in addition to the space applications. Such 'Make in India' precision instruments can compete in domestic and global markets, particularly in developing countries, thereby nurturing domestic precision-instrument manufacturing ecosystems while strengthening India's space programme.

*** These instruments are classified under the Harmonized Commodity Description and Coding System – HS Code 9027 – ranging from refractometers, spectrometers, polarimeters, gas and smoke analysis, those for measuring viscosity, porosity, expansion, surface tension, or quantifying heat, light and sound.*

4.2. Recommendation 2: Build an Indian Deep Space Network Global Triad

The U.S.-China competition over supremacy in global telecommunications connectivity infrastructure is not limited to the Earth. It also involves Deep Space Networks (DSNs). Typically, a DSN is a triad of large radio communication antennae that are placed at angles of 120 degrees from each other all around the Earth. As the Earth rotates, each of these antennae can communicate with an interplanetary spacecraft without interruption. Currently, the U.S., Russian, Chinese space agencies and ESA each possess independent DSN triads; India does not.

NASA's Chinese Exclusion Policy has time and again prohibited collaboration between U.S. and Chinese space scientists[34] due to the warranted suspicion that Chinese scientists engage in technological espionage. This drove Beijing to build its own DSN. The Chinese Lunar Exploration Programme (CLEP) and Mars missions – Huoxing-1 – to be launched in 2020 will be supported by the Chinese DSN, which stretches from Neuquen in Argentina, Swakopmund in Namibia, to Kashgar and Heilongjiang in China.[35]

Indian satellite-launch vehicles and satellites currently use ground-based services from Telemetry, Tracking and Command (TTC) stations belonging to various countries around the world.
The unresolved issue is that a TTC antenna has a standard dish size (11 metres in diameter), enabling it to communicate only with spacecraft and satellites that are in low-Earth and geostationary orbits and to monitor paths of launch vehicles. By contrast, DSN antennae are larger than 32 metres in diameter, and can communicate with spacecraft bound for lunar and interplanetary travel.

India's Chandrayaan-1 (2008), Mars Orbiter Mission (2013), and Chandrayaan-2 (2019) relied on NASA's DSN triad, located in California, Spain, and Australia.[36] As outer-space traffic increases due to commercialisation of space exploration, the NASA DSN will give priority to U.S. civilian and commercial missions. In such a likely scenario, transmission slots for Indian spacecraft will become difficult to obtain, making dependency unbearable.

India, therefore, must initiate diplomatic engagements with friendly countries in the eastern and western hemispheres that can host two DSN antennae for it in addition to an existing 32-m antenna located in Byalalu near Bengaluru. These large antennae also will give India an independent communications capability for distant interplanetary missions. The development of an independent DSN will spin off new communications technologies – particularly since DSN technology is slowly evolving from radio technology to laser or optical communications. India's DSN indigenisation will also help it attain competence in inter-orbit and inter-satellite communication systems – which will be important for space situational awareness and managing satellite constellations. The Indian DSN could be made element of India's constructive space diplomacy with nations hosting the antennae along with others.

4.3. Recommendation 3: Mapping the Space Exploration Capacity Landscape of India

Several Indian central government ministries collaborate with the DoS on specific projects. For instance, ISRO's Geostationary Satellites (GSAT) for communications are fundamental to rural (last-mile) broadband connectivity provided by the Ministry of Telecommunications internet service company, Bharat Broadband Internet Limited (BBIL), helping it meet the goals of the Digital India campaign.[37] The National Highways Authority of India (NHAI) of the Ministry of Road Transport and Highways uses ISRO's Bhuvan application and GAGAN (GPS-aided Geo Augmented Navigation) navigation system for management of road assets. The Centre for Railway Information Systems (CRIS) of the Ministry of Railways recently began to install GAGAN navigation equipment on railway locomotives for real-time tracking of trains.[39] The Confederation of Indian Industry (CII) regularly organises exhibitions, attracting Indian and overseas industries with space products in their portfolios.[40]

These collaborations, which are based on DoS' satellite communications and remote sensing capabilities, are largely one-on-one, ministry-specific applications, and do not exploit the potential for trans-ministerial cooperation. Only recently (2018), the Ministry of Science and Technology, Ministry of Defence, and the Prime Minister's Office launched a first, archetypal trans-ministerial collaboration in the form of the Gaganyaan programme.[41] This is good.

