# Measuring and Evaluating the Impacts of Anthropogenic Light in the Nocturnal Environment

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# Outline

--The natural moonless nighttime environment

--Measuring light pollution
- Photometers
- Cameras – calibrated high dynamic range monochrome
- Multi-band imaging
- Cameras – Digital RGB low dynamic range

--Spectrum of outdoor light
- Protecting the dark adapted eye for visual observing
- The melatonin suppression band
- Effects on sky glow from models and measurements

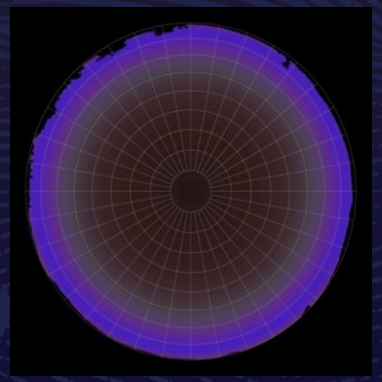
--Remote sensing from VIIRS day/night band
- Calibrated upward radiance global database
- Limitations and importance of calibration with ground observations
- Input to physical or empirical landscape scale models

# The reference condition – natural darkness

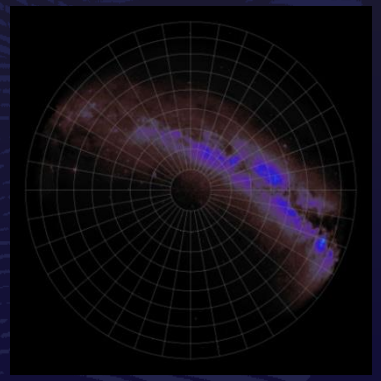
- Is intrinsically very dark compared to full daylight
- Is a valuable scenic and cultural resource
- Is an integral part of nocturnal ecosystem function

# The reference condition – natural darkness

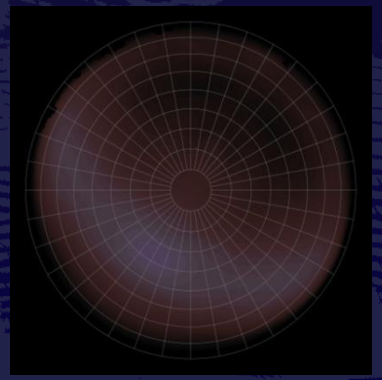
- The night sky without the moon provides natural sources of light
- These values become the reference, or “natural background” to which anthropogenic sources may be compared
- The median condition over the solar cycle may be quantified in luminance and illuminance measures



