Protecting Night Sky Resources With Fully Sustainable Outdoor Lighting

City of Fort Collins Contractor Training

April 27th 2016

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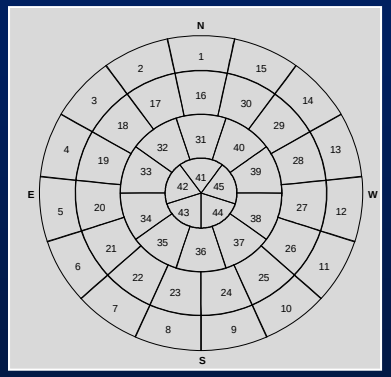
National Park Service
U.S. Department of the Interior
Natural Resources Stewardship and Science

Natural Sounds and Night Skies Division

Topics of Discussion

- Measuring night sky brightness
- The effect of sky glow in the environment
- Local Night Sky Conditions
- Ecological Considerations
- Human Health Considerations
- Economic Benefits
- Fully Sustainable Outdoor Lighting

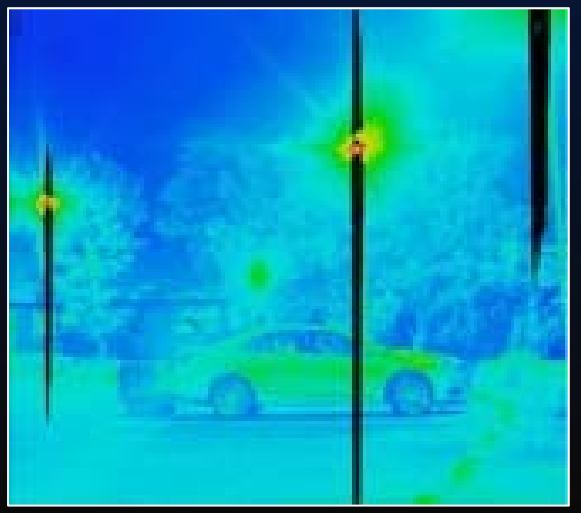
Measuring the Night Sky

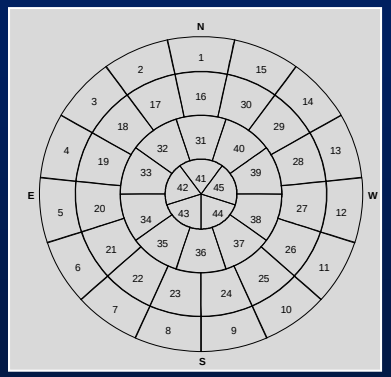


16 bit monochrome image, photometric calibration from standard stars

Calibration applied to each pixel gives brightness measurement (luminance)

Same system to measure local scene luminance

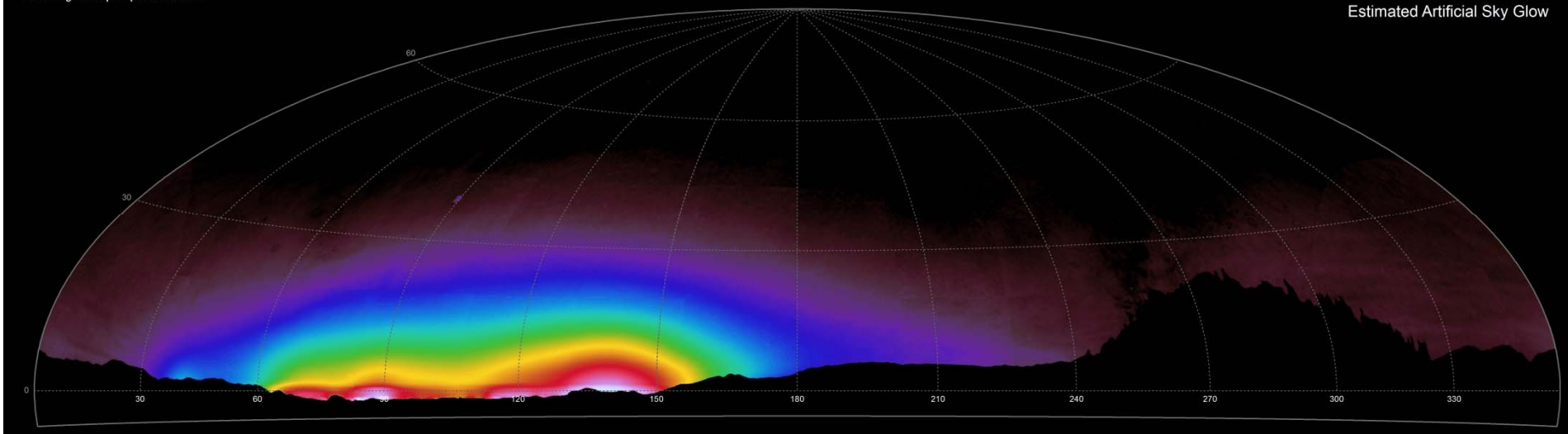




Visual Magnitudes per square arc-second

Rocky Mountain National Park Rainbow Curve September 24, 2008 23.5 hours LMT

Estimated Artificial Sky Glow



U.S. National Park Service
Night Skies Program

Data collected by: C Moore
Data processed by: J White

Hammer-Aitoff Equal Area Projection

SKY GLOW

Is light scattered and reflected off of air molecules and atmospheric aerosols. The observer sees anthropogenic light originating on the ground in the sky. The sky appears luminous.

This type of light pollution damages the aethetics of the night sky, *and* illuminates the observer and the landscape unnaturally.

ILLUMINANCE

Is a measure of luminous flux on a surface of a given area, or luminous flux density. It is what matters most when the human eye is trying to examine objects by reflected light. Illuminance is a very useful measure in quantification of anthropogenic light in the natural environment.

1 lux is defined as 1 lumen per meter squared of detector area.
1 footcandle is the British unit equivalent and equals 0.093 lux or about 1/10 lux.

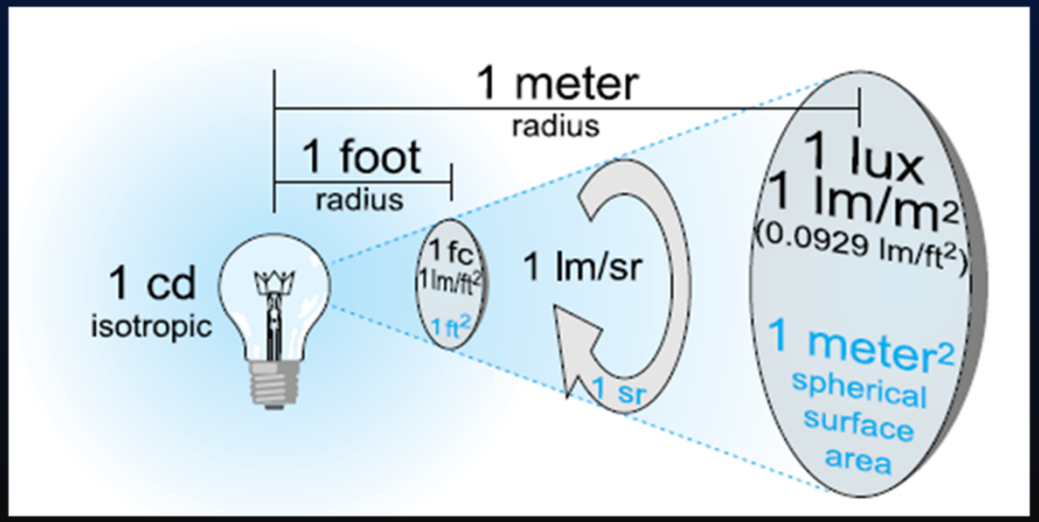
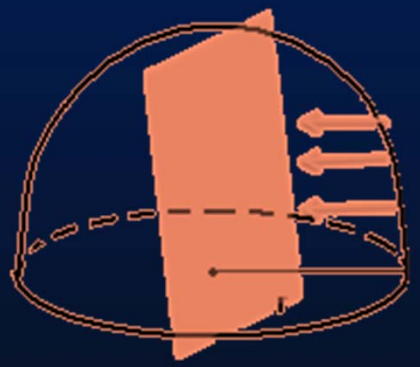


Figure 23. Illustration of measurement geometry for illuminance (Ryer 1997).

ILLUMINANCE GEOMETRIES

Horizontal Illuminance – Illuminance from light source measured on a surface of horizontal plane. A good indicator of zenith sky brightness or measuring illuminance from a pole mounted luminaire.

Vertical Illuminance - Illuminance from a light source at a distance on the horizon (or from the sky facing a certain direction) may be measured with the detector in a vertical plane, usually normal to the direction of the light source.



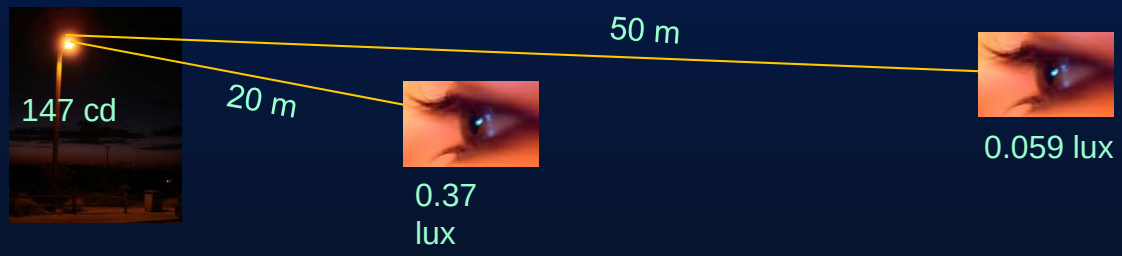
Hemispheric illuminance - Illuminance from the entire sky striking an imaginary hemispheric surface (like the top of a golf ball on the ground) is an unbiased measure of the light reaching the observer from the entire sky.

ILLUMINANCE

From a single source may be predicted by the inverse square law and the cosine law.

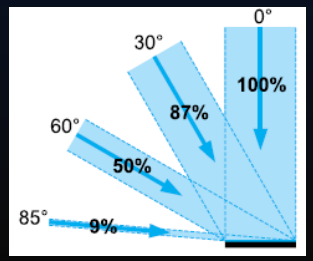
Illuminance from a given light source of constant output will vary as the inverse of the square of the distance from light to detector. For long distances, the extinction of the atmosphere must also be taken into account.

$$E = I / d^2$$



Illuminance from a point source will vary as the cosine of the angle to the measurement surface. This is known as Lambert's cosine law.

$$E_\varphi = E \cos\varphi$$

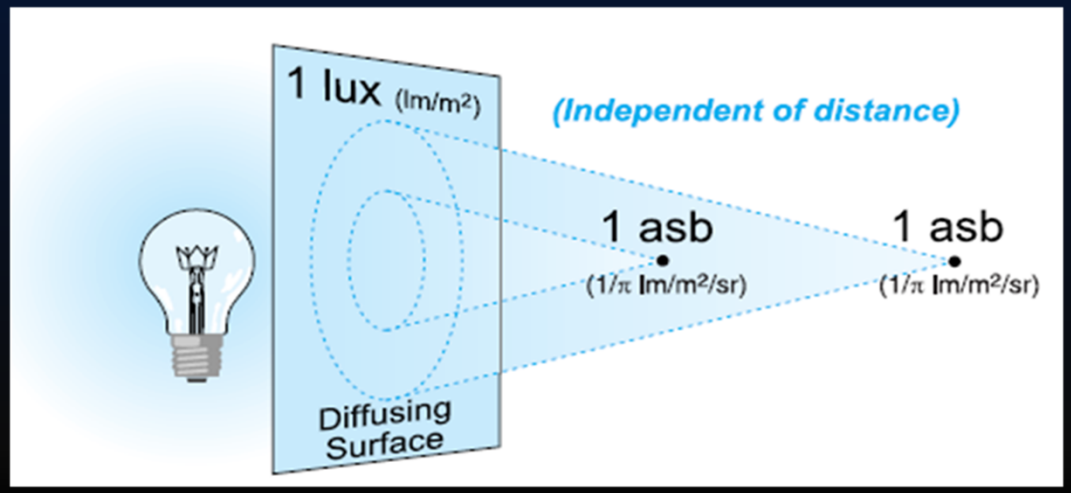


LUMINANCE

Is Luminous Intensity per unit area (candela/m^2). It is sometimes called "perceived brightness", or "surface brightness" of an extended area.

The unit apostilb (asb) contains π, 1 cd/m^2 = π asb, and is rarely used. The unit cd/m^2 is also called the nit, but this term is rarely used.

Luminance is independent of distance, since when the observer moves away, the same viewed angle subtends a larger area on the object. An exception is when the object viewed is so far away that atmospheric extinction must be considered.



