**1AC**

**Plan: The appropriation of outer space by private entities for Starlink satellite constellations is unjust.**

**Advantage**

**Starlink will soon be 2/3rds of all total satellites**

**Young 3-30**-22

(Chris, https://interestingengineering.com/starlink-to-double-satellites)

SpaceX will double the number of Starlink satellites in orbit over the next year and a half, according to a new update from Elon Musk. SpaceX CEO Musk took to Twitter yesterday to state that progress with the private space company's Falcon 9 and Starlink launches is going well. On Tuesday, March 30, Musk tweeted that he is "expecting over 4,200 Starlink satellites in operation within 18 months, **which is ~2/3 of all active satellites of Earth."** If Musk's estimations are correct, not only will Starlink's massive satellite constellation account for more than half of all operational satellites in orbit, the number of operational Starlink satellites will have doubled within the next 18 months. The evolution of SpaceX’s rockets That increased coverage will allow SpaceX to provide internet to more users throughout the globe, while also increasing the quality and speed of its internet service. To make that possible, SpaceX will have to continue its **steady cadence** of Starlink missions. The company currently launches its Starlink satellites using its reusable Falcon 9 rockets. In a separate tweet, Musk added that the "SpaceX Falcon team is making excellent progress – aiming for 60 launches this year." Musk also recently stated that the revenue from Starlink will help with the development costs for SpaceX's Mars-bound Starship launch vehicle, which could make its orbital maiden flight as soon as May. The SpaceX CEO recently announced a price hike for Starlink, citing inflation, which he previously stated has the potential to bankrupt the company. NASA's warning to SpaceX over its Starlink mega constellation SpaceX's Starlink service is currently serving 250,000 Starlink subscribers worldwide, and the increased growth of the satellite network will improve the speed and latency of the service, which currently provides download speeds of approximately 100Mbps for users in the U.S. SpaceX's Starlink operations have been praised and derided in equal measure. On the one hand, they provide internet access to subscribers anywhere in the world and have helped to keep civilians and troops connected amid the ongoing conflict in Ukraine. On the other hand, the Starlink satellites are already hampering astronomical observations to the point that NASA has warned they may **reduce its ability to detect** an asteroid on a collision course with Earth. SpaceX has so far sent more than 2,000 Starlink satellites into orbit since its first Starlink launch in May 2019, and more than 1,600 of those are operational. The company has permission from the FCC to launch 12,000 more and it is currently waiting on approval to send approximately 30,000 more up to orbit.

**Starlink will be misperceived as a weapon causing Russia and China to First strike- this escalates to nuclear weapons use**

**Chyba. MPhil/PhD, 20**

(Christopher E., New Technologies & Strategic Stability, (2) Spring 2020 Dædalus, the Journal of the American Academy of Arts & Sciences)

Satellite deployments already underway indicate that this idea may not be incredible on a twenty-year timescale.53 For example, SpaceX is deploying a constellation of optically cross-linked mass-produced small satellites (individual satellite masses of hundreds of kilograms) to create a space-based Internet communication system called “Starlink.” SpaceX hopes to deploy twelve thousand of these satellites in three shells of low-Earth orbits with over two thousand in orbit by the mid-2020s, and a possible ultimate expansion to forty-two thousand.54 The size of this constellation may be compared to the approximately 2,100 active satellites orbiting Earth in August 2019.55 **Starlink does not perform ground surveillance**, but its numerical scale shows what is possible. In fact, swarms of surveillance satellites are already being put into orbit by the private sector. Planet Labs’ more than three hundred miniature satellites now monitor Earth’s entire landmass daily at three-to-five-meter resolution; the company’s website promises “persistent global monitoring with low latency tasking to deliver early intelligence” for defense and intelligence purposes.56 And Capella Space is launching a constellation of forty-kilogram radar imaging satellites in polar orbits that will allow all-weather “hourly coverage of every point on Earth, rendered in sub-meter resolution.”57 **None of these constellations does, nor is intended to do, what would be required for monitoring ongoing positions of Russian or Chinese road-mobile ICBMs.** To reach that objective, persistent all-weather overhead imaging would need almost continuously to surveil vast areas, coupled with an AI able to sift and interpret the enormous data set that would be returned in near real time. Even then, there would be legitimate questions about the efficacy of defensive measures: clever ways to hide road mobile forces, including simply taking advantage of particular terrain or tunnels; flooding the roads with decoys; or using cyber, jamming, or other techniques to hack or confound the satellite constellations.58 But because of the powerful potential threat to Russian and Chinese second-strike capabilities that it could pose, such a system, **even if objectively imperfect and vulnerable, would likely be destabilizing** from the perspective of the countries that felt themselves targeted. **Even if such a constellation were openly devoted to other purposes**, potential adversaries might plan on the assumption that it was either nevertheless **intended to support a first strike**, or that it could in the future, in a change of doctrine rapidly become so intended. That conclusion has likely been **reinforced by analogy,** in the decision by the United States in its 2019 Missile Defense Review to state explicitly that U.S. missile defense “policy, strategy and capabilities” must also address anticipated advanced Russian and Chinese delivery systems, not just the missiles of North Korea and Iran.59 Some of the defensive measures that China and Russia would seem likely to take in response to such AI-enabled surveillance swarms **would be destabilizing**. The construction of multiple road-mobile decoys would in itself be stabilizing by making a first strike harder to execute, even while making strategic arms control, and the broadly stabilizing confidently known quantitative knowledge that comes with it, harder to execute. Defensive efforts to jam, blind, or cyber-corrupt large numbers of targets in satellite constellations might be interpreted as a **prelude to nuclear use**, rather than as motivated by furthering nuclear target survival. And the country being surveilled might decide that even its road-mobile launchers were so vulnerable that their employment had to include the capability and **doctrine appropriate for launch-on-warning.** Now evaluate this scenario from the perspective of the elements of the framework above. The combination of surveillance **perceived as threatening** to road mobile second-strike systems, hypersonic weapons with the accuracy to strike located road-mobile systems rapidly before their location was lost, and counter space and cyber weapons intended to degrade either that surveillance or its command and control (the framework element considering potential for misinterpreting a technology’s employment as preparatory to a first strike) would be a **dangerous brew.** In a conventional war, many of these capabilities would be employed for reasons other than nuclear first strike, but in an environment in which decisions could increasingly have to be made at “machine speed,” since AI-enabled systems will require each party to exhibit the same rapidity of decisions and actions or be at a disadvantage. Even were this not done autonomously, and humans remained in or at least on the loop, the amount of data that would be processed, interpreted, and presented by AI might lead to automation bias, in which humans surrender judgment to an intelligent decision-support system that they may feel they have no choice but to trust.60 This landscape seems almost **designed to realize the criteria** of normal accident theory summarized in the framework above (considering if a technology deployment scenario would likely fulfill the criteria for normal accidents), suggesting a reasonable likelihood for misinterpretation or mistakes that in this context **could lead to nuclear escalation.**

**US-China conflict escalates for six reasons – interdependence doesn't check.**

**Mearsheimer, PhD, 21** [John J. Mearsheimer, Professor of Political Science at the University of Chicago, PhD in Government from Cornell, author of The Great Delusion: Liberal Dreams and International Realities. "The Inevitable Rivalry," Foreign Affairs November/December issue, accessed 10-21-2021, https://www.foreignaffairs.com/articles/china/2021-10-19/inevitable-rivalry-cold-war] HWIC

THE DANGER OF A HOT WAR

Engagement’s remaining defenders now portray the downward spiral in U.S.-Chinese relations as the work of individuals who are bent on creating a U.S.-Soviet-style confrontation—“New Cold Warriors,” in the words of the former George W. Bush administration official Robert Zoellick. In the engagers’ view, the incentives for further economic cooperation outweigh the need to compete for power. Mutual interests trump conflicting interests. Regrettably, the proponents of engagement are whistling in the wind. Cold War II is already here, and when one compares the two cold wars, it becomes apparent that the U.S.-Chinese rivalry is **more likely to lead to a shooting war than the U.S.-Soviet rivalry** was.

