

# Light Pollution



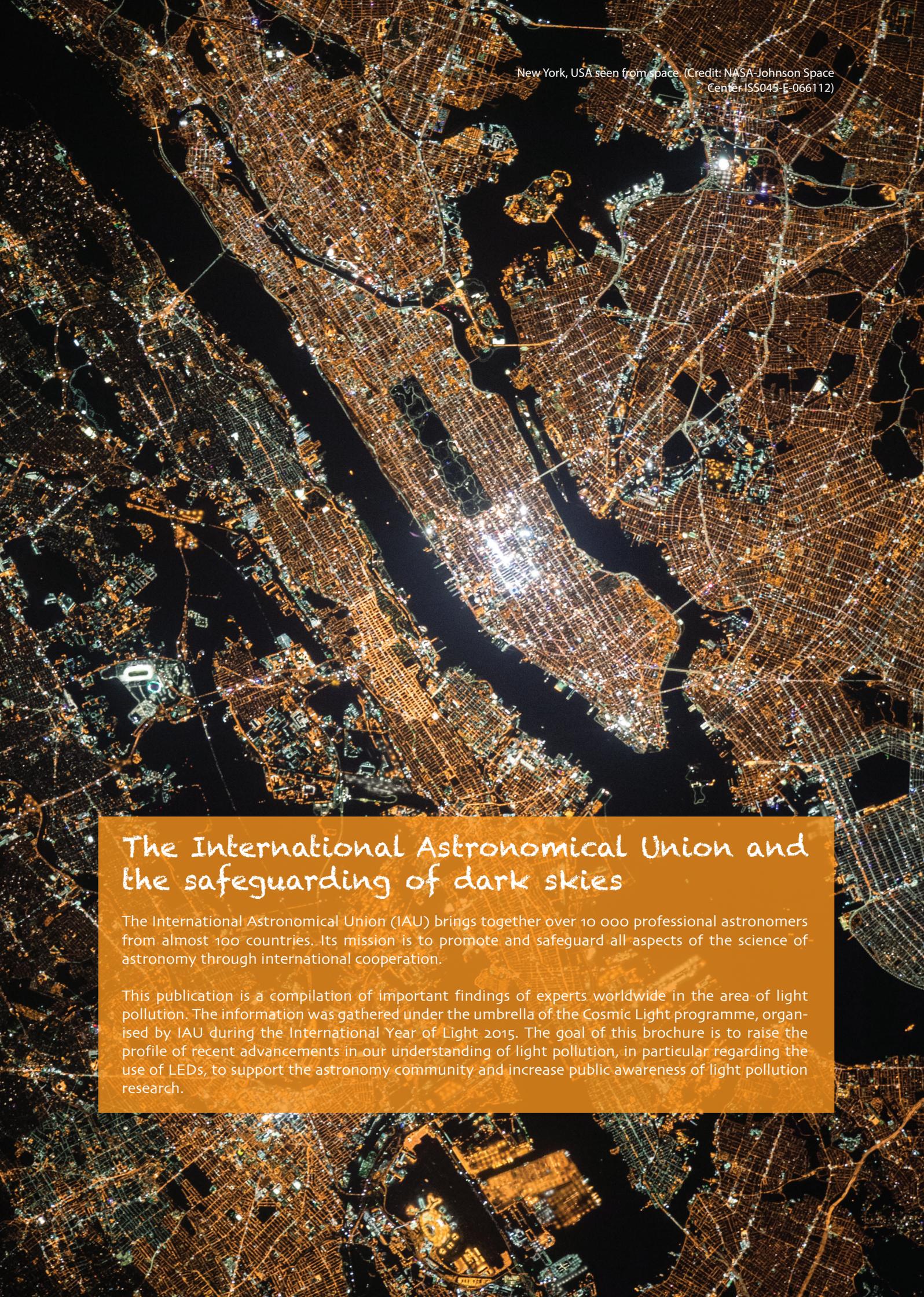
## Astronomy and Light Pollution

Without dark skies, astronomers are unable to receive the faint signals of light from distant objects in outer space. Dark skies are a critical scientific resource for understanding the mysteries of the universe. Dark skies are also an important part of the cultural and natural heritage of all civilizations.

Many astronomical observatories are built in remote locations in an effort to escape the light of cities and towns. Even so, these observatories are threatened by light pollution. For example, the bottom left of this page shows city lights encroaching upon the mountaintop of Mauna Kea, Hawaii. Mauna Kea Observatories is one of the best astronomical sites in the world. Lighting ordinances are an important tool to protect these sites from light pollution.