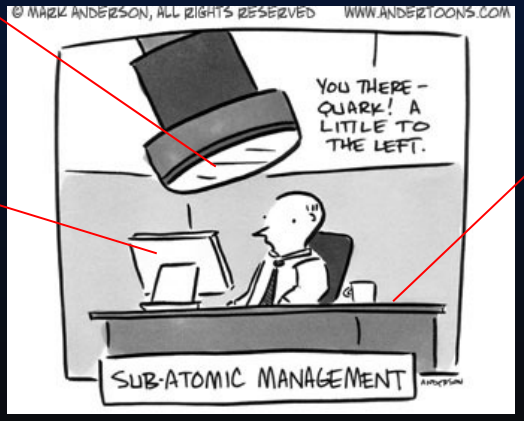
D Duriscoe

LUMINANCE

Illuminance from a source is reflected off an object, then the object observed at some distance and angle. The brightness of the surface of the object is its Luminance. Or an extended (not a point) source can produce its own light, like a computer monitor screen or the surface of the sun. Each part (angle of view from the point of the observer) of these objects has a luminance measure, and the combined light (illuminance) of all or part of the object may also be measured.

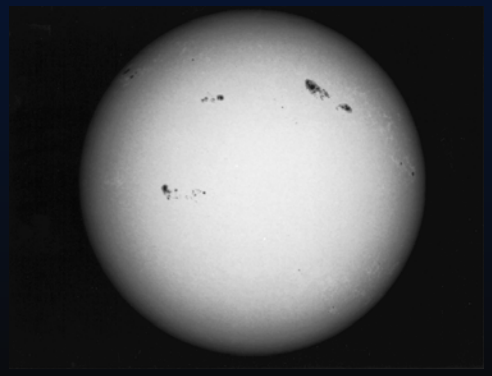
Ceiling light
Illuminance = 300 lux

Average backlit computer screen luminance = 100 cd/m^2



Paper on desk under reflected light luminance = 20 cd/m^2

Sun' surface
Average luminance 1,600,000,000 cd/m^2
Total illuminance 121,570 lux



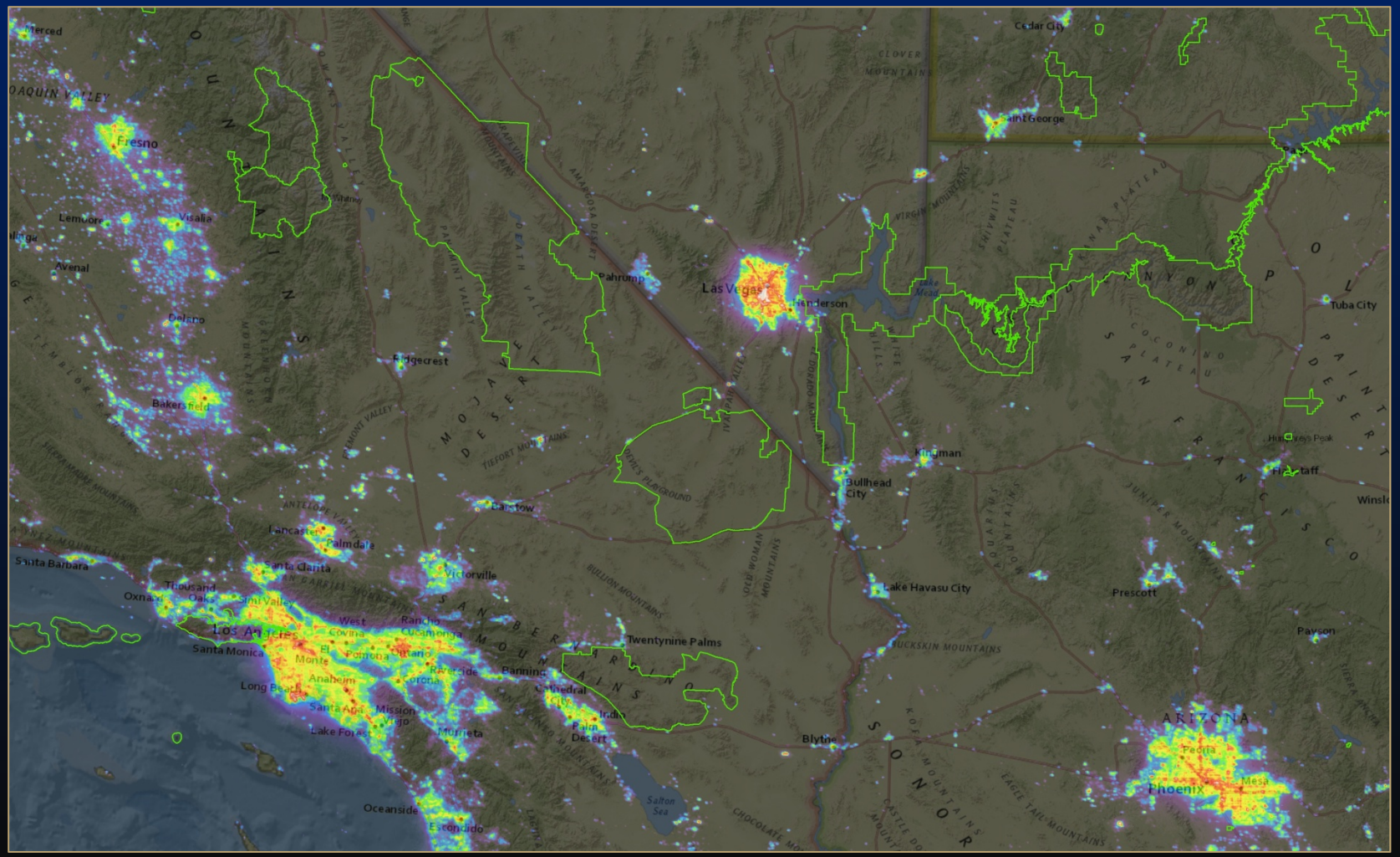
D Duriscoe

LIGHT POLLUTION RATIO

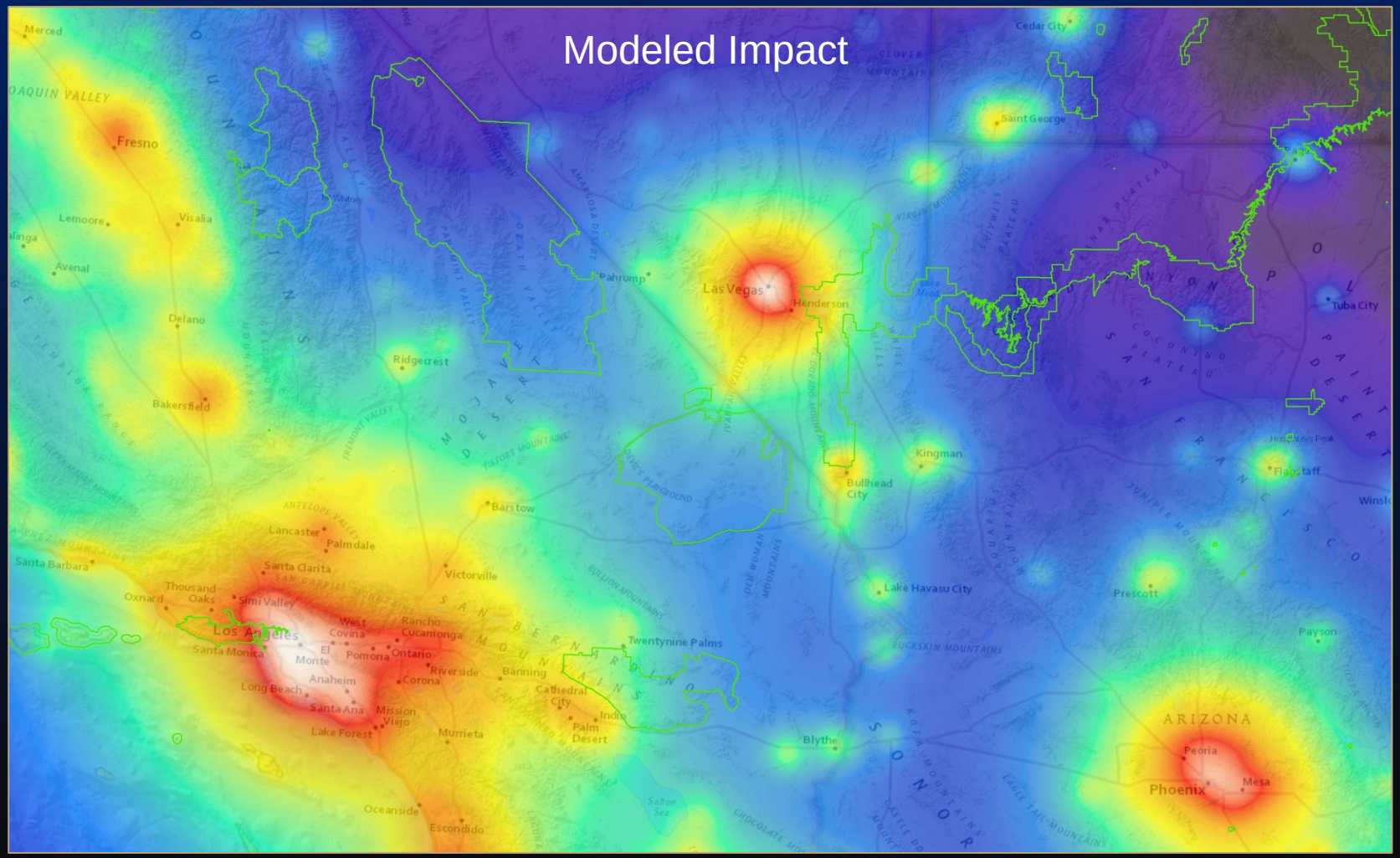
Indicator	Observed		Estimated Artificial		Light Pollution Ratio (Artificial/Natural)
Sky Luminance Measures					
	mag/ arcsec²	µcd/ m²	mag/ arcsec²	µcd/ m²	
Zenith	21.77	212	> 24.5	< 17	< 0.10
Mean all-sky	21.11	391	22.27	132	0.53
Brightest	17.76	8,407	17.79	8,210	48.01
Darkest	21.97	175	> 24.5	< 17	< 0.10
Median	21.49	272	25.01	11	0.04
Illuminance Measures					
	mags	milli-lux	mags	milli-lux	
Horizontal	-6.33	0.86	-4.09	0.11	0.14
Max Vertical	-6.69	1.20	-5.96	0.62	1.54

