

SPACE-BASED DATA CENTERS ROADMAP: THE CASE FOR CAUTION

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CHAPTER 2.1:

Night Sky and Astronomy

Alexis Abramson and David Sandalow



Innovation for Cool Earth Forum

WORKING PAPER

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CHAPTER 2.1:

NIGHT SKY AND ASTRONOMY

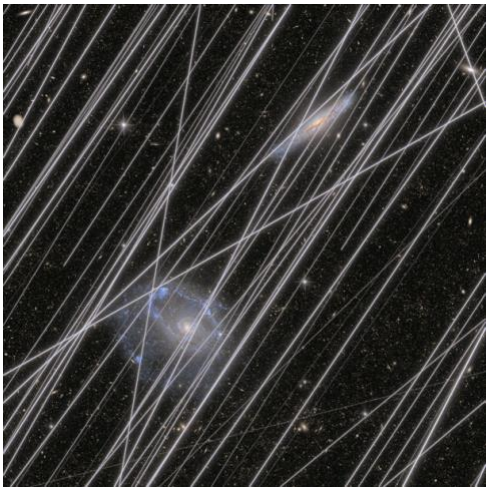
Alexis Abramson and David Sandalow

MAIN MESSAGES

- Constellations of space-based data centers could transform night skies around the world. More satellites than stars could be visible at many times in many places.
- Impacts on observational astronomy could be especially devastating.
- Technical measures could reduce impacts but would involve operational tradeoffs and would not eliminate the need to radiate waste heat.
- Policy responses include brightness limits, pre-launch impact assessments, required mitigation measures, caps on satellite numbers and international standards.

Space-based data centers (SBDCs) could transform night skies around the world. If announced plans for SBDCs are fully implemented, most visible points of light in the sky during much of the night in much of the world could be satellites, not stars. Unlike stars, these satellites would drift visibly across the night sky.[1-3]

The impacts would not be limited to what the eye can see. Large SBDC constellations would severely disrupt professional astronomy, streaking images from wide-field survey telescopes (which detect faint light sources) and contaminating observations from infrared telescopes (which would register





Left: Simulated satellite trails streaking images from space telescopes. Source: NASA / Borlaff, Marcum, Howell (Nature, 2025). CC BY-NC-SA 4.0. Right: Satellite streaks over Orion; digital combination of 65 exposures. Source: NASA/Amir H. Abolfath

the satellites' substantial waste heat, detecting wavelengths invisible to the naked eye). The American Astronomical Society (AAS) filed a strong opposition to SpaceX's January 2026 request for approval to launch and operate one million SBDCs, writing that the proposal "represents an unprecedented threat to the visual integrity of the night sky."[1]

These impacts are due to the size, nature and number of proposed SBDCs.

- SBDCs are far larger than typical satellites. SpaceX's AI1 satellite has a 70-meter wingspan—more than twice the size of Starlink satellites. Some experts estimate that SBDCs could reach 100 meters from tip to tip due to their large solar arrays and radiators. SBDCs could be among the largest structures ever placed in orbit.4,5
- SBDCs' size and design could make them unusually bright from reflected sunlight, depending on their surface properties and orientation. Their large heat-rejection systems would also make them substantial sources of infrared emission. Radiator panels drive both effects: their coatings are engineered both to reflect sunlight (so the panel avoids absorbing additional heat) and to emit infrared efficiently (so it can shed heat). The first property makes them highly reflective in visible light, and the second is a source of infrared radiation. (The large solar arrays contribute differently. Because they are designed to absorb sunlight, they appear dark most of the time, but their flat, mirror-like surfaces can throw brief, intense flashes when the Sun, satellite and observer align.)
- SBDCs could dramatically increase the number of satellites in orbit. SpaceX alone proposes to increase the number of satellites in low Earth orbit (LEO) by a factor of 100. Starcloud has proposed a constellation of 88,000 SBDCs, and Orbital has filed an application to launch and operate up to 100,000 satellites. The cumulative impact of large numbers of satellites can degrade night skies and interfere with astronomy, even if individual satellites themselves do not create problems.[6]

SBDCs' orbits would affect the times and places they are visible from the Earth's surface. SpaceX proposes to operate SBDCs in two distinct orbital regimes. Some would fly in Sun-synchronous, near-polar orbits calibrated to the day-night terminator (the line where day turns to night), which keep the satellites in sunlight more than 99% of the time for continuous power and compute. A second set would fly in lower-inclination orbits at 30°, passing over latitudes between 30° North and 30° South. (See Figure 1.) The terminator satellites would be visible during morning and evening twilight, while the 30°-inclination satellites would be visible across a wider range of the night in the world's more populated mid- and low-latitude regions.

A. Harms

What harms would result from transforming the night sky?

