# 1AC

### Plan

#### Plan: Private entities ought not appropriate outer space via Large Satellite Constellations in Lower Earth Orbit

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 “L”SC thresholds

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.

#### 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.

#### Constellations couldn’t support more than 1 user for every 10 km2 – only useful in extremely remote areas.

Ogutu and Oughton 21 “A Techno-Economic Cost Framework for Satellite Networks Applied to Low Earth Orbit Constellations: Assessing Starlink, OneWeb and Kuiper” Osoro B. Ogutu and Edward J. Oughton [O. Ogutu is with the Department of Geography and Geoinformation Science, George Mason University; E. Oughton is an assistant professor with the Department of Geography and Geoinformation Science, George Mason University] August 2021 <https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=9568932> SM

At maximum network density, each Starlink satellite covers approximately 101,000 km2, OneWeb 708,000 km2 and Kuiper 157,000 km2. At a subscriber density of 0.05 users per km2, the corresponding number of subscribers per satellite for Starlink, OneWeb and Kuiper are 5,000, 35,400 and 7,900 respectively. Since the aggregate capacity is shared among the subscribers, Starlink provides the highest mean capacity followed by Kuiper and OneWeb as shown in Figure 4. Therefore, an increase in population density (and logically a higher subscriber density) leads to a drastic decrease in mean capacity.

We also plot the potential cost in Figure 5. The NPV for a single satellite asset over the study period was estimated at US$ 0.6 million, US$ 5.6 million, and US$ 3 million for Starlink, OneWeb and Kuiper, respectively. Thus, the NPV cost per user for each constellation can then be plotted, which logically reduces as each subscriber density increases. Starlink incurs the least cost per user over the study period (2020–2025) that ranges US$ 100-US$ 10 for the subscriber density range of 0.005–1.0 (km2). Kuiper records the largest cost per user ranging between US$ 400 and US$ 30 for the same subscriber density range. The important caveat to these estimates is that there would be a major impact on the capacity available for each subscriber at the maximum adoption rate, due to increased contention. Hence, active constellations such as Starlink have already begun limiting adoption in high demand areas, to ensure QoS can be guaranteed to existing customers, ensuring the available broadband services remain competitive against competing technologies.

Figure 3 illustrates population density globally by sub-national region for population deciles ranging from below 5 people per km2, to over 45 people per km2. These decile boundaries were selected because we know a priori that higher density areas will be less suitable for LEO broadband constellations, and that they will be focusing on the bottom 5% of the market not currently served by conventional terrestrial broadband services using either fixed or wireless technologies.

We can see large parts of Asia (India, China etc.) will be unsuitable, along with most of mainland Europe (e.g. Germany, Italy) and central America (e.g. Mexico). However, the constellations can choose to limit the number of subscribers in such regions to provide relatively higher speeds and ensure QoS. In the USA, the West and South West have large areas which could be suitable, along with much of Canada, Australia and New Zealand.

In South America large parts of the Amazon may also have low enough population density to be suitable, as well as much of the Sahara region in Africa, although whether incomes would enable the purchasing of such services would be a main concern.

Therefore, to explore the suitability of these constellations we use a 1% adoption rate among the local population to explore capacity per user in the busiest hour of the day. Generally, Starlink provides impressive capacity for remote regions with global coverage thanks to its high asset density. In regions with very low population density Starlink provides a mean of over 90 Mbps per user, such as in parts of Canada, the West and South West of the USA, Central and South America, Sahara Africa, South-west Africa, Australia, Russia and remote parts of Asia. Kuiper performs similarly, with only slightly reduced performance. However, OneWeb offers generally lower capacity per user, although still reaching impressive peak rates in areas with very low population density.

SECTION VII.Discussion

In this paper a generalizable techno-economic assessment model was developed for satellite broadband constellations. The approach was used to estimate the capacity and related costs for three LEO constellations, including Starlink, OneWeb and Kuiper. The open-source codebase is provided to help boost scientific reproducibility, as well as support other engineers or business analysts working in this research area. The method consisted of a mix of engineering simulation, cost estimation and Geographical Information System (GIS) techniques, combined to provide new insight into the per user capacity and cost. Such analytics are very useful to help narrow the broadband availability gap in rural and remote areas by providing geospatial insight on the suitability of these technologies. The results demonstrate the connectivity opportunities and constraints of different LEO systems, as well as their viability. This section now revisits the research questions posed in the introduction of the paper. The first research question was articulated as follows:

A. How Much Capacity can be Provided by Different LEO Broadband Constellations?

The findings support existing theory whereby the capacity provided by the constellation is a function of the number of satellites. Fewer satellites result in a larger coverage area and vice versa. Unlike GEO, a satellite located at LEO will also have a shorter path length. As more satellites are added into the constellation, the coverage area per satellite reduces. Furthermore, the instantaneous number of satellites available to a ground user increases. We find that for network densities of 5,040, 720 and 3,240 satellites for Starlink, OneWeb and Kuiper respectively, the estimated coverage areas equate to 101,000, 708,000 and 157,000 km2.

