Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

Application of	)	
SPACE EXPLORATION HOLDINGS, LLC	)	Call Signs:
For Approval of Orbital Deployment And Operating Authority for the SpaceX Gen2 NGSO Satellite System	)	File No. _____

APPLICATION FOR APPROVAL FOR ORBITAL DEPLOYMENT AND OPERATING AUTHORITY FOR THE SPACEX GEN2 NGSO SATELLITE SYSTEM

William M. Wiltshire
Paul Caritj

HARRIS, WILTSHIRE & GRANNIS LLP
1919 M Street, N.W.
Suite 800
Washington, DC 20036
202-730-1300 tel
202-730-1301 fax

Counsel to SpaceX

David Goldman
Director of Satellite Policy

SPACE EXPLORATION TECHNOLOGIES CORP.
1155 F Street, N.W.
Suite 475
Washington, DC 20004
202-649-2700 tel
202-649-2701 fax

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SUMMARY

SpaceX's first-generation non-geostationary orbit ("NGSO") satellite constellation is poised to offer unprecedented satellite broadband service to Americans in even the most remote corners of the country. Yet even as SpaceX prepares to deliver service to consumers using its first system, it understands that the demand for broadband continues to surge. The need for connectivity has never been more stark, whether to support children doing homework, parents working from home, doctors providing telehealth services, first responders coordinating activities to address emergencies, or any number of other important activities. While existing networks have stood up admirably during the COVID pandemic, the current crisis is laying bare the true cost for those stuck on the wrong side of the digital divide.

To address this surging demand, terrestrial providers are densifying their networks. While 4G networks required roughly ten times as many cells as 3G networks, 5G networks will require yet another tenfold increase. Wireless operators are planning to deploy hundreds of thousands of cells across the country over the next several years, while wireline operators have deployed millions of miles of fiber that can both deliver services direct to customers and also support 5G expansion. Together, these investments will provide essential services to those living in urban, suburban, and even some rural areas. But they cannot bridge the gap in the near term for the millions of Americans who live in the most rural and remote areas. Without an infusion of new tactics and capabilities, reaching the rest of the population—and providing a choice to millions more who have limited options—could take years or even decades, assuming it is ever achieved.

Fortunately, dramatic improvements in launch services and satellite technology can help meet the growing need for innovation. This revolution in space has enabled satellite providers to plan systems for the first time at the scale necessary to meet not just current demand, but also

future calls for truly high-speed, low-latency broadband even to underserved and unserved areas. To meet this challenge, SpaceX is proposing its Gen2 System of 30,000 NGSO satellites. More than 85% of this system will operate at very low altitudes below 400 km, using eight total orbital altitudes ranging from 328 km to 614 km. Just as large deployments of new densified 5G networks are helping those in more urban environments, the densified satellite constellation SpaceX proposes will substantially increase capacity and drive up the number of consumers even in rural and remote areas with access to truly robust broadband. While SpaceX's next-generation constellation will use only a small fraction of the number of antennas being deployed for terrestrial technologies, its spectrally efficient designs and intensive spectral reuse will allow it to bring to rural areas the type of services and prices previously reserved only for urban customers.

By operating at low and very low altitudes, the SpaceX Gen2 System will enable smaller spot beams and greater satellite diversity, achieving the intensive frequency reuse needed to heighten capacity available anywhere in the world. And by guaranteeing multiple satellites in view for every customer located at any point on the ground, SpaceX's next-generation system incorporates the flexibility necessary to coordinate with other spectrum users while still delivering robust service, even in a crowded spectrum setting.

But in a shared space environment, the ability to coexist spectrally is just the beginning—every satellite operator also has a fundamental obligation to maintain a sustainable orbital environment. As SpaceX is on the brink of becoming the first private launch provider to carry astronauts into orbit, this responsibility has never been more vital. SpaceX's deep commitment to safety drove its development of a system architecture that is safe by design. Rather than taking traditional approaches that add on safety features to a system that is otherwise complete, SpaceX explicitly designed its next-generation architecture with safety in mind from the beginning. And

just as critically, these safety measures will not be frozen in time—use of space promises to become ever more intensive and we cannot assume today's technology will be sufficient to meet tomorrow's challenges. To ensure its system is more reliable as technologies progress, SpaceX will leverage its unique iterative approach to continue to learn and upgrade its system as it deploys new satellites and replaces older models.