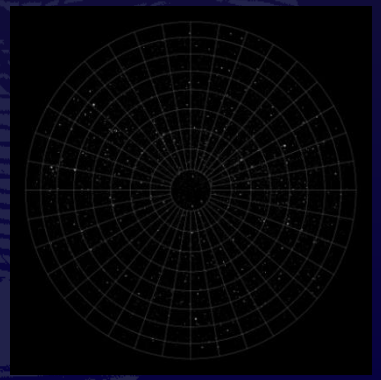
Airglow 48%



Galactic 19%



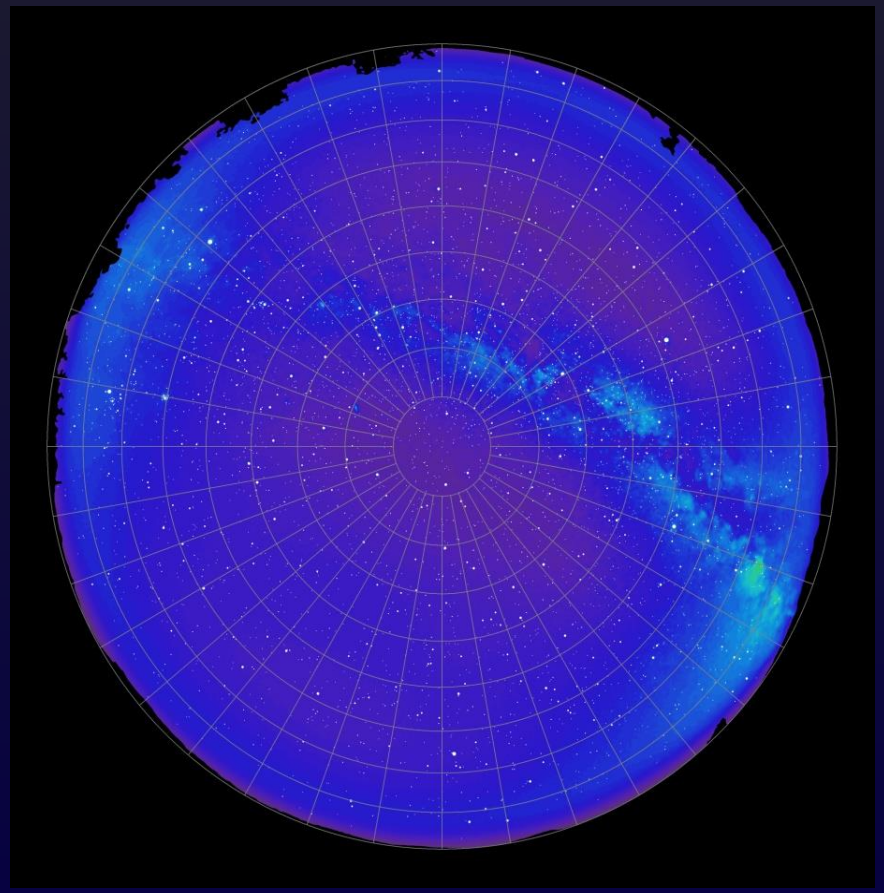
Zodiacal 28%



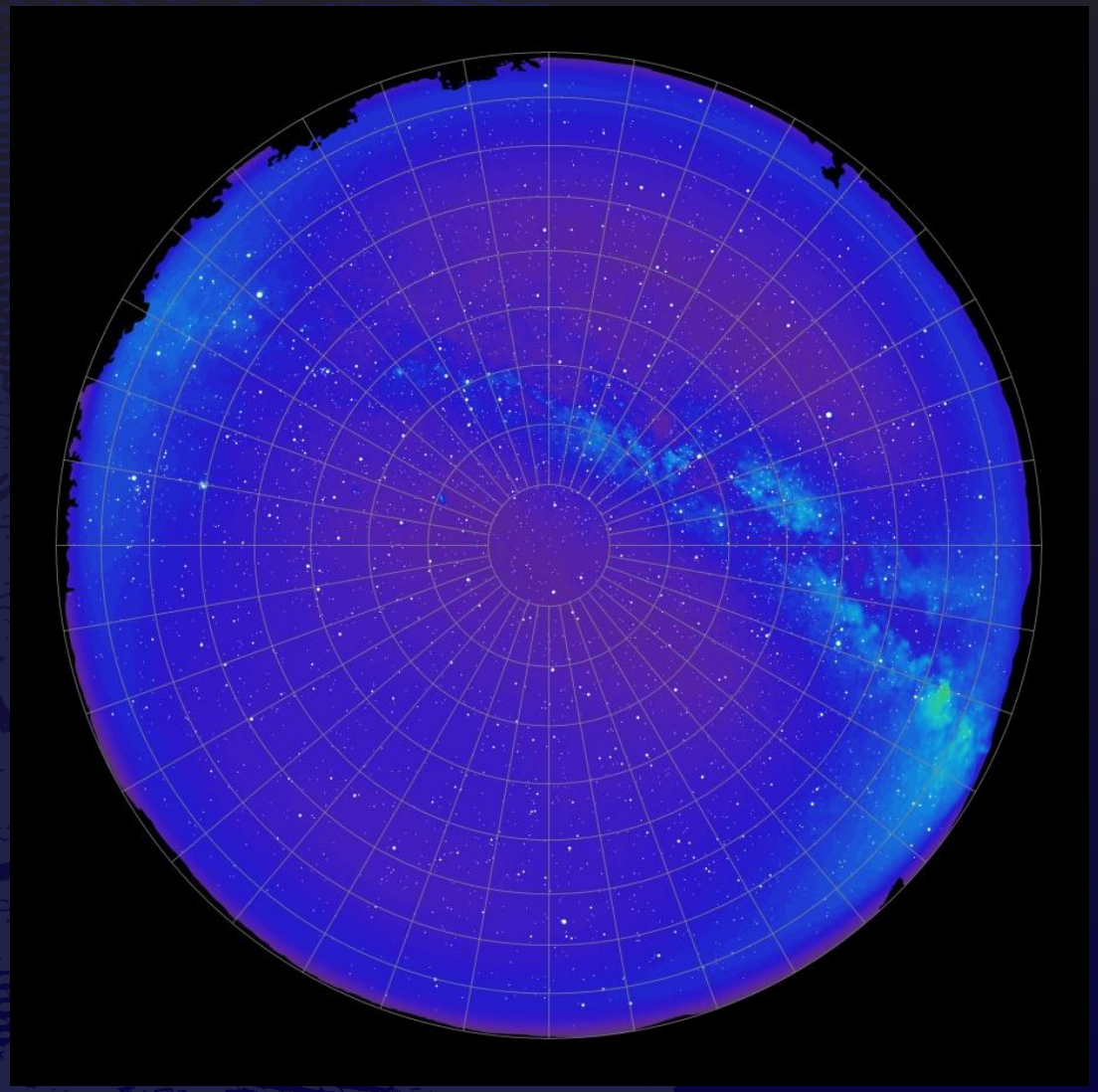
Stars 5%

## Luminance

| | mcd $m^{-2}$ |
|---|---|
| Average luminance | 0.250 |
| Maximum luminance | 0.794 |
| Zenith luminance | 0.174 |



# The reference condition – natural darkness



Illuminance

| | mlx |
|---|---|
| Horizontal illuminance | 0.80 |
| Minimum vertical illuminance | 0.38 |
| Average vertical illuminance | 0.41 |
| Maximum vertical illuminance | 0.43 |
| Scalar illuminance (R = 0) | 0.41 |
| Scalar illuminance (R = 0.15) | 0.47 |
| Scalar illuminance (R = 0.80) | 0.74 |

