# Sunlight on Demand? Rethinking the Promise and Risks of Space Mirrors

**An interdisciplinary perspective on the promises, pitfalls, and open questions surrounding orbital space mirrors and Sunlight-on-demand.**

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*The recent approval of Reflect Orbital's first demonstration satellite by the U.S. Federal Communications Commission (FCC) has sparked intense debate. Supporters see orbital mirrors as a promising technology with applications ranging from emergency response and search-and-rescue to solar energy on demand and agriculture. Critics warn of far-reaching consequences for astronomy, wildlife, human health, space traffic management, international space governance and the commercialization of the night sky. Meanwhile, newspaper articles and social media have amplified both excitement and concern, often blurring the line between established science and speculation.*

*In this article, researchers from a wide range of disciplines at the University of Zurich, members of UZH Space, including astrophysics, Earth observation, environmental and social science, law, ethics and theology, look at this controversial emerging space technology. What has been approved? What are the plausible opportunities, risks, and challenges? What questions remain unanswered? The goal of the article is to provide a science-informed perspective that helps separate evidence-based assessments from speculation.*

## WHAT'S ALL THE FUSS ABOUT?

California-based start-up Reflect Orbital promises clean and abundant solar energy available on demand.[1] To achieve this, the company plans to launch its first demonstration satellite, *Eärendil-1*, later this year after receiving the approval from the U.S. FCC on 9 July, 2026.[2] According to Reflect Orbital's official FCC filings, Eärendil-1 is authorised to operate at approximately 625 kilometres altitude and to deploy a 18-by-18 metre thin-film reflector that can reflect sunlight onto Earth's surface. Hence, the term "space mirror". The resulting illuminated footprint on Earth would have a minimum diameter of about 5

[1] FCC Order, MO&O, paras. 1-2; Reflect Orbital company website and public roadmap, accessed 28 July 2026 <https://www.reflectorbital.com>.
[2] FCC Order, grant, p. 2-7, MO&O, para. 26.

km, when the satellite is at zenith.[3] The delivered illumination by Eärendil-1 will be roughly 0.1 lux (1 mW/m$^2$), equivalent to the brightness of the full moon. The company presents Eärendil-1 as an initial test of future services intended to meet government, commercial, and humanitarian needs, such as directing reflected sunlight to targeted areas to "augment energy projects by extending usable hours for solar cells" and "provide an illuminated solution for critical operations."[4]

If the demonstration is successful, Reflect Orbital's current roadmap projects a constellation of more than 50,000 satellites by 2035, each carrying a 54-by-54-metre reflector.[5] This has prompted strong opposition from astronomers, environmental and public-health organisations, and more than 1,800 individual submissions, citing concerns that include the disruption of the natural ecosystem, health and safety, severe interference with astronomy and orbital congestion.[6] Moreover, recent modelling indicates that large constellations could affect not only directly illuminated areas but the overall brightness of the night sky.[7]

## WHAT THE FCC APPROVED AND WHAT IT DID NOT – A LEGAL ASSESSMENT

*written by MLaw LL.M. R. Messerli*

The authorisation covers the deployment and operation of Eärendil-1[8] as an FCC-licensed "space station", using specified S-, X- and UHF-band frequencies for command, telemetry and payload data. In the grant, "satellite" and "space station" both refer to Eärendil-1 as the object placed into orbit and operated under the licence.[9]

The scope of the FCC's regulatory approval is limited. It governs the authorised radiofrequency operations and related matters such as orbital-debris mitigation but does not amount to comprehensive regulatory approval of the reflector's broader consequences, including its potential effects on astronomy, aviation safety, human health, wildlife and the night sky.[10]

The FCC reviewed matters within its communications mandate, principally radiofrequency interference and orbital-debris mitigation, imposing detailed coordination and non-interference conditions.[11] The licence concerns one demonstration satellite and has a two-year term beginning once Reflect Orbital certifies that Eärendil-1 has been placed in orbit and its operations comply with the authorisation.[12] Although the application anticipated a launch in 2026, the grant requires launch and operation only by 9 July 2032.[13]

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[3] FCC Order, grant, p. 2, "Orbital Location"; Reflect Orbital, ODAR, pp. 1-2; Technical Annex, p. 1; Hiroko Tabuchi, F.C.C. Approves Test of Space Mirror to Light Night Sky Despite Outcry, The New York Times, 10 July 2026, accessed 31 July 2026 <https://www.nytimes.com/2026/07/10/climate/fcc-space-mirror.html>; Reflect Orbital company website, accessed 31 July 2026 <https://www.reflectorbital.com>.

[4] Reflect, Orbital, Application Narrative, p.5; FCC Order, grant p. 2.

[5] Reflect Orbital company website, accessed 31 July 2026 <https://www.reflectorbital.com>.

[6] FCC Order, MO&O, para. 3 and fn. 4, para. 16 fn. 55-56, para. 18, para. 20 and paras. 22-23 fn. 84, 90-91.

[7] FCC Order, MO&O, para. 3 fn. 4; Olivier R. Hainaut, Large or Bright Satellite Constellations: Effects on Observations, Including on the Background Sky Brightness, *arXiv preprint arXiv:2604.09427* (2026), pp. 10-14

[8] The name is fitting: Tolkien's Eärendil crosses the heavens carrying a radiant jewel, while this Eärendil is meant to send light back down, although under the less romantic constraints of spectrum licensing and orbital-debris rules. See J.R.R. Tolkien, The Silmarillion, ch. 24, Of the Voyage of Eärendil and the War of Wrath.

[9] FCC Order, grant, p. 2, "Scope of Grant" and "Frequencies".

[10] FCC Order, grant, pp. 2-7, MO&O, paras. 13-23, especially para. 13. That does not mean it did not consider these concerns at all. The Order considered aviation safety (e.g. para. 16), human-health (e.g. para. 20), wildlife, circadian health (e.g. paras. 22-23 and fn. 84) and broader dark-sky concerns, but it did not treat them as matters comprehensively regulated under the FCC licence. See especially paras. 13, 16 and 20-23.

[11] FCC Order, grant, pp. 2-6, conditions 1-11, MO&O paras. 5-10 and 13.

[12] FCC Order, grant, p. 7, condition 16, MO&O para. 11 and fn. 39.

[13] Reflect Orbital, Application Narrative, p. 1; FCC Order, grant, p. 7, conditions 15(b) and 16.

During its review, the FCC requested information about possible interference with optical intersatellite links used by satellites operating at lower altitudes.[14] The final order nevertheless drew a clear jurisdictional line: it treated the reflector's broader effects as outside the FCC's authority except where they related to matters the Commission regulates, such as interference or orbital-debris mitigation.[15] The order therefore neither authorises orbital mirrors generally nor approves Reflect Orbital's projected constellation of more than 50,000 satellites.[16]

The FCC also treated concerns about optical astronomy as falling outside its review and authorisation of Eärendil-1.[17] Reflect Orbital committed to coordinate with NASA, the National Science Foundation and the wider astronomical community. However, the Commission declined to impose the more detailed safeguards requested by astronomical organisations.[18]

The environmental review was similarly narrow.[19] The FCC classified its licensing action, namely authorising Eärendil-1's use of specified radio frequencies, as "categorically excluded" and thus normally not requiring an Environmental Assessment under its National Environmental Policy Act (NEPA) rules.[20] However, this procedural classification did not itself constitute a finding that the reflector would have no environmental effects.[21] Rather, the FCC concluded that operation of the solar reflector was "too attenuated" from its approval of spectrum use, and therefore beyond the scope of the Commission's NEPA obligation.[22] In other words, the FCC regarded itself as licensing Eärendil-1's radio communications, not the reflector's direction of sunlight or its resulting environmental effects.[23]

Even assuming that the reflector's effect fell within the FCC's environmental review, the Commission found that the record did not show clearly enough that a single demonstration satellite might have a significant environmental effect requiring an Environmental Assessment.[24] It also declined to assess Eärendil-1 as part of a future constellation, because no such constellation was before the FCC for approval.[25] Nevertheless, the order left open the broader question whether NEPA applies generally to activities conducted "entirely in outer space".[26]

**In short, the FCC:**

**Authorised:** One demonstration satellite, its radio communications, and compliance with spectrum and orbital-debris requirements.