Space exploration should be a national mandate, not a vertical undertaking of the DoS alone. There are vast, unmapped possibilities for additional cross-sectoral and inter-ministerial collaborations involving space exploration. There is immense untapped potential for various ministries of the Government of India to assist in the development of the national space exploration agenda (Figure 4). More inter-ministerial collaborations can be initiated if the Prime Minister formulates a national vision for space exploration and becomes the chief patron of such endeavours. Some potential scientific and technological areas of interest to each ministry are listed in Table 4.

For instance, the Ministry of Earth Sciences (MoES) undertakes scientific projects related to development of underwater and polar (Arctic and Antarctic) exploration technologies. The expertise the MoES has gained allows it to comprehend and build the technological requirements for exploration of the icy and ocean-bearing moons of Jupiter and Saturn – particularly Enceladus, Ganymede, and Europa. Likewise, the Geological Survey of India (GSI), which is administered by the Ministry of Mines, can be the lead agency, maintaining the extra-terrestrial surveys of the Moon and Mars, obtained through rigorous planetary remote sensing missions. The GSI can also be involved in the development of space payloads that can be used for both Earth-oriented as well as lunar and Mars-oriented remote sensing.

Once ministries identify their areas of interest in space exploration, they can activate numerous RDTE institutions, public sector units, and private sector enterprises both at the front- and back-ends of innovation to deliver and commercialise space technologies (Figure 4). This will enable India to tap into the under-utilised potential for space exploration and increase the share of the Indian space ecosystems in the growing global space economy.

Figure 4: The Public-Private Space Exploration Stakeholder Landscape in India.