The variation in the FSPL due to the orbital altitude and network density among the three constellations results in different received power. To compensate for high path loss, Kuiper and OneWeb opt for high receiver antenna gain, transmitted power and diameter. In contrast, the ultra-dense network and low orbital altitude enables Starlink to maintain large minimum elevation angles for its users compared to the other three systems, leading to superior QoS. This explains the constellation’s Business-to-Consumer (B2C) approach as users can easily connect to its satellites with minimum engineering requirements. In contrast, the limited capacity demonstrated in this analysis for OneWeb suggests why a more enterprise-focused approach is being adopted to provide Business-to-Business (B2B) global connectivity services, ranging from cellular backhaul to logistics for emergency services redundancy.

B. What is the Potential Capacity Per User From Different Constellations?

Related to the previous question, the per user capacity is therefore also positively correlated with the increase in the number of satellites for each constellation. The highest mean user capacity is achieved with the lowest subscriber densities, which occur in the most rural and remote regions where network contention is at its lowest. For instance, with 1 user every 10 km2 (0.1 users per km2) the best performing constellation (Starlink) records a very modest mean per user capacity of 24.94 ± 0.72 Mbps. This is worse for Kuiper and OneWeb with 10.30 ± 0.25 Mbps and 1.01 ± 0.02 Mbps, respectively. Hence, this explains why LEO broadband providers have been making a strong business case for the usage of satellites in the final 3 percent of customers in the hardest-to-reach rural and remote regions of the USA, Canada, United Kingdom, Australia and New Zealand (among other countries) due to their competitive advantage in these challenging deployment situations. While the aggregate speeds estimated are impressive, each satellite asset can easily become saturated, especially in higher populated urban and suburban areas, meaning SNOs will have to strictly manage spatial adoption rates. There is no doubt that the potential speeds per user which could be provided are highly desirable (and indeed revolutionary) for users who have struggled to gain a decent broadband connection from traditional providers. The potential services available would be more than adequate to enable intensive applications such as High Definition (HD) video streaming without buffering (providing QoS was well managed).

C. What is the Potential Cost Per User as Subscriber Penetration Increases?

The largest capital expenditure costs are incurred by rocket launches, building ground stations and acquiring spectrum. As more satellites are launched, the cost per user would increase, partly due to the rising operating costs, but this would ensure a better QoS for each user terminal thanks to smaller coverage areas with fewer shared spectrum resources. With more satellites in each constellation, the ground station energy requirements, maintenance, continual engineering and staff costs increase. At a low subscriber density, high capacity per user is available but the cost could be prohibitively expensive for some. In contrast, at a high subscriber density, the cost of broadband connectivity services is much more affordable but there is a major trade-off in QoS, with only very modest speeds being delivered.

The results open a question on whether LEO constellations could break into the urban broadband market given that MNOs and other operators can offer the services at a lower cost per user. While acquiring a segment of the urban market cannot be ruled out, the possibility of succeeding in developed countries where constellations such as Starlink are testing their products is low (driven by the need to limit the number of active users). Consequently, LEO broadband systems are more likely to play a significant role in providing global communications for niche industrial activities which require substantial mobility with high reliability. For example, maritime, rail, aviation and integration into other supply chain IoT architectures, thanks to LEO pole-to-pole coverage. Furthermore, LEO systems might also have a useful niche in delay sensitive applications such as monitoring offshore solar and wind farms in smart grid applications, thanks to the lower latency they can achieve relative to other technologies such as GEO. Alternatively, LEO broadband constellations can present a viable cost-effective solution for developing countries with growing urban centers that are yet to enjoy decent cellular and fiber infrastructure availability. However, this very much depends on the necessary spectrum being allocated in appropriate bands by each telecommunications regulator.

D. Which Parts of the World are LEO Constellations Most Suitable for?

The performance of the three constellations in areas of different population density shows a general trend. Regions with low population density generally experience higher capacity per user with Starlink and Kuiper providing superior speeds.