Stars, Pleiades and Venus together with the world's largest telescopes  
– Keck Observatory and Subaru Telescope on Hawaii's mountaintop.  
(Credit: Dr. Hideaki Fujiwara - Subaru Telescope, NAOJ)





New York, USA seen from space. (Credit: NASA-Johnson Space Center ISS045-E-066112)

## The International Astronomical Union and the safeguarding of dark skies

The International Astronomical Union (IAU) brings together over 10 000 professional astronomers from almost 100 countries. Its mission is to promote and safeguard all aspects of the science of astronomy through international cooperation.

This publication is a compilation of important findings of experts worldwide in the area of light pollution. The information was gathered under the umbrella of the Cosmic Light programme, organised by IAU during the International Year of Light 2015. The goal of this brochure is to raise the profile of recent advancements in our understanding of light pollution, in particular regarding the use of LEDs, to support the astronomy community and increase public awareness of light pollution research.

## Skyglow

Light pollution is the improper use of artificial outdoor lighting, which can cause adverse effects on the environment. Wasteful light from artificial sources emitted upward (at horizontal angles and higher) is scattered by aerosols such as clouds and fog or small particulates like pollutants in the atmosphere. This scattering forms a diffuse glow that can be seen from very far away. Skyglow is the most commonly known form of light pollution.

A standalone light source creates a greater impact on skyglow in rural areas than in cities because of secondary scattering. According to Martin Aube, ten percent of skyglow in cities and fifty percent of skyglow in rural areas result from secondary reflection.



Stars and skyglow over Salzburg, Austria  
(Credit: Andreas Max Böckle)

## Light trespass

Light trespass is another common problem that can even affect our health. Unwanted light at night can seep through the windows of houses and apartments, causing sleeping disorders due to overexposure to light.



Credit: Ducky Tse / Friends of the Earth (HK)

## Glare

Excessive brightness at night creates high contrast and decreased visibility, causing discomfort or, in extreme cases, a blinding effect. Elderly people with ageing eyes and cataracts suffer the most.



Credit: E. Hanlon



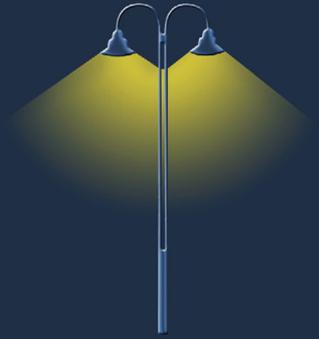
**VERY BAD**



**BAD**



**BETTER**



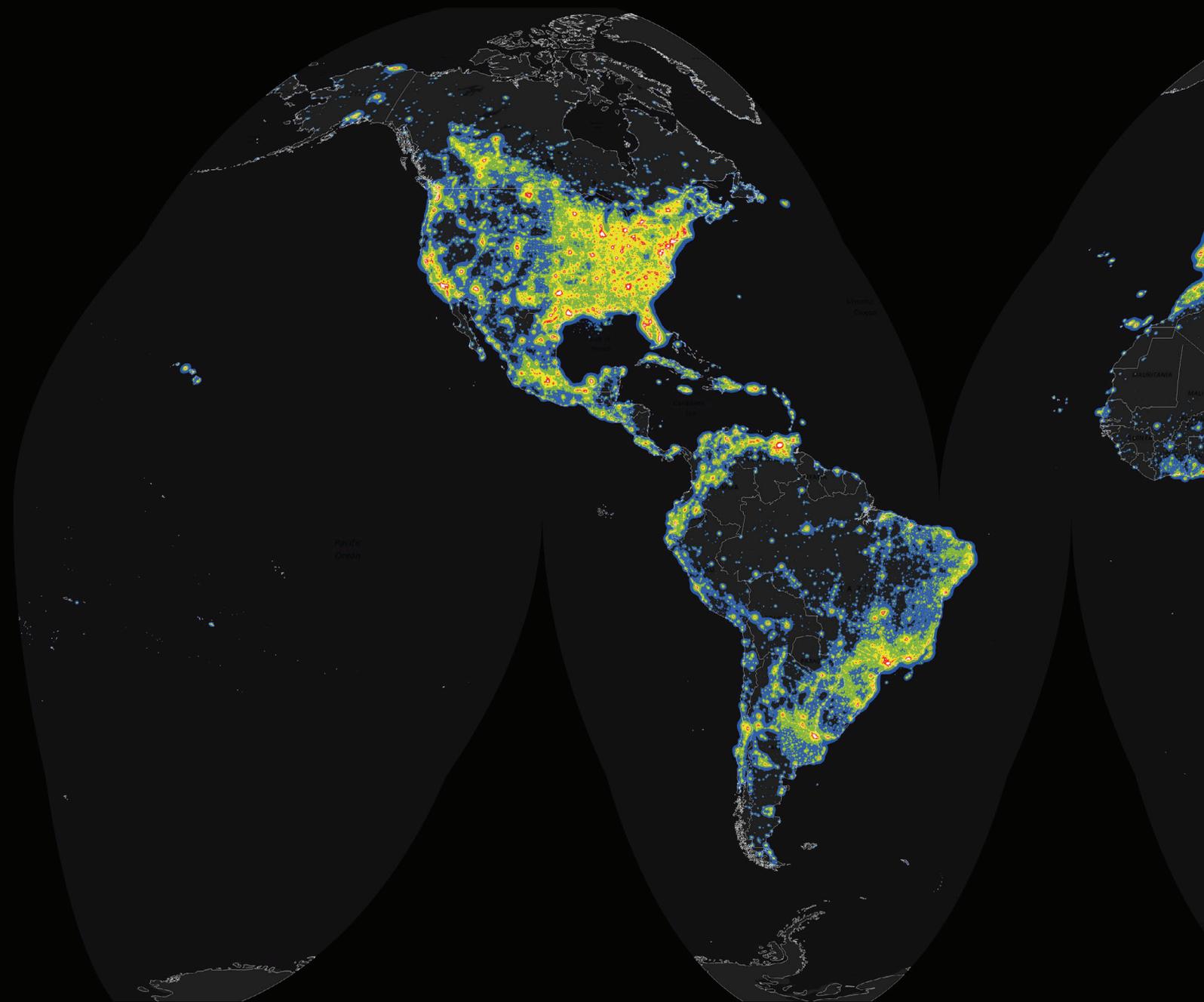
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## Solution