From the beginning of its deployment, every satellite launched as part of SpaceX's next-generation system will be equipped with SpaceX's advanced propulsion system. This cutting-edge capability is used in concert with industry-leading navigation functions to conduct active maneuvers to avoid collisions with both debris and other spacecraft throughout the life of its satellites, even through the de-orbit phase until the spacecraft enters the atmosphere. The Commission deems NGSO systems with such maneuvering capability to have zero collision risk. Yet, rather than rely solely on this capability, SpaceX has also designed its system to leverage the inherent advantages of operating at very low altitudes. Thus, in the unlikely event that an issue arises at any stage of operation, atmospheric drag will ensure that any debris quickly disintegrates in the atmosphere and poses no further danger to space operations or life on the ground. These complimentary aspects of SpaceX's safe-by-design architecture ensure its next-generation constellation can maintain an orbital environment sustainable for competitive services in the future, while driving broadband capacity to customers even in the most remote corners of the country.

But the need to preserve the orbital environment goes beyond protecting services for people on Earth. Sustainability is essential for exploration. While effects on optical astronomy fall outside the Commission's jurisdiction, SpaceX is nonetheless dedicated to ensuring its satellite systems have no meaningful impact on astronomy—or anyone looking to the skies. SpaceX has

been working closely with leading optical astronomers in the U.S. and around the world to ensure its satellites do not impede scientific discoveries from ground-based optical telescopes. SpaceX is employing discoveries made through that collaboration to drive engineering choices that reduce satellite brightness at all operational phases. And moving beyond optical astronomy, SpaceX is proud to have been the first licensee in the first NGSO processing round to reach an agreement with U.S. radio astronomers that safeguards radio observatories.

Extending true broadband connectivity to those on the wrong side of the digital divide—especially those in remote areas—will not be easy and necessitates innovative approaches and cutting-edge technologies that complement existing infrastructure. Terrestrial broadband providers are taking this on by deploying millions of miles of fiber and hundreds of thousands of new densified 5G small cells to serve urban, suburban, and some rural areas. SpaceX is complementing these efforts by investing in a Gen2 System that operates at the scale necessary to provide high-capacity, low-latency broadband service to reach even those in rural and other underserved areas. Critically, SpaceX will achieve this goal by making efficient use of spectrum that does not cause harmful interference to other licensees, ensures safety of the orbital environment, and preserves the wonder of the night sky. Accordingly, the Commission should find that grant of this application would serve the public interest.

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APPLICATION FOR APPROVAL FOR ORBITAL DEPLOYMENT AND OPERATING AUTHORITY FOR THE SPACEX GEN2 NGSO SATELLITE SYSTEM

In this application, Space Exploration Holdings, LLC ("SpaceX") requests operating authority (that is, approval for orbital deployment and a station license) for use of Ku-band, Ka-band, and E-band frequencies with a non-geostationary orbit ("NGSO") satellite system in the Fixed-Satellite Service ("FSS"). A completed Form 312, accompanying Schedule S, Technical Attachment, and Waiver Request are associated with this application, consistent with the information required by the Commission's rules in support of the requested authorization.

Similar to the way 5G terrestrial wireless networks increase capacity through cell densification, SpaceX will leverage a densified constellation of satellites specifically designed to power an expansion of high-speed, low-latency broadband to more of the country and the world. SpaceX's next-generation network (the "Gen2 System") will complement terrestrial 5G networks that typically provide their best service in urban areas. In contrast, SpaceX's Gen2 System will be optimized to first drive up capacity for those consumers in the hardest to reach rural and remote areas.

DISCUSSION

I. GRANT OF THE APPLICATION WOULD SERVE THE PUBLIC INTEREST BY QUICKLY DELIVERING BROADBAND TO MORE AMERICANS IN REMOTE AREAS OF THE UNITED STATES

The Commission authorized SpaceX in 2018 to construct, deploy, and operate its first-generation NGSO constellation consisting of 4,425 satellites using Ku- and Ka-band spectrum.[1] The Commission also authorized SpaceX to construct, deploy, and operate a very-low-Earth orbit constellation of more than 7,500 satellites using V-band frequencies, while also adding V-band frequencies to its previously authorized satellites.[2] The Commission granted SpaceX two modifications to its Ku-/Ka-band license: the first in April 2019 to relocate 1,584 satellites previously authorized to operate at an altitude of 1,150 km to an altitude of 550 km;[3] and the second, in December 2019, to allow SpaceX to respace its licensed satellites within the 550 km altitude to place coverage and capacity more evenly and rapidly across more of the U.S.[4] SpaceX recently applied for its third modification to lower its remaining Ku-/Ka-band satellites to safer altitudes.[5] This system is now on the brink of delivering truly high-speed, low-latency broadband across the United States—including to the most remote corners and Polar Regions of the country that too often get left behind.

Despite the unprecedented capacity of SpaceX's first-generation constellation, the demand for more broadband is surging and the need for connections at home has never been more important. This necessity is particularly acute in the U.S., which is home to 4.3% of the world's

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1 *See Space Exploration Holdings, LLC*, 33 FCC Rcd. 3391, ¶ 11 (2018) ("*Initial Authorization*").

