RECORD NOS. 21-1123(L), 21-1125, 21-1127, 21-1128

ORAL ARGUMENT HAS NOT YET BEEN SCHEDULED

In The

United States Court of Appeals

For The District of Columbia Circuit

VIASAT, INC.; DISH NETWORK CORPORATION; THE BALANCE GROUP,

Appellants,

v.

FEDERAL COMMUNICATIONS COMMISSION,

Appellee.

SPACE EXPLORATION HOLDINGS, LLC,

Intervenor for Respondent

ON APPEAL FROM THE FEDERAL COMMUNICATIONS COMMISSION IBFS FILE NO. SAT-MOD-20200417-00037

BRIEF OF PROFESSOR ANDY LAWRENCE AS *AMICUS CURIAE* IN SUPPORT OF VACATUR

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CERTIFICATE AS TO PARTIES, RULINGS, AND RELATED CASES

A. Parties and *Amici*

The following are the individuals or entities that participated in the proceedings before the Federal Communications Commission in this matter:

Akiak IRA Council
American Astronomical Society
Astroscale U.S. Inc.
AT&T Services, Inc.
The Balance Group
Cass Cable TV, Inc.
Computer & Communications Industry Association
DIRECTV Enterprises, LLC
DISH Network Corporation
DISH Network LLC
Go Long Wireless, Ltd.
Hughes Network Systems, LLC
INCOMPAS
Kepler Communications Inc.
Kodiak Archipelago Rural Regional Leadership Forum
Kuiper Systems LLC
O3b Limited
Pacific Dataport Inc.
RS Access, LLC
SES Americom, Inc.
Space Exploration Technologies Corp.
Spire Global, Inc.
Story Communications, LLC
Telesat Canada
Viasat, Inc.
Vision Broadband, LLC
WorldVu Satellites Limited, Debtor-in-Possession

Ada Agiak
John Agiak
Lucas Aishanna
Andrea Brower
Jacob Calderwood
Carey Halnier
Kalea Kaleak
Billy Killbear
Jonah Koonce
Kaden Kulukhon
Prof. Andy Lawrence
Jonathan McDowell
Vernon Samson
Collin Solomon
Joel M. Thomas
John Wallace

At present, the parties in this Court are:

Viasat, Inc., appellant/petitioner in Nos. 21-1123, 21-1125
DISH Network Corporation and DISH Network LLC, appellants in No. 21-1127
The Balance Group, appellant in No. 21-1128
Federal Communications Commission, appellee/respondent
United States of America, respondent in No. 21-1125 under 28 U.S.C. § 2344
Space Exploration Holdings, LLC, intervenor for appellee/respondent and Professor Andy Lawrence as *amicus curiae*

B. Rulings Under Review

The Order of the Federal Communications Commission under review ("Order") is captioned In the Matter of Space Exploration Holdings, LLC; Request for Modification of the Authorization for the SpaceX NGSO Satellite System, *Order and Authorization and Order on*

Reconsideration, IBFS File No. SATMOD-20200417-00037, Call Signs S2983 and S3018, FCC 21-48 (released April 27, 2021). The Order has not yet been published in the FCC Rcd.

C. Related Cases

The case on review was not previously before this court or any other court. Counsel are not aware of any other related cases currently pending in this court or in any other court, other than the consolidated cases: *Viasat, Inc. v. FCC*, Case No. 21-1125; *DISH Network Corp. v. FCC*, Case No. 21-1127; *The Balance Group v. FCC*, Case No. 21-1128.

Dated: August 13, 2021

Respectfully submitted,

/s/ Jean-Claude André
Jean-Claude André
Counsel for Amicus Curiae
Professor Andy Lawrence

CORPORATE DISCLOSURE STATEMENT

Pursuant to Fed. R. App. 29(a)(4)(A) and Circuit Rule 29(b), the *amicus curiae* submitting this brief states that he is not a corporation.

STATEMENT REGARDING CONSENT TO FILE

Per the conditions in Fed. R. App. P. 29(a)(2) and Circuit Rule 29(b), the *amicus curiae* submitting this brief states that all parties have consented to its filing.

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IDENTITY OF *AMICUS CURIAE*, INTEREST IN THE CASE AND SOURCE OF AUTHORITY TO FILE

Professor Andy Lawrence is the Regius Professor of Astronomy at the University of Edinburgh. Professor Lawrence has decades of experience in astronomy at many wavelengths, from the ground and from space, and is the author of several hundred scientific publications. He is also the author of a non-technical book on large satellite constellations, entitled *Losing the Sky* (2021). In the Federal Communication Commission's administrative proceeding, Professor Lawrence submitted a letter in response to the application of Intervenor Space Exploration Holdings, LLC ("SpaceX") underlying these appeals. *See* Commission Order at 8 ¶ 5 n.36.

Professor Lawrence has coordinated this brief with assistance from Dr. Meredith Rawls, Ph.D., of the University of Washington; Professor Moriba Jah, Ph.D., Associate Professor, Department of Aerospace Engineering and Engineering Mechanics, at the University of Texas at Austin; and numerous community contributions.

Professor Lawrence is (and the other astronomers are) interested in this case because the Commission's order underlying it has significant potential consequences for astronomy and humans' access to the sky. The

United States and international astronomical communities have had multiple meetings to discuss how to address the new landscape of increasing numbers of bright low-Earth orbit satellites like the satellites authorized by the Commission's order in this case. Astronomers have also engaged with satellite companies to discuss ways to mitigate the problems, but none of these mitigations can avoid low-Earth orbit satellite constellations harming astronomical science.