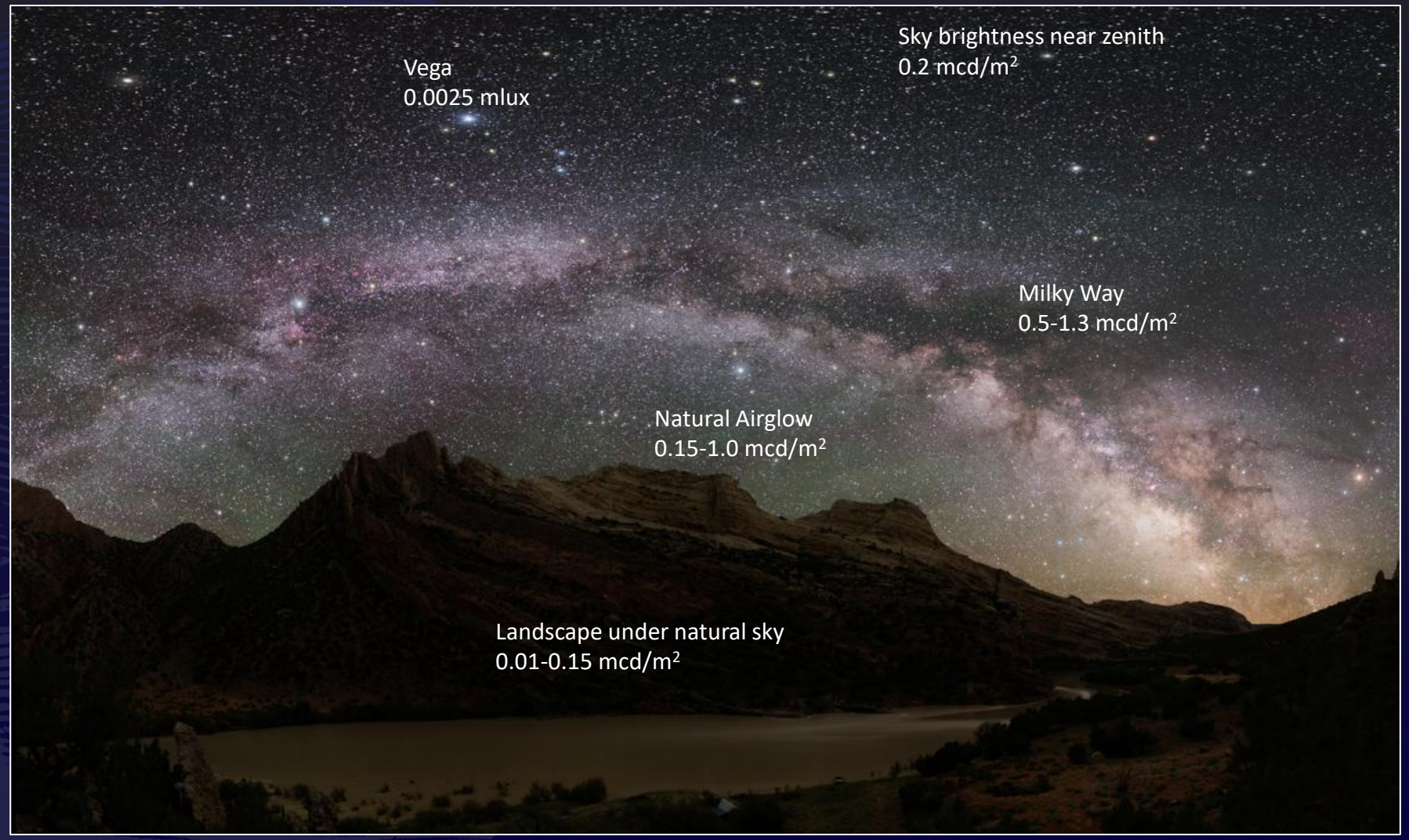
Duriscoe, Dan M. "Measuring anthropogenic sky glow using a natural sky brightness model." *Publications of the Astronomical Society of the Pacific*125.933 (2013): 1370.