A first answer is primal and deeply rooted in the human experience. At some level it seems unimaginable that a few companies could radically alter the night sky for everyone on Earth. The stars have been a core part of the human experience since *Homo sapiens* first walked the Earth hundreds of thousands of years ago.[7-9] Across cultures and religions, people find spiritual meaning in

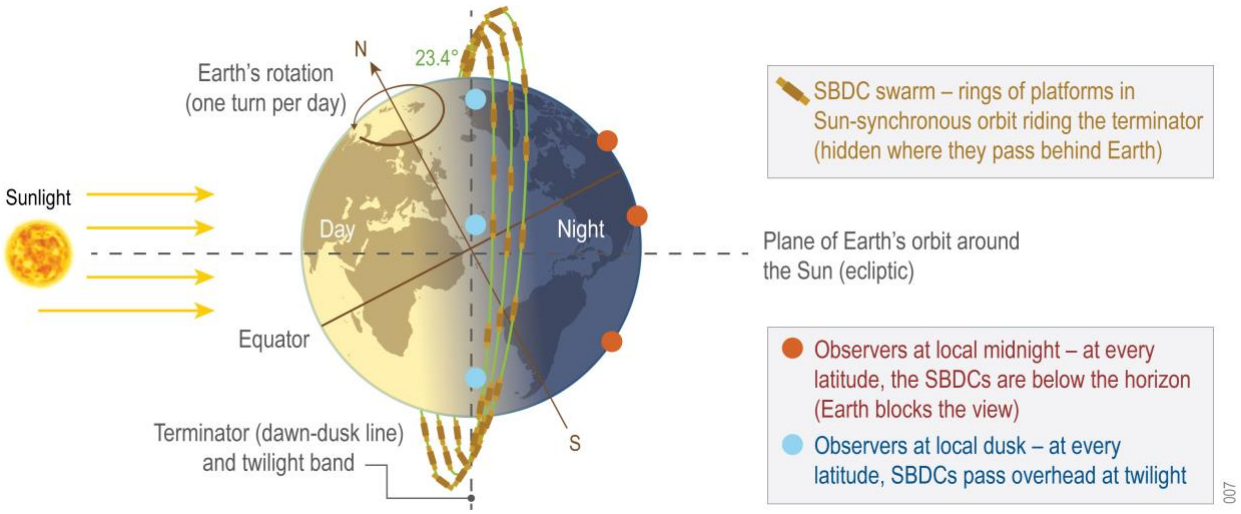


Figure 1. *A constellation of SBDCs in Sun-synchronous orbit. SBDCs ride the dawn-dusk line (the "terminator").*

the stars. Transforming the night sky so visibly would bring loud and vigorous objections from many people around the world.

Changing the night sky would have unknown and unpredictable impacts on ecosystems, as well. A night sky filled with thousands of moving points of light each night could confuse animal species whose navigation systems depend on fixed points in the night sky. Increase in night sky brightness could affect animal species by obscuring celestial cues as well. Research on satellites' effects on animal species is developing, but several studies suggest that at light levels lower than "sky glow," animal species may experience distorted cues on the time of day or season and interference with predator-prey interactions and be rendered unable to navigate using the stars.[10]

Astronomers point to other risks. The AAS argues that SpaceX satellites "would blind us to incoming hazardous asteroids and disable the observations required for space situational awareness, compromising national security."[1] The Royal Astronomical Society (RAS) predicts that as much as 10% of data captured by the European Southern Observatory's (ESO's) Very Large Telescope could be affected by satellite streaks.[11] A 2025 study modeling the full deployment of proposed large telecommunication constellations predicts that roughly one-third of Hubble Space Telescope exposures and 96% of exposures from the space-based SPHEREx astronomical observatory will be affected.[12,13]

These effects arise from reflected sunlight. Infrared astronomy faces a different but equally serious threat. Much of what we know about the birth of stars, the composition of distant worlds and the earliest galaxies comes from infrared observation, at wavelengths the eye cannot see. Because they detect such faint heat, infrared telescopes are exquisitely sensitive to any stray warmth; the James Webb Space Telescope carries a sunshield the size of a tennis court (see Figure 3) and chills its mid-infrared instruments to below 7 Kelvin, colder than almost anywhere in nature, so that its own heat