**Did not authorise:** A commercial constellation, the broader use of orbital mirrors, nor did it provide regulatory approval of the broader environmental, astronomical or societal effects of reflected sunlight.

**Did not conclude:** That space mirrors are environmentally harmless or suitable for large-scale deployment.

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[14] FCC Request Letter, 4 December 2025, pp. 2-3, question 9 and fn. 15.
[15] FCC Order, MO&O, para. 13.
[16] FCC Order, MO&O, para. 16 fn. 54, para. 22 fn. 86; Reflect Orbital, company website, accessed 17 August 2026 <https://www.reflectorbital.com>.
[17] FCC Order, MO&O, para. 19.
[18] FCC Order, MO&O, para. 19 and fn. 66-72, FCC Order, grant p. 2
[19] FCC Order, MO&O, paras. 21-23.
[20] FCC Order, MO&O, paras. 21 and fn. 78-79; 47 CFR § 1.1306(a).
[21] FCC Order, MO&O, paras. 21-23.
[22] FCC Order, MO&O, para. 21.
[23] FCC Order, MO&O, paras. 13 and 21.
[24] FCC Order, MO&O, paras. 22-23.
[25] FCC Order, MO&O, para. 22 and fn. 86.
[26] FCC Order, MO&O, para. 22 and fn. 83.

## Beyond Eärendil-1: What international space law questions would a larger system raise?

International space law is the body of international rules governing activities in outer space. Its central instrument is the 1967 Outer Space Treaty (OST), which establishes foundational principles including freedom of exploration and use, non-appropriation, State responsibility and due regard for the interests of other States.[27] Every major space-faring nation, including the United States, Russia, China, India and Japan, is State party to the OST. The Treaty is framed in general terms, and its principles apply to new forms of exploration and use, including orbital-mirror missions, even though no provision specifically addresses that technology. Accordingly, the limits of the FCC's domestic mandate do not limit the scope of the United States' international obligations under the Treaty.[28]

### State responsibility, authorisation and continuing supervision

Article VI OST makes States internationally responsible for national activities in outer space, including those conducted by private entities, and requires activities of non-governmental entities to be authorised and continuously supervised by the appropriate State Party.[29] In practical terms, this means that the United States must ensure that space activities conducted by US private companies such as SpaceX, Blue Origin and Reflect Orbital comply with the Treaty, provided that the activities in question constitute US national activities within the meaning of Article VI OST.[30] In the case of Eärendil-1, the United States bears responsibility under Article VI OST.

However, the OST does not prescribe a specific domestic institutional model or require a single agency or one all-encompassing licence to cover every aspect of the activity.[31] The FCC's limited mandate therefore raises a broader Article VI question: whether United States regulatory arrangements, taken together, ensure that the operation of orbital mirrors is authorised and continuously supervised in a manner that secures conformity with the Outer Space Treaty.[32]

### Due regard

Article IX OST requires States to conduct their space activities with "due regard" to the corresponding interests of all other States Parties.[33] It functions as a limitation on the freedom of exploration and use of outer space provided for in Article I of the OST.[34] The obligation has been interpreted as entailing due diligence: States should avoid measures aimed at impeding space activities of other States and take

[27] Arts. I, II, VI and IX OST.

[28] Compare Art. VI OST; Art. 27 VCLT; FCC Order, MO&O, para. 13.; See also Tanja Masson-Zwaan and Mahulena Hofmann, Introduction to Space Law (5th edn, Kluwer Law International 2025), pp. 17-25.

[29] Art. VI OST.

[30] Art. VI OST begins by stating "States Parties to the Treaty shall bear international responsibility for national activities in outer space, including the moon and other celestial bodies, whether such activities are carried on by governmental agencies or by non-governmental entities, and for assuring that national activities are carried out in conformity with the provisions set forth in the present Treaty. The activities of non-governmental entities in outer space, including the moon and other celestial bodies, shall require authorization and continuing supervision by the appropriate State Party to the Treaty." See also Michael Gerhard, 'Article VI' in Stephan Hobe, Bernhard Schmidt-Tedd and Kai-Uwe Schrogl (eds), Cologne Commentary on Space Law, Volume I: Outer Space Treaty (Carl Heymanns Verlag 2009), pp. 116–117.

[31] Compare Art. VI OST; FCC Order, grant p. 2, "Licensee/Grantee" and "Administration". See also Gerhard, 'Article VI', pp. 119-122.

[32] Art. VI OST; FCC Order, MO&O, paras. 13-14 and 21; Gerhard, 'Article VI', pp. 116-120.

[33] Art. IX OST, first sentence: "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."

[34] Art. I para. 2 of the OST, to be more precise; See also Sergio Marchisio, 'Article IX' in Stephan Hobe, Bernhard Schmidt-Tedd and Kai-Uwe Schrogl (eds), Cologne Commentary on Space Law, Volume I: Outer Space Treaty (Carl Heymanns Verlag 2009), p. 175

appropriate care to prevent harmful interference.[35] The "due regard" principle is to be interpreted according to the circumstances and facts of the case.[36]

This principle is particularly relevant to orbital mirrors because their beam, scattered light and contribution to sky brightness may produce effects far beyond the authorising State.[37] Due regard does not establish automatic prohibition or a veto for other States but requires consideration of competing interests and proportionate precautions in light of the scale, foreseeability and severity of potential interference.[38]

Astronomy presents a clear and direct legal concern because Article I OST protects the freedom of scientific investigation in outer space and scholarly analysis treats ground-based astronomy as an activity in the exploration and use of outer space.[39] Beyond astronomy, the FCC record raised concerns about effects on wildlife and circadian rhythms, human health and eye safety, aviation, and aesthetic and recreational interests in the night sky.[40] Their legal relevance under Article IX is not identical, however: Interference with another State's scientific activities presents the most straightforward application of the Treaty's 'potentially harmful interference' clause, which specifically concerns interference with activities of other States Parties in the peaceful exploration and use of outer space. Ecological, health, safety and aesthetic effects remain relevant to the broader due-regard assessment, however, and could also engage the consultation clause where they interfere with such protected activities.[41] Some scholars give due regard a strong precautionary dimension, arguing that Article IX OST should be read together with the international law duty not to cause harm to other States and the precautionary principle. On that interpretation, they regard the FCC's licensing of approximately 12,000 Starlink satellites without an environmental impact assessment as violating both the OST and customary international law.[42]

Where the United States has reason to believe that an activity planned by it or its nationals would cause potentially harmful interference with another State's peaceful exploration or use of outer space, Article IX requires appropriate international consultation before the activity proceeds.[43] Other States may themselves request consultation if they consider their activities threatened, although, again, Article IX does not grant them a formal veto.[44]

## Transparency and the importance of scale

Article XI OST supports transparency by requiring States Parties, "to the greatest extent feasible and practicable," to inform the United Nations Secretary-General, the public and the international scientific community about the nature, conduct, locations and results of their space activities.[45] For orbital mirrors,