One recommended solution to minimize skyglow is to fully shield light fixtures so that their footprint on the ground is visible at a distance but the source of the light is not. The International Dark-Sky Association estimates that at least thirty percent of outdoor lighting in the U.S. is wasted, mostly by lights that aren't shielded. Unshielded light that shines skyward and can be seen from space is mostly wasted energy. Another strategy is to minimize the locations and number of hours lights are on, only using them where and when needed. These solutions would also reduce light trespass and glare. Planting more trees can also help block secondary reflected light from shining skyward.



# 2016 world map

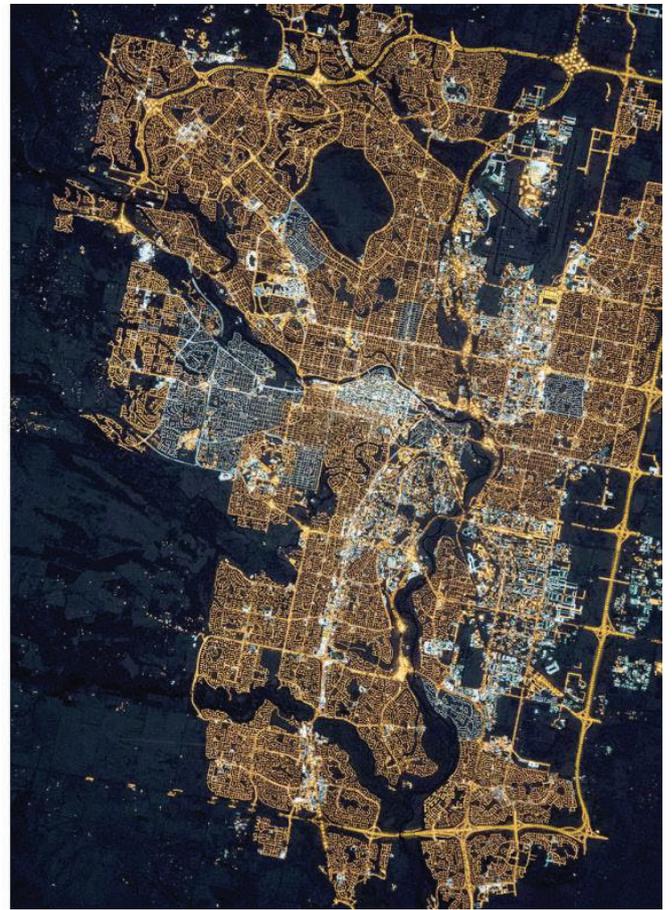


In 2016, the latest world map of light pollution was published by Fabio Falchi et al.

The map's colours indicate different levels of light pollution – black indicates a pristine sky, followed by blue, green, yellow, and red to specify progressively worse levels of light pollution. White places on the map indicating "cones active" are cities where light pollution is the worst.