The Impact of Sky Glow on the Landscape

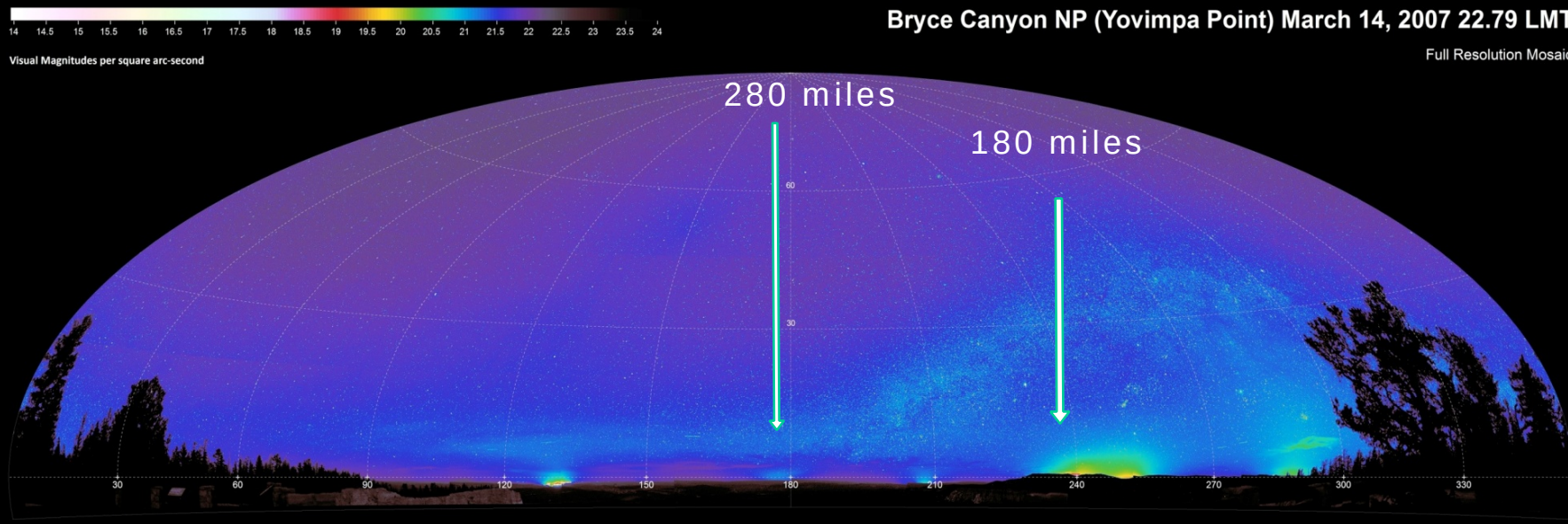
UPWARD RADIANCE



MODELED IMPACT - ALR

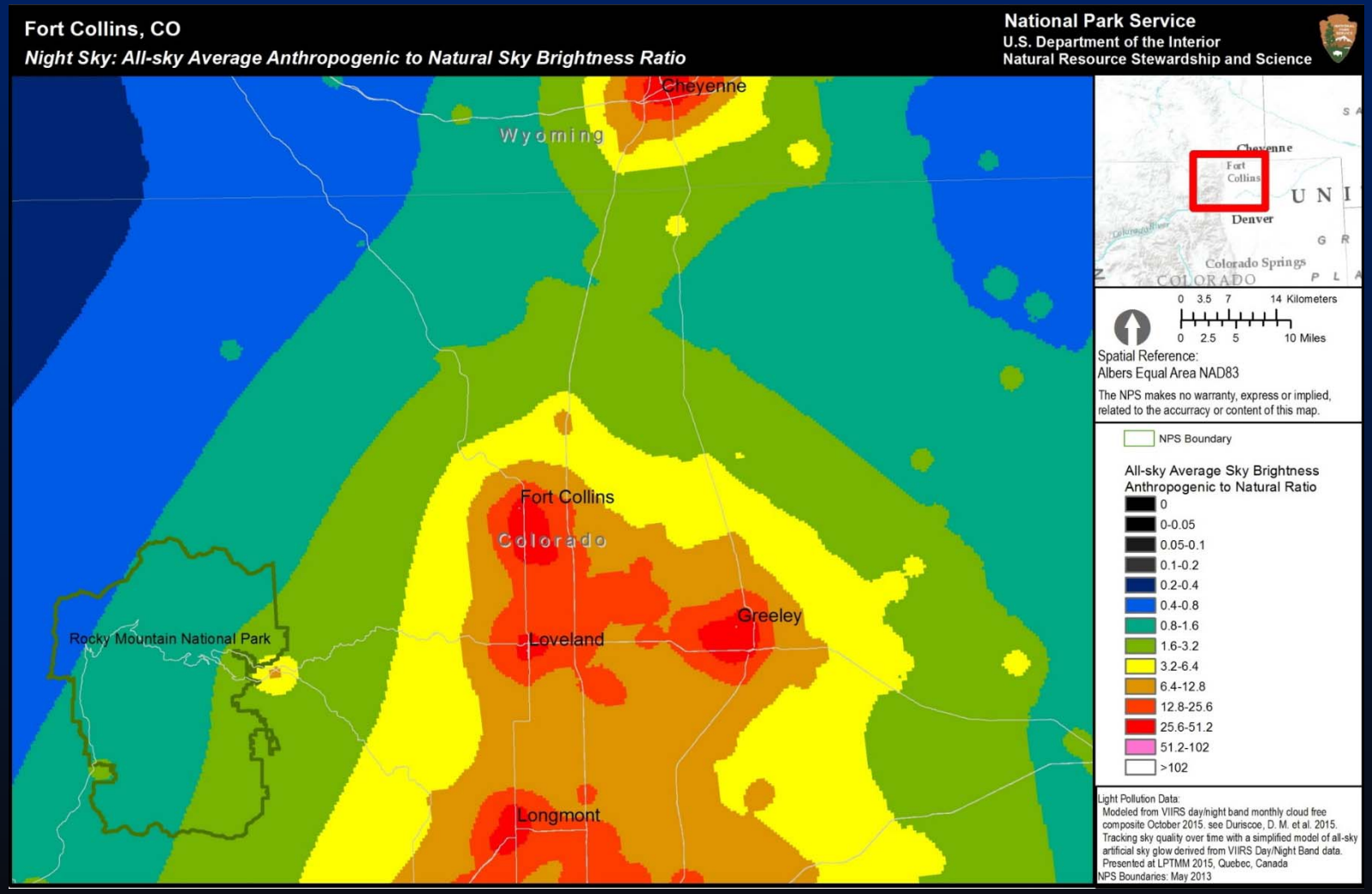


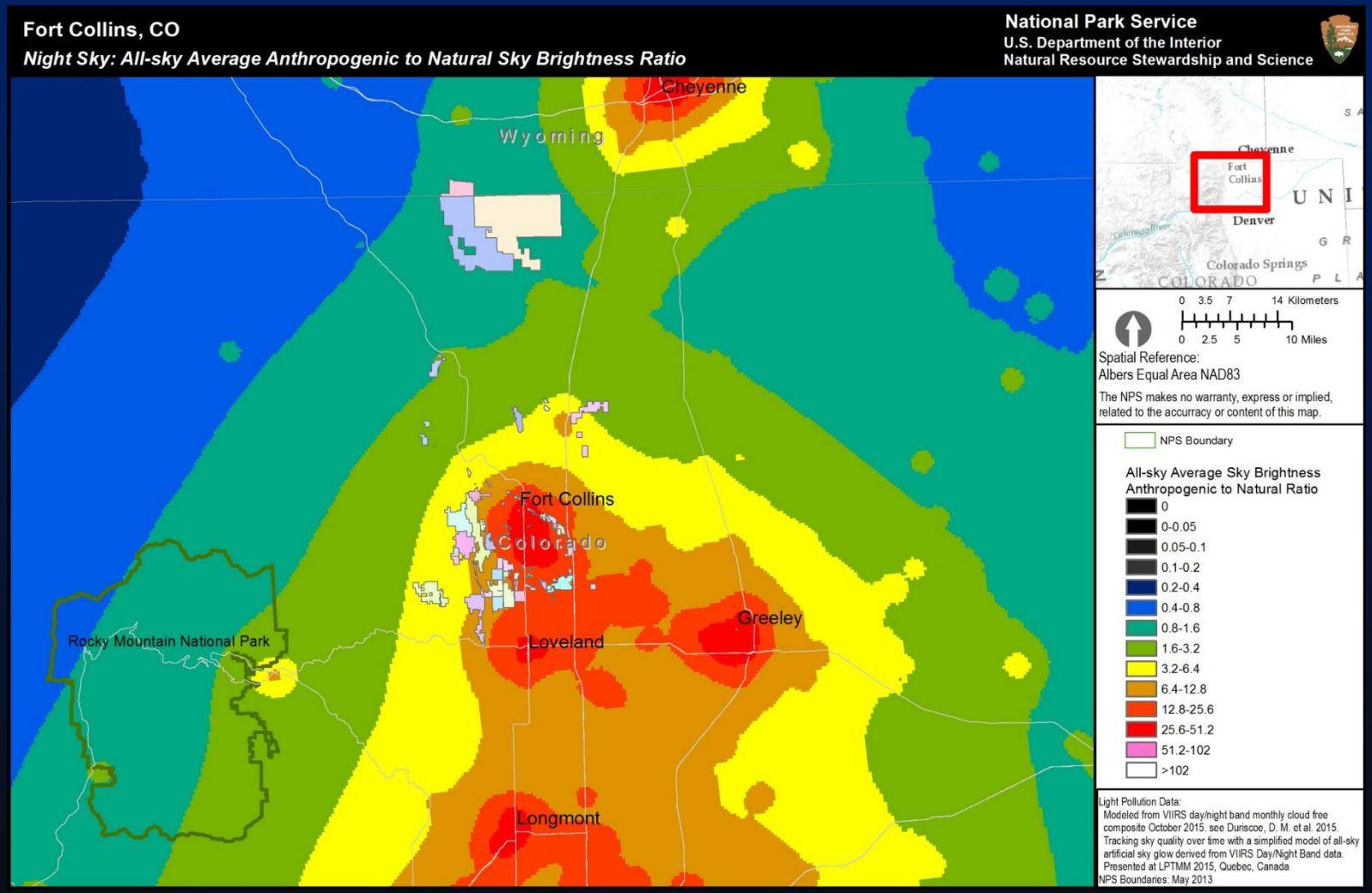
FAR REACHING IMPACTS OF SKY GLOW



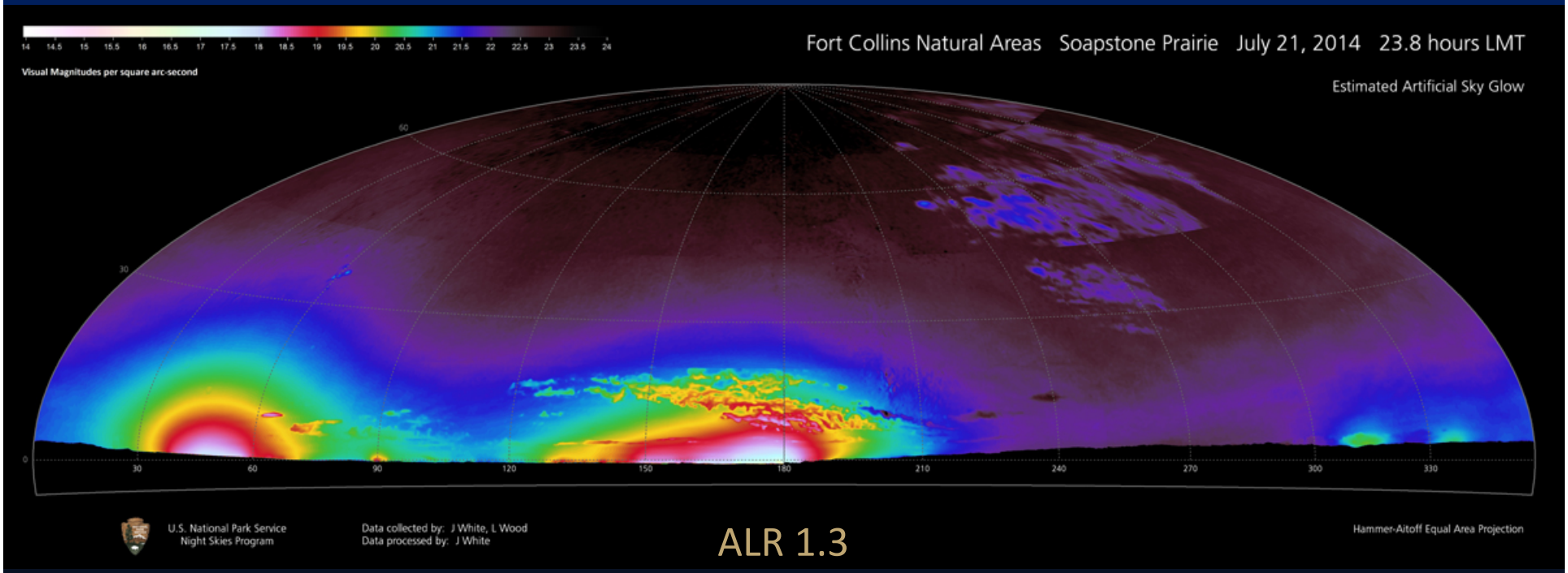
Bryce Canyon National Park, UT

Local Night Sky Conditions



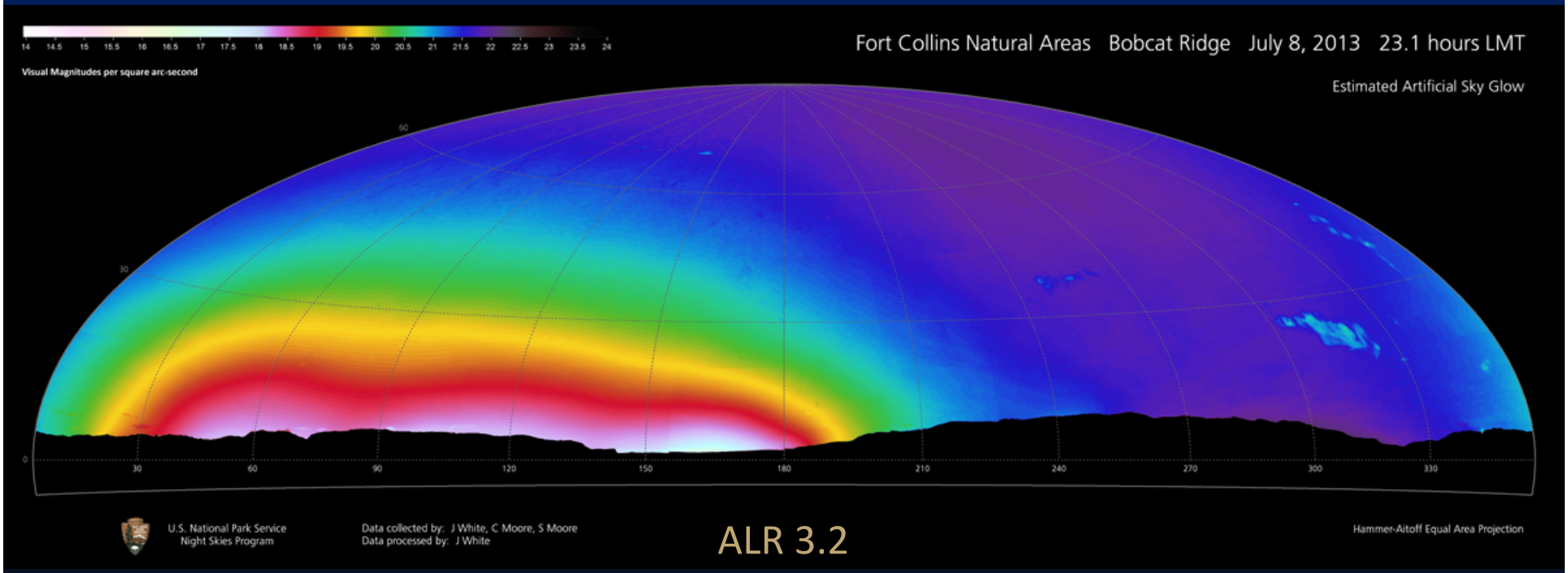

Fort Collins, CO
Night Sky: All-sky Average Anthropogenic to Natural Sky Brightness Ratio
National Park Service
U.S. Department of the Interior
Natural Resource Stewardship and Science
Cheyenne
Wyoming
Fort Collins
Colorado
Rocky Mountain National Park
Loveland
Greeley
Longmont
Denver
Colorado Springs
COLORADO
0 3.5 7 14 Kilometers
0 2.5 5 10 Miles
Spatial Reference:
Albers Equal Area NAD83
The NPS makes no warranty, express or implied, related to the accurracy or content of this map.
NPS Boundary
All-sky Average Sky Brightness Anthropogenic to Natural Ratio
0
0-0.05
0.05-0.1
0.1-0.2
0.2-0.4
0.4-0.8
0.8-1.6
1.6-3.2
3.2-6.4
6.4-12.8
12.8-25.6
25.6-51.2
51.2-102
>102
Light Pollution Data:
Modeled from VIIRS day/night band monthly cloud free composite October 2015. see Duriscoe, D. M. et al. 2015. Tracking sky quality over time with a simplified model of all-sky artificial sky glow derived from VIIRS Day/Night Band data. Presented at LPTMM 2015, Quebec, Canada
NPS Boundaries: May 2013

