Toward a Blockchain-Space Nexus: Challenges and Opportunities to Security, Stability, and Sustainability on the Final Frontier

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Abstract:

Blockchain technology concerns the decentralized distribution of information over a network via a shared immutable database. This paper explores present and future applications of Blockchain for Space and Space for Blockchain, providing deep examination and review of substantive technical content. We propose new opportunities including: space-based data feeds for decentralized oracle networks and the trustless execution of smart contracts by and for space, the distributed ledger as a next generation of Transparency and Confidence Building Measures (TCBMs) and for the enhancement of global cybersecurity, and their integration into existing legal, insurance, and economic frameworks.

The first successful blockchain, machine learning, and non-fungible token demonstration on the ISS was conducted on December 17th, 2021, heralding a new dawn of economic opportunity in space. The marriage of blockchain and space, two exponential technologies in their own right, is creating a bidirectional accelerating feedback loop of tremendous proportions. This symbiotic nexus goes both ways: blockchain is disrupting space just as space is upending the status quo in the blockchain ecosystem on Earth. Blockchain will play a key role in the continued democratization of space, a cornerstone for TCBMs in an industry that strives to represent a guiding light of trust and cooperation in an otherwise turbulent geopolitical environment.

Blockchain applications are facilitating new space developments while actively making space a safer, more secure, and more trusted commercial environment for all actors:

With space data, algorithmically maintained smart contracts and oracles, “incontrovertible-truth-as-a-service”, can serve an increasingly diverse array of critical domains including orbital debris and space situational awareness.

A concentration of data and communications management in the hands of the few has made space more vulnerable to cybersecurity threats. Satellites are bringing decentralization to new heights, spawning blockchain networks’ first “nodes in the sky”, providing a secure environment for space actors.

Blockchain applications have the potential to enhance governing legal and economic regimes, empowering transparency while securing space commerce and operations.

If the past is prologue, inflexible institutions and legal systems will fail to adapt to the combination of exponential developments in both space and blockchain. This lack of requisite regulation has either hampered progress or fostered misuse, damaging public welfare and their reputation. This paper spurs discourse regarding this emerging, unified blockchain-space frontier that will require new, next-generation leadership and cooperation to foster, rather than inhibit, a secure and sustainable future of innovation and growth in the space industry.

Keywords: Blockchain, TCBMs, Cybersecurity, Legal Frameworks, Smart Contracts, Space Governance

1. Introduction to Blockchain & The Coming Blockchain-Space Nexus

Blockchain technology concerns the decentralized distribution of information over a network via a shared immutable database. Representing a subset of databases, entries are stored in chains of nodes (computers) on a distributed ledger. When a block of data reaches its predetermined capacity, new ones are added, contributing to a chain of information accessible to all members of the network.

The first successful blockchain, machine learning, and non-fungible token demonstration on the ISS was conducted on December 17th, 2021, led by Artist Cecilie Waagner Falkenstrøm of ARTificial Mind, Lonestar, Canonical, and Redwire Space. A February 1, 2022 press release detailed a "ground breaking data storage and edge processing tech demo aboard the International Space Station has paved the way for a new era in digital art". [1] Falkenstrøm and her team developed a machine learning algorithm "trained on thousands of images of existing planets, stars, and nebulas across the cosmos" that can transform cosmic radiation into images of novel and unique celestial objects, minting a blockchain-enabled non-fungible token (NFT), an immutable, digitally signed representation and proof of authenticity. "Something new is being made in space," she said. [Ibid][2]

As the public would come to learn in the months to follow, this massless, software-defined, payload collaboration, a first for the international space station, represented a small step in an initiative that endeavors to be a giant leap for immutable data storage and computation off-world. Aboard the space station, key capabilities were demonstrated that will help to facilitate Lonestar's push toward the moon, capitalizing on a "premium segment of the $200 billion global data storage industry while addressing key environmental and growing biosphere concerns triggered by the increasing growth of data centers around the world." [3] Through "providing a platform for critical data infrastructure, edge processing, (and) further leveraging its ITU spectrum filings to enable broadband communications" Lonestar aims to be front and center "as the world's data takes this next giant leap." [Ibid] Our data is going interplanetary today and blockchain will be along for the ride.