Human eyes' retinas are composed of cones and rods cells. They are the photoreceptors responsible for transmitting





Switch over from sodium lamps to LEDs in Calgary, Canada. (Credit: NASA)

## LED revolution?

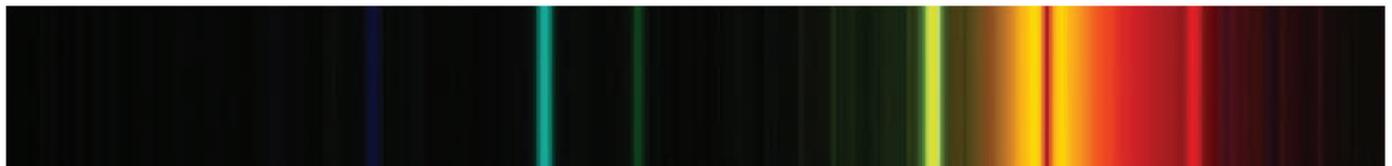
The photo above shows the change of lighting to LEDs over Calgary, Canada. The rich blue of the LEDs is clearly visible. LEDs, or "light-emitting diodes," are known for their low cost, long lifespan, lower energy consumption, environmental friendliness, and ease of regulation, and are therefore being mass produced and used widely. Public lighting has started to replace traditional lighting fixtures with more environmentally friendly LEDs.

Recent studies have indicated that energy-saving LEDs do not help decrease light pollution. People tend to use the money saved by the low-cost LEDs to install more lighting, thus making locations brighter. LEDs also have other important problems related to the strong blue component in their spectrum, which scatters easily and affects our ecosystems and public health.

