

Light Pollution, Radio Interference, and Space Debris: Threats and Opportunities in the 2020s

Thematic Areas and Summary

Recent rapid advances in technology have created potentially substantial threats to ground-based and space-based astronomy in the upcoming decade. Around the world, communities are transitioning away from legacy outdoor lighting such as high-pressure sodium to light-emitting diode (LED) fixtures. A dramatic increase in artificial light at night (ALAN) is occurring, and it will worsen if the default adoption of broad-spectrum white LEDs continues. In space, a sudden and dramatic increase in the number of satellites is occurring, including enormous proposed fleets of 10,000 or more in low Earth orbit, threatening to swamp ground-based astronomy and perhaps even visual appreciation of the night sky, and increasing the risk of proliferating space debris through collisions. And the radio frequency (RF) landscape is becoming increasingly crowded due to ongoing advances in wireless connectivity and other pressures, putting bandpasses used for sensitive information relevant to astronomy at risk. In this white paper, we will outline the principal risks in each area and specify key principles and policy points that the AAS and other advocates can use in mitigating the threats to astronomy posed by these developments.

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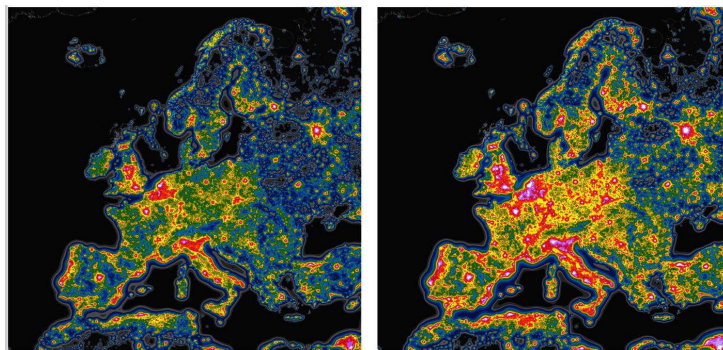
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Light Pollution

Overview

Light pollution, and the skyglow resulting from it, is a truly global phenomenon, now affecting over 80% of the world's population.¹ Artificial light at night on Earth, as detected with remote sensing, has grown substantially in recent years. Both the indications of light, as a fraction of land area of various countries, and the total upward radiance have increased at a global average rate of 2% per year, with some countries seeing double-digit percentage growth.²

An important driver of change in this area during the past decade is the emergence and eventual market dominance of solid-state lighting products, and in particular white light-emitting diodes (LEDs). The shift in spectral power distribution away from emission line sources like low- and high-pressure sodium to pseudo-continuum sources like white LED puts much more power into short wavelengths than before; a consequence of this is a fundamental shift in the color characteristics of artificial light at night emitted into the nighttime environment.³ Small-particle scattering in the atmosphere of blue-rich white LED light can greatly extend the reach of these sources, when compared lumen-for-lumen to earlier lamp technologies, far from the emitting source.⁴ The figure below, taken from Falchi et al. 2016¹, shows the dramatic projected visual impact in Europe from a continent-wide conversion from current lighting (left panel) to 4000K correlated color temperature (CCT) white LEDs (right panel) even when the number of lumens emitted is held constant.



¹ F. Falchi et al. 2016 *Science Advances*, 2, 6, e1600377, DOI:[10.1126/sciadv.1600377](https://doi.org/10.1126/sciadv.1600377).

² C. Kyba et al. 2017 *Science Advances*, 3, 11, e1701528, DOI:[10.1126/sciadv.1701528](https://doi.org/10.1126/sciadv.1701528).

³ A. Sánchez de Miguel et al. 2017 *MNRAS* 467, 2966, DOI:[10.1093/mnras/stx145](https://doi.org/10.1093/mnras/stx145).