The simulation of possible geographical areas of adoption indicates that most parts of Central Asia, Middle East, South East Asia, South America, Sub-Saharan Africa and Eastern Europe are less suitable for LEO constellations with quite low capacity provided (below 10 Mbps) using the modeling parameters explored.

These results are arrived at by only considering population density. Future research should recognize the roles of adoption factors such as disposable income, perceived relevance of the Internet, literacy and cellular network penetration, as these may affect the number of people who can actually afford to pay for broadband services.

SECTION VIII.Conclusion

Connecting the global population who are still unable to access a decent broadband service remains a key part of the United Nation’s Sustainable Development Goals (specifically Target 9.c).

Motivated by these developments, the framework applied in this paper introduces a techno-economic modeling approach for the integrated assessment of data capacity and investment cost per user by constellation. The model presents the engineering and economic simulation results using a single framework, unlike other approaches where this may be undertaken by two separate groups of professionals (engineers and business analysts). This theoretical model allows for estimation of the constellation capacity based on the known engineering parameters filed with local or global regulatory authorities such as Federal Communication Commission (FCC) and ITU. Using the information publicly available from such organizations, and estimation based on financial statements filed by publicly traded GEO, MEO and LEO broadband companies, the values can be imputed in the model to approximate the capacity and cost of delivering satellite Internet. The model has been tested for three different constellations with varying number of simulated satellites to derive the per user capacity and costs. The codebase for the model is fully open-source and available from the online repository, enabling anyone to access and further enhance the capability developed [71]. Future research could include addressing the issue of non-linearity in the multiple access of satellite resources, which would improve on existing simplifications. Moreover, as the modeling approach is generalizable for satellite constellations, the framework can be further adapted for other planned constellations, such as Telesat.

The results of the model reveal that at the 95% confidence level, mean aggregate capacity speeds of 11.72 ± 0.04 Gbps, 3.43 ± 0.01 Gbps and 7.53 ± 0.03 Gbps are achievable for Starlink, OneWeb and Kuiper, respectively. The current anticipation associated with the benefits of LEO broadband constellations is very high, but success will depend on maintaining relatively low spatial subscriber densities, preferably below 0.1 users per km2 (so less then 1 user per 10 km2), otherwise the services provided may offer little benefit against other terrestrial options. For example, the model has shown that at 0.1 users per km2, only a mean per user capacity of 24.94 ± 0.72 Mbps, 1.01 ± 0.02 Mbps and 10.30 ± 0.25 Mbps can be achieved by Starlink, OneWeb and Kuiper respectively in the busiest hour of the day.

### Adv – Collisions

#### 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.

Chart, line chart

Description automatically generated

A graph showing the growing number of close encounters in space involving Starlink satellites as plotted by Professor Hugh Lewis using data from the Socrates database. (Image credit: Hugh Lewis)

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 will be involved in 90% of all close approaches, Lewis’ calculations suggest.

**Chart, line chart

Description automatically generated**

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.

#### 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

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.

#### 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.

### Adv – Astronomy

#### Constellations sabotage modern astronomy – tweaks like DarkSats don’t solve. That guts asteroid detection and preparedness.

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.”

#### 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.

#### Independently, astronomy is key to avert solar flares which are coming now and wreck the grid.

Siegel 20 “This Multi-Trillion Dollar Disaster Is Coming, And Solar Astronomy Is Our Prime Defense” Ethan Siegel [Ph.D. astrophysicist, author, and science communicator, who professes physics and astronomy at various colleges] January 31, 2020 <https://www.forbes.com/sites/startswithabang/2020/01/31/this-multi-trillion-dollar-disaster-is-coming-and-solar-astronomy-is-our-prime-defense/?sh=6ecc0e367613> SM

On December 12, 2019, the world's most powerful solar observatory — the National Science Foundation's Daniel K. Inouye Solar Telescope — opened its eyes for the first time. With a whopping 4-meter diameter primary mirror and a unique, off-center design, the Inouye Solar Telescope is capable of imaging features as small as 30 km in size on the Sun. Already, in its first light images released on January 29, 2020, features in-between the Texas-sized convective cells were revealed for the first time ever.

But the Inouye Solar Telescope offers so much more than just gorgeous images of our parent star; it's one of a number of solar astronomy projects that are all working together to protect our planet from a multi-trillion dollar disaster that's definitely coming: a catastrophic solar flare. It could come anytime this year or not for another few centuries, but studying the Sun is the only way to be prepared. Here's the science behind these beautiful images and videos.

