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#### Plan: Private entities ought not engage in the exclusive and permanent use of Low Earth Orbit via Large Satellite Constellations.

Takaya et al 18 “The Principle of Non-Appropriation and the Exclusive Uses of LEO by Large Satellite Constellations” Yuri Takaya-Umehara [Visiting researcher at the University of Tokyo since April 2017. She was affiliated to the Kobe University to provide a course on space law to post-graduate students (2011-2017). She chairs a working group on the formulation of global norms in space law organized by the Keio University since 2018. She obtained her Ph.D. degree at the IDEST of Paris XI University in France, LL.M. at the Leiden University in the Netherlands.] Quentin Verspieren [Ph.D. in public policy @ The University of Tokyo, Assistant Professor of Space Policy @UTokyo, General Manager, Global Strategy @ArkEdge Space Inc., Associate Research Fellow @ESPI] Goutham Karthikeyan [The University of Tokyo & Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (ISAS-JAXA)] 2018 https://www.researchgate.net/publication/328094878\_The\_Principle\_of\_Non-Appropriation\_and\_the\_Exclusive\_Use\_of\_LEO\_by\_Large\_Satellite\_Constellations SM

* LSC = large satellite constellations
* Outlines density/minimum distance thresholds for exclusive use via LSCs
* Private entities are the actors of the plan – no treaty or alteration of international law would enforce a prohibition on large satellite constellations
* Exact density thresholds would be based on collision risk and determined on a constellation by constellation basis by an impartial 3rd party – candidates include the ITU or UNCOPUOS

By investigating expected large satellite constellation projects and by reviewing existing interpretations of international space law, this paper argues that the exclusive use of specific LEO orbits by a large constellation of satellite could constitute a violation of the non-appropriation principle by means of occupation and by means of use, drawing a parallel between orbits as resources and the exploitation of tangible mineral resources in space. Based on this, the important question to be raised is what constitutes an exclusive use of a specific orbit. In other words, an important hurdle in the concrete evaluation of whether a planned or established constellation potentially violates the non-appropriation principle through an exclusive use of LEO resides in the lack of clear definition on what can be considered an exclusive use. While the authors claim that legal issue can be clearly solved in abstracto, it naturally shifts towards a regulatory challenge.

This regulatory challenge consists in first defining qualitatively what is the exclusive use of an orbit before translating this definition into measurable, technical rules. In this paper, the authors define an exclusive use of an orbit by a state40 as any use that would prevent/hinder the usage of the same orbit by any other state. Translating this definition into an applicable regulation could consist in defining a threshold of orbital collision risk or a threshold of density of satellites along an orbit based on its altitude, shape, relative velocity of neighbouring objects, etc. It is however not the purpose of this space law paper. What is more appropriate here is to think about which organization or forum would be in charge of elaborating this technical definition. Serious candidates could be the ITU, with excellent track-record in dealing with the use of the GEO region but which would have to review its “first come, first served” principle, or the UNCOPUOS, aiming for the widespread adoption of a new piece of international law. Moreover, even if its rules suffer from a low implementation rates, the IADC would be an appropriate discussion platform thanks to its very deep technical focus.

6. Conclusion

The various announced projects of LSC, also called mega-constellations, push existing regulations and practices to their limit, forcing researchers and practitioners around the world to rethink the applicability of existing space law principles to this new trend. In this paper, the authors, after providing background information on current LSC plans as well as recalling the legal status of the LEO region, investigate whether the deployment of an LSC having an exclusive use of an orbit constitutes a violation of the nonappropriation principle as stated in OST Article II. This paper concludes that:

The exclusive use of an orbit by an LSC constitutes a violation of the non-appropriation principle by means of occupation due to the innate nature of orbit being a specific location in space that can be occupied, but most notably by means of use, considering orbits as “limited natural resources” and invoking parallels with the exploitation of natural resources in outer space;

ITU’s “first come, first served” principle is reaching its limits with current LSC projects and should be re-evaluated;

The main challenge ahead is not legal but technical and regulatory and consists in defining precisely what can constitute an exclusive use of an orbit and in translating such definition into a clear regulation or code of conduct.

#### Preliminary estimates of the minimum distance threshold for exclusive use occur on a system-by-system basis and range from 11-17 kilometers – collisions are a mathematical certainty outside this threshold

Liang et al. 21 J. Liang, A. U. Chaudhry and H. Yanikomeroglu, "Phasing Parameter Analysis for Satellite Collision Avoidance in Starlink and Kuiper Constellations," 2021 IEEE 4th 5G World Forum (5GWF), 2021, pp. 493-498, doi: 10.1109/5GWF52925.2021.00093. mvp

In this work, we investigate the phasing parameter for two biggest upcoming satellite constellations, namely Starlink Phase 1 Version 3 and Kuiper Shell 2. The phasing parameter determines the relative position of the satellites, which in turn affects the minimum distance between them. The satellite collisions within a constellation can be avoided if the value of F that provides the maximum value of the minimum distance between satellites is selected while designing a constellation. After simulating the two constellations and analyzing the minimum distance between satellites for each value of F in each constellation, we find the most suitable value of F with the highest ranking for Starlink Phase 1 Version 3 constellation as 17, and for Kuiper Shell 2 constellation as 11. Using these values of F, the intra-constellation collisions between satellites in these constellations can be avoided.

#### Privatization is driving uncontrolled satellite internet constellations that profit at the expense of cooperation and sustainability – perpetuates internet inequality.

Song and Bloom 20 “Big Tech is leading the new space race. Here's why that's a problem” Steve Song is a Fellow with the Mozilla Foundation where he works to promote policy and regulation that will increase equitable and affordable access to communication in rural and underserved regions of the world. Peter Bloom is a community digital defense activist and the founder and General Coordinator of Rhizomatica, an international non-profit that helps communities build their own communications infrastructure. He is a former Shuttleworth Foundation fellow and was named an Innovator under 35 by MIT Technology Review and appeared on Foreign Policy's 100 Leading Global Thinkers list in 2015. November 14, 2020 <https://www.salon.com/2020/11/14/big-tech-is-leading-the-new-space-race-heres-why-thats-a-problem/> SM

Big Tech is leading the new space race. Here's why that's a problem

New satellite tech could bring billions more online. But will Big Tech bring their extractive ethos into space?

The coronavirus pandemic has made having a stable and reliable internet connection a matter of extreme urgency, as people all over the world struggle to work, access education, and participate in society while staying safe. Yet universal affordable access is far from being achieved; indeed, half of the world still lacks access to the Internet, despite sustained efforts from governments and corporations.

One popular proposal for ubiquitous connectivity comes from Low Earth Orbit (LEO) satellite constellations. LEO boosters claims that such satellites will have the ability to deliver high-speed broadband anywhere on the planet. These satellites provide internet access from space, and require placing thousands of satellites into orbit at a much closer proximity to Earth than traditional satellites.

The prospect of a globe-encircling mesh of broadband communication satellites has attracted the interest and investment of billionaires ranging from Bill Gates in the 1990s to Elon Musk and Jeff Bezos today. Currently there are at least four major LEO initiatives from the US and Europe, including Starlink (SpaceX), Project Kuiper (Amazon), OneWeb, and Telesat. China has announced at least three LEO constellations, and Russia one. The size and scope of these projects are massive. To put current LEO satellite ambitions in context: the current total number of satellites of any kind orbiting Earth is just over 2,500. Starlink, who already have nearly 900 satellites in orbit, recently petitioned the US communications regulator for permission to launch a total of 12,000 satellites. Not to be outdone, OneWeb recently applied for permission to launch 48,000 satellites.

So what's not to love?

While the goal of these companies to ensure broadband anywhere and everywhere is laudable, the technology and the approach to connectivity are not free from concerns. Recent history, especially the development of the Internet itself, has shown us that simply having the capability to build something doesn't necessarily make it a good idea. The Silicon Valley ethos of "move fast and break things," perhaps valid in developing small applications, becomes irresponsible when the consequences of failure may be catastrophic and irreversible. Criticism of LEO constellations to date have focused on practical concerns around a variety of issues, including: the economic viability of the constellations, the occlusion of the night sky from astronomers, wireless interference between different constellations, and the potential chain reaction of collisions from a single error in satellite trajectory, leaving near-space an inaccessible junkyard of debris.

Beyond that, LEO constellations have deeper and longer-term implications that have yet to find their way into mainstream public debate. For one, LEO constellations are part of a larger process in which space exploration is being redefined and reframed in military and commercial terms. Closer to Earth, LEO constellations raise important concerns around the potential for the further entrenchment of a global internet oligopoly that increases inequality and disempowers citizens.

The scramble for space

Over the past seven decades, as our ability to explore beyond our planet has evolved, national security interests in space have aligned with commercial ones to an extent that they are nearly indistinguishable today. In the United States, private space launch companies like SpaceX and United Launch Alliance are major recipients of government contracts and now provide the bulk of US launch capacity for both scientific and military missions. While close ties between the defense and aerospace industries is nothing new, we are in a decidedly new phase of this relationship due to technological advancement, new policy priorities and the rise of private actors.

As commercial launch capacity has increased and space exploration technologies have advanced, the decades-old agreements around how we treat space and recognize our solar system as a commons for the benefit of all humanity are beginning to unravel. One clear example of this is the White House's recent "Executive Order on Encouraging International Support for the Recovery and Use of Space Resources," which emphasizes that "the United States does not view outer space as a 'global commons'" and refers to the Moon Agreement as "a failed attempt at constraining free enterprise."

It is necessary to better understand the deep ties of LEO companies to the hegemonic designs of national governments on near space. Recently, in exchange for $28 million USD, Starlink provided the services of its satellites for live-fire demos with the US Air Force to test its Advanced Battle Management System and lay the groundwork for a military Internet of Things. Speaking after the latest live-fire demo, William Roper, Air Force acquisition chief, opined that "the military needs to be ready to play a strategic role because we need communications in many areas of the world that there are no commercial providers . . . we can be the stability case for companies like SpaceX and others who want to sell communications worldwide."

SpaceX's connections to the military-industrial complex were made clear in comments by SpaceX president Gwynne Shotwell in 2018, who stated that her company would be willing to launch a space weapon to protect the US, in contravention of established space norms. Only weeks ago, SpaceX signed a contract with the Pentagon to jointly develop a rocket that can deliver up to 80 tons of cargo and weaponry anywhere in the world in just one hour.

The Internet, too, from its very inception until today, has proven to be a useful tool for pursuing military and security objectives. Of these, surveillance remains at the heart of Silicon Valley's highly profitable business model of manipulating our attention and preferences for the sake of profit. This profit model facilitates the designs of space-obsessed billionaires like Jeff Bezos who make it no secret that their ultimate goal and passion is the human colonization of other planets in our solar system. In general terms, with material and economic support from taxpayers through defense spending, the profits from the colonization of our data-bodies are being invested in the militarization, privatization and colonization of space.

Telecommunications: driving inequality or empowering citizens?