The damage caused by satellite constellations will have a direct cost, including extending or requiring the repetition of observations, which consumes scientist time and can damage careers. Deploying mitigations will also impose significant costs, either on the astronomical community or on the satellite operator companies, or both. This is a classic example of environmental damage: the externalization of true costs. Although the Commission's order encourages SpaceX to continue engagement with the astronomical community, that engagement ought to proceed under the context and guidance of meaningful environmental assessment.

STATEMENTS REGARDING AUTHORSHIP AND FUNDING

Professor Lawrence states that (i) no party's counsel authored this brief in whole or in part; (ii) no party, nor a party's counsel contributed money that was intended to fund preparing or submitting this brief; and (iii) no person—other than Professor Lawrence or his counsel—contributed money that was intended to fund preparing or submitting this brief.

I. INTRODUCTION

Humans have interacted with the night sky for thousands of years. Only recently, however, have humans begun launching objects into near-Earth orbital space. Presently, there are over 4,500 active satellites in the near-Earth orbital space, and by 2030, that number may reach 100,000. In this case, the Federal Communications Commission had a chance to review whether these novel, massive satellite launches "*may*" have significant impacts on the human environment, but the Commission looked the other way.

In the order under review by the Court, the Commission authorized the deployment of over 2,800 satellites without requiring a formal assessment of the deployment's impact on the environment—that is, without a meaningful evaluation of the deployment's externalized costs. That order should be vacated with directions for the Commission to conduct or require a meaningful environmental assessment because the potential externalized costs are many and significant.

As amicus will explain, each anthropogenic space object has the potential to affect how humans interact with the sky and with space. This is true whether the object is a large, reflective satellite closer to

Earth and visible to all naked eyes or whether the object is a smaller, less-reflective satellite that prevents professional astronomers like amicus from using their tools to observe the space beyond. This is also true whether the object is durable, able to withstand collisions with existing space debris, and able to be decommissioned without creating new debris or whether the object is delicate and likely to create more debris upon collision or decommission. Much like what happens in more-familiar ecosystems, when there are drastic changes in near-Earth orbital space—even if over time—those changes have impacts on humans and the human environment. Accordingly, before the Commission authorizes a large-scale deployment of objects into near-Earth orbital space, it should at least assess whether that authorization "*may*" have a significant impact on the human environment. Under the National Environmental Policy Act of 1969 and its implementing regulations, that assessment is called an "environmental assessment," and the Commission should have required one in this case.

Instead, the Commission refused to consider the question. Relying on its 35-year-old "categorical exclusion" framework, which reflects a terrestrially focused definition of the human environment that is no longer apt, the Commission circularly determined that it would not have to assess the environmental impacts of its order because, essentially, the effects of the order would not have been understandable in 1986. At the same time, because the satellite launch fits within the overbroad set of actions that, in 1986, would not have predictably had cumulatively significant effects on the human environment, the Commission decided that it should not have to assess whether this launch of thousands of satellites might have cumulative effects worth considering.

In both of these respects, the Commission's order is unreasonable, and therefore arbitrary and capricious, and should be vacated.

II. BACKGROUND

A. NEPA and the Commission's Environmental Assessment Regulations

Under the National Environmental Policy Act of 1969 (NEPA), an agency is required to provide an environmental impact statement if it will be undertaking a "major Federal actio[n]," which "significantly affect[s] the quality of the human environment." 42 U.S.C. § 4332(2)(C)(i).

The Federal Communications Commission has regulations that it uses to implement this requirement. Those regulations set up a two-step process. First, the Commission determines whether its proposed action fits within a "categorical exclusion." *See* 47 C.F.R. §§ 1.1306–1.1307; 40 C.F.R. § 1501.4(a)(2) (2020). If the proposed action does fit within a "categorical exclusion," the Commission will not review its environmental effects by means of an environmental assessment or more rigorous environmental impact statement. *See id.* Since 1986, the Commission has categorically excluded all of its actions from NEPA review except for a small number of exceptions—each of which focuses on terrestrial projects—listed in its regulations. *See* 47 C.F.R. § 1.1306(a) (categorically excluding from environmental review all actions except for actions affecting wildlife and wilderness, historic and Native American sites, floodplains, "surface features," and "residential neighborhoods"). Second, where the proposed action fits within a "categorical exclusion" but an "interested person" has nonetheless requested an environmental assessment—as Appellants Viasat, Inc., and The Balance Group did here—the Commission must determine whether the proposed action "*may* have a significant environmental impact." *See* 47 C.F.R. § 1.1307(c) (emphasis added).

B. The Commission's Order Permitting SpaceX's Deployment of Thousands of Satellites

To provide orbital infrastructure for a satellite-based internet service marketed under the name Starlink, SpaceX applied to the Commission for authorization to deploy 2,824 low-Earth orbit ("LEO") satellites. LEO constitutes the orbit 100 km to 1,200 km above the Earth's surface, and it contains many anthropogenic space objects at around 500 km from Earth.[1] Scientific missions, Earth-observation

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[1] Atmospheric drag—the atmospheric force (friction) acting opposite to the relative motion of an object, which can pull orbital objects back toward Earth over time absent corrective measures—changes fast with height in this region. Thus, for example, at around 500 km from Earth, a satellite's orbit will decay within a few months to a few years. In contrast, around 1,500 km from Earth, a satellite will remain in orbit for hundreds of years even after it is defunct.