Fort Collins - Soapstone Prairie NA



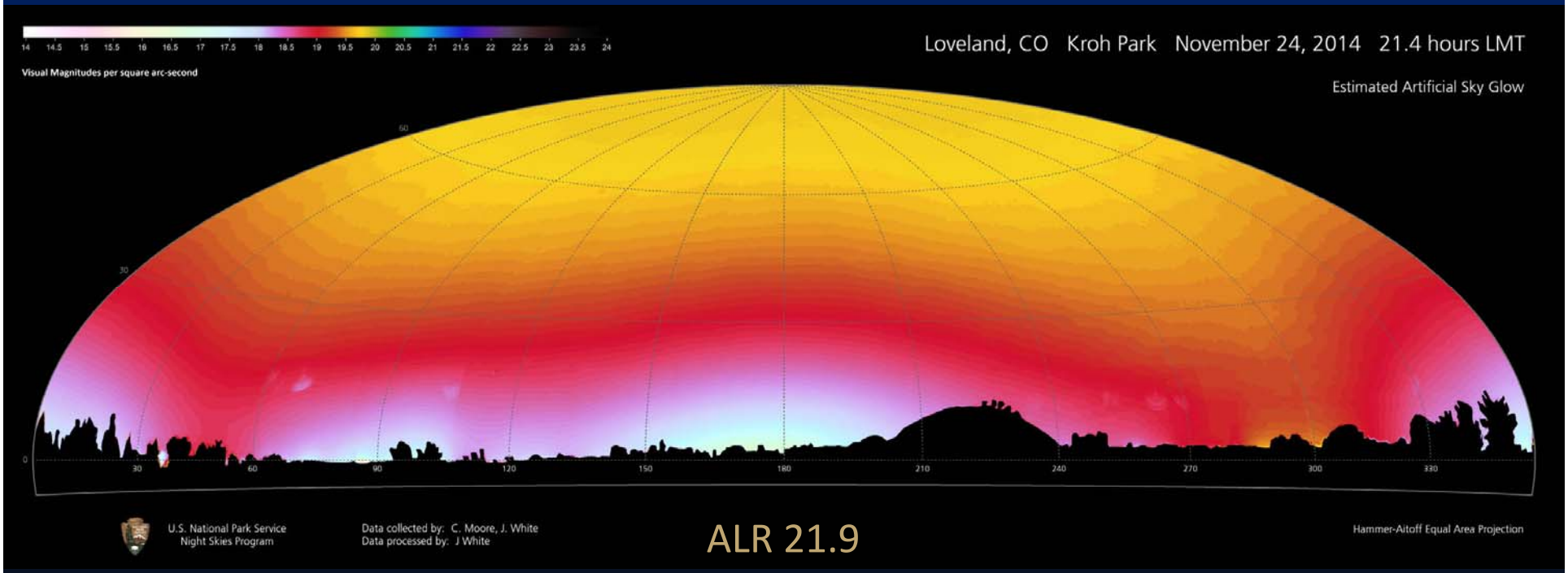
ALR 1.3

Fort Collins – Bobcat Ridge NA



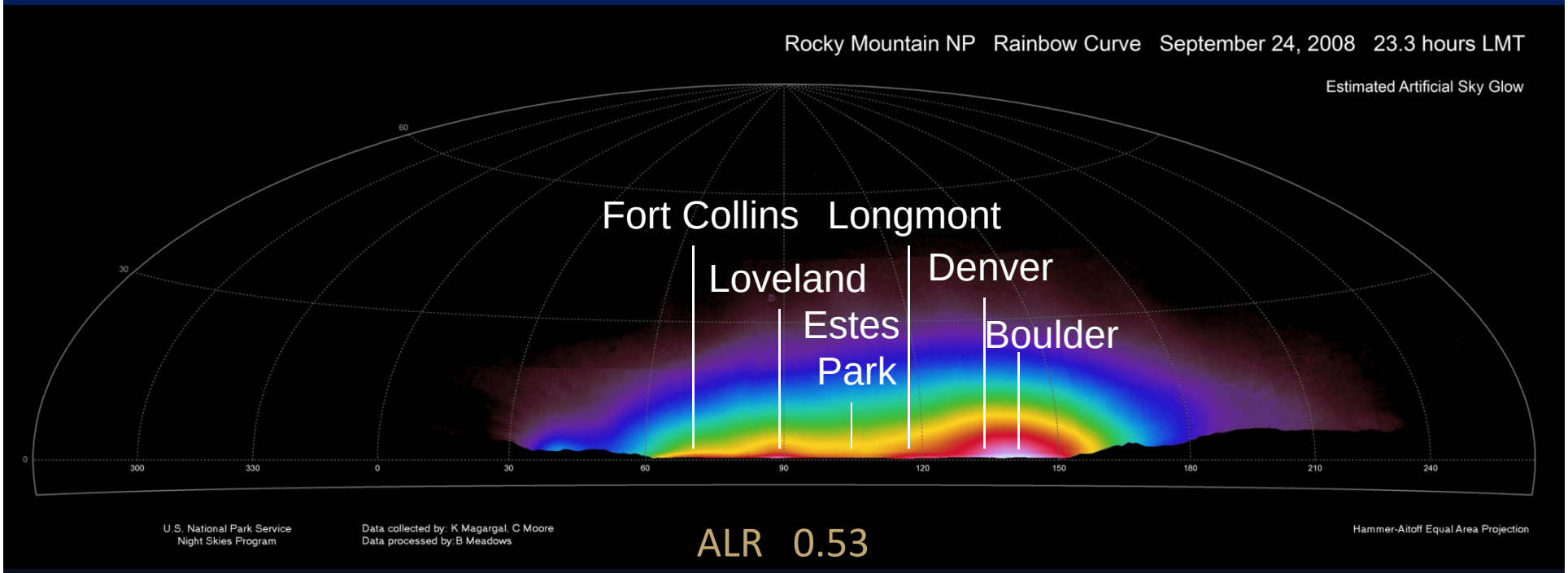
ALR 3.2

North Loveland – Kroh Park

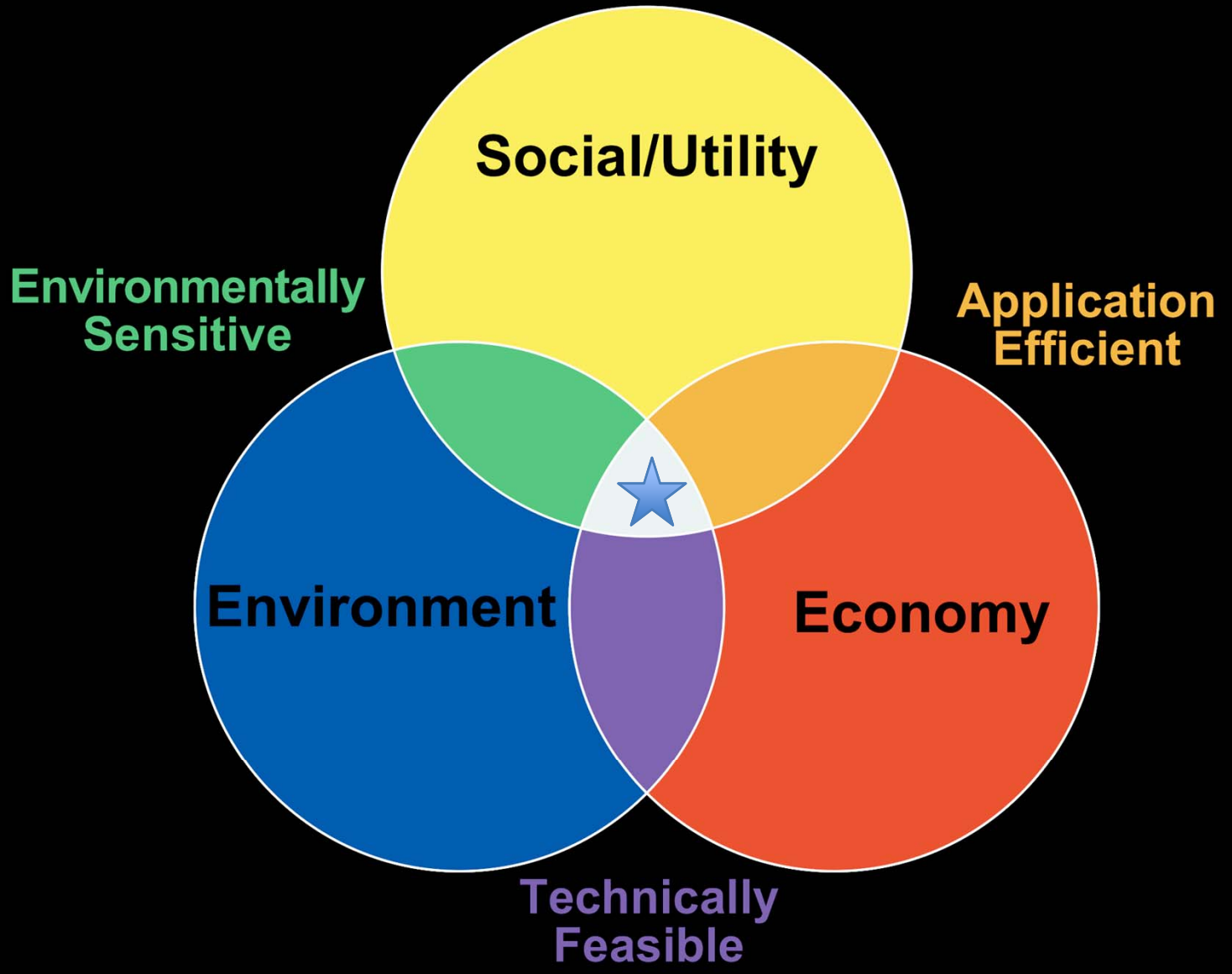


ALR 21.9

Rocky Mountain National Park



Fully Sustainable Lighting

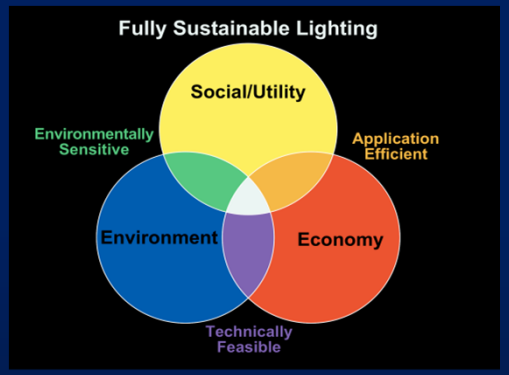


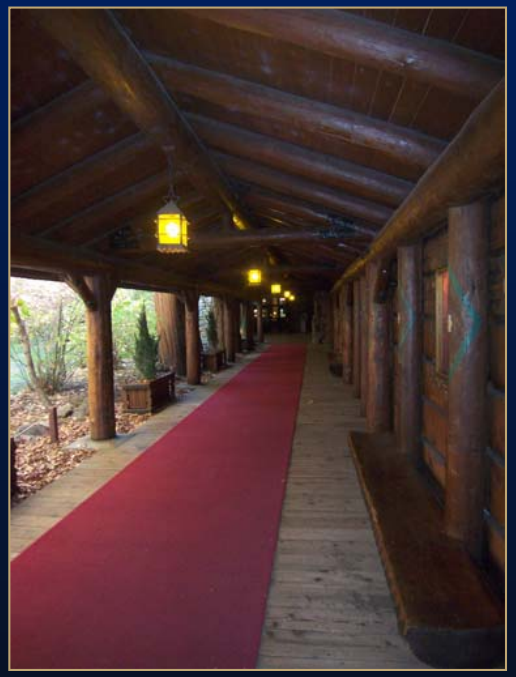
Fully Sustainable Outdoor Lighting

- Light only where you need it
- Light only when you need it
- Shield lights and direct them downward
- Use the minimum amount of light necessary
- Select lamps with warmer colors
- Use the most energy efficient lamps and fixtures

Fully Sustainable Outdoor Lighting

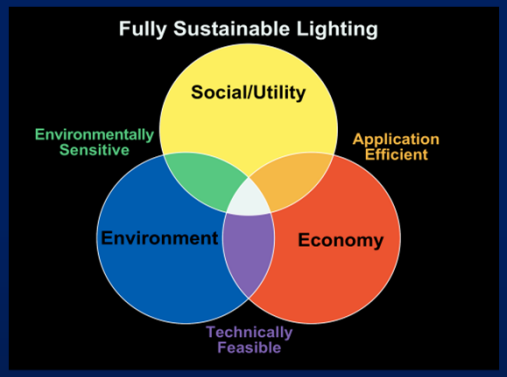
Meets basic accessibility and social needs

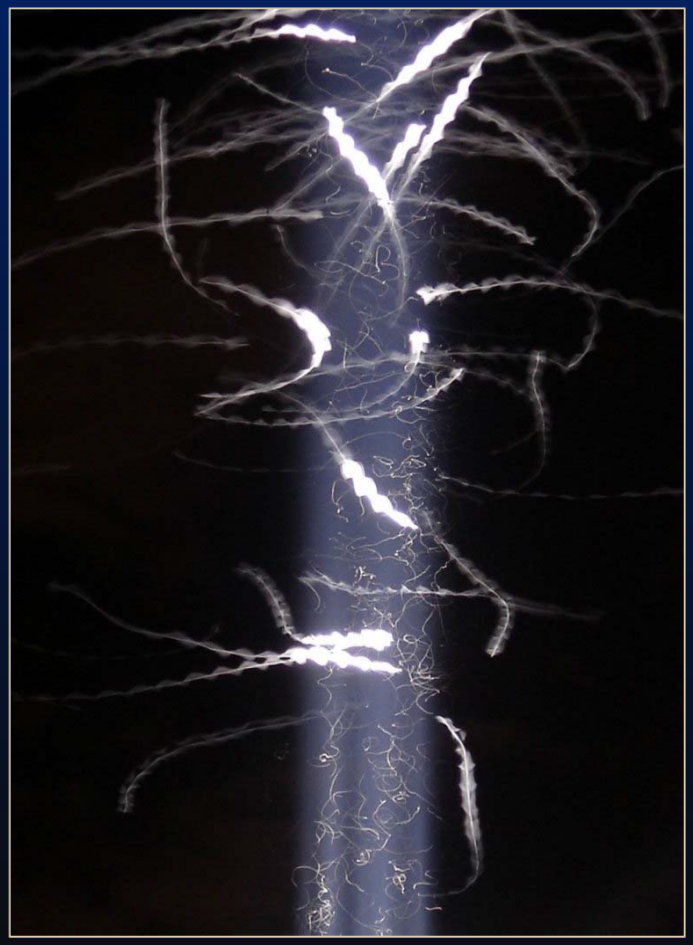


