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Executive Summary

Low Earth orbit (LEO) satellites are enabling access beyond the terrestrial confines of the Earth to a broader range of consumers of space and space services. This commercialization of a previously government- and military-dominated sector presents opportunities and risks for the U.S. Government and the Department of Defense (DoD). As access to space has grown in recent years, so too has the number of companies and organizations launching satellites into orbit each year. Although the inherently high costs and risks of the space economy mean that many of these companies could fail (as has occurred in previous rushes to space),[1] the sheer number of entrants implies a more accessible and competitive space ecosystem than ever before. Space watchers have projected that LEO will see dozens of new competitors in the next few years, some of which have significant financial backing and state sponsorship.[2] This dynamic suggests that DoD will need to work harder to maintain and secure national assets targeted by peer competitors engaged in gray zone[3] competition.

Space has played a critical role in enabling DoD communications and operations for decades. Space is a joint domain and the U.S. Army in particular is reliant on space-based services. As recently noted by the Secretary of the Army, "The Army is the largest user of space-enabled systems in the Department of Defense."[4] The U.S. Army's public statements have indicated that it is interested in how LEO can be used to the advantage of the warfighter but that it is not necessarily looking to invest in its own constellation.[5] Commercial providers can provide an opportunity for DoD to leverage their services to provide high-speed connections to units worldwide. DoD understands the advantages of partnering with commercial providers to provide enhanced connectivity to the battlefield without having to pay the high capital cost of setting up a large LEO constellation on their own. This document examines the emerging LEO market, provides examples of gray zone competition[6] activities that could impact the LEO value chain, describes DoD and Army initiatives relevant to LEO technologies, and concludes with suggestions for future focus.

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[1] Daehnick et al. 2020.

[2] Kulu 2021b; Daehnick et al. 2020; Lal et al. 2017.

[3] Gray zone activities are non-kinetic actions, typically economic in nature, used to challenge or disrupt the competitiveness of the United States or other nation state entities.

[4] https://www.defensenews.com/digital-show-dailies/smd/2020/08/21/army-space-and-missile-defense-command-firms-up-role-with-new-space-command/#:~:text=The%20Army%20has%20had%20a,domain%20for%20communications%20and%20surveillance.&text=The%20ASMDC%20now%20serves%20as,service's%20expanding%20role%20in%20space.

[5] https://www.army.mil/article/233587/army_looks_to_leverage_low_earth_orbit_satellites.

[6] Gray zone activities are non-kinetic actions, typically economic in nature, used to challenge or disrupt the competitiveness of the United States or other nation state entities.

The Shifting LEO Sector

LEO satellites enable access to space for a broad range of consumers and space services. A shift from a previously government- and military-dominated sector to a commercialized environment with global consumers presents opportunities and risks for the U.S. Government and the Department of Defense (DoD). The DoD's Defense Space Strategy (DSS) acknowledges this shift, citing the need to "maintain space superiority" and to take advantage of the commercialization in space, as well as protect commercial space capabilities against adversaries.[7]

DoD is actively moving in this field, communicating to the emerging commercial space industrial base that DoD is creating "plans to protect, support, and leverage commerce in space" while also establishing new partnerships.[8] These policy decisions have resulted in significant changes to the DoD space construct, creating new organizations and oversight groups to help accomplish this goal. The U.S. military and government have put policy guardrails in place to protect critical segments of space. As an example, in December 2017, the U.S. Government adopted legislation prohibiting the U.S. Secretary of Defense from procuring satellite services provided by satellites that were launched using a launch vehicle from Russia or "other covered foreign country."[9] Any company that uses "covered" foreign launch vehicles after 2022 will not be permitted to do business with DoD.

The LEO Value Chain and Examples of Gray Zone Competition

Space architectures (or the space value chain) are typically broken into three segments: space (i.e., satellite), ground (i.e., ground station, launch facility), and user (i.e., customer terminals). In 2019, DoD, acknowledging the shifting market forces surrounding space and the need for a more robust architecture, developed the National Defense Space Architecture (NDSA). The NDSA identifies seven layers:

- Transport Layer, to provide assured, resilient, low-latency military data and communications connectivity worldwide to the full range of warfighter platforms;
- Battle Management Layer, to provide architecture tasking, mission command and control, and data dissemination for time-sensitive kill chain closure at campaign scales;
- Tracking Layer, to provide global indications, warning, tracking, and targeting of advanced missile threats, including hypersonic missile systems;
- Custody Layer, to provide 24-7, all-weather custody of time-sensitive, left-of-launch surface mobile targets (e.g., for targeting advanced missiles);
- Navigation Layer, to provide alternate positioning, navigation, and timing (PNT) for Global Positioning System (GPS)-denied environments;

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[7] 2020 Defense Space Strategy.
[8] State of the Space Industrial Base 2020.
[9] https://www.law.cornell.edu/uscode/text/10/2279.

- Deterrence Layer, to deter hostile action in deep space (beyond GEO up to lunar distances); and
- Support Layer, to enable ground and launch segments to support a responsive space architecture.

Many technologies support these seven layers and expand beyond the traditional architecture of space, ground, and user. By integrating traditional views and the NDSA components, the LEO value chain can be viewed not just in terms of its existing components, but broadened to include the items that are expected to have an outsized role in the future of LEO deployments. This report provides details on each segment, including technology advancements, major players, and indications of gray zone activity.

DoD and Army LEO Initiatives

The Army is one of the largest consumers of satellite-based resources in DoD[10] and will be one of the biggest users of the Space Development Agency's (SDA's) LEO efforts. For example, the Tactical Intelligence Targeting Access Node (TITAN) system already has several contracts connected to its development with LEO connectivity in mind.[11] The TITAN system is being developed to take in data from multiple domains and to be a "key piece in the sensor-to-shooter chain."[12] The Army's budget books for Tactical Electronic Surveillance System through 2025 identify the LEO Tactical Space Layer as one of the key components that the TITAN system will use. Demonstrations and prototypes for the TITAN system connecting to a LEO network are underway.

The next generation of Blue Force Tracker, the Mounted Mission Command-Transport (MMC-T), is also being designed with LEO in mind. Although the next generation is still in early development after being announced in 2019,[13] it will likely be able to connect with the Battle Management Layer of SDA's new LEO network to handle mission command and control. Future command and control will likely feed through SDA's LEO constellation, indicating the important role LEO will play for the Army.

One of the Army's key missions is missile defense, which is primarily accomplished with the Terminal High Altitude Area Defense (THAAD) and Patriot missile defense systems. Hypersonic glide vehicles (HGV) pose a new threat due to their ability to maneuver and change direction after release.[14] The low altitude and lack of ballistic trajectory could pose challenges to existing

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[10] https://www.defensenews.com/digital-show-dailies/smd/2020/08/21/army-space-and-missile-defense-command-firms-up-role-with-new-space-command/#:~:text=The%20Army%20has%20had%20a,domain%20for%20communications%20and%20surveillance.&text=The%20ASMDC%20now%20serves%20as,service's%20expanding%20role%20in%20space.

[11] https://insidedefense.com/insider/army-awards-otas-support-tactical-intelligence-targeting-access-node.

[12] https://www.c4isrnet.com/battlefield-tech/space/2021/01/13/army-issues-17-million-in-contracts-for-titan-development/.

[13] https://www.army.mil/article/231121/army_program_to_modernize_bft.

[14] https://fas.org/sgp/crs/natsec/IF11459.pdf.

detection systems.[15] Defense officials have stated that "existing terrestrial- and space-based sensor architectures are insufficient to detect and track hypersonic weapons," and the SDA's Tracking Layer is being developed to track hypersonic weapons in conjunction with the Hypersonic and Ballistic Tracking Space Sensor (HBTSS).[16] It is likely the Army will be called on contribute to the new defense mission regarding hypersonic weapons.

Space has played a critical role in enabling DoD communications and operations for decades. The U.S. Army's public statements have indicated that it is interested in how LEO can be used to the advantage of the warfighter but that it is not necessarily looking to invest in its own constellation.[17] Commercial providers can provide an opportunity for DoD to leverage their services to provide high-speed connections to units all over the globe. DoD understands the advantages of partnering with commercial providers to provide enhanced connectivity to the battlefield without having to pay the high capital cost of setting up a large LEO constellation on their own.

The gateway to space and the industry sectors that enable it are at an inflection point. Although the U.S. is the clear leader in space technology, the lowering of barriers to entry has created an opportunity for peer and near-peer nations to exploit commercial elements to gain a competitive advantages. Other nations are heavily investing in LEO and working to build up their commercial sectors to compete. The U.S. has the largest share of new companies seeking a presence in LEO, but it still represents under 50% of the total,[18] with the rest distributed over a wide array of both friendly and adversary nations. The U.S. holds a competitive advantage in terms of number of satellites and the ability to launch; however, the U.S. must stay engaged in innovating new technologies and protecting intellectual property from adversaries.

To bolster competition and innovation in the space industry, government agencies and departments can build on previous experience to create strategies that support their strategic interests. Key focal points include prioritizing spectrum availability for space users, working to fund research into next-generation technologies, and providing clear signals about expected future demand. Through this, the United States can balance maintaining and enabling the competitive advantage it holds in many segments of the space sector while monitoring and protecting critical technology from gray zone competition. The U.S. Government needs to foster the long-term stability of this industry in coordination with national goals, especially as the government adjusts its role from the primary developer to an important consumer of space products and services.

[15] https://fas.org/sgp/crs/weapons/IF11623.pdf.
[16] Ibid.
[17] https://www.army.mil/article/233587/army_looks_to_leverage_low_earth_orbit_satellites.
[18] Kulu 2021a; Union of Concerned Scientists 2020.

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Figures and Tables

1. LEO Satellites and Potential Gray Zone Competition

Low Earth orbit (LEO) satellites are enabling access beyond the terrestrial confines of the Earth to a broader range of consumers of space and space services. This commercialization of a previously government- and military-dominated sector presents opportunities and risks for the U.S. Government and the Department of Defense (DoD). As access to space has grown dramatically in recent years, so too has the number of companies and organizations launching satellites into orbit each year. Although the inherently high costs and risks of the space economy mean that many of these companies could fail (as has occurred in previous rushes to space),[19] the sheer number of entrants implies a much more accessible and competitive space ecosystem than ever before. Space watchers have projected that LEO will see dozens of new competitors in the next few years, some of which have significant financial backing and state sponsorship.[20] This dynamic will require DoD to work harder to maintain and secure national assets targeted by peer competitors engaged in gray zone[21] competition.

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The U.S. Air Force has already partnered with SpaceX to test connecting their aircraft to Starlink, with initial tests on a C-12 demonstrating data throughput of 610 megabits per second (Mbps) in flight.[24] The U.S. Air Force also successfully tested Starlink on an AC-130 through an exercise to test the Air Force's battle management system, and it plans to connect the platform

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[19] Daehnick et al. 2020.

[20] Kulu 2021b; Daehnick et al. 2020; Lal et al. 2017.

[21] Gray zone activities are non-kinetic actions, typically economic in nature, used to challenge or disrupt the competitiveness of the United States or other nation state entities.

[22] https://www.defensenews.com/digital-show-dailies/smd/2020/08/21/army-space-and-missile-defense-command-firms-up-role-with-new-space-command/#:~:text=The%20Army%20has%20had%20a,domain%20for%20communications%20and%20surveillance.&text=The%20ASMDC%20now%20serves%20as,service's%20expanding%20role%20in%20space.

[23] https://www.army.mil/article/233587/army_looks_to_leverage_low_earth_orbit_satellites.

[24] https://spacenews.com/spacex-plans-to-start-offering-starlink-broadband-services-in-2020/.

during its Global Lightning exercise, along with plans to evaluate other providers like Iridium, OneWeb, and L3Harris.[25] As the constellations come online and mature, there will be a strong economic incentive to use their service to provide cost-effective solutions to the DoD's satellite communication needs. However, it will be important to understand that relying on commercial providers may also mean accepting their security practices for DoD communications traffic and positioning data. Traditional risks, such as naturally occurring solar flares, collisions with other spacecraft or space debris, and adversarial cyber targeting, remain. These risks must also be weighed against rapid commercialization, shifting global regulatory dynamics, reduced cost of entry, and continuous mergers, acquisitions, investments, and leadership changes that can all present opportunities for adversaries to undermine U.S. dominance.

A. The Emerging LEO Market[26]

Previously, there were two main limitations of LEO use: (1) antennas and supporting technologies could not efficiently track and process data, and (2) the large number of satellites that would need to be developed and launched to make a useful constellation was not viewed as a profitable venture for corporations. Because of this, geosynchronous orbits (GEO), which are further away and easier to track, dominated satellite communications for decades, with nation-state militaries primarily bearing the expense and risk of launching satellite platforms. Today, technological advancements and governmental decisions to open the market and support commercial enterprises put LEO increasingly within the purview of both startups and established commercial ventures. Improvements in performance specifications also are indicative of why LEO investments are now being seen as a worthy business venture and strategic asset for many nation states. When comparing the different platforms, LEO specifications outperform GEO and Medium Earth Orbit (MEO), especially with regard to latency, a critical indicator for user adoption as seen in Table 1-1. Given that most modern applications require numerous exchanges between users and remote servers, low latency is critical for responsive connections and especially for encrypted traffic.[27]

Table 1-1. Specifications across Satellite Platforms[28]

Platform	Latency (Typical)	Orbital Period	Size (Mean Launch Mass)
GEO	600–800 ms	24 hr	4,100 kg
MEO	125–250 ms	2–24 hr	1,230 kg
LEO	30–50 ms	1.5–2 hr	390 kg

[25] https://www.defensenews.com/air/2020/01/22/the-us-air-force-tested-its-advanced-battle-management-system-heres-what-worked-and-what-didnt/.
[26] Appendix A provides a summary of the history of LEO and additional market indicators.
[27] Telesat 2020.
[28] Union of Concerned Scientists 2021; Telesat 2020.

Whereas satellite communication was previously a niche product marketed largely toward government, rural, and maritime customers, new LEO constellations are expected to challenge the dominance of not only other satellite platforms, but also terrestrial fiber. Increased bandwidth and further improvements of latencies could rival (or even beat) fiber.[29] According to pilot users, SpaceX's Starlink constellation is currently delivering 80 Mbps to 150 Mbps download speeds, about 30 Mbps upload speeds, and the latency comes in at around 30 ms. Both the bandwidth and latency specifications are on par with ground-based Internet.[30]

With governmental support and updates to regulations, commercial ventures could more easily pursue LEO ventures. Figure 1-1 shows a clear increase in LEO launches after 2016, aligning with the opening up of the market. The other space platforms remain near static or even observe a decrease (i.e., GEO and MEO).