Until 1859, solar astronomy was extremely simple: scientists studied the light from the Sun, the sunspots that occasionally dotted the Sun's surface, and viewed the corona during solar eclipses. But in 1859, solar astronomer Richard Carrington happened to be looking at the Sun, tracking a large, irregular sunspot, when something unprecedented occurred: a "white light flare" was observed, intensely bright and moving across the spot itself for around 5 minutes before disappearing entirely.

This turned out to be the first-ever observation of what we now call a solar flare. Some 18 hours later (about three to four times the speed of most solar flares), the largest geomagnetic storm in recorded history occurred on Earth. Aurorae were observed around the world: miners awoke in the Rockies; newspapers could be read by the aurora's light; the bright green curtain appeared in Cuba, Hawaii, Mexico and Colombia. Telegraph systems, even when disconnected, experienced their own induced currents, causing shocks and even starting fires.

If such an event were to occur today, the infrastructure we have for electricity and electronics would experience devastating effects that could easily cause trilions of dollars in damage. The problem is that geomagnetic storms, formed when certain space weather events penetrate our magnetosphere and interact with the atmosphere, can cause massive currents to flow even in electronic circuits that are completely disconnected.

A key science goal for solar astronomy is to understand how the interplay between the Sun, the space weather that causes these storms, and the effects on Earth itself are all related. This is why the NSF's Inouye Solar Telescope has, as its prime science goal, to measure the magnetic field of the Sun at three different layers:

at the photosphere,

in the chromosphere,

and throughout the solar corona.

With its enormous 4-meter diameter and its five science instruments — four of which are spectro-polarimeters designed for measuring the Sun's magnetic properties — it will measure the magnetic fields on and around the Sun as never before.

Measuring the magnetic field at various layers on the Sun is the most important thing we can do for predicting space weather, which comes as a surprise to most people. In the late 1980s, everyone was talking about solar flares as the drivers of space weather, and that's what most discussions still focus on. However, that only tells a tiny part of the story, since sometimes solar flares can cause spectacular geomagnetic storms on Earth, but at other times, they have no effect.

Our first major step towards understanding the role of magnetic fields came in 1995, when NASA's SOHO observatory was launched. What it saw was not just solar flares occurring at the photosphere, but a new type of phenomenon: coronal mass ejections (CMEs), which originate farther away from the Sun than the photosphere. If you've ever seen a blue animation of the Sun where the solar disk is blocked by a coronagraph, you've seen an image from SOHO.

When CMEs come to Earth, that's what causes a space weather event. A solar flare without a CME won't be capable of causing a large geomagnetic storm; one of the things that SOHO taught us is that that the Earth's magnetic field will protect us from normal solar flares extremely well, leading to a minor auroral event at most.

But many solar flares will lead to coronal mass ejections, particularly if there's a solar prominence nearby. Prominences are high-density collections of material that reside in the corona, and CMEs typically occur where the prominences found on the Sun magnetically break, which leads to the ejection of material. The CMEs themselves are directionally oriented, and it's only the ones that wind up striking Earth that put us at risk. When a CME goes off to the side, there's no worry; but when we see an annular CME from our perspective, that's when they're headed right for us.

But even solar flares that cause CMEs that are directed right at Earth don't necessarily cause geomagnetic storms; there needs to be one other piece of the puzzle that lines up just right: there needs to be the right magnetic connection. Remember that magnets typically have North and South poles, where like poles (North-North or South-South) repel, but opposite poles (North-South or South-North) attract.

Earth has its own magnetic field, which — from a distance — looks kind of like a bar magnet aligned close to our axis of rotation. If the magnetic field of the material ejected during a CME is aligned with Earth's field, the solar particles will be repelled, and no geomagnetic event will occur on Earth. But if the fields are anti-aligned, like they almost certainly were 161 years ago for the infamous Carrington event, you'll get a spectacular (and possibly dangerous) event, with the greatest auroral displays and much, much more.

Since the 2000s, our best tools for measuring the magnetic fields of the charged particles from CMEs that head towards Earth are the slew of satellites and observatories placed at the L1 Lagrange point: a point in space located about 1,500,000 km away from Earth on the Sun-facing side. Unfortunately, that's already 99% of the way from the Sun to the Earth; we typically only get about ~45 minutes from when a CME arrives at L1 until it arrives on Earth, and either produces a geomagnetic storm or not.

Ideally, what our next generation of solar observatories would bring us is a great increase in the amount of time we'll have to know whether we need to take the appropriate mitigating actions when such a potentially catastrophic coronal mass ejection occurs. There are plenty of things we can do, but we need more than an hour of advanced notice in order to do them.