2 *See Space Exploration Holdings, LLC*, 33 FCC Rcd. 11434 (2018).

3 *See Space Exploration Holdings, LLC*, 34 FCC Rcd. 2526 (IB 2019) ("*First Modification*").

4 *See Space Exploration Holdings, LLC*, 34 FCC Rcd. 12307 (IB 2019).

5 *See* Application, IBFS File No. SAT-MOD-20200417-00037 (filed Apr. 17, 2020).

population but generates nearly one-third of global IP traffic.[6] The demand for data is turning into a deluge. IP traffic is expected to grow more than 2.6 times in the next five years (a 21% average annual growth rate),[7] which is enough demand to stress networks to the breaking point.

While existing networks have stood up admirably during the COVID pandemic, the current crisis is laying bare the true cost for those stuck on the wrong side of the digital divide.

- *Homework gap*: Students increasingly must go online for educational instruction and to complete homework assignments. But nearly one-third of U.S. households still have no Internet connection.[8] Many of these homes are in the hardest to reach areas of the country, such as Alaska.
- *Telework*: Up to half of Americans are working from home and that portion is likely to remain high.[9] For the record-high number of unemployed Americans, broadband connections are necessary for job interviews that take place through videoconferencing.
- *Telehealth*: Demand for remote medicine has spiked this year, yet a quarter of Americans do not have a primary care provider, often because of geographic limitations.[10] Institutions are now working to add new broadband capabilities that will benefit patients for years.

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6 *See* USTelecom, "Industry Metrics and Trends 2020," slide 36 (Feb. 2020) ("USTelecom 2020 Report"), https://www.ustelecom.org/wp-content/uploads/2020/02/USTelecom-State-of-Industry-2020.pdf.

7 *See id.* slide 32.

8 *See* Brian Heater, "Nearly a third of US households don't have a broadband connection," TECHCRUNCH (July 25, 2019), https://techcrunch.com/2019/07/25/nearly-a-third-of-u-s-households-dont-have-a-broadband-connection/.

9 *See* Katherine Guyot and Isabel V. Sawhill, "Telecommuting will likely continue long after the pandemic," BROOKINGS (Apr. 6, 2020), https://www.brookings.edu/blog/up-front/2020/04/06/telecommuting-will-likely-continue-long-after-the-pandemic/.

10 *See* Amy Norton, "Fewer Americans Have a Primary Care Doctor Now," U.S. NEWS (Dec. 17, 2019); https://www.usnews.com/news/health-news/articles/2019-12-17/fewer-americans-have-a-primary-care-doctor-now; Kirk Siegler, "The Struggle to Hire and Keep Doctors in Rural Areas Means Patients Go Without Care," NPR (May 21, 2019), https://www.npr.org/sections/health-shots/2019/05/21/725118232/the-struggle-to-hire-and-keep-doctors-in-rural-areas-means-patients-go-without-c.

- *Precision agriculture*: As the country is working to protect and deliver a consistent food supply, the U.S. Department of Agriculture found that deployment of broadband to improve precision agriculture could lead to over $47 billion in annual economic benefits.[11]
- *National security*: In times of emergency, immediate access to information is critical to secure the country.
- *First responders*: Emergency medical personnel, police, firefighters, and other public safety officials depend on high-speed connectivity to coordinate their operations and keep us safe.

The list goes on. But clearly, the need to stay connected is more urgent than ever for all Americans—no matter where they live. The demands brought to the fore today will outlast the current crisis. The volume of traffic flowing over the world's networks continues to grow, with one report estimating more traffic in 2022 alone than in the 32 years combined since the Internet started, and more than six people in ten in the world being online.[12]

To address this surging demand, terrestrial network providers are mobilizing. Network densification will be an important part of this response, given that 4G networks are roughly ten times denser than 3G, and 5G networks will need to be roughly ten times denser still to deliver the high capacity and low latency consumers need.[13] Wireless providers are planning to deploy 800,000 cells across the country by 2026.[14] Cable and telecommunications companies have

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[11] *See* Press Release, "USDA Releases Report on Rural Broadband and Benefits of Next Generation Precision Agriculture," U.S. DEPT. OF AGRICULTURE (Apr. 30, 2019), https://www.usda.gov/media/press-releases/2019/04/30/usda-releases-report-rural-broadband-and-benefits-next-generation.

[12] News Release, "Cisco Predicts More IP Traffic in the Next Five Years Than in the History of the Internet," CISCO (Nov. 27, 2018), https://newsroom.cisco.com/press-release-content?type=webcontent&articleId=1955935.

[13] *See* Luke Getto, "The Challenges of 5G Network Densification," MICROWAVE JOURNAL (May 14, 2019), https://www.microwavejournal.com/articles/32235-the-challenges-of-5g-network-densification.