There are, of course, other orbits. Below about 80 km to 100 km, which commonly is known as the "edge of space," atmospheric drag is so severe that a spacecraft falls back to Earth in a single orbit or less.

Above LEO, roughly around 20,000 km from Earth, is the medium-Earth orbit. This is the regime of navigation satellites such as GPS and GLONASS, and recently of some internet communications systems. The orbital period is around twelve hours, and each satellite can communicate with a large fraction of the Earth. From the perspective of a person on Earth, a spacecraft in middle-Earth orbit will move across the sky much more slowly, and remain in the field of view for an hour.

The geosynchronous orbit—so called because the orbital period is exactly one day—is at roughly 35,786 km. Depending on its orbit, a satellite will hover or do a slight waggle over a fixed spot on the Earth's surface, but it is visible from a large fraction of the Earth's surface. This missions, some military missions, and some communications systems have dominated its use.

As "interested persons" within the meaning of § 1.1307(c), Viasat, The Balance Group, and others petitioned the Commission to require an environmental assessment. *See* Commission Order at 4 ¶ 5. In their view, an environmental assessment was necessary because of the potential impact of launching and deorbiting large numbers of satellites on the composition of the Earth's atmosphere and global climate change; the risk of SpaceX's satellites surviving reentry and causing damage inside Earth's atmosphere; the increased light pollution caused by the modified SpaceX constellation; the impact on the safety and sustainability of the orbital environment; and the impact of the satellites' radiofrequency emissions. *See id.* at 42 ¶ 76.

The Commission mentioned each of these proposed impacts. But relying on its "categorical exclusion" framework, which is informed by its

orbit is well above LEO, and it is where communications satellites, like those providing internet service to remote locations, usually operate.

Most anthropogenic space activity is therefore between altitudes of 100 km to 36,000 km. In this brief, that range is called "near-Earth orbital space," to make clear that the discussion does not contemplate areas as far from Earth as the Moon, the rest of the Solar System, or beyond.

narrow, terrestrial-focused view of the "human environment" as a starting point, the Commission determined that "the record before us does not support a need for further environmental review." Commission Order at 51 ¶ 92. Further, the Commission refused to "speculate" regarding the cumulative effects of SpaceX's application. *Id.* at 43 ¶ 78. Accordingly, despite the requests by Viasat, The Balance Group, and others for meaningful environmental review, the Commission refused to perform or require an environmental assessment and granted SpaceX's application. *Id.* at 51, 53 ¶¶ 92, 96.

Following the Commission's order, Viasat and The Balance Group appealed to this Court as parties aggrieved by the Commission's order. *See* 42 U.S.C. § 402(b)(1)(2).

C. The Administrative Procedure Act Permits Judicial Review of Federal Orders That Fail to Comply with NEPA's Requirements

The Administrative Procedure Act ("APA") controls this Court's review of an agency's compliance with NEPA's environmental-assessment obligations. *See Marsh v. Or. Nat. Res. Council*, 490 U.S. 360, 376 (1989). As relevant to this case, under the APA, a reviewing court must "hold unlawful and set aside agency action, findings, and conclusions found to be . . . arbitrary, capricious, an abuse of discretion, or otherwise not in accordance with law[.]" 5 U.S.C. § 706(2)(A). The "arbitrary and capricious" standard requires that agency action be both reasonable and reasonably explained. *Fed. Commc'ns Comm'n v. Prometheus Radio Project*, 141 S. Ct. 1150, 1158 (2021). Among other things, an agency action is not reasonable if the agency "entirely failed to consider an important aspect of the problem." *Motor Vehicle Mfrs. Ass'n of U.S. v. State Farm Mut. Auto. Ins. Co.*, 463 U.S. 29, 43 (1983).

III. SUMMARY OF THE ARGUMENT

This Court should vacate the Commission's order granting SpaceX's application and rejecting Viasat's and The Balance Group's protests because the order was unreasonable, and therefore arbitrary and capricious, in at least two respects.

First, the Commission's reliance on its "categorical exclusion" framework was unreasonable because space activity has outgrown the narrow, terrestrially focused, 1986 definition of "human environment" that it reflects. Technological advances have resulted in the ability to deploy large constellations of satellites, like the constellation at issue in this appeal, into near-Earth orbital space, and into the LEO, in particular. The result will be a congested LEO with a high turnover of satellites—meaning many launches, de-orbits and derelicts—that will invariably lead to increased satellite debris, none of which was reflected when the Commission adopted its "categorical exclusion" framework to implement NEPA 35 years ago. This increase in anthropogenic space objects affects the "human environment" on Earth and the interactions of people with that environment—whether they are casual stargazers, professional astronomers, telecommunications companies, or future space travelers. Accordingly, the legal concept of the "environment" should consider the environmental impacts that satellites in near-Earth orbit have on Earth and on human interactions with space. The Commission relied on an outdated framework to avoid meaningfully considering issues that NEPA simply does not let it avoid. By doing so, the Commission entirely failed to consider important environmental aspects of SpaceX's application; the Commission's resulting order was unreasonable.

The Commission's order was also unreasonable because—again leaning on its categorical framework—it refused to consider the order's cumulative effects. Considered individually, the environmental impact of any particular proposed deployment may be modest. But SpaceX's proposal is not modest, its effects will exacerbate current conditions in near-Earth orbital space, and its effects will be compounded by future launches of satellite constellations. In light of the finite "carrying capacity" of near-Earth orbital space, over time those deployments not just "*may* have a significant impact on the environment," they *will* have a significant impact.