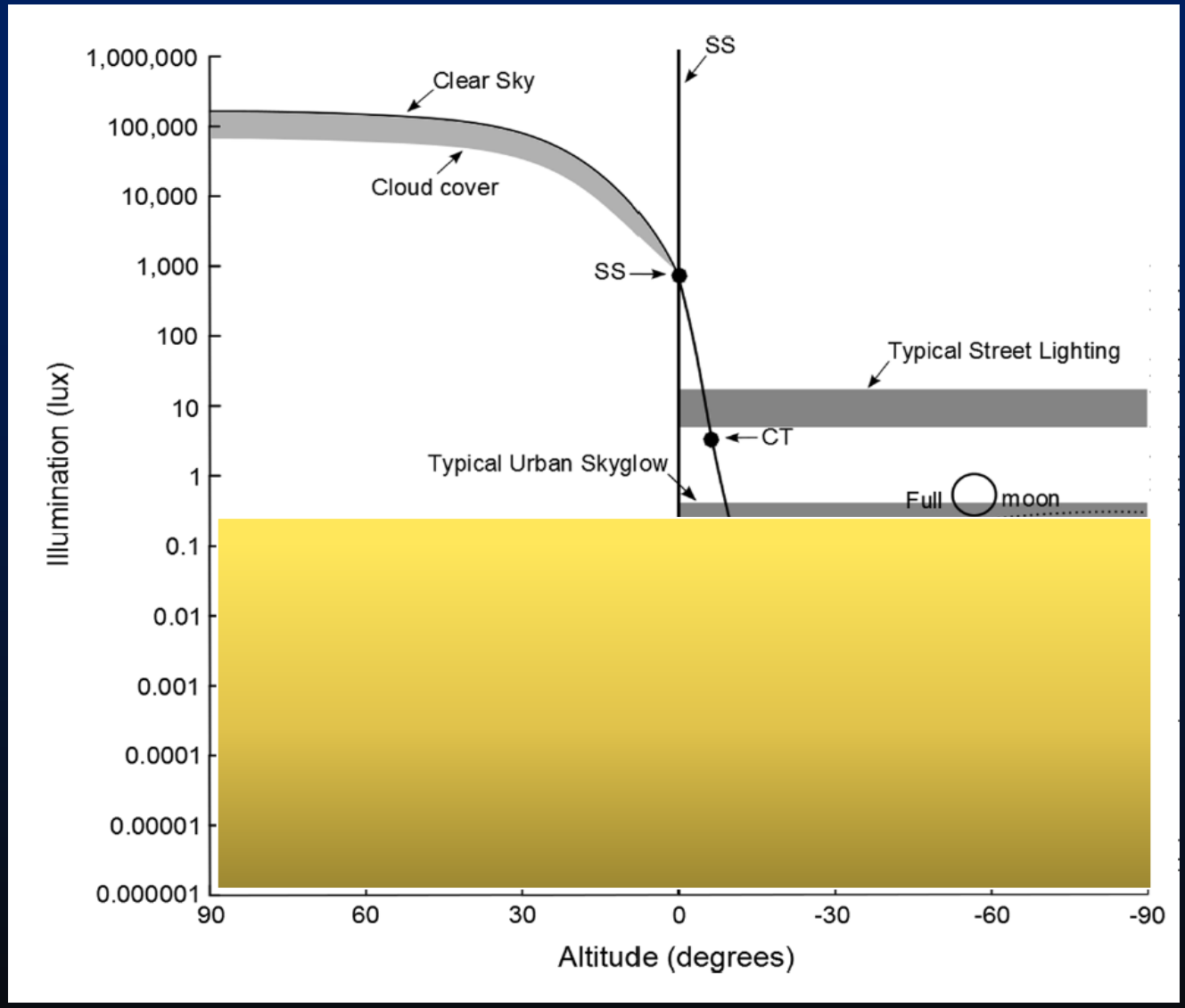


Fully Sustainable Outdoor Lighting

Does no harm to the surrounding environment






1,000,000
100,000
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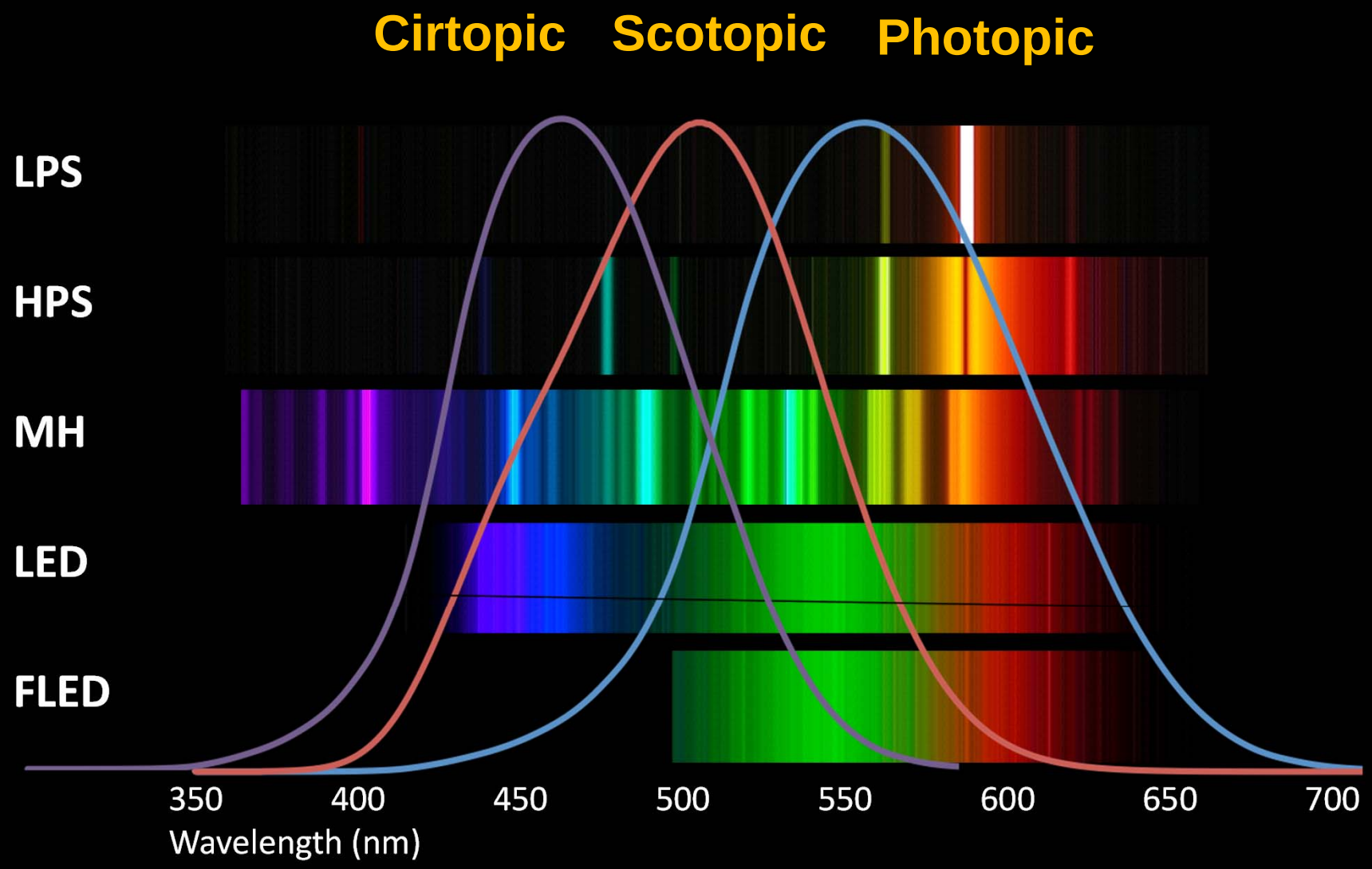
10
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
Illumination (lux)
90
60
30
0
-30
-60
-90
Altitude (degrees)
SS
Clear Sky
Cloud cover
SS
Typical Street Lighting
CT
Typical Urban Skyglow
Full
moon

Lamp Spectra



Luginbuhl. 2013

International Agency for Research on Cancer

World Health Organization

U.S. Department of Health and Human Services
National Institutes of Health
National Institute of Enviromental Health Sciences

ehp ENVIRONMENTAL HEALTH PERSPECTIVES

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Environ Health Perspect. 2009 Jan; 117(1): A20–A27.