# Measuring the nocturnal photic environment

## Luminance and Illuminance

# Measuring the nocturnal photic environment

## Luminance and illuminance




Illuminance from the Whole Sky

Horizontal
0.8 mlux

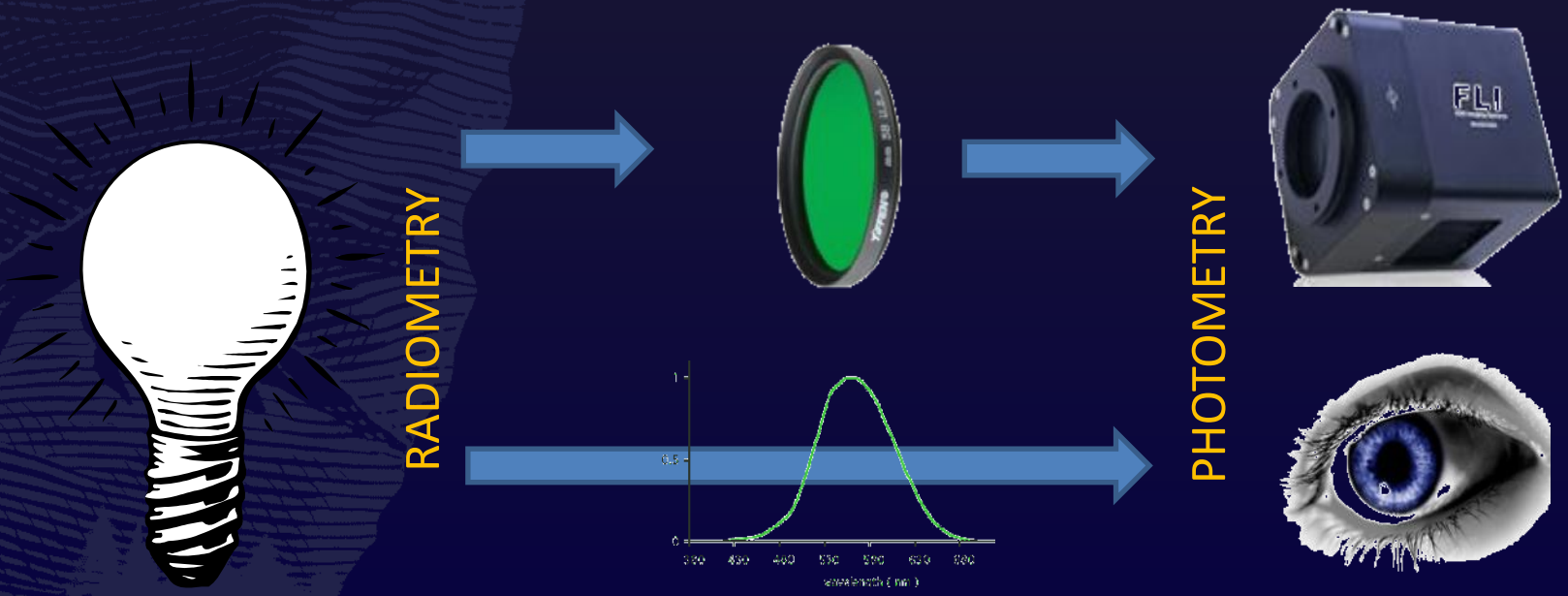
Vertical
0.3-0.7 mlux

All-sky
1.6 mlux

# Measuring the effects of outdoor lighting

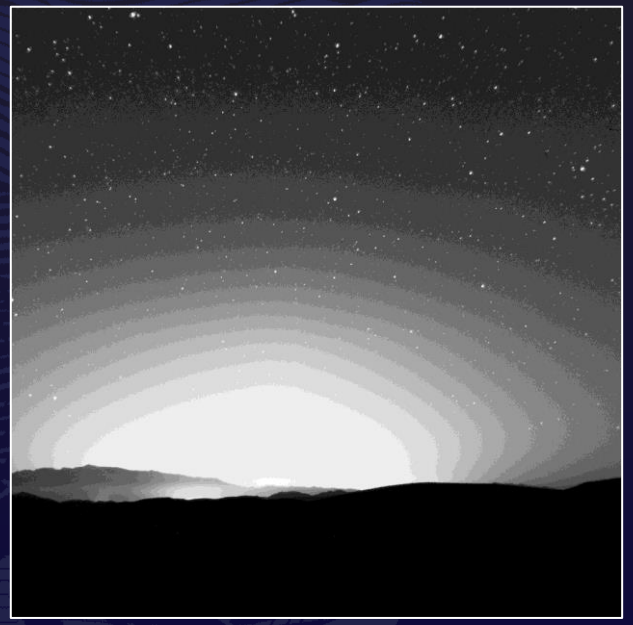
Quantify existing conditions

- In absolute units of radiance and irradiance
- In absolute units of luminance and illuminance
- Identify artificial sources
- In units relative to the natural reference condition



# Measuring sky glow as luminance and light trespass as illuminance


Sky glow (luminance)