The telecommunications sector has always been a battleground for regulation. While the early days of the Internet seemingly teemed with competition and diversity, power and control has ultimately become concentrated with the growth of giant internet companies that now dominate our online life. The consequences of unregulated, technology-fueled expansion of globalization and inequality can now be seen in almost every aspect of life.

Digital technology plays a critical role in amplifying inequality, highlighting the need to reframe how we approach network technology development. Some governments and citizen groups understand the connection between economic mobility and tech skills development.

One great example of this comes from Broadband for the Rural North (B4RN), a cooperative in Northern England, that delivers 1 gigabit-per-second fiber-optic capacity to homes in a region deemed economically unviable by the incumbent telecommunications giant. B4RN's ability to build and sustain an affordable internet service at speeds many times that of commercial offerings is based upon the investment they make in both community engagement and the development of local capacity. Contrast this with the prospect of a broadband service from a LEO constellation, in which the role of the citizen is that of a consumer only. It is also worth noting that B4RN's profits are reinvested locally, while revenues from LEO constellations are beamed straight out of the country.

The failure to invest in alternatives that build local capacity replicates itself at the national level as well. LEO constellations have the potential to further abstract Internet service to a supra-national level in a manner that disempowers not just individuals but nation-states themselves in terms of domestic expertise and infrastructure. Investment and deployment costs for LEO constellations are so "astronomical," and in many cases so tied to national/military investment and subsidies, that only a small handful of corporations/countries will be capable of owning and managing their own constellation. This is likely to open up a new front in the ongoing wrangling by geo-political power blocs over the future of the Internet.

Furthermore, it is far from clear that LEO constellations have either the capacity or the economic model to deliver on their claims of providing affordable connectivity to the unserved in most parts of the world. Consider that the half of the world's population that remains unconnected to the Internet are the most economically disadvantaged. As such, most people will not be direct consumers of LEO services but will instead need to rely on a telco building infrastructure and using LEO as backhaul—a scenario which already exists with conventional satellite services. A further concern is that LEO constellations may ultimately create a disincentive to investment in rural connectivity, based on the assumption by service providers and governments that LEO constellations will address that gap.

It is troubling that companies like Amazon and Google (the third largest shareholder in SpaceX), which already wield tremendous power and influence over society, are vying to expand their dominance by becoming global internet service providers with support from taxpayers via subsidies and military spending. With their hands in essentially every layer of the communication stack, it will prove challenging to regulate or even know about the data they harvest and how those are used to competitive advantage in other areas of their businesses.

At the time of their emergence, both space exploration and the Internet served as beacons of hope and of potential transcendence for humanity—one of shared imagination and resources, and of cooperation in human development. In both cases, that hope has been dimmed in a quest for profit and geo-political power. If we want to recover a sense of shared purpose as a species, the question as to "who gets to put their satellites into low earth orbit?" is more important than we might think. Is space for everyone, or just a few huge corporations and global superpowers? This is the question we ask when we ask who gets to park their satellites in orbit.

There is an opportunity to return to the spirit of internationalism that infused the early days of space exploration in which space was held as a shared resource to be protected and guarded from exploitation. Similarly, here on Earth, we see successful efforts to manage Internet infrastructure as a commons in contrast to Silicon Valley's model of surveillance capitalism. Recognizing that individual and collective empowerment and agency are as important as the actual infrastructure itself is the key to a more egalitarian Internet. LEO satellite networks may deliver connectivity (although many doubts remain), but they are less likely to empower people and move us toward a more equitable world. The development of a healthy Internet that actually benefits humanity involves not just the end result of affordable access, but also the process through which people gain that access.

### Scenario 1 – Debris

#### Satellite internet constellations accelerate collision risks – more close encounters and less transparency means bad decisions are inevitable.

Pultarova 21 “SpaceX Starlink satellites responsible for over half of close encounters in orbit, scientist says” Tereza Pultarova [Master's in Science from the International Space University, France, to her Bachelor's in Journalism and Master's in Cultural Anthropology from Prague's Charles University. She worked as a reporter at the Engineering and Technology magazine, freelanced for a range of publications including Live Science, Space.com, Professional Engineering, Via Satellite and Space News and served as a maternity cover science editor at the European Space Agency.], August 18, 2021 <https://www.space.com/spacex-starlink-satellite-collision-alerts-on-the-rise> SM

SpaceX Starlink satellites responsible for over half of close encounters in orbit, scientist says

Starlink satellites might soon be involved in 90% of close encounters between two spacecraft in low Earth orbit.

Operators of satellite constellations are constantly forced to move their satellites because of encounters with other spacecraft and pieces of space junk. And, thanks to SpaceX's Starlink satellites, the number of such dangerous approaches will continue to grow, according to estimates based on available data.

SpaceX's Starlink satellites alone are involved in about 1,600 close encounters between two spacecraft every week, that's about 50 % of all such incidents, according to Hugh Lewis, the head of the Astronautics Research Group at the University of Southampton, U.K. These encounters include situations when two spacecraft pass within a distance of 0.6 miles (1 kilometer) from each other.

Lewis, Europe's leading expert on space debris, makes regular estimates of the situation in orbit based on data from the Socrates (Satellite Orbital Conjunction Reports Assessing Threatening Encounters in Space ) database. This tool, managed by Celestrack, provides information about satellite orbits and models their trajectories into the future to assess collision risk.

Lewis publishes regular updates on Twitter and has seen a worrying trend in the data that reflects the fast deployment of the Starlink constellation.

"I have looked at the data going back to May 2019 when Starlink was first launched to understand the burden of these megaconstellations," Lewis told Space.com. "Since then, the number of encounters picked up by the Socrates database has more than doubled and now we are in a situation where Starlink accounts for half of all encounters."

The current 1,600 close passes include those between two Starlink satellites. Excluding these encounters, Starlink satellites approach other operators’ spacecraft 500 times every week.

In comparison, Starlink's competitor OneWeb, currently flying over 250 satellites, is involved in 80 close passes with other operators' satellites every week, according to Lewis' data.

And the situation is bound to get worse. Only 1,700 satellites of an expected constellation of tens of thousands have been placed into orbit so far. Once SpaceX launches all 12,000 satellites of its first generation constellation, Starlink satellites of all close approaches, Lewis’ calculations suggest.will be involved in 90%

**Chart, line chart

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A graph showing the number of close encounters between Starlink satellites and spacecraft of other operators plotted by Professor Hugh Lewis based on data from the Socrates database.A graph showing the number of close encounters between Starlink satellites and spacecraft of other operators plotted by Professor Hugh Lewis based on data from the Socrates database. (Image credit: Hugh Lewis)

The risk of collision

Siemak Hesar, CEO and co-founder of Boulder, Colorado, based Kayhan Space, confirms the trend. His company, which develops a commercial autonomous space traffic management system, estimates that on average, an operator managing about 50 satellites will receive up to 300 official conjunction alerts a week. These alerts include encounters with other satellites as well as pieces of debris. Out of these 300 alerts, up to ten might require operators to perform avoidance maneuvers, Hesar told Space.com.

Kayhan Space bases their estimates on data provided by the U.S. Space Surveillance Network. This network of radars and telescopes, managed by the U.S. Space Force, closely monitors about 30,000 live and defunct satellites and pieces of debris down to the size of 4 inches (10 centimeters) and provides the most accurate location data of the orbiting objects.

The size of this catalog is expected to increase ten times in the near future, Hesar added, partly due to the growth of megaconstellations, such as Starlink, and partly as sensors improve and enable detection of even smaller objects. The more objects in the catalog mean more dangerously close encounters.

"This problem is really getting out of control," Hesar said. "The processes that are currently in place are very manual, not scalable, and there is not enough information sharing between parties that might be affected if a collision happens."

Hesar compared the problem to driving on a highway and not knowing that there has been an accident a few miles ahead of you. If two spacecraft collide in orbit, the cloud of debris the crash generates would threaten other satellites travelling through the same area.

"You want to have that situational awareness for the other actors that are flying in the neighbourhood," Hesar said.

Bad decisions

Despite the concerns, only three confirmed orbital collisions have happened so far. Earlier this week, astrophysicist and satellite tracker Jonathan McDowell, who's based at the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts, found evidence in Space-Track data that the Chinese meteorological satellite Yunhai 1-02, which disintegrated in March this year, was actually hit by a piece of space debris.

The worst known space collision in history took place in February 2009 when the U.S. telecommunication satellite Iridium 33 and Russia's defunct military satellite Kosmos-2251 crashed at the altitude of 490 miles (789 kilometres). The incident spawned over 1,000 pieces of debris larger than 4 inches (10 cm). Many of these fragments were then involved in further orbital incidents.

Lewis is concerned that with the number of close passes growing, the risk of operators at some point making a wrong decision will grow as well. Avoidance maneuvers cost fuel, time and effort. Operators, therefore, always carefully evaluate such risks. A decision not to make an avoidance maneuver following an alert, such as that made by Iridium in 2009, could, however, clutter the orbital environment for years and decades.

"In a situation when you are receiving alerts on a daily basis, you can't maneuver for everything," Lewis said. "The maneuvers use propellant, the satellite cannot provide service. So there must be some threshold. But that means you are accepting a certain amount of risk. The problem is that at some point, you are likely to make a wrong decision."

Hesar said that uncertainties in the positions of satellites and pieces of debris are still considerable. In case of operational satellites, the error could be up to 330 feet (100 meters) large. When it comes to a piece of debris, the uncertainty about its exact position might be in the order of a mile or more.

"This object can be anywhere in this bubble of multiple kilometres," Hesar said. "At this point, and for the foreseeable future, avoidance is our best recourse. People that say 'I'm going to take the risk', in my humble opinion, that's an irresponsible thing to do."

Starlink monopoly

Lewis is concerned about the growing influence of a single actor — Starlink — on the safety of orbital operations. Especially, he says, as the spaceflight company has entered the satellite operations world only recently.

"We place trust in a single company, to do the right thing," Lewis said. "We are in a situation where most of the maneuvers we see will involve Starlink. They were a launch provider before, now they are the world's biggest satellite operator, but they have only been doing that for two years so there is a certain amount of inexperience."

SpaceX relies on an autonomous collision avoidance system to keep its fleet away from other spacecraft. That, however, could sometimes introduce further problems. The automatic orbital adjustments change the forecasted trajectory and therefore make collision predictions more complicated, according to Lewis.

"Starlink doesn't publicize all the maneuvers that they're making, but it is believed that they are making a lot of small corrections and adjustments all the time," Lewis said. "But that causes problems for everybody else because no one knows where the satellite is going to be and what it is going to do in the next few days."

#### LEO collisions due to constellations take out ISR and other military assets – debris cascades into different altitudes and triggers Kessler Syndrome.