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[35] See Art. VI OST; Marchisio, "Article IX", pp. 175-176.
[36] Marchisio, "Article IX", pp. 169 ff., esp. pp. 175–176.
[37] Olivier R. Hainaut, pp.1 ff.; FCC Order, MO&O, para. 19 fn. 64 and para. 22 fn. 84.
[38] Byers and Boley, Who Owns Outer Space? (Cambridge University Press 2023), pp. 105-109; Marchisio, "Article IX", pp. 175-180.
[39] See for example Byers and Boley, Who Owns Outer Space?, pp. 99-104; Art. I OST.
[40] FCC Order, MO&O para. 16 fn. 55-56, paras. 20, 22 and 25.; Also compare Hainaut, pp. 2 and 14.
[41] Art. IX OST, first and third sentences; Marchisio, 'Article IX', pp. 175-180; Byers and Boley, Who Owns Outer Space?, pp. 99-105.
[42] See for example Byers and Boley, Who Owns Outer Space?, pp. 107-108.
[43] Art. IX OST. The third sentence reads: "If a State Party to the Treaty has reason to believe that an activity or experiment planned by it or its nationals in outer space, including the moon and other celestial bodies, would cause potentially harmful interference with activities of other States Parties in the peaceful exploration and use of outer space, including the moon and other celestial bodies, it shall undertake appropriate international consultations before proceeding with any such activity or experiment."
[44] Art. IX OST, fourth sentence.
[45] Art. XI OST; Also see Jean-François Mayence and Thomas Reuter, "Article XI", in in Stephan Hobe, Bernhard Schmidt-Tedd and Kai-Uwe Schrogl (eds), Cologne Commentary on Space Law, Volume I: Outer Space Treaty (Carl Heymanns Verlag 2009), pp. 189 ff., esp. pp. 195-196.

meaningful disclosure could therefore include orbital and pointing information, illumination schedules, measured brightness and scattering data, and the results of the demonstration mission.[46]

Scale is crucial to the assessment.[47] Scientific modelling of Reflect Orbital-type constellations indicates that thousands of very bright reflectors could generate substantial atmospheric scattering, increase background sky brightness and cause significant losses for certain astronomical instruments even where the principal illumination beam is directed away from observatories.[48] These results depend on assumptions, but they illustrate why any future authorisation of a large constellation would have to be assessed separately for conformity with Articles VI and IX OST, taking account of its scale and cumulative effects.[49] Therefore, the Eärendil-1 authorisation does not predetermine approval of Reflect Orbital's longer-term vision.

If orbital illumination developed into the large-scale infrastructure envisioned by Reflect Orbital, compliance with the FCC's requirements would not, by itself, establish compliance with all relevant obligations under the Outer Space Treaty.[50] Relevant obligations would include authorisation and continuing supervision under Article VI, due regard for the corresponding interests of other States under Article IX, appropriate international consultation where the Article IX threshold is met, and information-sharing under Article XI to the greatest extent feasible and practicable.[51]

Eärendil-1 may be only one demonstration satellite. The harder legal questions begin when one becomes thousands.

**In short:**

- The FCC's limited domestic mandate does not limit the United States' international obligations under the Outer Space Treaty.
- Under Article VI OST, States remain internationally responsible for national space activities conducted by private companies and must provide authorisation and continuing supervision.
- The principle of "due regard" requires States to take the interests of other States seriously and to exercise appropriate care in light of their circumstances.
- If a State has reason to believe that a planned activity would cause potentially harmful interference with another State's peaceful exploration or use of outer space, Article IX requires international consultation before the activity proceeds, although this does not give other States an automatic veto.
- Scale matters: authorisation of a single demonstration satellite does not predetermine approval of a large constellation. A larger system would need to be assessed separately, with particular attention to continuing supervision, effects on other States' interests, consultation where required and transparency.

[46] Compare the commenters inputs at FCC Order, MO&O, para. 19 fn. 69-71; Also see Mayence and Reuter, "Article XI", pp. 196–197.
[47] Also see FCC Orde, MO&O, paras. 8, 16 and 22; Hainaut, pp. 12-14.
[48] Hainaut, pp. 10-14.
[49] FCC Order, MO&O, para. 16 fn. 54 and para. 22 fn. 86; Art. VI and IX OST; Hainaut, pp. 12-14.
[50] Compare FCC Order, MO&O para. 13; Arts. VI, IX and XI OST.
[51] Taking into account the requirements of Art. I, VI, IX and XI OST.

## FROM AN ASTRONOMY POINT OF VIEW

*written by Prof. Dr. Ravit Helled and Dr. J-N. Mettler*

Ground-based astronomy relies on naturally dark skies. Any increase in artificial brightness directly reduces astronomers' ability to observe the faintest objects in the Universe.

Since 2019, the number of satellites orbiting Earth has increased to more than 14,000, dominated by SpaceX's Starlink constellation. Current proposals would increase that number dramatically, with more than 1.7 million additional satellites planned to be launched into orbit. According to a recent study by the European Southern Observatory (ESO), such numbers would have devastating consequences for astronomy.[52]

Among the proposed satellite constellations, Reflect Orbital raises particular concern because its reflector satellites would become the brightest artificial objects ever placed in orbit. According to ESO's simulations, an observer located within an illuminated beam would see the reflecting satellite appear approximately four times brighter than the full Moon. Even when no beam is directed at the observer, each reflector would still appear as bright as the planet Venus. From a light-polluted city such as Munich, ESO notes that these reflector satellites could become the only "stars" visible in the night sky.

The impact extends beyond what can be seen with the naked eye. Satellites illuminated by the Sun are much brighter than the distant galaxies astronomers are trying to observe. Observing such faint objects requires long-exposure imaging to collect sufficient light. If a Sun-illuminated satellite crosses the telescope's field of view during exposure, it leaves a bright trail across the image that obscures the astronomical objects behind it.

Simulations conducted by ESO show that even with current proposals for large satellite constellations, dozens of satellite trails could appear in a single image taken with the Very Large Telescope's (VLT) workhorse camera, FORS2, resulting in field-of-view losses of up to 28%. For wide-field survey instruments such as the Vera C. Rubin Observatory, for example, the impact could be even greater. If satellites are only slightly brighter, most long-exposure images acquired over several hours each night could be rendered unusable. Modern astronomical instruments employ highly sensitive detectors with complex, high-density electronics. A satellite trail bright enough to saturate the detector produces not only a broad streak across the image but also a series of ghost trails that multiply the losses and can potentially contaminate the entire image.

Satellite constellations also affect astronomy in less obvious ways. Even satellites that are too faint to be seen directly introduce a diffuse background glow, while brighter satellites scatter light throughout the atmosphere. Both effects increase the overall brightness of the night sky. For Reflect Orbital's proposed constellation, the study by Hainaut et al. estimates that the night sky could become three to four times brighter overall. The increased sky brightness is due to sunlight being scattered by air molecules and aerosols throughout the atmosphere, while additional light is reflected back from the illuminated ground, producing a diffuse glow that extends well beyond the illuminated area.[53] Recent atmospheric modelling suggests that, under cloud-free conditions, the nighttime sky could be measurably affected for observers up to about 30 km from the illuminated beam. Thin cirrus clouds at e.g. 10 km could scatter part of the reflected light over even greater distances, although the extent of this effect depends strongly on cloud properties and the relative geometry of the source, clouds and observer. [54]

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[52] Hainaut, O. R. (2026). *Large or bright satellite constellations*. *Astronomy & Astrophysics* (accepted manuscript). European Southern Observatory; ESO Webpage, accessed 10.08.26 < https://www.eso.org/public/news/eso2607/>.

[53] Kocifaj, M., Bakos, G. Á., & Kundracik, F. (2026). *Atmospheric Light Pollution by Proposed Reflect Orbital Space Mirrors*. arXiv preprint arXiv:2608.06433.