The first point of contrast between the two conflicts concerns **capabilities**. China is already closer to the United States in terms of latent power than the Soviet Union ever was. At the height of its power, in the mid-1970s, the Soviet Union had a small advantage in population (less than 1.2 to 1) and, using GNP as a rough indicator of wealth, was almost 60 percent as wealthy as the United States. In contrast, China now has four times as many people as the United States and is about 70 percent as wealthy. If China’s economy continues growing at an impressive rate of around five percent annually, it will eventually have more latent power than the United States. It has been projected that by 2050, China will have a population advantage of approximately 3.7 to 1. If China has half of the United States’ per capita GDP in 2050—roughly where South Korea is today—it will be 1.8 times as wealthy as the United States. And if it does better and reaches three-fifths of U.S. per capita GDP by then—roughly where Japan is today—it will be **2.3 times as wealthy** as the United States. With all that latent power, Beijing could build a **military that is much more powerful** than the United States’, which would be contesting China’s from 6,000 miles away.

Not only was the Soviet Union poorer than the United States; during the height of the Cold War, it was also still recovering from the horrific devastation wreaked by Nazi Germany. In World War II, the country lost 24 million citizens, not to mention more than 70,000 towns and villages, 32,000 industrial enterprises, and 40,000 miles of railroad track. It was in no position to fight the United States. China, in contrast, **last fought a war in 1979** (against Vietnam) and in the ensuing decades became an **economic juggernaut**.

There was another drag on Soviet capabilities that is largely absent in China’s case: troublesome **allies**. Throughout the Cold War, the Soviet Union maintained a huge military presence in Eastern Europe and was deeply involved in the politics of almost every country in that region. It had to contend with insurrections in East Germany, Poland, Hungary, and Czechoslovakia. Albania, Romania, and Yugoslavia routinely challenged Moscow’s economic and security policies. The Soviets also had their hands full with China, which switched sides midway through the Cold War. These allies were an albatross around Moscow’s neck that distracted Soviet leaders from their principal adversary: the United States. Contemporary China has few allies and, except when it comes to North Korea, is far less tied to its friends than the Soviets were to theirs. In short, Beijing has greater **flexibility to cause trouble abroad**.

What about ideological motivations? Like the Soviet Union was, China is led by a nominally communist government. But just as Americans during the Cold War were wrong to view Moscow as primarily a communist threat, determined to spread its malign ideology around the globe, it would be a mistake to portray China as an ideological menace today. Soviet foreign policy was influenced only on the margins by communist thinking; Joseph Stalin was a hardcore realist, as were his successors. Communism matters even less in contemporary China, which is best understood as an authoritarian state that embraces capitalism. Americans should wish that China were communist; then it would have a lethargic economy.

But there is an “ism” that China has in spades, one that is likely to exacerbate its rivalry with the United States: **nationalism**. Normally the world’s most powerful political ideology, nationalism had limited influence in the Soviet Union because it was at odds with communism. Chinese nationalism, however, has been gathering steam since the early 1990s. What makes it especially dangerous is its emphasis on China’s “century of national humiliation,” a period beginning with the First Opium War, during which China was victimized by great powers, especially Japan but also, in the Chinese narrative, the United States. The effects of this potent nationalist story were on display in 2012–13, when China and Japan skirmished over the Diaoyu/**Senkaku Islands**, igniting anti-Japanese protests across China. In the coming years, the intensifying security competition in East Asia will surely **ramp up Chinese hostility** toward Japan and the United States, increasing the likelihood of a hot war.

Also raising the odds of war are China’s **regional ambitions**. Soviet leaders, busy recovering from World War II and managing their empire in Eastern Europe, were largely content with the status quo on the continent. China, by contrast, is deeply committed to an **expansionist agenda** in East Asia. Although the main targets of China’s appetite certainly have strategic value for China, they are also considered sacred territory, which means their fate is bound up with Chinese nationalism. This is especially true of **Taiwan**: the Chinese feel an emotional attachment to the island that the Soviets never felt for Berlin, for example, making Washington’s commitment to defend it all the riskier.

The new cold war is more war-prone than the old one.

Finally, the **geography** of the new cold war is more war-prone than that of the old one. Although the U.S.-Soviet rivalry was global in scope, its center of gravity was the Iron Curtain in Europe, where both sides had massive armies and air forces equipped with thousands of nuclear weapons. There was little chance of a superpower war in Europe, because policymakers on both sides understood the fearsome risks of nuclear escalation. No leader was willing to start a conflict that would likely have destroyed his own country.

In Asia, there is **no clear dividing** line like the Iron Curtain to anchor stability. Instead, there are a handful of potential conflicts that would be limited and would involve **conventional** arms, which **makes war thinkable**. They include fights for control over **Taiwan**, the **South China Sea**, the **Diaoyu/Senkaku Islands**, and the **maritime routes** that run between China and the Persian Gulf. These conflicts would be fought mainly in open waters between rival air and naval forces, and in those instances in which control of an island was at play, small-scale ground forces would likely take part. Even a fight over Taiwan, which might draw in Chinese amphibious forces, would not involve huge nuclear-equipped armies crashing into each other.

None of this is to say that these limited-war scenarios are likely, but they are more plausible than a major war between NATO and the Warsaw Pact was. Still, **one cannot assume that there would be no nuclear escalation** should Beijing and Washington fight over Taiwan or the South China Sea. Indeed, if one side were losing badly, it would at least consider employing nuclear weapons to rescue the situation. Some decision-makers might conclude that nuclear weapons could be used without an unacceptable risk of escalation, provided the attacks took place at sea and spared the territory of China and the United States and its allies. Not only is a great-power war more likely in the new cold war, but so is nuclear use.