Wong 19 “Congested Outer Space: Increased Deployment of Small Satellite Constellations Could Hamper Military Space Operations” 2019 Arthur Wong [Strategic Development of Forces Division, SHAPE. Prior to working at SHAPE he has worked at NATO HQ, within the Defence Investment Division on interoperability for NATO’s multinational battlegroups.] <https://www.japcc.org/congested-outer-space/> SM

Since the production of a large number of small satellites in a factory environment will lower the cost of the overall programme, companies such as SpaceX, Amazon and OneWeb have been creating a satellite constellation within the LEO and Medium Earth Orbit (MEO).8, 9 OneWeb is a new company which plans to create an initial constellation of 648 satellites to provide global satellite internet broadband services. Each satellite weighs approximately 150 kg and will be programmed to operate in 20 different orbital planes at an altitude of 1,200 km.10 Creating a large constellation within the LEO could mitigate transmission delays and latency due to their closer range to ground stations while allowing users to send and receive data in a timely manner. The first six of the 648 satellites were launched in early 2019 with more launches scheduled to occur throughout this year.

Both SpaceX and Amazon have also announced their intention of creating a separate constellation for internet communication systems. SpaceX satellite constellations, named Starlink, will be the largest constellation ever built when it is completed. The constellations consist of nearly 12,000 satellites in more than 20 different orbital planes.11 The altitude of Starlink will range between 550 km to 1,150 km. SpaceX aims to have a minimum of 2,200 satellites in the next five years and achieve initial commercial operation by 2020.12 Amazon’s version of constellation, named Kuiper, has also been seeking approval from the Federal Communications Commission (FCC) to launch more than 3,200 satellites between 590 km to 630 km in the LEO.13

Space Debris Threat Increases in the LEO

The usage of cube satellite has provided positive impacts in various fields, ranging from environmental studies to offering worldwide internet access in rural areas through communication constellations. However, the current space environment is becoming congested. Hundreds of satellites have already been scheduled to launch each year before the construction of the constellation programme by OneWeb, SpaceX and Amazon. To further worsen the space debris situation in the LEO, direct-ascent Anti-Satellite Testing (ASAT) was conducted in recent years and more debris will be created through such testing. During the Chinese ASAT in 2007, some debris from the collision was blasted outward away from the Earth, causing a potential threat to satellites above the altitude where the ASAT testing occurred.14 Nine years after the incident happened, there are still more than 3,000 traceable pieces in orbit.

In 2009, two satellites collided at a speed of 10 km/s at an altitude of 800 km. This was the first time a collision had happened between two satellites. The incident created more than 1,000 pieces of debris larger than 10 cm. Such activity could initiate a chain reaction, creating more collisions from the initial impact. This phenomenon is known as the Kessler Syndrome.15

From early 2019, there were approximately 34,000 pieces of debris larger than 10 cm (similar to the size of a cube satellite) and more than 900,000 pieces of debris ranging from one cm to 10 cm in size. Objects that are smaller than one cm in size are expected to be more than 100 million within the LEO.16 Despite the small size of the space debris, they are travelling at a speed of more than seven km/s. At this speed, tiny objects could harm any large satellite orbiting in the LEO. While satellites can increase their physical hardening to protect the on-board instruments from impact, some satellites cannot be hardened due to the size and dimensional constraints. Furthermore, hardened materials would also increase the overall cost of the satellite.

Constellation in the Making Could Impact Space-Based Military Assets

The previous examples revealed the congestion of the LEO. With companies continuing to launch thousands of small satellites, the chances of a collision in space will continue to increase. This will hinder space-based Intelligence, Surveillance and Reconnaissance (ISR) support to provide valuable information to military operations. A majority of the ISR assets are orbiting in the LEO. NATO relies on space-based assets to assist its operations. Increasing the number of spacecraft in the LEO could raise problems and threats to military assets as well as access to space assets to support operations. If the orbital path of these smaller objects were not tracked by the Space Operation Centre regularly, larger satellites or manned-space stations could be penetrated by the non-propulsion satellites, making them a potential kinetic kill vehicle.

Most satellites within the 600 km region of the LEO are affected by the atmospheric drag, which is helping to bring down some of the obsolete satellites. However, satellites orbiting above 800 km are less likely to be affected by the atmospheric drag, making cube satellites or small satellites without propulsion systems difficult to deorbit once they have reached the EOL.17, 18 The altitude for some of the OneWeb, Starlink and Kuiper constellations is planned to be above the atmospheric drag region. Despite this, Starlink satellites will have propulsion system for orbital manoeuvre and EOL deorbiting, tracking the full constellation with 12,000 satellites could be challenging for the company and the Combined Space Operations Center (CSpOC).19 Additionally, there is the possibility of losing contact with satellites before they reach their EOL. Envisat, an 8,210 kg satellite that is currently drifting at an altitude of 785 km, poses a collision threat with other satellites. Envisat was expected to decommission in 2014 but the European Space Agency (ESA) lost contact with the satellite in 2012.20 If no interaction will be made with the Envisat, it is expected to stay in orbit for the next 150 years.21

#### Collisions with early warning satellites causes miscalc and goes nuclear – magnified by the Kessler effect

Blatt 20 [Talia, joint concentration in Social Studies and Integrative Biology at Harvard, specialization in East Asian geopolitics and security issues] “Anti-Satellite Weapons and the Emerging Space Arms Race,” Harvard International Review, May 26, 2020, <https://hir.harvard.edu/anti-satellite-weapons-and-the-emerging-space-arms-race/> TG

Despite their deterrent functions, ASATs are more likely to provoke or exacerbate conflicts than dampen them, especially given the risk they [pose](https://thebulletin.org/2019/06/arms-control-in-outer-space-the-russian-angle-and-a-possible-way-forward/) to early warning satellites. These satellites are a crucial element of US ballistic missile defense, capable of [detecting missiles](https://www.globalsecurity.org/space/world/japan/warning.htm) immediately after launch and tracking their paths.

Suppose a US early warning satellite goes dark, or is shut down. Going dark could signal a glitch, but in a world in which other countries have ASATs, it could also signal the beginning of an attack. Without early warning satellites, the United States is much more susceptible to nuclear missiles. Given the strategy of counterforcing—[targeting](https://www.belfercenter.org/sites/default/files/files/publication/isec_a_00273_LieberPress.pdf) nuclear silos rather than populous cities to prevent a nuclear counterattack—the Americans might believe their nuclear weapons are imminently at risk. It could be [twelve hours](https://books.google.com/books?id=ET8lDwAAQBAJ&pg=PA1&lpg=PA1&dq=%22Protecting+Space+Assets%22+johnson-freese&source=bl&ots=6Oq0IdeBjw&sig=ACfU3U1G6Hj8QdP4JlCRNxA6i5XplZwHyg&hl=en&sa=X&ved=2ahUKEwj1n-jT2YzpAhUugnIEHUuMCu4Q6AEwA3oECAkQAQ#v=onepage&q=%22Protecting%20Space%20Assets%22%20johnson-freese&f=false) before the United States regains satellite function, which is too long to wait to put together a nuclear counterattack. The United States, therefore, might move to mobilize a nuclear attack against Russia or China over what might just be a piece of debris shutting off a satellite.

Additionally, accidental warfare, or strategic miscalculation, is uniquely likely in space. It is [much easier](https://books.google.com/books?id=VyXTDwAAQBAJ&pg=PA339&lpg=PA339&dq=space+offense+dominant&source=bl&ots=Mw0bgJ51qf&sig=ACfU3U3DeZiEHpr9nfszlCbJZIoyyssIpg&hl=en&sa=X&ved=2ahUKEwjrs-WD3IzpAhVulHIEHbL0AE4Q6AEwCXoECAoQAQ#v=onepage&q=space%20offense%20dominant&f=false) to hold an adversary’s space systems in jeopardy with destructive ASATs than it is to [sustainably defend](https://www.cnas.org/publications/commentary/the-us-military-should-not-be-doubling-down-on-space) a system, which is expensive and in some cases not technologically feasible because of limitations on satellite movement. Space is therefore [considered](https://books.google.com/books?id=VyXTDwAAQBAJ&pg=PA339&lpg=PA339&dq=space+offense+dominant&source=bl&ots=Mw0bgJ51qf&sig=ACfU3U3DeZiEHpr9nfszlCbJZIoyyssIpg&hl=en&sa=X&ved=2ahUKEwjrs-WD3IzpAhVulHIEHbL0AE4Q6AEwCXoECAoQAQ#v=onepage&q=space%20offense%20dominant&f=false) offense-dominant; offensive tactics like weapons development are prioritized over defensive measures, such as [improving GPS](https://www.politico.com/story/2018/04/06/outer-space-war-defense-russia-china-463067) or making satellites more resistant to jamming.

As a result, countries are left with poorly defended space systems and rely on offensive posturing, which increases the risk that their actions are perceived as aggressive and incentivizes rapid, risky counterattacks because militaries cannot rely on their spaced-based systems after first strikes.

There are several hotspots in which ASATs and offensive-dominant systems are particularly relevant. Early warning satellites [play](https://www.politico.com/story/2018/04/06/outer-space-war-defense-russia-china-463067) a central role in US readiness in the event of a conflict involving North Korea. News of North Korean missile launches comes from these satellites. Given North Korea’s [history](https://www.bbc.com/news/world-asia-pacific-11813699) of nuclear provocations, unflinchingly hostile rhetoric towards the United States and South Korea, and diplomatic opacity, North Korea is always a threatening, unknowable adversary, but recent developments have magnified the risk. With the health of Kim Jong-un [potentially in jeopardy](https://apnews.com/f5d302ae65b03838173e40848223b771), a succession battle or even civil war on the peninsula [raises the chances](https://www.express.co.uk/news/world/1273890/Kim-Jong-un-dead-North-Korea-nuclear-weapon-news-latest-death-US) of loose nukes. If the regime is terminal, traditional MAD risk calculus will become moot; with nothing to lose, North Korea would have no reason to hold back its nuclear arsenal. Or China [might decide](https://foreignpolicy.com/2020/04/28/kim-jong-un-china-north-korea/) to seize military assets and infrastructure of the regime. If the US does not have its early warning satellites because they have been taken out in an ASAT attack, the US, South Korea, and Japan are all in imminent nuclear peril, while China could be in a position to fundamentally reshape East Asian geopolitics.

The South China Sea is another hotspot in which ASATs could risk escalation. China [is developing](https://missiledefenseadvocacy.org/missile-threat-and-proliferation/todays-missile-threat/china-anti-access-area-denial-coming-soon/) Anti-Access Area Denial (A2/AD) in the South China Sea, a combination of long range radar with air and maritime defense meant to deny US freedom of navigation in the region. Given the disputed nature of territory in the South China Sea, the United States and its allies do not want China to successfully close off the region.

#### Nuke war causes extinction – Ice Age, famines, and war won’t stay limited

Edwards 17 [Paul N. Edwards, CISAC’s William J. Perry Fellow in International Security at Stanford’s Freeman Spogli Institute for International Studies. Being interviewed by EarthSky. How nuclear war would affect Earth’s climate. September 8, 2017. earthsky.org/human-world/how-nuclear-war-would-affect-earths-climate] Note, we are only reading parts of the interview that are directly from Paul Edwards -- MMG

In the nuclear conversation, what are we not talking about that we should be?