[54] Ibid., p.10

Based on these studies, preserving modern ground-based astronomy will require limiting both the number and brightness of satellites in low-Earth orbit. Hainaut et al. recommends a maximum of approximately 100,000 satellites, provided they remain fainter than naked-eye visibility (visual magnitude 7). Should satellites be brighter than this threshold, the total number would need to be substantially lower. The study further emphasises the need for astronomers, engineers, satellite operators and regulators to work together to adopt effective mitigation measures while managing the continued commercialization of low-Earth orbit.

**In short:**

- Ground-based astronomy depends on naturally dark skies. Both the number and brightness of future satellites will determine how much access to the Universe can be preserved.
- Reflect Orbital's proposed constellation would introduce the brightest satellites ever placed in orbit, affecting astronomy through both satellite trails and increased background sky brightness.
- Preserving access to the Universe will require limiting both the number and brightness of satellites, alongside effective mitigation measures and close collaboration between astronomers, industry and regulators.

## SPACE MIRRORS FOR EMERGENCY RESPONSE AND SEARCH AND RESCUE

*written by Prof. Dr. D. Scaramuzza, edited by Dr. J-N. Mettler*

Reflect Orbital promotes illuminating disaster zones and search-and-rescue (SAR) operations as one of the key applications of orbital mirrors. At first glance, the concept appears compelling: providing additional illumination exactly where and when it is needed. But would a 5 km wide beam of reflected sunlight from orbit offer a genuine operational advantage, or could existing technologies such as drones, aerial imaging and ground-based infrastructure achieve the same objectives more effectively while minimising impacts on ecosystems and the surrounding environment?

A 5 km wide area illuminated at approximately full-moon brightness could provide some situational benefit during an emergency, particularly for human responders operating across a large area without functioning electrical infrastructure. However, it would not turn night into day and would only be effective under favourable weather conditions with little or no cloud cover. At around 0.1 lux, the illumination might improve general visibility and potentially support some conventional cameras, but it would remain far below the lighting levels typically required for emergency operations. Whether it materially improves drone navigation or aerial imaging would depend strongly on the terrain, weather, viewing geometry and sensors being used. At the same time, sudden or unintended illumination could pose a risk to crewed aircraft by affecting pilots' vision, meaning that the use of orbital illumination during emergency operations may require coordination with fixed-wing and helicopter operations.[55]

For comparison, emergency medical operations generally require illumination in the range of 1-10 lux, while US occupational-safety standards specify considerably higher minimum levels for certain emergency work environments, including approx. 54 lux for general areas and 320 lux for first-aid stations.[56] Achieving such illumination levels from orbit would therefore likely require a coordinated use of multiple reflectors.

Modern SAR drones generally do not require broad visible illumination. They can carry their own precisely directed lights and use thermal cameras, low-light cameras, radar or other sensors. Their light can follow the search area, illuminate objects from a useful angle and be deployed where and when it is needed. Ground teams can similarly use portable lighting systems. These solutions are much more localised and controllable than illuminating a 5 km spot from orbit. Thermal imaging, which is often particularly valuable for detecting people at night, would also gain little from reflected visible sunlight.

The orbital approach could nevertheless have a niche advantage when a very large, remote or inaccessible area must be illuminated rapidly and local infrastructure has failed or cannot be transported there. Possible examples might include a major earthquake zone, a remote maritime accident, flooding or a large-scale infrastructure failure. It could provide broad-area illumination without first sending generators, lighting towers or aircraft into the affected region. This benefit would, however, disappear or be greatly reduced under clouds, fog, smoke or dense vegetation—conditions that are common in precisely the emergencies in which search-and-rescue operations take place. Moreover, several conditions would need to coincide: a major emergency would have to occur within the geographical and temporal window in which orbital illumination is available, while weather conditions would need to permit

[55] Air Line Pilots Association, International (ALPA), comments submitted in Reflect Orbital Inc., Application to Construct, Launch and Operate EARENDIL-1, FCC ICFS File No. SAT-LOA-20250701-00129 (2026); see also American Astronomical Society, Reply Comments in the Matter of Reflect Orbital Application to Construct and Launch an NGSO Satellite, FCC ICFS File No. SAT-LOA-20250701-00129, 30 March 2026.

[56] U.S. Occupational Safety and Health Administration (OSHA), 29 CFR §1926.65(m), Hazardous Waste Operations and Emergency Response, Table D-65.1, Minimum Illumination Intensities in Foot-Candles; see also 29 CFR § 1926.56(a), Illumination, Table D-3.

the reflected sunlight to reach the affected area. This considerably narrows the circumstances in which space mirrors could provide a practical advantage.

### Evidence needed before large-scale deployment

Before considering deployment at scale, evidence from operational trials involving emergency services would be needed to demonstrate that space mirrors offer a genuine advantage over existing solutions rather than only showing that a bright spot can be produced. Relevant evidence would include:

- measurable improvements in detection probability and search time for people or hazards;
- comparisons with thermal cameras, drone-mounted lights and portable ground lighting;
- illumination stability, duration, positioning accuracy and availability at short notice;
- performance through clouds, smoke, haze and difficult terrain;
- effects on pilots, autonomous vision systems and people outside the intended target area;
- a complete cost comparison that includes the constellation, launches, operations and end-of-life disposal.

The single Eärendil-1 mission can be justified as an experiment: it may provide useful measurements and test an unusual engineering concept. But successfully reflecting light is not the same as demonstrating a compelling emergency service. The much larger proposal for tens of thousands of satellites would require a substantially higher level of evidence because its environmental and societal footprint would be global.

Space technologies often attract attention because they are novel and there is certainly a risk that the novelty of “sunlight on demand” attracts disproportionate attention and investment. In most emergencies, better communications, robust power supplies, thermal imaging, rapidly deployable drones and improved coordination between responders are likely to provide more immediate and targeted benefits. Orbital mirrors should therefore be evaluated against these alternatives using the same operational and economic criteria—not treated as inherently superior because they are space-based.

Space mirrors might eventually complement existing emergency technologies in a small number of exceptional, broad-area scenarios. We do not currently see them replacing drones or ground-based lighting. The appropriate sequence would be to demonstrate a measurable operational advantage in carefully controlled trials, investigate unintended effects, and only then discuss whether deployment beyond a few experimental satellites is warranted.

**In short:**

- Current emergency-response technologies such as drones, thermal imaging and portable lighting are likely to provide more flexible, precise and effective solutions for most search-and-rescue operations.
- Orbital mirrors may complement existing technologies in a small number of exceptional, broad-area emergency scenarios, but their effectiveness would depend strongly on weather conditions and satellite availability.
- Demonstrating a measurable operational advantage through operational trials should be a prerequisite before considering deployment beyond experimental missions.

## FROM AN EARTH OBSERVATION PERSPECTIVE

*written by Dr. A. Hüni, edited by Dr. J-N. Mettler*

Earth-observation satellites monitor our planet consistently over time. Artificial illumination from orbital mirrors therefore raises a number of questions. Could reflected sunlight interfere with sensor calibration or the interpretation of satellite imagery? Might large constellations affect long-term environmental observations, or could they even create new opportunities, for example by enabling optical imaging during emergencies?

The proposed constellation of Reflect Orbital could illuminate selected targets for up to two hours after sunset and before sunrise near the equator, and potentially throughout the night at high northern latitudes during summer.

From a remote sensing perspective, a single demonstration satellite is unlikely to create major issues. Likewise, even Reflect Orbital's proposed constellation of thousands of space mirrors would probably have little to no impact on the calibration of Earth-observation satellites, provided that illumination remains confined to the day–night transition zone (the so-called terminator). Many Earth-observation sensors rely on naturally dark regions on the Earth's night side, typically areas unaffected by light pollution, to perform so-called *dark calibration*, providing a reference measurement for the sensor. Many spaceborne sensors do not have mechanical shutters, largely for cost reasons, and therefore depend on naturally dark scenes for calibration. Artificial illumination of these areas could interfere with this process and ultimately affect subsequent measurements.