**Megaconstellations destroy the ozone layer through rocket launches and deterioration**

**Delbert 21**

(Caroline, <https://www.popularmechanics.com/space/satellites/a36651845/satellite-pollution-starlink-ozone/>, 6-17)

The hole in the ozone layer, Earth’s protective chemical shield that absorbs most of the sun’s ultraviolet rays, has slowly healed over the last few decades since the global ban of chlorofluorocarbons (CFCs). But scientists are now raising the alarm about puncturing a new hole in the ozone layer—this time without any noticeable CGCs in sight. Instead, the surprising cause is **deterioration of the aluminum in megaconstellation** satellites like SpaceX’s Starlink network. For our purposes, a satellite is a human-made object put into low-Earth orbit (LEO) for a planned lifespan. There are about 5,000 active and defunct satellite sin LEO, with over 40,000 Starlink sats planned in the future, plus satellite projects from national space agencies and private companies around the world, researchers from the University of British Columbia say in their new Scientific Reports study. The human-made distinction may seem obvious, but it hasn’t always been. That’s because, as Space.com reports, scientists spent decades favorably comparing satellite “junk” to the amount of material deposited and burned up in our atmosphere by meteorites. As long as meteorites were so much more of the material by volume while doing almost no harm to the planet, how bad could human-made satellites be? Well, as it turns out, it’s a matter of quality rather than quantity. That’s because meteorites are made of a different constellation of minerals and elements than our custom-manufactured sky robots. “We have 54 tonnes (60 tons) of meteoroid material coming in every day,” lead study author Aaron Boley told Space.com. “With the first generation of Starlink, we can expect about 2 tonnes (2.2 tons) of dead satellites reentering Earth’s atmosphere daily. But meteoroids are mostly rock, which is made of oxygen, magnesium and silicon. These satellites are mostly aluminum, which the meteoroids contain only in a very small amount, about 1 [percent].” Aluminum is key to everything at stake here. First, it burns into reflective aluminum oxide, or alumina, which could turn into an unwitting geoengineering experiment that could alter Earth’s climate. And second**, aluminum oxide could damage and even rip a new hole in the ozone layer**. Let’s look at each threat separately and try to figure it out. Geoengineering is the umbrella term for technologies that seek to alter the climate or other physical realities about the planet. The major meaning that most people associate with the word is solar geoengineering, an experimental idea to fight climate change. Yes, this includes launching reflective aerosols that will “block the sun” back into space and ostensibly cool the planet, which is what Bill Gates eventually wants to try. But we just don’t know how large-scale geoengineering could affect the planet’s climate. (In the sci-fi flick Snowpiercer, **geoengineering has turned Earth into a lifeless iceball** whose only survivors must crowd aboard an unceasing train. That’s probably our worst-case scenario.) Aluminum oxide scatters more light than glass, with a refractive index of about 1.76 compared with just 1.52 for glass and about 1.37 for plain aluminum. The researchers write: “Anthropogenic deposition of aluminum in the atmosphere has long been proposed in the context of geoengineering **as a way to alter Earth’s albedo**. These proposals have been scientifically controversial and controlled experiments encountered substantial opposition. Mega-constellations [of satellites] will begin this process as an **uncontrolled experiment.”** Another Hole in the Ozone? What, then, of the ozone layer? Once again, aluminum oxide comes to the forefront. As aluminum burns, it can chemically react with ozone in the air to form aluminum oxide, thereby depleting the naturally protective supply of ozone in the atmosphere. The atmosphere can absorb a small amount of these chemicals without ill effect, but with tens of thousands of satellites in play, the quantities **will naturally go up.** **That’s in addition to the ozone damage done by each rocket launch to put satellites into LEO**. “Rockets threaten the ozone layer by depositing radicals directly into the stratosphere, with solid-fueled rockets causing the most damage because of the hydrogen chloride and alumina they contain,” the researchers write.

**Ozone loss threatens extinction**

**Rosenberg 21**

(Lizzy, <https://www.greenmatters.com/p/what-happens-ozone-layer-gone>, 9-17)

Climate change is continuously threatening plant and wildlife, it's causing extreme weather conditions, and it's the reason why water levels and temperatures are continuously rising. But one of the more threatening side effects of climate change is the daunting hole that's formed in the ozone layer over the years. Scientists attribute it to destructive human activity — specifically the use of chlorofluorocarbons and aerosols — and the prospect of the ozone layer being totally gone is terrifying. "Ozone is Earth's natural sunscreen, absorbing and blocking most of the incoming UV radiation from the sun and protecting life from DNA-damaging radiation," reads a report from NASA. That said, a world without it could be pretty bleak. What will happen if the ozone layer is gone? As previously mentioned, the ozone player protects life on planet Earth from exposure to UV rays and radiation. The stratospheric layer, which lies 10 to 30 miles above Earth's surface, consists of naturally created ozone molecules. But in the 1970s, researchers discovered a "hole" in the ozone that was caused by the use of CFCs, which destroy ozone molecules, according to NASA. And as per the EPA, the hole is causing more UV radiation to make its way to life on planet Earth. UV ray exposure can cause skin cancer, cataracts, and immune system problems among human beings. as well as famine in humans and wildlife due to lower crop yield and destruction of marine life. So if the hole in the ozone layer gets much bigger — or if the ozone layer depletes entirely — it could cause increased life-threatening problems to human, animal, and plant life. It could ultimately make **planet Earth truly uninhabitable** — even more than it is as of right now.

**Current space debris levels are manageable, megaconstellations push us over the brink given their number, cheap design, and planned obsolescence**

**Boley and Byers, PhDs, 21**

(Aaron, Department of Physics and Astronomy, The University of British Columbia, Vancouver, Canada. 2 Michael, Department of Political Science, The University of British Columbia, Vancouver, Canada Satellite mega‑constellations create risks in Low Earth Orbit, the atmosphere and on Earth Scientifc Reports | (2021) 11:10642 | https://doi.org/10.1038/s41598-021-89909-7)