The way we can best mitigate the damage from space weather events on Earth is to have power companies cut off the currents in their electrical grids, and disconnect (and sufficiently ground) stations and substations instead, so that the induced current doesn't flow into homes, businesses and industrial buildings. Because of the enormous magnitude of the currents, they need to be safely and gradually ramped down, which typically takes around a day, rather than an hour, to enact.

The key to knowing whether a CME has the appropriate component of its magnetic field aligned or anti-aligned well in advance of its arrival on Earth is to measure the magnetic field on the Sun; instead of ~45 minutes of lead time, you can get the full ~3 days or so that it typically takes ejected coronal material to travel from the Sun to the Earth.

The Inouye Solar Telescope is precisely this amazing solar-measuring magnetometer that we need to make these observations.

Practically every problem we're trying to solve about the Sun is a magnetic problem. If we want to understand what's occurring at the Sun's photosphere, it's driven by the heating from the inner layers of the Sun, but is distributed according to the magnetic field and its distribution throughout the Sun's outer layers. Magnetic connectivity extends from the photosphere to the chromosphere to the corona, which provides heating, winds, and enables the corona to be so energetic.

The winds generated in the hot corona creates the magnetic connection between the Earth and the Sun, and in fact between the Sun and the remainder of the Solar System, relevant for aurorae on planets even in the outer Solar System. No matter how well we measure the other properties of material from the Sun — velocity, kinematics, energy, calorimetry, etc. — the magnetic properties are key to understanding what drives the Sun's processes.

To understand what's going to impact Earth and how, we need a comprehensive understanding of what's occurring not only on the Sun itself, but from the particles ejected from it at every level:

from the photosphere,

through the chromosphere,

to the corona,

through interplanetary space,

through the L1 Lagrange point,

and onto our planet itself.

A combination of the Inouye Solar Telescope, the Parker Solar Probe, the upcoming Solar Orbiter mission, along with L1 satellites such as SOHO and SDO, will enable us to understand the magnetic connection between the Sun and the Earth as never before. The NSF's Inouye Solar Telescope, which measured not only the Texas-sized convective cells on the Sun to better precision than ever but also features lining the space between those cells for the first time, is an indispensible part of that.

Although the largest solar flares are rare, they do occur with some regularity. Some of them create coronal mass ejections; some coronal mass ejections head directly towards Earth; some of the ones that do head towards Earth have exactly the right properties to create spectacular aurorae and potentially catastrophic geomagnetic storms. Only now, with this new generation of solar astronomy tools, are we finally in position to scientifically prepare for the inevitable disaster.

For decades, we've avoided the ruination of our modern infrastructure through sheer luck alone. A Carrington-level event, if it were to strike us unawares, would certainly cause trillions of dollars worth of damage worldwide. With the advent of these new heliophysics-focused observatories, led by the NSF's Daniel K. Inouye Solar Telescope, we'll finally have the opportunity to know when "the big one" is coming.

#### Grid collapse cascades---extinction

Alice Friedemann 16. Transportation expert, founder of EnergySkeptic.com and author of “When Trucks Stop Running, Energy and the Future of Transportation,” worked at American Presidential Lines for 22 years, where she developed computer systems to coordinate the transit of cargo between ships, rail, trucks, and consumers, citing Dr. Peter Vincent Pry. Pry is executive director of the Task Force on National and Homeland Security, a Congressional advisory board dedicated to achieving protection of the United States from electromagnetic pulse and other threats. Dr. Pry is also the director of the United States Nuclear Strategy Forum, an advisory body to Congress on policies to counter weapons of mass destruction. Dr. Pry has served on the staffs of the Congressional Commission on the Strategic Posture of the United States, the Commission to Assess the Threat to the U.S. from an EMP Attack, the House Armed Services Committee, as an intelligence officer with the CIA, and as a verification analyst at the U.S. Arms Control and Disarmament Agency. (1/24/16, “Electromagnetic pulse threat to infrastructure (U.S. House hearings)” http://energyskeptic.com/2016/the-scariest-u-s-house-session-ever-electromagnetic-pulse-and-the-fall-of-civilization/.