Spectrum of Low-Pressure Sodium Lamp



Spectrum of High-Pressure Sodium Lamp

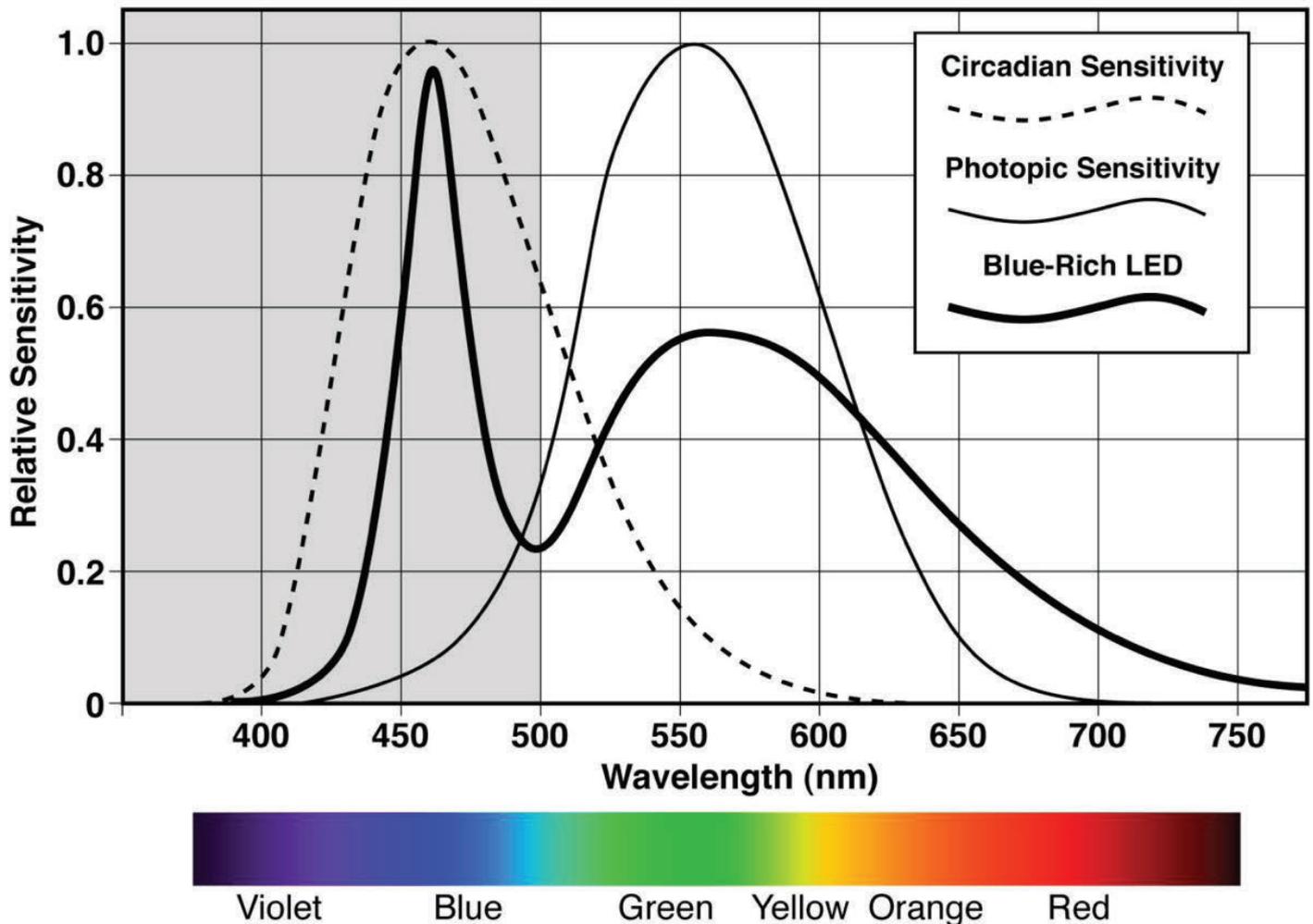


Spectrum of 4100K LED



# Understanding the LED spectrum

Traditional lighting, such as Low-Pressure Sodium (LPS) lamps and High-Pressure Sodium (HPS) lamps, have spectra with relatively narrow bands which can be filtered out during astronomical observations. However, LEDs typically have a broad spectrum, which is not as easy to filter out. Narrow-band LEDs such as phosphor-converted amber LEDs are coming on the market and may eventually prove to be an acceptable choice in terms of filtering, energy efficiency, and even colour rendition.



Credit: International Dark-Sky Association

In 2014, the Nobel Prize in Physics was awarded to recognize the “invention of efficient blue light-emitting diodes which has enabled bright and energy-saving white light sources.” This statement revealed an important characteristic of modern-day white LEDs – the low-cost, energy-saving white LEDs are essentially blue-rich (see the thick solid line on the diagram).

The solid line on the above diagram indicates our eyes’ sensitivity under well-lit conditions. The dashed line indicates our body’s sensitivity to the circadian rhythm, the day-night cycle.

Blue-rich LEDs overlap with our bodies’ circadian sensitivity, therefore imposing a significant influence on our sleeping behaviour.

## Blue light affects sleep

In the 1990s, scientists discovered a third type of light-sensing cell in the human eye, distinct from the well-known cone and rod cells. This third type of light-sensing cell contains “melanopsin,” a kind of photopigment that carries out the function of identifying and tracking the day-night cycle. Melanopsin showed a peak of sensitivity towards blue light.

Melanopsin controls the production of “melatonin” – a hormone that makes you feel sleepy. When the melanopsin cells detect light (normally in the daytime), melatonin production is suspended, making you feel more awake. When it is dark and melanopsin cells don't detect light, you feel tired because of the melatonin produced. When you are exposed to blue light at night for long periods of time, it keeps you awake.

Nerve Cells of Eye's Retina (Credit: Wei Li, National Eye Institute, National Institutes of Health)

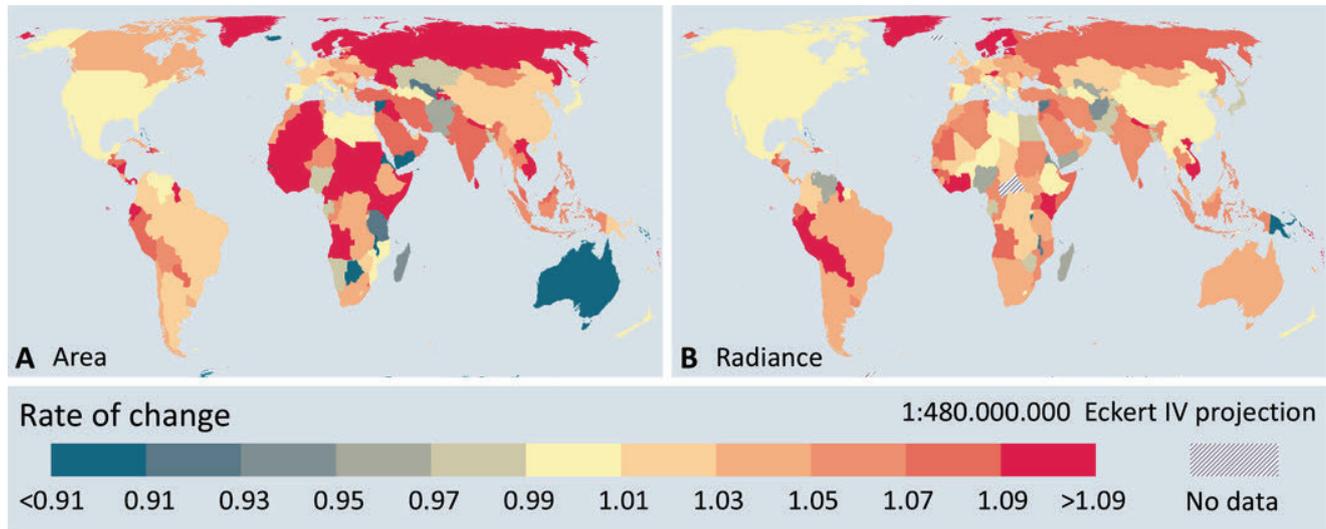
## Light pollution and our health

Melatonin is also an antioxidant that benefits our body beyond sleep; it helps to repair our body and regulates hormones related to cancer-correcting processes. LEDs are rich with blue light and thus have a strong effect on suspending melatonin production.