⁴ M. Aubé, J. Roby and M. Kocifaj 2013 *PLOS One* 8, e67798, DOI:[10.1371/journal.pone.0067798](https://doi.org/10.1371/journal.pone.0067798); C. Luginbuhl, P. Boley and D. Davis 2014 *Journal of Quantitative Spectroscopy and Radiative Transfer*, 139, 21, DOI:[10.1016/j.jqsrt.2013.12.004](https://doi.org/10.1016/j.jqsrt.2013.12.004)

Ground-based astronomical observatories are therefore more sensitive than before to light from distant cities, rendering vulnerable sites formerly considered relatively 'safe'. As more world cities convert to LED, they are generally maintaining lighting levels used with previous lamp technologies, so the increase in short-wavelength light is very considerable. The changing spectral power distribution of light complicates our ability to sense both upward radiance seen from space as well as scattered light seen from the ground in the form of skyglow. As an example, the main remote sensing platform for measuring night lights, the Visible Infrared Imaging Radiometer Suite Day-Night Band (VIIRS-DNB) aboard the *Suomi NPP* satellite, is effectively blind to light with wavelengths of less than 500 nm, so it fails to detect light from the 'blue peak' of white LED emissions around 450 nm.⁵

Although an increasing number of world cities now have some form of outdoor lighting policy, there is still little in the way of meaningful regulation of lighting in a general sense and no international conventions for the protection of astronomical observatories. Regional legislation intended to protect observatory sites in certain parts of the world has stumbled at the implementation/enforcement phase.⁶ Even when local initiatives succeed, the increasing reach of light from distant cities not subject to these regulations can adversely impact observatories.

Further complicating matters, evidence from remote sensing exists to suggest that the plummeting price of white LED lighting products has fueled elastic demand for lighting, leading to a 'rebound effect' in which cost savings from increased energy efficiency of lighting are being redirected into the deployment of more lighting.⁷ However, in other cases, LED may contribute positively to site protection if it is implemented properly. The strong directionality of LED sources, their dimming capability, and tunable spectral power distributions enable the deployment of sources whose emissions are controlled to meet public needs while reducing overall light emissions and resulting skyglow.⁸

The completion of world conversion to LED seems inevitable at this point, but emerging best practices for deployment of LED in the vicinity of observatories means that poor outcomes for astronomy aren't necessarily inevitable. Effective means to confront this threat are (1) to reduce the global consumption of light by promoting appropriate lighting levels to counter the trend of higher luminous efficacy of lighting products and (2) to advocate for lower-impact

⁵ C. Kyba *et al.* 2015 *Remote Sensing*, 7, 1–23, DOI:[10.3390/rs70100001](https://doi.org/10.3390/rs70100001).

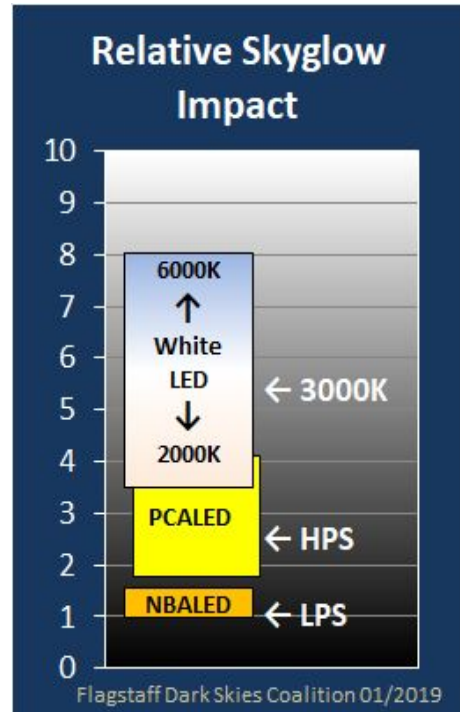
⁶ See, e.g., "[Light pollution threatens Chile's dark skies](#)", Phys.org, 17 February 2018. Chile's "Norma Lumínica" (Supreme Decrees N° 686/1998 and 43/2012) requires full shielding and spectrum management of lighting in three northern provinces near major international astronomical observatories: Antofagasta, Atacama and Coquimbo.

⁷ C. Kyba *et al.* 2017.