At the global scale, climate monitoring is unlikely to be significantly affected by a number of orbital mirrors. The amount of energy reflected onto selected locations on Earth would probably be too small to be detectable in global climate records. Regional effects, however, cannot be ruled out. Artificially extending daylight hours could alter the local radiation budget, for example by maintaining higher temperatures in urban areas for longer into the evening. Whether such illumination would significantly delay nocturnal cooling would require dedicated modelling and quantitative assessment.

Artificial illumination at night could also create new opportunities. Additional light may enable optical Earth-observation sensors to acquire imagery during hours of darkness, potentially supporting emergency response and disaster management. Whether the available illumination would be sufficient for useful imaging, however, would first require dedicated sensitivity studies to determine whether enough reflected light reaches the ground to achieve an adequate signal-to-noise ratio.

**<u>In short:</u>**

- Impacts on Earth-observation sensor calibration are likely to remain limited unless orbital mirrors illuminate naturally dark areas used for dark calibration.
- Global climate monitoring is unlikely to be significantly affected, while potential regional effects require further assessment.
- Orbital illumination could create new opportunities for nighttime optical imaging, but its practical usefulness remains to be demonstrated.

## GREEN ENERGY OR GREENWASHING?

*written by Dr. M. Timpe, edited by Dr. J-N. Mettler*

Reflect Orbital presents space mirrors as a sustainable technology that can provide “clean” energy. The company promotes them as a way to reduce energy consumption from ground-based lighting and to increase the output of solar farms after sunset and before dawn by providing additional sunlight. However, these proposed benefits should be evaluated alongside the wider environmental, ecological, cultural, socioeconomic and geopolitical implications of deploying large constellations of orbital mirrors. The expected gains may be relatively modest compared with the potential impacts of illuminating large areas from space. Assessing the sustainability of such a system therefore requires looking beyond its intended benefits and considering its full life cycle and societal consequences.

In the case of solar farms, for example, a peer-reviewed study estimated that a 20-reflector constellation of very large reflectors (200 m) could provide approximately 728 MWh of additional solar energy per day – a 0.4% increase over existing global output.[57] Reflect Orbital claims that their full 50,000-reflector constellation would increase these solar farms’ capacity factor by 20% globally, implying a global production increase of 36 GWh per day. For context, a typical modern offshore wind turbine (10 MW with a capacity factor of 45%) produces about 108 MWh per day. Reflect Orbital’s 50,000 space mirrors would therefore only produce the equivalent of about 335 offshore wind turbines (there are an estimated 15,000 offshore wind turbines globally). This raises the question of whether deploying thousands of reflector satellites would offer advantages over modestly expanding existing and proven renewable-energy infrastructure.

Similarly, several of the proposed applications already have terrestrial alternatives. Urban lighting can be improved through more efficient lighting technologies deployed only where needed, while alternative concepts for space-based solar power transmit energy at microwave or infrared wavelengths rather than through visible light, thereby avoiding direct interference with biological light-sensitive systems, although not necessarily eliminating impacts on astronomy.

Taken together, these comparisons raise a broader question: do the expected benefits justify the environmental and societal costs of deploying orbital reflector constellations, particularly where alternative solutions already exist? Sustainability claims, or greenwashing, of this kind are a relatively recent phenomenon in the space industry, but are likely to become more common as the commercialization of space progresses.

If Reflect Orbital were to deploy its proposed constellation of 50,000 reflector satellites, or even a substantially smaller fraction of it, the implications would extend far beyond the illuminated areas themselves. A large-scale deployment could have environmental, ecological, cultural, socioeconomic, safety and geopolitical consequences.

**Environment:** Widespread artificial illumination could substantially increase light pollution, globally, rendering all but the brightest stars invisible for observers located near an illuminated beam.

**Ecological**: Artificial light pollution has the potential to disrupt environmental cues that species across terrestrial, aquatic and aerial ecosystems depend on to regulate critical biological, physiological, and behavioural functions.

**Cultural:** Many human societies that still actively depend on or interact with the natural night sky, raising concerns that artificial light pollution could negatively impact these functional and cultural practices.

[57] Çelik, O., & McInnes, C. R. (2024). A constellation design for orbiting solar reflectors to enhance terrestrial solar energy. Acta Astronautica, 217. https://doi.org/10.1016/j.actaastro.2024.01.031.

**Socioeconomic:** Many communities around the globe, especially rural indigenous communities, depend on dark sky regions and night sky tourism to support their local economies. Artificial light pollution from space mirrors may therefore disproportionately affect rural and indigenous communities.

**Safety**: Proposed space mirrors are significantly brighter and more concentrated than the full moon, raising concerns about risks to eye health for observers within the beams and disorientation for pilots and drivers operating at night.

**Geopolitical:** Artificial light pollution generated by space mirrors is inherently of a cross-border nature and Reflect Orbital's own indication is that its reflectors are intended to be dual-use, meaning that will also serve military, applications.

Assessing sustainability also requires considering the complete life cycle of such a constellation. Beyond the impacts of artificial illumination itself, thousands of reflector satellites would need to be launched, operated and eventually deorbited throughout the lifetime of the system. Given the large cross-sectional area of the deployed reflectors, substantially greater atmospheric drag than for conventional satellites can be expected, potentially affecting their operational lifetime and the frequency of replacement launches and re-entries required to maintain the constellation.

The large surface area of the reflectors is also relevant to collision risk. A larger collision cross-section increases the area exposed to potential encounters with other spacecraft and orbital debris, making collision avoidance and space-traffic management an important consideration. Eärendil-1 is therefore equipped with onboard propulsion for collision avoidance and active deorbiting.[58] While such risks can be managed for an individual spacecraft, the challenge changes considerably at constellation scale. Operating hundreds, thousands or potentially tens of thousands of large reflectors would increase the cumulative number of potential conjunctions that need to be monitored and, where necessary, avoided.

Orbital geometry adds another consideration. Eärendil-1 is planned to operate in a near-polar orbit with an inclination of approximately 88 degrees. If a future constellation were deployed in similarly high-inclination orbital planes, the resulting traffic environment and interactions with other spacecraft operating in heavily used regions of low-Earth orbit would require careful assessment. More broadly, this challenge must be considered in the context of an increasingly populated low-Earth-orbit environment, where multiple large constellations may compete for overlapping orbital regions.

The long-term sustainability of orbital mirrors therefore depends not only on their environmental effects on Earth, but also on their footprint in the orbital environment. Atmospheric drag, collision risk, collision-avoidance requirements, replacement launches, re-entries and end-of-life disposal would all need to be considered when assessing the sustainability of a constellation at the scale envisioned by Reflect Orbital.

Whether orbital mirrors ultimately become part of future energy or climate adaptation strategies will depend not only on technical feasibility, but also on governance and societal priorities. Widespread deployment would require convincing evidence that the benefits clearly outweigh the environmental, societal and geopolitical costs, particularly where alternative solutions already exist.

[58] Reflect Orbital, Inc. (2025). Technical Annex for EARENDIL-1, Exhibit A to Application, FCC ICFS File No. SAT-LOA-20250701-00129, p. 1.

**In short:**

- The potential benefits of orbital mirrors need to be weighed against existing alternatives, particularly where comparable services or energy gains may be achieved without deploying large satellite constellations.
- Large-scale deployment could have environmental, ecological, cultural, socioeconomic, safety and geopolitical consequences that extend well beyond the areas being illuminated.
- Large-scale deployment would require convincing evidence that its benefits outweigh the environmental, societal and geopolitical costs across the full life cycle of the system.