We are not talking enough about the climatic effects of nuclear war. The “nuclear winter” theory of the mid-1980s played a significant role in the arms reductions of that period. But with the collapse of the Soviet Union and the reduction of U.S. and Russian nuclear arsenals, this aspect of nuclear war has faded from view. That’s not good. In the mid-2000s, climate scientists such as Alan Robock (Rutgers) took another look at nuclear winter theory. This time around, they used much-improved and much more detailed climate models than those available 20 years earlier. They also tested the potential effects of smaller nuclear exchanges. The result: an exchange involving just 50 nuclear weapons — the kind of thing we might see in an India-Pakistan war, for example — could loft 5 billion kilograms of smoke, soot and dust high into the stratosphere. That’s enough to cool the entire planet by about 2 degrees Fahrenheit (1.25 degrees Celsius) — about where we were during the Little Ice Age of the 17th century. Growing seasons could be shortened enough to create really significant food shortages. So the climatic effects of even a relatively small nuclear war would be planet-wide. What about a larger-scale conflict? A U.S.-Russia war currently seems unlikely, but if it were to occur, hundreds or even thousands of nuclear weapons might be launched. The climatic consequences would be catastrophic: global average temperatures would drop as much as 12 degrees Fahrenheit (7 degrees Celsius) for up to several years — temperatures last seen during the great ice ages. Meanwhile, smoke and dust circulating in the stratosphere would darken the atmosphere enough to inhibit photosynthesis, causing disastrous crop failures, widespread famine and massive ecological disruption. The effect would be similar to that of the giant meteor believed to be responsible for the extinction of the dinosaurs. This time, we would be the dinosaurs. Many people are concerned about North Korea’s advancing missile capabilities. Is nuclear war likely in your opinion? At this writing, I think we are closer to a nuclear war than we have been since the early 1960s. In the North Korea case, both Kim Jong-un and President Trump are bullies inclined to escalate confrontations. President Trump lacks impulse control, and there are precious few checks on his ability to initiate a nuclear strike. We have to hope that our generals, both inside and outside the White House, can rein him in. North Korea would most certainly “lose” a nuclear war with the United States. But many millions would die, including hundreds of thousands of Americans currently living in South Korea and Japan (probable North Korean targets). Such vast damage would be wrought in Korea, Japan and Pacific island territories (such as Guam) that any “victory” wouldn’t deserve the name. Not only would that region be left with horrible suffering amongst the survivors; it would also immediately face famine and rampant disease. Radioactive fallout from such a war would spread around the world, including to the U.S. It has been more than 70 years since the last time a nuclear bomb was used in warfare. What would be the effects on the environment and on human health today? To my knowledge, most of the changes in nuclear weapons technology since the 1950s have focused on making them smaller and lighter, and making delivery systems more accurate, rather than on changing their effects on the environment or on human health. So-called “battlefield” weapons with lower explosive yields are part of some arsenals now — but it’s quite unlikely that any exchange between two nuclear powers would stay limited to these smaller, less destructive bombs.

### Scenario 2 - Hacking

#### Independently causes cyberwar and satellite hacking which escalates.

Falco 19 “Opinion: Our satellites are prime targets for a cyberattack. And things could get worse.” Gregory Falco [Gregory Falco is a cyber research fellow at Harvard University’s Belfer Center and a postdoctoral security researcher at the Massachusetts Institute of Technology’s Computer Science and Artificial Intelligence Laboratory. He is the founder and chief executive of NeuroMesh, a tech security company.] May 7, 2019 <https://www.washingtonpost.com/opinions/our-satellites-are-prime-targets-for-a-cyberattack-and-things-could-get-worse/2019/05/07/31c85438-7041-11e9-8be0-ca575670e91c_story.html> SM

One minute. That’s how long it took me last month to demonstrate to a major broadcasting company and production team how to access and restart a leading satellite Internet provider’s control system. Five minutes is how long it took me to demonstrate how to gain full control of it.

Hackers are always improving their ability to break into our digital infrastructure. Yet the computer systems running our satellites haven’t kept up, making them prime targets for an attack. This makes our space assets a massive vulnerability — and it could get much worse if we’re not careful.

This past weekend, SpaceX won approval from the Federal Communications Commission to increase the number of low-flying satellites as part of its Starlink project so that they can provide faster Internet access to the world. Unfortunately, access will be faster for both legitimate users and hackers alike. The FCC does not require applicants to publicly demonstrate how they will secure these satellites or the Internet they plan to provide. SpaceX, like other private space companies, has shared virtually no information about its cybersecurity efforts or plans.

This is extremely disconcerting, considering the potential ramifications of a satellite being hacked. The most mundane outcome is that the satellite will no longer function, but the other extreme is for an attacker to break into a satellite and take over any thrusters (which SpaceX has insisted its satellites will have) and then propel the satellite into critical infrastructure and military satellites in other orbits. In other words, attackers could possibly use the hacked satellite as a kinetic weapon.

There has long been a void of attention to securing space infrastructure, ranging from space-faring rovers to satellite ground-control systems that manage all the space-based assets. Virtually no policy or oversight agency exists concerning securing space assets — something I’ve discussed with government leadership to little avail. While the FCC regulates communications, it should not necessarily be responsible for all things space security. Perhaps the new Space Development Agency could be.

This leaves space security in the hands of the private sector, which is exploiting the recent ease of access to space. The advent of small satellites known as CubeSats offers the chance to launch a satellite into orbit for as little as $30,000 . And because the government wants to encourage economic activity in this area, requirements to do so are extremely light. This leaves those who are creating the satellites responsible for the cybersecurity of their assets, which is not usually part of the rocket scientist’s traditional skill set.

As a space cybersecurity researcher, I am excited about the renewed interest in space from both the commercial and exploratory perspectives. But we need to be strategic about the security of these space systems. Unlike “Internet of things” devices such as baby monitors, which we purchase for less than $100 and discard or sell once a new model comes out, satellites often remain in orbit for much longer and are less dispensable. So if we don’t consider the cybersecurity of the space asset now, we’ll likely be dealing with the ramifications of that for several years to come. The lack of government intervention in satellite security does not mean that we can ignore cybersecurity as an issue.

Private space companies such as SpaceX, OneWeb and Blue Origin need to join the conversation about cybersecurity and help consumers understand that they are taking it seriously (if they are). (Blue Origin’s founder and owner, Jeff Bezos, also owns The Post.) Right now, there are several job openings for information security analysts at private space companies, indicating that they are likely hurting for talent and are behind in figuring out their security. This isn’t surprising given that space is hard, and traditional IT experts don’t have the right skill sets for a space cybersecurity job. Space systems have unique requirements that are more akin to an industrial control system, such as an energy smart meter, than to an email server.

Private space companies need to start a dialogue with the security research community about their particular challenges so that we can help. They should also be transparent with the FCC that they need help in securing their infrastructure. The last thing we need is for China or Russia to take over SpaceX’s satellites and wreak havoc on our space assets.

#### Empirics prove it’s possible and likely by state and nonstate actors – especially true given private sector cost cutting.

Akoto 20 “Hackers could shut down satellites -- or turn them into weapons” February 13, 2020 William Akoto [a postdoctoral research fellow at the University of Denver.] <https://www.upi.com/Top_News/Voices/2020/02/13/Hackers-could-shut-down-satellites-or-turn-them-into-weapons/4091581597502/> SM

Feb. 13 (UPI) -- Last month, SpaceX became the operator of the world's largest active satellite constellation. As of the end of January, the company had 242 satellites orbiting the planet with plans to launch 42,000 over the next decade. This is part of its ambitious project to provide Internet access across the globe. The race to put satellites in space is on, with Amazon, U.K.-based OneWeb and other companies chomping at the bit to place thousands of satellites in orbit in the coming months.

These new satellites have the potential to revolutionize many aspects of everyday life -- from bringing Internet access to remote corners of the globe to monitoring the environment and improving global navigation systems. Amid all the fanfare, a critical danger has flown under the radar: the lack of cybersecurity standards and regulations for commercial satellites, in the United States and internationally. As a scholar who studies cyber conflict, I'm keenly aware that this, coupled with satellites' complex supply chains and layers of stakeholders, leaves them highly vulnerable to cyberattacks.

If hackers were to take control of these satellites, the consequences could be dire. On the mundane end of scale, hackers could simply shut down satellites, denying access to their services. Hackers could also jam or spoof the signals from satellites, creating havoc for critical infrastructure. This includes electric grids, water networks and transportation systems.

Some of these new satellites have thrusters that allow them to speed up, slow down and change direction in space. If hackers took control of these steerable satellites, the consequences could be catastrophic. Hackers could alter the satellites' orbits and crash them into other satellites or even the International Space Station.

Commodity parts

Makers of these satellites, particularly small CubeSats, use off-the-shelf technology to keep costs low. The wide availability of these components means hackers can analyze them for vulnerabilities. In addition, many of the components draw on open-source technology. The danger here is that hackers could insert back doors and other vulnerabilities into satellites' software.

The highly technical nature of these satellites also means multiple manufacturers are involved in building the various components. The process of getting these satellites into space is also complicated, involving multiple companies. Even once they are in space, the organizations that own the satellites often outsource their day-to-day management to other companies. With each additional vendor, the vulnerabilities increase as hackers have multiple opportunities to infiltrate the system.

Hacking some of these CubeSats may be as simple as waiting for one of them to pass overhead and then sending malicious commands using specialized ground antennas. Hacking more sophisticated satellites might not be that hard either.

Satellites are typically controlled from ground stations. These stations run computers with software vulnerabilities that can be exploited by hackers. If hackers were to infiltrate these computers, they could send malicious commands to the satellites.

History of hacks

This scenario played out in 1998 when hackers took control of the U.S.-German ROSAT X-Ray satellite. They did it by hacking into computers at the Goddard Space Flight Center in Maryland. The hackers then instructed the satellite to aim its solar panels directly at the sun. This effectively fried its batteries and rendered the satellite useless. The defunct satellite eventually crashed back to Earth in 2011. Hackers could also hold satellites for ransom, as happened in 1999 when hackers took control of the U.K.'s SkyNet satellites.

Over the years, the threat of cyberattacks on satellites has gotten more dire. In 2008, hackers, possibly from China, reportedly took full control of two NASA satellites, one for about two minutes and the other for about nine minutes. In 2018, another group of Chinese state-backed hackers reportedly launched a sophisticated hacking campaign aimed at satellite operators and defense contractors. Iranian hacking groups have also attempted similar attacks.

Although the U.S. Department of Defense and National Security Agency have made some efforts to address space cybersecurity, the pace has been slow. There are no cybersecurity standards for satellites and no governing body to regulate and ensure their cybersecurity. Even if common standards could be developed, there are no mechanisms in place to enforce them. This means responsibility for satellite cybersecurity falls to the individual companies that build and operate them.

As they compete to be the dominant satellite operator, SpaceX and rival companies are under increasing pressure to cut costs. There is also pressure to speed up development and production. This makes it tempting for the companies to cut corners in areas like cybersecurity that are secondary to actually getting these satellites in space.