⁸ J. Barentine *et al.* 2018 *Journal of Quantitative Spectroscopy and Radiative Transfer*, 212, 10, DOI:[10.1016/j.jqsrt.2018.02.038](https://doi.org/10.1016/j.jqsrt.2018.02.038); C. Baddiley 2018 *Journal of Quantitative Spectroscopy and Radiative Transfer*, 219, 142, DOI:[10.1016/j.jqsrt.2018.05.011](https://doi.org/10.1016/j.jqsrt.2018.05.011); M. Aubé *et al.* 2018 *Monthly Notices of the Royal Astronomical Society*, 478(2), 1776, DOI:[10.1093/mnras/sty1143](https://doi.org/10.1093/mnras/sty1143).

alternatives to white LED such as filtered LED (FLED) or phosphor-converted (PCA) or narrow band (NBA) amber (see figure at right, courtesy the Flagstaff Dark Skies Coalition, which shows the much lower skyglow impact of PCA and NBA).

The adverse effects of light pollution, and especially excess blue light at night, on human health and wildlife are widely accepted and increasingly studied in medical and biological fields, with numerous institutes and journals devoted to the science of circadian rhythms, melatonin suppression, elevated rates of cancer due to exposure to artificial light at night, etc.⁹ In the environmental advocacy world, light pollution is being seen more and more as a destructive force on natural ecosystems and on humans' ability to experience nature.¹⁰ These public health, environmental, and societal concerns present astronomy with important potential allies in the fight against light pollution.



In response to these issues, the AAS issued in 2017 a resolution¹¹ endorsing both the IAU 2009 Resolution B5, "In Defence of the Night Sky and the Right to Starlight,"¹² which affirms that access to a dark night sky is a universal human right, and makes quality outdoor lighting a worldwide imperative, and the AMA report (2016). The United Nations Educational, Scientific and Cultural Organization (UNESCO), along with the IAU and the International Astronautical Congress, adopted in 2007 a statement that "an unpolluted night sky that allows the enjoyment and contemplation of the firmament should be considered an inalienable right [of humankind] equivalent to all other socio-cultural and environmental rights".¹³ The US National Park Service states that a "dark night is a resource integral to many natural processes".¹⁴ These statements of principle provide context and add weight and urgency to our efforts to protect the night sky.

⁹ American Medical Association 2016 *Human and Environmental Effects of Light Emitting Diode (LED) Community Lighting* CSAPH Report 2-A-16

https://www.darksky.org/wp-content/uploads/bsk-pdf-manager/AMA_Report_2016_60.pdf

¹⁰ Sierra Club magazine cover story, February 2018,

<https://www.sierraclub.org/sierra/2018-2-march-april/feature/hunt-for-stars-dark-skies-preserves-and-parks>

¹¹ <https://aas.org/governance/society-resolutions#light>

¹² https://www.iau.org/static/resolutions/IAU2009_English.pdf

¹³ <https://www3.astronomicalheritage.net/index.php/show-theme?idtheme=21>

¹⁴ <https://www.nps.gov/subjects/nightskies/natural.htm>

Strategic plan

The U.S. astronomy community should:

- Advocate for the widespread adoption of alternatives to white light, such as phosphor-converted amber LED, especially (but not necessarily only) near astronomical observatories, and against the use of white light generally except where its use is particularly justified;¹⁵
- Take a more proactive role in advocating for sensible and practicable lighting policies at the national to local levels, with special policy considerations for sensitive regions around observatory sites;
- Work with lighting designers and manufacturing companies to influence the design and installation of future outdoor lighting products;
- Support research, development, and standardization of night sky brightness measurement protocols, particularly those involving spatially resolved and radiometrically calibrated all-sky imaging, to better characterize the threat to observatories from distant light sources; and
- Continue to coordinate with partner organizations on public messaging campaigns and policy initiatives.