## FROM A SOCIO-ECOLOGICAL PERSPECTIVE

*written by Dr. N. Bathla and Prof. Dr. Norman Backhaus, edited by Dr. J-N. Mettler*

Proposals such as the one by Reflect Orbital are perhaps best understood not simply as a new technology, but as a socio-technical imaginary, a vision of the future that seeks to normalise a particular technological pathway while reshaping how society imagines the urban night. Similar ideas have emerged before. Perhaps the closest historical parallel is Znamya, an orbital mirror project proposed and realized by Soviet engineer Vladimir Syromiatnikov during the 1990s, which promised to illuminate parts of Siberia from space before ultimately proving technically impractical and being abandoned.

From an urban lighting perspective, the proposed cost of US$5,000 per hour to illuminate a 5-kilometre area is not necessarily the primary concern.[59] Depending on the application, such costs may even be comparable to illuminating a similarly sized urban area using conventional lighting infrastructure. The more significant issue is what this proposal represents institutionally, i.e., the privatization and platformisation of urban illumination.

Public lighting has traditionally been treated as a municipal public good, governed through democratic planning processes and increasingly negotiated against ecological concerns, accessibility, and public safety. A commercial “sunlight-on-demand” service would instead transform illumination into a centrally controlled commodity operated by a private platform. As we have seen with other platform businesses, control over essential infrastructures can gradually shift pricing power and governance away from public institutions toward corporate actors**.** A familiar example is surge pricing in platform-based services such as Uber, AirBNB, and Dileveroo.

There are also practical questions about whether illumination from several hundred kilometres above the Earth’s surface could meaningfully replace conventional urban lighting. Reflected sunlight would inevitably produce highly uneven lighting conditions, with strong contrasts between illuminated and shadowed areas created by buildings and urban morphology. Similar lightning conditions are often found in prison compounds. Contemporary lighting research increasingly shows that uniformity, careful contrast management and location-specific lighting are essential for both perceived and actual safety. Highly contrasted environments may therefore increase rather than reduce feelings of insecurity.[60]

Perhaps most importantly, orbital mirrors appear to move in the opposite direction of current urban lighting policy. Across Switzerland and elsewhere, cities are moving toward nocturnal rewilding, increasingly adopting adaptive lighting, dynamic dimming and dark ecological corridors to reduce unnecessary artificial illumination, protect biodiversity, improve human health and preserve the

[59] Chang, Kenneth, and Hiroko Tabuchi. "A Night Light in the Sky? Reflect Orbital Wants to Launch a Big Space Mirror." The New York Times, 9 Mar. 2026, www.nytimes.com/2026/03/09/climate/space-mirror-satellite-solar.html.

[60] Briers, S. (2023). *Infrastructures of freedom: Public light and everynight life on a Southern city’s margins*. JOVIS. https://doi.org/10.1515/9783868597806

experience of the natural night sky. Projecting additional sunlight from space would instead extend artificial illumination into periods and places where darkness is increasingly recognised as an important ecological and public resource.

For these reasons, Reflect Orbital’s proposal is less of a realistic solution to contemporary urban lighting challenges than a socio-technical imaginary that seeks to commodify both the nocturnal commons and low Earth orbit. Whether such systems ever become technically viable is questionable, but they already raise important questions about who governs darkness, who controls artificial illumination, and whether the night should become another platform-mediated infrastructure.

**In short:**

- Orbital illumination is not only a technological proposition; it could reshape how urban lighting is governed and how society relates to the night.
- Reflected sunlight from orbit could create highly uneven urban lighting conditions, while shifting control over illumination from public institutions towards private platform operators.
- Orbital illumination runs counter to current trends towards nocturnal rewilding and adaptive lighting, which increasingly recognise darkness as an important ecological and public resource.

## FROM A STRATEGIC AND DEFENSE APPLICATION POINT OF VIEW

*written by Dr. A. Hüni and Dr. J-N. Mettler*

Beyond civilian applications, orbital illumination could also have strategic and military uses. Reflect Orbital explicitly identifies defence as one of its target markets, proposing its technology for uninterrupted solar power and lighting for critical defence operations. The company has also received a Phase II SBIR contract through AFWERX to advance satellite-based sunlight-redirection technology, framing the capability in terms of nighttime energy and light as well as energy independence and resilience.[61]

The potential advantages depend strongly on the application. An orbital system could provide wide-area illumination to remote locations without first deploying lighting infrastructure or generators. Its potential contribution to military power supply is less straightforward. Reflect Orbital redirects sunlight onto existing photovoltaic arrays rather than transmitting concentrated electrical power to a dedicated receiver. Providing meaningful amounts of electricity would therefore require a sufficiently large area of solar panels at the receiving location. This differs from other military power-beaming concepts that use narrow-beam lasers to deliver power to dedicated ground receivers, e.g., mounted on military-size trucks. For forward operating bases and similarly constrained locations, orbital mirrors may therefore be more plausible as a source of wide-area illumination than as a direct substitute for conventional power infrastructure.

Reflect Orbital also envisages the illumination itself as configurable: the target area can be relocated, brightness adjusted and the light switched off by changing the orientation of the satellite. At sufficient scale, such characteristics could make orbital illumination relevant to operations in locations where conventional infrastructure is unavailable, damaged or difficult to supply.

[61] America’s seed fund SBIR website, accessed 11 August 2026 <https://www.sbir.gov/portfolio/2304081>; Reflect Orbital website, accessed 11 August 2026 <https://www.reflectorbital.com/press/reflect-orbital-selected-for-sbir-phase-ii-contract-by-afwerx-to-advance-satellite-based-sunlight-redirection-technology>.

For military operations, however, illumination can be both an asset and a constraint. Lighting an operational area could improve visibility and support activities that benefit from visible light, but the same illumination could also make personnel, vehicles or infrastructure more observable. This is particularly relevant for technologically advanced armed forces, which have invested heavily in night-vision and infrared capabilities precisely to operate effectively in darkness while retaining a tactical advantage over less well-equipped adversaries. Wide-area visible illumination could reduce that advantage by making the same environment more readily observable to both sides. The usefulness of orbital illumination would therefore depend heavily on who controls the illumination, where and when it is provided, and whether it can be delivered with sufficient precision and reliability. As with the emergency-response application, weather would remain an important physical limitation: reflected sunlight cannot provide the intended illumination where clouds prevent it from reaching the surface.

At larger scale, the strategic significance may therefore lie less in simply "turning night into day" than in the ability to control access to illumination and potentially solar energy at particular places and times. A privately operated constellation providing such a service to military customers would consequently raise questions about access, prioritisation and control of infrastructure with both civilian and defence applications. In this respect, control over artificial illumination bears similarities to the strategic importance of communication infrastructure such as Starlink, where access (or denial of access) can influence operational capabilities.

At the same time, the military utility of orbital illumination remains largely unproven. Reflect Orbital's current roadmap projects progressively brighter and longer-duration illumination as the constellation expands. While the initial demonstration is intended to provide approximately full-moon illumination for only a few minutes (0.1 lux for 5 min), later stages envision substantially greater brightness and duration (36,000 lux for hours).[62] Whether such projected capabilities would translate into meaningful operational advantages for defence applications remains to be demonstrated.

**In short:**

- Orbital illumination could provide light and additional solar energy to remote or infrastructure-poor locations, potentially supporting critical defence operations without relying on local lighting or power infrastructure.
- Its strategic significance may lie not only in illumination itself, but in who controls access to light and energy, raising questions about the role of privately operated infrastructure in military operations.
- The military utility of orbital illumination remains largely unproven: whether the projected increases in brightness and duration translate into meaningful operational advantages will need to be demonstrated in practice.