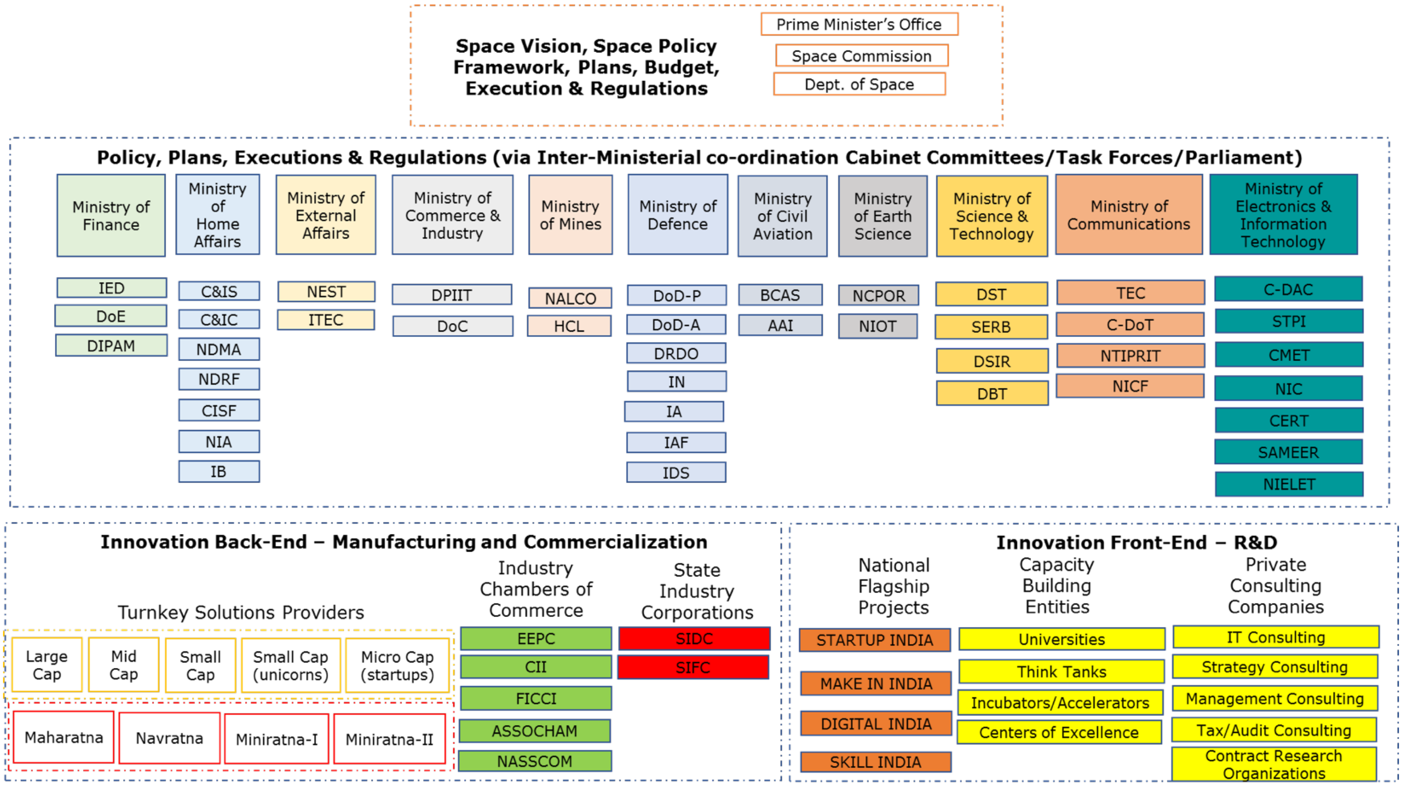


Table 4: Ministries of the Government of India and their potential technological interests in Space Exploration

MINISTRIES OF THE GOVERNMENT OF INDIA	POTENTIAL INTEREST IN SPACE EXPLORATION
Ministry of Coal	Subterranean robotics; carbon sequestration; planetary terraforming
Ministry of Mines	Hyperspectral remote sensing; planetary or astro-geological, astro-geochemical and astro-geophysical surveys
Ministry of Earth Sciences	Planetary meteorology and atmospheric monitoring; icy-world (Europa, Enceladus, Ganymede) exploration; payload development; Martian polar exploration; extreme-climate (extra-terrestrial) human habitation
Ministry of External Affairs	Foreign policy and diplomacy across emerging and strategic technology, space, cyber, defence domains
Ministry of Civil Aviation	Aviation safety and traffic management; commercial space transport; spaceport development and operations
Ministry of Science and Technology	Space payload development; space payload science; astronomy; space payload and precision instrumentation, and sensor research, development, testing, and utilisation; laboratory-based space simulations; emerging technology development
Ministry of Communications	Telecommunications spectrum management; interplanetary communications network; ground-station management; spectral interference regulation and resolution
Ministry of Agriculture and Farmers' Welfare	Controlled ecological life-support systems; aeroponics and plant cultivation units onboard space stations and planetary habitats
Ministry of Electronics and Information Technology	Design, R&D, testing and evaluation of space-grade electronics; information technology data management; cybersecurity
Department of Atomic Energy	Radioisotope thermoelectric generator; space payload science; space payload, emerging technologies, precision instrumentation and sensor research, development, testing, and utilisation
Ministry of Defence	Human spaceflight; space medicine; human-rated spacecraft; space payload science; emerging technologies, precision instrumentation and sensor research, development, testing, and utilisation; interception and deflection of potentially hazardous celestial objects; space situational awareness

4.4. Recommendation 4: Establish Advanced Space Concepts Laboratories for Introducing Industry 4.0 Technologies in Space Exploration

The Space Commission should encourage the use of emerging Industry 4.0 technologies for space-exploration missions along with proven and heritage space technologies.

The DoS currently supports special research laboratories called 'Space Cells' in numerous non-DoS RDTE establishments – mostly the National Institutes of Technology, Indian Institutes of Technology, and central and state universities.[42] Space Cells undertake R&D projects in the host institutions and utilise the highly skilled human resources available there. However, the scope of the R&D is limited to areas of immediate utility to ISRO. Similarly, ISRO also disburses funds under its RESPOND programme to various non-DoS universities and institutions for a variety of scientific research projects,[43] but these too are awarded to projects of immediate utility to the agency. Such a transactional model will perennially under-deliver on innovation and creativity. To overcome this deficiency, the Space Commission should form new 'Advanced Space Concepts Laboratories' (ASCL) with non-DoS public or private entities and ecosystems (Figure 5).

The ASCLs can execute high-risk, high-reward RDTE on experimental cutting-edge technologies. They can use global best practices and resources from public and private R&D laboratories and India's high-technology companies. The invention and upstream innovation of the ASCLs can be supported by R&D laboratories, while downstream commercialisation can be supported by public and private manufacturing entities, including the DoS-governed Antrix and New Space India Limited (NSIL).