In fact, they already are having a significant impact on the human environment, particularly in amicus' field of astronomy. Bright LEO satellites frequently obscure distant (and therefore faint) celestial objects like those that professional astronomers like amicus study. The radio emissions from LEO satellites similarly interfere with radio astronomers' ability to capture faint radio signals. Because of their proximity to each other, the light from LEO satellites has already corrupted evidence from images captured by space astronomy instruments (*i.e.*, satellite-based telescopes). And even amateur astronomers using conventional binoculars, telescopes, and cameras have their view of the sky confused and corrupted by LEO satellite light pollution.

Current studies suggest that by the end of this decade, there may be over 100,000 satellites—over 20 times the current quantity—in LEO. Given the rapid growth and projected continued growth of the space-object population, the Commission must consider not just the present effects of a particular proposed deployment, but the cumulative effect that it and projected future deployments may have. Because the Commission failed to do so here, its order was unreasonable.

IV. ARGUMENT

In granting SpaceX's application and rejecting Viasat's and The Balance Group's protests, the Commission's order was unreasonable in at least two ways.

To evaluate SpaceX's application, the Commission relied on its "categorical exclusion" framework, under which all but a few terrestrial-focused classes of projects will presumptively avoid environmental review because the Commission "deemed" all but those few exempted classes of projects "individually and cumulatively to have no significant effect on the quality of the human environment." 47 C.F.R. § 1.1306(a). In rejecting Viasat's and The Balance Group's protests, the Commission next applied its "may have a significant environmental impact" standard, but did so by similarly focusing on terrestrial effects and without considering the full range of cumulative effects that SpaceX's application would have terrestrially *and* in near-Earth orbital space.

The Commission's "categorical exclusion" framework, including the narrow terrestrially focused definition of "human environment" that it reflects must evolve to meet the rapid growth of space-object population and Congress's expectation that federal agencies would respect human interactions with the environment however far those interactions may reach as technology evolves. Similarly, when applying that framework, the Commission—and this Court in reviewing the Commission's application of it—must consider the cumulative effects of the proposed action even if those effects are manifested by human interaction with near-Earth orbital space that the Commission would not have even considered possible in 1986.

A. Space Activity Has Outgrown the Commission's "Categorical Exclusion" Framework and Its Understanding of the "Human Environment"

In the NEPA context, categorical exclusions sometimes make sense, which is why less than a decade after NEPA's enactment, the Council on Environmental Quality promulgated their use. *See* 43 Fed. Reg. 55,978, 56,003–04 (Nov. 29, 1978) (promulgating 40 C.F.R. § 1508.4). Likewise, when the Commission promulgated its particular framework in 1986 "to conform its environmental rules to the regulations issued by the Council," the Commission was justifiably focused on mitigating the terrestrial effects that telecommunications projects might then have in light of extant technology, such as protecting sensitive areas like wildlife preserves, protecting people in their homes from intense lighting, and protecting the public from unsafe radio frequencies. *See* 51 Fed. Reg. 14,999–50 (Apr. 22, 1986). After all, Congress had not provided a definition for its use of the term "human environment" in NEPA. *See generally* 42 U.S.C. § 4370m. And although humans have been launching objects into space since 1957, there were only 389 active satellites in Earth's orbit in 1986.

Over the last 35 years, humans began to propose (and are now) placing very large constellations in space. Previously, a large constellation meant perhaps a few dozen spacecraft. But by the end of 2018, there were 2041 active satellites.

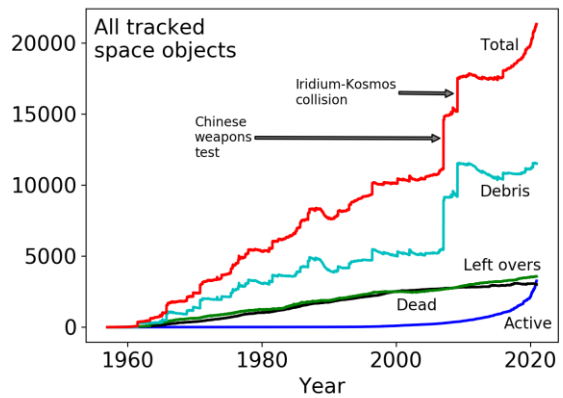
Commercial development has meant that build and launch costs have come down, making a mass-production approach to satellite manufacture and placement financially plausible. The result has been, in just the last two years, a sea change in deployment, as new large fleets of satellites—many thousands or tens of thousands—have been proposed and launched into the near-Earth orbital space.[2] Moreover, telecommunications satellites previously operated in geosynchronous orbit. But operators like SpaceX are intent on putting these satellite constellations closer to the Earth to minimize latency (signal delay time) and to reduce their launch costs. Because LEO satellites can access only a small portion of the Earth, operators like SpaceX need many more satellites in LEO to achieve global coverage.

At LEO, harsh space conditions mean that a realistic lifespan for a satellite is about five years. Thus, operators will replace satellites, which will require frequent launches and deliberate de-orbiting, leading to a

[2] Proposals and plans around the world suggest that a population of 100,000 satellites is possible within this decade. *See The impact of large constellations of satellites*, 2021, JASON programme office, Mitre corporation, document JSR-20-2H. Report sponsored by National Science Foundation, at 15, https://www.nsf.gov/news/special_reports/jasonreportconstellations/, last accessed Aug. 12, 2021 ("The most concrete conclusion we can draw from this table is that a lot of companies with deep pockets think that constellations of communication satellites are a profitable endeavor, and we could very quickly wake up on a world with over 100,000 communications satellites in LEO.").

constant turnover within LEO and the risk of more derelicts from failed satellites.