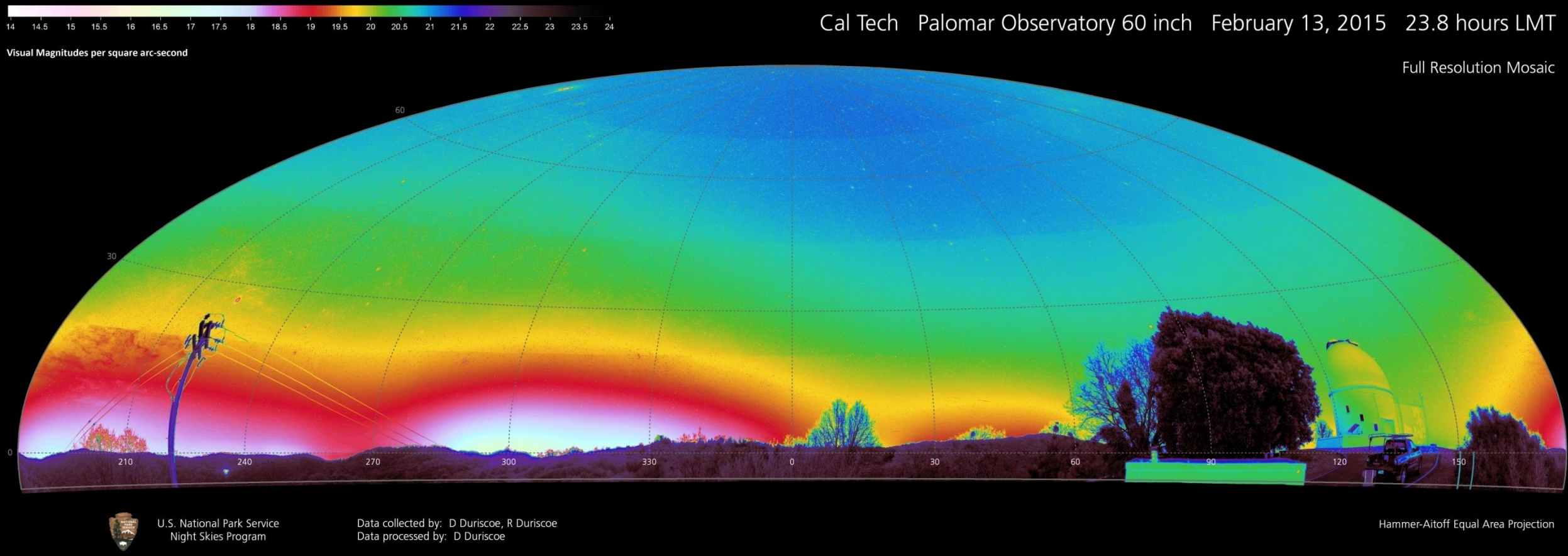



Center of bright light dome
Luminance = 10-100 mcd/$m^2$
Ratio to natural 60-600

Light trespass (illuminance)