The American Medical Association (AMA) passed a resolution in 2009 stating that “light trespass has been implicated in disruption of the human and animal circadian rhythm, and strongly suspected as an etiology of suppressed melatonin production, depressed immune systems, and increase in cancer rates such as breast cancers.” In 2016, the AMA issued an official policy statement about LEDs, explaining that “white LED lamps have five times greater impact on circadian sleep rhythms than conventional street lamps.”

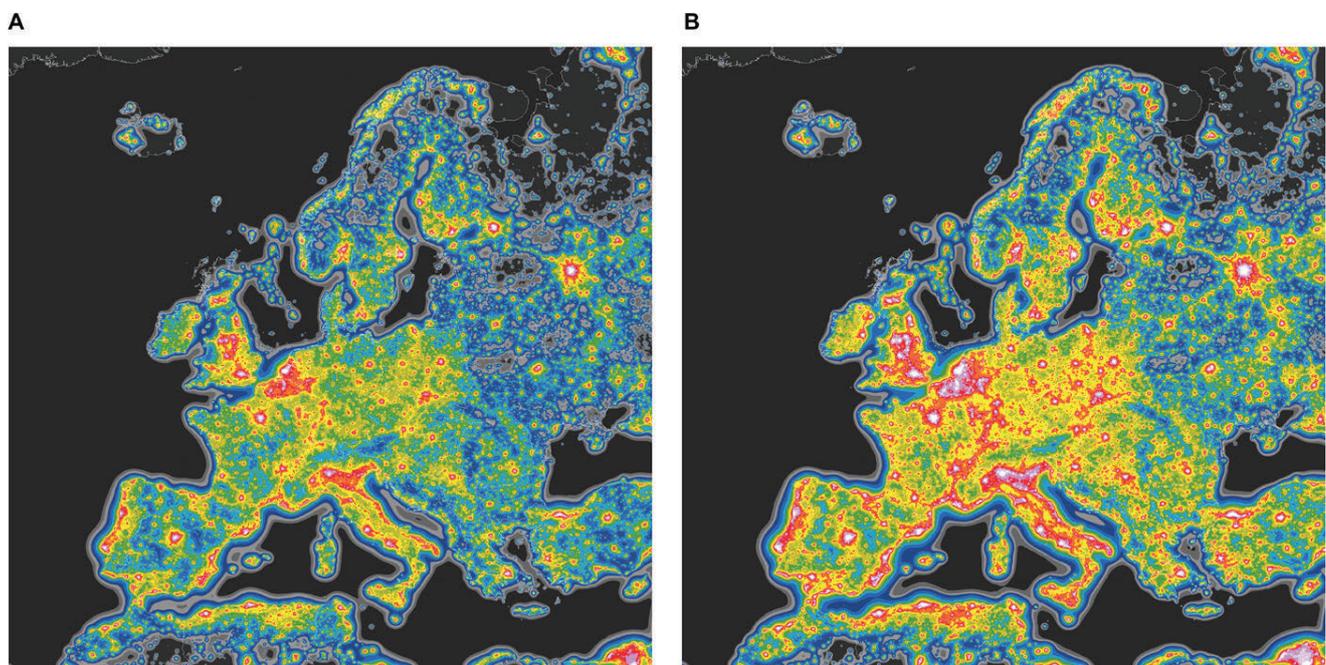
# LEDs make light pollution worse

Not only do LEDs fail to combat light pollution, but they make light pollution worse. A study conducted by Christopher C. M. Kyba et al. using satellite data has indicated our world brightened by 9.1% from 2012 to 2016.



Credit: Christopher C. M. Kyba et al. Sci Adv 2017

The above maps show the annual rate of change of artificial lighting in terms of increase/decrease of (A) area, (B) brightness. Most of the world shows an increase in brightness, with a few exceptions showing a decrease, including a few countries that are at war—Yemen and Syria, for example.



Credit: Fabio Falchi et al. Sci Adv 2016

The blue-rich LEDs easily scatter and create a bigger light pollution footprint. The above maps show Europe's artificial sky brightness compared to natural sky brightness. The map on the left (A) shows the current light pollution level. The map on the right (B) shows the forecast of the perceived sky brightness if all lighting changes to 4000K LEDs.