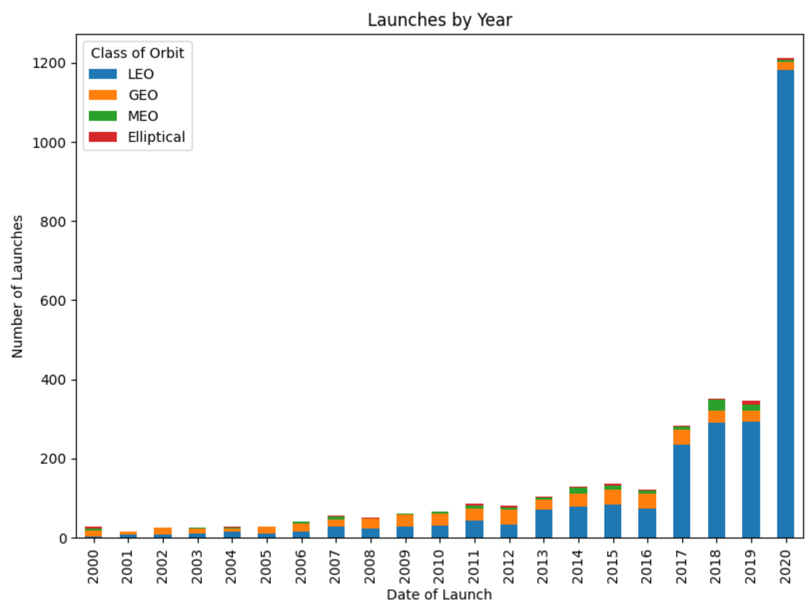

Figure 1-1. Launches by Space Platform

Data on equity investments for LEO-aligned companies also supports the idea that LEO is now seen as a profitable venture for commercial entities. Figure 1-2 depicts a significant uptick in capital expenditure and investment since 2013.

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[29] Placido 2020.

[30] https://www.pcmag.com/how-to/what-is-starlink-spacex-satellite-internet-service-explained#:~:text=Starlink%20is%20currently%20delivering%2080Mbps,par%20with%20ground%2Dbased%20internet.

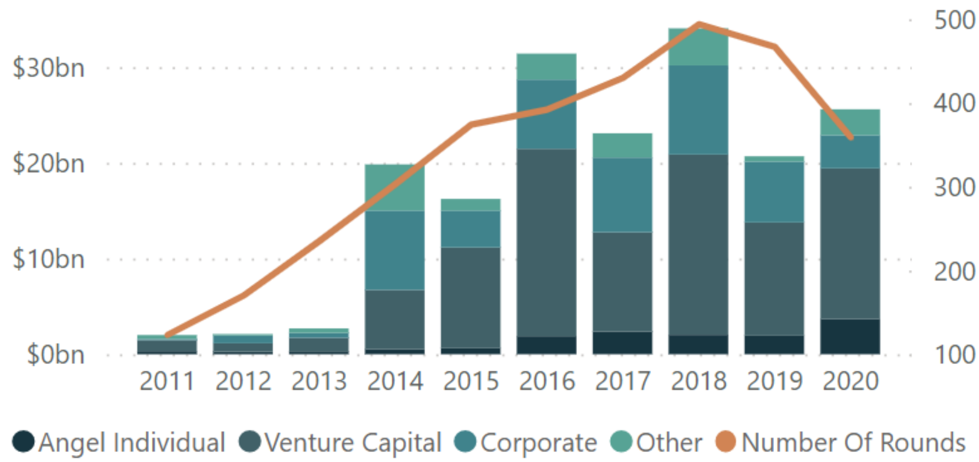

Figure 1-2. Equity Investments in LEO-Aligned Technology by Investor Type[31]

This pattern is similar to those seen in other high-tech sectors like biotechnology, artificial intelligence (AI), and additive manufacturing. Established companies in the satellite market have traditionally been sustained by government contracts. It can be difficult for smaller firms to enter the market without that same access to capital. However, these established businesses are at risk if government spending decreases. With the technological disruption from LEO and the emergence of new competitive entities, many companies understand the value of broadening their user base between both the public and private sectors.

The LEO market includes smaller businesses—sometimes offshoots from universities or incubators—who are developing new technology across the LEO value chain and attempting to draw financing to their projects from a variety of sources. Successful projects can lead to partnerships and joint ventures as an increase in mergers and acquisitions (M&A) occurs across the market. These areas can attract gray zone activity from adversarial nations that leverage economic means to extract valuable technology from U.S.-based companies before they are in even in production. The gateway to space and the industry sectors that enable it are at an inflection point. The lowering of barriers to entry has created an opportunity for peer and near-peer competitors to exploit commercial elements to gain an advantage in the space race for dominance.

B. U.S. Competitive Advantage

Although the United States is a leader in space technology and in many of the LEO value-chain components, the market is a global one. Other nations are heavily investing in LEO and working to build up their commercial sectors to compete. The U.S. has the largest share of new companies seeking a presence in LEO, but it still represents under 50% of the total,[32] with the rest distributed over a wide array of both friendly and adversary nations. Table 1-2 represents the

[31] Space Investment Quarterly, *Space Capital*. https://www.spacecapital.com/quarterly. Number of Rounds signifies the number of times that a space commercial entity has organized an event to seek funding from outside investors in exchange for equity in the company.

[32] Kulu 2021a; Union of Concerned Scientists 2020.

number of satellites and launches per country. The U.S. holds a competitive advantage in terms of number of satellites and the ability to launch; however, the U.S. must stay engaged on innovating new technologies and tracking when other nations use gray zone activity to hinder U.S. competitiveness.

Table 1-2. Total LEO Footprint by Country (2020)[33]

	Total satellites	LEO satellites	Organizations with 2+ launches	Organizations with 2+ LEO launches
USA	1878	1633	80	46
China	405	307	43	30
Russia	174	102	19	11
United Kingdom	166	127	9	4
Japan	82	53	15	9
India	60	30	3	2
ESA	59	27	6	3
Canada	43	28	8	7

A key part of the U.S. advantage in LEO is its ability to launch satellites with reusable U.S. rockets from within its own borders. Improvements to launch capabilities in terms of reusability (and therefore cost) is perhaps the most disruptive technological change that affects LEO due to the innovation of U.S.-based commercial providers. Per a 2018 NASA study, the cost for the launch of the space shuttle was approximately $54,500 per kilogram, while SpaceX's Falcon 9 costs only $2,720 per kilogram, a cost reduction factor of over 20.[34] According to the Government Accountability Office (GAO), the LEO launch cost for the majority of other nations severely lags behind the United States, as shown in Table 1-3.

Table 1-3. GAO LEO Launch Cost Comparison (2017)[35]

Country	Rocket	Cost per Kilogram ($)
USA	Falcon Heavy*	1,400
USA	Falcon 9	2,864
Russia	Proton M	2,826
India	Polar Satellite Launch Vehicle	6,642 – 9,538
China	Long March 3A	8,235
ESA	Ariane 5	8,476
China	Long March 2D	8,571
India	Geosynchronous Satellite Launch Vehicle	9,400

[33] Kulu 2021a; Union of Concerned Scientists 2020. ESA = European Space Agency.
[34] https://ntrs.nasa.gov/api/citations/20200001093/downloads/20200001093.pdf.
[35] https://www.gao.gov/assets/gao-17-609.pdf.

USA	Delta IV Medium/Heavy	13,894–17,410
Russia/ESA	Soyuz 2	16,495

*Source: NASA

Reducing launch costs means a constellation can be operational, globally competitive, and profitable sooner. Russia has a mature space program and is the nearest peer to the U.S. in achieving launch cost minimization. Although Russia has had success in providing commercial launches and ridesharing, some experts suggest that the country's efforts in space are stagnating due to funding limitations, brain drain, or other organizational issues.[36] There have been some efforts made to spur private innovation, in particular through the Skolkovo Innovation Center's dedicated space cluster.[37] The Skolkovo Foundation, which includes the innovation center, is ultimately financed by the Russian Government and has drawn criticism for being a means in which the Russian government gains access to the U.S. classified research. In 2014, the FBI issued a warning that the foundation was acting as "means for the Russian government to access our nation's sensitive or classified research, development facilities and dual-use technologies with military and commercial applications."[38] Activity of the foundation as it relates to space and LEO should continue to be monitored.

Chinese spacecraft and launches are largely procured through state-owned enterprises and their subsidiaries, such as the China Aerospace and Industry Corporation (CASIC) and the China Aerospace Science and Technology Corporation (CASC). In addition to these state-owned enterprises, a number of private ventures have emerged in recent years. Some have attributed this rise to a 2014 policy shift that encouraged private investment and competition in the space sector in China.[39] Working to merge space-based offerings into its belt and road initiatives, China is actively working to build up its capabilities to share with the world: "Most countries will be unable to support a full suite of space activities, and likely China will open its space infrastructure to other countries in what could be considered an act of goodwill, an attempt to win market share, or both."[40] However, China's efforts to gain market share involve gray zone competition and tactics targeting U.S. companies with technology that would benefit to China. U.S. Congressman Jim Banks recently introduced legislation to mitigate the predatory acquisition of U.S.-based companies by the Chinese, "Often those acquisitions will occur—or get some ways down the process of the acquisition [before] becoming final—and then they rip off the IP, take it back to China and let those companies sort of dry up on the vine…We fully anticipate that their tactics will continue."[41] Continuous monitoring of investments, M&A, leadership changes, and partnerships is needed around key LEO entities and Chinese-affiliated organizations. Additional

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36 McClintock 2017; Graham 2021.
37 McClintock 2017.
38 https://www.politico.com/magazine/story/2018/07/27/silicon-valley-spies-china-russia-219071/
39 The policy document is Document 60 (Guiding Opinions of the State Council on Innovating the Investment and Financing Mechanisms in Key Areas and Encouraging Social Investment).
40 http://interactive.satellitetoday.com/via/september-2020/2020-a-turning-point-for-chinese-commercial-space/.
41 https://www.nationaldefensemagazine.org/articles/2020/7/2/officials-fear-chinese-predatory-acquisitions-during-pandemic.

details on key nation-state LEO efforts, including those from India and Japan, are included in Appendix B.

C. What Can the U.S. Government Do to Mitigate Gray Zone Risks and Remain Competitive?

The U.S. as a whole has been shifting its space policy toward commercialization, especially at the LEO level. According to the National Space Council in the White House, LEO commercialization is a critical component of the U.S.'s space strategy going forward.[42] The DoD's Defense Space Strategy (DSS) acknowledges this shift, citing the need to "maintain space superiority" and to take advantage of the commercialization in space, as well as protect commercial space capabilities against adversaries.[43] DoD is actively moving in this field, communicating to the new commercial space industrial base that DoD is creating "plans to protect, support, and leverage commerce in space" while also establishing new partnerships.[44] These policy decisions have resulted in significant changes to the DoD space construct, creating new organizations and oversight groups to help accomplish this goal.

DoD is currently pivoting toward the use of LEO satellites as a major technology asset through the use of several programs, summarized in Table 1-4. The major driver in this push has been the Space Development Agency's (SDA) National Defense Space Architecture (NDSA). This architecture describes the SDA's phased approach, starting with initial tests of systems in its Tranche 0 program. In parallel, DARPA is supporting this effort by field testing several key technologies needed for commercial LEO constellations through its Blackjack program. The Missile Defense Agency (MDA) is using LEO to develop a new Hypersonic and Ballistic Tracking Space Sensor that will be integrated into the new NDSA. The pivot to the NDSA, the programs, and the technology are still in early development. Several commercial partners are vying for selection by DoD while also growing their businesses and expanding their market reach globally. This presents opportunities for gray zone hazards by competitors, making it critical to monitor suppliers across the key programs and across the value chain to protect DoD interests.

Table 1-4. Key DoD U.S. LEO Programs

DoD Agency	LEO Program
DARPA	Blackjack
Missile Defense Agency (MDA)	Hypersonic and Ballistic Tracking Space Sensor
Space Development Agency (SDA)	Tranche 0

To bolster competition and innovation in the space industry, government agencies and departments can build on previous experience to create concrete strategies that support their strategic interests. Key focal points include prioritizing spectrum availability for space users, working to fund research into next-generation technologies, and providing clear signals about

[42] *A New Era for Deep Space Exploration and Development.*
[43] 2020 Defense Space Strategy.
[44] State of the Space Industrial Base 2020.

expected future demand. Through this, the United States can balance maintaining and enabling the competitive advantage it holds in many segments of the space sector while monitoring and protecting critical technology from gray zone competition.

The U.S. military and government have been focused on putting policy guardrails in place to protect critical segments of space. For example, in December 2017, the U.S. Government adopted legislation that prohibits the U.S. Secretary of Defense from procuring satellite services provided by satellites that were launched using a launch vehicle from Russia or "other covered foreign country."[45] Any company that uses "covered" foreign launch vehicles after 2022 will not be permitted to do business with DoD. Telesat, a Canadian-based constellation company partnering with DARPA for its Blackjack program, acknowledges this as a risk, as it has used Russian rockets for past launches, and is adjusting its strategy, likely with an impact to the competitiveness of their offerings.[46] The United States can protect its leading commercial constellations through access to U.S. launch facilities and commercially competitive U.S.-made rockets.

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[45] https://www.law.cornell.edu/uscode/text/10/2279.

[46] https://www.sec.gov/Archives/edgar/data/1465191/000121390020004875/f20f2019_telesatcanada.htm.

2. The LEO Value Chain and Examples of Gray Zone Competition

LEO has benefitted from several technological advances over recent years. Cheaper launch costs, improvements in digital signal processing, and manufacturing efficiencies all play an important role, especially in enabling the large constellations that LEO deployments often require. The needs of a pervasive network can now be served by a large number of much smaller (and therefore less costly) satellites. Furthermore, advances in computation, the use of cloud resources, and AI have greatly reduced the overhead required in controlling and managing such a constellation.[47] The largest industry segment to benefit from LEO services are communications (including Internet and Internet-of-Things (IoT) providers) and earth observation (including optical and synthetic-aperture radar (SAR) imaging), with a smaller number of companies providing various on-orbit services like space situational awareness.[48] There are also an array of terrestrial service providers for LEO ventures, including manufacturing, parts suppliers, launch, ground station access, tracking and collision avoidance, and data processing and analysis, all of which have a wide global spread. Figure 2-1 provides an encompassing view of the primary LEO value chain segments.

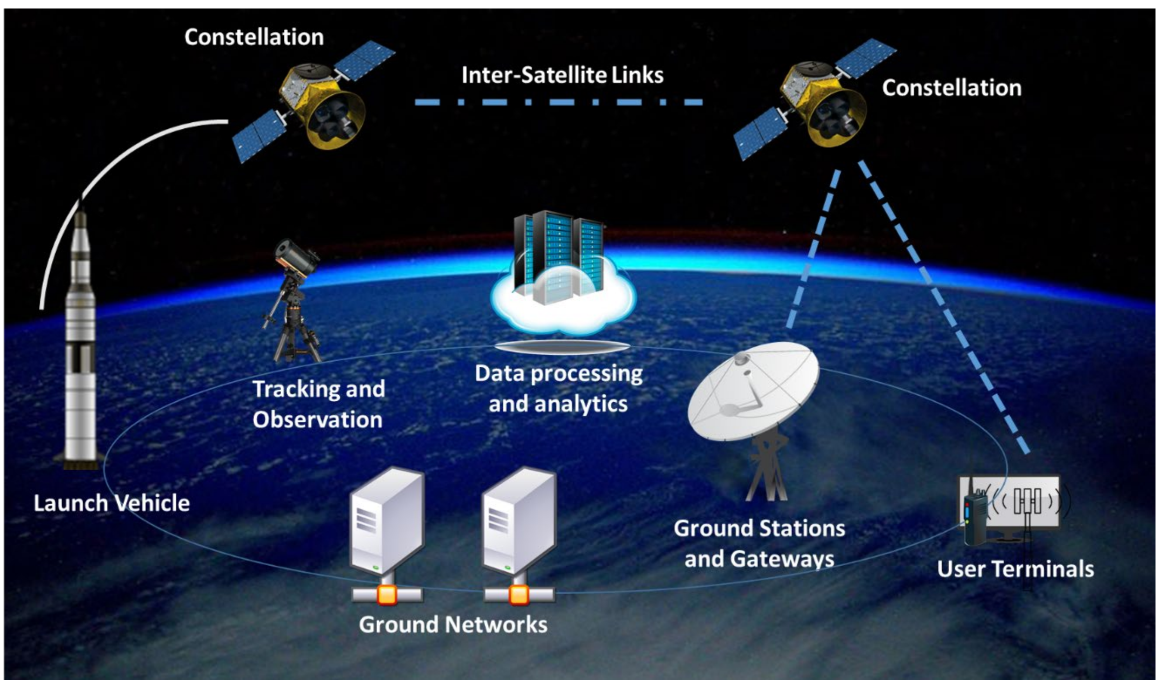

Figure 2-1. LEO Value-Chain Segments

[47] Seals 2018.