With ASCL-like interfaces, the DoS can overcome its deficit of commercially viable patents and build a repository of commercially-profitable spin-in and spin-off technologies, while absorbing best practices from both public and private domains.

Figure 5: The Advanced Space Concepts Laboratories and their centrality in aggregating public-private next-generation invention capacities in India

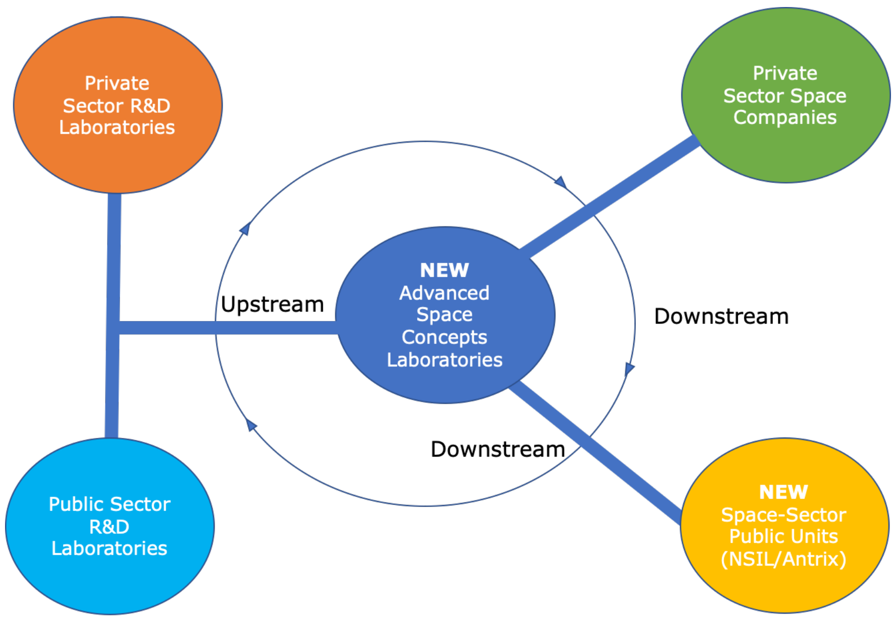


Table 5: Space agencies and their respective advanced concepts programmes

SPACE AGENCIES	ADVANCED CONCEPTS PROGRAMMES
National Aeronautics and Space Administration	NASA Innovative Advanced Concepts Program
European Space Agency	Advanced Concepts Team
Japan Aerospace Exploration Agency	JAXA Space Innovation through Partnership and Co-Creation

The idea of an ASCL is not new. The U.S. (NASA)[43], European (ESA)[44] and Japanese (JAXA)[45] space agencies all operate dedicated advanced-concepts programmes (Table 5).

In the Indian context the ASCL can be institutionalised as a network of laboratories that operate autonomously within ISRO. The autonomy can be used to give it a mandate for developing futuristic and high-risk-high-reward space exploration projects that incorporate Industry 4.0 plus technologies (Table 6). The ASCLs can be funded in multi-year blocks and via project or concept-specific public-private partnerships. The benefits are two-fold: such risky projects will not be entirely reliant on the government's space budget, and with private sector participation, the opportunities to commercialise technology spin-offs will increase.

For example, extra-terrestrial in situ resource utilisation or asteroid and lunar mining is currently not prioritised by ISRO, but it can be initiated under the ambit of ASCL. The private companies and start-up partners in the ASCL can undertake RDTE and commercialisation of technologies necessary for asteroid and lunar mining – hyperspectral mapping cameras, asteroid and lunar sampling and caching devices, sample-return technologies – which they will co-develop through human resource and financial investments.

Through this model, the ASCL can build a repertoire of novel space exploration technologies via alternative funding mechanisms and reduce the burden that ISRO bears by pursuing space technology RDTE entirely by itself. The ASCL will give India the chance to assume a leading role in putting into effect the global space exploration plan of the International Space Exploration Cooperation Group (ISECG).**[47]

*** ISECG is a leading non-binding global alliance of space agencies that share knowledge of space missions from conceptual to end-of-mission stages. ISRO is a member of this alliance.*

Table 6: Emerging technologies that can be researched by the Advanced Space Concepts Laboratories (ASCLs) and their applications in space exploration