Blockchain has transformed the way we create, store, and share information. Unlike traditional centralized modes of information storage, where entries can be modified by their users or creators, once information enters the blockchain, it is permanent and irreversible, immutable. [4] By recording metadata, for instance timestamping each new entry and its node location, the decentralized structure makes it nearly impossible for tampering or mistakes to occur. As new information enters the chain chronologically, all information entered into the nodes across the world are validated by the peers. Any error in a node can be corrected by the several thousand other nodes that contain the correct data. [5]

Blockchain's decentralized nature makes modification only possible if a predetermined amount of nodes in a network, typically a 51% majority, achieve consensus. As each node is paired with a unique cryptographic hash, it is easy for all other nodes to cross-reference and rapidly trace a block that has been tampered. The combination of consensus requirements and near perfect information shared across peers (users) makes interference costly and impractical. In blockchain, this resilience to fraud is referred to as immutability. [4] Blockchain is uniquely suited therefore to applications such as secure digital transactions. Information entered on any blockchain is made public, anonymous, and encrypted for all peers. That way, they all can validate any transaction while the privacy of the executor is assured.

Blockchains come in 3 main forms: public, private and community (also known as commissioned or consortium). In a public chain, anyone can join the network to send and receive transactions as long as all peers reach consensus to add another block to the network. To have a chance at "casting their vote" in a process called mining, each peer can solve a complex mathematical problem via Proof of Work consensus (PoW), or by demonstration of token ownership (Proof of Stake). Adding transactions to public blockchains in a proof of work consensus configuration is a computationally and time-intensive process. In a private blockchain, the system is more centralized. Only a limited number of authorized individuals may join and contribute to the network. A community blockchain offers a customized service, where peers can join based on policies, rather than having to be fully authorized as in the private networks.

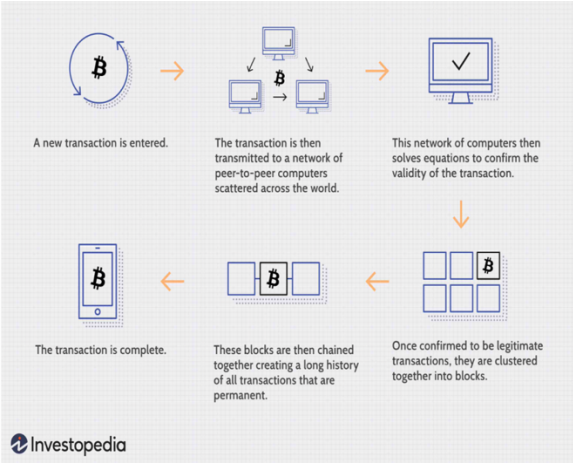

Figure : [Conway 2021]

Although best known for digital currency applications, blockchains can effectively be universal stores of information. The variety of space-blockchain applications are wide, where blockchain has the potential to be more than a database, a secure firewall. Secured voting and ballot counting is one possible future opportunity that a Space-Blockchain Nexus can offer to society. A node in space can be the perfect and most secure recipient for voting and counting of elections. Voters could send out their encrypted ballots by phone from the comfort of their homes, and each vote in any election could be electronically saved with a hash and timestamp. Each vote's metadata could be anonymously trackable, solving issues of disputes, recounting, and safeguarding democracy from both domestic and foreign meddling with no single authority able to interfere.

While this new way of holding public elections may be light years away, blockchain is already making businesses more intelligent. Smart Contracts, algorithmically self-executing contracts built on top of blockchains, were first proposed by Nick Szabo in 1994. The algorithms that execute the contract, which like in every blockchain transaction, keeps the keys anonymously, protecting the identity of the user while also maintaining the information trackable, and irreversible. This eliminates the need for centralized supervision, promising a world with, at a minimum, reduced legal fees and overhead. [5]

The combined blockchain-space revolution seems only a block away – content distribution, real estate, online advertisement, energy industry, climate change, health care, supply chain, finance, currency, banking are few industries that could benefit society through the utilization of smart contracts. Blockchain has the potential to make every industry in which it is implemented faster, better, cheaper, and more cyber-secure.