Changes between 2012 and 2016 in India and the surrounding area.  
(Credit: NASA Earth Observatory images by Joshua Stevens, using Suomi NPP VIIRS data from Miguel Román, NASA's Goddard Space Flight Center)

## What colour shall we use?

Blue light has another impact for astronomy – it scatters immediately (that's why our sky is blue), and the information in many newborn stars and galaxies peaks in blue. Also, considering the impact it has on ecosystems and public health, blue lighting is not recommended.

Red light has the longest legs for direct propagation, creating an artificial sky glow at the greatest distances. So red lighting is not recommended either.

We strongly recommend amber or yellow light, with the narrowest possible energy range, consistent with requirements for colour rendition.



## Ecologically responsible and astronomically friendly LEDs

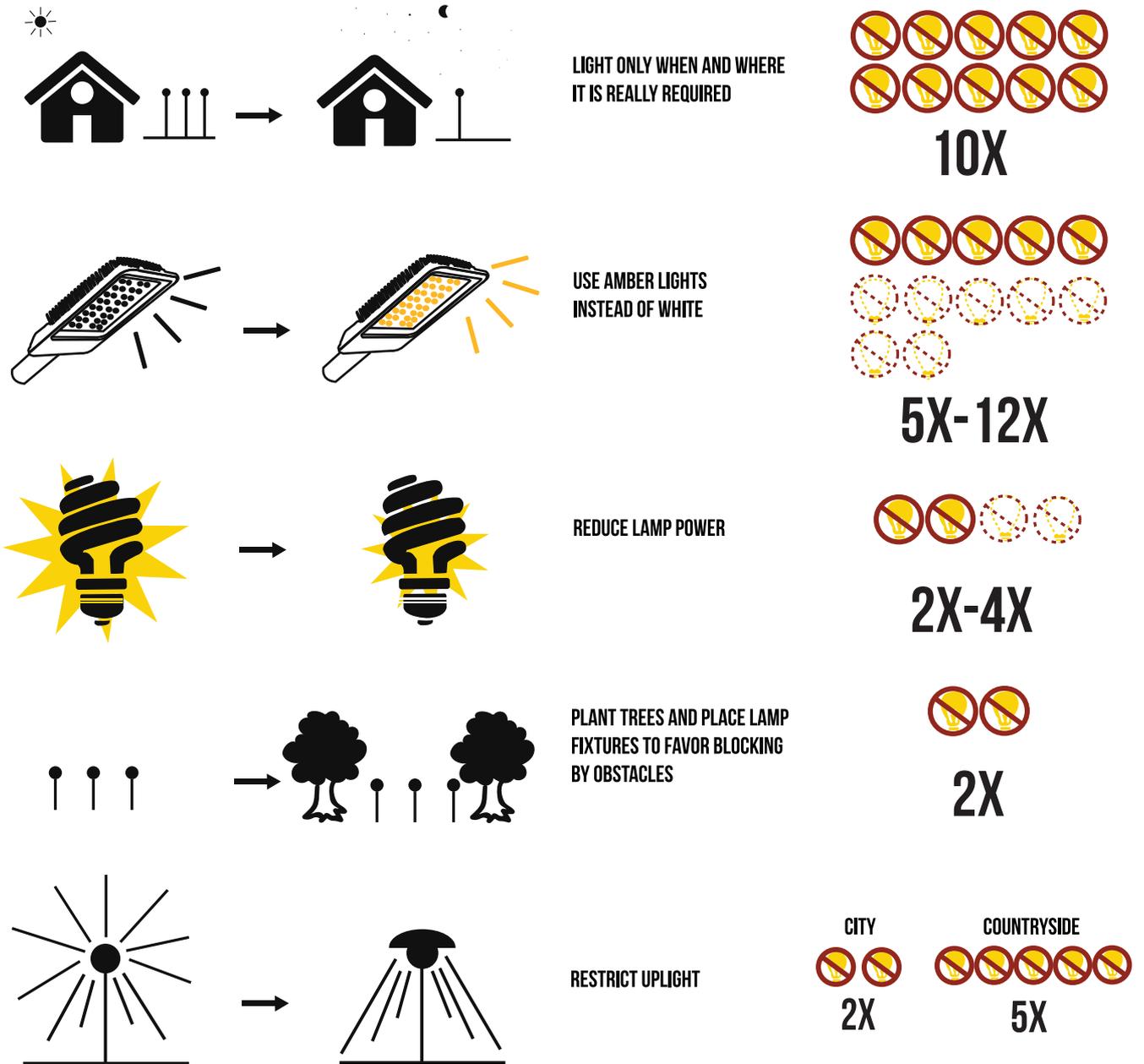
Since blue-rich LEDs have a powerful effect on human health and the environment, the industry is developing new technologies to create environmentally friendly LEDs. True amber LEDs were developed a few years ago with a very narrow bandwidth that is similar to the LPS lamp, which has the least ecological and astronomical impact. But because true amber LEDs' efficacy is low, they are not an ideal commercial product.