Partner organizations

- Astronomical
 - International Astronomical Union
 - American Astronomical Society
 - European Southern Observatory
 - International Dark-Sky Association
- Environmental
 - Sierra Club
 - Audubon Society
 - Appalachian Mountain Club

¹⁵ To the extent that white light is used, it should emit the least possible amount of short-wavelength (<500 nm) light possible to avoid both environmental harm as well as to minimize Rayleigh and Willis–Tyndall scattering.

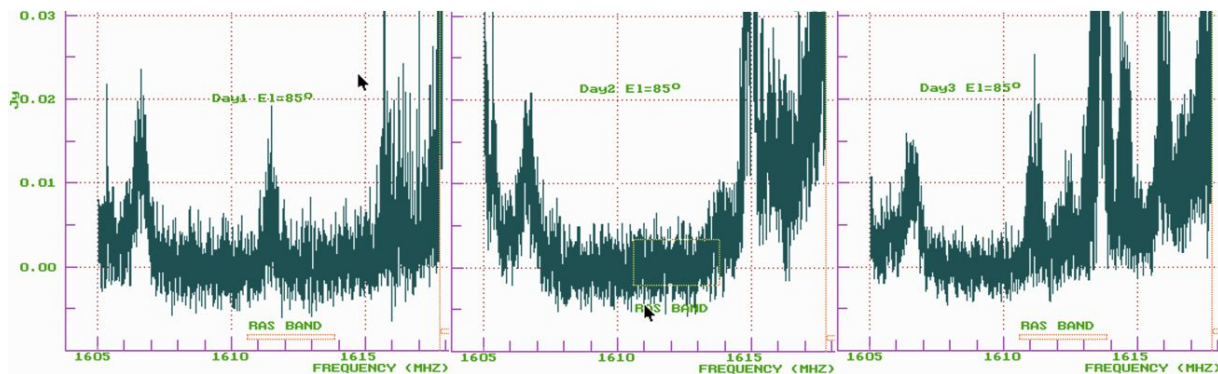
Radio Interference

Overview

Maintaining a usable spectrum environment for radio astronomy involves:

- Site testing and maintenance to avoid generating interference or importing interfering devices
- Monitoring the ambient spectrum and tracking the occurrence of interference
- Spectrum management to influence regulation governing use of radio spectrum

All of these are affected by increasing commercialization of the spectrum, proliferation of mobile, air- and space-borne transmitters, and expansion of commercial use to higher frequencies and wider bandwidths. All are also affected by comparable advances in radio astronomy.



The figure above shows satellite interference observed in 2019 May at the Green Bank Telescope while parked pointing due south at 85 degree elevation. The protected radio astronomy band at 1610.6 - 1613.8 MHz used to observe the 1612 OH maser line from evolved stars is marked. All signals arise from satellite emissions. Uncontrolled spurious emissions from a satellite constellation's downlink at 1618 - 1626.5 MHz bleed into the astronomy band from above and can extend across and below the astronomy band. Signals below 1608 MHz could also arise from satellites used for global positioning (although not from the US GPS system itself). Peak satellite signal levels may exceed 1,000,000 Jy.

Strategic Plan

Site Maintenance

Radio observatories set rules for on-site spectrum use that are followed by employees and visitors. Rules are based on measuring RF emissions of devices that will be installed or allowed on-site, or could impinge on site operations from outside. Higher sensitivities are needed, at higher test frequencies, under a broader range of test conditions than are now available. For instance, automotive radars operate at 24 and 76-81 GHz, and the National Highway Traffic Safety Administration is considering a rule that would make this equipment standard on all new cars in the USA. Additionally, early 5G will operate at 24-30 GHz but the highest test frequencies in Green Bank and at the VLA are 18 (indoors) and 40 GHz, respectively. ***The frequency range, capability and sensitivity of onsite test equipment must be extended.***

Spectrum Monitoring

Checking compliance with local frequency coordination arrangements like the National Radio Quiet Zone rules, preventing self-generated radio frequency interference (RFI), etc can be assessed only by spectrum monitoring. Current efforts are spotty in time and frequency coverage and have limited sensitivity. They do not provide a record for documenting the occurrence of interference in protected bands or the general availability of spectrum. ***A real-time record and historical archive should be available at observable frequencies.***