[14] *See* Industry Data, "Towers and Small Cells," CTIA, https://www.ctia.org/the-wireless-industry/infographics-library?topic=22.

millions of miles of fiber crisscrossing the United States. Together, these investments will provide essential services to those living in urban, suburban, and even many rural areas. But they cannot bridge the gap for those who live in the most rural and remote areas. Fixed broadband is approaching only 85% penetration in the U.S. and mobile penetration is just 83% of households.[15] Without an infusion of new tactics and capabilities, reaching the rest of the population could take years or even decades, assuming it is ever achieved.

Thanks in part to dramatic improvements in launch services over the past few years, there is a new alternative that promises to help bridge this divide. Changes in launch technology have made it possible for the first time for satellite providers to plan systems at the scale necessary to bring truly high-speed, low-latency broadband to underserved and unserved areas. Just as large deployments of new densified 5G networks are helping those in more urban environments, SpaceX's densified satellite constellation will substantially increase capacity and drive up the number of consumers even in rural and remote areas with truly robust broadband while using only a small fraction of the number of antennas being deployed for terrestrial 5G networks.

Due to its low altitudes, SpaceX's Gen2 System will provide service with latency of its transmissions below 50 milliseconds, which is nearly unnoticeable to consumers. This system will ensure that all Americans—even those in Polar Regions—enjoy the same low latency services. Only just over half the population living in rural Alaska and no one on Alaskan Tribal Lands has access to fixed broadband service at speeds that meet even the Commission's minimum definition for broadband.[16] And residential consumers are not the only beneficiaries of this improved service. For many Federal broadband users, satellite service is the only communications option to support

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[15] *See* USTelecom 2020 Report, slides 16-17.

[16] *See Inquiry Concerning Deployment of Advanced Telecommunications Capability to All Americans in a Reasonable and Timely Fashion*, 34 FCC Rcd. 3857, Appendices 6 and 7 (2019).

critical missions. Improving capacity and latency for these users could have significant national security benefits.

Significantly, SpaceX's next-generation constellation will employ a host of cutting-edge innovations to ensure its system does not cause significant spectral interference for others. As demonstrated in the Technical Attachment accompanying this application, the system will not create harmful interference to geostationary orbit ("GSO") satellites, to other NGSO systems, or to terrestrial networks. By operating at low and very low altitudes, the new SpaceX Gen2 System will enable smaller spot beams and greater satellite diversity, achieving a higher degree of frequency reuse and thereby significantly enhancing the data capacity that can be made available anywhere in the world. And by ensuring every consumer has multiple satellites in view from any given point on the ground, SpaceX's next-generation system will have flexibility to deliver robust service, even in a crowded spectrum environment. These same attributes will give SpaceX the agility to address any spectrum coordination issues that may arise in the E-band, where the Commission has not yet adopted service rules or licensed other satellite operators. As it has done with its first-generation NGSO system, SpaceX will seek in every case to reach coordination agreements that optimize spectrum efficiency and allow for the greatest operational flexibility possible among licensed systems.

Finally, SpaceX takes seriously its responsibility to protect the shared orbital environment. To meet that responsibility, SpaceX is leveraging the built-in advantages of operating at low altitude and applying its unique iterative and integrated approach to take a series of unprecedented steps that minimize the effect its constellation will have on other operating spacecraft and other orbital resources. SpaceX has designed its system so that normal operations should not generate any debris, but in the unlikely event that any does result, atmospheric drag will ensure that such

debris will quickly disintegrate in the atmosphere and pose no further danger to space operations or life on the ground. Moreover, its satellites will have sufficient maneuverability to avoid other satellites and orbital debris throughout their mission lifetime and through the de-orbit process. Thus, these Gen2 spacecraft will contribute a great deal of capacity to serve consumers without imposing undue risk to safety in space.

II. SPACEX'S NEXT-GENERATION CONSTELLATION

A. SpaceX Background

SpaceX is a private company founded in 2002 to revolutionize space technologies, with the ultimate goal of enabling humanity to become a multi-planetary species. The company designs, manufactures, and launches advanced rockets and spacecraft. It has over 6,000 employees based in the United States at the company's headquarters in Hawthorne, California and facilities located across the country.

Since its founding in 2002, SpaceX has achieved a series of historic milestones. In December 2010, SpaceX became the first private company ever to successfully launch and return a spacecraft (Dragon) from low-Earth orbit. In May 2012, the company again made history when Dragon berthed with the International Space Station ("ISS"), delivered cargo, and returned safely to Earth–a technically challenging feat previously accomplished only by governments. In December 2015, SpaceX successfully returned a first stage rocket booster to land after carrying a payload to space, and has since landed 50 more times and has reflown 35 boosters, including up to five reflights of a single booster. And by leveraging the reusability of its rockets, SpaceX has launched over 420 of its own satellites, which will be used to provide high-speed broadband across the country and around the world.