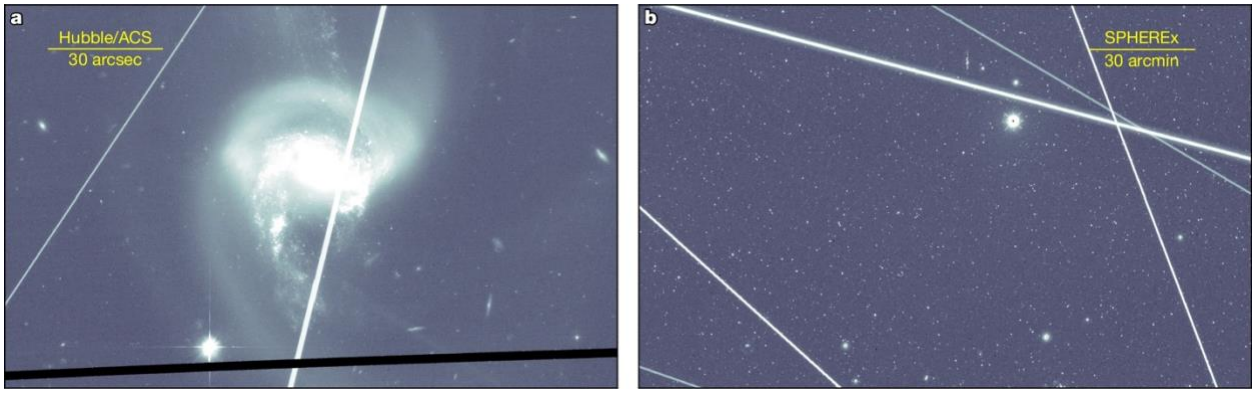


Figure 2. *Cropped simulation of Hubble (a) and SPHEREx (b) exposures with satellite trails. Source: NASA / Borlaff, Marcum, Howell (Nature, 2025). CC BY-NC-SA 4.0*

does not blind it.[14] To such an instrument, a heat source drifting across the sky is precisely the contamination it was built to escape.

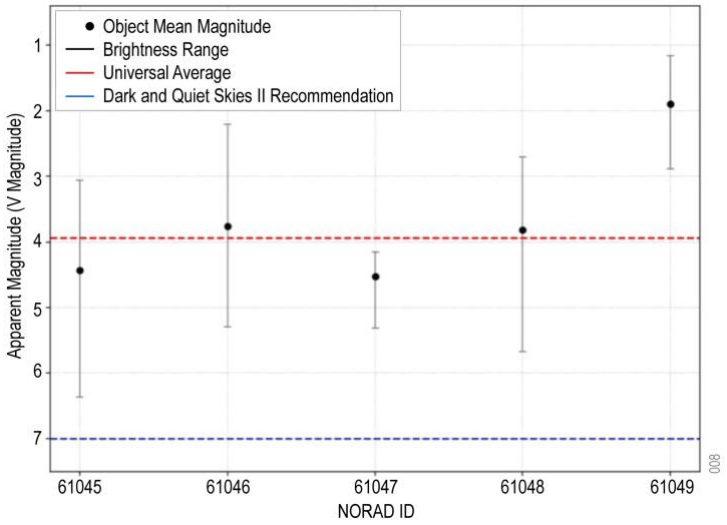
SBDCs would be exactly that. A radiator's function is to convert waste heat into infrared radiation and shed it, and so a megawatt-class SBDC is by design a megawatt-scale infrared source, radiating day and night for as long as it computes. Pointing the radiators toward deep space—and away from Earth—could substantially reduce the problem for ground-based observatories but may not fully resolve it. A radiator does not emit its heat in a narrow beam that can be aimed away from a telescope; like a bare bulb, it glows across nearly every direction it faces. Orientation can reduce the infrared reaching a given location, but the telescope cannot fully avoid the hemispherical emission from the radiator. The observatories most exposed are those operating in the mid-infrared, where a radiator near typical operating temperatures emits most strongly. Astronomical observatories around the world, representing hundreds of millions if not billions of dollars of invested capital, could have their usefulness for astronomical research significantly diminished.[1]

B. Mitigation

A central question is whether these impacts can be mitigated at all. Visible brightness comes from reflected sunlight and can be lessened by darkening films or by orienting radiators edge-on to the Sun. But darkening a radiator raises the sunlight it absorbs, degrading its cooling, so this protection is bought at a thermal and therefore economic cost. The radiator's infrared emission is different in kind: it is the heat itself leaving the system, and so its total is fixed by the compute load. While coatings might be used to manipulate wavelength or the direction of thermal radiation,



Figure 3. *The James Webb telescope's sunshield in test deployment. Source: NASA/Chris Gunn*



Brightness range of the five satellites observed (x-axis values = satellite IDs).
Source: Owen Miller et al 2026.[20] Open Access CC BY 4.0

no measure can reduce the total emission because the full heat load must be radiated. Consequently, reflected sunlight can be partially managed at a price; the total infrared output of a radiatively cooled data center is fixed by thermodynamics.