[48] Curzi et al. 2020; Kulu 2021a; Lal et al. 2017.

Space architectures are typically broken into three segments: space (i.e., satellite), ground (i.e., ground station, launch facility), and user (i.e., customer terminals). In 2019, DoD, acknowledging the shifting market forces surrounding space and the need for a more robust architecture, developed the NDSA. The NDSA identifies seven layers:

- Transport Layer, to provide assured, resilient, low-latency military data and communications connectivity worldwide to the full range of warfighter platforms;
- Battle Management Layer, to provide architecture tasking, mission command and control, and data dissemination for time-sensitive kill chain closure at campaign scales;
- Tracking Layer, to provide global indications, warning, tracking, and targeting of advanced missile threats, including hypersonic missile systems;
- Custody Layer, to provide 24-7, all-weather custody of time-sensitive, left-of-launch surface mobile targets (e.g., for targeting advanced missiles);
- Navigation Layer, to provide alternate positioning, navigation, and timing (PNT) for Global Positioning System (GPS)-denied environments;
- Deterrence Layer, to deter hostile action in deep space (beyond GEO up to lunar distances); and
- Support Layer, to enable ground and launch segments to support a responsive space architecture.

Many technologies support these seven layers and expand beyond the traditional architecture of space, ground, and user. By integrating traditional views and the NDSA components, the LEO value chain can be viewed not just in terms of its existing components, but broadened to include the items that are expected to have an outsized role in the future of LEO deployments.

Details on each segment, including technology advancement, major players, and indications of gray zone activity, are provided in the next section.

A. Constellations[49]

Several aspects of LEO make it particularly attractive for certain applications, especially in light of new technological developments. LEO has largely been the domain of earth observation satellites, which transverse the planet's entire surface over time at a relatively low altitude in a polar orbit. For most communication satellites, however, LEOs present ground users with fast-moving targets and frequent satellite changeovers that necessitate a large constellation and sophisticated tracking antennas (or a severe sacrifice in bandwidth). Furthermore, atmospheric drag greatly limits LEO satellite lifetimes. Given the limits of satellite costs and antenna technologies, geostationary orbits have dominated satellite communications for decades.

[49] The primary focus of this research is on commercial mega-constellations, but it should be noted that there are additional innovative LEO satellite companies focused on earth observation, IoT, 5G, and others.

In the U.S., SpaceX and Amazon are the two highest-profile companies working on "megaconstellations" of hundreds to thousands of satellites to provide global Internet connectivity. Unlike previous global satellite communication networks, these firms aim to provide low-latency broadband directly to consumers, starting in under-connected rural areas (though governments, airlines, network backhaul, and maritime users will remain important markets). Although these networks have yet to be fully implemented, the initial operating capabilities have shown promising performance metrics, leading to significant interest and funding from both the private and public sectors.[50] The importance of this momentum-building process is hard to understate. Both companies have estimated that a full constellation will take approximately $10 billion to build out, not to mention the frequent replenishment missions required for these especially low-altitude constellations.[51] However, large potential revenues await companies able to bridge the immense developmental costs and provide a robust network to consumers.[52]

SpaceX's Starlink, a planned 12,000-satellite constellation with a potential for expansion to 42,000, is close to crossing what their CEO has called the "deep chasm of negative cash flow" required to develop a functional system.[53] With roughly 1,000 Ku/Ka-band satellites already launched, the constellation has already seen successful testing by first responders[54] and is currently rolling out a public beta program.[55] The Army has also signed a Cooperative Research and Development Agreement (CRADA) with SpaceX to begin testing the company's network.[56] Much work remains, especially with regard to launching satellites with optical intersatellite links (OISLs) that would reduce the need for large numbers of ground stations (as well as decrease the potential for interference).[57] However, Starlink is well on its way to providing a LEO-based broadband network in North America, with a few early testers reporting speeds up to 200 Mbps and latencies as low as 30 ms.[58] If the constellation can continue to achieve these results as the number of users grows, its goals of tens of thousands of satellites and a fully global network could soon be realized.

Like SpaceX, Amazon is pursuing a large consumer-focused broadband constellation in LEO, but it has been much quieter about its plans and progress. In July 2020, the company received FCC approval for 3,236 Project Kuiper satellites.[59] Amazon has also released high-level plans for a low-cost Ka-band antenna.[60] However, the company has not yet launched any satellites, despite their FCC filing requiring the deployment of half of the constellation by 2026.[61] Though lagging behind SpaceX on launches and testing, Amazon has some notable advantages. Most significantly, the company stands ready to integrate a satellite constellation with its existing network infrastructure,

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[50] Hardy and Dougherty 2015.
[51] Lal et al. 2017; Curzi et al. 2020; Sheetz 2021a.
[52] Daehnick et al. 2020; Sheetz 2021b.
[53] Sheetz 2021b.
[54] Sheetz 2020.
[55] Sheetz 2021b; Koziol 2019.
[56] Erwin 2020b.
[57] Brodkin 2021.
[58] Brodkin 2020; Duffy 2020; Wood 2020.
[59] Amazon 2020a.
[60] Amazon 2020b.
[61] Sheetz 2021a.

including Amazon Web Services (AWS). Amazon has already been building satellite ground stations with direct tie-ins to the larger AWS network.[62] Similarly, Amazon has the unique opportunity of leveraging its existing customer base via bundled services or other mechanisms.

Historically part of a global industry, satellite operators, manufacturers, and suppliers abroad are also looking to expand their presence in LEO, with Canada's Telesat and the UK's OneWeb being key constellation competitors.

[62] Amazon Web Services, Inc. 2021; Henry 2020.

Gray Zone Competition – Telesat and OneWeb Constellations

Telesat is on contract to provide LEO communications capacity to the DARPA Blackjack program, which aims to test the ability of the military to use commercial satellite networks in a hybrid fashion for lower costs and more frequent technology refreshes. Telesat is procuring two new satellites based on an Airbus design for that effort. Telesat is also looking to deploy its own LEO constellation starting in 2023. Called Lightspeed, it will be comprised of nearly 300 satellites (built by Thales Alenia Space) and be largely focused on the enterprise customers who are already familiar with Telesat. In 2015, Telesat partnered with APT, a company majority-owned by the Chinese Aerospace Science and Technology Corp (CASC), an entity subject to U.S. sanctions due to its connections to the Chinese military. The partnership was to replace a jointly owned satellite that provides coverage to the majority of mainland China. Telesat and APT had originally planned to launch the satellite on China's Long March Rockets, but they were restricted by U.S. laws regarding technology transfer to China. For its LEO constellation, Telesat has used a Russian launch service and Russian rockets to launch its initial satellites. Russian-based services are not yet subject to the same U.S. restrictions, though updated provisions that include Russia go into effect in 2022. Telesat has documented that its lack of a launch provider puts the business at risk. (Telesat 10/14/2020, Sheetz 2021c, Telesat APT.)

OneWeb was one of the earliest entrants into the race for LEO broadband. Softbank was the primary financer of OneWeb before it went into bankruptcy in 2019. After emerging from bankruptcy in 2020 with new ownership including the UK government and Bharti Global (an Indian conglomerate), the company has now amassed over $1.4 billion in its current funding round to continue building out its Phase 1 constellation (though with a reduced number of satellites). Since 2020, Softbank has reinvested for ownership share. Of note, the Bharti CEO is also on the board of Softbank. Hughes, a U.S.-based space company also invested in OneWeb post-bankruptcy and has been contracted to provide much of the ground segment for the OneWeb constellation. OneWeb has FCC approval to provide service within the United States, but it is also aiming to provide global service. Interestingly, although Chinese law prevents its companies and citizens from using foreign satellites providers, China is working with OneWeb to put three of its ground stations in country. Without its own launch capability, OneWeb also relies on Russian rockets and launch locations. The most recent launch of satellites was done on a Russian-developed rocket out of a Russian spaceport (the Vostochny Cosmodrome). Both the use of Russian rockets and portions of the ground segments located in China could present risks for the OneWeb constellation and its users' data to be exploited. (Lunden 2021; Foust 2020b.)

There is also growing concern that the constellation market could be limited by current spectrum licensing and availability. Globally, satellite communication frequencies are regulated along with satellite orbits by the International Telecommunication Union (ITU), a specialized agency of the United Nations.[63] The ITU has adopted a "first-come, first-served" model of allocating frequencies. After filing plans for spectrum usage, satellite operators must also bring

[63] International Telecommunication Union 2021.

10% of their constellations into use within nine years (while meeting additional milestones) for the ITU to continue reserving their section of spectrum.[64] Such a regulatory structure rewards early movers with valuable spectrum allocations, a scarce resource that has already seen significant controversy.[65] From 2017 to 2019, four major constellation suppliers pushed hard to claim the spectrum by quickly building and launching satellites. Those that are already in orbit must navigate an increasingly crowded electromagnetic spectrum to communicate with the ground or with other satellites, and those satellites that have yet to launch may already be too late to market.

B. Ground Stations, Antennas, and User Terminals

Ground stations are the means by which satellite operators monitor status of a satellite and transfer, store, or access data for analysis across the terrestrial infrastructure. User terminals are the devices used by customers on the ground to receive and process satellite services. While similar basic technology is found in ground stations and user terminals, the size, cost, and complexity of ground stations is substantial. Current GEO-based ground antennas can range from $1 million to $2 million each.[66] Current estimates from SpaceX indicate the full deployment of the 4,400 satellites in the Starlink constellation could require 3,500 antennas to achieve maximum throughput.[67] Ground is one of the most expensive segments of the LEO value chain and it is pushing industry to find efficiencies in design, engineering, and business relationships.

LEO satellite constellations also pose a unique problem for the traditional GEO parabolic-dish ground stations. LEO mega-constellations are made up of hundreds, if not thousands, of satellites, and the satellites themselves move at extremely high speeds, making any connection to the ground brief.[68] The ground station must also be capable of distinguishing between satellites and communication bands, as they are operating in a crowded spectrum environment. These unique requirements have led to technological advancements that are beginning to emerge as cost-effective solutions. For example, developments in phased-array or electronically steerable antennas (sometimes "electronically scanned array") allow terrestrial users to track non-geostationary satellites at a greatly reduced cost and difficulty and to communicate with multiple satellites simultaneously, easing handoff problems.[69]

Michigan-based Atlas Space Operations has successfully tested a new phased array system in partnership with the U.S. Air Force and Defense Innovation Unit.[70] Their coherent beam forming allows the antennas to scale through both LEO and GEO with multiple simultaneous

[64] International Telecommunication Union 11/20/2019. Previously, satellite owners only had to bring one satellite into use within seven years to continue reserving their spectrum.
[65] Reklaitis 2019.
[66] https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/large-leo-satellite-constellations-will-it-be-different-this-time
[67] Ibid.
[68] https://www.satelliteevolutiongroup.com/articles/LEO-Constellations&Tracking.pdf.
[69] Intelligent Aerospace 2019.
[70] https://www.satellitetoday.com/ground-systems/2020/12/22/atlas-space-operations-completes-testing-on-phased-array-antenna-system/

contacts, an industry first.[71] Atlas is planning a global ground antenna network with 30 of these ground stations dispersed across the world to be used by commercial and government satellite operators.[72] Commercial antenna suppliers, like Atlas, will look to take advantage of the global market and distribute ground stations across many nations. DoD's use of commercial constellations must take this into consideration and evaluate the risk and technical parameters of data protection and countermeasures offered by commercial providers. Some constellation providers are looking to develop their own ground stations instead of depending on a commercial partner. According to FCC filings, SpaceX currently operates over 50 active ground stations using the Ka and Ku frequency band throughout the United States.[73] Each ground station is authorized to have eight antennas. SpaceX has not reported what specific technology is being used in their ground stations. OneWeb plans to build 45 ground stations, three of which are being planned in mainland China, as noted in the Gray Zone Competition call-out box for Telesat and OneWeb Constellations. This choice exemplifies the risk associated with ground stations: The economic incentives and the geographic significance of China could entice companies to build connections there. Ground station providers who are building in or expanding into China risk potential exploitation of their own systems as well as their customers.

Intersatellite links (ISLs) can mitigate the concern of foreign-located ground stations. This would allow for fewer ground stations, as individual satellites would no longer need to ensure ground station connectivity and would instead rely on the other satellites in the constellations to provide connection to the ground.[74] The technology for ISLs is still in the demonstration phase, with multiple companies (e.g., Telesat and SpaceX) testing their feasibility, but currently there are no full-scale implementations of the technology.

Another key area of commercialization within the LEO market sector has been the race to decrease the cost of user terminals. Due to the nature of LEO, most providers have looked to providing phased-array antenna terminals for their users, but phased-array devices have traditionally been too expensive for commercial use, thus limiting them to military use. SpaceX, for example has managed to reduce the production cost of their Starlink terminals from $3,000 to $1,500 per unit, but it will still subsidize the cost to individual customers, only charging $499 for the equipment necessary to connect to their constellation.[75] SpaceX is trying to reduce the cost by vertically integrating their company, but other providers like Telesat have partnered with long-time phased-array provider ThinKom to develop a user terminal for their Lightspeed constellation.[76] In testing, the new terminal was capable of switching between individual satellite beams in less than 100 milliseconds and was able to hand off between satellites in less than a

[71] Ibid.
[72] https://atlasground.com/antenna-network/
[73] https://fcc.report/company/SpaceX-Services-Inc.
[74] Ibid.
[75] https://www.businessinsider.com/spacex-starlink-terminal-cost-spacex-gwynne-shotwell-president-2021-4#:~:text=SpaceX%20is%20spending%20%241%2C500%20to,charged%20%24499%2C%20its%20president%20says&text=Each%20Starlink%20terminal%20used%20to,customers%20%24499%20for%20the%20terminal.
[76] https://www.thinkom.com/thinkom-and-telesat-to-jointly-develop-an-enterprise-user-terminal-for-telesats-global-leo-satellite-constellation/.

second. Telesat demonstrated a 370 Mbps downlink using ThinKom's Ka band. OneWeb has tested ThinKom's Ku band array system and achieved a downlink of greater than 350 Mbps and return greater than 125 Mbps—latency was less than 50 ms. Both ThinKom's Ka and Ku band arrays are interoperable across LEO, MEO, and GEO. These specifications are comparable to what commercial beta testers have reported for SpaceX's Starlink services, with speeds up to 200 Mbps downlink and an average latency of 30 milliseconds.[77]

Comtech Telecommunications Corp. is a U.S.-based company with several product offerings related to ground stations and antennas. It has a multitude of contracts with the U.S. Government, including a February 2021 award with NASA for a fast-tracking ground station antenna system.[78] The IDA team identified a gray zone hazard regarding Comtech in November 2020. This is detailed in IDA's publication "Gray Zone Competition Hazard Associated with U.S. Army Blue Force Tracker and Other DoD Programs: Comtech Acquisition of UHP Networks," which is controlled unclassified information and restricted to U.S. Government agencies only (requests for the document should be referred to HQDA, ODCSA G-3/5/7).