The nexus of blockchain and outer space has already begun as companies including SpaceChain, BlockStream, and Cryptosat have been hard at work placing the first nodes in outer space, providing "space as a service" to a blossoming terrestrial blockchain ecosystem. [6]

SpaceChain reaffirms that nodes in space will enable unparalleled network redundancy and resiliency for all peers, with the potential "to create more space-based use
cases over time," as they continue to build their open operating system for the next generation of decentralized infrastructure. [7]

2. NASA & Blockchain

Aside from Elon Musk's half serious, half sardonic interest in putting Dogecoin on the Moon, NASA also has been keenly interested in testing blockchain-enhanced multi-sensor satellite constellation architectures.

According to the paper "Blockchain application within a multi-sensor satellite architecture" supported by the SGT KBRWyle and NASA's Earth Science Technology Office, NASA interests in blockchain features are threefold:

> "(1.) Distributed, accurate, and secure logging and tracking of command and control events across a network of ground stations;
>
> (2.) Autonomous control of satellite constellations, with or without satellite-to-satellite communication;
>
> (3.) Secure and prioritized data and command communication among groups and space-based sources" [8].

Each peer, such as a ground station (including antennas) and satellites, will run the nodes for smart contracts through predefined algorithms, allowing them to be sent or received to and from satellites.

According to the study, there remains much to be learned about the limitations of node hardware in the harsh outer space environment. Blockchain's offering, however, of secure and autonomous

communication among satellites and ground systems without a single point of failure is indisputable.

NASA has tested numerous other applications and models of integration in various scenarios with private, public, and consortium types of blockchains. One of those applications is the System Tool Kit (STK), software developed by Analytical Graphics Inc (AGI). STK makes it possible to analyze blockchains in different ground station and satellite configurations, also allowing accurate modeling for various cases of data collection.

In one experiment, NASA utilized STK to test a scenario in which a constellation of four satellites monitored a determined location along the coast of California. Only three out of the four satellites had access to the position. The access time to the area was of two hours and was correlated to the sensor range of the spacecraft. The further the range, the greater the view and the time access to the location. The goal was to have one of the satellites detect the position and notify the blockchain network so that peers could autonomously inform the other spacecraft when to increase or decrease range. [Ibid]

NASA's approach was successful. The blockchain network of four satellites and their ground stations utilized a Python script to receive and send data with STK and the Hyperledger Fabric software. The satellites shared with one another their name, location, latitude, longitude, and status (confirmation of meteorological phenomena detected). The blockchain network was able to autonomously update the satellites with new ranges without satellite-to-satellite communication. With this, it's possible to conclude that blockchain allows autonomous control of multiple satellite constellations. It accurately and flawlessly saves data and information; flawlessly controls nodes which haven't access to the data but are still utilized as peers to deliver information. In this scenario, only the period to validate the transactions must be further examined. (Ibid)

In many other scenarios, while blockchain exceeded expectations in limited scope, there's much work to be done. NASA tested different secured channels of communication and integration of blockchain with older technologies. It concluded that it would not be too hard to incorporate blockchain with other languages like Python. It concluded also that blockchain weighed positively on the tradeoffs of advantages and disadvantages of its technology application in space.

For all of its demonstrated merits, NASA's interest in blockchain, however, has been slow to gain financial traction. Under the Small Business Technology Transfer program, it has awarded a few companies in the sector with cash investment awards, contracts, and prizes. In 2020, it granted $124,817 to orbit logic for its SCRAMBL (Space Communication Reconstruction and Mapping with Blockchain Ledgering) project for inter-satellite communication. [9]

NASA's interest in blockchain bodes well for its future adoption and application in space. With its support for this technological marriage, one can only expect that other agencies and large government entities may follow suit.

3. Blockchain & Cybersecurity in Outer Space

Is blockchain the solution for the immense breadth of cybersecurity threats in space? The short answer is yes, if deployed properly with humans out-of-the-loop. From what we know so far, blockchain software will work as a firewall and be effective against some common vulnerabilities. However, as seen in the NASA study, there is still much to learn on how its robust hardware, which requires significant power to operate, will be resilient not only to the harsh space environment but also against man-made cyber and military threats.

Cyberspace encompasses a great variety of technical efforts to protect information mostly captured and shared through the internet. The digitalization and technology growth worldwide brings new challenges to maintain private information safely. Threats to cyber security have been found in most sectors of the global economy and to individuals, as well. Any person, company or institution that uses electronic devices to communicate can be a target of cybercrime by a hacker. According to the report "The Hidden Costs of Cybercrime" the world has lost approximately $945 billion dollars due to cybercrime, despite spending nearly $1 trillion dollars on cybersecurity in 2020 alone [10]. The Covid-19 pandemic has been one of the culprits. Many businesses suddenly changed to operate remotely, without being properly secured against cyberattacks, thereby becoming easy targets for hackers.