SpaceX's current and planned space-based activities underscore its commitment to space safety. SpaceX is proud that NASA has entrusted the company to safely carry American astronauts in the coming days to and from the ISS, a more than $100 billion multinational facility with human beings onboard. Nothing is more important to SpaceX than safely and successfully accomplishing this mission. The company is highly experienced with space-based operations and debris mitigation practices. SpaceX maintains deep ties with the domestic and international institutions tasked with ensuring the continued safety of space operations, which facilitates aggressive and effective space-debris mitigation practices. SpaceX brings this commitment and experience to all aspects of its space-based operations.

B. The Gen2 System

The SpaceX Gen2 System consists of a constellation of low and very low Earth orbit satellites, which will leverage SpaceX's existing ground equipment and user terminals, as well as add new equipment to optimize performance for consumers. This new system is highly spectrum-efficient, sharing Ku-, Ka-, and E-band spectrum with conventional GSO satellite and terrestrial networks without causing harmful interference. It will operate under new network filings—separate from those made for SpaceX's original Ku-/Ka-band license—made on behalf of SpaceX at the ITU by the United States.

SpaceX has designed its system to achieve the following objectives:

- *High capacity*: Each initial Gen2 satellite will have three times the data capacity of SpaceX's current satellites. And just as it has done with its first-generation system, SpaceX will continue to iteratively improve the satellites over the course of the multi-year deployment of the system, which will further increase capacity.

- *High adaptability*: The system leverages phased array technology to dynamically steer a large pool of beams to focus capacity to meet consumer demand. Optical inter-satellite links will permit flexible routing of traffic on-orbit. Further, the constellation ensures that frequencies can be reused effectively across different satellites to enhance the flexibility, agility, capacity, and robustness of the overall system.
- *True broadband services*: The system will be able to provide high-throughput speeds, with latencies under 50 milliseconds.
- *Remote/Polar coverage*: The network is designed to bring to remote and Polar Regions the same quality service that has been traditionally available only to urban customers.
- *Low cost*: SpaceX is designing the overall system from the ground up with cost-effectiveness and reliability in mind, from the design and manufacturing of the space and ground-based elements, to the launch and deployment of the system using SpaceX launch services, development of the user terminals, and end-user subscription rates.
- *Ease of use*: SpaceX's phased-array user antenna design will allow for a low-profile user terminal that is easy to install. User terminal installation should generally require two steps: point it at the sky and plug it in.

The various space and ground facilities comprising the Gen2 System are described below and in more detail in Schedule S and the Technical Attachment (Attachment A) accompanying this application.

i. Space Segment

The Gen2 System will consist of 30,000 second-generation satellites, configured as follows and using elevation angles described in the Technical Attachment:

Altitude (km)	Inclination (degrees)	Orbital Planes	Satellites per Plane
328	30	1	7,178
334	40	1	7,178
345	53	1	7,178
360	96.9	40	50
373	75	1	1,998
499	53	1	4,000
604	148	12	12
614	115.7	18	18

This constellation will enable SpaceX to provide full and continuous coverage of the Earth. As each satellite is launched and brought into operation, it will be immediately integrated into the system and used to enhance broadband service offerings.

The Gen2 System will use Ka-band spectrum for communications between satellites and both gateways and user terminals, Ku-band spectrum for communications between satellites and user terminals only, and E-band spectrum for communications between satellites and gateways only. SpaceX requests authority to operate on the following frequencies:

Type of Link and Transmission Direction	Frequency Ranges
User Downlink Satellite-to-User Terminal	10.7 – 12.75 GHz[17] 17.8 – 18.6 GHz 18.8 – 19.3 GHz 19.7 – 20.2 GHz
Gateway Downlink Satellite to Gateway	17.8 – 18.6 GHz 18.8 – 19.3 GHz 71.0 – 76.0 GHz
User Uplink User Terminal to Satellite	12.75 – 13.25 GHz[18] 14.0 – 14.5 GHz 28.35 – 29.1 GHz 29.5 – 30.0 GHz
Gateway Uplink Gateway to Satellite	27.5 – 29.1 GHz 29.5 – 30.0 GHz 81.0 – 86.0 GHz
TT&C Downlink	12.15 – 12.25 GHz 18.55 – 18.60 GHz
TT&C Uplink	13.85 – 14.00 GHz

A more precise description of the frequency and channelization plan for the Gen2 System is included in Schedule S and the Technical Attachment accompanying this application.

[17] SpaceX does not seek authority to provide service in the United States using the 12.7-12.75 GHz band, but proposes to use that spectrum in other areas of the world where allowed.