Gray Zone Competition – ThinKom

Founded in 2000, ThinKom is based out of Hawthorne, CA. Much of its initial funding came from U.S. Government grants and an investment from In-Q-Tel, a venture capital group that supports the U.S. intelligence community. ThinKom was awarded its first U.S. government contract in 2003 and has since received approximately $26M from DoD and NASA contracts. ThinKom specializes in phased-array technology that is designed to connect space assets to ground stations, aircraft, ships, and individual user terminals. With the entire market shifting toward LEO, ThinKom has been developing products to reach that market. ThinKom already partners with many commercial airlines for antennas, but the potential size of the LEO marketplace could continue to push the technology offered by ThinKom into the global mainstream. ThinKom, which previously focused on business with DoD, is also partnering with two foreign-based constellations: Telesat in Canada and OneWeb in the UK. There is a risk that ThinKom will no longer focus on developing technology for the national security space, as the commercial market may provide a larger and more profitable market for their products. DoD must be aware of suppliers such as ThinKom and ensure the proper incentives stay in place for these companies to continue innovation of military-centric technology. LEO, in particular, touches on elements that have historically belonged only to the military, but the suppliers for that space could face major disruptions as the market receives more commercial interest. (ThinKom, ThinKom Funding.)

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[77] https://www.cnbc.com/2021/04/15/spacexs-starlink-early-users-review-service-internet-speed-price.html#:~:text=SpaceX%20told%20the%20Federal%20Communications,at%20or%20below%2031%20milliseconds.%E2%80%9D.

[78] https://www.comtechtel.com/news-releases/news-release-details/comtech-telecommunications-corp-awarded-fast-tracking-ground

C. Communication and Laser Technology

Improvements in ISLs could enable significant reach and resiliency for LEO constellations. As noted in the ground station segment, without robust ISLs, each satellite in a constellation must directly communicate user data to an in-range ground station and to be operational, constellations need hundreds to thousands of ground stations and antenna gateways. ISLs would greatly reduce the number of ground stations needed for global coverage, one of the most expensive segments of the LEO value chain. ISLs could also reduce the latency of global transmissions over ground-based routing. While less technically mature than radiofrequency ISLs, OISLs are expected to have much higher throughputs and be more resistant to interference or jamming. OISLs are still in the testing stages for a number of upcoming LEO systems, but they have garnered significant interest, especially for national security applications.[79]

Domestic efforts to develop operational laser communication equipment are proceeding quickly. Although little is known about the status of integrated proprietary efforts to develop these technologies, the U.S. has significant domestic expertise in laser technologies that can be leveraged toward enabling cost-effective OISLs. Bringing costs down is a key concern in large LEO constellations, as the number of links, especially to satellites in different orbital planes, is expected to increase costs dramatically.[80] One company hoping to supply LEO with low-cost high-performance laser terminals is Space Micro, an established partner of the U.S. government for space systems. It recently won a $3 million contract with the Space Force for its 100-Gbps optical communications terminal.[81] Although many U.S. companies have done initial tests and integrations with optical satellite links, there are also foreign providers of laser terminal equipment engaged in the market.

Gray Zone Competition – Optical Satellite Links

In a recent test, General Atomics, a U.S.-based company, demonstrated laser communications for SDA, with their optical terminal interfacing with a laser communication terminal made by German company Tesat-Spacecom. Another leader in laser terminals, Mynaric, is a 2009 spinoff from the German Aerospace Center (DLR). Mynaric is supplying Telesat with optical terminals for their DARPA Blackjack satellites. China also appears to be interested in this technology, as it attempted to form a partnership with Mynaric. In 2018, Mynaric opened an office in Shanghai to sell their technology to China's aerospace communication market. However, Mynaric closed the office in 2019 due to the German government blocking the export of laser communication products to an unnamed Chinese customer. Mynaric pivoted and opened a Washington D.C. office to be closer to U.S. Government organizations. These initial attempts to sell to China and Chinese interest in the technology indicate potential future gray zone competition for laser based-technology. (Mynaric.)

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[79] Zafar 2020; Telesat 10/14/2020.
[80] Ingersoll 2020.
[81] Werner 2020.

D. Cloud Processing and Analytics

Cloud-based technologies have emerged as a new supporting element for LEO tracking, analytics, and data processing. Amazon, which is planning to launch their own LEO constellation, is building ground-station services into their AWS platform. Amazon claims to have built a "global network of ground stations in close proximity to our global network of AWS infrastructure regions."[82] In marketing material, Amazon hopes to provide ground stations for handling command and control, digesting data, and merging data from the satellites with its AWS cloud services.[83] The business model follows Amazon's traditional pricing model for cloud services—allowing customers to pay per minute of antenna use—and claims to be able to connect to any LEO or MEO satellites that operates on the X- or S-band frequency.[84] Microsoft is also expanding into the Ground-Station-as-a-Service model with their announcement of Microsoft Azure Orbital in 2020.[85] Figure 2-2 depicts Microsoft's vision of how cloud services can support and enhance the architecture.

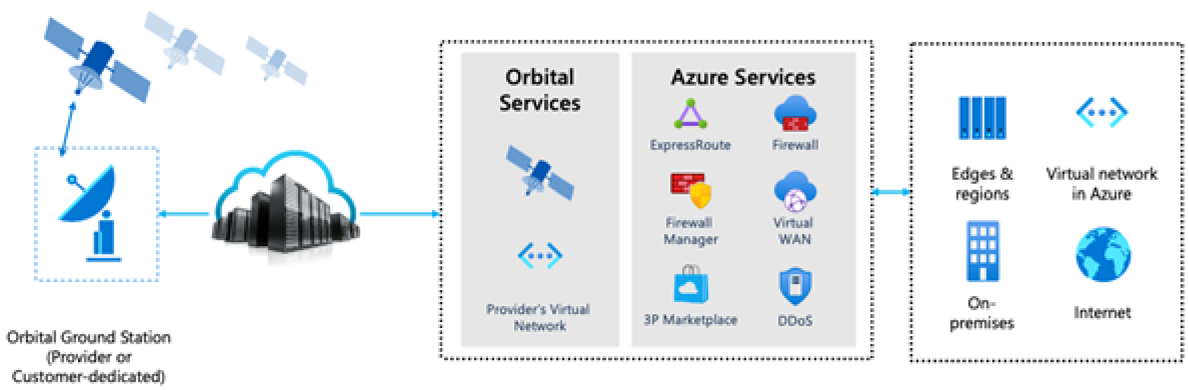

Figure 2-2. Microsoft Ground-Station-as-a-Service Offering[86]

Major cloud providers like Amazon and Microsoft building LEO-based offerings is another indicator of the projected value of the market. Cloud integration of space assets could provide enhancements to existing and future DoD programs with the underlying security risks that any cloud offering presents. Many smaller companies are also developing specialized data processing capabilities for LEO that can be used in conjunction with cloud offerings.

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[82] https://aws.amazon.com/ground-station/.
[83] Ibid.
[84] https://aws.amazon.com/ground-station/features/.
[85] https://azure.microsoft.com/en-us/blog/introducing-azure-orbital-process-satellite-data-at-cloudscale/.
[86] https://azure.microsoft.com/en-us/blog/introducing-azure-orbital-process-satellite-data-at-cloudscale/.

Gray Zone Competition – Kubos

Kubos Corporation, founded in Texas and based in Oregon, is a software company offering cloud-based satellite infrastructure and constellation flight management capabilities. Its primary software offerings are open source but can be tailored with security features and integration support. Marketing materials highlight "International Trade in Arms Regulation (ITAR) Compliance" as a major feature. In 2020, Kubos partnered with Microsoft for integration into the new Azure Orbital platform. From 2018 to 2020, the U.S. Air Force awarded three contracts to Kubos worth approximately $115,000. The R&D contracts explored integration of Kubos software into the Air Force's system for tracking orbital objects in space.

Kubos has received several investments from Chinese-connected entities. In 2017, the firm had a seed round, raising $1.7M from five investors, at least two of which have ties to China. One of the investors, GGV Capital, is "U.S.-based," but two of its four offices are in mainland China. Three of the managing partners also have significant ties to China, with one being a member of China's Thousand Talents Program. Another investor, DFJ DragonFund, is a joint venture between Draper Fisher Jurvetson (DJF) and DragonVenture. DFJ DragonFund was established in 2006 to focus on China-centric early- and middle-staged companies in the technology market. There appear to be two Chinese funds associated with the DFJ DragonFund: one located in Shanghai and one in Beijing. Research indicates the Beijing-based fund has several high-ranking Chinese Communist Party (CCP) members with ownership stakes in the firm. There also appears to be another Chinese firm with a 17% stake in the Beijing fund that operates a Military Industrial Park, described as "a military science and technology project, technology research and development center, incubation center, manufacturing center, service center, distribution center, and military science and technology investment institution gathering center." Additional research is required to understand the full extent of the relationship between the Chinese-based funds and personnel and the access the investments gave into Kubos. Any association between a Chinese military linked fund and a company providing the U.S. military services is of concern. (Kubos, Kubos Contracts)

E. Tracking and Observation

Beyond the technology enabling LEO constellations to function, the tracking of objects in space is a necessary component in making space a functional and cooperative domain. The expansion of LEO inherently implies a major increase in space objects, as mega constellations can be made up of hundreds or thousands of satellites. Physical collisions in space can have significant consequences across the entire domain, creating new, threatening space debris; destroying communication channels; and rendering billion-dollar investments unusable. Collisions and near-collisions can be natural occurrences or targeted adversarial actions. In either case, it is critical to have sensors, systems, and networks set up to track every object in space. The commercialization of LEO has complicated tracking and observation coordination. Established communication channels between governments need to be expanded to include commercial entities. The European Space Agency (ESA) documented a near collision between one of their satellites and one of Starlink's in 2019. Using tracking data made available by the U.S. Air Force, which is tasked with tracking all objects in space,[87] the ESA predicted a collision would occur unless one of the satellites repositioned itself, as seen in Figure 2-3.[88]

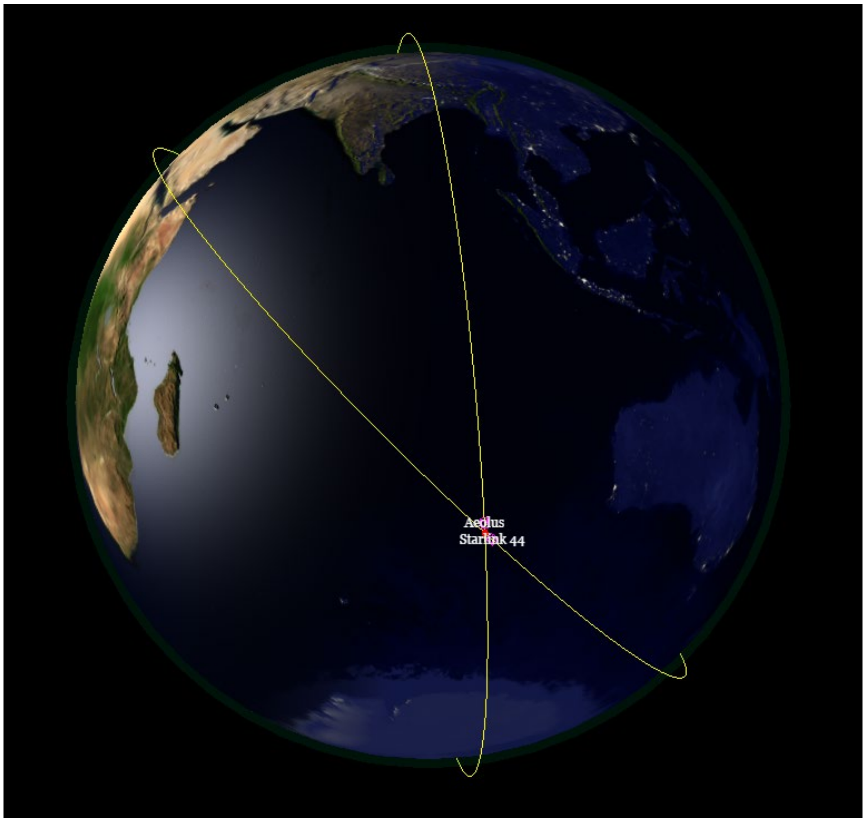

Figure 2-3. Predicted Satellite Collision

SpaceX and ESA had not established communication nor maneuver protocols. They attempted to coordinate over email and, as the threat grew beyond ESA's risk threshold, they performed maneuvers to counter any collision.[89] ESA officials noted that this is likely to be happen more often as more objects enter orbit and that it is not something that can or should be managed manually.[90] Many organizations are exploring how to incorporate AI into the modeling, notification, and maneuvering of spacecraft. The management of thousands of constellations can be supported by advanced analytics and AI while reducing response times and operating costs.[91] At least one major defense contractor is being recognized for its AI-related contributions to LEO applications: Lockheed Martin. "[Lockheed Martin's AI developments] span predictive maintenance of spacecraft, anomaly detection, human-machine augmentation assistance, adaptive cyber protection, and space modeling and simulation. The company has been increasing its

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[87] https://www.peterson.spaceforce.mil/About/Fact-Sheets/Display/Article/2356622/18th-space-control-squadron/.
[88] https://www.esa.int/Safety_Security/ESA_spacecraft_dodges_large_constellation.
[89] https://www.esa.int/Safety_Security/ESA_spacecraft_dodges_large_constellation.
[90] https://www.space.com/spacex-starlink-esa-satellite-collision-avoidance.html.
[91] https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/large-leo-satellite-constellations-will-it-be-different-this-time.

investment to continue bringing forward innovations in AI and autonomy that can be adopted and scaled to tackle complex, far-reaching and rapidly evolving challenges."[92]

Another organization, LeoLabs, is an emerging company recognized as the first commercial entity to provide situational awareness specifically for LEO.[93,94]

Gray Zone Competition – LeoLabs

LeoLabs, based in Menlo Park, CA, was founded in 2015 by a former NASA astronaut and the director of space debris tracking at the nonprofit SRI International. LeoLabs provides automated satellite and space debris tracking in real time as a tailored web service for customers, using their own radar network. LeoLabs was the first commercial entity to provide commercial radar data for satellite tracking in LEO, and they did so at a much lower cost than other commercial companies that typically used optical telescopes for tracking objects in GEO. The intent is to provide tracking-as-a-service, so emerging commercial and nation state LEO providers do not need to invest in their own costly radars or computing infrastructure. LeoLabs has four radars deployed and operational in Alaska, Texas, New Zealand, and Costa Rica. LeoLabs's major innovation is the size of the objects they are able to track. The U.S. Air Force, the main global space-tracking provider, is only able to track objects that measure greater than 10 centimeters. LeoLabs' S-band radars in New Zealand and Costa Rica can track objects or debris as small as two centimeters. Additionally, locating one of their radars in the southern hemisphere and the other on the equator remedies an existing gap in tracking coverage and allows for updates several times a day, as opposed to once every 24 hours. LeoLabs's software, AI, and analytic processing provide real-time situational awareness for subscribing organizations, and its ability to accurately track objects and debris in space is critical for mitigating the risk of collisions in the increasingly crowded segment of LEO. (LeoLabs.)