Relatedly, various processes have led to an increasing population of small pieces of "space debris," illustrated in the graph below:[3]



Telescopes on Earth can track space debris as small as 10 cm, and there are roughly 20,000 such pieces.[4] The following image captures the phenomenon:[5]

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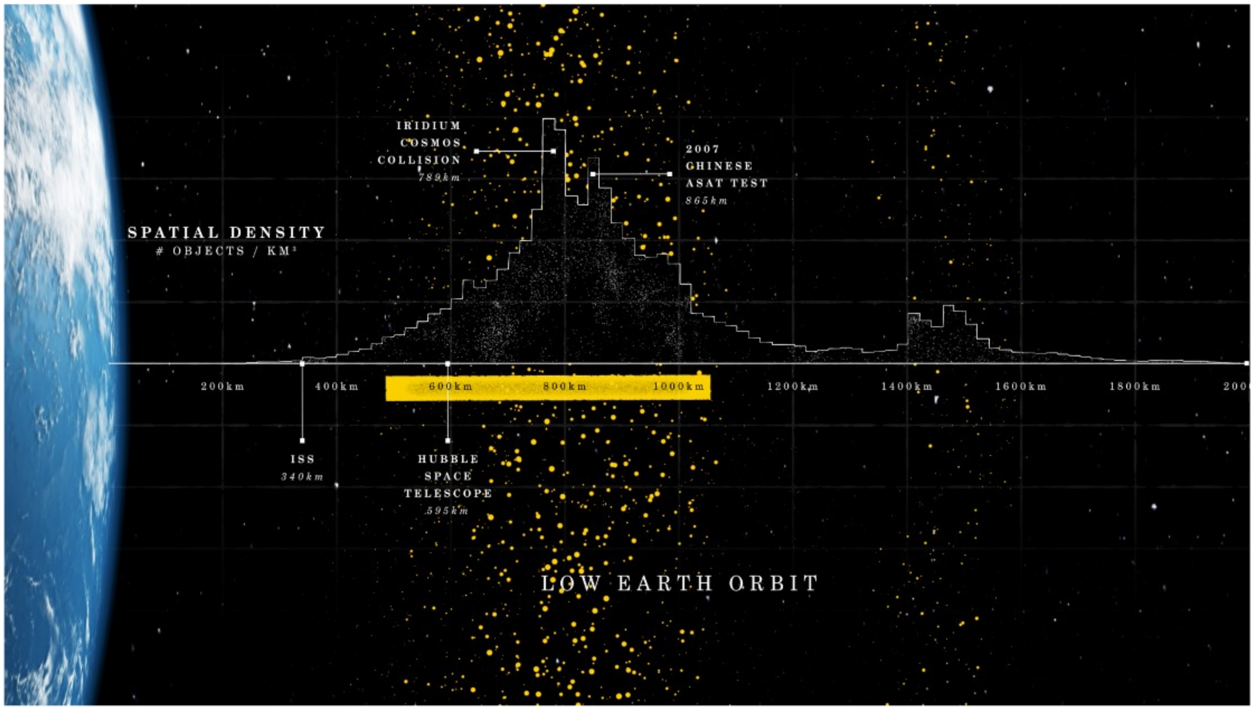
[3] A. Lawrence, *Losing the Sky* 64 fig. 7.4 (2021). This graph tracks not only the steady growth of debris over time, which is increasing faster than the leftovers population, but also (1) large punctuations due to the Irridium-Kosmos collision in 2009 and the Chinese weapons test in 2007 and (2) the sharp upturn in "active" space objects (the blue line at the bottom) *in the last two years* driven by SpaceX's Starlink satellites.

[4] There are estimates of between 500,000 and 900,000 smaller, untraceable pieces of space debris.

[5] Illustration of the density of objects in LEO. Taken from a video by Asher Ishbrucker at https://www.youtube.com/watch?v=fajxaDxmu_4, last accessed Aug. 12, 2021.



Velocities in orbit are so high that even small pieces of debris cause considerable damage. Active satellites can (in principle) maneuver to avoid large objects, but near misses with small pieces of debris happen and collisions occur often, leading to more debris and a potentially ever-escalating increase in orbit population.[6]

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[6] *See, e.g.*, JASON Report, *supra* n.2, at 23 ("We estimate . . . that the mean time for a catastrophic collision for an individual satellite with existing debris at 800 km is about 2000 years . . . unless they succeed in maneuvering to avoid all collisions."). An analysis of the possible future is given in the recent comprehensive JASON report. This includes allowance for continually de-orbiting satellites at the end of their five-year lifetime. For a target population of 10,000 active satellites, debris grows only slowly, but there will be 300 disabling collisions after 30 years. *See id.* at 97–98. For a target population of 40,000, debris growth is dramatic and there will be hundreds of disabling collisions within a few

The Commission's order did not meaningfully address any of this. By applying its outdated "categorical exclusion" framework based on a 1986 understanding of what constitutes the "human environment," the Commission effectively gave itself a free pass on any obligation to consider "an important aspect of the problem" that it was asked to address: the effect of large-scale orbital deployments like SpaceX's. *State Farm*, 463 U.S. at 43. That framework must be updated to reflect present-day realities, and that update should start with reconsidering what constitutes the "human environment."