Environews

Focus

Missing the Dark: Health Effects of Light Pollution

Ron Chepesiuk

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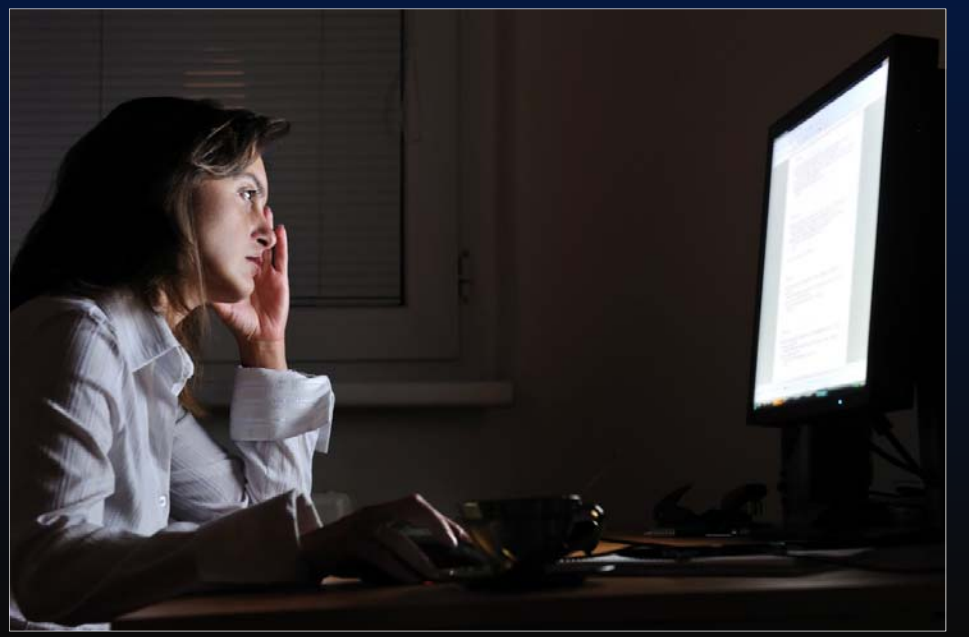
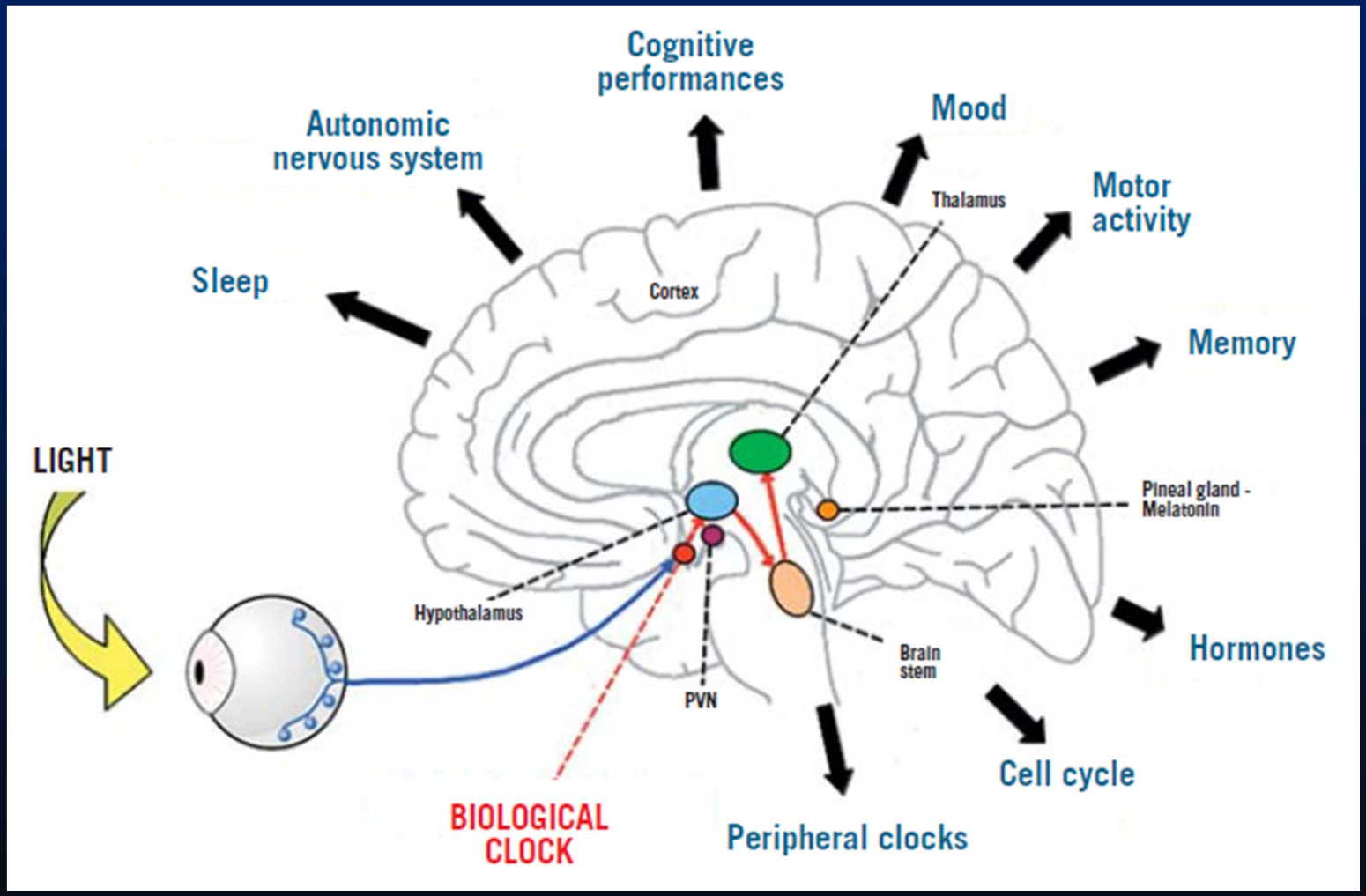
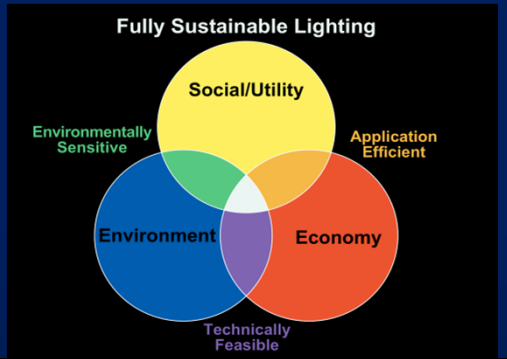


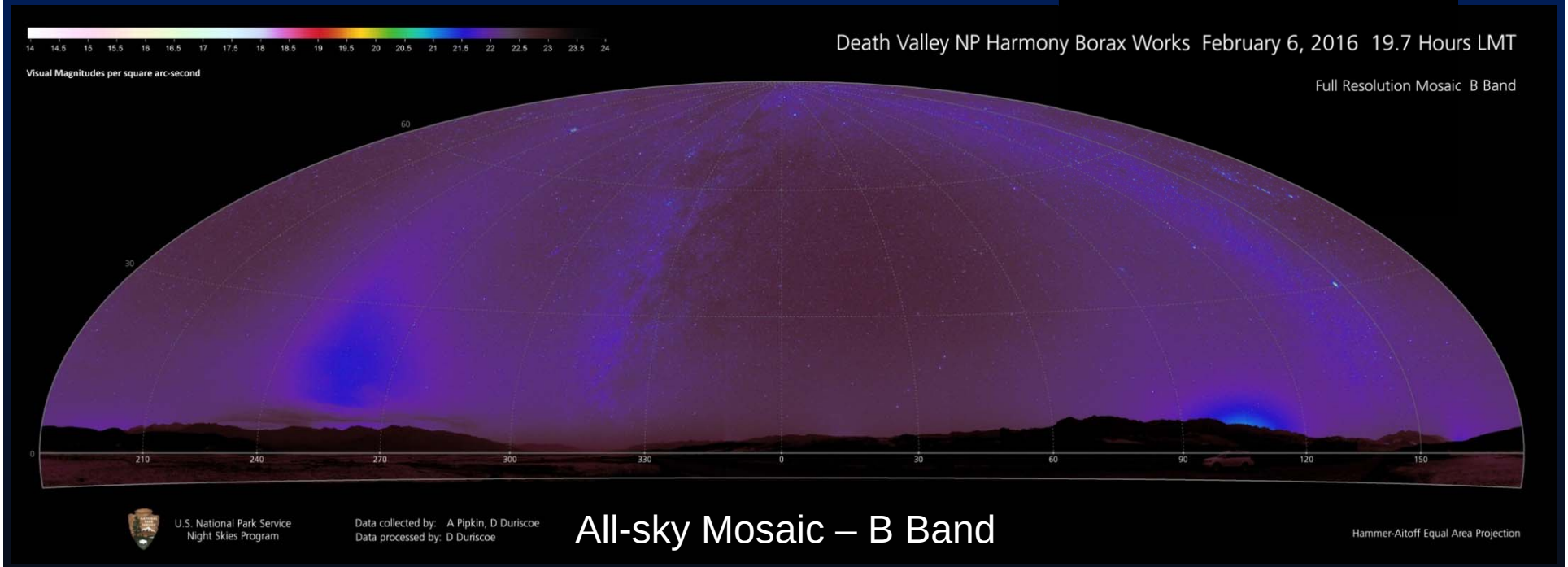


Claude Gronifer. Points de Vue, International Review of Ophthalmic Optics, N68, Spring, 2013