LeoLabs receives investments from at least one company with Chinese ties: Horizon Ventures, which is based in Hong Kong. Horizon Ventures provided the lead investment during the seed round and another investment during Series A funding. There is no apparent connection between Horizon Ventures and the PRC Government. On the U.S. government side, the U.S. Army awarded LeoLabs a $3.7 million dollar contract in 2019 to study use of their product for space situational awareness. In 2020, DoD designated $15 million from the Defense Production Act to LeoLabs in order to protect critical technology for national defense and ensure "resultant critical capabilities are retained within the U.S." The U.S. Government recognizes the importance of LeoLabs's contribution to LEO and is working to protect them from potential gray zone competition. Influence from foreign investments and risks presented by the global location of LeoLabs infrastructure requires continued monitoring. (LeoLabs Funding, LeoLabs DPA.)

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[92] http://interactive.satellitetoday.com/via/march-2020/the-top-10-hottest-satellite-companies-in-2020/.
[93] https://www.leolabs.space/company/
[94] https://www.satellitetoday.com/innovation/2021/04/22/leolabs-costa-rica-space-radar-facility-is-now-fully-operational/

F. Launch

The most disruptive technological change affecting LEO may be improved launch capability. A 2018 NASA study reports that the cost per kilogram for the launch of the space shuttle was approximately $54,500, whereas SpaceX's Falcon 9 today costs only $2,720 per kilogram, a cost reduction factor of over 20.[95] This disruption is also one of the U.S.'s largest competitive advantages in space currently. According to the GAO, the launch cost for the majority of other nations for LEO severely lags behind the United States (as noted earlier in Table 1-3).

Rockets range from "Light" to "Heavy," which characterizes the payload capacity. The Defense Intelligence Agency (DIA) characterizes light-lift vehicles as having the capacity to lift less than 2 metric tons, medium lift as 2–20 metric tons, heavy lift as 20–50 metric tons, and "Super Heavy" as over 50 metric tons.[96] One category that will likely become increasingly relevant is the "Super Heavy" launch vehicle. The U.S. previously had a "Super Heavy" launch vehicle, the Saturn V, which was rated at 140 tons,[97] but it currently does not have anything close to that lift capability. However, both NASA and SpaceX are developing "Super Heavy" class launch vehicles: Space Launch System (SLS) and Starship (respectively). The SLS will fill a more scientific role (it is being developed primarily for interplanetary missions)[98] and will cost over $2B per launch, whereas the Starship will be a fully reusable launch platform costing around $2M per launch.[99] SLS will be capable of launching an estimated 130-ton load into LEO[100] and is planned to have its first launch later in 2021.[101] Starship has already had several successful test flights, has an approximate 100–150-ton capacity,[102] and is scheduled for regular orbital trips beginning as early as the summer of 2021.[103] SpaceX already has the majority of the market share for launches in the United States, and currently has the lowest cost platform with its Falcon Heavy; however, if Starship is able to push operational costs to $2M per flight with a 150-ton capacity, it could push the cost as low as $10 per kg into LEO. This will likely further accelerate commercialization and utilization of space while also driving other nations to compete.

China and Russia are developing new launch capabilities to match the U.S.'s technological lead, but their development lags behind. China's new Jielong-3, or Smart Dragon-3, is a small-lift rocket that can launch up to 20 satellites per launch (1.5-ton capacity) and is slated for commercial

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[95] https://ntrs.nasa.gov/api/citations/20200001093/downloads/20200001093.pdf.

[96] https://www.dia.mil/Portals/27/Documents/News/Military%20Power%20Publications/Space_Threat_V14_020119_sm.pdf.

[97] https://www.cbo.gov/sites/default/files/109th-congress-2005-2006/reports/10-09-spacelaunch.pdf.

[98] https://www.space.com/33691-space-launch-system-most-powerful-rocket.html.

[99] https://www.cnbc.com/2021/02/19/spacex-valuation-driven-by-elon-musks-starship-and-starlink-projects.html#:~:text=%22Starship%20is%20really%20a%20significant,about%20%2428%20million%20per%20launch.

[100] https://www.lpi.usra.edu/lunar/constellation/SLS_FactSheet_long.pdf.

[101] https://spacenews.com/nasa-sees-reasonable-chance-of-first-sls-launch-this-year/#:~:text=That%20test%2C%20the%20culmination%20of,Stennis%20Space%20Center%20in%20Mississippi.

[102] https://www.popularmechanics.com/science/a32052844/spacex-starship-user-guide-payload/.

[103] https://www.nasaspaceflight.com/2021/03/starship-sn11-spacex-orbital-flight-summer/.

use in 2022.[104] It costs roughly four times as much per kilogram as the Falcon 9. The Russians are much closer with their Proton M rocket, which is roughly comparable in cost to the Falcon 9 but has suffered from reliability concerns.[105,106] Russia is currently developing the Yenisei super heavy rocket slated for completion in 2028, while China is currently updating its Long March style rockets. China's Long March 8 will use a reusable rocket and is scheduled for test launches in 2021, and the Long March 9, the super heavy launch vehicle with a payload capacity of 140 tons, will be test launched by 2030.[107]

In addition to cost and capacity, another important factor for comparing different launch platforms is availability. A limited number of launches occur annually and only from specific locations. Figure 2-4 below indicates all of the global launch sites, but even fewer are open to commercial launches.

Figure 2-4. Global Launch Sites[108]

Even with the ability to reuse rockets, there will be significant downtime between launches for maintenance and safety protocols. The complexity of launch dynamics for LEO constellations of several thousand satellites may incentivize the use of whatever launch platforms are available to meet regulatory or user demand. Although launch price is an important metric and driver for

[104] https://www.techtimes.com/articles/257696/20210304/china-jielong-3-rocket-vs-elon-musks-falcon-9-10.htm.
[105] https://www.rand.org/content/dam/rand/pubs/external_publications/EP60000/EP67235/RAND_EP67235.pdf.
[106] https://www.gao.gov/assets/gao-17-609.pdf.
[107] https://spacenews.com/china-reveals-details-for-super-heavy-lift-long-march-9-and-reusable-long-march-8-rockets/.
[108] https://www.nationalgeographic.com/science/article/news-spaceports-cosmodromes-maps-world-space-week.

space commercialization, it is critical for companies to get their satellites in orbit, so they will pay higher prices for available services. However, there are a few companies looking to disrupt the availability issue by increasing supply through additive manufacturing.

Relativity Space is a U.S.-based, venture-capital-backed launch vehicle company. The company has developed the "world's largest metal 3D printer," code named Stargate, that allows them to build launch vehicles with significantly fewer parts and complexity.[109] Marketing materials indicate that a traditional rocket engine requires over 100,000 parts and two years of building time, but Relativity can build their "Aeon" engines with less than 1,000 parts and 2 months of build time, dramatically reducing the supply chain needed while increasing reliability.[110] The main product from the Stargate process is Relativity's "Aeon" engine, which is featured on their Terran 1 and Terran R launch vehicle. Terran 1 is the more mature vehicle, with its first launch planned for late 2021. Its payload capacity to LEO is 1,250 kg and a dedicated launch mission costs $12M, which is roughly $9,600 per kg, putting it roughly at the same capability as China's Smart Dragon-3 rocket. Terran 1 already has several customers, including NASA, DoD, Iridium, and Telesat for launch services. Terran R, which is planned to be a fully reusable rocket, is also slated for its first launch sometime in 2021 and will feature a 22,000 kg payload capacity, putting it much closer to SpaceX's current offering. Relativity has invested heavily in the infrastructure required for rocketry to develop these launch vehicles. They have a factory in California, they are building a rocket launch facility on Vandenberg AFB and a launch pad at Cape Canaveral, and they are leasing space at NASA's Stennis Space Center for rocket testing.[111] The technology that has been developed so far has propelled the company to a valuation of over $2.3B. In addition, the company has recently completed series D funding, raising over $500M in new funding.

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[109] https://www.relativityspace.com/stargate.
[110] Ibid.
[111] https://www.relativityspace.com/infrastructure.

Gray Zone Competition – Relativity Space

The most recent funding round for Relativity Space included an investment firm with significant ties to the PRC named Taihill Venture. Taihill Ventures, formally known as Skylight Investment, is listed as an investment firm based in Boston, but it is "supported by well-established Chinese partners Taiyou Fund and New Oriental." The majority of the partners of Taihill appear to be young professionals with educational and work histories linked to the PRC. Yu Tianyi, a founding partner, was previously an investment manager for the Taiyou Fund. Hongkai He, another founding partner, attended Sun Yat-Sen University, was a member of the Guangdong High Performance Computing Society, and worked at the Guangdong Province Key Laboratory of Computational Science. Sun Yat-Sen University is on the U.S. entity list due to the National Supercomputing Center's military ties. An additional founding member, Xu Tianmeng, is currently listed as a "Graduate Consultant" for the U.S. Military Academy at West Point but has significant ties to financial regulatory agencies in China. She has worked at the China Securities Regulatory Commission, Bank of China, and for a "National Government Offices Administration" in Beijing. Two advisors for Taihill listed on the website, Yu LongWen and Cynthia Yu, also have long-standing relationships to Chinese financial institutions. Yu LongWen founded the Taiyou Fund but also appears to be a Communist party official in the PRC and has significant experience working for PRC state institutions including roles as Deputy Mayor of Beihai City in Guangxi, Deputy Director of Guangxi Investment Promotion Bureau, and Director of General Office of China Everbright Group. He is listed as having helped reform and reorganize the Everbright Group, one of China's largest banks that has allegedly been linked to espionage activity in Australia. Cynthia Yu was a General Manager for China Citic bank, which manages several of the PRC's Sovereign wealth funds.

Although Taihill was not the lead investor in the most recent funding round for Relativity Space and did not gain board membership, it is unknown how much access Taihill gained to Relativity Space's operations or technology. Any investment by a company that has close ties to the People's Liberation Army of the PRC into a company deeply connected to the U.S. military is of concern. (Tahill, Tahill Advisor, Tahill Advisor, Entity List, Bios.)

Changes in the launch industry have also made LEO a more appealing prospect for many ventures. In addition to decreases in direct launch costs, providers are now able to provide both lower prices and flexibility,[112] as well as more responsive times-to-orbit for customers with immediate needs.[113] For the first group, smaller satellites and unified platforms, such as the CubeSat architecture, help enable ridesharing and mass deployment systems where dozens of satellites can be deployed per launch.[114] Though orbital drag significantly diminishes LEO satellite lifetimes, many in the industry have started to view this as a blessing in disguise, substituting large

[112] Clark 2019; Lal et al. 2017.
[113] Clark 2020a; Hitchens 2019.
[114] Lal et al. 2017; NASA CubeSat Launch Initiative.

upfront investments for continual replenishment missions and the frequent technological refreshes they enable.

Russia is also developing its commercial launch capability and leveraging its existing partnerships with the ESA to provide ride-sharing services. The ESA and Russia entered into an agreement in 2005 that enables Russian Soyuz rockets to use European spaceports to launch satellites—the most recent launch, a French military satellite, was in late December 2020.[115]

Ridesharing poses a new risk for government customers, who traditionally have been able to control every item that accompanies a payload into space, but economic pressure could transform that business model. SpaceX has started pushing commercial rideshare on its launches of Starlink satellites and has already seen incredible demand for slots so far.[116] Specific space ridesharing companies have also been created, like U.S.-based SpaceFlight or German-based Exolaunch, whose entire business is connecting customers to launch providers (mainly SpaceX and Soyuz missions so far). As launch prices see downward pressure, it might become cost effective for DoD to start utilizing these services instead of contracting entire launch vehicles for their payloads. If that happens, the U.S. will likely become a target for adversarial action. Risks such as unknown payloads on a launch vehicle might be able to interfere with or gather information on DoD payloads also on the craft. Adversaries might also use this method as a means to exfiltrate information on the launch vehicles and companies themselves by using commercial third parties to do the work for them. As launch prices disrupt the industry, it is critical to identify and mitigate the risk of increasing commercialization diminishing U.S. advantages. The U.S. Government has considered this and, in 2018, a law was updated to prevent DoD satellites from being launched by rockets from Russia or other adversarial nations.[117]

[115] https://www.nasaspaceflight.com/2020/12/arianespace-cso-2-french-satellite/.
[116] https://spacenews.com/spacexs-record-setting-rideshare-mission-a-challenge-for-space-traffic-control/.
[117] https://www.law.cornell.edu/uscode/text/10/2279.

3. U.S. Government and DoD LEO Efforts

U.S. space policy has been shifting toward commercialization, especially at the LEO level. According to the National Space Council in the White House, LEO commercialization is a critical component of the U.S.'s space strategy going forward.[118] The DoD's Defense Space Strategy (DSS) reflects this shift, citing the need to "maintain space superiority" and to take advantage of the commercialization in space, as well as to protect commercial space capabilities against adversaries.[119] DoD is actively moving in this field, communicating to the new commercial space industrial base that it is creating "plans to protect, support, and leverage commerce in space" while also establishing new partnerships.[120] These policy decisions have resulted in significant changes to how DoD organizes itself in relations to space, creating new organizations and oversight groups to help accomplish this goal.

Over the last three years, DoD has been pivoting toward space with a greater emphasis on space assets and competition. In 2019, the U.S. Space Force (USSF) was formed to "protect U.S. and allied interests in space and to provide space capabilities to the joint force." One area deemed critical was acquisition of space-based assets in DoD and National Security Space. The NDAA 2020, in addition to providing funding to the new USSF, established a new Space Force Acquisition Council, charging it to "oversee, direct, and manage acquisition[s] . . . across the national security space enterprise." A critical component of the new NDSA is the deployment of a network of LEO satellites that will operate in a series of layers and integrate with the different branches of the military. As described in the previous section, the NDSA is comprised of seven layers: Transport, Battle Management, Tracking, Custody, Navigation, Deterrence, and Support.

Currently, the SDA is operationalizing the layer approach by launching a series of tranches that will address the different needs of the entire program in each iteration. Tranche 0 will be the first, and is designed to be more of a test platform to demonstrate capability of the technology, as well as an opportunity to improve on later tranches if any issues arise. Only small parts of the Transport and Tracking Layers are included in the first tranche, which will include 28 satellites. Development and launch of the initial tranche are slated for 2020–2023, after which Tranche 1 will begin in 2024 and will include 100 to 150 satellites created by several different vendors. The important aspect of the layers is the modular nature of the program, allowing different payloads to be integrated based on mission needs. The Request for Information (RFI) SDA published for Tranche 1, lists the need for mass-producible satellite components for the satellite vehicles used in

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[118] *A New Era for Deep Space Exploration and Development.*
[119] 2020 Defense Space Strategy.
[120] State of the Space Industrial Base 2020.

the constellation.[121] The NDSA is attempting to take advantage of the commercialization of LEO by using commercial products that can be integrated into specialized modules for military use.

In Figure 3-1, the SDA identifies how the initial Tranche 0 constellation will be organized. The Transport Layer "creates [a] meshed communications network in low-Earth orbit that will serve as the backbone for all its other proposed system."[122] The SDA has already awarded a $281.5M contract for Tranche 0's Transport Layer to both Lockheed Martin and York Space Systems; however, Telesat U.S. Services partnered with Lockheed to actually produce 20 space vehicles for the layer. The SDA jointly awarded $342.8M to L3Harris Technologies and SpaceX for the Tracking Layer in this tranche, tasking both companies to produce "four Overhead Persistent Infrared (OPIR) imaging satellites." The two programs will collaborate on a Wide Field of View (WFOV) program and a Medium Field of View (MFOV) program for the initial Tracking Layer. The SDA also awarded $120M for a ground round-based satellite tracking capability that will be located at the Naval Research Laboratory's Blossom Point Tracking Facility. A $156.3M launch services contract for the 28 satellite vehicles was awarded to SpaceX.