[62] Ibid,. Section: Our constellation and markets will continuously expand.

## FROM AN ETHICAL PERSPECTIVE

*written by Dr. Ning Wang, edited by Prof. Dr. Ravit Helled*

Reflecting sunlight onto Earth after sunset is an extension of an old human ambition – overcoming the limits imposed by darkness. From the ethics perspective, this proposal does not simply lie in the brightness of an individual satellite; instead it lies in the possibility of transforming darkness from a naturally occurring condition into a service that can be bought, sold, and delivered on demand.

This technology raises important ethical questions beyond the practical feasibility – Should a private company be permitted to alter a fundamental feature of the shared environment? And, if yes, who should have the authority to decide when, where, and for whose benefit that alteration may occur?

### Who should have the authority to decide when and where artificial sunlight is directed?

The first question concerns **ownership** – does Reflect Orbital's ownership of a satellite entail its ownership of the environmental effects produced by that satellite? A company can own a factory without owning the atmosphere into which its emissions enter; it can own a ship without owning the ocean on which it sails. Similarly, a company can own an orbital reflector without owning the night sky beneath it.

The illuminated area may be geographically local; but the ethical consequences extend beyond the customer purchasing the service. This leads a fundamental problem of **authority without consent**. A company could potentially sell illumination to a solar farm, a construction site, an event organizer, a city government, or a military organization, while the ecological and cultural consequences are experienced by people and non-human organisms that never agreed – or was asked to agree – to the transaction in the first place.

The reason why this matters is because darkness is not merely the absence of light. It is a natural and environmental condition to which species and organisms have adapted throughout the evolutionary history. Research on artificial light at night has documented effects on circadian rhythms, migration, reproduction, foraging and predator-prey interactions, while light pollution can alter ecological processes even at relatively low levels of illumination.

Consequently, decisions about artificial sunlight should not be left exclusively to the company providing the service or the customer purchasing it. Rather, they should be treated as decisions about **a shared environmental commons**. Although the Outer Space Treaty does not provide a tailor-made regulatory regime for orbital sunlight, its underlying principle signifies private participation in space does not eliminate public responsibility over activities whose consequences extend beyond private property.

Decisions about where and when artificial sunlight may be directed should involve regulators, scientists, affected communities, and the relevant international bodies. At minimum, communities underneath illumination zones should have a voice in decisions that could repeatedly alter their nighttime environment. Astronomers should have a role because optical astronomy depends upon darkness. Ecologists should be involved because the consequences for wildlife cannot be inferred simply from human perceptions of brightness. And since the effects can cross national borders, international coordination will be necessary.

The ethical principle is straightforward: **the greater the geographical, ecological, and temporal consequences of an intervention, the less legitimate it is for a private actor to make the decision unilaterally**.

### Is this simply another satellite mega-constellation problem?

The second question concerns **governance** – Should private actors be allowed to intentionally modify the natural environment to create a new commercial service? For a conventional satellite constellation, the question may be how much environmental disruption society should tolerate in exchange for the benefits of the service. With orbital reflectors, the question shifts because private infrastructure in space can change the conditions under which everyone else uses a shared environment.

Astronomers, for example, have raised concerns about the effects of large numbers of bright satellites on optical observations. From an environmental perspective, most satellite mega-constellations are sources of unwanted effects, which can impose costs on people who are not the customers. While the satellite operators generally do not intend to illuminate an astronomical observatory or alter the appearance of the night sky, Reflect Orbital's proposed system is qualitatively different – altering the terrestrial light environment is not an accidental externality, it is the very product being sold.

This makes artificial sunlight closer to a form of **deliberate environmental intervention** which, in turn, bears ethical significance. There are precedents for deliberate environmental modification. Humanity already changes rivers, landscapes, atmospheric chemistry and ecosystems for economic or social purposes. While such interventions are not automatically wrong, they do require some combination of environmental assessment, public regulation, licensing, monitoring, and mitigation.

Artificial sunlight, therefore, deserves comparable scrutiny. Existing artificial light pollution is already a global environmental problem; adding another mechanism for introducing light into previously dark environments raises yet an additional question of **cumulative impact**. A new source of illumination cannot be ethically evaluated as though it were entering an otherwise untouched environment. It represents a new category of environmental intervention – it potentially allow humanity to manipulate the planet's natural light-dark cycle remotely, from orbit, and according to commercial demand.

Eärendil-1 should be treated as an experiment, not merely as the first unit of an inevitable commercial constellation. Independent observers should measure its effects on astronomical observations, wildlife management, atmospheric scattering, aviation, communities, and nighttime ecosystems. The measurements should be public and, most importantly, regulators should establish in advance what findings would prevent or modify further deployment.

The ethical principle is one of proportionality: **the greater the social necessity, the greater the environmental disruption that can be justified, following a precautionary approach to scaling**.

### Who bears the costs?

The third question concerns **access and distribution** – How should the costs be distributed among those who could pay for the economic benefits of orbital sunlight and those who could not? A solar company might gain additional electricity production. A construction company might gain additional working hours. An event organizer might gain additional illumination. But the night sky seen by a nearby community could become brighter. Astronomers could lose observing opportunities. Nocturnal animals could experience a changed habitat. Future generations could inherit a nighttime environment containing tens of thousands of artificial reflectors.

This is a classic problem of **environmental externalities**: the person making the economically beneficial decision is not necessarily the person bearing its environmental costs. This is why the debate over Eärendil-1 should not be reduced to a dispute between technological optimism and environmental conservatism. The technology might produce some level of social benefits; what matters, however, is that a previously natural environmental condition has been deliberately altered, yet not by those who could afford those benefits.

It is also an issue of **intergenerational justice**. Future generations cannot participate in today's licensing proceedings. They cannot vote against a constellation. They cannot negotiate compensation for losing access to a darker sky. Yet they may live with the consequences of such decisions for decades. Even if today's society agreed that there were little value in preserving a dark sky, future societies may value it for astronomical, ecological, cultural, and scientific reasons, or event simply for the experience of an unmodified night.

The ethical principle is that of fairness: **those who bear the consequences should be part of the decision-making process, and should have a genuine opportunity to influence whether, where, and under what conditions the technology can be deployed**.

## Conclusion

The Reflect Orbital case shows that humanity has acquired the technological ability to manipulate the boundary between day and night from orbit. The fact that we can do so does not mean that its use can be permitted. Before we turn darkness into a commodity, we should decide whether the night is something that anyone can sell, whether the night belongs to all of us and, if it does, who has the right to change it, at what cost, and for whose benefits.

**In short:**

- Artificial sunlight raises a fundamental question of authority: should darkness remain part of a shared environmental commons, or become a service that can be bought, sold and delivered on demand?
- The benefits and costs of orbital illumination may fall on different groups. Those who experience its environmental, ecological, cultural and scientific consequences should therefore have a meaningful role in decisions about its deployment.
- Eärendil-1 should be treated as an experiment rather than the first step towards inevitable large-scale deployment: further deployment should depend on independent evidence and whether its benefits are proportionate to its environmental and societal impacts.

## FROM A THEOLOGICAL PERSPECTIVE

*written by PD Dr. A. Losch*

Eärendil the Mariner is character in J.R.R. Tolkien's Middle-earth legendarium, depicted as carrying a Silmaril – a primordial jewel bright as the morning star – across the sky, on his brow[63]. And bright as the morning star Orbital Reflect's first satellite may well shine at the night sky. Many of the US tech elite are fond of Tolkien's mythology although it may be questioned if they heeded his appreciation of environmental care embedded into his sagas[64][65].