EMERGING TECHNOLOGIES THAT CAN BE RESEARCHED BY ASCLs	APPLICATIONS OF THE EMERGING TECHNOLOGIES IN SPACE EXPLORATION
Space Station-based Micro-Manufacturing	Build modular Earth-orbiting space stations and rent them to pharmaceutical, speciality chemicals, advanced composites materials, and electronic companies for R&D and micro-manufacturing
Reusable Earth-Moon Transport System	Develop a rapid, safe, reusable and efficient transportation system between Earth and Moon based on ISRO's Reusable Launch Vehicle and DRDO's AVATAR concepts
Earth-Moon Telecom Network	Support a competition for telecom start-ups to test a seamless and low-latency, laser-based sixth generation plus (6G+) internet transmission network in the near-Earth space between the orbits of the Earth and Moon
Planetary Defence, Space Situational Awareness and Surveillance System	Develop a wide-field infrared and radar-based planetary defence system that will augment current global capacities to monitor potentially hazardous objects and track lost spacecraft
Next-generation opto-electronics, optics, artificial intelligence and big data-enabled astronomy	India's information technology and artificial intelligence R&D start-ups can be encouraged to work on pattern recognition-enabled, space-based telescopes at the Earth-Moon Lagrange point. Such an observatory can view distant regions of the ancient universe, scout habitable exoplanets, and identify destructive – pulsar, quasar and black hole – events in the near galaxies at higher resolutions than that possible from Earth-based observatories
Clean and Renewable Space Propulsion	Utilise India's policy and commercial leadership in solar and renewable energy – International Solar Alliance – to undertake R&D of solar sails and ion propulsion for planetary exploration spacecraft, space-based telescopes, and the Indian space station
Uninterrupted Power System for Space Exploration	R&D of nuclear-powered (next-generation radio-isotope thermoelectric generators) space-probes for exploration of darker (non-solar-illuminated) regions on the Moon, Mars and planetary objects of the outer Solar System.
Extra-terrestrial in situ Resource Utilisation	Develop technologies to extract, isolate and cache minerals from asteroids and the Moon, which can be brought to Earth via sample-return missions.

4.5. Recommendation 5: Provide Incentives for Industries Engaging in Space Exploration Activities

If India is to develop a space economy, the central government must incentivise space exploration RDTE ventures. These require legislation to provide risk coverage and legal support, and to ensure accountability of entities venturing into economic activities related to space exploration. Innovation incentives offered by the Department of Scientific and Industrial Research (DSIR) within the Ministry of Science and Technology can serve as models. They are applied under the Income Tax Act, 1961 and are specifically modified to suit the needs of space inventions and innovations.[49] Some of the current DSIR incentives can be amended for space start-ups and industry in the following manner:

- tax-deductions from 100% (normal) to 200% (weighted) for capital expenditure (consumables and labour costs) incurred in space-Industry 4.0 R&D activities;
- tax holidays of 100% for one year for successful R&D output;
- relief to space R&D start-ups, refunds on R&D expenditure, and subsidies for purchase of instruments and equipment necessary for R&D.

ASCLs also can be offered concessions under the draft National Innovation Act, 2008. Specific space-innovation amendments to this Act should be considered.[49] Incentives specific to the space industry can stimulate R&D capacities in universities, start-ups, medium and small enterprises, and conglomerates. They also will increase private-sector investment and reduce the nation's dependency on government outlays for space exploration.

5. Conclusion

Space exploration is modern India's most crucial, yet underrated, socio-economic need. It can stimulate human potential, invigorate invention, and mobilise India's economy beyond the current $5-trillion GDP target. To realise its full potential, space exploration must be unshackled from the limited ambit of the DoS and opened to participation by the large number of untapped, yet qualified, domestic stakeholders.

More than space exploration is at stake. Advancing and emerging economies around the world have begun to mobilise their domestic competencies and resources in order to play a role in Industry 4.0 as well as Space 2.0. India must decide whether it wants to play a leading role in this field or find itself subject to the dominance of other, more ambitious nations.

The expansion of India's footprint into outer space in the 21st century will depend on the country's ability to scout and utilise human resources, build new institutions, and distribute space capabilities across civilian, defence, and commercial realms. A key is to recognise that Space 2.0 and Industry 4.0 technologies are not mutually exclusive. They are interdependent. The sooner India develops creative, robust strategies around this recognition for the coming technological revolution, the higher it will rise on the global astropolitical power pyramid of the future.

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