Nowadays, it is still possible that with low level technology, affordable, and off the shelf hardware, criminals can corrupt satellites from anywhere and still go undetected. With that said, there is obviously a market to protect space assets from cybercrime. The immutability capacity of blockchain to resist fraud

and its model of cryptographic hash to every node and byte of information, may prove reliable in protecting the huge amount of data transmitted through satellites.

$1 trillion dollars will be the approximate revenue of the global space economy by 2040 [11]. Together with space, blockchain could offer solutions to other types of security issues. As an example, vessel operators often jam and spoof outer space monitoring systems of maritime activities when attempting to enter false information and get away with wrongdoing [12]. The illegal activities can include overfishing, smuggling of drugs and merchandise. If instead, blockchain was utilized to operate those transmissions, it would be impossible for hackers to tamper the system, as it would be necessary to trick most of the nodes, as discussed in the introduction.

While there are no international legal treaties to regulate cybercrime, countries have passed national cybersecurity legislation. The European Union (EU) has passed the Cybersecurity Act, and the United States has adopted the Cybersecurity Framework. However, in the case of outer space, there still to be greater effort to develop a global cybersecurity binding legal effort. The implications of cybersecurity regulations to the building of satellites, design, and operation of space systems, are still unknown and unclear for the industry. Because of this international legal void, blockchain may be the most practical solution against cyberthreat there is today. The industry must follow closely SpaceChain, BlockStream, and Cryptosat nodes in space as pilot projects and examples of the space-blockchain nexus discussed here.

To create such a framework for governance of space cybersecurity, it is necessary to create a global approach, where blockchain peers may be involved as legitimate stakeholders. The peer's presence will contribute to the self-governed, softly regulated but highly effective regime. [Ibid] Additional contingencies and limitations will be addressed in section 7.

4. Enhancing Stability & Fostering Growth in Space Commerce

It is an auspicious moment for companies such as SpaceChain, BlockStream, and Cryptosat, just now beginning to tap into a multibillion dollar blockchain tech ecosystem in the space industry. Despite the Covid-19 Pandemic, the space economy has retained stability, having grown 6.6% to a staggering $447B in 2020, continuing to expand its reach, collaborating with previously non-space sectors [13]. This provides a "launchpad" for new space startups to blossom in areas where space is now developing strong ties. According to The Space Report, commercial space revenue grew with the following exciting news:

> "Infrastructure and Support Industries grew the most, by 16%, surpassing $137B;
>
> Products and Services grew 1.2%, accounting for over 60% of commercial space;
>
> More than 1,100 SmallSats launched in 2020, 92% of all spacecraft deployed"

Blockchain has also taken a slice of the Space-to-Space solutions pie. Cryptocurrency has great opportunities to become the paying method for those services and products, as products and services continue to grow and represent the biggest slice of the commercial space revenue. JP Morgan's Onyx network recently demonstrated a successful execution of "a transaction between two LEO satellites, which validated the approach towards a decentralized network where communication with earth is not necessary. This breakthrough opens the door to a potential peer-to-peer DvP ('data versus payment') satellite marketplace in the long term, as private companies prepare to launch their own constellations." [14] In the near future, there will exist a fully independent space economy where transactions of products and services will be paid through nodes located in orbit – a space-to-space run economy, near-fully autonomous, devoid of human error, and highly secure.

The concurrent growth of 16% in infrastructure and support industries means that blockchain companies have even more opportunities coming up to enjoy the stable growth of the space industry. Blockchain has the capacity to bridge the space steady economy to other sectors in a faster and more decentralized way.

Perhaps the biggest economic marriage of blockchain and space is the acquisition of Planetary Resources by Consensys, in 2018. According to the company's CEO, Joe Lubin, also a co-founder of Ethereum, acquiring Planetary Resources strengthens his belief that Ethereum can assist humankind in developing the potential to go beyond our solar system. That acquisition is illustrative of the far reaches of blockchain in the deep space industry. Blockchain is now behind a pioneering commercial enterprise that will search water present in asteroids and power

humankind to commercially exploit the solar system and beyond.