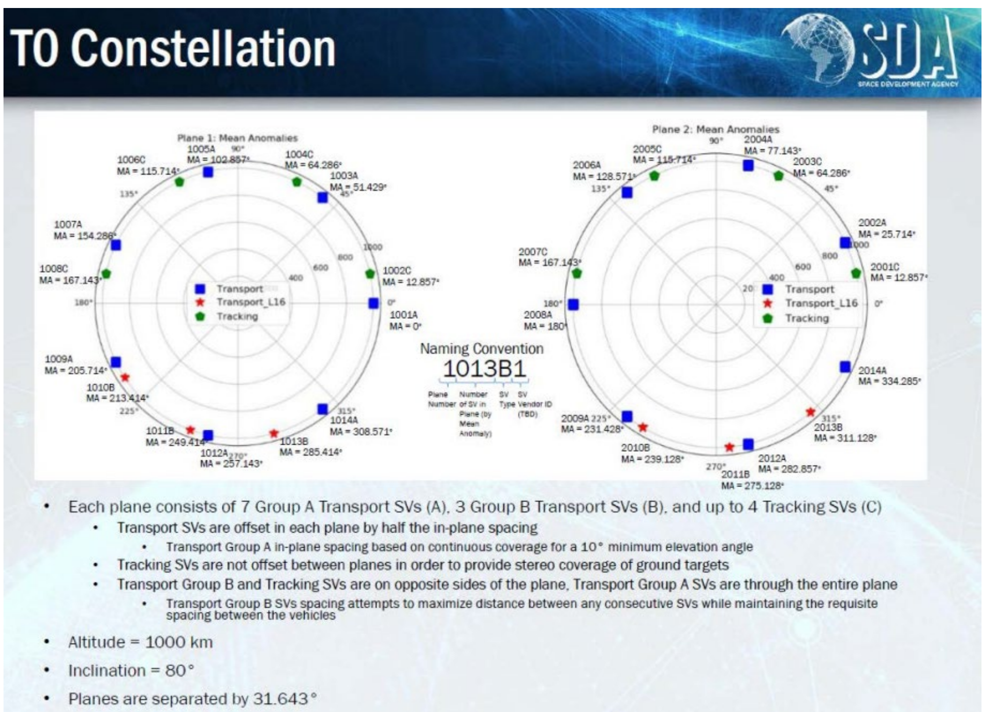

Figure 3-1. Tranche 0 Constellation

Along with Tranche 0, two main programs have been established to both test the feasibility of a large LEO constellation and to meet new mission requirements. DARPA's Blackjack program hopes to take advantage of the commercialization of space to help reduce costs, as well as to develop a modular architecture that could rapidly adapt to new mission requirements. MDA's

[121] https://beta.sam.gov/opp/8a79b8c74bcd4072a698755dea5caef3/view?keywords=%22space%20development%20agency%22&sort=-relevance&index=&is_active=true&page=1.

[122] https://www.nationaldefensemagazine.org/articles/2020/4/2/sda-director-lays-out-goals-for-transport-layer-satellites.

Hypersonic and Ballistic Tracking Space Sensor (HBTSS) is designed to use aspects of LEO that would make it easier to track hypersonic missiles. Both programs will directly feed into developing Army programs and will be key elements for the Army. Figure 3-2 depicts the major U.S. efforts and their key suppliers.

In Figure 3-2, green circles indicate government agency, purple circles indicate major program, magenta circles indicate subprogram, and blue circles indicate contractors. Solid lines indicate regular relationships, blue lines indicate prime contractor relationships, and dotted black lines indicate subcontractor relationships unless otherwise noted. Notably, Telesat is a major provider of satellite buses for both the Blackjack and Tranche 0 programs, and L3Harris has significant ties to the next generation of hypersonic and ballistic tracking systems, with a prime contractor relationship to both Tranche 0’s Tracking Layer and HBTSS.

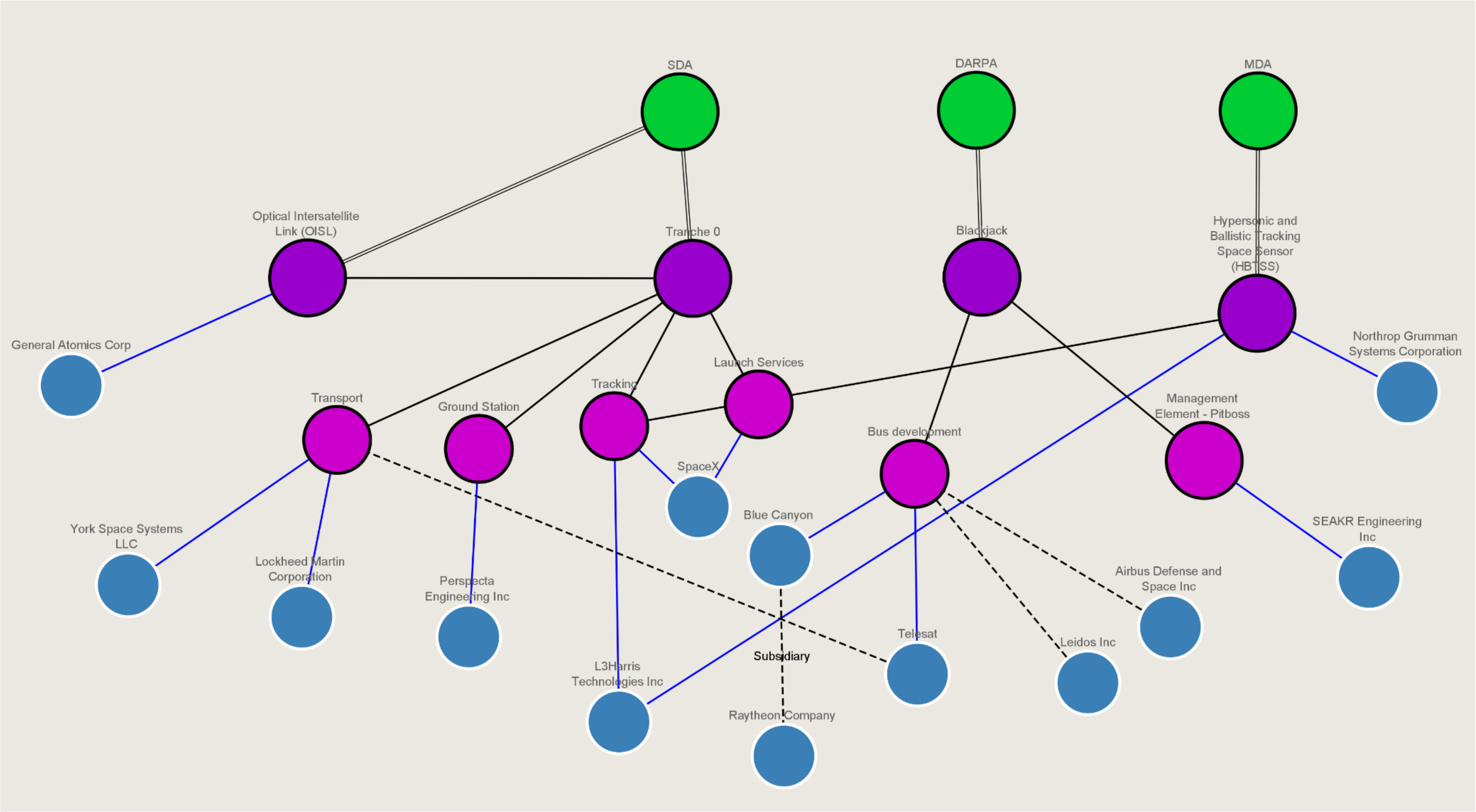

Figure 3-2. U.S. LEO Efforts and Their Suppliers

A. DARPA Blackjack

DARPA launched its Blackjack program to test the ability of LEO satellites to match current capabilities in space while costing significantly less and incorporating commercial elements into the program. DARPA identified three key objectives for the program to accomplish:[123]

1. "Develop payload and mission-level autonomy software and demonstrate autonomous orbital operations including on-orbit distributed decision processors.
2. Develop and implement advanced commercial manufacturing for military payloads and the spacecraft bus.
3. Demonstrate payloads in LEO to augment NSS assets. The driver will be to show LEO performance that is on par with current systems in geosynchronous orbit with the spacecraft combined bus, payload(s), and launch costs under $6 million per orbital node while the payloads meet size, weight, and power constraints of the commercial bus."

The first objective is being addressed through a sub-program, codenamed Pit Boss. The $110.3M contract for Phases 2 and 3 of Pit Boss was awarded to SEAKR Engineering. Pit Boss will be an "autonomous mission management system" and will include computing and encryption software that will be added onto each LEO satellite. This hardware unit requires a "high speed processor," and while it is unclear what exact processor will be used from publicly available information, it shows the need for a secure leading-edge integrated circuit (IC) chip producer for DoD. At this time, there are no domestic leading-edge producers in the U.S., and the world is currently experiencing a large shortage of foundry capacity for IC chips. This means it will be difficult to find even a foreign manufacturer for chips.[124] The lack of domestic capability will likely force the program to use a much older chip or procure chips from foreign sources, either of which will add additional risks to the program. Overall, Pit Boss is meant to be the architecture by which different elements of a LEO constellation can link together and coordinate the different capabilities of the satellites in the constellations.

The second and third objectives are being addressed through the development of 20 satellite buses. A satellite bus is a standard satellite model designed for multi-production with the infrastructure in place to support multiple satellite payloads. The buses will be standard commercial buses made by current commercial satellite providers with the ability to have modular military payloads added onto them. Currently, two providers have been selected to build test buses for the program. Blue Canyon, which was recently acquired by Raytheon, received a $99.4M contract, and Canadian-based Telesat received $175.6M to provide the busses for Blackjack. Telesat, however, teamed with Airbus and Leidos on their contract for Blackjack. These busses will be loaded with various payloads for different mission parameters to test if LEO can match current capabilities of existing space assets. The busses will also house OISLs to determine if the laser-based technology is feasible for a LEO constellation.

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[123] https://www.darpa.mil/program/blackjack.

[124] IDA Report D-21590. Supply Chain Risk in Leading-Edge Integrated Circuits. March 2021.

Blackjack has the ability to revolutionize the way the military uses space and could provide a huge advantage over the U.S.'s adversaries, but it also adds new attack vectors and risks that DoD would need to mitigate. The key aspect of the Blackjack program is the use of commercial elements, representing both a huge potential advantage and a large potential risk for the United States. By using commercial satellite buses to reduce the cost of each orbital platform combined with the dramatic reduction in price in U.S. launch services by commercial providers, the U.S. would have a large competitive advantage over its adversaries. Using hundreds of smaller and cheaper satellites to provide similar or better performance than current assets would dramatically increase the robustness of any program relying on space assets. Kinetic attacks from adversaries would pose a significantly decreased threat, and the modular nature of the new system could allow for rapid adaptability to future needs. However, the commercial element also presents new risks in terms of space assets that DoD has not previously had to manage.

Economic forces are pushing more and more commercial entities to use space for commerce, and if DoD taps into the market forces, it could help reduce prices while also exposing DoD to adversaries using economic warfare. Adversaries could take advantage and use these commercial entities to send their own hardware into space, steal technology, acquire leading edge technology through M&A activity, plant board members on key commercial providers, and attempt to drive important providers out of business. Shifting space assets to smaller, more robust platforms changes the potential attack vectors for the adversaries. Instead of kinetic capabilities, the adversaries will be much more likely to use means like cyber to exploit commercial providers, target technologies such as ground stations, attack the network of the commercial providers, or even insert malicious elements through supply chain attacks.

B. Hypersonic and Ballistic Tracking Space Sensor (HBTSS)

One system that will be integrated with the NDSA is HBTSS, which is being developed by MDA with funding collaboration from SDA. Building on experience from DARPA's Blackjack program, HBTSS is intended to become part of the sophisticated kill chain required to track and engage maneuverable hypersonic threats.[125] Distinct from but working in tandem with (and potentially cued by) SDA's Tracking Layer, HBTSS focuses on providing low-latency targeting information to ground-based interceptors.[126] HBTSS will possess both wide- and medium-field-of-view sensors that will then become part of an integrated system to track missiles and provide high-quality fire control data to interceptors like the Army's THAAD and Patriot systems.[127] HBTSS will eventually be folded into the Tracking and Transport Layers of the NDSA. Recently, MDA announced that the Phase II-b contracts for launch and early orbit testing of the program were awarded to L3Harris and Northrop Grumman. Previous participants included Leidos and Raytheon.[128]

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[125] Missile Defense Agency 1/22/2021.
[126] Kelley M. Sayler et al. 2021.
[127] Keller 2021; Erwin 2020c.
[128] Missile Defense Agency 1/22/2021; Keller 2021.

Due to the potential for secure, high-bandwidth communications resistant to interference and jamming, there has been growing interest in OISLs across the national security sector. By using lasers instead of radio waves, OISLs could also save valuable spectrum resources for other uses, such as communication with the ground where atmospheric interference may be more difficult for optical systems to overcome. Exploring the possibilities of optical links is another key part of DARPA's Blackjack program,[129] and SDA recently awarded General Atomics with a $5.5M optical link demonstration contract.[130] The company Space Micro also recently won a $3M contract to provide the U.S. Space Force's Space and Missile Systems Center with an optical communications terminal.[131]

These demonstrations are expected to directly inform upcoming efforts to build robust LEO networks. Both HBTSS and SDA's Transport Layer are likely to use OISLs for high-performance communications over a mesh network.[132] Some notable hurdles remain, however, as the effects of launch and the space environment on the sensitive electronics required for laser communication are not completely known, nor are the risks of dazzling[133] by adversaries. NASA has seen some success in using optical technologies for deep space communications, but at a high cost.[134] In proliferated LEO networks, lower costs and interoperability across systems are key considerations that will require diligent attention to the supply chain.

C. Army Integration

The Army is one of the largest consumers of satellite-based resources in DoD and would be one of the biggest users of SDA's new LEO constellation. The Tactical Intelligence Targeting Access Node (TITAN), already has several contracts connected to its development with LEO connectivity in mind.[135] There are at least two 2019 pre-solicitations from the Army regarding new LEO sensors and AI enabled analytics. The TITAN system is being developed to take in data from multiple domains and be a "key piece in the sensor-to-shooter chain."[136] The Army's budget books for Tactical Electronic Surveillance System through 2025 identify the LEO Tactical Space Layer as one of the key components that the TITAN system will use to function. Demonstrations and prototypes for the TITAN system connecting to a LEO network are underway. The Tactical Space Layer should align to SDA's tranche system and SDA's Transport, Tracking, and Battle Management Layers. The Army also lists "Low Earth Orbit (LEO) Satellite Capability" as a budget

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[129] Defense Advanced Research Projects Agency 2020.
[130] General Atomics 6/5/2020.
[131] Werner 2020.
[132] Space Development Agency 2020; Erwin 2020d.
[133] *Dazzling* is a mechanism to effectively "blind" a satellite by pointing a laser at it, traditionally from the ground. https://www.satellitetoday.com/government-military/2017/03/29/defending-us-space-assets-foreign-attacks/
[134] Werner 2019.
[135] https://insidedefense.com/insider/army-awards-otas-support-tactical-intelligence-targeting-access-node.
[136] https://www.c4isrnet.com/battlefield-tech/space/2021/01/13/army-issues-17-million-in-contracts-for-titan-development/.

item and has awarded two contracts—one for a ground terminal for the TITAN, and another for a prototype ground station.