Phosphor-converted (PC) amber LEDs are one of the new technologies developed in recent years. Although they have a broader spectrum and greater ecological impact than true amber LEDs, they have better colour rendering and double the efficacy of true amber LEDs, making them a reasonable compromise.

The above photos show the change at Bishop's University campus in Sherbrooke, Canada, before and after the switch from 4000K white LEDs to PC amber LEDs, and reducing the power of the LED by half using the same optics. Calculations from Martin Aubé et al. show that this change decreased the sky glow perceived by the human eye to twelve percent of that caused by 4000K white LEDs, and also reduced melatonin suppression to four percent of the original level. This is an enormous reduction. To achieve this reduction, simply decrease the luminous efficiency and change the colour of the LEDs from white to amber.

# How can we effectively reduce the impacts of light pollution?

## LIGHT POLLUTION REDUCTION EFFECTIVENESS



Data source: Martin Aubé (Cégep de Sherbrooke)  
 Illustration: Elian Abril Diaz Rosas / IAU Office for Astronomy Outreach

This diagram summarizes the effectiveness of ways to reduce light pollution. The most effective way is simply to turn off or reduce the amount of lighting. The change from white to yellow light also makes a major difference. We can plant more trees to reduce secondary reflections. Using fully shielded light fixtures to prevent light from shining upward is also helpful. Secondary reflections play a more important role in rural areas than in cities. Therefore, the solutions we describe above have a more significant impact in rural areas.

# How can you partner with international programmes to support the effort to prevent light pollution?

The following educational programmes and resources from international organisations can help you promote light education in schools and communities.



## Globe at Night

Globe at Night is an international citizen-science campaign to raise public awareness of the impact of light pollution by inviting citizen-scientists to measure & submit their night sky brightness observations.

[www.globeatnight.org](http://www.globeatnight.org)



## Quality Lighting Teaching Kit

The kit was developed for the International Year of Light. The kit offers six "problem-based" activities that use quality lighting to solve problems related to light pollution's effect on wildlife, the night sky, our eyes, energy consumption, safety and light trespass into buildings.

[www.noao.edu/education/qltkit.php](http://www.noao.edu/education/qltkit.php)



## Dark Skies Rangers

This programme educates students on how to identify inefficient lighting, provides alternatives and tools that reduce consumption, keeps energy costs in check, and helps communities regain and safeguard a precious resource - the dark night time sky.

[www.globeatnight.org/dsr/](http://www.globeatnight.org/dsr/)



## International Dark-Sky Association Resources

The International Dark-Sky Association (IDA) mission is to preserve and protect the nighttime environment and our heritage of dark skies through environmentally responsible outdoor lighting. The following is a list of resources produced by IDA.

[www.darksky.org/resources/](http://www.darksky.org/resources/)

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Publication Date:  
April 2018

### References

Aubé, Martin. (2015). Physical behaviour of anthropogenic light propagation into the nocturnal environment. *Philosophical Transactions of The Royal Society B Biological Sciences*. 370. 10.1098/rstb.2015.0143.

Aubé, Martin. (2016). The LED outdoor lighting revolution: Opportunities, threats and mitigation for urban and rural citizens.

Falchi, Fabio et al. (2016) The New World Atlas of Artificial Night Sky Brightness. *Science Advances* 10 Jun 2016 : e1600377

Kyba, Christopher et al. (2017). Artificially Lit Surface of Earth at Night Increasing in Radiance and Extent. *Science Advances* 22 Nov 2017 : e1701528

AMA Adopts Guidance to Reduce Harm from High Intensity Street Lights  
American Medical Association Press Releases  
<https://www.ama-assn.org/ama-adopts-guidance-reduce-harm-high-intensity-street-lights>



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A world without stars would be like  
a world without flowers.

— Silvia Torres-Peimbert, President of the  
International Astronomical Union

at the closing ceremony of the International Year of Light 2015.

City lights and stars as seen from the International Space Station. (Credit: NASA)



International Astronomical Union  
Office for Astronomy Outreach

[www.iau.org/public](http://www.iau.org/public)

In collaboration with the  
IAU Commission C.B7  
Protection of Existing and Potential  
Observatory Sites



International  
Day of Light