SpaceX's efforts to dim its Starlink satellites offer useful lessons.[15] The company first tried a darkening coating (its 2020 'DarkSat'[16-18]), which reduced brightness by roughly a factor of 2.5 but caused precisely the problem expected: the black surfaces absorbed more sunlight and overheated. Further, astronomers noted the added heat interfered with mid-infrared observations. SpaceX abandoned the coating and switched to a deployable sun visor ('VisorSat') that blocked sunlight from reaching the reflective surfaces, cutting brightness by about a factor of three. However, the visors interfered with the satellites' laser communication terminals and were dropped in turn. They were replaced by a dielectric mirror film on the underside that redirects sunlight back into space rather than toward the ground. Even after these iterations, the satellites remained brighter than astronomers' recommended threshold. This history illustrates both that visible brightness can be partially mitigated and that each fix carries a cost: thermal, operational or optical. Moreover, none of these measures has been demonstrated on structures whose solar arrays and radiators are many times larger than a Starlink satellite.

Recent experience with a small constellation of communications satellites underscores the challenges. In 2024, the US Federal Communications Commission (FCC) granted AST SpaceMobile a license to operate a constellation of five communications satellites, requiring AST to “make a good faith effort to demonstrate an optical brightness with an initial aim of 6th magnitude.”[19] A team monitoring the brightness of those satellites from November 2024 to June 2025 found that the satellites missed that target by a wide mark, averaging roughly seven times brighter than the FCC’s target.[20]



Visualization of space-based data centers in the southern sky just after sunset. Actual views will depend on many factors including number of satellites and brightness mitigation. Source: Shutterstock AI.

For infrared, the challenge is even greater, but it does not follow that nothing can be done. A substantial body of research demonstrates that micro structured and metamaterial coatings can engineer both the wavelength and the direction of thermal emission.[21-23] In principle, such coatings could shift a radiator's emission away from specific observation bands or bias it toward specific directions, offering partial, targeted protection at some cost in cooling performance. These techniques, however, have been demonstrated only over narrow wavelength ranges and at laboratory scale; their application to space-durable radiators of hundreds of square meters, across constellations of thousands of satellites, remains undeveloped. And they face a fundamental limit: the full waste-heat load must still be radiated, and so these methods can relocate the emission in wavelength or angle but cannot eliminate it. Whether such approaches can meaningfully lighten the burden on infrared astronomy is an open question that deserves research attention.

The impacts of altitude on night sky visibility and astronomy are complicated. Satellites at higher altitudes are less bright than identical satellites at lower altitudes, so some impacts of SBDCs on the night sky can be mitigated by flying them in higher orbits. However satellites at lower altitude cross the sky more quickly and are visible for less of the night, which offers clear benefits for astronomical

research. Some astronomers have recommended operating satellite constellations at lower altitudes for that reason.[24,25] Samantha Lawler et al. write

"There is no perfect solution—higher altitude orbits may be better overall for naked-eye stargazers, but lower orbits are thought, based on the astronomy community's current understanding of satcon operation plans, to be better for large research facilities."[26]

The most effective mitigation measure, of course, is to limit the number of SBDCs in orbit. To reduce night-sky impacts, there is no substitute for fewer bright and warm objects in the sky.[25,27]

C. Policy Options

A range of policy options could help address the impacts of SBDCs on the night sky and astronomical research. They include the following:

1. Brightness limits. National regulatory authorities could limit the brightness of individual satellites as license conditions. The International Astronomical Union (IAU)'s Centre for the Protection of the Dark and Quiet Sky has called for visible magnitude limits of 7 or greater, depending on the satellite's altitude.[28] Satellites meeting that standard would be invisible to the naked eye from dark locations and would reduce, although not eliminate, interference with astronomical observations.[6,24]

2. Limits on number of satellites. Even if individual SBDCs cannot be seen with the naked eye, the cumulative impact of hundreds of thousands of SBDCs could produce diffuse light that brightens night skies and disrupts astronomical research. A June 2026 paper by O. R. Hainaut from the European Southern Observatory recommends combining an individual satellite brightness limit of 7 with a limit of no more than 100,000 satellites in LEO.[6,29]

3. Require darkening coatings, sunshades and other technical measures to reduce brightness. These measures may not fully mitigate the problem and will come at an operational cost but have the potential to reduce impacts.

4. Require dark-sky and astronomy impact assessments as conditions for license approvals. In this regard, the longstanding categorical exclusion for satellite launches under the US National Environmental Policy Act (NEPA) should be repealed, as recommended by the US Government Accountability Office (GAO).[30]

5. Pursue international brightness standards through the Committee on Peaceful Uses of Outer Space (COPUOS). This process would take years with no guarantee of success, given the consensus-based decision-making process at COPOUS. But the dialogue itself could have educational benefits and help shape behavior of key actors, even in the absence of agreed standards.[29]

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