DARK MATTERS!

Photo courtesy of NASA Earth Observatory image by Robert Simmon

Why should we preserve the night sky? We have advanced technology to the point that we can now strike out the dark of night and replace it with a perpetual twilight. No longer do we have to fear the dark and the scary monsters that come out when the sun goes down. Why does Dark Matter anymore?

All life on Earth evolved with a natural day and night cycle, over millions of years. Night is part of life's DNA.

Appreciation of the night time sky is ingrained into our very being. Humans have been inspired by the night sky for over ten thousand years. Early humans looked at the stars and created an oral culture surrounding the constellations that has been woven into our very nature over time. We have long been inspired by the nighttime sky and that inspiration appears in mathematics, science, art, poetry, music, and religion.

If we take away the dark of night many plant and animal species will be lost; human health will be negatively impacted; our children will lose the infinite star-filled vista that fills us with a sense of mystery and wonder; and much of the culture of our distant ancestors will cease to have meaning.

As Ronald Reagan said in 1984,

> If we've learned any lessons during the past few decades, perhaps the most important is that preservation of our environment is not a partisan challenge; it's common sense. Our physical health, our social happiness, and our economic well-being will be sustained only by all of us working in partnership as thoughtful, effective stewards of our natural resources.

And that includes a dark night sky.

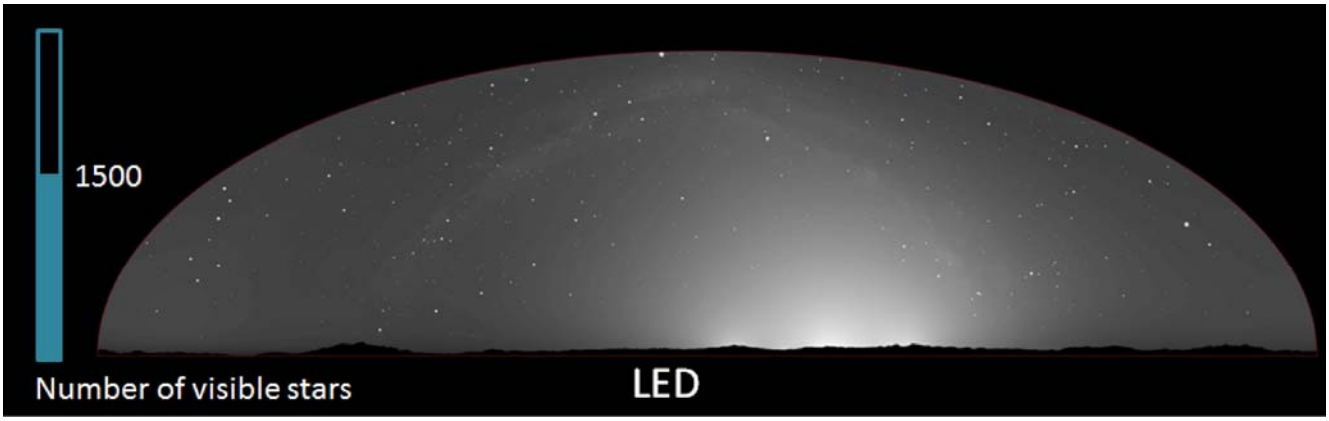
So does Dark Matter anymore? Yes it does. And it's worth preserving and protecting.

This page was last updated 9th December, 2014

LAMP SPECTRUM AND LIGHT POLLUTION

Color Matters!

Yellow light is night-friendly light: Low-pressure sodium is not just for turtles and astronomers.



Effect of changing from Low-pressure sodium to LED 4100K CCT

Sky as seen from Sunset Crater National Monument, with artificial sky glow arising from Flagstaff AZ. Hammer-Aitoff equal-area all-sky simulations by D. Duriscoe (U.S. National Park Service) and C. Luginbuhl (U.S. Naval Observatory Flagstaff Station)

The spectrum of outdoor lighting influences many aspects of light pollution, from glare and human health to activities of animals (notably sea turtles) and insects and biological processes in many organisms – a good overview of these issues can be found here. The blue and green part of the spectrum especially has disproportionate impacts (see here). On this page we describe the influence on the darkness of the sky and the visibility of stars, specifically the results of new research on the visual brightness of sky glow.