Fully Sustainable Outdoor Lighting

Does no harm to the surrounding environment

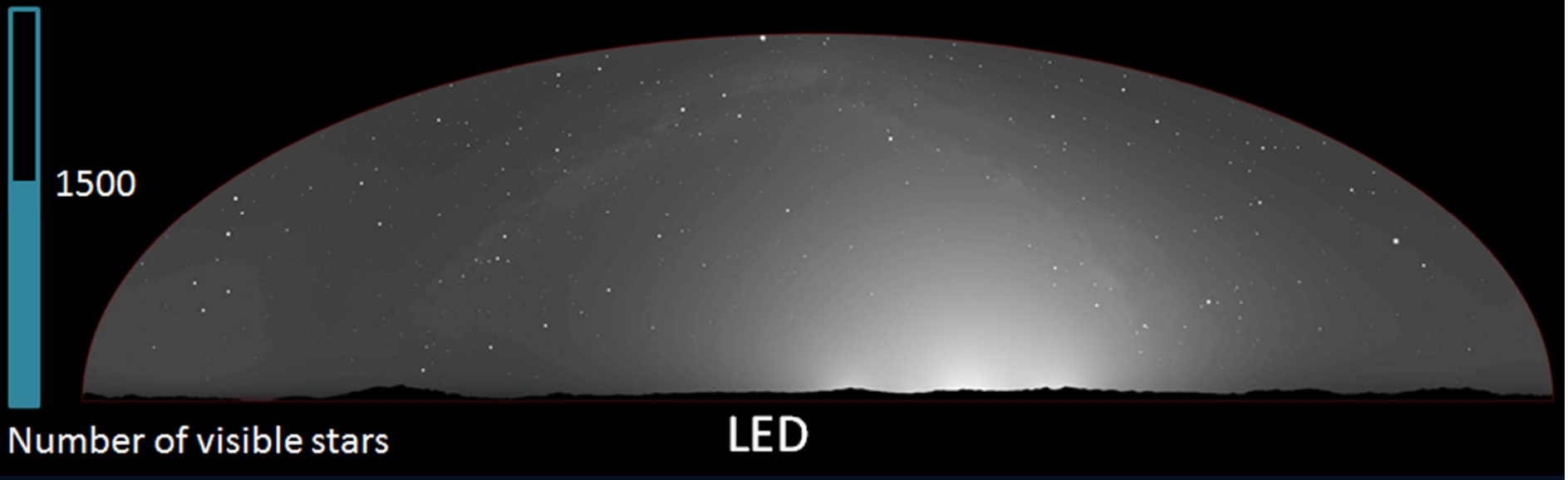




All-sky Mosaic – B Band

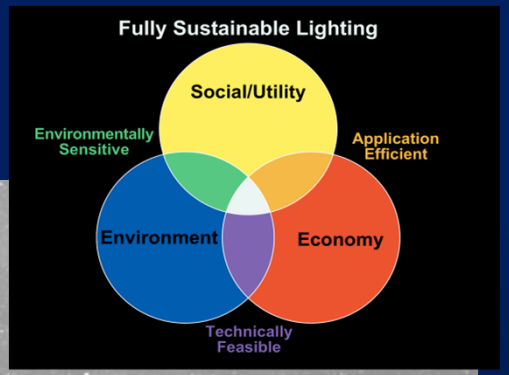
Fully Sustainable Outdoor Lighting

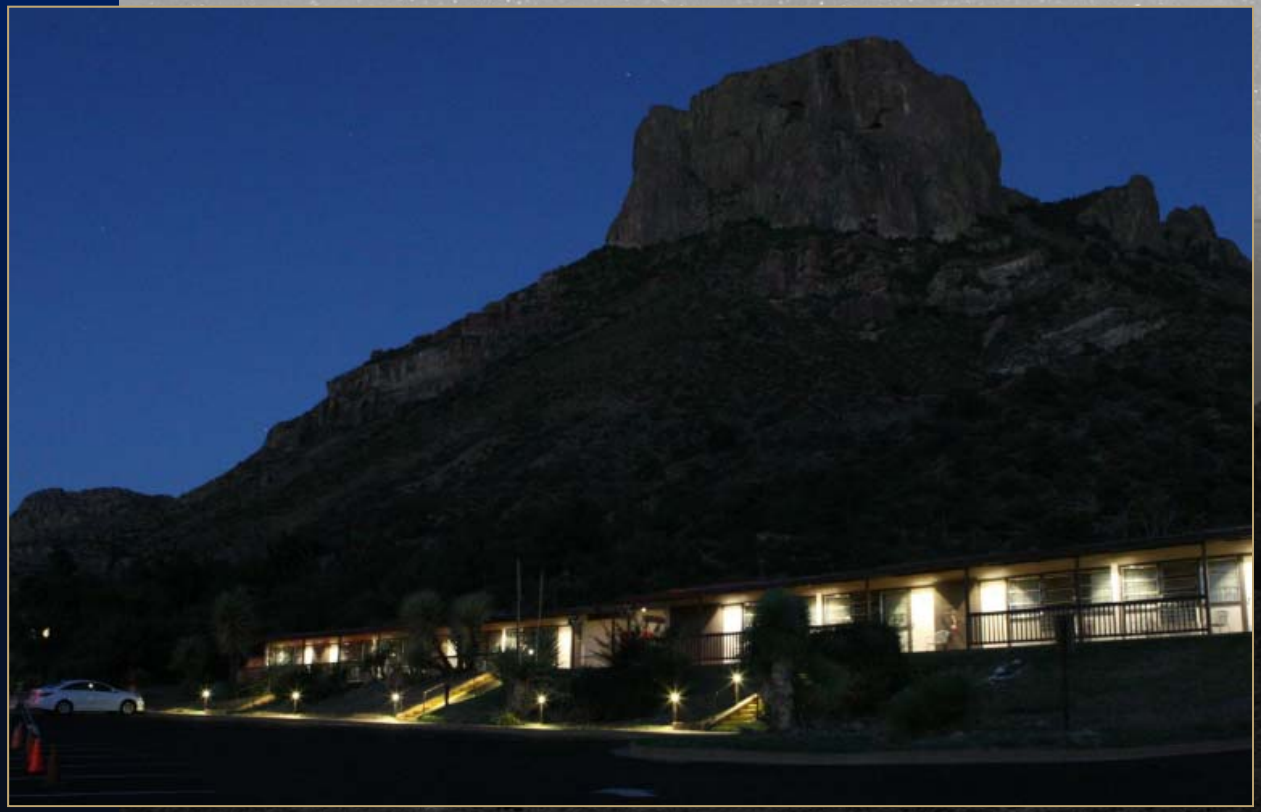
Does no harm to the surrounding environment



Fully Sustainable Outdoor Lighting

Does no harm to the surrounding environment

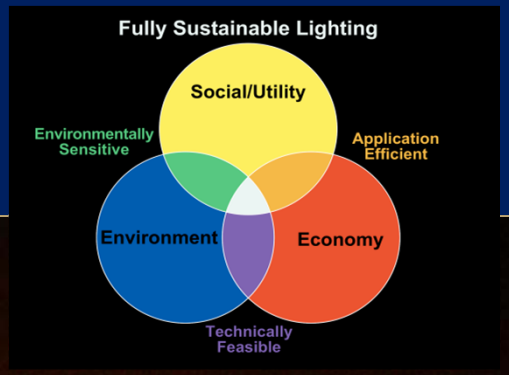




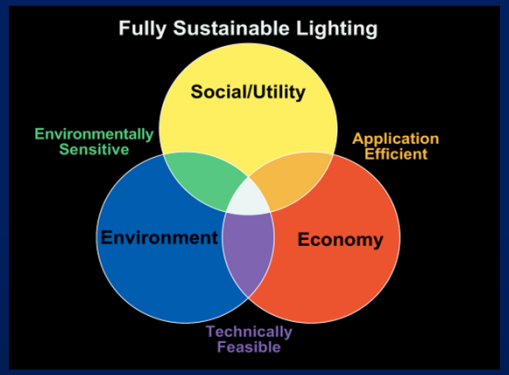
2011

Fully Sustainable Outdoor Lighting

Is Economical to install and maintain



Fully Sustainable Outdoor Lighting



Is Economical

Bryce Canyon (2012) – Astronomy related attendance accounted for over 50,000 visits and $2 million contributed to local economies

How to implement fully sustainable lighting

- Define lighting zones based upon land use
- Identify desired conditions within each zone
- Inventory existing conditions (lights and illumination levels)
- Analyze existing and potential environmental impacts
- Design retrofit or new installation to meet guidelines
- Perform installation including measuring results
- Ideally, have a Lightscape Management Plan and follow it

Outdoor Lighting Zones

LZ0

LZ0-H

LZ1

NDZ

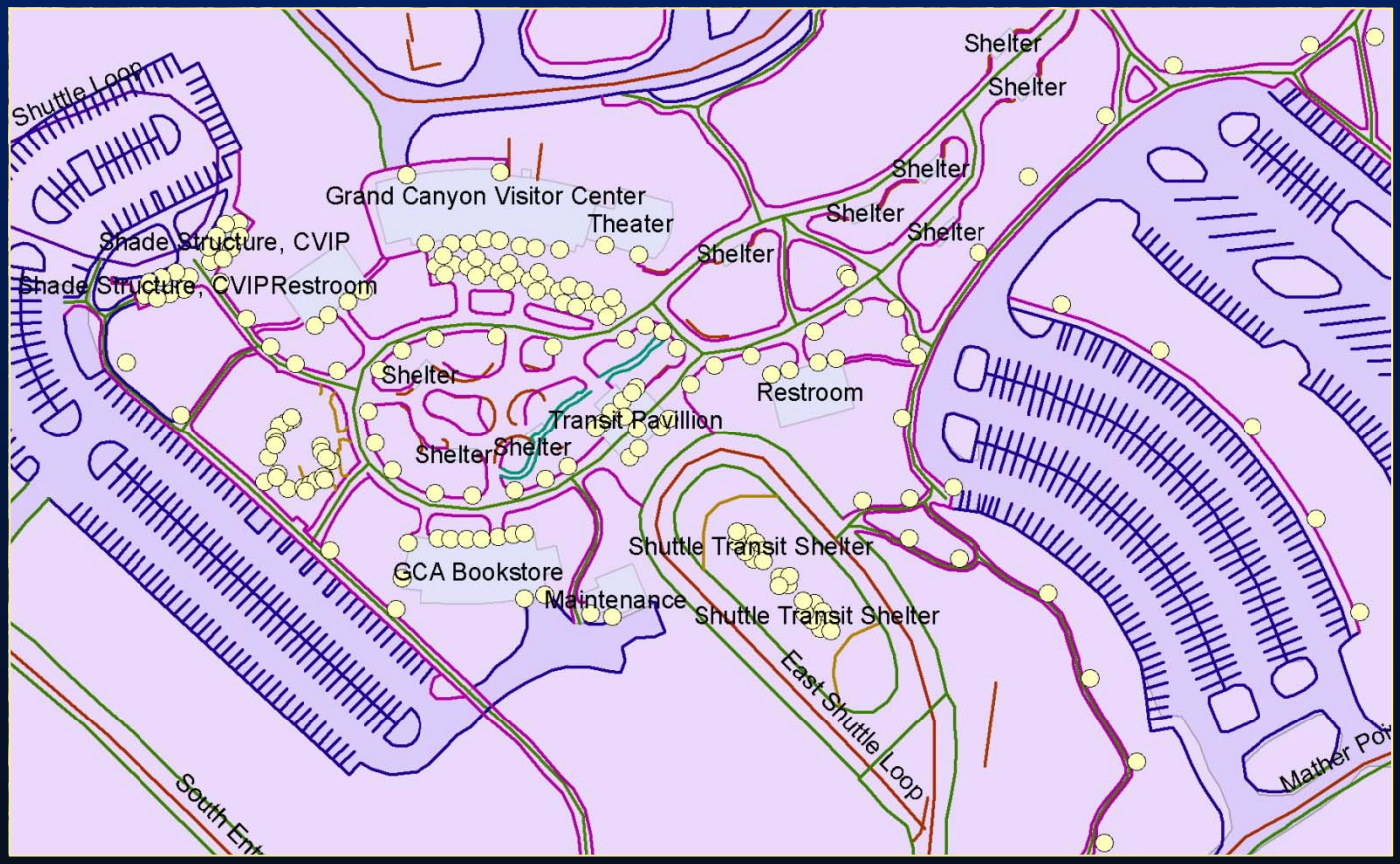
LZ0	LZ0-H	LZ1	LZ2	NDZ
Residential	Historic Structure	Maintenance Area	Urban Area Parks	Naturally Dark Zone

Outdoor Lighting Inventory

Location

Photo

Attributes



GRAND CANYON VISITOR CENTER

Design for desired conditions

Mock-up test at Grand Canyon before final design

Install including results measurement

Page, Arizona Observed Anthropogenic Sky Glow

Population (2010 census)	Lumens per capita (VIIRS)	Estimated Lumens per capita (model fit)	Percent uplight
8,690	10,368	--	10.0

Lumens/capita ratio to Flagstaff

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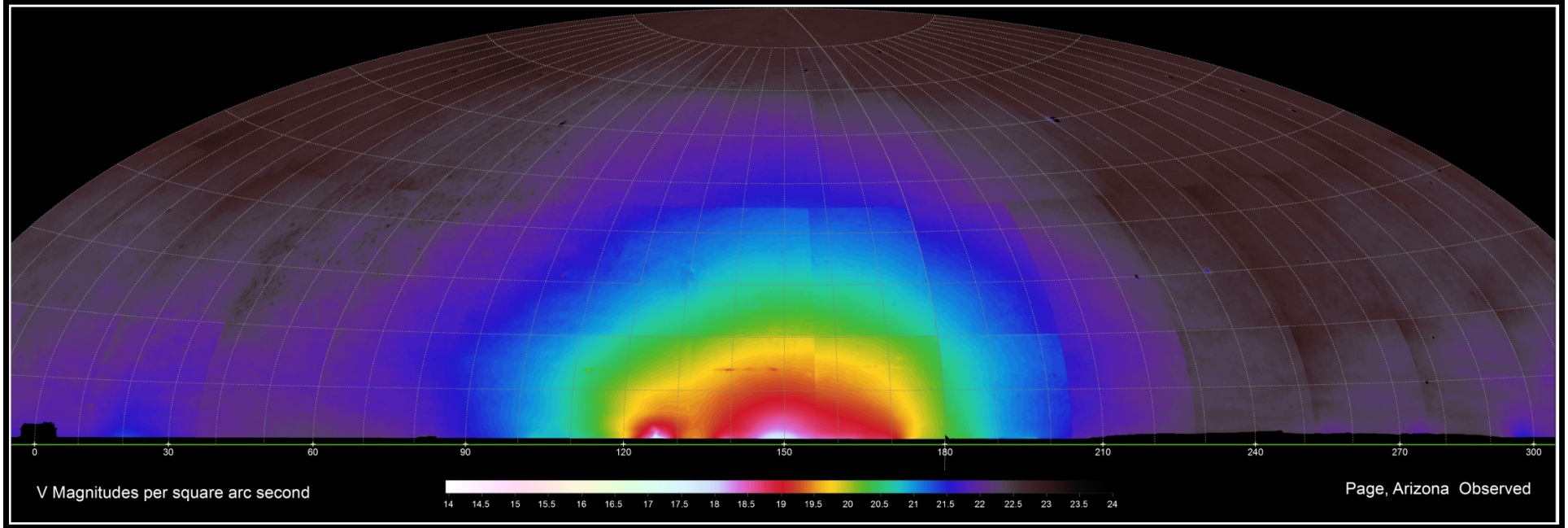