#### Interconnectedness and surface area are key

Graczyk et al 21, Rafal, Paulo Esteves-Verissimo, and Marcus Voelp. "Sanctuary lost: a cyber-physical warfare in space." arXiv preprint arXiv:2110.05878 (2021). (University of Luxembourg, Interdisciplinary Center for Security, Reliability and Trust (SnT) - CritiX group)//Elmer

NewSpace is on course of enabling satellites to become interconnected, creating orbital networks with many nodes and numerous points of entry that are eventually connected to the Internet. It leads to the creation of (mega-)constellations (i.e., formations of spacecrafts cooperating in achieving a common goal, typically for telecommunication but also for real-time Earth observation and similar activities [36]), which on the one hand enables operators and users to utilize the greater potential of these new services and increases the availability and robustness against accidental faults. At the same time, NewSpace approach, and use of large constellations in particular, also increases the attack surface, making it harder to defend and maintain control on the system. The trend of increasing the size of satellite constellation along with simplifying and miniaturizing the satellites themselves starts to spill into the traditional space industry [37], and most likely will become even more significant in the future.

### Scenario 3 - Astronomy

#### Constellations sabotage modern astronomy – tweaks like DarkSats don’t solve.

Grush 20 “The true impact of SpaceX’s Starlink constellation on astronomy is coming into focus” Loren Grush [science reporter for The Verge] Mar 24, 2020 <https://www.theverge.com/2020/3/24/21190273/spacex-starlink-satellite-internet-constellation-astronomy-coating> SM

Ever since SpaceX launched its first batch of internet-beaming satellites last year, astronomers have watched with dread as the company continued to blast more spacecraft into orbit. Could this ballooning constellation of bright satellites fill the night sky with artificial light and muck up observations of the Universe for years to come? Now, new data is partially validating what many astronomers have feared since that first launch.

Up until now, people have been somewhat in the dark about the true impact of SpaceX’s internet-from-space project called Starlink, which envisions nearly 12,000 of these satellites orbiting Earth. SpaceX’s satellites are super bright compared to others, and astronomers have been worried that with so many luminous satellites in the sky, the odds of one passing in front of a telescope and obscuring an image will increase.

It turns out, some astronomers have reason to be concerned. Certain types of astronomy may be more negatively affected than others, one peer-reviewed study shows, particularly those kinds that scour large swaths of the sky over long periods of time looking for faint, faraway objects. That means scientists looking for distant objects beyond Neptune — including the hunt for the mysterious Planet Nine — might have trouble when Starlink is complete. Additionally, Starlink may be much more visible during twilight hours, or the first few hours of the night, which could be a major problem in the hunt for massive asteroids headed toward Earth. “It depends on what science you’re doing, and that’s really what it comes down to,” Jonathan McDowell, an astrophysicist at Harvard and spaceflight expert who wrote the study accepted by Astrophysical Journal Letters, tells The Verge.

Meanwhile, scientists are also learning if SpaceX’s effort to mitigate the brightness of its satellites is actually going to work. The company coated one of its satellites in an attempt to make it appear less visible in the sky. Now, the first observations of that satellite are being published, and the coating is working — but it might not be enough to make everyone happy. “It doesn’t solve the issue,” Jeremy Tregloan-Reed, a researcher at the University of Antofagasta and lead author on the study, which is undergoing peer review at Astronomy and Astrophysics Letters, tells The Verge. “But it shows that SpaceX has taken on board astronomers’ concerns, and it does appear to be trying to solve the situation.”

HOW STARLINK WILL AFFECT THE ASTRONOMERS

For astronomers, light is everything. Observing celestial objects in different wavelengths of light is the best method we have for exploring the Universe. That’s why adding artificial light to the sky freaks out so many scientists. Some astronomers take long-exposure images of the sky, gathering as much light as possible from distant objects — and when a bright satellite reflecting light from the Sun passes overhead, it can leave a long white streak that ruins the picture.

Of course, the sky is a big canvas, and one tiny satellite isn’t going to be a major headache. A host of factors dictate exactly how and when satellites will be a problem. A satellite’s size, shape, height, and path around Earth all affect exactly how much light it reflects from the Sun and where people will see it the most. Meanwhile, the time of year and the time of night determine how much sunlight is shining on a satellite at any given moment.

To figure out Starlink’s exact impression on the night, McDowell made a comprehensive simulation based on what we know about where all of the Starlink satellites are going. Ahead of launching its constellation, SpaceX had to file multiple requests with the Federal Communications Commission, detailing where the company planned to send all of its spacecraft. Using that information, McDowell came up with a snapshot of which areas will see the most satellites overhead and what times of night will be the worst for observations.

In the more northern and southern latitudes, Starlink satellites will dominate the horizon during the first and last few hours of the night. In the summertime, it’ll be much worse, with hundreds of satellites visible for those in rural areas away from city light pollution. “Where I live in [Boston], I can see the planes hovering over Logan [Airport] on the horizon,” says McDowell. “That’s what it will look like, but it’ll be satellites and it’ll be a lot of them.” SpaceX declined to comment for this story.

While people living in cities and towns won’t really notice, this spells bad news for those hunting really distant faint objects using long exposures. “The longer that you have the shutter open for, the more that you’re likely to have an observation impeded by one of these streaks that are quite bright,” Michele Bannister, a planetary astronomer at the University of Canterbury in New Zealand who helped McDowell with his research, tells The Verge. That means those hunting Planet Nine and objects at the edge of the Solar System have some cause for alarm.

Additionally, asteroid hunters are going to be extra affected by this constellation, says McDowell. “They’re really hosed, because they need to look at twilight,” he says. Scientists looking for asteroids orbiting near Earth often look for these objects near the Sun; they observe just after sunset when they can see the part of the sky near the Sun that’s too bright to see during the day. “That’s where the problem with illuminated Starlink satellites is the worst,” he says. “Even from regular 30-degree latitude observatories, they’re going to have serious problems.”

As for what that means for these astronomy fields, one obvious concern is that a potentially hazardous asteroid could go unnoticed until it’s too late to act appropriately. It’s also possible observers will have to take expensive countermeasures to get the kinds of images they want. “It may mean you have to observe twice as long, if you have to throw away half your data,” says McDowell. “So that’s expensive. Or you may need to make changes to your telescope design, to stop reflections from a satellite.”

The silver lining here, at least, is that McDowell’s study found that Starlink may not really have a big effect on a lot of other astronomers’ work, especially those who only look at small slices of the night sky for certain periods of time. But his work does fly in the face of what SpaceX CEO Elon Musk has said about Starlink and its astronomy repercussions. “I am confident that we will not cause any impact whatsoever in astronomical discoveries. Zero,” Musk said during a space conference at the beginning of March. “That’s my prediction. And we’ll take corrective action if it’s above zero.”

Despite Musk’s brazen proclamation, the truth is SpaceX has already taken some corrective action, but new research shows it may not be enough to silence all of the company’s critics.

A COAT OF NO COLORS

On its third Starlink launch in January, SpaceX included a satellite that had been painted with an experimental coating, meant to darken the spacecraft’s reflectivity. Nicknamed DarkSat, the spacecraft has been of particular interest to amateur satellite trackers. Various observatories have taken images of DarkSat as it’s passed overhead to gauge just how much fainter it appears compared to its cohort.

The answer, it seems, is that DarkSat is indeed darker but only slightly. Once it reached its final orbit, the satellite appeared 55 percent fainter compared to another bright Starlink satellite, according to Tregloan-Reed’s study. That’s based on the initial observations he made using a telescope at the Ckoirama Observatory in Chile. “The DarkSat coating does push the satellite beyond being able to be seen with the naked eye,” says Tregloan-Reed.

That’s a big reduction, but 55 percent may not be enough for some observatories. The Vera Rubin Observatory in Chile is still under construction, but it has the massive task of surveying the entire night sky. “It’s going to be able to give us the history of the Solar system in absolutely intricate and amazing detail,” says Bannister of the survey. “And I think that’s definitely something that is under threat.” People at the observatory have estimated that the Starlink satellites would need to be even fainter than DarkSat in order to truly stay out of the way and not saturate the images gathered.

The good news is that SpaceX has hinted that more extreme countermeasures may be on their way. During its latest launch, a SpaceX employee noted that while the coated satellite showed “a notable reduction” in brightness, a future Starlink satellite may be equipped with a sunshade to further reduce reflectivity. “We have a couple other ideas that we think could reduce the reflectivity even further, the most promising being a sunshade that would operate in the same way as a patio umbrella, or a sun visor — but for the satellite,” Jessica Anderson, a lead manufacturing engineer at SpaceX, said during the live stream.

Tregloan-Reed says he’s hopeful about some kind of shade. “If that was to work then in theory it would block out the sunlight completely,” he says.

Still, that doesn’t solve every single astronomy problem because even a darkened satellite can still be a nuisance. Astronomers searching for planets beyond our Solar System, for instance, often take very sensitive measurements of distant stars, looking for dips in their brightness that might indicate a foreign planet passing by. If a satellite, even a dark one, were to pass in front of a star someone was observing, it could throw off the search for these alien worlds.

No matter what, it seems that a giant constellation is going to have some kind of negative impact on someone — it can’t be helped. And looking at the big picture, SpaceX isn’t alone in its attempt to create a mega-constellation of satellites. The company just gets the most attention because it’s proposing the largest number of spacecraft, and its vehicles are big, bright, and lower in the sky compared to other proposed constellations. Others like OneWeb and Amazon want to also fill the sky with internet-beaming vehicles.

Such a large influx of artificial bright spots is really the heart of the issue. “I understand the importance of Starlink; I can see the benefits of worldwide internet,” says Tregloan-Reed. “It’s just the sheer numbers that are worrying me.”

#### Space based astronomy fails

Siegel 2/4 “Ask Ethan: Do we still need ground-based astronomy?” Ethan Siegel is a Ph.D. astrophysicist and author of "Starts with a Bang!" February 4, 2022 <https://bigthink.com/starts-with-a-bang/ground-based-astronomy/> SM

So why not just put everything in space, then? After all, we have a suite of space-based observatories, and they’ve been among the most valuable astronomical facilities of all-time.

The simple answer is: we can’t, not unless we invest a tremendous amount above-and-beyond what we’ve ever invested in astronomy, and not unless we’re also willing to accept second-rate science compared to what we’d get on the ground were satellite pollution not an issue. That’s right: doing astronomy from the ground enables us to do things that we cannot do from space: not as well, or in some cases, not at all. The five ways, in general, that staying on the ground is superior to going to space are:

Size. In space, you’re limited by the dimensions and the payload capacity of the launch vehicle. On the ground, you can build as large and as heavy as you want.

Reliability. Launch failures happen, and when they do, the mission is a total loss. NASA’s Orbiting Carbon Observatory, designed to measure how carbon dioxide moves through the atmosphere from space, crashed into the ocean 17 minutes after takeoff. There are no launch failures on the ground.

Versatility. Want to catch that once-in-a-lifetime event? Jupiter occulting a quasar; an asteroid occulting a background star; the critical moment of a hybrid eclipse; the chance to measure a Kuiper belt object’s atmosphere? If you have a ground-based telescope in the right spot — and some ground-based observatories are mobile — you can see it no matter where it occurs. In space? You rely solely on luck.