[18] At this time, SpaceX seeks authority to use this band in the United States only with individually-licensed earth stations. No such limitations would apply outside the U.S. In the future, SpaceX may seek authority to operate blanket-licensed user terminals in the U.S. as well.

ii. Ground Segment

The Gen2 System will leverage the three broad categories of earth stations used by its first-generation system (tracking, telemetry and control ("TT&C") stations; gateway earth stations; and user terminals) as well as add additional infrastructure. The TT&C stations will be on the order of five meters in diameter, and relatively few in number (e.g., primary and back-up TT&C locations in the United States, with several more locations distributed internationally). The gateway earth stations will use parabolic dishes, with several hundred locations anticipated within the U.S., co-located with or sited near major Internet peering points to provide the required Internet connectivity to the satellite constellation. To speed deployment of service to consumers, the Gen2 System will be backwards compatible with the licensed Ku-band phased-array user terminal technology used by the first-generation system. These terminals have been designed for high efficiency, low cost, and ease of installation.

While SpaceX plans to leverage its existing ground infrastructure and user terminals, it will submit applications to the Commission as needed to request individual licenses for any additional TT&C stations, enterprise user terminals, and gateway earth stations, and a blanket license for new user terminals to be located in the United States, pursuant to Sections 25.115 and 25.130 of the Commission's rules.

III. SPACEX HAS TAKEN EXTENSIVE STEPS TO PROTECT PHYSICAL OPERATIONS IN SIMILAR ORBITS

While SpaceX's commitment to human spaceflight alone would be sufficient incentive to take all practical measures to ensure that the orbital environment remains safe, the company also depends on a clean environment for its commercial satellite customers for whom SpaceX must safely deliver satellite payloads to their proper orbital altitudes. For other missions, SpaceX must reliably transport cargo to the ISS. SpaceX is privileged to be trusted by NASA and its

International Partners to approach and berth or dock with the ISS—a highly complex operation with stringent safety protocols and virtually no margin for error. SpaceX's operational experience in being one of the world's few "visiting vehicles" to the ISS highlights its capability to maintain safe space operations. Because of its reliability, NASA has chosen SpaceX as the first private company ever to deliver astronauts to the ISS.

In addition, SpaceX has used the experience gained by operating its initial satellites at 550 km to prove out several important features of operating at lower altitude. First and foremost, as noted above, the natural atmospheric advantage of lower altitude helps reduce the impact of potential debris from other sources. As the Commission has recognized, objects de-orbit more quickly below 650 km.[19] At these altitudes, the Earth and its atmosphere sweep the orbit clean—atmospheric drag naturally removes objects from orbit, including loose debris. But while these environmental advantages during nominal operations are substantial, the lower altitude also improves safety during off-nominal events if satellites fail to fully complete their active disposal operations. The passive orbital decay of a satellite at higher orbits such as 1,000 km can take centuries, but Gen2 satellites will take less than three months to de-orbit at its lowest altitudes and less than ten years (even under worst-case assumptions) to de-orbit at its highest altitude. Moreover, SpaceX has reduced risk still further by designing its Gen2 System with the vast majority of its satellites operating below the ISS. A satellite flying at 350 km is 21,000 times less likely to have a collision with a piece of space debris than one flying at 800 km.

[19] *See Mitigation of Orbital Debris in the New Space Age*, FCC 20-54, ¶ 43 (rel. Apr. 24, 2020).

A. SpaceX Will Avoid Collisions with Non-Propulsive Small Satellites and Already Employs the Most Aggressive Collision Space Traffic Management in the Industry

Some small satellite operators have in the past expressed concerns that authorizing other systems to operate at altitudes similar to theirs would make deployment of their non-propulsive systems more difficult, given their own limited capability for collision avoidance.[20] SpaceX has made clear that it intends to conduct active maneuvers to avoid collisions with both debris and non-maneuverable spacecraft throughout the life of its satellites, even through the de-orbit phase until the spacecraft enters the atmosphere. SpaceX has invested in advanced propulsion capabilities for its satellites, meaning collision risk should be considered to be zero.[21] In any event, just as SpaceX has contacted each of the licensed systems from the initial NGSO processing rounds, it will coordinate its physical operations with other NGSO systems (which are also obligated to conduct physical coordination even if they lack propulsive capabilities).[22]

Nonetheless, as an operational matter, SpaceX's industry-leading navigation and propulsive capabilities enable it to avoid non-propulsive systems unilaterally. Yet, these types of voluntary steps would be a poor basis for license conditions. This sort of condition would put additional regulatory burden on the system that invested in advanced maneuvering capabilities, which could inadvertently create a race to the bottom where operators make their systems as non-maneuverable as possible in an effort to avoid regulatory burdens and transfer responsibility to others for protecting their own space investments.