Distance to City Center 8.1 km

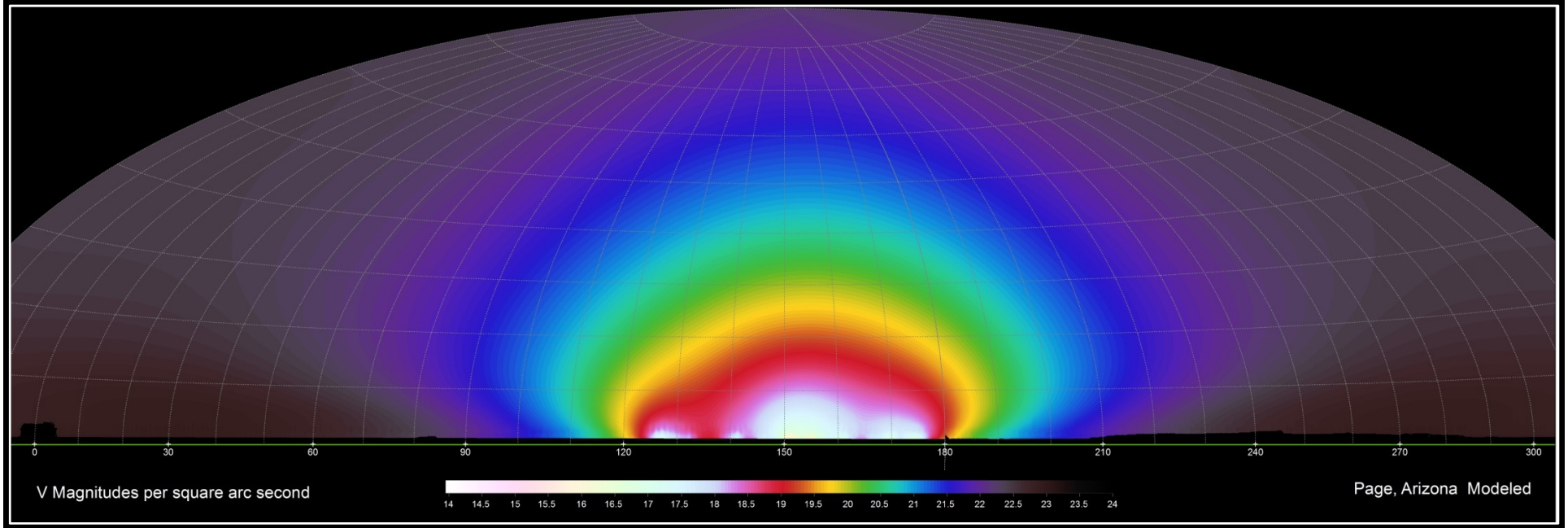
Duriscoe, Luginbuhl and Elvidge. 2013

Page, Arizona Modeled Current Anthropogenic Sky Glow

Population (2010 census)	Lumens per capita (VIIRS)	Estimated Lumens per capita (model fit)	Percent uplight
8,690	10,368	5702	10.0

Lumens/capita ratio to Flagstaff

2.75



Distance to City Center 8.1 km

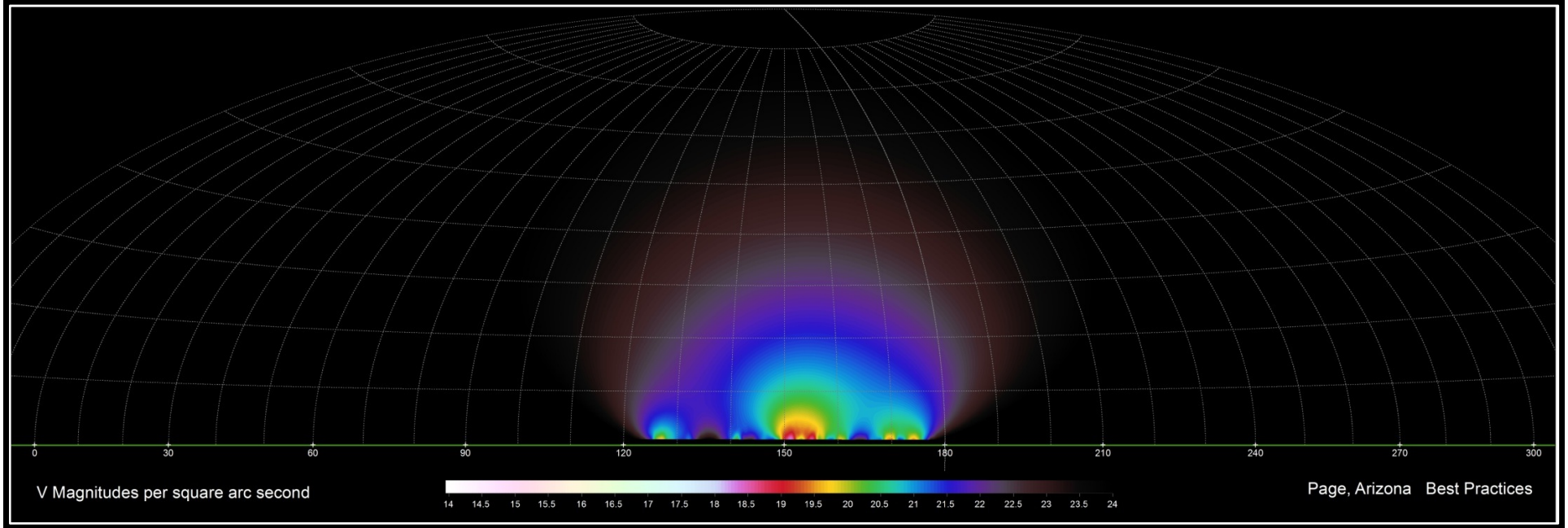
Duriscoe, Luginbuhl and Elvidge. 2013

Page, Arizona Modeled Best Practices Anthropogenic Sky Glow

Population (2010 census)	Lumens per capita (VIIRS)	Estimated Lumens per capita (best prac.)	Percent uplight
8,690	--	2075	0.0

Lumens/capita ratio to Flagstaff

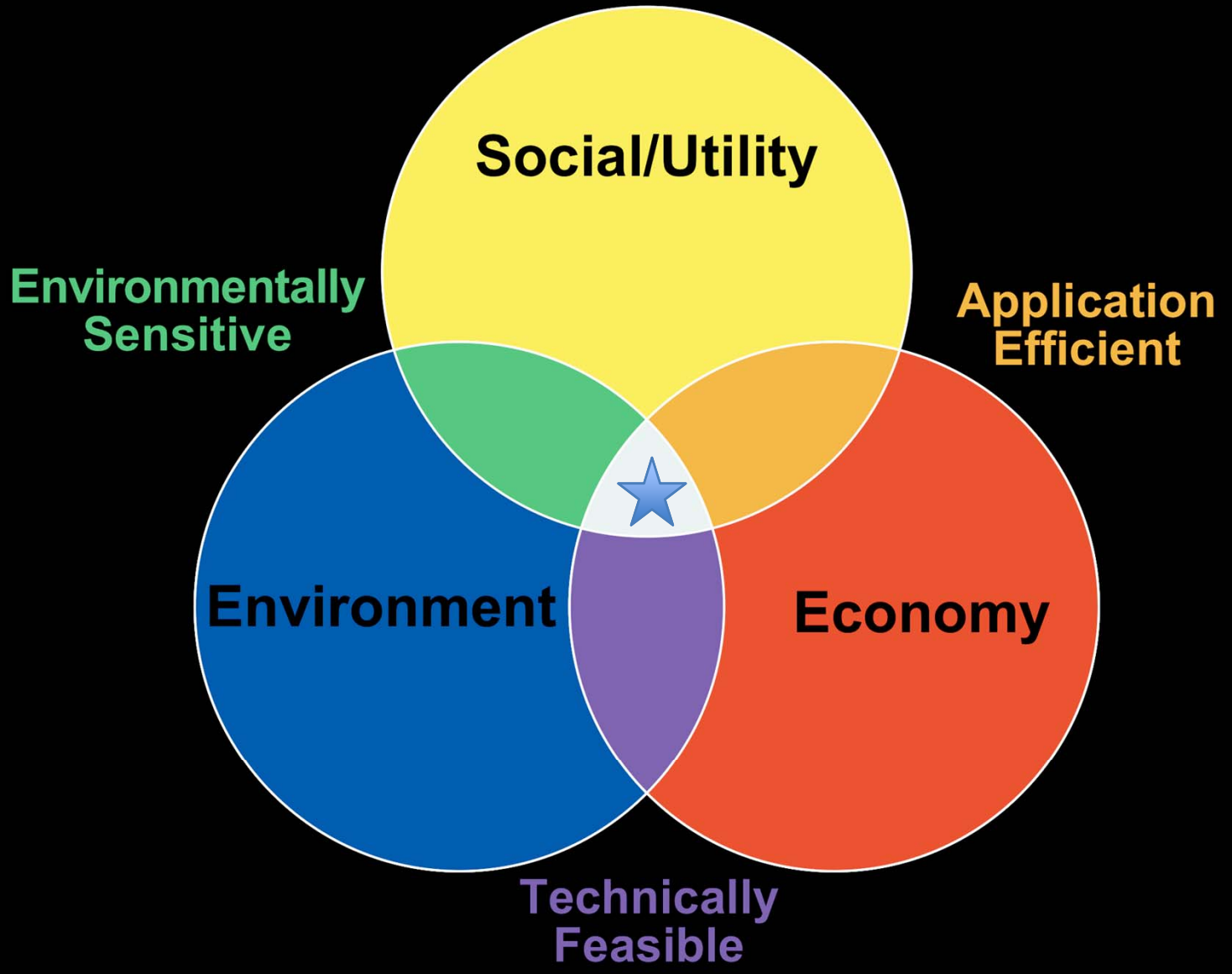
1.0

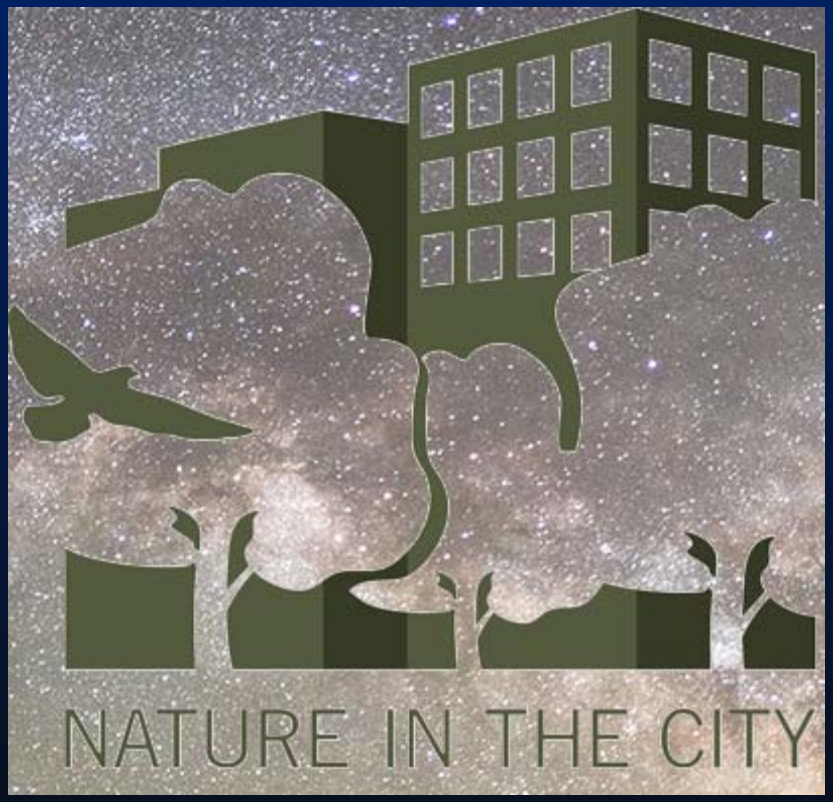


Distance to City Center 8.1 km

Duriscoe, Luginbuhl and Elvidge. 2013

Fully Sustainable Lighting




NATURE IN THE CITY