Maintenance. Put simply: there’s more infrastructure on the ground than you’ll ever have in space. If a component fails, wears out, degrades, etc., you have to send a servicing mission to space to fix it. On the ground? You can replace or repair anything, and can even have maintenance facilities on-site.

Upgradeability. Want to upgrade your ground-based observatory? Just build a new instrument and swap the old one out. Want to upgrade your space-based observatory? It’s one of the most difficult and expensive tasks you can undertake.

[Figure omitted]

The same cluster has been imaged with two different telescopes, revealing very different details under very different circumstances. The Hubble Space telescope (L) viewed globular cluster NGC 288 in multiple wavelengths of light, while the Gemini telescope (from the ground, R) viewed only in a single channel. Yet, once adaptive optics is applied, Gemini’s larger aperture, superior resolution, and enhanced light-gathering power allow it to see additional stars at better resolution than Hubble, even at its best, is capable of. (Credit: NASA/ESA/Hubble (L); Gemini Observatory/NSF/AURA/CONICYT/GeMS-GSAOI (R))

There are also some facts about the limitations of space-based observatories that are not generally appreciated. The instrument and camera technology launched aboard space telescopes is always obsolete, even before it’s launched. You have to:

decide what you want your telescope to do,

design the instruments that will enable it to do so,

build those instruments,

install them and integrate them onto the observatory,

and then launch, commission, and calibrate the observatory it’s a part of.

#### Asteroids threats are existential – increasingly likely

Spencer ’18 - senior editor for Salon. He manages Salon's science, tech, economy and health coverage Keith Spencer, “The Asteroids Most Likely to Hit Earth,” Salon, January 14, 2018, <https://www.salon.com/2018/01/14/the-asteroids-most-likely-to-hit-earth/>.

Like earthquakes and volcanoes, the most frightening thing about asteroid strikes is their inevitability. Our solar system formed from a planetary nebula of dust and gas that slowly coalesced into rocks, planets, moons, and the Sun. And there are plenty of rocks still floating around. Astronomers estimate that between 37,000 and 78,000 tons of solar system debris hit Earth every year, though luckily these usually rain down in tiny pieces that burn up in the atmosphere — rather than large chunks that explode on the ground. (Although those hit us too.)

As a result, our planet is littered with little geologic memento mori that foreshadow what is to come. The Chesapeake Bay looks the way it does because of a massive impact of a three- to five-kilometer-wide asteroid that hit about 35 million years ago; even today, the region’s freshwater aquifer is at risk of being contaminated by an adjacent salty underground reservoir that was created in the wake of the impact. Oil drillers and water management agencies in the region must mitigate for a 35-million-year-old natural disaster.

Unsurprisingly given how often we get hit with space debris, meteors rank high on the list of existential horrors; some of our civilization’s most popular books and films are about the fear of a meteor impact–related disaster. Likewise, scientists periodically sound the alarm bells over the lack of resources being devoted to hazardous asteroid detection and — perhaps someday — diversion. Luckily, NASA, the California Institute of Technology and other agencies have done a fair bit of sky-scouring to track and monitor nearby hazardous space rocks of varying sizes.

The trick with estimating likely impact candidates is knowing that while many of the things on this list have a low probability of hitting us in the next century, they have higher — but more difficult to estimate accurately — probabilities of striking Earth in coming centuries. So why do most lists of potentially hazardous asteroids only estimate their orbits as far as a hundred years in advance? Partly because we are trapped in our own human perspectives — 100 years is about as long as our children will live — and partly because any orbital uncertainty is compounded year to year.

In estimating the precise location of an asteroid and extrapolating its future path, precision is key; being off by, say, 40 kilometers today will equate to an orbital uncertainty thousands of times greater many years in the future. That could easily mean the difference between a strike and a miss. (Incidentally, 40 kilometers of uncertainty is the approximate uncertainty of 3200 Phaethon, a near-miss that grazed Earth last month.)

All of this is to say that the asteroids on this list move in and out of our planet’s orbit — on a long enough timescale, we’re either going to have a close encounter or an impact, provided ours or another planet doesn’t gravitationally slingshot these space rocks into a less hazardous orbit. In picking and choosing asteroids for inclusion here, I tried to pick ones that were A) big enough to at least cause a nuclear winter, and B) that have a decent likelihood of eventual collision. The way that near-Earth objects are ranked by astronomers takes into account the number of opportunities for the orbit to intercept Earth; most of these have elliptical orbits that will swing past our planet many times.

3200 Phaethon

The aforementioned asteroid, which I wrote about last month when it had a close encounter with Earth, is rumored to be the source of the Geminid meteor shower. An asteroid creating meteor showers on Earth is unusual; but 3200 Phaethon is a weird asteroid. The atmosphere-free, 3.6 mile-wide rock swings very close to the Sun, rapidly heating the asteroid's surface, and — scientists believe — creating fractures in its surface as its temperature changes, thus releasing dust. That dust then creates the Geminid meteors, tiny particles that rain down periodically on Earth.

3200 Phaethon has a very elliptical orbit, meaning it passes close to the Sun before swinging far out again. Its motion moves it in and out of Earth’s near-circular orbit, which is how it ended up grazing us by 6.2 million miles back in December, at which point it was visible from Earth with a small telescope.

A 3.6 mile-wide asteroid like 3200 Phaethon probably wouldn’t end most life on Earth, but it would certainly muck things up for a bit. This size is just slightly bigger than the asteroid implicated in the aforementioned Chesapeake Bay asteroid impact. That asteroid created a crater over 50 miles wide and almost a mile deep, according to the US Geological Survey. Even outside that 50-mile-wide diameter, earthquakes, dust clouds and heat levels made a large swath of North America uninhabitable for a while.

Accordingly, NASA lists 3200 Phaethon as “potentially hazardous.”

2017 XO2

Despite being only 330 feet wide, 2017 XO2 merits inclusion on this list solely because this 2-million-ton rock keeps crossing Earth’s path. Like the bee that won’t stop buzzing you at the picnic, 2017 XO2 will take many passes at Earth, each with their own small probability of collision. Notably: April 28, 2041, April 29, 2047, April 28, 2053, April 29, 2059, and April 28, 2065, all have impact probabilities greater than 0.00001 percent. The Center for Near-Earth Object Studies (CNEOS) only calculates trajectories up to 2111 — uncertainties rise after that point — but it seems to swing near us around the end of April every few years, up to April 30, 2111. CNEOS calculates a cumulative impact probability of 0.002 percent between now and 2111. Threateningly, it may keep swinging by Earth for thousands more years.

2017 YZ1

Some asteroids on this list are going to cross Earth’s path again and again and keep scaring us, but 2017 YZ1 has one shot before it loses it. If it were overtime in the NBA championship game and the score were tied, 2017 YZ1 is trying desperately to dunk — by which I mean, violently collide with Earth. This 1,000-foot-wide asteroid has a non-zero chance (0.00015 percent) of hitting Earth on June 30, 2047. Those aren’t great odds, but still a much better chance than you have of winning the lottery. I suspect some actuary at Lloyd’s of London is selling 2017 YZ1 insurance by now.

Fortunately, 2017 YZ1 is only about a thousand feet in diameter, which isn’t big enough to cause an extinction event. Yet if it struck land it might create a cataclysmic explosion that would mess up our weather for a few years.

Jot down June 30, 2047, in your calendar, and then pull out your telescope, watch it sail by and toast your good fortune.

2018 AE2

As its “2018” designation hints, 2018 AE2 is hot off the observational data tables. Between 2094 and 2112, 2018 AE2 will have a number of low-probability chances to hit Earth. At 50 million tons with an impact velocity of 53,000 miles per hour, 2018 AE2 would have a destructive capacity (3,200 megatons) equal to about half the world’s nuclear arsenal. If the theory of nuclear winter is true — that the amount of smoke and ash sent into the troposphere from such a large explosion could temporarily dim the Sun’s flux on Earth, resulting in crop loss, colder days, and the probable deaths of millions or billions — we would indeed be in for trouble.

If you glean any politics from this article, take away the moral imperative for our civilization to improve our long-term thinking and invest well in planetary asteroid detection and deflection. We’re in the middle of a political era of “individual responsibility,” where it’s every person for themselves, but space hazards like these hint at the long-term absurdity of that kind of right-wing positioning. No number of tax credits or bootstrap-yanks are going to stop the asteroid from personally affecting you (and everyone else); these are equal-opportunity planet destroyers that require cooperative solutions. In a future article, I'll explore the ways that humanity might come together to deflect a hazardous asteroid, many of which are actually quite simple if done far enough in advance of impact.

### Scenario 4 - Ozone

#### Mega-constellations destroy the ozone layer.

Pultarova 21 “Air pollution from reentering megaconstellation satellites could cause ozone hole 2.0” Tereza Pultarova [Master's in Science from the International Space University, France, to her Bachelor's in Journalism and Master's in Cultural Anthropology from Prague's Charles University. She worked as a reporter at the Engineering and Technology magazine, freelanced for a range of publications including Live Science, Space.com, Professional Engineering, Via Satellite and Space News and served as a maternity cover science editor at the European Space Agency.], June 7, 2021 <https://www.space.com/starlink-satellite-reentry-ozone-depletion-atmosphere> SM

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The aluminum from re-entering satellites also has a potential to damage the ozone layer, a problem well known to humanity, which has been successfully solved by widespread bans on the use of chlorofluorocarbons, chemicals used in the past in aerosol sprays and refrigerators.

In their paper, Boley and his colleague Michael Byers cite research by their counterparts from the Aerospace Corporation, a U.S. non-profit research organization, which identified local damage to the planet's ozone layer triggered by the passage of polluting rockets through the atmosphere.

"We know that alumina does deplete ozone just from rocket launches themselves because a lot of solid-fuel rockets use, or have, alumina as a byproduct," Boley said. "That creates these little temporary holes in the stratospheric ozone layer. That's one of the biggest concerns about compositional changes to the atmosphere that spaceflight can cause."

The ozone layer protects life on Earth from harmful UV radiation. The depletion of ozone in the stratosphere, the second lowest layer of the atmosphere extending between altitudes of approximately 7 to 40 miles (10 to 60 kilometers), led to an increased risk of cancer and eye damage for humans on Earth.

Gerhard Drolshagen, of the University of Oldenburg, Germany, who has published papers about the effects of meteoroid material on Earth, told Space.com that reentering satellites usually evaporate at altitudes between 55 and 30 miles (90 and 50 km), just above the ozone-rich stratosphere. However, he added, the particles created as a result of the satellites' burning will eventually sink to the lower layers.

Boley said that as the alumina sinks into the stratosphere, it will cause chemical reactions, which, based on existing knowledge, will likely trigger ozone destruction.

Drolshagen, who wasn't involved in the recent study, agreed that because "satellites are mostly made of aluminum, the amount of aluminum deposited in the atmosphere will certainly increase."

Concerns about the effects of aluminium oxides on the atmosphere have been cited by U.S. telecommunications operator Viasat in its request to the US Federal Communications Commision to suspend launches of SpaceX's Starlink megaconstellation until a proper environmental review of its possible impacts is conducted.

