QUICK STUDY

John Barentine is an astronomer and principal at Dark Sky Consulting in Tucson, Arizona. He coleads the Community Engagement Hub of the International Astronomical Union's Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference.

Threats to the dark and quiet sky

John Barentine

Night-sky contamination is a problem not just in the visible spectrum, and it's getting worse.

Dutch postimpressionist painter Vincent van Gogh wrote to his brother Theo in 1888, "For myself, I declare I don't know anything about [death]. But the sight of the stars always makes me dream." Indeed, understanding the cosmos and our place in it has been the dream of many humans over countless generations. But the mere sight of stars at night is now impossible for many people because of light pollution. Exquisitely sensitive detectors of light, especially at both radio and optical wavelengths, are threatened by anthropogenic pollution of the electromagnetic spectrum. And as humanity establishes a more extensive presence in space, those threats now come from both above and below.

Confronting the problem requires a more systemic approach than has historically been taken. The present and future of astronomical discovery depends on preserving what has come to be called the dark and quiet sky, where "dark" refers to an absence of visible light pollution and "quiet" refers to a lack of radio interference. The preservation movement pursues reduction of pollution sources both on the ground and in space and across the electromagnetic spectrum.

Light pollution

Light from outdoor sources on Earth's surface travels upward either directly from the source or indirectly after reflecting off the ground. Although most of that light escapes the atmosphere, what's left scatters and is redirected back toward the ground. The scattered light creates sky glow, which lowers the contrast between celestial objects and the background sky and reduces the number of stars visible to the unaided eye.

For observations made with telescopes, sky glow competes with the light of astrophysical sources, especially faint ones. It lowers the signal-to-noise (S/N) ratio of observations of a given exposure time. For observations limited by photon noise and the sky background, the exposure time required to reach a given S/N is proportional to the square of the S/N ratio. Sky glow therefore imposes a steep exposure-time cost on science performed with ground-based telescopes.

Sky glow can be reduced through effective legislation. For example, Chile has nationwide lighting standards that regulate the allowed average level of outdoor lighting. The standards impose strict limits on the use of fixtures, such as LEDs, that emit bluer light, which is more susceptible to Rayleigh scattering and thus creates more sky glow, and also promote the use of redder, longer-wavelength light. Smaller-scale legislation is also in force in the US, including around many US observatories.

Unfortunately, sky glow respects no political boundaries and often drifts hundreds of kilometers from its sources. The problem is accelerated by a lack of coordination between jurisdictions and the order-of-magnitude increase in the typical brightness of light fixtures brought about by the advent of white LED technology in the global lighting market. In a 2023 paper in *Science*, researchers reported that the brightness of the night sky increased at a global average rate of 7–10% per year from 2011 to 2022.

A NIGHTTIME LANDSCAPE IMAGE captured near Hanksville, Utah, during a five-and-a-half-hour exposure. The night sky is crisscrossed with light streaks mainly from sunlight reflected from satellites in two orbital shells. Sky glow from distant cities appears on the horizon at bottom center. (Photo © Jeff Warner–CatchingTime.com)

To evade the influence of sky glow, astronomers have for decades built observatories in locations far from cities. The proliferation of LED lighting now threatens observatories everywhere, and nowhere is safe from it—not even places with legislation to reduce light pollution. The spread of blue-rich LED lighting is a potentially existential threat for major facilities, both existing and planned for the future. And those facilities represent billions of dollars of public investment. They include the Very Large Telescope, the Vera C. Rubin Observatory, the Giant Magellan Telescope, and the Extremely Large Telescope, all of which are in Chile.

Radio interference

The radio spectrum is subject to international allocation and regulation between frequencies of about 8 kHz and 3000 GHz.

Certain frequency ranges are set aside specifically as protected bands for radio astronomy. Those frequencies are adjacent to ones used for either terrestrial or space-based communications. Sometimes, radio transmitters leak radiation into protected frequencies. Noise-limited observations are particularly susceptible to interference, which is becoming more common given the development of ultrasensitive radio receivers, such as those used in studies of the cosmic microwave background.

Spectrum management and regulation committees attempt to find a balance between the competing interests of radio astronomers and others, such as users working in commercial enterprises and militaries. The conventional solution is to build radio observatories in designated radio quiet zones (RQZs), inside which the emission of energy at radio frequencies is substantially prohibited. In the US, the National Radio Quiet Zone spans 34 000 km^2 around the Green Bank Observatory and the US Navy's radio receiving facilities in West Virginia.