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[20] *See* Comments and Petition to Defer ("CSSMA Comments"); Petition to Defer ("Astro Digital Petition"); Petition to Defer ("Planet Labs Petition); and Petition to Defer ("Spire Petition"). All these filings were submitted in IBFS File No. SAT-MOD-20181108-00083 on January 29, 2019.

[21] *See, e.g., First Modification*, ¶ 22.

[22] *See id.*

In addition to its voluntary steps to autonomously avoid non-propulsive systems, SpaceX leads the industry in the transparency measures it has taken with its first-generation system to ensure a safe space environment. For instance, SpaceX provides all of its ephemeris data to other operators via spacetrack.org and other public means. SpaceX is also the first operator to optimize the usefulness of this data by supplementing it with co-variance data, which allows other operators to better assess the potential for collision between their own vehicles and SpaceX satellites. Going forward, SpaceX will extend these activities to its new system and encourages all operators to follow these same practices.

IV. SPACEX IS WORKING WITH ASTRONOMERS TO ENSURE ITS OPERATIONS HAVE NO MATERIAL IMPACT ON VIEWS OF THE NIGHT SKY

While many were excited after SpaceX's first-generation satellite launches, some in the optical astronomy community voiced concern that the light reflected from those satellites could interfere with their space observations.[23] Because SpaceX believes in the importance of scientific discoveries by astronomy and a natural night sky for all of us to enjoy, it remains committed to promoting all forms of space exploration. SpaceX is proud to be the first NGSO licensee in its processing round to reach an agreement with U.S. radio astronomers to ensure its service does not interfere with radio observatories in keeping with ITU and Commission recommendations, and has extended spectrum coordination discussions with leading radio astronomers in Europe and elsewhere.[24] SpaceX has also been working closely with leading optical astronomers in the U.S. and around the world to understand exactly how its satellites are observed by ground-based optical

[23] *See, e.g.,* Shannon Hall, "After SpaceX Starlink Launch, a Fear of Satellites That Outnumber All Visible Stars," NEW YORK TIMES (June 1, 2019), https://www nytimes.com/2019/06/01/science/starlink-spacex-astronomers html.

[24] *See* National Science Foundation, Press Statement 19-005, "Statement on NSF and SpaceX Radio Spectrum Coordination Agreement" (June 4, 2019), https://www nsf.gov/news/news_summ.jsp?cntn_id=298678.

telescopes and the range of astronomical observations underway to use that information to drive engineering changes that can reduce satellite brightness at all operational phases.

Although the Commission does not have jurisdiction over the visibility of satellites, SpaceX nonetheless has undertaken considerable efforts to mitigate the effect of its satellites for optical astronomers and those observing the night sky. While no established guidelines or standards exist for acceptable levels of reflection from spacecraft, SpaceX is working with U.S. and international astronomy organizations and observatories to measure scientifically the actual effect of its satellites, with the goal of integrating novel techniques to ameliorate the effect to the greatest extent feasible. As noted by SpaceX founder and CEO Elon Musk, "we'll make sure Starlink has no material effect on discoveries in astronomy."[25] For its initial constellation, SpaceX has applied its iterative engineering, design and manufacturing approach to field and test mitigation solutions in early launches and then integrate validated solutions as standard spacecraft design features for upcoming satellites in the initial constellation, as well as its next-generation system.

With the astronomy community, SpaceX has been studying the brightness of its satellites at all phases of operation, and is pursuing the following goals in its work to mitigate the brightness of Gen2 satellites so as not to harm space exploration or discovery:

1. Ensure its satellites are generally invisible to the naked eye within a week of launch.
2. Minimize the effect any SpaceX satellite will have on astronomy.

To meet the first goal and keep the satellite "trains" essentially invisible during the weeks following Gen2 launches, SpaceX is employing two operations that will greatly reduce the brightness of the satellites as they make their way to their on-station orbital positions. First,

[25] @elonmusk, TWITTER (May 27, 2019, 3:11 AM).

SpaceX will roll orbit raising satellites during visible periods. Second, SpaceX will reposition the solar array of parked satellites. SpaceX has determined that during the shorter orbit-raising phase of its operations, the satellites are closely clustered after launch and their solar arrays are in a special low-drag configuration, making them more visible from the ground. The operational "roll" technique and solar array repositioning have already been tested and have been observed to reduce the visibility of the satellites significantly, both for naked eye observation and for astronomers.