As described on the Outdoor Lighting Codes page, to effectively limit adverse impacts of outdoor lighting, lighting codes must address the three principal aspects of lighting that increase light pollution:

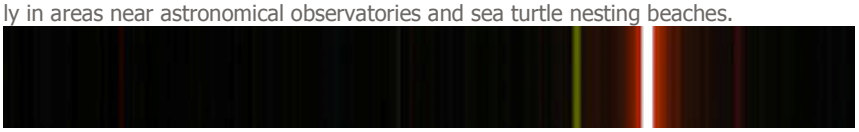
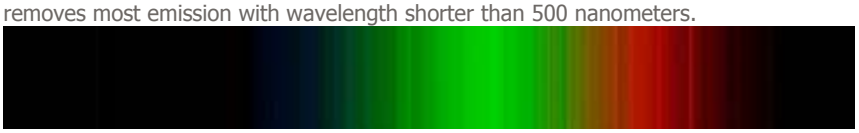
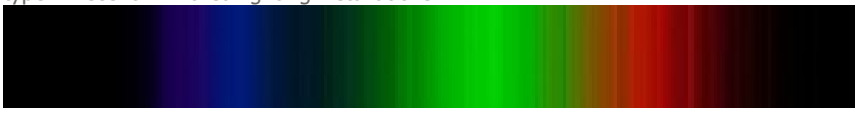
1. **Shielding** of fixtures

2. **Spectrum** of lamps
3. **Amount** of light

Fully shielded, low-pressure sodium lighting at 50,000 lumens per acre in this Flagstaff OfficeMax parking lot – exhibits all three aspects critical to minimize sky glow, glare, and ecological impact. Recent research shows that high-pressure and low-pressure sodium lighting cause 1/3 and 1/6 the sky glow (respectively) from the typical 4100K CCT white LED or metal halide.

Though the negative impacts of poorly shielded fixtures and overlighting are widely understood, the impact of lighting color is not widely known, and most lighting codes do not address lamp types. But recent research shows that white lighting (such as LED, fluorescent and metal halide) has a dramatically greater impact – lumen-for-lumen – on sky glow than the currently most common high-pressure sodium (HPS) and especially low-pressure sodium (LPS).

Two recently published studies (Luginbuhl et al., 2014; Aubé et al., 2013) have evaluated the visible sky glow brightness caused by the following lamp types:

Type	Description	Sky Glow* (relative to LPS)	Sky Glow* (relative to HPS)
LPS**	Low-pressure sodium – a nearly monochromatic yellow-orange light source used mostly in areas near astronomical observatories and sea turtle nesting beaches. 	**1.0**	**0.4**
HPS***	High-pressure sodium – A golden-yellow light source, widely used throughout the world. 	**2.4**	**1.0**
FLED****	Filtered warm-white light-emitting diode – a straw-yellow LED lamp with a filter that removes most emission with wavelength shorter than 500 nanometers. 	**3.6**	**1.5**
LED 2400K	Light-emitting diode with "correlated color temperature" (CCT) of 2400K – a "warm-white" LED. This type of LED has not seen wide use. 	**4.3**	**1.8**
LED 4100K	Light-emitting diode with CCT of 4100K – a "cool-white" LED. This is a common LED type in recent LED area lighting installations. 	**6.4**	**2.7**
LED 5100K	Light-emitting diode with CCT of 5100K – a "cool-white" LED. This also is a common LED type in recent LED area lighting installations. 	**7.9**	**3.3**

*Ratios vary with distance and position in the sky: values shown are for 1 km distance and overhead in the sky.