The next generation of Blue Force Tracker, the Mounted Mission Command-Transport (MMC-T), is also being designed with LEO in mind. Pre-solicitation documents in 2019 outline identified one of the requirements for the new system as the capability to connect to LEO.[137] Although the next generation is still in early development after being announced in 2019,[138] it will likely have the ability to connect with the Battle Management Layer of SDA's new LEO network, as it is designed to handle mission command and control. Only Tranche 0 and Tranche 1 currently have funding, but after the backbone is operationalized in the Tracking and Transport Layer, the Battle Management Layer will be close behind. In this way, future command and control will likely feed through SDA's new LEO constellation, showing the importance of LEO to the Army.

One of the Army's key missions is missile defense, which is primarily done with the THAAD and Patriot missile defense systems. Hypersonic glide vehicles (HGV) pose a new threat due to their ability to maneuver and change direction after release.[139] The low altitude and lack of ballistic trajectory could pose challenges to existing detection systems.[140] Defense officials have stated that "existing terrestrial- and space-based sensor architectures are insufficient to detect and track hypersonic weapons," and SDA's Tracking Layer is being developed to track hypersonic weapons in conjunction with HBTSS.[141] DARPA is also partnering with Northrop Grumman to develop an anti-hypersonic weapon program called Glide Breaker, which is likely connected to the Integrated Air and Missile Defense Battle Command System Northrop is developing for the Army. Due to the Army's current missile defense mission, it is likely the Army will be called on to contribute to the new defense mission regarding hypersonic weapons. LEO, through SDA's Tracking Layer, and MDA's HBTSS will play a key role in providing the tracking ability for hypersonic vehicles, which would feed into any missile defense system the Army may deploy.

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[137] Solicitation PL84110013.
[138] https://www.army.mil/article/231121/army_program_to_modernize_bft.
[139] https://fas.org/sgp/crs/natsec/IF11459.pdf.
[140] https://fas.org/sgp/crs/weapons/IF11623.pdf.
[141] Ibid.

4. United States Future Focus

Due to the increasing reliance on space assets for both government and commercial activities, some have advocated that space be considered part of the critical infrastructure of the United States.[142] Such a designation would allow the federal government to take additional steps to ensure the reliability and security of such systems, even if many aspects of it are managed by private entities. Currently, 16 other sectors are designated as critical infrastructure, including the communications and information security sectors, which are overseen by the Department of Homeland Security in collaboration with other sector-specific agencies.[143]

The U.S. has already taken some steps to protect vital aspects of the space industry by requesting that operators incorporate cyber defenses into their systems while considering supply chain risks.[144] The Space Acquisition Council, a congressionally mandated meeting of high-level defense officials created to “oversee, direct, and manage acquisition and integration” of space systems and programs across departments, has also taken steps to ensure the industry is resilient to threats like the current pandemic.[145] Although the designation of space as a critical infrastructure sector (or its incorporation into another sector) is unlikely to bring about immediate changes to commercial space activities; it would allow the government to better communicate security guidelines, best practices (e.g., workforce requirements during the COVID-19 pandemic),[146] and an awareness of current threats to the industry. Furthermore, such a designation would emphasize the importance of a secure and resilient space sector for U.S. strategic interests. Such goals are also well served by healthy competition.

The U.S. is leading the current wave of new companies and technical innovation in the space sector. To foster the long-term stability of this industry in coordination with national goals, it must provide both stable guidance and predictable demand, especially as the federal government adjusts its role from the primary developer to an important consumer of space products and services. Such lessons have become clear in other industries such as telecommunications.[147] To bolster competition and innovation in the space industry, government agencies and departments can build on previous experience by creating concrete strategies to support their strategic interests. Key focal points include prioritizing spectrum availability for space users, working to fund research into next-generation technologies, and providing clear signals about expected future demand.

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[142] The Aspen Institute 2020; Konkel 2020; Cahan and Sadat 2021.
[143] Cybersecurity & Infrastructure Security Agency 2021.
[144] The White House 2020.
[145] United States Congress 2019; Erwin 2020a.
[146] Cybersecurity & Infrastructure Security Agency 8/18/2020.
[147] Medin and Louie 2019; Kania 2020.

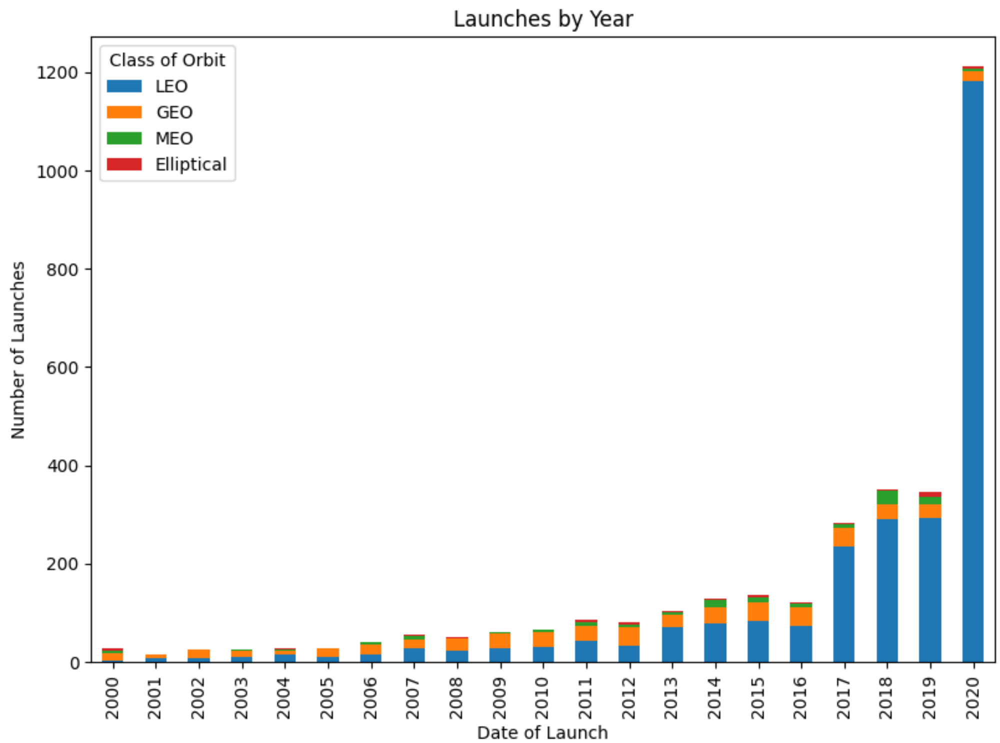
Appendix A. The Emergence of Commercialized LEO

Formerly dominated by nation-state militaries that could bear the expense and risk of launching satellite platforms, LEO is increasingly within the purview of both startups and established commercial ventures. Approved use of LEO began in the 1990s and 2000s, primarily for earth observation or limited global connectivity means.[148] However, the technology was not advanced enough nor was there enough demand for connectivity for it to be a profitable venture until a shift occurred around 2010. Today, as both the applications and users of satellite services increasingly demand more data,[149] satellite owners must increasingly compete for higher-bandwidth portions of spectrum, such as the K_a and K_u bands.[150] That spectrum was opened up to commercial application and review by the FCC after 2015. Figures A-1 and A-2 highlight the significant recent growth of satellite deployment, especially into LEO. Figure A-1 shows the total number of satellites placed into orbit over the past two decades, with colors indicating the orbit. It is helpful to look beyond total satellite numbers to understand current trends, as many applications necessitate wide and consistent coverage (such as communications) and require many more LEO satellites than GEO satellites. There also is potential for physical risks of overcrowding in LEO space given the number of satellites being put into orbit.

[148] https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/large-leo-satellite-constellations-will-it-be-different-this-time.

[149] Del Portillo et al. 2019.

[150] Named for the portions of microwave frequencies near but “above” and “under” the interfering water vapor resonance peak at 22.24 GHz.



Data Source: UCS Satellite Database (last updated August 1, 2020)

Figure A-1. Satellites Entering Into Orbit Binned by Year of Launch and Class of Orbit

Figure A-2 depicts the number of new satellite operators or owners entering orbit each year, highlighting both the increasing number of firms entering space, as well as the rise in commercial prevalence of LEO. Of note, after a large increase 2018, the number of operators has been falling. This could be an indication that the market for constellation owners has become oversaturated due to spectrum rules. Globally, satellite communication frequencies are regulated along with satellite orbits by the International Telecommunication Union (ITU), a specialized agency of the United Nations.[151] The ITU has adopted a "first-come, first-served" model of allocating frequencies. After filing plans for spectrum usage, satellite operators must also bring 10% of their constellations into use within nine years (while meeting additional milestones) for the ITU to continue reserving their section of spectrum.[152] Such a regulatory structure rewards early movers with valuable spectrum allocations, and the move has already seen significant controversy.[153] From 2017 to 2019, four major constellation suppliers pushed hard to claim the spectrum by quickly building and launching satellites. Those satellites already in orbit must navigate an increasingly crowded electromagnetic spectrum to communicate with the ground or with other satellites, and those that have yet to launch may already be too late to market.

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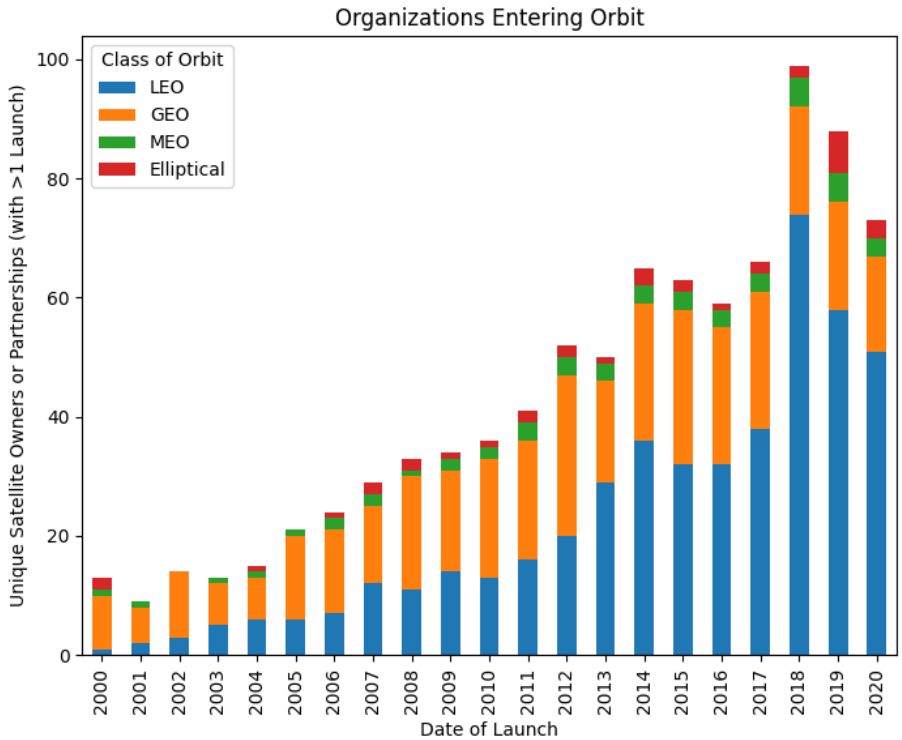
[151] International Telecommunication Union 2021.

[152] International Telecommunication Union 11/20/2019. Previously, satellite owners only had to bring one satellite into use within seven years to continue reserving their spectrum.

[153] Reklaitis 2019.



Data Source: UCS Satellite Database (last updated August 1, 2020)

Figure A-2. Owners/Organizations with Two or More Satellite Launches Binned by the Date and Orbit of Their First Launch

Another metric for examining the growth of LEO satellites is the number of patents being filed for technology related to their use. Figure A-3 displays a dramatic uptick in LEO patents in the U.S. and China over the past several years, showing clear business interest in the area.

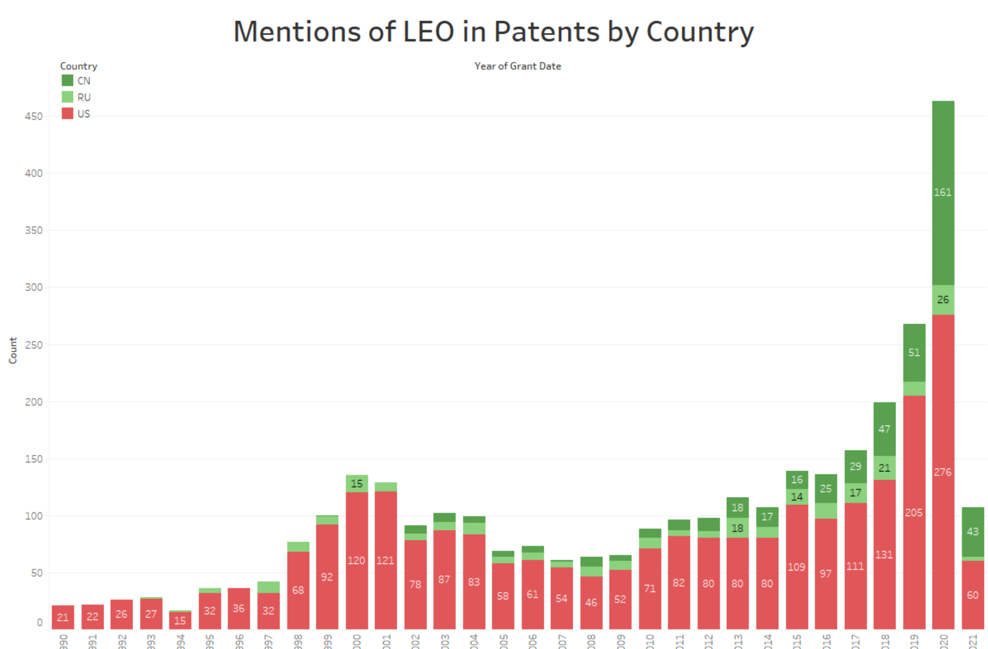


Figure A-3. Google Patent Data on LEO

This technological growth also follows the amount of venture capital funding that has been going into the space sector. As seen in Figure A-4, there has also been a corresponding amount of venture capital and corporate funding that has flooded the commercial space market.

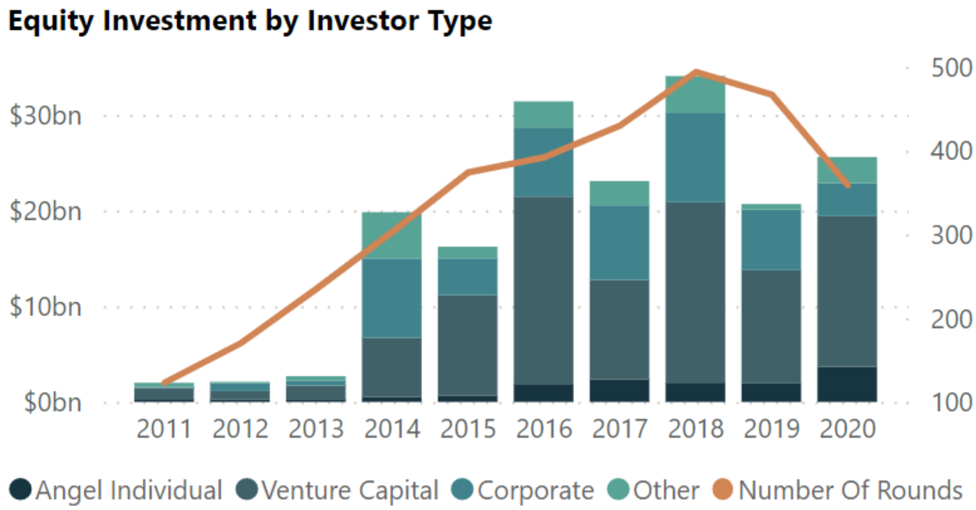


Figure A-4. Space Capital Overall Space Investments Worldwide[154]

This pattern is similar to that seen in high-tech sectors like biotechnology, AI, and additive manufacturing. Smaller offshoots, usually from universities or incubators, start developing new technology for a sector and attempt to draw financing to their project. If the project is successful, the company either will partner with or be bought by a larger company in the sector. However, these areas are already rife with gray zone activity from adversaries that leverage economic means to extract valuable technology from U.S.-based companies, even before they create a product that DoD might use. Now that this sector is beginning to boom, it is critical to monitor economic activity at all stages to ensure that national interests are addressed and prevent adversaries from exploiting commercial elements to steal the competitive advantage away from the United States.