Thousands of satellites and 1500 rocket bodies provide considerable mass in LEO, which can break into debris upon collisions, explosions, or degradation in the harsh space environment. Fragmentations increase the cross-section of orbiting material, and with it, the collision probability per time. Eventually, collisions could dominate on-orbit evolution, a situation called the Kessler Syndrome3 . There are already over 12,000 trackable debris pieces in LEO, with these being typically 10 cm in diameter or larger. Including sizes down to 1 cm, there are about a million inferred debris pieces, all of which threaten satellites, spacecraf and astronauts due to their orbits crisscrossing at high relative speeds. Simulations of the long-term evolution of debris suggest that LEO is already in the **protracted initial stages** of the **Kessler** Syndrome, but that this could be **managed** through active debris removal4 . The **addition of satellite mega-constellations** and the general proliferation of low-cost satellites in LEO stresses the environment further5–8 Results The overall setting. The rapid development of the space environment through mega-constellations, predominately by the ongoing construction of Starlink, is shown by the cumulative payload distribution function (Fig. 1). From an environmental perspective, the slope change in the distribution function defnes NewSpace, an era of dominance by commercial actors. Before 2015, changes in the total on-orbit objects came principally from fragmentations, with efects of the 2007 Chinese anti-satellite test and the 2009 Kosmos-2251/Iridium-33 collisions being evident on the graph. Although the volume of space is large, individual satellites and satellite systems have specifc functions, with associated altitudes and inclinations (Fig. 2). This increases congestion and requires active management for station keeping and collision avoidance9 , with automatic collision-avoidance technology still under development. Improved space situational awareness is required, with data from operators as well as ground- and space-based sensors being widely and freely shared10. Improved communications between satellite operators are also necessary: in 2019, the European Space Agency moved an Earth observation satellite to avoid colliding with a Starlink satellite, afer failing to reach SpaceX by e-mail. Internationally adopted ‘right of way’ rules are needed10 to prevent games of ‘chicken’, as companies seek to preserve thruster fuel and avoid service interruptions. SpaceX and NASA recently announced11 a cooperative agreement to help reduce the risk of collisions, but this is only one operator and one agency. When completed, Starlink will include about **as many satellites as there are trackable debris pieces today**, while its total mass will equal all the mass currently in LEO—over 3000 tonnes. Te satellites will be placed in narrow orbital shells, creating **unprecedented congestion**, with 1258 already in orbit (as of 30 March 2021). OneWeb has already placed an initial 146 satellites, and Amazon, Telesat, GW and other companies, operating under diferent national regulatory regimes, are soon likely to follow. Enhanced collision risk. Mega-constellations are composed of mass-produced satellites with few backup systems. This **consumer electronic model** allows for short upgrade cycles and rapid expansions of capabilities, but also **considerable discarded equipment**. SpaceX will actively de-orbit its satellites at the end of their 5–6-year operational lives. However, this process takes 6 months, so roughly 10% will be de-orbiting at any time. If other companies do likewise, thousands of de-orbiting satellites will be slowly passing through the same congested space, posing collision risks. Failures will increase these numbers, although the long-term failure rate is difcult to project. Figure 3 is similar to the righthand portion of Fig. 2 but includes the Starlink and OneWeb megaconstellations as fled (and amended) with the FCC (see “Methods”). Te large density spikes show that some shells will have satellite number densities in excess of n = 10−6 km−3 . Deorbiting satellites will be tracked and operational satellites can manoeuvre to avoid close conjunctions. However, this depends on ongoing communication and cooperation between operators, which at present is ad hoc and voluntary. A recent letter12 to the FCC from SpaceX suggests that some companies might be less-thanfully transparent about events13 in LEO. Despite the congestion and trafc management challenges, FCC flings by SpaceX suggest that collision avoidance manoeuvres can in fact maintain collision-free operations in orbital shells and that the probability of a collision between a non-responsive satellite and tracked debris is negligible. However, the flings do not account for untracked debris6 , including untracked debris decaying through the shells used by Starlink. Using simple estimates (see “Methods”), the probability that a single piece of untracked debris will hit any satellite in the Starlink 550 km shell is about 0.003 afer one year. Thus, if at any time there are 230 pieces of untracked debris decaying through the 550 km orbital shell, there is a **50% chance** that there will be one or more collisions between satellites in the shell and the debris. As discussed further in “Methods”, such a situation is plausible. Depending on the balance between the de-orbit and the collision rates, if subsequent fragmentation events lead to similar amounts of debris within that orbital shell, **a runaway cascade of collisions could occur**. Fragmentation events are not confned to their local orbits, either. Te India 2019 ASAT test was conducted at an altitude below 300 km in an efort to minimize long-lived debris. Nevertheless, debris was placed on orbits with apogees in excess of 1000 km. As of 30 March 2021, three tracked debris pieces remain in orbit14. Such long-lived debris has high eccentricities, and thus can cross multiple orbital shells twice per orbit. A major fragmentation event from a single satellite could afect all operators in LEO. Even if debris collisions were avoidable, meteoroids are always a threat. Te cumulative meteoroid fux15 for masses m > 10–2 g is about 1.2× 10–4 meteoroids m−2 year−1 (see “Methods”). Such masses could cause nonnegligible damage to satellites16. Assuming a Starlink constellation of 12,000 satellites (i.e. the initial phase), there is about a 50% chance of 15 or more meteoroid impacts per year at m > 10–2 g. Satellites will have shielding, but events that might be rare to a single satellite could become common across the constellation. One partial response to these congestion and collision concerns is for operators to construct mega-constellations out of a smaller number of satellites. But this does not, individually or collectively, eliminate the need for an all-of-LEO approach to evaluating the efects of the construction and maintenance of any one constellation.

**Debris cascades cause global nuke war**

Les **Johnson 13**, Deputy Manager for NASA's Advanced Concepts Office at the Marshall Space Flight Center, Co-Investigator for the JAXA T-Rex Space Tether Experiment and PI of NASA's ProSEDS Experiment, Master's Degree in Physics from Vanderbilt University, Popular Science Writer, and NASA Technologist, Frequent Contributor to the Journal of the British Interplanetary Sodety and Member of the American Institute of Aeronautics and Astronautics, National Space Society, the World Future Society, and MENSA, Sky Alert!: When Satellites Fail, p. 9-12 [language modified]