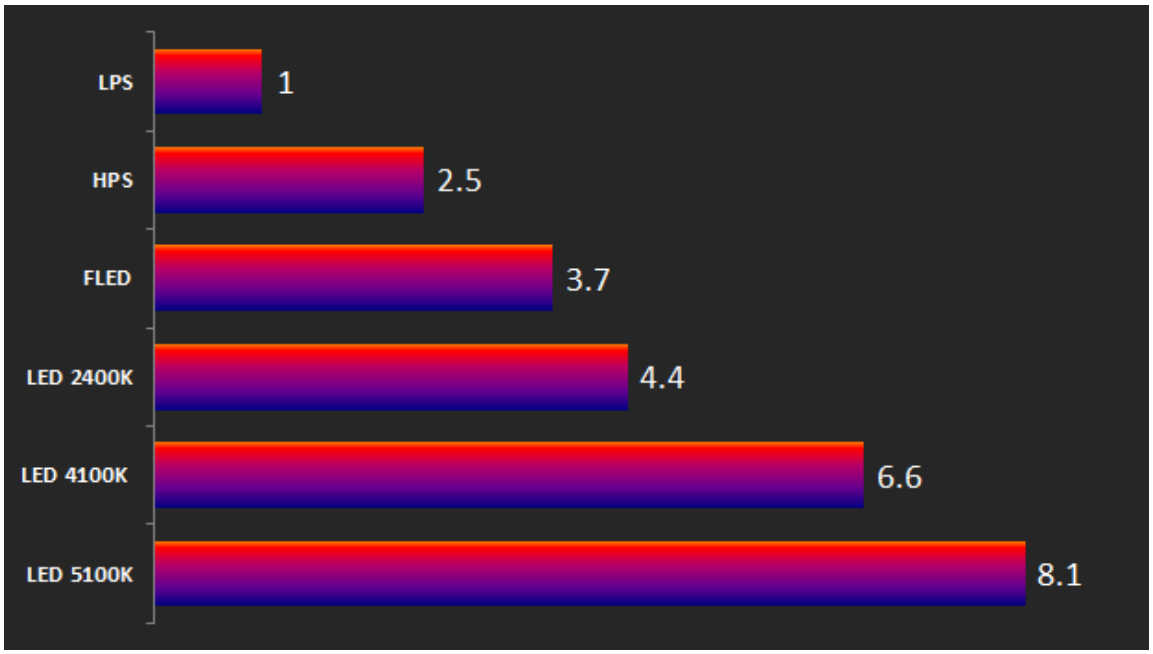
**Narrow-band amber LED (NBALED; AlInGaP with peak emission at 590nm) have sky glow impacts essentially the same as LPS.

***Some phosphor-converted amber LED (PCALED) have sky glow impacts very similar to HPS.

****The filtered LED used on the island of Hawai'i is different than the FLED analyzed by Luginbuhl et al. The Hawai'ian version has an estimated sky glow impact 4.4x LPS and 1.8x HPS – very similar to the 2400K CCT LED

Due primarily to the increased sensitivity of the human eye to blue and green light at the very low brightnesses seen in the clear night sky – even in light-polluted skies – all of the LED sources cause much brighter sky glow. Sky glow from the lowest-impact commonly used LED (4100K CCT) appears nearly seven times as bright as that from an equal amount of LPS, and 2.7x times brighter than HPS. This is a dramatic effect. Even without changing light amount or shielding, switching a lighting installation from HPS to 4100K LED will increase sky glow as if the amount of HPS light had been increased 170%, or nearly doubled; if changing from LPS the sky glow brightness would increase 540%.

A focus on using lower CCT LEDs misses much of the problem, because the colors causing the greatest impact (blue-green and green) are still strong in low-CCT LEDs.



Sky glow impacts, relative to low-pressure sodium lighting, of common outdoor lighting types.

And brighter sky glow means fewer stars are visible. In a moderately polluted sky with artificial sky glow caused by mostly LPS outdoor lighting (here we assume the sky is 50% brighter than a natural sky at the zenith), about 2,700 stars are visible. If outdoor lighting were changed from LPS to 4100K CCT LED, the artificial component of sky glow would increase 6.6x, and total (artificial + natural) would appear 3x brighter (now the sky would be 200% brighter than a natural sky at the zenith). Instead of 2,700 stars you would now see only 1,500 stars. Simply changing the lighting type to a purportedly

"environmentally friendly" LED light – with no increase in the amount of light (in lumens, footcandles or lux) – would obscure almost half of the stars in the night sky.

Flagstaff Low-Pressure Sodium Area Lighting

The effect of switching from HPS is somewhat less dramatic, with the visual brightness of the artificial component increasing 2.7x (160%); if the example above was switching to 4100K CCT LED from HPS, the total sky brightness would increase 1.9x at zenith.

We often hear that we must use white lights (especially in recent years LEDs) because "everybody" wants or needs white light, or "nobody" likes yellow light, or that white light is better for visibility. Yet if the benefits and drawbacks of all lamp types are fairly described, many communities may choose the lower impact yellow light, as Flagstaff, Sedona, and Coconino County Arizona have.