But as commercial uses of the radio spectrum continue to ramp up, the radio skies grow louder. An increasing number of orbiting satellites with passive emission in protected bands and ones designed to communicate directly with mobile phones anywhere in the world threaten to undermine the efficacy of RQZs.

Space objects

Satellites and space debris—collectively, space objects—have affected astronomical observations since the launch of the first artificial satellite in 1957. Disruptions from satellites come in more forms than just radio transmission from communications satellites interfering with sensitive radio astronomy observations.

Orbiting high above Earth, satellites and disused pieces of launch hardware, such as rocket bodies, remain illuminated by sunlight. They can be seen from the ground, even by the naked eye, after local sunset or before sunrise as points of light moving across the night sky. In addition, space objects can obscure astronomical objects and lead to data loss by leaving streaks or trails of light in images from ground- and space-based telescopes.

Small pieces of debris, whether shed by intact satellites or generated from collisions of space objects, threaten to create even more junk by damaging, disabling, or destroying other satellites. Even such small particles, if reflective enough, are able to scatter and reflect so much light to the ground that they significantly elevate the brightness of the sky background—a new variety of sky glow.

For decades, the number of large, artificial objects orbiting Earth increased at a slow rate. But the rate skyrocketed in 2019, when private commercial enterprises began launching what are sometimes known as megaconstellations: collections of hundreds to tens of thousands of satellites to relay telecommunications signals with near-global coverage. Simulations of large satellite constellations predict serious problems for ground-based astronomy without adequate mitigation of their optical, IR, and radio brightnesses, both reflected and emitted. Voluntary efforts by major commercial space operators have begun to reduce the harm posed by their satellites to astronomy through techniques such as changing the exterior material to be less reflective and adjusting the satellites' orbits, but the problem is far from solved.

The steps to a solution

Although the effects of terrestrial light pollution on astronomical observations were reported as early as the 18th century, astronomers didn't begin organizing to combat terrestrial light pollution until the 1980s (see Physics Today, December 1984, page 63.) Their efforts focused both on increasing the availability of astronomy-friendly outdoor lighting products, such as low-pressure sodium lamps, and enacting appropriate local regulations, such as switching off billboard illumination after midnight. And they successfully lobbied for the creation of RQZs to protect radio astronomy.

When the large satellite constellation issue dawned a few years ago, astronomers again organized to advocate for their field in the face of a novel threat. Taking a page from the terrestrial dark-sky movement, astronomers coordinated with people outside their field—in this case, commercial satellite manufacturers and operators. Astronomers encouraged them to innovate in satellite design and operation to reduce impacts on astronomy.

A 2021 conference resulted in publication of a landmark report, *Dark and Quiet Skies for Science and Society*, which examines potential harms of light pollution to both astronomy and human and animal well-being and makes a series of recommendations to address them. Among the recommendations are limitations on where artificial light is used, the wavelengths of such light, and shielding of the light source to direct light downward. The conference and report were organized at the request of the United Nations Committee on the Peaceful Uses of Outer Space, an international governing body established by the UN General Assembly in 1959 to consider legal issues arising from the exploration and use of outer space. The committee establishes the rules-based international order, to which UN member states generally adhere in enacting their own national space policies.

The ideal of a dark and quiet sky—with brilliant stars that inspire dreams—is one many astronomers fight to protect. Steps need to be taken to reduce the influence of electromagnetic pollution on the planet that is our shared home. Preservation of the night sky across the electromagnetic spectrum is an extension of the stewardship of a human environment that now goes beyond our planet and reaches toward the cosmic ocean. It is also key to the future of astronomical discoveries.

Additional resources

- A. C. Boley, M. Byers, "Satellite mega-constellations create risks in low Earth orbit, the atmosphere and on Earth," *Sci. Rep.* **11**, 10642 (2021).
- J. Barentine, *Artificial Light at Night: State of the Science 2024*, DarkSky International (2024).
- W. van Driel, "Radio quiet, please!—Protecting radio astronomy from interference," *Proc. Int. Astron. Union* **5**(S260), 457 (2009).
- Dark Sky Oases, Optical Astronomy, Bioenvironment, Satellite Constellation, and Radio Astronomy Working Groups, *Dark and Quiet Skies for Science and Society: Report and Recommendations*, Zenodo (2022).
- F. Falchi, S. Bará, "Light pollution is skyrocketing," *Science* **379**, 234 (2023). PT