Whatever the initial cause, the result may be the same. A **sat**ellite destroyed in orbit will break apart into thousands of pieces, each traveling at over 8 km/sec. This virtual shotgun blast, with pellets traveling 20 times faster than a bullet, will quickly spread out, with each pellet now following its own orbit around the Earth. With over 300,000 other pieces of junk already there, the tipping point is crossed and a runaway series of collisions **begin**s. A few orbits later, two of the new debris pieces strike other satellites, causing them to explode into thousands more pieces of debris. The rate of collisions increases, now with more spacecraft being destroyed. Called the "Kessler Effect", after the NASA scientist who first warned of its dangers, these debris objects, now numbering in the millions, cascade around the Earth, **destroy**ing every **sat**ellite in **l**ow **E**arth **o**rbit. Without an atmosphere to slow them down, thus allowing debris pieces to bum up, most debris (perhaps numbering in the millions) will remain in space for hundreds or thousands of years. Any new satellite will be threatened by destruction as soon as it enters space, effectively rendering many Earth orbits **unusable**. But what about us on the ground? How will this affect us? Imagine a world that suddenly **loses all of its space technology**. If you are like most people, then you would probably have a few fleeting thoughts about the Apollo-era missions to the Moon, perhaps a vision of the Space Shuttle launching astronauts into space for a visit to the International Space Station (ISS), or you might fondly recall the "wow" images taken by the orbiting Hubble Space Telescope. In short, you would know that things important to science would be lost, but you would likely not assume that their loss would have any impact on your daily life. Now imagine a world that suddenly loses network and cable television, accurate weather forecasts, Global Positioning System (GPS) navigation, some cellular phone networks, on-time delivery of food and medical supplies via truck and train to stores and hospitals in virtually every community in America, as well as science useful in monitoring such things as climate change and agricultural sustainability. Add to this the [destruction] ~~crippling~~ of the US military who now depend up**on** spy satellites, space-based communications systems, and GPS to know where their troops and supplies are located at all times and anywhere in the world. The result is a **nightmarish world**, one step away from **nuclear war**, **economic disaster**, and potential **mass starvation**. This is the world in which we are now perilously close to living. Space satellites now touch our lives in many ways. And, unfortunately, these satellites are **extremely vulnerable** to risks arising from a half-century of carelessness regarding protecting the space environment around the Earth as well as from potential adversaries such as China, North Korea, and Iran. No government policy has put us at risk. It has not been the result of a conspiracy. No, we are dependent upon them simply because they offer capabilities that are simply **unavailable any other way**. Individuals, corporations, and governments found ways to use the unique environment of space to provide services, make money, and better defend the country. In fact, only a few space visionaries and futurists could have foreseen where the advent of rocketry and space technology would take us a mere 50 years since those first satellites orbited the Earth. It was the slow progression of capability followed by dependence that puts us at risk. The exploration and use of space began in 1957 with the launch of Sputnik 1 by the Soviet Union. The United States soon followed with Explorer 1. Since then, the nations of the world have launched over 8,000 spacecraft. Of these, several hundred are still providing information and services to the global economy and the world's governments. Over time, nations, corporations, and individuals have grown accustomed to the services these spacecraft provide and many are dependent upon them. Commercial **aviation**, **shipping**, **emergency** services, vehicle fleet tracking, financial transactions, and **ag**riculture are areas of the economy that are increasingly **reliant** on space. Telestar 1, launched into space in the year of my birth, 1962, relayed the world's first live transatlantic news feed and showed that space satellites can be used to relay television signals, telephone calls, and data. The modern telecommunications age was born. We've come a long way since Telstar; most television networks now distribute most, if not ali, of their programming via satellite. Cable television signals are received by local providers from satellite relays before being sent to our homes and businesses using cables. With 65% of US households relying on cable television and a growing percentage using satellite dishes to receive signals from direct-to-home satellite television providers, a large number of people would be cut off from vital information in an emergency should these satellites be destroyed. And communications satellites relay more than television signals. They serve as hosts to corporate video conferences and convey business, banking, and other commercial information to and from all areas of the planet. The first successful weather satellite was TIROS. Launched in 1960, TIROS operated for only 78 days but it served as the precursor for today's much more long-lived weather satellites, which provide continuous monitoring of weather conditions around the world. Without them, providing accurate weather forecasts for virtually any place on the globe more than a day in advance would be nearly impossible. Figure !.1 shows a satellite image of Hurricane Ivan approaching the Alabama Gulf coast in 2004. Without this type of information, evacuation warnings would have to be given more generally, resulting in needless evacuations and lost economic activity (from areas that avoid landfall) and potentially increasing loss of life in areas that may be unexpectedly hit. The formerly top-secret Corona spy satellites began operation in 1959 and provided critical information about the Soviet Union's military and industrial capabilities to a nervous West in a time of unprecedented paranoia and nuclear risk. With these satellites, US military planners were able to understand and assess the real military threat posed by the Soviet Union. They used information provided by spy satellites to help avert potential military confrontations on numerous occasions. Conversely, the Soviet Union's spy satellites were able to observe the United States and its allies, with similar results. It is nearly impossible to move an army and hide it from multiple eyes in the sky. Satellite information is critical to **all aspects** of US intelligence and military planning. Spy **sat**ellite**s** are used to monitor compliance with international arms treaties and to assess the military activities of countries such as **China**, **Russia**, **Iran**, and **North Korea**. Figure 1.2 shows the capability of modem unclassified space-based imaging. The capability of the classified systems is presumed to be significantly better, providing much more detail. Losing these satellites would place global militaries on **high alert** and have them operating, literally, in the blind. Our military would suddenly become vulnerable in other areas as well. GPS, a network of 24-32 satellites in medium-Earth orbit, was developed to provide precise position **info**rmation to the military, and it is now in common use by individuals and industry. The network, which became fully operational in 1993, allows our armed forces to know their exact locations anywhere in the world. It is used to guide bombs to their targets with unprecedented accuracy, requiring that only one bomb be used to destroy a target that would have previously required perhaps hundreds of bombs to destroy in the pre-GPS world (which, incidentally, has resulted in us reducing our stockpile of non-GPS-guided munitions dramatically). It allows soldiers to navigate in the dark or in adverse weather or sandstorms. Without GPS, our **military advantage** over potential adversaries would be dramatically reduced or **eliminated**.

**Independently, collisions with Russian nuclear powered spacecraft radiate the globe.**

Yuri **Zaitsev**, academic adviser with the Russian Academy of Engineering Sciences, **‘9**, “Russia to develop nuclear-powered spacecraft for Mars mission” http://en.rian.ru/analysis/20091111/156797969.html

Soviet and U.S. nuclear spacecraft programs were marred by a number of accidents. In April 1964, a U.S. Navy Transit navigation satellite with a radio-isotopic generator onboard failed to reach orbit and disintegrated in the atmosphere, spewing out over 950 grams of plutonium-238. This was more than the total amount of plutonium released during all nuclear explosions by 1964. In January 1978, Kosmos-954, a Soviet Radar Ocean Reconnaissance Satellite (RORSAT) with a nuclear reactor onboard reentered the atmosphere, after the satellite's reactor core failed to separate and boost it into a nuclear-safe orbit, and fell in Canada, contaminating 100,000 sq. km. of its territory. In February 1983, the nuclear-powered Soviet satellite Kosmos-1402 went down in the South Atlantic. The most serious threat involved Cassini-Huygens, a joint NASA/European Space Agency/Italian Space Agency robotic spacecraft mission currently studying the planet Saturn and its many natural satellites, that was launched on October 15, 1997 and which made a gravitational-assist flyby of the Earth on August 18, 1999. The spacecraft, which had a nuclear reactor with 32.7 kg of plutonium-238, passed only 500 km above the Earth. Up to **five billion people could have got radiation poisoning had the spacecraft plunged into the atmosphere.** On February 10, 2009, the Iridium-33 telecommunications satellite owned by U.S. company Iridium Satellite LLC and its defunct Russian equivalent, the Kosmos-2251 with a nuclear propulsion unit, collided over northern Siberia. This resulted in potentially hazardous space debris. At present, **30 Russian** and **seven U.S. spacecraft** with nuclear systems onboard are orbiting the earth at 800-1,100-km altitudes, where **similar collisions can take place**. This makes up for about **40 "potential nuclear explosions**." If any of these satellites hits a fragment of space junk, it will slow down and eventually **re-enter the atmosphere**, spewing radiation above the Earth and on its surface.

**Recent comprehensive studies show mitigation efforts fail- megaconstellations will irreparably damage astronomy**

**Sutter, PhD, 10-6-21**

(Paul M. Sutter is an astrophysicist at SUNY Stony Brook and the Flatiron Institute in New York City. Paul received his PhD in Physics from the University of Illinois at Urbana-Champaign in 2011, and spent three years at the Paris Institute of Astrophysics https://www.space.com/megaconstellations-could-destroy-astronomy-no-easy-fix)