Spectrum management

The radio regulatory scheme is inverted relative to that for visible light: control of radio spectrum is exercised nationally or internationally. Radio spectrum management requires a commitment that can be sustained only by a few entities: The NAS Committee on Radio Frequencies (CORF), the NSF Electromagnetic Spectrum Management Unit and the NRAO through its spectrum manager. While effective, this effort lacks tools to do the most complex regulatory compatibility studies and the career path to practice radio astronomy spectrum management is uncertain at best. ***Better tools and training and career paths should be provided.***

To provide safe harbors, recent major international radio instruments are protected by national radio quiet zones of which the US National Radio Quiet Zone around Green Bank was first. The VLA operated successfully without a radio quiet zone while its bandwidth and frequency coverage were limited to 1st-generation electronics, but the absence of national spectrum protection around the VLA is now a dangerous anachronism. ***The ngVLA proposed to succeed the VLA in New Mexico should be protected by a radio quiet or coordination zone.***

Space Debris

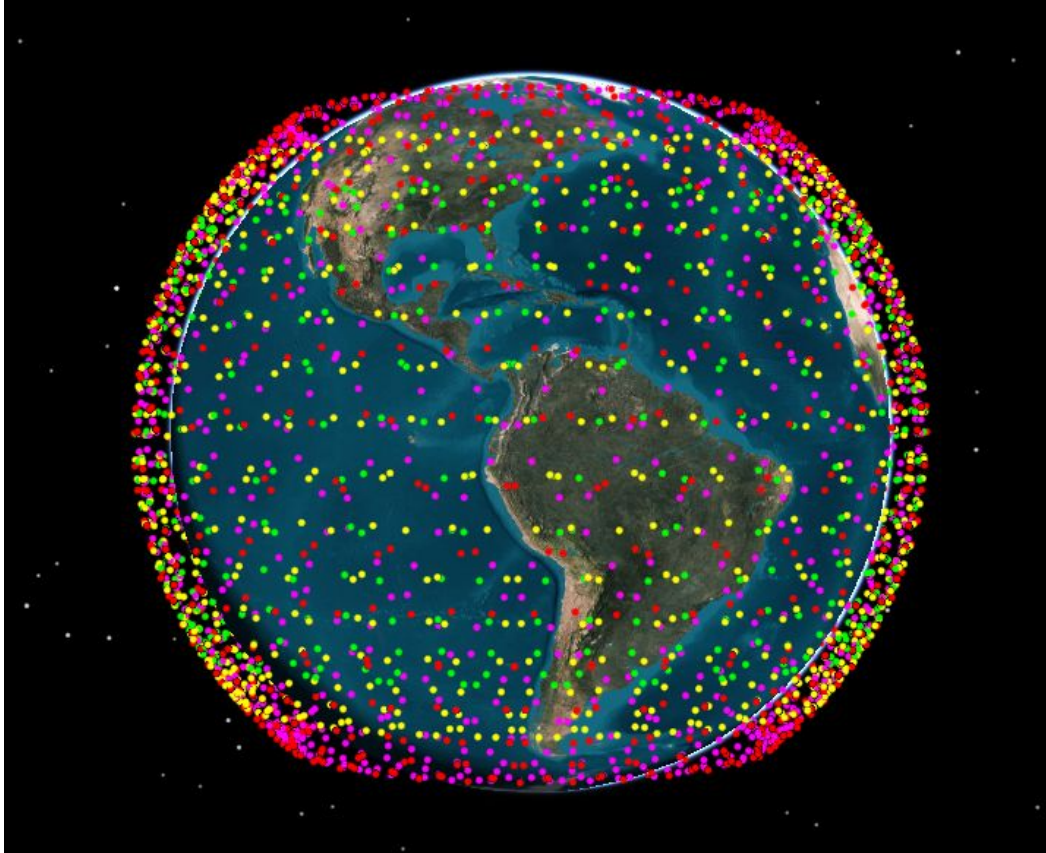
Overview

Issues associated with the recent launch of the first 60 satellites in a new satellite constellation into Low Earth Orbit (LEO) illustrate well the challenges facing the astronomical community from artificial objects in Earth orbit. There are currently over 18,000 such objects larger than 10 cm with well determined orbits, of which less than 10% are active satellites. There are projects planned that could add another 20,000 active satellites to this population, mostly in LEO (less than 2000 km altitude). Astronomers have the following concerns:

- Radio Interference, as described in the previous section.
- The pollution of the night sky visible to the unaided eye. Currently there are several hundred Earth orbiting satellites brighter than 6th magnitude - the night sky will appear very different if this number increases by a factor of 10 or more.
- Contamination of sidereally tracked images by streaks caused by satellites moving across the field of view during the exposure. For large fast telescopes such as LSST, these streaks may well saturate the detectors.
- Collision risk to operational space telescopes such as Hubble from other active satellites, inactive satellites, and smaller pieces of space debris.

Even if all new satellite launches were stopped today, these issues would continue to be a problem.

Constellations such as Starlink (planned number = 1584 satellites at 550 km altitude) and Kuiper (planned number = 3,236 satellites at altitudes ranging from 590 to 630 km) are the first of a new series of satellites planned for LEO. These systems include communication satellites like Starlink, radar satellites with large Earth facing antennas (read potentially bright), and others. Smaller satellites such as CubeSats are being flown with deployable drag sails to enable them to reenter the Earth's atmosphere to minimize space debris issues. Again, these sails could potentially be quite bright.



*Illustration of 4,820 new satellites from Starlink and Kuiper constellations.
Orbital information taken from public FCC filings.*

Many of these satellites might be visible only during evening and morning twilight since they are in LEO and the shadow cone of the Earth is quite broad here. Detailed studies would be necessary to quantify the visibility.

Strategic Plan

- The astronomical community should emphasize to spacecraft builders and operators the importance to minimize the reflectivity of new satellites. Of particular interest would be designs to minimize glints or flares which could be interpreted as rapid transient events in LSST-like data systems.
- Satellite operators should be encouraged to provide the most accurate and precise orbits possible of their satellites that can be used to schedule astronomical observations in fast, wide -field telescopes like LSST. The schedules would be chosen to avoid satellites - even a delay of 1 second might leave an image completely clear of a bright streak.

- All future astronomy missions in space should meet or exceed the most stringent orbital debris mitigation guidelines.
- International policy should be developed to manage the brightness of new satellite constellations.

Costs

To the extent our recommendations in this State of the Profession paper comprise a “project,” we do not at this time have detailed cost estimates for our recommendations.

However, the recommendations in our strategic plans call principally for time and effort from individuals and groups in advocacy and awareness-building. With the possible exception of coordinating the last bullet above (developing international policy on satellite constellations), the advocacy and tracking efforts recommended should fall well within the “small” category of ground-based projects as specified in the APC guidelines. Furthermore, many of the efforts may be independently supported (e.g., by community service T&E support from home institutions, other organizations such as the IDA, or even on a volunteer basis, as they frequently already are through local and regional grass-roots efforts).

Effective progress can also be made simply by encouraging engagement from within the astronomical community, which we have often found to be lacking. Preserving the source of our data must be supported as professionally relevant and meaningful for graduate students and senior faculty alike, and time and professional credit should be provided within otherwise busy research and service careers to develop skills and allow attention to be given to these essential topics.

Given the magnitude of some of the threats, the potential benefit from even modest support appears substantial relative to the cost incurred.

End Note

This white paper was written collaboratively by the members of the AAS Standing Committee on Light Pollution, Radio Interference, and Space Debris. All members of the Committee had the opportunity to view, edit, and comment on the document. The views expressed in this paper represent the consensus of the Committee members. Views in this paper are not necessarily the views of the AAS, its Board, or its membership.