As noted above, Congress did not provide a definition for its use of the term "human environment" in NEPA. *See generally* 42 U.S.C. § 4370m. But Congress did provide some guideposts. First, Congress intended the agencies of the federal government to "assure for all Americans *safe*, healthful, productive, *and esthetically and culturally pleasing* surroundings." 42 U.S.C. § 4331(b)(2) (emphasis added). And to ensure that federal agencies vindicated Congress' intent, it created the

years. *See id.* at 97 ("Once [the number of live satellites] passes the threshold of 40,000 the debris density starts running away, with the effect that after 50 years satellites are destroyed faster than they are launched.").

Council on Environmental Quality to guide their implementation of NEPA's requirements. *Id.* §§ 4321, 4342, 4344(2)–(3).

The Council understood the comprehensive nature and centrality of the human experience—beyond just "environmental effects at the earth's [sic] surface," Commission Order at 41–42 ¶ 72—in Congress's intent. *See* 43 Fed. Reg. 55,978, 55,988, 56,004 (Nov. 29, 1978) (promulgating and explaining the regulatory definition of "human environment"). As the Council explained:

> In its proposed form, [40 C.F.R.] § 1508.14 stated that the term "human environment" shall be interpreted comprehensively to include the natural and physical environment and the interaction of people with that environment. A few commenters expressed concern that this definition could be interpreted as being limited to the natural and physical aspects of the environment. This is not the Council's intention. . . . The full scope of the environment is set out in Section 101 of NEPA [43 U.S.C. § 4331]. *Human beings are central to that concept.* In § 1508.14 the Council replaced the word "interaction" with the word "relationship" to ensure that the definition is interpreted as being inclusive of the human environment.

Id. at 55,988 (emphasis added).

While humans have carried out activities in space since 1957, modern civilization has reached a point where human activities *in space* affect the natural and physical environment *on Earth* and the interactions of people *on Earth* with that environment.

Moreover, it has never been necessary to be in space to be interacting with it. Astronomers, and all human stargazers, carry out their activities by looking through near-Earth orbital space to the objects beyond. Human cultures around the world with strong traditions tied to the night sky—such as Maori, whose New Year is associated with the heliacal rising of the Pleiades, and Indigenous Hawaiians, who have used star-based navigation—have been continuous users of near-Earth orbital space for thousands of years. For this to occur, light must travel from celestial bodies through near-Earth orbital space to reach our eyes and our instruments on Earth. Therefore, the sky is the working environment for astronomy and stargazing, and this includes near-Earth orbital space.[7] Accordingly, the legal concept of the "environment" should

[7] *Accord* Outer Space Treaty, art. IX (1967), at UN Office for Outer Space Affairs, https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/outerspacetreaty.html, ("In the exploration and use of outer space, including the moon and other celestial bodies, States Parties to the Treaty *shall be guided by the principle of co-operation and mutual assistance* and shall conduct all their activities in outer space, including the moon and other celestial bodies, *with due regard to the corresponding interests* of all other States Parties to the Treaty."), last accessed Aug. 12, 2021.

consider the environmental impacts that satellites in near-Earth orbital space have on Earth and in space.[8]

B. The Commission Failed to Consider the Cumulative Effects of Its Order, and the Effects Are Serious

The Commission's use of its "categorical exclusion" framework also enabled its avoidance of the "cumulative effects" of its order. "Categorical exclusions" are supposed to be available for only "a category of actions which do not individually *or cumulatively* have a significant effect on the human environment." 40 C.F.R. § 1508.4 (2020) (emphasis added); 47 C.F.R. § 1.1306(a); *accord* 43 Fed. Reg. 55,978, 55,979, 56,003–04 (1978) (promulgating 40 C.F.R. § 1508.4 and explaining it). But when pushed on cumulative effects, the Commission did not say that there would be none, which is the circumstance when a "categorical exclusion" is appropriate. *See* Commission Order at 44 ¶ 78. Instead, because the Commission had chosen to work within its "categorical exclusion" framework, it permitted itself to ignore cumulative effects. *Id.*

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[8] *See, e.g.*, Liability Convention of 1972 (providing that a launching State shall be liable to pay compensation for damage caused by its space objects on the surface of the Earth), https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introliability-convention.html,last accessed Aug. 12, 2021.

The incremental impact of any single proposal for a satellite constellation may be relatively modest (although, it might alone be significant), but if all such proposals are allowed because their individual impacts are modest, the cumulative impact could be serious. For example, much like other ecosystems, near-Earth orbital space has a finite "carrying capacity" for traffic. It should be evident to the Commission that if everyone freely populates orbital space, this orbital carrying capacity is likely to become saturated, making specific orbital "highways" useless for the safe sustenance of space operations and observational activities.

To this end, the cumulative effects of large-scale satellite deployments like SpaceX's are significant, particularly for astronomers and other humans who interact with the sky and space.

Many objects studied by astronomers are faint—billions of times *fainter* than the brightness of LEO satellites. This huge dynamic range means that telescope cameras are often specialized to detect faint objects. In those situations, bright objects can cause multiple "ghost" images and even damage the detector. But science requires evidence, and some observations are unrepeatable and time-sensitive—exploding stars, discovering exoplanets, and comets and asteroids, for example. Similarly, some observations can only occur at specific times of night or year. For instance, spotting near-Earth asteroids that may be "killer rocks" careening toward Earth can only be done near twilight. But the light from a LEO constellation might prevent spotters from spotting the asteroids. Finally, a streak in an image destroys the information underneath that piece of sky. Astronomers like Professor Lawrence can "airbrush" an image with a satellite trail to mostly remove the streak and make it look nice, but they cannot look "behind" the streak.