Modern civilization cannot exist for a protracted period without electricity. Within days of a blackout across the U.S., a blackout that could encompass the entire planet, emergency generators would run out of fuel, telecommunications would cease as would transportation due to gridlock, and eventually no fuel. Cities would have no running water and soon, within a few days, exhaust their food supplies. Police, Fire, Emergency Services and hospitals cannot long operate in a blackout. Government and Industry also need electricity in order to operate. The EMP Commission warns that a natural or nuclear EMP event, given current unpreparedness, would likely result in societal collapse. Terrorists, criminals, and even lone individuals can build a non-nuclear EMP weapon without great trouble or expense, working from Unclassified designs publicly available on the internet, and using parts available at any electronics store. In 2000, the Terrorism Panel of the House Armed Services Committee sponsored an experiment, recruiting a small team of amateur electronics enthusiasts to attempt constructing a radiofrequency weapon, relying only on unclassified design information and parts purchased from Radio Shack. The team, in 1 year, built two radiofrequency weapons of radically different designs. One was designed to fit inside the shipping crate for a Xerox machine, so it could be delivered to the Pentagon mail room where (in those more unguarded days before 9/11) it could slowly fry the Pentagon’s computers. The other radiofrequency weapon was designed to fit inside a small Volkswagon bus, so it could be driven down Wall Street and disrupt computers— and perhaps the National economy. Both designs were demonstrated and tested successfully during a special Congressional hearing for this purpose at the U.S. Army’s Aberdeen Proving Ground. Radiofrequency weapons are not merely a hypothetical threat. Terrorists, criminals, and disgruntled individuals have used home-made radiofrequency weapons. The U.S. military and foreign militaries have a wide variety of such weaponry. Moreover, non-nuclear EMP devices that could be used as radiofrequency weapons are publicly marketed for sale to anyone, usually advertised as ‘‘EMP simulators.’’ For example, one such simulator is advertised for public sale as an ‘‘EMP Suitcase.’’ This EMP simulator is designed to look like a suitcase, can be carried and operated by one person, and is purpose-built with a high energy radiofrequency output to destroy electronics. However, it has only a short radius of effect. Nonetheless, a terrorist or deranged individual who knows what he is doing, who has studied the electric grid for a major metropolitan area, could—armed with the ‘‘EMP Suitcase’’— black out a major city. A CLEAR AND PRESENT DANGER. An EMP weapon can be used by state actors who wish to level the battlefield by neutralizing the great technological advantage enjoyed by U.S. military forces. EMP is also the ideal means, the only means, whereby rogue states or terrorists could use a single nuclear weapon to destroy the United States and prevail in the War on Terrorism or some other conflict with a single blow. The EMP Commission also warned that states or terrorists could exploit U.S. vulnerability to EMP attack for coercion or blackmail: ‘‘Therefore, terrorists or state actors that possess relatively unsophisticated missiles armed with nuclear weapons may well calculate that, instead of destroying a city or military base, they may obtain the greatest political-military utility from one or a few such weapons by using them—or threatening their use—in an EMP attack.’’ The EMP Commission found that states such as Russia, China, North Korea, and Iran have incorporated EMP attack into their military doctrines, and openly describe making EMP attacks against the United States. Indeed, the EMP Commission was established by Congress partly in response to a Russian nuclear EMP threat made to an official Congressional Delegation on May 2, 1999, in the midst of the Balkans crisis. Vladimir Lukin, head of the Russian delegation and a former Ambassador to the United States, warned: ‘‘Hypothetically, if Russia really wanted to hurt the United States in retaliation for NATO’s bombing of Yugoslavia, Russia could fire an SLBM and detonate a single nuclear warhead at high altitude over the United States. The resulting EMP would massively disrupt U.S. communications and computer systems, shutting down everything.’’ China’s military doctrine also openly describes EMP attack as the ultimate asymmetric weapon, as it strikes at the very technology that is the basis of U.S. power. Where EMP is concerned, ‘‘The United States is more vulnerable to attacks than any other country in the world’’: ‘‘Some people might think that things similar to the ‘Pearl Harbor Incident’ are unlikely to take place during the information age. Yet it could be regarded as the ‘Pearl Harbor Incident’ of the 21st Century if a surprise attack is conducted against the enemy’s crucial information systems of command, control, and communications by such means as… electromagnetic pulse weapons… Even a superpower like the United States, which possesses nuclear missiles and powerful armed forces, cannot guarantee its immunity…In their own words, a highly computerized open society like the United States is extremely vulnerable to electronic attacks from all sides. This is because the U.S. economy, from banks to telephone systems and from power plants to iron and steel works, relies entirely on computer networks… When a country grows increasingly powerful economically and technologically…it will become increasingly dependent on modern information systems… The United States is more vulnerable to attacks than any other country in the world.’’ Iran—the world’s leading sponsor of international terrorism—in military writings openly describes EMP as a terrorist weapon, and as the ultimate weapon for prevailing over the West: ‘‘If the world’s industrial countries fail to devise effective ways to defend themselves against dangerous electronic assaults, then they will disintegrate within a few years… American soldiers would not be able to find food to eat nor would they be able to fire a single shot.’’ The threats are not merely words. The EMP Commission assesses that Russia has, as it openly declares in military writings, probably developed what Russia describes as a ‘‘Super-EMP’’ nuclear weapon—specifically designed to generate extraordinarily high EMP fields in order to paralyze even the best protected U.S. strategic and military forces. China probably also has Super-EMP weapons. North Korea too may possess or be developing a Super-EMP nuclear weapon, as alleged by credible Russian sources to the EMP Commission, and by open-source reporting from South Korean military intelligence. But any nuclear weapon, even a low-yield first generation device, could suffice to make a catastrophic EMP attack on the United States. Iran, although it is assessed as not yet having the bomb, is actively testing missile delivery systems and has practiced launches of its best missile, the Shahab–III, fuzing for high- altitude detonations, in exercises that look suspiciously like training for making EMP attacks. As noted earlier, Iran has also practiced launching from a ship a Scud, the world’s most common missile—possessed by over 60 nations, terrorist groups, and private collectors. A Scud might be the ideal choice for a ship-launched EMP attack against the United States intended to be executed anonymously, to escape any last-gasp U.S. retaliation. Unlike a nuclear weapon detonated in a city, a high-altitude EMP attack leaves no bomb debris for forensic analysis, no perpetrator ‘‘fingerprints.’’ Under present levels of preparedness, communications would be severely limited, restricted mainly to those few military communications networks that are hardened against EMP. Today’s microelectronics are the foundation of our modern civilization, but are over 1 million times more vulnerable to EMP than the far more primitive and robust electronics of the 1960s, that proved vulnerable during nuclear EMP tests of that era. Tests conducted by the EMP Commission confirmed empirically the theory that, as modern microelectronics become ever smaller and more efficient, and operate ever faster on lower voltages, they also become ever more vulnerable, and can be destroyed or disrupted by much lower EMP field strengths. Microelectronics and electronic systems are everywhere, and run virtually everything in the modern world. All of the civilian critical infrastructures that sustain the economy of the United States, and the lives of 310 million Americans, depend, directly or indirectly, upon electricity and electronic systems. Of special concern is the vulnerability to EMP of the Extra-High-Voltage (EHV) transformers, that are indispensable to the operation of the electric grid. EHV transformers drive electric current over long distances, from the point of generation to consumers (from the Niagara Falls hydroelectric facility to New York City, for example). The electric grid cannot operate without EHV transformers—which could be destroyed by an EMP event. The United States no longer manufactures EHV transformers. They must be manufactured and imported from overseas, from Germany or South Korea, the only two nations in the world that manufacture such transformers for export. Each EHV transformer must be custom-made for its unique role in the grid. A single EHV transformer typically requires 18 months to manufacture. The loss of large numbers of EHV transformers to an EMP event would plunge the United States into a protracted blackout lasting years, with perhaps no hope of eventual recovery, as the society and population probably could not survive for even 1 year without electricity. Another key vulnerability to EMP are Supervisory Control And Data Acquisition systems (SCADAs). SCADAs essentially are small computers, numbering in the millions and ubiquitous everywhere in the critical infrastructures, that perform jobs previously performed by hundreds of thousands of human technicians during the 1960s and before, in the era prior to the microelectronics revolution. SCADAs do things like regulating the flow of electricity into a transformer, controlling the flow of gas through a pipeline, or running traffic control lights. SCADAs enable a few dozen people to run the critical infrastructures for an entire city, whereas previously hundreds or even thousands of technicians were necessary. Unfortunately, SCADAs are especially vulnerable to EMP. EHV transformers and SCADAs are the most important vulnerabilities to EMP, but are by no means the only vulnerabilities. Each of the critical infrastructures has their own unique vulnerabilities to EMP: The National electric grid, with its transformers and generators and electronic controls and thousands of miles of power lines, is a vast electronic machine—more vulnerable to EMP than any other critical infrastructure. Yet the electric grid is the most important of all critical infrastructures, and is in fact the keystone supporting modern civilization, as it powers all the other critical infrastructures. As of now it is our technological Achilles Heel. The EMP Commission found that, if the electric grid collapses, so too will collapse all the other critical infrastructures. But, if the electric grid can be protected and recovered, so too all the other critical infrastructures can also be restored. Transportation is a critical infrastructure because modern civilization cannot exist without the goods and services moved by road, rail, ship, and air. Cars, trucks, locomotives, ships, and aircraft all have electronic components, motors, and controls that are potentially vulnerable to EMP. Gas stations, fuel pipelines, and refineries that make petroleum