The majority of the billions of dollars in federal satellite communication contracts currently go to GEO providers like Viasat[155] and Hughesnet, companies that can provide reliable but slow connections. These companies are starting to see a surge in competition from LEO with its potential for higher bandwidth and lower latency communications. LEO is also proving to be competitive with fiber-based capabilities. In response, terrestrial fiber and broadband providers have doubled down on the fact that fiber, especially fiber-to-the-home (FTTH), will always have a higher theoretical bandwidth than any wireless alternative. As expected user data demands increases, terrestrial providers will further lean on those with high performance and uptime requirements. Furthermore, representatives of the broadband industry have spoken up about their opposition to SpaceX's receipt of nearly $900 million to fund broadband to rural customers. They argue that the Starlink network will be unable to keep its promises as the network grows.[156]

[154] https://app.powerbi.com/view?r=eyJrIjoiNGY4MWI4OWEtMjNmZS00OTM3LWE5M2QtYTgxZTdjODk3YTllIiwidCI6IjYzMDZkMTJjLTEwODMtNGNhOS04Yjk2LTdjYzM3ODcwMWIzMiIsImMiOjN9.

[155] Viasat 7/21/2010.

[156] Brodkin 2021a; Cao 2021.

However, terrestrial broadband providers lag behind on providing an alternative, with many customers still lacking options beyond DSL. According to a 2018 FCC report, over 24 million customers did not have access to fixed broadband that met a speed benchmark of 25 Mbps.[157] However, when wireless LTE services were considered, 98.1% of the country had access to Internet that met standards. As terrestrial LTE and 5G networks improve, Internet service providers may pursue further bundling and agglomeration of wired and wireless Internet services to meet customer demand where infrastructure costs are high.[158]

[157] Federal Communications Commission 2018.
[158] AT&T 2021.

Appendix B. Key Nation State LEO Programs

Space is a global industry. While the U.S. has the largest share of new companies seeking a presence in LEO, it still represents well under 50% of the total.[159] The rest are spread over a wide array of countries in both friendly and adversary nations. By number of launched satellites, the U.S. leads in LEO, followed by China, Russia, the United Kingdom, and Japan, as seen in Table B-1.[160]

Table B-1. Satellite Statistics by Country (Top 15)

Country	Total satellites	LEO satellites	Organizations with 2+ launches	Organizations with 2+ LEO launches
USA	1878	1633	80	46
China	405	307	43	30
Russia	174	102	19	11
United Kingdom	166	127	9	4
Japan	82	53	15	9
India	60	30	3	2
ESA	59	27	6	3
Canada	43	28	8	7
Germany	40	38	9	8
Luxembourg	36	4	2	1
Argentina	28	26	4	3
Spain	21	11	5	3
South Korea	17	9	5	2
Israel	16	13	4	3
Australia	13	6	3	1
Other	334	198	76	47
Total	3372	2612	291	180

1. China

Among countries with growing interests in LEO, China has seen a surge of new space ventures in recent years. Currently, Chinese spacecraft and launches are largely procured through state-owned enterprises and their subsidiaries, such as the China Aerospace and Industry Corporation (CASIC) and the China Aerospace Science and Technology Corporation (CASC). CASIC has a number of prominent ventures, including Hongyun (a planned communication

[159] Kulu 2021a; Union of Concerned Scientists 2020.
[160] Kelso 2021.

constellation with 864 satellites, of which only 1 has been launched),[161] Xingyun (a planned 80 satellite IoT narrowband data constellation similar to Orbcomm,[162] of which 2 satellites have been launched),[163] ExPace (a launch provider aiming for agile, low cost access to LEO),[164] and a number of other large-scale broadband projects, including airships and drones.[165] CASC is also pursuing a 300+ satellite LEO constellation called Hongyan.[166]

In addition to these state-owned enterprises, a number of private ventures have emerged in recent years. Some attribute this rise to a 2014 policy shift that encouraged private investment and competition in the space sector in China.[167] A recent report found that the vast majority of an estimated 78 private space firms in China were founded since 2015.[168] However, there are a number of important, complex elements of China's emerging space ecosystem. Most notably, a large domestic market and stringent export controls on Western technology mean that Chinese companies are largely pursuing homegrown solutions and supply chains. Although the central government offers little in the way of subsidies or contracts for private space ventures, there is intense competition among provincial governments to attract these high-tech industries. The incentives offered by regional entities have certainly contributed to a huge boom in the number of companies, but many of these new entrants do not have much experience in the industry or strong business cases.[169] Many seem to be technological followers, perhaps attempting to emulate prominent space entrepreneurs like Elon Musk. Furthermore, intense government control over the communications industry (along with a disorganized spectrum regulation process that lags behind the international competition) largely limit private ventures to the launch and earth observation sectors.[170]

However, the sheer amount of interest, along with the chance to bring these technologies to countries participating in the Belt and Road Initiative, point to a huge opportunity for growth for both private and government-backed ventures in China. Just recently, a new Chinese entity named GW submitted filings for 13,000 satellites in two LEO broadband constellations seemingly aimed at the global market.[171] Exactly how the Chinese central government will continue to participate in and manage this nascent industry remains to be seen.[172] Nevertheless, if recent experiences in other industries are any example, the Chinese presence in LEO will develop quickly and in strong support of the country's larger strategic objectives.

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[161] Press 2019, 2020.
[162] Orbcomm is a U.S.-based mobile network provider focused on IoT and machine-to-machine communications.
[163] Clark 2020b.
[164] Jones 2020.
[165] Press 2019.
[166] Krebs 2018.
[167] The policy document is Document 60 (Guiding Opinions of the State Council on Innovating the Investment and Financing Mechanisms in Key Areas and Encouraging Social Investment).
[168] Liu et al. 2019; Foust 2020a.
[169] Liu et al. 2019.
[170] Ars Technica 2020.
[171] International Telecommunication Union 2020; Press 2020; Payer 2020.
[172] Major Liane Zivitski 2020; Liu et al. 2019.

2. Russia

As a country with a very capable space sector that has been a longstanding source of national pride, Russia's efforts to stay at the forefront of international space efforts have had mixed results in recent years. The recently opened Vostochny space launch center was plagued by delays and corruption scandals since work began in 2007.[173] However, its opening has facilitated multiple successful launches of OneWeb satellites, and it now promotes itself as a center for commercial ventures. Russia's Proton-M rocket, a single-use, heavy-lift launch vehicle, has also seen numerous failures in recent years.[174] Some of these issues have spurred reorganizations, with most of country's space sector currently being directly owned by the Russian government.[175] Although Russia has seen some success in providing commercial launches and ridesharing, some experts suggest that the country's efforts in space are stagnating due to funding limitations, brain drain, or other organizational issues.[176] This lag, combined with its comparatively low reliance on space assets for military operations compared to its competitors, are perhaps key motivators for Russia's recent focus on developing capabilities to degrade or destroy satellites. These include anti-satellite weapons, ground-based laser dazzling, and electronic and cyber warfare capabilities.[177]

Russia's space future is uncertain. While some efforts have been made to spur private innovation in the sector, such as with a dedicated space cluster as part of the Skolkovo Innovation Center, the preeminence of state control seems to have limited the horizons of industry driven space efforts.[178]The Skolkovo Foundation, which includes the Skolkovo Innovation Center, is representative of Russia's use of state funded entities to reach U.S. or global markets through venture capital investments. Founded in 2010 by Russian president Dmitry Medvedev,[179] the foundation is headquartered in Russia but has an office in Santa Clara, CA. In 2014, the FBI issued a warning that the foundation was acting as "means for the Russian government to access our nation's sensitive or classified research, development facilities and dual-use technologies with military and commercial applications."[180] The Skolkovo Foundation is currently controlled by Russian oligarch and energy baron Viktor Vekselberg, who is on the U.S sanctions list. Mikhail Kokorich, a Russian national and graduate of Skolkovo's management program, is the founder of two U.S.-based space companies that are attempting to work with the U.S. Government.[181] The two companies are Astro Digital, which develops open APIs for satellite imagery, and Momentus, which has developed in-space transportation technology. Efforts associated with Skolkovo-linked entities should be monitored closely.

[173] McClintock 2017; Pillow 2019.
[174] McClintock 2017.
[175] Defense Intelligence Agency 2019.
[176] McClintock 2017; Graham 2021.
[177] Defense Intelligence Agency 2019; Hendrickx 2020; Gohd 2020.
[178] McClintock 2017.
[179] https://www.themoscowtimes.com/2020/12/03/chubais-a72220
[180] https://www.politico.com/magazine/story/2018/07/27/silicon-valley-spies-china-russia-219071/
[181] https://www.crunchbase.com/person/mikhail-kokorich

Geography also shapes Russia's space investments, as it pursues arctic climate monitoring satellites and GEO rather than LEO, communications satellites (which some leaders see as a more efficient use of resources given the country's large landmass).[182] Overall, Russia may see some isolated successes in LEO technologies in the coming years, but a robust presence in LEO is not expected. Given the country's currently limited resources, most of its efforts will likely be focused on sustaining its existing capabilities, as well as countering those of other countries, through traditional and gray zone activity.

3. India

India is emerging in the space industry and is developing a competitive space program and satellite business environment. The India Space Research Organization (ISRO) was founded in 1969 and has seen successes and failures in its space endeavors. In 2008, it had a successful lunar mission and helped confirm the presence of water and ice on the moon.[183] In 2014, ISRO put a satellite in orbit around Mars, beating out China and becoming the fourth space agency to successfully reach Mars. In 2019, its lunar rover crashed on the moon's surface after a landing system malfunction. However, ISRO is planning a human mission for 2022, where it could join the United States, Russia, and China as the only other countries who have been able to send humans into space.[184] Recognizing the potential for space and satellite business, the Indian government implemented several reforms to promote private space grants and investments. ISRO also has promoted itself as a means for different countries to reach space using India's rockets and launch infrastructure. As of February 2021, ISRO had launched 328 satellites for 33 countries, generating a revenue of approximately $25 million.[185] India has two operational launch vehicles: the Polar Satellite Launch Vehicle (PSLV) and the Geosynchronous Satellite Launch Vehicle (GSLV).[186] In 2018, Canadian-based Telesat launched its first LEO satellite aboard a PSLV.[187] After building its own rockets and space port (the Satish Dhawan Space Center (SHAR)), India reduced its reliance on other nations to get to space and has created a market for India to participate in the global satellite boom.

Several Indian start-ups are gaining traction in the global market, including Agnikul, Pixxel, and Vesta Space.[188] Agnikul Cosmos is designing and developing 3D-printed launch vehicles.[189] Pixxel is building out a fleet of LEO earth observation satellites with high-resolution imaging, and it has received the largest seed funding rounds in India's history.[190] Vestaspace Technology is

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[182] Reuters 2021; Holmes 2020.
[183] https://www.npr.org/2020/01/01/792927666/india-announces-plans-for-its-first-human-space-mission.
[184] Ibid.
[185] Ibid.
[186] https://www.isro.gov.in/launchers.
[187] https://www.telesat.com/press/press-releases/telesat-begins-deploying-its-global-low-earth-orbit-leo-constellation-with-successful-launch-of-phase-1-satellite/.
[188] http://interactive.satellitetoday.com/via/april-2021/the-rise-of-the-indian-satellite-market/.
[189] https://www.crunchbase.com/organization/agnikul-cosmos/company_financials.
[190] https://www.businessinsider.in/business/startups/news/indian-spacetech-startup-pixxel-space-gets-7-3-million-funding-before-the-launch-of-its-first-satellite/articleshow/81562421.cms.

manufacturing a 5G constellation to be launched into LEO and GEO with a focus on building in AI-enabled analytics.[191] It recently received $10M from U.S.-based Next Capital. In addition, Bellatrix Aerospace is focused on water-based propulsion systems.[192] It is also notable that India's telecommunications conglomerate Bharti Enterprise partnered with the UK government to bring OneWeb out of bankruptcy.

4. Japan

As a technologically advanced country with a long-standing interest in promoting beneficial international norms, Japan has directed a large portion of its national space enterprise toward collaborative scientific ventures and, more recently, efforts to mitigate space debris.[193] However, the country's current security considerations are potentially forcing a reconsideration of that stance, with the government considering an involvement with U.S. LEO-based missile tracking constellations. This could be a mutually beneficial arrangement given Japan's advanced capacity to produce the specialized infrared sensors required by such satellites.[194] The country has also seen numerous initial successes with space-based laser communications.[195]

Japan also hosts significant private interest in LEO. However, some of these efforts have been delayed by recent setbacks, and others remain focused on GEO. For example, Sky Perfect JSAT, a large satellite-broadcasting firm, has maintained that GEO is the company's way forward after an investment in the now-bankrupt LeoSat venture.[196] Nevertheless, JSAT has recently begun building out a network of ground stations for LEO-based telecommunications.[197]

Many current Japanese efforts are focused on launch, with companies such as Interstellar and SpaceOne hoping to provide cheap access to LEO for payloads under 300 kg. Currently, the country has a strong reliance on foreign launch providers.[198] However, development is underway on the H3 rocket, a flexible and relatively low-cost rocket system. The rocket is being built by Mitsubishi Heavy Industries under the direction of the Japan Aerospace Exploration Agency (JAXA), and it is expected to come into regular use at the Tanegashima Space Center over the next few years.[199]

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[191] https://www.satellitetoday.com/launch/2020/05/26/indias-vestaspace-technology-plans-for-constellation-of-5g-satellites/.
[192] https://spacenews.com/indian-startup-bellatrix-aerospace-raises-3-million/.
[193] Vijayakumar 2020.
[194] Hatakeyama 2021.
[195] Howell 2020.
[196] Henry 2020c.
[197] Sky Perfect JSAT Corporation 2021.
[198] Obe 2020.
[199] Henry 2020a.

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14. ABSTRACT

Low Earth orbit (LEO) satellites are enabling access beyond the terrestrial confines of the Earth to a broader range of consumers of space and space services. This commercialization of a previously government- and military-dominated sector presents opportunities and risks for the U.S. Government and the Department of Defense (DoD). As access to space has grown dramatically in recent years, so too has the number of companies and organizations entering into orbit each year. Although the inherently high costs and risks of the space economy mean that many of these companies could fail (as has occurred in previous rushes to space), the sheer number of entrants imply a much more accessible and competitive space ecosystem than ever before. Space watchers have projected that LEO will see dozens of new competitors in the next few years, some of which have significant financial backing and state sponsorship. This dynamic will require DoD to work harder to maintain and secure national assets targeted by peer competitors engaged in gray zone competition.

15. SUBJECT TERMS

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