Satellites are visible from Earth because they reflect sunlight. How bright they are depends on several factors, such as their sizes, reflective properties, heights above the Earth and orientations. For context, the newest satellites in LEO constellations are about as bright as the faintest stars that an unaided eye can see—millions or billions of times brighter than the typical targets of modern astronomers.[9] Immediately after the

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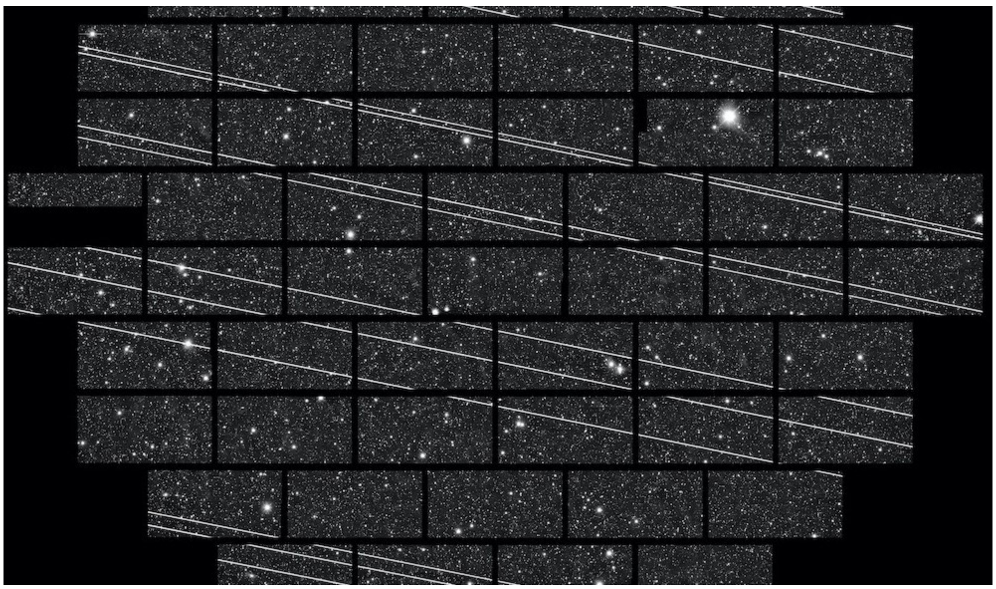
[9] American Astronomical Society, *Impact of satellite constellations on optical astronomy and recommendations towards mitigations*, (Constance Walker et al. eds.) (2020), https://ui.adsabs.harvard.edu/abs/2020BAAS...52.0206W/abstract, last accessed August 13, 2021; J. Anthony et al., *Mitigation of LEO satellite brightness and trail effects on the Rubin Observatory LSST* 226, Astronomical J., Vol. 160 (2020), https://ui.adsabs.harvard.edu/abs/2020AJ....160..226T/abstract, last accessed August 13, 2021.

launch of a new batch of satellites, they are brighter still (as bright as the brightest stars), and remain so for weeks or months as they rise to their orbits. Moreover, satellites orbit quickly in LEO so that they do not fall to the Earth. During an astronomical exposure, they leave streaks across the image, as shown below:[10]



In this image of the sky taken by the Dark Energy Survey Camera in 2019, there were only a few Starlink satellites, but their effect is severe because many clumped together during the bright-orbit raising phase.

Only some satellites are visible above the horizon at a time. Assuming, for simplified purposes, that in 2030, there are 100,000

[10] Credit: CTIO/NOIRLab/NSF/AURA/DECam DELVE Survey. This is an image of the sky taken by the Dark Energy Survey Camera in 2019.

satellites at a height of 600 km, roughly 4,300 would be above the horizon at any one time, and they would cross the sky in approximately 13 minutes. For an astronomer using a very narrow field of view to isolate the light for a single target with a 30-minute exposure, there is roughly a 5% chance of a streak going across or very near the target. In that situation, the observation is wasted. Similarly, consider a 3.5-degree-wide field imager like the one that will be used by the Vera C. Rubin Observatory nearing completion in Chile, with an exposure time of thirty seconds; every exposure will contain a streak, and sometimes multiple streaks.[11] Laboratory experiments using Rubin Observatory camera detectors show that simulated satellite streaks tend to cascade and create several fainter streaks. This effect is "non-linear electronic crosstalk," and it can render some scientific analyses impossible because it alters the statistics of the background sky brightness. To avoid the crosstalk problem, the satellites would need to be several times fainter than the faintest stars visible to the unaided eye.

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[11] Tyson, J.A., et al. "Mitigation of LEO satellite brightness and trail effects on the Rubin Observatory LSST," Astronomical Journal, Volume 160, p.226, https://iopscience.iop.org/issue/1538-3881/160/5, last accessed Aug. 13, 2021.

Further, as an object in space rotates, a brief, bright flash or "glint" can occur. These bright and short-duration events can mimic some of the most exciting phenomena in modern astronomy. A study in 2020 identified such a flash as the sign of a gamma-ray burst at the edge of the Universe—an exciting discovery. The following year, however, it was determined that the reflection of sunlight off an old Russian Proton rocket part caused the flash.[12] Nobody yet knows—and certainly not the Commission—how frequent this kind of problem will become as the LEO satellite population grows.