To accomplish the second goal of minimizing the effect on astronomy during the satellites' life on orbit, SpaceX is employing spacecraft design changes to reduce the reflected sunlight (albedo) from the body of on-station satellites. To test ways to bring its satellites closer to total invisibility to the naked eye, SpaceX used an experimental darkening treatment on a single first-generation satellite. Measurements from astronomers around the world indicate that this initial "Darksat" test satellite successfully reduced the visibility level by 55%.[26] To further mitigate brightness beyond detection with the unaided eye and to dramatically reduce the impact that its satellites have on the detectors at even the most sensitive ground-based optical telescopes, SpaceX will next deploy a second test satellite with visors to block sunlight from hitting the brightest parts of the spacecraft. Once validated, these visors will be integrated into the standard spacecraft design for the initial constellation going forward and for Gen2. SpaceX is committed to making future satellite designs as dark as possible, and the next-generation satellites will be specifically designed to minimize brightness while also increasing the number of consumers that it can serve with high-speed Internet access. Moreover, for scheduling observations around satellites, SpaceX will use its ephemeris data to generate two-line elements ("TLEs") that will be publicly available on

[26] *See* J. Tregloan-Reed, A. Otarola, E. Ortiz, V. Molina, J. Anais, R. González, J. P. Colque, and E. Unda-Sanzana,, "First Observations and Magnitude Measurement of SpaceX's Darksat," Astronomy and Astrophysics (Apr. 16, 2020), https://arxiv.org/pdf/2003.07251.pdf.

spacetrack.org. To further help with observation scheduling, SpaceX will also work with Celestrak.com to publish predictive TLEs for each launch.[27] These predictive TLEs enable observation scheduling for the short period between satellite insertion and the availability of regularly updated TLEs.

Based on experience gained from its first-generation system, SpaceX is on the forefront of mitigating the effects of constellations such that satellites can be deployed without impeding scientific discovery, space exploration, or appreciation of a starry night. This experience will enable SpaceX to bring the substantial benefits of broadband access to underserved populations around the world without materially impacting views of the night sky.

Finally, while SpaceX will be operating at altitudes lower than most other satellites, other systems operating at higher orbits should still carefully assess and take steps to mitigate their effect on optical astronomy. Although satellites operating at a higher altitude will tend to be less bright to the unaided eye, they will also be subject to a number of other factors that will actually increase their potential to harm astronomical observations as well as enjoyment of the night sky. These satellites will be visible to a larger section of the Earth, for a longer period, later into the night. Additionally, due to the decreased angular velocity with respect to the observer, the satellites will take longer to streak across a pixel, making them more likely to saturate pixels than an object of equal apparent magnitude orbiting at a lower altitude.

Given these complexities, SpaceX encourages all satellite operators to work with astronomers to consider what steps they can take to protect astronomical discovery. SpaceX is committed to preserving not only the science of astronomy, but also the human inspiration of the

[27] @TSKelso, TWITTER (Jan. 4, 2020, 2:56 a.m.).

natural sky, and will share the experience gained in working with astronomers and testing mitigation techniques with the broader satellite community.

V. ITU COST RECOVERY

SpaceX is aware that, as a result of the actions taken at the 1998 Plenipotentiary Conference, as modified by the ITU Council in 2005, the ITU now charges processing fees for satellite network filings. As a consequence, Commission applicants are responsible for any and all fees charged by the ITU. SpaceX confirms that it is aware of this requirement and accepts responsibility to pay any ITU cost recovery fees associated with this application. Invoices for such fees may be sent to the contact representative listed in the accompanying FCC Form 312.

VI. ELIGIBILITY AND OPERATIONAL REQUIREMENTS

To the extent necessary, SpaceX confirms that (1) it has no right that would run afoul of the prohibition in Section 25.145(e) of the Commission's rules, nor will it acquire any such right in the future; (2) it will post a surety bond as required under Section 25.165 of the Commission's rules; (3) it will comply with the Commission's milestone requirements; and (4) it does not have any other application for an NGSO-like satellite system license on file with the Commission, or any licensed-but-unbuilt NGSO-like system, in any frequency band involved in this application.

CONCLUSION

For the foregoing reasons, and for the reasons set forth in the accompanying materials, SpaceX requests that the Commission find that granting approval for orbital deployment and a station license (i.e., operating authority) for the SpaceX's Gen2 System would serve the public interest, and issue such grant expeditiously.

Respectfully submitted,

SPACE EXPLORATION HOLDINGS, LLC

By: */s/ David Goldman*
David Goldman
Director of Satellite Policy

William M. Wiltshire
Paul Caritj
HARRIS, WILTSHIRE & GRANNIS LLP
1919 M Street, N.W.
Suite 800
Washington, DC 20036
202-730-1300 tel
202-730-1301 fax

Counsel to SpaceX

SPACE EXPLORATION TECHNOLOGIES CORP.
1155 F Street, NW
Suite 475
Washington, DC 20004
202-649-2700 tel
202-649-2701 fax

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