Banking in outer space represents a promising market for fintech companies as blockchain offers a safe and efficient medium for transactions. As nodes in spacecraft keep records of all transactions, it is accurate to say that banking in space is already a functional space-to-earth solution. A self-sufficient banking system in space is now possible with the creation of crypto banks.

The state of Wyoming, for example, has conceded two crypto bank charters to fintech companies: one to Kraken and another to Aviant banks, in 2020. The Federal Reserve Bank of Arkansas City may also concede the two applications from Wyoming and other states may also follow suit. The two institutions are primarily focused on business-to-business activities to lower the risks of money laundering and risk secrecy with retail customers [15]. As every technology faces new legal questions, crypto banks are no different. Aviant, for instance, wants to utilize "tokenized" and electronic bank notes, which is being questioned if it is in accordance with (the not yet amended) the Uniform Commercial Code [16].

The two concessions from Wyoming exemplify an initiative of banking decentralization that once integrated with space technology presents the possibility of lifting millions of people out of poverty. According to the World Bank, there are 1.7 billion people currently unbanked until 2017 [17]. With the efforts of companies like OneWeb and Starlink's proliferated LEO constellations dedicated to delivering low-cost internet around the world, crypto banks accounts will be one step away from connecting millions of individuals and informal retailers to shared financial networks to which they would not have had access otherwise. This is by far one of the most promising applications of the space-blockchain nexus, banking the unbanked, creating business, increasing competition, and bringing prices down. The blockchain-space nexus is another hope that a renewed form of capitalism will benefit society, this time in a more sophisticated, high-tech and safe manner.

5. Blockchain & Outer Space Governance

Blockchain developments have been pertinent to the creation of new cybersecurity legal frameworks, which can mitigate a significant portion of the global economy's trillion-dollar-plus losses due to cyberattacks. Like cybersecurity, space will require new governance frameworks to wrangle blockchain applications for information sharing and beyond in its already foreign domain. This is the case for example, of lunar settlements and their commercial exploitation. As explained in The Space Report's "Getting Along on a Busy Moon," our natural satellite will soon become congested and contested with human activities, space exploration, and commercial exploitation. These activities will, at least initially, be primarily executed by the NASA Artemis Program with its goal to carry the next astronauts to the Moon, joined by space missions of at least nine other countries. [18] Without adequate governance, collaboration in this unfamiliar domain will be significantly impeded.

The need for information sharing is growing exponentially in every aspect of space governance. Sharing knowledge of activities conducted around Earth's orbit, cislunar, and deep space needs to be facilitated by multiple actors at multiple levels. This has been reflected in the Outer Space Treaties, specifically in the Convention on Registration of Objects Launched into Outer Space of 1976, ratified by 70 countries as of 2021. [19]

As the article details, the Global Expert Group Sustainable Lunar Activities (GEGSLA), is currently drafting a proposal of guidelines to the United Nations Committee on the Peaceful Uses of Outer Space (UNOOSA), on how to coordinate information sharing of Moon activities. The multiple lunar stakeholders are encouraged to share information and data of their activities for the following reasons:

> "To avoid causing adverse changes to the lunar environment or cislunar space, including the harmful contamination of the Moon in contravention of planetary protection policies
>
> To mitigate the creation of lunar orbital debris
>
> To avoid causing harmful interference with existing or planned lunar activities
>
> To avoid causing adverse changes to internationally endorsed sites of significant scientific or historical interest." [Ibid]

Blockchain, as it has in terrestrial applications, could once more provide precision-guided aid for treaty compliance and monitoring. Information sharing for interoperability is required by governmental agencies and contractors for the safety of operations on the

Moon and it falls within the premises of various articles of the Outer Space Treaty (OST) of 1967.