Learning from past mistakes

In their study, Boley and his colleagues looked only at the effects of the first generation of the Starlink megaconstellation, which is expected to consist of 12,000 satellites. More than 1,700 of these have already been launched. As a result of SpaceX's activities (and to a lesser extent those of other constellation operators), the number of active and defunct satellites in low Earth orbit, the region of space below the altitude of 620 miles (1,000 km), has increased by 50% over the past two years, according to the paper.

"The problem is that there are now plans to launch about 55,000 satellites," Boley said. "Starlink second generation could consist of up to 30,000 satellites, then you have Starnet, which is China's response to Starlink, Amazon's Kuiper, OneWeb. That could lead to unprecedented changes to the Earth’s upper atmosphere."

Megaconstellation operators, inspired by the consumer technology model, expect fast development of new satellites and frequent replacement, thus the high amount of satellites expected to be burning in the atmosphere on a daily basis.

"Humans are exceptionally good at underestimating our ability to change the environment," said Boley. "There is this perception that there is no way that we can dump enough plastic into the ocean to make a difference. There is no way we can dump enough carbon into the atmosphere to make a difference. But here we are. We have a plastic pollution problem with the ocean, we have climate change ongoing as a result of our actions and our changing of the composition of the atmosphere and we are poised to make the same type of mistake by our use of space."

#### Ozone hole recovering now but depletion causes extinction.

Browne 20 “Scientists warn erosion of ozone layer could lead to a modern mass extinction event” EDWARD BROWNE May 28, 2020 <https://www.express.co.uk/news/science/1287983/ozone-layer-global-warming-mass-extinction-dinosaurs-Southampton> SM

Scientists warn erosion of ozone layer could lead to a modern mass extinction event

AN unexplained mass extinction event that occurred 359 million years ago may have been caused by erosion of the ozone layer, a UK study has found.

It could have alarming implications for the way our current world is headed, regarding rising global temperatures. Researchers from the University of Southampton have been investigating an extinction event that occurred at the end of the Devonian geological period.

During their study, they found evidence that plant spores from around the time had been damaged by UV radiation, suggesting that the Earth’s ozone layer was not providing sufficient protection from the sun’s deadly rays.

While it is already known that ozone depletion could lead to an extinction event, the scientists were alarmed by the reason behind why the ozone depletion seemed to have occurred.

The researchers discovered that this particular ozone erasure could have been linked to global warming, which the scientists described as a “new mechanism for mass extinctions.”

Mass extinction events have occurred a number of times in Earth’s past, with known causes being asteroid impacts and large-scale volcanic eruptions, Phys.org reports.

Many will associate the asteroid impact event as the one that led to the extinction of the dinosaurs.

The extinction event that the Southampton scientists were studying came after a period of rapid global warming after an ice age, Phys.org continues.

As part of their study, the researchers collected rocks from sites in Greenland as well as Bolivia in order to study any clues about what Earth conditions may have been like way back 360 million years ago.

Indeed, these rocks held some clues as to what had been happening around the time of the Devonian period.

The researchers found that the rocks contained plant spores – which plants use to reproduce – that had been preserved within them for hundreds of millions of years.

They discovered that some of these spores appeared to have been damaged by something, noting that they had “malformed sculpture and pigmented walls”.

This sort of damage is similar to what would occur if the spores had been hit by high levels of ultraviolet light – also called UV rays – that are given off by the sun.

The researchers explained: “This indicates the temporary loss of the global protective ozone layer.”

This is because the ozone layer absorbs some of the UV light – a particular type called UBV – that travels from the sun to the Earth.

The US Environmental Protection Agency (EPA) notes that UVB light has been linked to skin cancer and can cause harm to crops and marine life.

The ozone layer is a part of Earth’s atmosphere located in the stratosphere between 9 and 18 miles up.

Professor Marshall, lead researcher for the team, said that “current estimates suggest we will reach similar global temperatures to those of 360 million years ago,” according to phys.org.

He added that this raises the possibility of another collapse in the ozone layer, which could have disastrous consequences for all life on Earth, including us.

In the study’s abstract, the team said: “ozone loss during rapid warming is an inherent Earth system process with the unavoidable conclusion that we should be alert for such an eventuality in the future warming world.”

As well as global warming, human activity is associated with the depletion of the Earth’s vital ozone layer.

Scientists have reported that a large ozone hole over the Antarctic is slowly beginning to recover amid international efforts to limit the amount of ozone-depleting substances belched out by mankind.

### FW

#### The introspective connection between pain and pleasure and phenomenal conceptions of intrinsic value and disvalue is irrefutable – everything else regresses – robust neuroscience proves.

Blum et al. 18 Kenneth Blum, 1Department of Psychiatry, Boonshoft School of Medicine, Dayton VA Medical Center, Wright State University, Dayton, OH, USA 2Department of Psychiatry, McKnight Brain Institute, University of Florida College of Medicine, Gainesville, FL, USA 3Department of Psychiatry and Behavioral Sciences, Keck Medicine University of Southern California, Los Angeles, CA, USA 4Division of Applied Clinical Research & Education, Dominion Diagnostics, LLC, North Kingstown, RI, USA 5Department of Precision Medicine, Geneus Health LLC, San Antonio, TX, USA 6Department of Addiction Research & Therapy, Nupathways Inc., Innsbrook, MO, USA 7Department of Clinical Neurology, Path Foundation, New York, NY, USA 8Division of Neuroscience-Based Addiction Therapy, The Shores Treatment & Recovery Center, Port Saint Lucie, FL, USA 9Institute of Psychology, Eötvös Loránd University, Budapest, Hungary 10Division of Addiction Research, Dominion Diagnostics, LLC. North Kingston, RI, USA 11Victory Nutrition International, Lederach, PA., USA 12National Human Genome Center at Howard University, Washington, DC., USA, Marjorie Gondré-Lewis, 12National Human Genome Center at Howard University, Washington, DC., USA 13Departments of Anatomy and Psychiatry, Howard University College of Medicine, Washington, DC US, Bruce Steinberg, 4Division of Applied Clinical Research & Education, Dominion Diagnostics, LLC, North Kingstown, RI, USA, Igor Elman, 15Department Psychiatry, Cooper University School of Medicine, Camden, NJ, USA, David Baron, 3Department of Psychiatry and Behavioral Sciences, Keck Medicine University of Southern California, Los Angeles, CA, USA, Edward J Modestino, 14Department of Psychology, Curry College, Milton, MA, USA, Rajendra D Badgaiyan, 15Department Psychiatry, Cooper University School of Medicine, Camden, NJ, USA, Mark S Gold 16Department of Psychiatry, Washington University, St. Louis, MO, USA, “Our evolved unique pleasure circuit makes humans different from apes: Reconsideration of data derived from animal studies”, U.S. Department of Veterans Affairs, 28 February 2018, accessed: 19 August 2020, <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6446569/>, R.S.

**Pleasure** is not only one of the three primary reward functions but it also **defines reward.** As homeostasis explains the functions of only a limited number of rewards, the principal reason why particular stimuli, objects, events, situations, and activities are rewarding may be due to pleasure. This applies first of all to sex and to the primary homeostatic rewards of food and liquid and extends to money, taste, beauty, social encounters and nonmaterial, internally set, and intrinsic rewards. Pleasure, as the primary effect of rewards, drives the prime reward functions of learning, approach behavior, and decision making and provides the **basis for hedonic theories** of reward function. We are attracted by most rewards and exert intense efforts to obtain them, just because they are enjoyable [10].

Pleasure is a passive reaction that derives from the experience or prediction of reward and may lead to a long-lasting state of happiness. The word happiness is difficult to define. In fact, just obtaining physical pleasure may not be enough. One key to happiness involves a network of good friends. However, it is not obvious how the higher forms of satisfaction and pleasure are related to an ice cream cone, or to your team winning a sporting event. Recent multidisciplinary research, using both humans and detailed invasive brain analysis of animals has discovered some critical ways that the brain processes pleasure [14].

Pleasure as a hallmark of reward is sufficient for defining a reward, but it may not be necessary. A reward may generate positive learning and approach behavior simply because it contains substances that are essential for body function. When we are hungry, we may eat bad and unpleasant meals. A monkey who receives hundreds of small drops of water every morning in the laboratory is unlikely to feel a rush of pleasure every time it gets the 0.1 ml. Nevertheless, with these precautions in mind, we may define any stimulus, object, event, activity, or situation that has the potential to produce pleasure as a reward. In the context of reward deficiency or for disorders of addiction, homeostasis pursues pharmacological treatments: drugs to treat drug addiction, obesity, and other compulsive behaviors. The theory of allostasis suggests broader approaches - such as re-expanding the range of possible pleasures and providing opportunities to expend effort in their pursuit. [15]. It is noteworthy, the first animal studies eliciting approach behavior by electrical brain stimulation interpreted their findings as a discovery of the brain’s pleasure centers [16] which were later partly associated with midbrain dopamine neurons [17–19] despite the notorious difficulties of identifying emotions in animals.

Evolutionary theories of pleasure: The love connection BO:D

Charles Darwin and other biological scientists that have examined the biological evolution and its basic principles found various mechanisms that steer behavior and biological development. Besides their theory on natural selection, it was particularly the sexual selection process that gained significance in the latter context over the last century, especially when it comes to the question of what makes us “what we are,” i.e., human. However, the capacity to sexually select and evolve is not at all a human accomplishment alone or a sign of our uniqueness; yet, we humans, as it seems, are ingenious in fooling ourselves and others–when we are in love or desperately search for it.

It is well established that modern biological theory conjectures that **organisms are** the **result of evolutionary competition.** In fact, Richard Dawkins stresses gene survival and propagation as the basic mechanism of life [20]. Only genes that lead to the fittest phenotype will make it. It is noteworthy that the phenotype is selected based on behavior that maximizes gene propagation. To do so, the phenotype must survive and generate offspring, and be better at it than its competitors. Thus, the ultimate, distal function of rewards is to increase evolutionary fitness

by ensuring the survival of the organism and reproduction. It is agreed that learning, approach, economic decisions, and positive emotions are the proximal functions through which phenotypes obtain other necessary nutrients for survival, mating, and care for offspring.

Behavioral reward functions have evolved to help individuals to survive and propagate their genes. Apparently, people need to live well and long enough to reproduce. Most would agree that homo-sapiens do so by ingesting the substances that make their bodies function properly. For this reason, foods and drinks are rewards. Additional rewards, including those used for economic exchanges, ensure sufficient palatable food and drink supply. Mating and gene propagation is supported by powerful sexual attraction. Additional properties, like body form, augment the chance to mate and nourish and defend offspring and are therefore also rewards. Care for offspring until they can reproduce themselves helps gene propagation and is rewarding; otherwise, many believe mating is useless. According to David E Comings, as any small edge will ultimately result in evolutionary advantage [21], additional reward mechanisms like novelty seeking and exploration widen the spectrum of available rewards and thus enhance the chance for survival, reproduction, and ultimate gene propagation. These functions may help us to obtain the benefits of distant rewards that are determined by our own interests and not immediately available in the environment. Thus the distal reward function in gene propagation and evolutionary fitness defines the proximal reward functions that we see in everyday behavior. That is why foods, drinks, mates, and offspring are rewarding.