products depend upon electronic components and cannot operate without electricity. Given our current state of unpreparedness, in the aftermath of a natural or nuclear EMP event, transportation systems would be paralyzed. Traffic control systems that avert traffic jams and collisions for road, rail, and air depend upon electronic systems, that the EMP Commission discovered are especially vulnerable to EMP. Communications is a critical infrastructure because modern economies and the cohesion and operation of modern societies depend to a degree unprecedented in history on the rapid movement of information—accomplished today mostly by electronic means. Telephones, cell phones, personal computers, television, and radio are all directly vulnerable to EMP, and cannot operate without electricity. Satellites that operate at Low-Earth-Orbit (LEO) for communications, weather, scientific, and military purposes are vulnerable to EMP and to collateral effects from an EMP attack. Within weeks of an EMP event, the LEO satellites, which comprise most satellites, would probably be inoperable. Banking and finance are the critical infrastructure that sustain modern economies. Whether it is the stock market, the financial records of a multinational corporation, or the ATM card of an individual—financial transactions and record keeping all depend now at the macro- and micro-level upon computers and electronic automated systems. Many of these are directly vulnerable to EMP, and none can operate without electricity. The EMP Commission found that an EMP event could transform the modern electronic economy into a feudal economy based on barter. Food has always been vital to every person and every civilization. The critical infrastructure for producing, delivering, and storing food depends upon a complex web of technology, including machines for planting and harvesting and packaging, refrigerated vehicles for long-haul transportation, and temperature-controlled warehouses. Modern technology enables over 98 percent of the U.S. National population to be fed by less than 2 percent of the population. Huge regional warehouses that resupply supermarkets constitute the National food reserves, enough food to feed the Nation for 30–60 days at normal consumption rates, the warehoused food preserved by refrigeration and temperature control systems that typically have enough emergency electrical power (diesel or gas generators) to last only about an average of 3 days. Experience with storm-induced blackouts proves that when these big regional food warehouses lose electrical power, most of the food supply will rapidly spoil. Farmers, less than 2 percent of the population as noted above, cannot feed 310 million Americans if deprived of the means that currently makes possible this technological miracle. Water too has always been a basic necessity to every person and civilization, even more crucial than food. The critical infrastructure for purifying and delivering potable water, and for disposing of and treating waste water, is a vast networked machine powered by electricity that uses electrical pumps, screens, filters, paddles, and sprayers to purify and deliver drinkable water, and to remove and treat waste water. Much of the machinery in the water infrastructure is directly vulnerable to EMP. The system cannot operate without vast amounts of electricity supplied by the power grid. A natural or nuclear EMP event would immediately deprive most of the U.S. National population of running water. Many natural sources of water—lakes, streams, and rivers—would be dangerously polluted by toxic wastes from sewage, industry, and hospitals that would backflow from or bypass wastewater treatment plants, that could no longer intake and treat pollutants without electric power. Many natural water sources that would normally be safe to drink, after an EMP event, would be polluted with human wastes including feces, industrial wastes including arsenic and heavy metals, and hospital wastes including pathogens. Emergency services such as police, fire, and hospitals are the critical infrastructure that upholds the most basic functions of government and society—preserving law and order, protecting property and life. Experience from protracted storm-induced blackouts has shown, for example in the aftermath of Hurricanes Andrew and Katrina, that when the lights go out and communications systems fail and there is no gas for squad cars, fire trucks, and ambulances, the worst elements of society and the worst human instincts rapidly takeover. The EMP Commission found that, given our current state of unpreparedness, a natural or nuclear EMP event could create anarchic conditions that would profoundly challenge the existence of social order.

#### Causes nuclear meltdowns---overcomes resilience and ends civilizations

Daniel Kinch 17. Pundit at Brooklyn Culture Jam, 12-21-2017, "What Are The Most Likely Extinction Events For Humanity?," Quora, https://www.quora.com/What-are-the-most-likely-extinction-events-for-humanity/answer/Daniel-Kinch-2.

Or we could have a crash of the global electricity grid. Once that happens, a lot of different things occur (no more water from taps, no more shipments of fossil fuels, etc). Critical is the loss of backup power to keep coolant over the nuclear fuel pools. That would probably come to pass in a few days (while all reactors have backup generators, those aren’t designed to be online for periods longer than a few days, and (see above) shipments of fuel will be halted). Runaway meltdowns would be enough to end things pretty quickly.

### Adv – 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

* Aaron Boley -- an associate professor of astronomy and astrophysics at the University of British Columbia, Canada

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 standard is consistency with hedonic act utilitarianism. 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.