While satellites reflecting sunlight affect optical astronomers, satellites emitting radio waves affect radio astronomers. Satellites use radio-downlink signals to communicate with ground stations, including user terminals. Radio astronomers do not make pictures the way optical astronomers use cameras. Instead, they scan the sky in multiple directions to pick up faint radio signals. No matter how well designed a radio antenna is, physics dictates that it is sensitive to signals at a range

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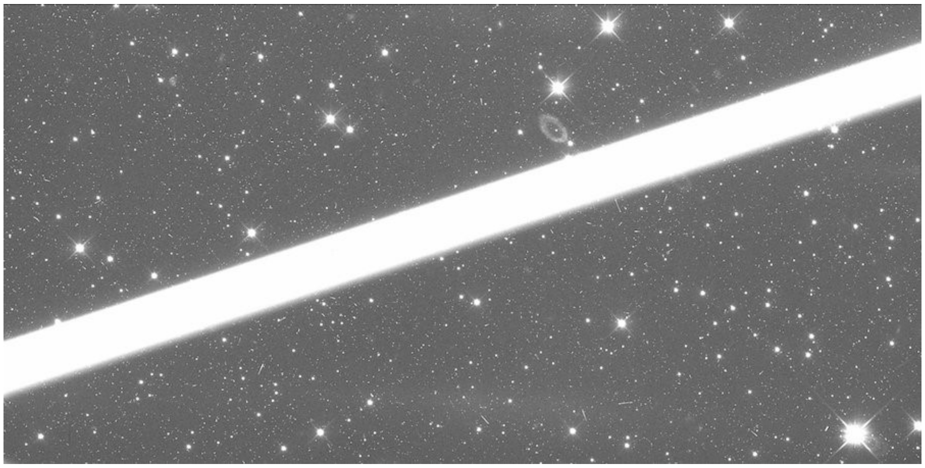
[12] Michael J. Michalowoski et al., *GN-z11 flash was a signal from a man-made satellite not a gamma-ray burst at redshift 11*, at 1, Nature Astronomy (2021), https://arxiv.org/abs/2102.13164, last accessed Aug. 13, 2021.

of frequencies coming from a broad range of directions in the sky. Detecting faint celestial objects is like trying to listen to very quiet music in a noisy room. The problem is severe, as the emissions from communications satellites can be a trillion times louder than the astronomical targets. Radio astronomers make detailed maps by combining the signals from many interlinked antennas, but the noise problem affects each antenna. A recent study showed that noise from planned constellations would make scientific observations take on average 70% longer.[13]

Space astronomy is affected too. Some spacecraft used for astronomy are very far from the Earth, such that LEO satellites will not affect them. Many, however, like the Hubble Space Telescope (HST), are in LEO, and can suffer from streaking. Occasionally, a satellite may pass close by (say, within 100 km), in which case the streak caused is a bright

[13] Square Kilometre Array Public Website, *SKAO needs corrective measures from satellite mega-constellation operators to minimise impact on its telescopes*, https://www.skatelescope.org/news/skao-satellite-impact-analysis/?fbclid=IwAR3Xu2qkLcLaWKaCoTR-y-rwBnK20CrIbyu13S1thFOdh-5onzsvnAF9p3M, last accessed Aug. 13, 2021.

out-of-focus stripe, obliterating a significant fraction of the image, as shown below:[14]



A recent study showed that, depending on which instrument an astronomer used, satellite streaks affected between 2% and 8% of HST images. That frequency changed with time, reflecting the historic growth of the satellite population.[15] If proposed constellations come to fruition, then by the end of the decade, a third of HST images will have that type of streak.

[14] Mikulski Archive for Space Telescopes (MAST), Science PI: Simon Porter. This is an observation made using HST in November 2020. The streak seems likely to have been made by Starlink 1619.

[15] This data was reported by Sandor Kruk of the European Space Agency at a presentation he gave at the July 2021 meeting of the European Astronomical Society meeting and currently being prepared for publication.

Even amateur astronomers without professional equipment are affected. It is possible that by reducing the brightness of satellites to below naked-eye visibility, the sky pollution problem can be more or less removed for casual stargazers; but this is not a strong enough limit to keep the night sky unspoiled for those who have an active pastime of binocular or telescope-aided stargazing. There are millions of amateur astronomers across the world, and at least tens of thousands across the United States. When looking at the sky with a pair of binoculars or small telescope, for example, all the planned satellites will be easily visible. For a typical 7-degree binocular field of view, by 2030, there would be approximately eight satellites visible every time one looks, and they will typically be the brightest objects in the field of view. They will move across the field of view in about ten seconds, continuously being replaced so approximately eight are always moving within the field of view. Meanwhile, many amateur astronomers make and publish beautiful digital images of the sky using a variety of equipment. They will suffer the same problem as professional astronomers of streaks in most of their images.

Given the rapid and projected growth of the space-object population and its significant effects on the environment, the Commission cannot anymore avoid scrutinizing its actions.

V. CONCLUSION

The rapid growth of the space-object population in LEO and the Commission's failure to engage with that growth—or even require SpaceX to address the basic environmental issues—have revealed the outdated nature of the Commission's approach to the environment and to the effects of its actions. These errors are serious, and they have serious implications for Professor Lawrence and others. The Court should set the Commission's order aside so that the Commission (and SpaceX) must assess the environmental impacts of the application.

Respectfully submitted,

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Dated: August 13, 2021

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Dated: August 13, 2021

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CERTIFICATE OF FILING AND SERVICE

I hereby certify that on this 13th day of August, 2021, I caused this Brief of Professor Andy Lawrence as *Amicus Curiae* in Support of Vacatur to be filed electronically with the Clerk of the Court using the CM/ECF System, which will send notice of such filing to all counsel of record as registered CM/ECF users.

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