There have been theories linking pleasure as a required component of health benefits salutogenesis, (salugenesis). In essence, under these terms, pleasure is described as a state or feeling of happiness and satisfaction resulting from an experience that one enjoys. Regarding pleasure, it is a double-edged sword, on the one hand, it promotes positive feelings (like mindfulness) and even better cognition, possibly through the release of dopamine [22]. But on the other hand, pleasure simultaneously encourages addiction and other negative behaviors, i.e., motivational toxicity. It is a complex neurobiological phenomenon, relying on reward circuitry or limbic activity. It is important to realize that through the “Brain Reward Cascade” (BRC) endorphin and endogenous morphinergic mechanisms may play a role [23]. While natural rewards are essential for survival and appetitive motivation leading to beneficial biological behaviors like eating, sex, and reproduction, crucial social interactions seem to further facilitate the positive effects exerted by pleasurable experiences. Indeed, experimentation with addictive drugs is capable of directly acting on reward pathways and causing deterioration of these systems promoting hypodopaminergia [24]. Most would agree that pleasurable activities can stimulate personal growth and may help to induce healthy behavioral changes, including stress management [25]. The work of Esch and Stefano [26] concerning the link between compassion and love implicate the brain reward system, and pleasure induction suggests that social contact in general, i.e., love, attachment, and compassion, can be highly effective in stress reduction, survival, and overall health.

Understanding the role of neurotransmission and pleasurable states both positive and negative have been adequately studied over many decades [26–37], but comparative anatomical and neurobiological function between animals and homo sapiens appear to be required and seem to be in an infancy stage.

Finding happiness is different between apes and humans

As stated earlier in this expert opinion one key to happiness involves a network of good friends [38]. However, it is not entirely clear exactly how the higher forms of satisfaction and pleasure are related to a sugar rush, winning a sports event or even sky diving, all of which augment dopamine release at the reward brain site. Recent multidisciplinary research, using both humans and detailed invasive brain analysis of animals has discovered some critical ways that the brain processes pleasure.

Remarkably, there are pathways for ordinary liking and pleasure, which are limited in scope as described above in this commentary. However, there are **many brain regions**, often termed hot and cold spots, that significantly **modulate** (increase or decrease) our **pleasure or** even produce **the opposite** of pleasure— that is disgust and fear [39]. One specific region of the nucleus accumbens is organized like a computer keyboard, with particular stimulus triggers in rows— producing an increase and decrease of pleasure and disgust. Moreover, the cortex has unique roles in the cognitive evaluation of our feelings of pleasure [40]. Importantly, the interplay of these multiple triggers and the higher brain centers in the prefrontal cortex are very intricate and are just being uncovered.

Desire and reward centers

It is surprising that many different sources of pleasure activate the same circuits between the mesocorticolimbic regions (Figure 1). Reward and desire are two aspects pleasure induction and have a very widespread, large circuit. Some part of this circuit distinguishes between desire and dread. The so-called pleasure circuitry called “REWARD” involves a well-known dopamine pathway in the mesolimbic system that can influence both pleasure and motivation.

In simplest terms, the well-established mesolimbic system is a dopamine circuit for reward. It starts in the ventral tegmental area (VTA) of the midbrain and travels to the nucleus accumbens (Figure 2). It is the cornerstone target to all addictions. The VTA is encompassed with neurons using glutamate, GABA, and dopamine. The nucleus accumbens (NAc) is located within the ventral striatum and is divided into two sub-regions—the motor and limbic regions associated with its core and shell, respectively. The NAc has spiny neurons that receive dopamine from the VTA and glutamate (a dopamine driver) from the hippocampus, amygdala and medial prefrontal cortex. Subsequently, the NAc projects GABA signals to an area termed the ventral pallidum (VP). The region is a relay station in the limbic loop of the basal ganglia, critical for motivation, behavior, emotions and the “Feel Good” response. This defined system of the brain is involved in all addictions –substance, and non –substance related. In 1995, our laboratory coined the term “Reward Deficiency Syndrome” (RDS) to describe genetic and epigenetic induced hypodopaminergia in the “Brain Reward Cascade” that contribute to addiction and compulsive behaviors [3,6,41].

Furthermore, ordinary “liking” of something, or pure pleasure, is represented by small regions mainly in the limbic system (

old reptilian part of the brain). These may be part of larger neural circuits. In Latin, hedus is the term for “sweet”; and in Greek, hodone is the term for “pleasure.” Thus, the word Hedonic is now referring to various subcomponents of pleasure: some associated with purely sensory and others with more complex emotions involving morals, aesthetics, and social interactions. The capacity to have pleasure is part of being healthy and may even extend life, especially if linked to optimism as a dopaminergic response [42].

Psychiatric illness often includes symptoms of an abnormal inability to experience pleasure, referred to as anhedonia. A negative feeling state is called dysphoria, which can consist of many emotions such as pain, depression, anxiety, fear, and disgust. Previously many scientists used animal research to uncover the complex mechanisms of pleasure, liking, motivation and even emotions like panic and fear, as discussed above [43]. However, as a significant amount of related research about the specific brain regions of pleasure/reward circuitry has been derived from invasive studies of animals, these cannot be directly compared with subjective states experienced by humans.

In an attempt to resolve the controversy regarding the causal contributions of mesolimbic dopamine systems to reward, we have previously evaluated the three-main competing explanatory categories: “liking,” “learning,” and “wanting” [3]. That is, dopamine may mediate (a) liking: the hedonic impact of reward, (b) learning: learned predictions about rewarding effects, or (c) wanting: the pursuit of rewards by attributing incentive salience to reward-related stimuli [44]. We have evaluated these hypotheses, especially as they relate to the RDS, and we find that the incentive salience or “wanting” hypothesis of dopaminergic functioning is supported by a majority of the scientific evidence. Various neuroimaging studies have shown that anticipated behaviors such as sex and gaming, delicious foods and drugs of abuse all affect brain regions associated with reward networks, and may not be unidirectional. Drugs of abuse enhance dopamine signaling which sensitizes mesolimbic brain mechanisms that apparently evolved explicitly to attribute incentive salience to various rewards [45].

Addictive substances are voluntarily self-administered, and they enhance (directly or indirectly) dopaminergic synaptic function in the NAc. This activation of the brain reward networks (producing the ecstatic “high” that users seek). Although these circuits were initially thought to encode a set point of hedonic tone, it is now being considered to be far more complicated in function, also encoding attention, reward expectancy, disconfirmation of reward expectancy, and incentive motivation [46]. The argument about addiction as a disease may be confused with a predisposition to substance and nonsubstance rewards relative to the extreme effect of drugs of abuse on brain neurochemistry. The former sets up an individual to be at high risk through both genetic polymorphisms in reward genes as well as harmful epigenetic insult. Some Psychologists, even with all the data, still infer that addiction is not a disease [47]. Elevated stress levels, together with polymorphisms (genetic variations) of various dopaminergic genes and the genes related to other neurotransmitters (and their genetic variants), and may have an additive effect on vulnerability to various addictions [48]. In this regard, Vanyukov, et al. [48] suggested based on review that whereas the gateway hypothesis does not specify mechanistic connections between “stages,” and does not extend to the risks for addictions the concept of common liability to addictions may be more parsimonious. The latter theory is grounded in genetic theory and supported by data identifying common sources of variation in the risk for specific addictions (e.g., RDS). This commonality has identifiable neurobiological substrate and plausible evolutionary explanations.

Over many years the controversy of dopamine involvement in especially “pleasure” has led to confusion concerning separating motivation from actual pleasure (wanting versus liking) [49]. We take the position that animal studies cannot provide real clinical information as described by self-reports in humans. As mentioned earlier and in the abstract, on November 23rd, 2017, evidence for our concerns was discovered [50]

In essence, although nonhuman primate brains are similar to our own, the disparity between other primates and those of human cognitive abilities tells us that surface similarity is not the whole story. Sousa et al. [50] small case found various differentially expressed genes, to associate with pleasure related systems. Furthermore, the dopaminergic interneurons located in the human neocortex were absent from the neocortex of nonhuman African apes. Such differences in neuronal transcriptional programs may underlie a variety of neurodevelopmental disorders.

In simpler terms, the system controls the production of dopamine, a chemical messenger that plays a significant role in pleasure and rewards. The senior author, Dr. Nenad Sestan from Yale, stated: “Humans have evolved a dopamine system that is different than the one in chimpanzees.” This may explain why the behavior of humans is so unique from that of non-human primates, even though our brains are so surprisingly similar, Sestan said: “It might also shed light on why people are vulnerable to mental disorders such as autism (possibly even addiction).” Remarkably, this research finding emerged from an extensive, multicenter collaboration to compare the brains across several species. These researchers examined 247 specimens of neural tissue from six humans, five chimpanzees, and five macaque monkeys. Moreover, these investigators analyzed which genes were turned on or off in 16 regions of the brain. While the differences among species were subtle, **there was** a **remarkable contrast in** the **neocortices**, specifically in an area of the brain that is much more developed in humans than in chimpanzees. In fact, these researchers found that a gene called tyrosine hydroxylase (TH) for the enzyme, responsible for the production of dopamine, was expressed in the neocortex of humans, but not chimpanzees. As discussed earlier, dopamine is best known for its essential role within the brain’s reward system; the very system that responds to everything from sex, to gambling, to food, and to addictive drugs. However, dopamine also assists in regulating emotional responses, memory, and movement. Notably, abnormal dopamine levels have been linked to disorders including Parkinson’s, schizophrenia and spectrum disorders such as autism and addiction or RDS.

Nora Volkow, the director of NIDA, pointed out that one alluring possibility is that the neurotransmitter dopamine plays a substantial role in humans’ ability to pursue various rewards that are perhaps months or even years away in the future. This same idea has been suggested by Dr. Robert Sapolsky, a professor of biology and neurology at Stanford University. Dr. Sapolsky cited evidence that dopamine levels rise dramatically in humans when we anticipate potential rewards that are uncertain and even far off in our futures, such as retirement or even the possible alterlife. This may explain what often motivates people to work for things that have no apparent short-term benefit [51]. In similar work, Volkow and Bale [52] proposed a model in which dopamine can favor NOW processes through phasic signaling in reward circuits or LATER processes through tonic signaling in control circuits. Specifically, they suggest that through its modulation of the orbitofrontal cortex, which processes salience attribution, dopamine also enables shilting from NOW to LATER, while its modulation of the insula, which processes interoceptive information, influences the probability of selecting NOW versus LATER actions based on an individual’s physiological state. This hypothesis further supports the concept that disruptions along these circuits contribute to diverse pathologies, including obesity and addiction or RDS.

#### Evolution proves the reliability of phenomenal introspection – when we introspect on data from our eyes or ears, such as whether one sees or smells food or a predator, we use the same part of the brain that introspects on hedonic tones and identifies their moral relevance.

#### Thus, the standard is consistency with hedonic act utilitarianism.