Over the next few years, companies across the world are planning to launch tens of thousands of satellites into orbit to provide global high-speed internet access. But that access comes at a cost: It will pollute the skies and **contaminate astronomical observations**. So is there a way to fix it? A team of researchers has modeled the effects of these satellites and explored various mitigation strategies. The answer, it seems, is not easy. Starlink, OneWeb, Kuiper, SatNet — these are just the beginning of the megaconstellations that will launch into Earth orbit over the coming years. Each will provide its own network of high-speed global internet access. The rise in orbiting satellites is **astounding.** There are currently more than 3,300 active artificial satellites in Earth orbit, according to the Union of Concerned Scientists, a science advocacy group. Meanwhile, the scientists behind new research note, generation 1 of SpaceX's Starlink will, by itself, consist of 11,926 satellites, and generation 2 will have 30,000 more. OneWeb, Amazon's Kuiper and China's SatNet combined will deploy over 20,000 satellites. Before these mega-constellations began launching in 2018, the largest constellation of satellites was Iridium's communication satellites, which totaled just 70. **Every single satellite is a source of contamination**. The satellite bodies themselves, as well as their expansive solar panels, reflect sunlight. To an astronomer using the largest telescopes on Earth to capture **the faintest objects** in the heavens, the megaconstellations aren't a boon, but a nuisance. When a satellite constellation crosses a telescope's field of view, it isn't just a single streak but multiple ones that can potentially **wreak havoc on astronomical observations**. Advocates of the megaconstellations have argued that the high altitudes of the satellites will reduce their impact on astronomy and that only certain kinds of observation programs will be at risk. So researchers decided to use available data to predict the impact of these megaconstellations on astronomical observations. Modeling the impact The image shows diagonal lines caused by the light reflected by a group of 25 Starlink satellites passing through the field of view of a telescope at Lowell Observatory in Arizona during observations of the NGC 5353/4 galaxy group on May 25, 2019. The image shows diagonal lines caused by the light reflected by a group of 25 Starlink satellites passing through the field of view of a telescope at Lowell Observatory in Arizona during observations of the NGC 5353/4 galaxy group on May 25, 2019. (Image credit: Victoria Girgis/Lowell Observatory) It's impossible to know just how bad the skies will get until all the satellites are up and astronomers try to do astronomy. But by then, it might be too late. In the meantime, a team of astronomers attempted to model the impact of megaconstellations on modern astronomy. The astronomers took their best guess, based on the publicly available information, for the orbital configurations of the future megaconstellations. Then, they modeled each satellite's size and brightness, which depends greatly on the angle between the satellite and the sun as seen from Earth. They then folded these models into simulated observations with different kinds of astronomical instruments, such as wide-field giant telescopes and high-resolution spectrographs. Advertisement The team found that almost every aspect of modern-day astronomy will be affected in some way, because the satellites will generally be bright enough to be seen by even moderately sized professional telescopes. However, some observing programs will fare much worse than others. Depending on the particular telescope, the time of year and the observing program, a typical science run observes anywhere from 0.01 to 20 satellite trails in every exposure. Narrow-field instruments, which image only a small portion of the sky at a time, will be the least affected, since they are unlikely to have a satellite cross into their field of view during any particular observation, the astronomers found. On the other hand, wide-field telescopes, such as the Vera C. Rubin Observatory, will face a lot of difficulties — at sunrise and sunset, for example — and the observatory could lose up to half of each image because of interfering satellite trails, the astronomers wrote in a paper recently published to the preprint server arXiv. Observations made during the first and last hours of the night will suffer the most, since the angle of the satellites from the ground will make them appear the brightest and most visible, the team found. Spectroscopy will be affected, too. Even though low- and mid-resolution spectroscopic instruments, which are attached to telescopes around the world and split light into the specific wavelengths of light it contains, will be less affected than instruments that produce images. But the level of contamination will be much higher for spectroscopic instruments, with the pollution from the satellites giving roughly the same size signal as the target science data. Saving astronomy This annotated image shows the sky above the European Southern Observatory's Paranal Observatory at twilight, with the blue rings showing degrees of elevation above the horizon and the location of satellites (marked in red and green). The area above 30 degrees is where most astronomical observations are made. This annotated image shows the sky above the European Southern Observatory's Paranal Observatory at twilight, with the blue rings showing degrees of elevation above the horizon and the location of satellites (marked in red and green). The area above 30 degrees is where most astronomical observations are made. (Image credit: ESO/Y. Beletsky/L. Calçada) Advertisement **Astronomy is a precision science in which every image matters**. Polluted portions of images are useless; they must be thrown out. In many cases, useful information can still be gleaned from the uncontaminated areas of the images. But in others, like exoplanet detection, the entire image has to be tossed. T**his could cost the astronomical community millions of dollars in lost time and processing power.** And this is only the start of the megaconstellation era; more satellites could be on the way.

**Planned starlink expansion will pollute every astronomical image**

**Mróz et al, PhDs, 22**

(Przemek Mróz1 , Angel Otarola2 , Thomas A. Prince3 , Richard Dekany4 , Dmitry A. Duev3,5 , Matthew J. Graham3 , Steven L. Groom6 , Frank J. Masci6 , and Michael S. Medford7,8 1 Astronomical Observatory, University of Warsaw, Al. Ujazdowskie 4, 00-478 Warszawa, Poland; pmroz@astrouw.edu.pl 2 European Southern Observatory, Alonso de Córdova 3107, Vitacura, Región Metropolitana, Chile 3 Division of Physics, Mathematics, and Astronomy, California Institute of Technology, Pasadena, CA 91125, USA 4 Caltech Optical Observatories, California Institute of Technology, Pasadena, CA 91125, USA 5 Weights & Biases, Inc., 1479 Folsom St., San Francisco, CA 94103, USA 6 IPAC, California Institute of Technology, 1200 E. California Blvd., Pasadena, CA 91125, USA 7 University of California, Berkeley, Department of Astronomy, Berkeley, CA 94720, USA 8 Lawrence Berkeley National Laboratory, 1 Cyclotron Rd., Berkeley, CA 94720, USA Received 2021 December 10; revised 2021 December 15; accepted 2021 December 25; published 2022 January 14 Impact of the SpaceX Starlink Satellites on the Zwicky Transient Facility Survey Observationshttps://iopscience.iop.org/article/10.3847/2041-8213/ac470a/pdf)

Figure 1 presents a number of ZTF images with at least one Starlink satellite trail in 10 days bins. The number of affected images is **clearly increasing with time**: from less than one affected image per night in early 2020 to nearly 20 streaked images per night in the second half of 2021. Multiple satellites (up to 15) may be visible in one image, and, on average, there are 1.09 satellite streaks per affected image. Figure 1 also shows the cumulative number of deployed satellites from the Starlink constellation. Currently about 1.2% of all deployed satellites are detected by ZTF in a given night. As expected by McDowell (2020) and Hainaut & Williams (2020), twilight and high-air-mass observations are particularly vulnerable to contamination from LEO satellite trails. About 64% of the detected trails were imaged during twilight (solar elevation greater than -18°) and about 70% (45%) were at elevation lower than 40° (30°). Figure 2 presents the fraction of ZTF images (taken when the solar elevation was greater than −18° and −30°) with at least one Starlink satellite trail. In late 2020, about 6% of images taken during twilight were affected, and this fraction went up to ≈18% in 2021 August. We expect that essentially **all ZTF images taken during** twilight may be affected once the size of the constellation exceeds ≈10,000. If the entire constellation of 42,000 was deployed, **every image taken during twilight would be contaminated with about 4 satellite streaks**

Chart, histogram

Description automatically generated

**Light pollution from megaconstellations specifically threatens detection of Near Earth Objects (NEOs)**

**Wall 20**

(Mike, <https://www.nbcnews.com/science/space/satellite-megaconstellations-could-have-extreme-impact-astronomy-report-finds-n1238178>, 8-26)