This page was last updated 29th April, 2015

OUTDOOR LIGHTING CODES

Purpose

The principal purpose of most lighting codes is to limit adverse impacts arising from the production and use of outdoor lighting on the general (public) environment – that is, on the sky (sky glow), on other property (glare; light trespass), on the power grid (energy use and efficiency; carbon dioxide production), or on ecosystems (disturbance to animals, insects and plants). Some lighting codes focus instead or in addition on lighting "quality" on the property where the lighting is installed (illuminance, uniformity). The usual approach to regulating cross-boundary impacts is through zoning law; the approach to on–property "quality" is sometimes instead through building codes.

Legal Issues

The legal basis for regulating the use of private property in the U.S. was originally based in the common law concept of "nuisance." Under common law, it is recognized that persons are entitled to "use and enjoyment" of their lands. If one property owner uses their land in a way that interferes with the use and/or enjoyment of another, the affected party may be entitled to a legal claim of nuisance and mitigation of its cause. Zoning laws or codes extend and improve the nuisance concept by providing proactive notice that certain uses are prohibited or limited on the basis of the cross-boundary impacts. Lighting codes, when enacted as part of zoning

(the most common practice), are thus generally not concerned with aspects of lighting design that do not directly relate to cross-boundary impacts (e.g. illumination levels on the property where the lighting is installed).

Technical Aspects

To address the cross-boundary impacts of lighting use, three principal aspects regarding the design of lighting hardware or systems are critical:

1. **Shielding** of fixtures
2. **Spectrum** of light sources
3. **Amount** of light

Though all three factors are important, the relative importance in limiting adverse impacts is generally ranked as shown. **Shielding:** Research shows that full shielding can reduce sky glow by 50% to over 90% when compared to a typical mix of partially shielded and unshielded lighting[1]. As shielding dramatically reduces glare and light trespass as well, it is and should be the highest priority in lighting codes. **Spectrum:** Specification of yellow light sources (high-pressure sodium and PC-amber LED, or low-pressure sodium and AlInGaP "narrow-band" amber LED) for the majority of lighting uses can reduce sky glow by 70% to almost 90% when compared to white sources such as metal halide, fluorescent and LED[2]. **Amount:** Finally, reasonable limitations on the total lighting (lumen) amount reduce the frequency and degree of careless and/or competitive over-lighting. Lumen caps of 50,000 – 100,000 lumens per acre have been shown in a study in Flagstaff[3] to reduce average lighting amounts (and thus all light pollution impacts) by 25% to 70% compared to average un-capped commercial lighting practice, and in particular applications such as service station canopy lighting by 90% or more.

1. Luginbuhl, C.B., et al., 2009, *Lighting and Astronomy*: see our Measuring and Modeling Sky Glow Light Pollution page

2. Luginbuhl et al., 2014; Aubé et al., 2013: see our Lamp Spectrum and Light Pollution page

3. Luginbuhl et al., 2009, *From the Ground Up I: Light Pollution Sources in Flagstaff, Arizona:* see our Measuring and Modeling Sky Glow Light Pollution page

Benefits

The implication of these figures is clear – lighting complying with good shielding, spectral and amount standards can have dramatically less adverse impacts on the sky and other properties.

Choosing minimum reductions from the ranges described above (i.e. 50% due to shielding, 70% due to spectrum, and 25% due to lighting amount), sky glow can easily be reduced 90% – to 1/10th that seen without regulation. Similar dramatic reductions can be achieved for other adverse impacts such as glare and trespass. And all this is achieved with no compromise to utility or safety. There is much to be gained from lighting codes.

As an often critical matter in the application and enforcement of lighting codes where community legal, lighting design, and enforcement resources or expertise are nearly always very limited, lighting codes based on easily quantifiable aspects of lighting use most directly related to cross-boundary impacts are much more efficient, requiring much less expertise and fiscal resources to administer. The codes offered as models below specify shielding, lamp type and amount standards that are demonstrated to be easily and effectively interpreted, applied and enforced without specialized technical training. Lighting codes using lighting design measures such as illumination levels or illumination uniformity are much more difficult to administer, require technical expertise to interpret, implement and enforce, and do not directly address light pollution impacts of general community concern.

Though the standards necessary to achieve good light pollution control are conceptually simple, writing a technically accurate and effective lighting code is not simple. If your community is seeking effective solutions to the problems created by common careless lighting practice, we highly recommend using a code such as listed below that has been tested and found technically sound and effective.