Article Eleven of the OST, for example, specifies that to promote peaceful cooperation in outer space, countries conducting activities on the Moon and other celestial bodies must disclose the nature and locations of their activities. Following that, Article Twelve also reads:

> "All stations, installations, equipment and space vehicles on the moon and other celestial bodies shall be open to representatives of other States' Parties to the Treaty on a basis of reciprocity. Such representatives shall give reasonable advance notice of a projected visit, in order that appropriate consultations may be held and that maximum precautions may be taken to assure safety and to avoid interference with normal operations in the facility to be visited." [20]

While experts at GEGSLA consider that a Public Registry of Priority Rights may be a method for treaty compliance and avoid conflict, this paper posits that blockchain-enabled smart contracts may be a simpler and safer solution for an autonomous legal ecosystem in space. The smart contract feature would help to facilitate an environment of open information sharing, with a crypto-ledger representing the repository of information required by Articles Eleven and Twelve of the OST.

With smart contracts, pre-established agreements for observable behavior could be autonomously executed in the remoteness of space, where conventional law enforcement and sanctions carry little weight. There, critical decisions from the ground could be delayed by minutes or even hours. In effect, meticulously planned terrestrial compliance could be baked into a new low friction legal system for space. Combined with carefully tested artificial intelligence, such a system could carry out the majority of legal decision making equally and justly across the solar system.

While blockchain has not yet ventured through the gates and over the bureaucratic hurdles of space governance, it is expected that it may encounter initial resistance and academic skepticism. Whether these will provide truly enforceable mechanisms is another story, an interdisciplinary challenge requiring collaboration between lawyers, policy experts, engineers, and technologists. However, with the aforementioned benefits in mind, we anticipate that commercial space actors will push for swift international resolutions that provide room for the space-blockchain market to grow.

6. New Opportunities for Terrestrial Sustainability

Blockchain and space present a myriad of opportunities for sustainability and the mitigation of climate change.

Governments around the world are broadly investing in the next generation of climate-resilient infrastructure, with the US having recently committed over $50B in its recently passed Bipartisan Infrastructure and Investment Jobs Act. With remote sensing and global navigation satellite systems having proven invaluable for their capabilities in mapping, agriculture, and weather monitoring, particularly in times of crisis, the space industry is well positioned to receive a significant portion of that investment. [21]

A tactical combination of space and blockchain is uniquely poised to spearhead this sea change in infrastructure, through mega Public-private Partnerships bridging the two industries. From facilitating provision and sharing of trusted data on emissions, deforestation, and ecological abuse to algorithmically ensuring compliance of terrestrial actors across the sustainability spectrum, the nexus has the potential to provide a space for earth service greater than the sum of its parts. Multiple proposed commercial climate-focused beneficiaries of this funding can be found in the table below.

Table 1: Business rationales for blockchain and climate change, Yakubowski 2021. [22]

Smart Contracts and Farming	MRV & funding matching	Carbon Credit	Sustainable Economy	De-carbonization	Emissions Data	Data Governance	Infrastructure
Use existing remote sensing space technology to monitor sustainable farming and reward farmers automatically through smart contracts.	Improve Measurement, Reporting and Verification to track climate change pledges. When paired with A.I (Artificial Intelligence) and IoT (Internet of Things), blockchain is also efficient in reducing peak energy demand.	Blockchain can assist with carbon credit transactions, tokenize and link them to smart contracts. This market will increase with the implementation of the Paris and other international climate agreements and the UN Sustainable Development Goals.	The minimization of blockchain hardware and maybe its integration with nano-space technology may speed a new sustainable economy.	Blockchain has the capability not only of redesigning current mechanisms but creating new ones to ensure compliance of carbon markets that are prone to fraud. Blockchain allows the implementation of financial incentives against carbon emissions.	Blockchain is excellent in providing reliable data on carbon and other greenhouse gasses, especially on avoiding fraudulent and double-counting of emissions.	Blockchain could supply the demand for global governance when providing validity for data concerning climate change and less carbon emissions. This means creating a framework for government and multilateral agreements.	Digital solutions may help achieve 15% of the Paris Agreement. Blockchain may achieve this through smart transportation, building smart grids and buildings, for example.

Already today, fledgling implementations combining remote sensing and blockchain are being undertaken, notably Daniel Oberhauser's smart contract facilitated payments for ecosystem services for wildlife conservation in Namibia. [23] In his remarkable implementation, "habitat integrity… is assessed by (cloud-based) remote sensing algorithms, which in turn trigger… smart contract payments to surrounding communities," enabling individuals to be matched with existing ecological conservation incentives. [Ibid] At time of writing, Oberhauser's platform: Blockchain Ecosystem Payments which won the Conservation X Labs Technology grand prize, is still in a state of active development.