Huge constellations of internet satellites could fundamentally change how astronomers study the night sky and how the rest of us experience it, a new report finds. The potential impacts of megaconstellations in low Earth orbit (LEO), such as SpaceX's Starlink network, "are estimated to range from negligible to **extreme,"** according to a report from the Satellite Constellations 1 (SATCON1) workshop, which was released Tuesday. SpaceX has already launched about 600 Starlink satellites, and that's just the beginning. Elon Musk's company has approval to operate 12,000 Starlink spacecraft and has applied for permission for up to 30,000 more. And SpaceX is not alone; for example, Amazon aims to launch about 3,200 broadband satellites for its own network, known as Project Kuiper. Related: SpaceX's Starlink satellite megaconstellation launches in photos For perspective: There are currently about 2,500 operational satellites circling Earth, and humanity has launched fewer than 10,000 objects since the dawn of the space age in 1957. The actual impact of this LEO population boom on the night sky depends on a number of factors, including the nature and goals of the observations being made; observers' ability to remove or mask satellite trails in their datasets; and the number, brightness and altitude of the satellites, the report's authors determined. For instance, satellite trails will pose a particular problem for telescopes that view wide swaths of sky in visible and infrared light, such as the upcoming **Vera C. Rubin Observatory in Chile**. Observing programs that rely upon data gathered during the twilight hours, such **as searches for potentially hazardous asteroids and comets**, will be **disproportionately affected** as well. That's because LEO satellites will remain illuminated by the sun at these times, the report explains. But big LEO networks could pose problems throughout the night if their constituent satellites are high enough up. For example, a large constellation orbiting 750 miles (1,200 kilometers) above Earth, as OneWeb's 74 broadband satellites do, "will be visible all night during summer and significant fractions of the night during winter, fall, and spring, and will have negative impacts on nearly all observational programs," the new report states. (OneWeb had intended to launch at least 650 internet satellites, but it's unclear if the constellation will ever get that big. OneWeb declared bankruptcy this year and will be bought by a consortium led by the British government and the Indian company Bharti Global.) Constellations that orbit less than 370 miles (600 km) above Earth won't have nearly the same all-night impact, the report's authors determined. Starlink falls into this category; its satellites fly at an altitude of about 340 miles (550 km).

**Don’t write off low probability events- an asteroid hit is the highest conceivable magnitude and can be prevented easily with early detection**

**Dreier 21**

(Casey Dreier is Senior Space Policy Adviser for The Planetary Society, an independent nonprofit organization based in California. <https://www.scientificamerican.com/article/why-an-asteroid-strike-is-like-a-pandemic/>, 7-25)

Imagine the following scenario. Scientists identify a potential global threat, but initial data are spotty—not enough to spur drastic action. Rapidly, relentlessly, the threat grows. What once was preventable becomes inevitable. The world has no choice but to endure the disaster at the cost of trillions of dollars and millions of lives. This is the story of COVID pandemic—but it could equally well be the story of a **catastrophic strike by a large asteroid**. As we emerge from the worst of COVID-19, we should heed this lesson: **low-probability, high-impact events do occur; but they can be mitigated if we prepare and act early enough**. Asteroids are like viruses in a sense: they number in the tens of millions but only a few types pose a threat to humans. For asteroids, it’s the “near-Earth” variety—those with orbits that come close to our own—that we must worry about. Also as with viral outbreaks, the likelihood of a catastrophe is unlikely in any given year, but **almost inevitable over time**. And just as we can in principle develop vaccines against emerging viruses before they cause too much damage, creating immunity without making people sick, we can similarly use modern technology to develop a level of global immune response to asteroid collisions. But this requires ongoing investments in research and preparedness—and while the U.S. spent more than $6.5 billion dollars on pandemic preparedness over the past decade (with admittedly mixed results), the nation spent less than a tenth of that on the work of asteroid detection and deflection. This is far too low. In fact, impacts from space happen all the time, but they are generally small and harmless. The Earth is peppered with meteors throughout the year that are mere inches across or less, which burn up as shooting stars when they enter our atmosphere. The threat comes from the bigger ones, which are house-sized or larger. These strike less frequently, but they do happen. In 2013, a 60-foot-diameter meteor exploded over the city of Chelyabinsk, injuring thousands of people. The really big ones—miles across—are even rarer, occurring every few hundred million years or so. **But the damage they do can be catastrophic**. **Think of the mass extinction** 65 million years ago that wiped out most of the dinosaurs. The good news is that we’ve found most of those and, fortunately for us, Earth is not in their crosshairs. But there is a middle ground that demands our attention: “city killer” asteroids that are about around the size of a football field and could unleash 10,000 times the energy of the atomic bomb that leveled Hiroshima. They seem to hit us every few thousand years, on average. There are likely many tens of thousands of them with orbits near Earth’s, yet we’ve only found about one third of these. And finding them is hard. Even the big ones are tiny, cosmically speaking, and are camouflaged against the blackness of space by their charcoal-like dark surfaces. Ground-based telescopes, which measure reflected light, **struggle to see these small, dim objects**. Only a few hundred are discovered each year. To significantly improve the rate of detection we need to move off the Earth, to the realm of the asteroids. We need a telescope in space. The Near-Earth Object (NEO) Surveyor is a modest space telescope currently under consideration by NASA. Instead of looking at reflected light, it would seek out heat signatures of asteroids, which glow with infrared radiation against the cold background of space. And in space, where there’s no bad weather and daytime that limit observations, the NEO Surveyor could find more city-killer asteroids in the next 10 years than have been discovered by all the telescopes on Earth over the past three decades. ADVERTISEMENT The mathematics of orbital mechanics that characterizes asteroids can be as heartless as the exponential growth that goes with viral outbreaks. And as with broad testing regimes that have been used during COVID, **a dedicated effort to discover potentially hazardous asteroids will be the key to preventing disaster**. It’s possible to alter an incoming asteroid’s orbit to protect the Earth, but that becomes increasingly more difficult depending on how close we are to impact. It is far easier to act years (if not decades) in advance. After more than a decade in bureaucratic purgatory, where the NEO Surveyor has struggled to gain approval, the project appears ready to move forward. The Biden administration recently proposed to fund this mission in its latest NASA budget; Congress should support this request. It will take years to build and launch, but as early as 2026 we may see the start of the first dedicated effort to understand the scope of the asteroid threat. We also need to invest in deflection technology, the “vaccine” of the asteroid response. Fortunately, NASA is close to launching a mission called the Double Asteroid Redirection Test (DART). In 2022, the spacecraft will ram into the tiny “moon” that orbits the near-Earth asteroid Didymos, slightly changing its orbit. Scientists will compare the exact degree of change to their predictions, which will help them understand how to alter asteroid orbits more effectively in the future. This is only a test, but it could serve the same function as the years of basic research into the field of mRNA vaccines that ultimately paid off when applied to COVID. We must also continue to support sky surveys by ground telescopes, which can support the work of space-based missions. **The Vera Rubin Observatory**, for example, now under construction **in Chile and especially good at finding fast-moving objects in the solar system, will greatly assist in asteroid detection**. (The **proposed “megaconstellations**” of Earth-orbiting satellites by Amazon, SpaceX, OneWeb, and others threaten to overwhelm our view of these dim objects and make asteroid **detections more difficult**. There is no easy solution to this, beyond further confirming the need for space-based detectors located in quieter regions of the solar system.) The coronavirus pandemic has many humbling lessons for humanity. But let this be one of them: low-probability, high-impact disasters do occur; and there is no **higher impact disaster than** a large asteroid collision with the Earth. We know that early awareness enables early action. Big problems later on can be prevented by small investments now. Let’s not be caught off-guard again.

