Education and Heritage in the era of Big Data in Astronomy
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Turn on the Night! Science and Education on Dark Skies Issues

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Abstract. The "Turn on the Night" associated event had presentations on the latest dark skies protection issues considered by the IAU′s Dark and Quiet Skies working groups. Presentations were also made on dark skies education programs and cultural/scientific heritage.

Keywords. dark skies protection, astronomy, dark skies oases, bio-environment, education, cultural and scientific heritage, nightscapes

1. Introduction and Science Update on Dark Skies Issues

The "Turn on the Night" associated event was divided evenly between science updates on the latest dark skies protection issues and education programs important to preserving the cultural heritage of starry night skies. For the science updates, topics included protection of ground-based observatories, dark skies oases and the bio-environment, as well as the impact of satellite constellations on astronomy. Material for the latter topic was drawn from research conducted by the Dark and Quiet Skies (D&QS) working groups sponsored by the IAU for the United Nations. This research, along with recommendations for mitigation solutions, can be found in the full report here: https://www.iau.org/static/publications/dqskies-book-29-12-20.pdf, and as a summary for the United Nations here: https://www.iau.org/static/publications/uncopuos-stsc-crp-8jan2021.pdf. For the dark skies education programs and cultural/scientific heritage section, the whys and hows were explored utilizing the international citizen-science program, Globe at Night, as a means to bring awareness of issues on and solutions to light pollution. The authors are members of Commission B7 on the Protection of Existing and Potential Observatory Sites.

1.1. *Protection of Ground-Based Observatories*

Ground-based observatories are critical to astronomy and are complementary to space astronomy missions. They can be built at a substantially larger scale and lower cost than those launched into orbit, and remain the engines of cutting-edge discovery. Rapidly growing artificial sky glow puts world observatories under threat. In the past decade, the globally averaged rate of increase of sky glow was 2% per year, roughly double the rate of world population growth. Even the darkest remote observatory sites are

impacted by human activity. In particular, solid-state LED lighting threaten astronomy through its higher blue content and low cost, which fuels demand for more light.

The IAU has defined the upper limit of artificial light contribution for a professional site adequate for true dark-sky observing to be 10% at an elevation of 45 deg in any azimuthal direction. The newest professional observatories are significantly below that limit. The goal of the model regulatory framework proposed for the UN is to slow, stop, and reverse the rate of increasing artificial skyglow specific to each major professional observatory in no more than a decade. The approach to achieving this goal is to design to match the illumination level to need, to limit unnecessary spectral content, to use precise optics to minimize spill light, and to employ active control to reduce light levels when usage is low. Professional observing sites should have a protected near zone of typically 30 km radius, within which both lighting levels and color rendition are sharply limited. For those urban areas within 300 km of observatories impacted by sky glow, the tightest limits on the range of recommended best practices and standards are applied, along with full shielding and curfews.

Provisions for the recommended regulatory framework are: 1. Exclusive use of luminaires with no light above horizontal; 2. Limiting lamps' spectral content in the blue region; 3. Limiting the brightness to the minimum required; 4. Implementing curfews and light level controls; 5. Making sure the light falls on the intended surfaces; 6. Designing lighting to minimize light propagating toward observatories; and 7. Lumen caps in the context of a regional lighting plan.

1.2. *The Impact of Satellite Constellations on Astronomy*

As the number of satellites continues to grow toward over 107,000 in the next decade, astronomy is facing a tipping point situation where increasing interference will jeopardize astronomical science. While regulatory and technical mitigations are possible, no combination can fully avoid impacts on astronomy. Astronomers are submitting a report to the United Nations on the need to create an international approach to equitably managing light and radio emissions from space and preventing undesired impacts. Without immediate action, all of humanity will lose a clear view of the Universe and its secrets. Without the implementation of the proposed recommendations to the UN, these satellites will be detectable by even the smallest optical or infrared telescopes, depending on the hour of night and the season. Moreover, up to several hundred satellites may be visible even to the unaided eye, particularly low on the horizon and in twilight hours.

Initial studies of the unmitigated effects of satellites show a variety of impacts on astronomy from minor to severe, depending on the nature of the telescope and satellite system. (Walker *et al.* 2020; Hainaut & Williams 2020; Ragazzoni 2020; McDowell 2020; Tyson *et al.* 2020). Observations with telescopes that view large portions of the sky will be severely impacted without substantial mitigations. While telescopes with narrow fields of view are less impacted, observations with long exposure times and particularly in the hours close to twilight and low on the horizon are still significantly affected. Wide-field astrophotography will be affected, too. The impacts are not limited to ground-based observatories; space-based telescopes in LEO will suffer as well, and in those cases, mitigations are more challenging to implement.

The recommendations toward mitigation solutions for the impact of satellite constellations on astronomy can be found in the full report and summary report for the UN mentioned in Section 1.

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1.3. *Protection of Dark Skies Oases*

A dark sky oasis (also often referred to as a "dark sky place") is a location where the darkness of the night sky is protected by an outdoor lighting policy or other legal bodies. In the DSO, the cultural, scientific, astronomical, touristic values and the natural landscape are preserved.