This class of space-for-Earth ventures has a unique intrinsic opportunity to garner governmental and legislative support in generating a "moral currency" for blockchain and space while symbiotically accelerating other pursuits across our rapidly growing nexus.

7. Blockchain's Constraints & Sustainability Limitations

Blockchain with space faces many structural constraints, from sustainability to, paradoxically, security. These constraints severely limit the Blockchain-Space Nexus' capabilities to generate utility and value, in many cases undoing the benefits they already provide.

PoW consensus configurations not only reduce the pace at which blocks can be added to a network but consume large amounts of energy from the computationally intensive incentivized mining process worldwide – consumption as high as that of the entire country of Denmark. [4]

While economic drivers have led some miners to independently seek independent sources of renewable energy, time will tell if their investments pay off, convincing others to make the switch. SpaceChain may find yet another solution by partnering, for example, with the high-speed Qtum blockchain which utilizes Proof of Stake (PoS) to facilitate smart contracts. In a period of public pressure to take action on climate change, crypto currencies will be forced to switch toward more sustainable processes

(architecture or incentive structure), thereby reducing the costs of blockchain services world and space-wide [20]. The solution for blockchain space applications and high energy consumption may go hand in hand with high-efficiency space-based solar power, one of the most promising technologies of the future. In her book titled *Back to Earth*, retired NASA Astronaut Nicole Stott argues intensively that the technology to nurture Earth with solar power from space already exists, but what doesn't exist is the will power of governments to act upon it. Stott compares solar-based power to a project like the ISS, now 20 years in the making, claiming it a distinct possibility if we are able to make the right choices now. [24].

> "We already have all the know-how to shift away from fossil fuels and meet our energy demands by harnessing energy from the Sun. We have known for years how to move the generation of solar power off the Earth, but it is still seen as an 'economically prohibitive' business…or business as usual mentality. If in 2021 we can choose to enact a $1.9 trillion stimulus bill in response to the COVID-19 pandemic, why can't we choose to enact a roughly $20 billion space based solar power development and implementation plan to enable a global energy solution?" Stott questions. [Ibid].

Spaced-based solar is pushing the boundaries of photovoltaic efficiencies where few other industries dare tread. Marginal improvements to solar technologies are multiplicative for a space system, with all elements of the critical size, weight, and power (SWaP) equation augmented in their wake. Blockchain applications have the potential to piggyback on larger and seemingly unaffiliated solar efforts, many of which are driven by space technology development itself, harnessing its power for nodes in space and on Earth, making the blockchain enterprise more sustainable for Earth's fragile environment and energy equilibrium.

Transitioning to security, many blockchains' assured confidentiality comes with a huge problem – crime! Users now protected from cybercrime find themselves in a playground for newly anonymized illegal activity in cyberspace. The stakes appear to be, and are, very high when employing the technology in risk averse space applications, particularly with the current space legal framework far from up to date with blockchain and associated technology advancements. Hence, there presently does not exist a favorable political landscape at the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) to reach consensus on any hard legislation surrounding blockchain. Given this constraint, if bad actors find a way to exploit or disrupt fledgling blockchain applications in space, existing forms of governance will struggle with an already challenging decentralization problem.

It is hard to define how long this new wave of technology will take and who will be the most affected by it. Hence, governments will need to act quickly to promote a safe and harmonious transition into the future, educating themselves and their populations on these new technologies and insulating them from the worst of their effects. The goal of blockchain, especially when partnered with space commerce, should be aligned with international space-based efforts to provide relief, solve global issues, and promote peace on Earth.

8. Conclusion: Toward a Fusion of Commercial Blockchain & Space Activities

Blockchain is increasingly moving beyond the hype, maturing into a formidable force for technological disruption in and with space. The multi dimensionality of blockchain's capabilities overlaps with commercial interest in the space sector for the sustainable exploitation of Earth orbit, other celestial bodies, and the identification of creative solutions for issues here on Earth. The initial investments generated and milestones achieved by blockchain enterprises can catalyze greater levels of sustainability, addressing climate change and make space more open and secure for fast and efficient business.

The space industry is in dire need of a conciliator that will fill the vacuum of legal systems caused by the governmental roadblocks for enabling new commercial space activities. This is eminent, for example, when there exist global efforts for the coordination of sustainable markets on the Moon and throughout the solar system. Blockchain has the power to enhance space governance, providing needed assurance and balance in a turbulent environment.