**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.

**Framing**

**The standard is maximizing expected well-being.**

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

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**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.

**Reject conventional risk calculus – the magnitude and inevitability of emerging NEO threats requires a totally different model for risk calculus**

**Koplow 19** [David A. Koplow. Professor of Law at Georgetown University. He specializes in the areas of public international law, national security law, and the intersection between international law and U.S. constitutional law. Koplow served as Special Counsel for Arms Control to the General Counsel of the Department of Defense (2009-2011); Deputy General Counsel for International Affairs at the Department of Defense (1997-1999); and as Attorney-Advisor and Special Assistant to the Director of the U.S. Arms Control and Disarmament Agency (1978-1981). A Rhodes scholar, Koplow graduated from Harvard College and Yale Law School. "Exoatmospheric Plowshares: Using a Nuclear Explosive Device for Planetary Defense against an Incoming Asteroid," UCLA Journal of International Law and Foreign Affairs 23, no. 1 (Spring 2019): 76-158]

Astronomers are fond of observing that the real question is not "whether" Earth will again be struck by a large asteroid, but "when." We can detect around the planet the remnants of scores of impact craters of diverse size and age left by previous NEOs, and the pockmarks are even more obvious on the Moon and other celestial bodies, where erosion has not degraded their silhouettes. As asteroids pinball around the Solar System, it is only a matter of time before the next jarring impact-time that might be measured in months or in millions of years.

The potential consequences of such a collision beggar belief Prehistoric experience demonstrates that **all of human civilization**, as well as most or all other forms of life on Earth, may **hang in the balance**. Even a more moderately sized asteroid could devastate a community or a country in an instant. As Igor Ashurbeyli assesses the stakes, developing countermeasures to this apocalyptic threat "must become the **most important task** that humanity must solve **in the 2 1st century**. "211

But the **time frame matters**, too. If we knew, hypothetically, that an extinction-level event was not going to occur for thousands or millions of years, why would we devote time, attention, and money to it now? A known risk of extermination, eons into the future, would pose profound philosophical and psychological conundrums, but preemptively responding to it would not be on anyone's active "to-do list" for generations.

Still, timing matters in another way, too. With our present state of astronomical intelligence, **we cannot be certain** about our planet's prolonged safety, and we must exhibit appropriate modesty about our confidence in the completeness of the inventory of known NEOs. Accordingly, the planet may **not have much advance notice** about the next Chicxulub, and we may be **no more able than the dinosaurs** to immediately invent our way out of an unanticipated fatal space specter. Frances Lyall and Paul B. Larsen summarize the issue this way: "Time might be too short adequately to deal with the crisis-missile or other **technology has to be prepared**." 2 12

It is **difficult for humans to think rationally about this** sort of problem-it is hard to get our collective minds around such enormous consequences and such tiny probabilities simultaneously-especially when people have so little first-hand experience with the causal phenomenon. A **2010 study** by the National Academy of Sciences referred to this as a **classic "zero times infinity" problem** that **thwarts human cognitive processing**.213 Cass Sunstein and Richard Zeckhauser label the resulting bias in decision-making as **"probability neglect"-**a propensity to **misunderstand the fearsome risks** that are so difficult to conceptualize.2 14 **Behavioral economics** literature abounds with examinations of the collective non-rationality in our species' approach to high-severity/low-probability events, leading to **extreme discounting of remote future catastrophes**, to the detriment of individuals and society.2 15

The **underdeveloped state of international law** on trans-border disasters reflects this cognitive deficit. Perhaps this should not be surprising-the tasks of preventing, responding to, and rebuilding after global catastrophes are daunting. These are topics that sovereign states, as well as individual human beings, **shy away from addressing-they are uncomfortable to think about**; they can involve sharing resources, as well as sympathy, with foreigners; and they seem to call for spending immense sums of money on vanishingly remote contingencies. It will never be easy to marshal political support for developing, improving, and sustaining planetary defense capabilities that in all likelihood will never be exercised during any government official's term in office or even lifetime.216 Nevertheless, planetary defense represents one of the occasions in which these **psychological barriers must be overcome**.

The extended time frame in dealing with asteroids places special burdens on the effort to think rationally about very-low-probability dangers, because the people at risk are (likely) not ourselves but our far-distant progeny, generations so remote that the emotional connection to them is strained. We can appreciate that the good work of IAWN and SMPAG today may help increase the odds of our species' survival, but we must also be aware that the counter-asteroid technology available to earthlings a century or two from now will surely surpass today's puny capabilities in ways we cannot imagine.2 17 Collision with a body of 3-5 km diameter) could **kill**, say, **half the world's population** (soon to reach eight billion people) sometime in the next million years. On an actuarial basis, that works out to 4,000 statistical deaths annually. That is surely a significant fatality rate-enough to warrant substantial financial investment-even though the incidents would be extraordinarily "lumpy," in the sense that for almost all of those one million years, there would be no deaths at all due to asteroids, but in one year there would be an unprecedented catastrophe. At this rate, asteroids would **rank above many other natural and bizarre phenomena** that people fear (and that societies attempt to do something about), such as floods, tornados, airplane crashes, **terrorism**, or choking. Asteroids, however, would still fall far below other leading causes of death, such as automobile accidents, communicable diseases, and tobacco use. 218

One plausible formula would be to posit that a major NEO impact (a collision with a body of 3-5 km diameter) could kill, say, half the world's population (soon to reach eight billion people) some time in the next million years. On an actuarial basis, that works out to 4,000 statistical deaths annually. That is surely a significant fatality rate-enough to warrant substantial financial investment-even though the incidents would be extraordinarily "lumpy," in the sense that for almost all of those one million years, there would be no deaths at all due to asteroids, but in one year there would be an unprecedented catastrophe. At this rate, asteroids would rank above many other natural and bizarre phenomena that people fear (and that societies attempt to do something about), such as floods, tornados, airplane crashes, terrorism, or choking. Asteroids, however, would still fall far below other leading causes of death, such as automobile accidents, communicable diseases, and tobacco use. 2 18

This weird combination of probabilities and consequences promotes what many call **the "giggle factor"**: humans' seemingly **congenital reluctance to discuss planetary defense** seriously without retreating to the silliest tropes about alien attacks or sci-fi thrillers. The topic seems to be ripped from kitschy movie trailers, not news headlines. 2 19

An additional fear factor here is the **danger of surprise**. If a significant asteroid were to arrive without warning-as in the Chelyabinsk incident-the afflicted **country might perceive** that it had been **attacked by a hostile neighbor**, rather than by a fickle Mother Nature. If, by further malign luck, the event happened to occur during a period of **heightened international tensions**, the **propensity to misinterpret**, and to **respond precipitously**, would rise. The unforeseen space object could thus **catalyze a larger human-caused tragedy**.2 20