Model Lighting Codes

Before you use another Model Lighting Code…

In 1989 innovative lighting codes were developed for Flagstaff and Coconino County that, in addition to effective standards for shielding and lamp type, were the first to restrict the amount of light permitted (per acre) in outdoor lighting installations. Their intent is to encourage lighting practices and systems that will:

- minimize artificial sky glow, glare, and light trespass;
- conserve energy and resources while maintaining night time safety, utility, security, and productivity; and
- curtail the degradation of the nighttime visual environment.

These lighting codes remain the only codes demonstrated through research and critical dark-sky analysis to actually reduce sky glow light pollution. If your community seeks to protect dark skies, the Flagstaff Dark Skies Coalition strongly recommends using these codes – particularly the Flagstaff and Coconino County codes or models based on them.

(see the updated Pattern Outdoor Lighting Code v2.0 July, 2010.)

These codes work. The critical general limits of 100,000 and 50,000 lamp lumens-per-acre (equivalent to about 70,000 and 35,000 fixture lumens-per-acre) and practical shielding standards have been in place for over twenty years. Hundreds of developments have been successfully built, including service stations, auto dealers, and national retail franchises (Home Depot, OfficeMax, Staples, Target, WalMart SuperCenter, Best Buy, Kohl's, etc.).

Other codes offered by the lighting industry and other authorities in dark sky protection in collaboration with the lighting industry have not been shown to assure real protection. Critically, analysis by C. Luginbuhl at the US Naval Observatory of the June 2010 draft of the Joint IES-IDA Model Lighting Ordinance[4] (MLO) indicated that this "model" would not improve dark skies. An updated soon-to-be-published analysis by the same author of the final Joint IES-IDA Model Lighting Ordinance, indicates that the MLO remains critically deficient, allowing substantially greater light pollution than these northern Arizona codes and, in most cases, greater light pollution than produced by even unregulated outdoor lighting. The IES-IDA MLO does not effectively address shielding or lighting amounts, and does not address lamp spectrum at all.

Note: Though there are dozens of lighting codes around the US that establish lumens per acre limits following the pattern of these local innovative lighting codes, the Flagstaff Dark Skies Coalition cannot recommend any of these as guides. Most or all have been substantially modified with the frequent introduction of lighting technical, legal and other errors; many have dramatically raised the lumen caps to the point where there will be no effective improvement over otherwise unregulated lighting. Any community using one of the codes recommended here as a base for their code should modify these codes with extreme caution. The IDA Outdoor Lighting Code Handbook provides good general guidance and background for anyone seeking to effectively tailor a lighting code to meet local priorities.

4. Though the IDA-IES MLO states (pg. 4) that it was "developed as a joint under-taking by the Illuminating Engineering Society and the International Dark-Sky Association," of the nine members of the "joint task force" responsible for the MLO's development, seven are directly associated with the lighting industries, including both of the co-chairs and three of five nominally representing IDA. It seems obvious to FDSC that regulations to protect night skies and the public from the deleterious effects of outdoor lighting should be informed by responsible lighting practices, but should not be writ-

ten by the lighting industry.

Some Very Good Codes and Information

Cities

Flagstaff AZ Lighting Code [*IDA International Dark-Sky City*] (updated Nov 2011) Official Title Flagstaff Zoning Code, Chapter 10-50 Division 10-50.70, and parts of Chapters 10-20 (Administration, Procedures and Enforcement), 10-50.100 (Sign Standards), and 10-80 (Definitions)

Cottonwood Lighting Code (adopted/amended 2000) Official Title: City of Cottonwood Zoning Ordinance, Section 408; link: unofficial copy)

Sedona Lighting Code [*IDA International Dark-Sky City*] (adopted/amended 2001) Official Title: Sedona Land Development Code, Article 9, Subsection 911.01; link: City of Sedona website

Counties

Coconino County AZ Lighting Code (adopted/amended 2001) Official Title: Coconino County Zoning Ordinance, Chapter 17

Lighting Ordinance Reference Materials

Ordinances for Regulating Outdoor Lighting Practices (Illinois Coalition for Responsible Outdoor Lighting)

IDA Outdoor Lighting Code Handbook

Updated Pattern Outdoor Lighting Code v2.0

Typical Lumen Outputs and Energy Costs for Outdoor Lighting

Digital Billboard Luminance Recommendations

Lumen Outputs for “Neon” Lighting

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