This post Covid-19 decade holds promise for both space and for blockchain. The space industry has grown exponentially, both in terms of revenues and simultaneously operating satellites. There exists an ever expanding opportunity for placing nodes on Earth orbit. As a bonus, there has been increasing direct capital investment from space actors, agencies, and consortiums to blockchain start-ups, solidifying

the creation of more Public-private Partnerships (PPPs) between space and new technologies. It is possible to see traces of that with the first crypto banks, blockchain implementations in space, and in tandem, numerous economically viable solutions for climate change and sustainability on Earth and in-space.

As the road to a Blockchain-Space Nexus continues to be paved, forward progress is symbolized by a nearly unstoppable vehicle that will undoubtedly meet some very serious roadblocks. In a sense, it's not a matter of if, but when. There is great anticipation that it will set in motion hyper-exponential change, far greater than the sum of its individually exponential parts. This emerging, unified blockchain-space frontier will require new, next-generation leadership and cooperation to foster, rather than inhibit, a mutually secure and sustainable future of innovation and growth in each respective industry. Notwithstanding certain limitations we discussed, it is our hope that continued discourse will provide the requisite grassroots support to preserve and nurture this Nexus of progress for all humankind.

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Benjamin Shapiro is a Master's Student at The International Space University in Strasbourg, France and a recent graduate of Cornell University in Ithaca, New York. At Cornell, he studied economics and astronomy, with an interest in decision-making and strategic behavior, particularly in the space domain. He has worked in NASA's Office of the Chief Technologist and at The Aerospace Corporation where he performed cost estimation, economic and market analysis, and technology forecasting for government acquisitions and technology development programs across civil and national security space. Growing up in the beautiful US Virgin Islands, Benjamin spent his nights looking skyward. Now, as an aspiring astropreneur, he is working to engineer a sustainable future in space and here on Earth, exposing capital to and matching it with extraordinary ideas.

Chris Stott – ISC Co-Founder

Chris Stott is the Founder, Chairman and CEO of ManSat, the world's largest commercial provider of satellite spectrum. He serves as the Chair Emeritus, alongside the late Sir Arthur C. Clarke, of the Space and Satellite Professionals International (SSPI), the largest professional association in the global space and satellite industry, which also named him Satellite Industry Mentor of the Year for 2015.

Chris serves on the Faculty of the International Space University where he teaches space law and regulation, entrepreneurialism, networking, and has served as the Chair of the University's School of Business and Management. Chris also serves on ISU's Board of Advisors. Chris presently speaks as a guest speaker in space law and regulation at MIT Media Labs and the Harvard Smithsonian Center for Astrophysics. He has also taught space law at the University of Houston.

He is a founder of the International Institute of Space Commerce. He is a published Fellow of both the Royal Astronomical Society and the International Institute of Space Law. His first work on space, 'A Space For Enterprise: the aerospace industries after government monopoly.', which was Europe's first work on space privatization, was published with the Adam Smith Institute of London in 1994.

Elias de Andrade Jr. – ISC Executive Director

Elias de Andrade Jr., is a professional who has dedicated his career for the greater good and for outer space. His several international and practical experiences include managing communities for Pastoral da Criança, a Unicef program, in Brazil for three years, and six years as a Brazilian diplomatic delegate at the United Nations Committee on the Peaceful Uses of Outer Space.

Elias holds the Erasmus Mundus Global Studies M.A from the University of Vienna, and a M.Sc. in Space Studies from the International Space University, as well as a B.A with triple major in Global Studies, Philosophy, and Sociology. He is the author of the book "Space Debris – A Great Leap Forward We Won't Take", author and co-author of several other publications. Elias has been appointed in May 2020 as the new Deputy Director of the Institute of Space Commerce.

Dr. Michael Potter – ISC Co-Founder

Dr. Michael Potter is a business and social innovator and entrepreneur, founder of Geeks Without Frontiers. Michael was appointed to the team advising the US FCC's Broadband Deployment Advisory Committee regarding strategies for helping to close the digital divide in the US. Potter is the Director of the space documentary, "Orphans of Apollo." Potter has served on two Space Policy Presidential Transition projects.

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