From a theological perspective, the lights at the sky – sun, moon and stars – are exactly that: just lights "to divide the day from the night; and let them be for signs, and for seasons, and for days, and years: And let them be for lights in the firmament of the heaven to give light upon the earth: and it was so» (Gen1, 14-15 KJV) – and not Gods, as in the *Enuma Elisch*, the Babylonian mythological creation epos roughly contemporary to the Biblical writings mentioned. This demythologization of originally Divine spheres marks not only the origins of Jewish-Christian thought but also the later revolutionary dawn of science replacing Aristotelian celestial imaginations[66].

Therefore, a theological assessment of Orbital Reflect's project needs to be divided: between an appreciation of the dawn of science and technology with it, but also a warning about what can go wrong if humankind «plays God» and sets something like additional stars onto the night sky. Now, humankind indeed has an important and creative role in the biblical narratives, perceived as being created in God's image. The question is how to interpret this role. Modern biblical exegesis is determined to understand it as a *responsibility* Divinely bestowed onto humankind to the take care about Earth, the so-called *dominium terrae*. Which is the source of the idea of stewardship. Maybe it is time to extend the discussion to include a *dominium coeli*, a stewardship of the sky, albeit with some caveats included[67]; in the past humankind has also been understood as the crown of creation, while many scholars are questioning this stance today. Even the whole era of technological progress following after the Jewish-Christian demythologization of nature has been questioned due to environmental concerns[68]. This justified criticism should not defer from discussing humankind's role on this planet. We should not forget that dust we are, stardust maybe[69], but grown out of the soil of this planet.

A responsible treatment of Orbital Reflect plans from a theological point of view hence has to include a complete environmental assessment.

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[63] https://en.wikipedia.org/wiki/Eärendil_and_Elwing.
[64] https://en.wikipedia.org/wiki/Environmentalism_in_The_Lord_of_the_Rings.
[65] https://www.nytimes.com/2025/05/23/books/tolkien-musk-thiel-silicon-valley.html.
[66] Chapter 10 in Andreas Losch, Der gestirnte Himmel über uns, Zürich 2022.
[67] Chapter 15 ibid.
[68] Lynn White, The historical roots of our ecologic crisis, in: Science (New York, N. Y.) 155/3767, 1967, 1203–1207.
[69] Traugott Jähnichen / Andreas Losch, We are stardust: Dignity and right of non-human life on and beyond our planet, HTS Teologiese Studies September 2023.

## FROM A CULTURAL PERSPECTIVE

*Written by Prof. Dr. Beth Singler*

Who owns the Sun? Or rather, will we come to accept that sunlight has been transformed into yet another commodity? From a cultural anthropological and historical perspective, the elemental materials that permeate and are produced by our planet have long undertaken a shift from discovered treasure to tradable commodity. Gold, held as precious by numerous cultures, was also discoverable by those with keen eyes within the rivers and streams of many different geological sites around the world. So, for some, it was as easy to collect very small amounts of gold as it was to draw out the water it lay in. Four and half thousand years ago, in ancient Egypt, gold was described by King Tushratta as "more plentiful than dirt".[70] However, millennia of gold rushes, deeper and deeper mining, commercially driven wars, and new financial trading systems have gotten us to a place where gold's value was the default underpinning standard for many of our world's economic systems and is still turned to in times of global uncertainty.[71]

Such contemporary commodification of resources has also given us water in plastic bottles, with their own environmental costs that so many of us have accepted, and even artisanal life-giving gases being sold at 'Oxygen Bars', or permeating the mansions of the wealthy through home oxygenation.[72] Science fiction has also presented us with worlds where such basics of life are scarce and metered, as in the corrupt company town of Venusville (which is actually on Mars) in the 1990 film Total Recall, based on the 1966 Philip K. Dick story, "We can Remember it for you Wholesale". Frequently gasping for breath, the mutant residents of Venusville are indebted to the colony's entrepreneurial owners for their lives and livelihoods. This company town model is also in the background of many real-world discussions of our interstellar future, such as Elon' Musk's own visions for Mars, based upon his current Earthly company towns, Starbase and Snailbrook, both in Texas.

But how readily will we silently adapt to a model where sunlight is also a controllable commodity? Will we, like the mutants of Mars, revolt and riot so it can free again? One cultural factor affecting the adaptation to this commodification will be emotion driven sentiment. The demythologising that the previous Theological response speaks of, is variable by culture and context. The Solar Eclipse in Western Europe in August 2026 has shown at least a spark of transcendent awe being generated by such a celestial event, with public spaces inundated with observers, and a very short lived 'gold rush' of another sort for specialised sunglasses. Specific studies have supported the role of celestial events such as eclipses in collective effervescence and awe, two factors in feeling more spiritually enthusiastic.[73] Further, many cultures have their own overt religious interpretations of the significance of the sun, more frequently than they do for elements like water or air.[74] As the centre of our system and for millennia the 'centre' of our universe, the stories of the gods of the Sun have also been our creation stories.[75] Such stories have helped us to make meaning, to 'understand' ourselves in ways that other commodified elements like gold do not. So, what price will we accept on sunlight, in service of a greater god known as Capitalism. And should we?

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[70] https://egypt-museum.com/gold-in-ancient-egypt/.
[71] https://www.imf.org/en/about/factsheets/sheets/2022/gold-in-the-imf.
[72] https://www.wsj.com/real-estate/luxury-homes/home-oxygenation-systems-luxury-homes-614a0f7d.
[73] https://news.web.baylor.edu/news/story/2026/viewing-solar-eclipse-together-amplifies-awe-baylor-researchers-find.
[74] https://www.historyextra.com/period/general-history/sun-gods-goddesses-deities/.
[75] https://www.astronomy.com/science/tales-of-the-sun-from-myth-to-modern-science/.

## CONCLUSION: FROM DEMONSTRATION TO DEPLOYMENT

*written by Dr. J-N. Mettler and Prof. Dr. Ravit Helled*

Space mirrors sit at an unusual intersection of technological ambition, scientific uncertainty and questions of governance. A single demonstration satellite such as Eärendil-1 may provide valuable data on whether sunlight can be redirected from orbit with the precision and reliability envisioned. But demonstrating that the technology works is not the same as demonstrating that deploying it at scale is desirable.

As the different perspectives in this article show, the answer depends strongly on the application and on scale. Orbital illumination could offer potential benefits in selected situations, from emergency response and nighttime Earth observation to energy and defence applications. At the same time, large constellations could introduce consequences for astronomy, the natural night sky, ecosystems and urban environments, while raising broader questions about international responsibility, transboundary effects and who ultimately controls access to artificial illumination.

Many of these questions cannot yet be answered conclusively. Eärendil-1 therefore represents not only a test of an emerging technology, but an opportunity to generate the evidence needed to evaluate its benefits, limitations and unintended effects. Before moving from a single experimental satellite to constellations numbering in the thousands or tens of thousands, that evidence will need to be weighed across disciplines, not only against what is technically possible, but against existing alternatives and the environmental and societal consequences of deployment.

Eärendil-1 is ultimately more than a technological ambition: it is a question that brings together science, engineering, environmental responsibility, economics, governance, ethics, theology and our shared imagination of the future. Seen from these different perspectives, it becomes clear that space can no longer be approached through isolated disciplines or competing interests. As humanity's presence beyond Earth continues to grow, the challenges and opportunities of space must be coordinated across borders, sectors, and fields of knowledge, guided by a common commitment to responsibility and sustainability. The future of space will therefore depend not only on what we are capable of building, but on how wisely we choose to build, regulate, and share it, ensuring that innovation serves both present needs and the long-term wellbeing of Earth, its orbital environment, and generations yet to come.