The main bodies giving accreditation for dark sky oases are the International Dark-sky Association (IDA), based in Tucson, U.S. and the Starlight Foundation, based in Tenerife, Canary Islands. Worldwide, there are 223 dark sky places in 27 different countries, constituting a total land area of just over 20 million hectares. The International Union for the Conservation of Nature operates the Dark Skies Advisory Group (IUCN-DSAG) which aims are, among others, to preserve the ecological integrity of natural environments, ensure the full enjoyment of a wilderness experience and appreciate the integrity, character and beauty of rural landscapes.

The D&QS Oases Working Group proposes the following main recommendations: the levels of sky brightness considered to be appropriate for different dark sky places are the ones defined by the IUCN DSAG and, in addition, assume the default condition of no artificial light for all protected dark sky oases. Blue light should be avoided or minimized. Lighting should be strictly controlled and switched on only when it is needed. All exterior lights should only distribute light below the horizontal, and the upward light output ratio (ULOR) should be no minimized. LED lights should have a central management system (CMS) to reduce or extinguish light output in off-peak hours. No development in or near highly ecologically sensitive sites should be permitted. Monitoring of nighttime conditions in/near dark sky oases is encouraged. Active management of nighttime darkness as a natural source is encouraged through recognized conservation best practices. Finally, restoration plans should be implemented when sky brightness thresholds are routinely exceeded.

1.4. *Protection of the Bio-Environment*

The vast majority of life on Earth needs darkness at night to thrive. Many species of fauna and flora show strong sensitivity to daily light and dark cycles. The growing body of scientific research shows that ALAN causes significant negative effects the health of humans and flora and fauna, including changes in habitat use, migration, reproduction, predator-prey relationship, ecosystem functions and services (food sources, scavengers, pollination, water clarification), effects in the immune response, and fatalities at significant enough levels to pose extinction threats so some species. Put simply, ALAN is a risk factor for biodiversity.

The DNA in human cells include multiple "clocks" that work on circadian timescales and ultimately regulate many of our most important functions, including hormone secretion, sleep, digestion, and metabolism. Short-term effects on sleep and cognition are no longer in dispute. The effects of artificial light at night on humans include glare, retinal damage provoked from short wavelength blue light and melatonin suppression. The evidence being collected shows more prevalence of cancer (breast and prostate, maybe others), obesity (altered leptin and ghrelin), diabetes (glucose metabolism) and mood disorders (depression, bipolar).

Recommendations: Promote the adoption of environmentally friendly lighting regulations for regions, countries, municipalities and communities. The strategy should be summarized in the four pilar of the efficient lighting scheme order to prevent environmental harm: "The right light, at the right place, at the right amount, for the right duration". Specifically, reduce radiant flux (and irradiance), improve control of directionality of the radian-luminous flux and minimize melanopsin-activating blue content within the radiant/luminous flux.

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2. Dark Skies Education and Heritage

2.1. *Globe at Night Citizen Science*

Everyone can undertake reasonable light pollution mitigation strategies, one of which is to participate in the Globe at Night program. Hosted by the NSF's NOIRLab, Globe at Night invites citizen-scientists worldwide to measure and submit (with their smartphone) their night sky brightness observations in an effort to raises awareness of the impact of light pollution. Other dark skies education programs and resources were mentioned during the associate event and URLs provided. The presentation also discussed what the issues are, what the solutions are and how to participate in Globe at Night to make a difference.

The international Globe at Night citizen-science campaign has run for 15 years. In that time over 660,000 people have been involved from 180 countries. Our team has given hundreds of workshops and developed educational programs, curricula and kits, hundreds of which were given at no cost to people in at least 50 countries (e.g., during IAU100). Globe at Night was part of a cornerstone in the International Year of Astronomy and the International Year of Light. Every year Globe at Night is involved with Global Astronomy Month as well as many other events worldwide. The program has made significant differences as a result in changing mindsets and encouraging action.

For more information, please visit http://www.globeatnight.org.

2.2. *Night Sky: A Scientific and Cultural Heritage*

Through the night sky, humanity managed to develop astronomy. The history of astronomy stand as a tribute to the complexity and diversity of ways in which people rationalised the cosmos and framed their actions in accordance with that understanding. This close and perpetual interaction between astronomical knowledge and its role within human culture underscores the importance of protecting dark skies.

The night sky is part of our cultural heritage, handed down from earliest times through to the present day. The recording and transmission of the astronomical activities is manifested in legends, folk tales, sacred landscapes, etc (https://www3.astronomicalheritage.net/index.php/tangible-fixed-heritage-category). These are the products of scientific activities in their cultural context.

The scientific and technological dimension of a starry night on the other hand is an essential part of the legacy of the sky. Dark skies are an essential condition to maintain windows to knowledge of the universe (Marin 2009).

Thus beyond the importance of the scientific and cultural legacy related to astronomy and starlight, there is a landscape dimension and the conservation of nature in relation with the beauty and the quality of the night sky, the related human activities and the nocturnal ecosystem. Thus the nightscape is of great importance and an international action in favor of intelligent outdoor lighting is urgently needed.

3. Summary

It takes a community which understands what is at stake to accomplish successfully a goal that benefits all of society. We are grateful to the organizers of IAU Symposium 367 for allowing us the opportunity to provide information that would lead toward that goal. For an update on future information, please stay in touch with IAU Commission B7 on the Protection of Observatory Sites or contact Connie Walker at connie.walker@noirlab.edu.

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