Unshielded streetlamps
Illuminance = 0.5-50 mlux
Ratio to natural 5-500


# Calibrated monochrome CCD camera is accurate

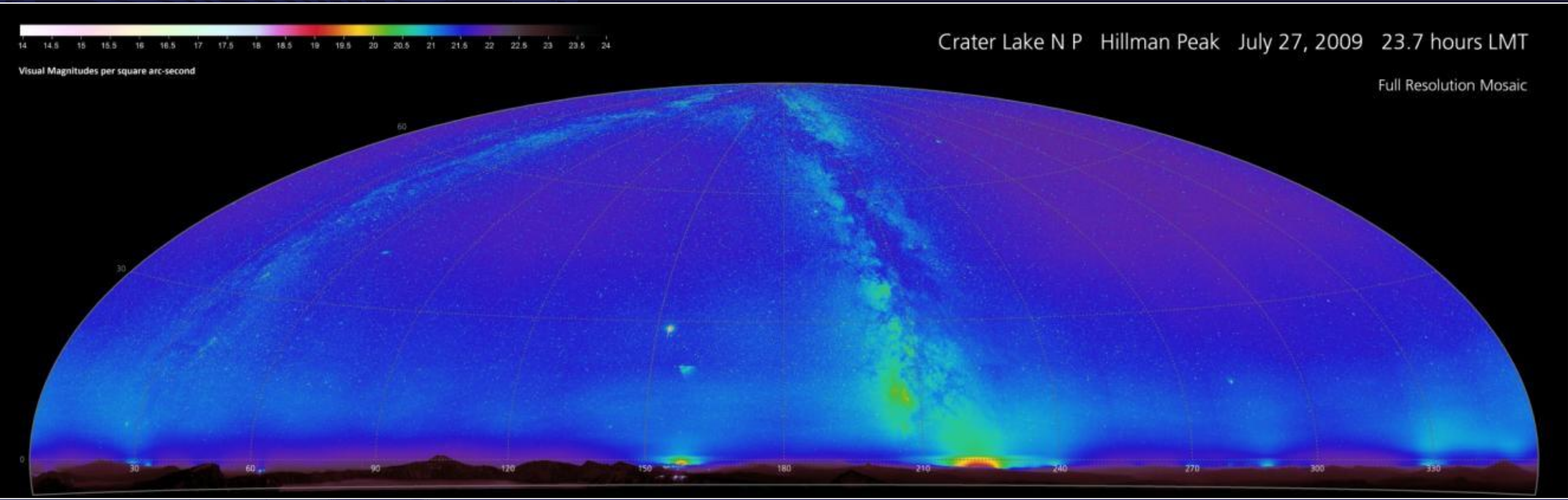



Ratio to Natural 1000 500 200 100 50 20 10 5 2 1 0.5

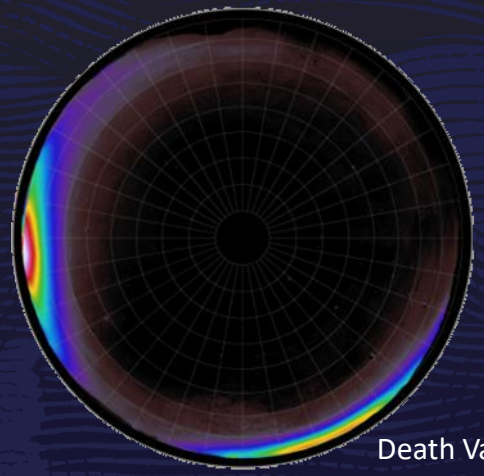
14 14.5 15 15.5 16 16.5 17 17.5 18 18.5 19 19.5 20 20.5 21 21.5 22 22.5 23 23.5 24

Visual Magnitudes per square arc-second

# Calibrated monochrome CCD camera is field portable

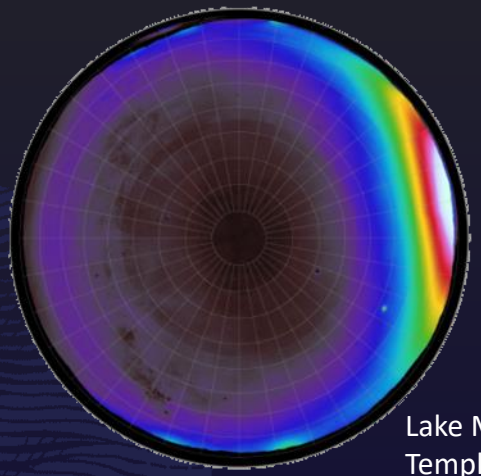


# All sky imagery allows calculation of indicators



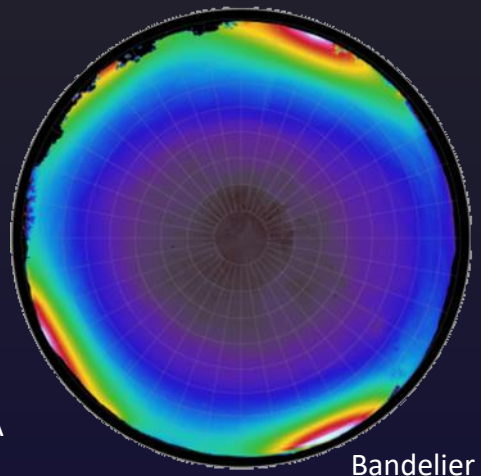
Death Valley N.P.

| zenith | average | maximum |
|---|---|---|
| 0.006 | 0.099 | 10.7 |



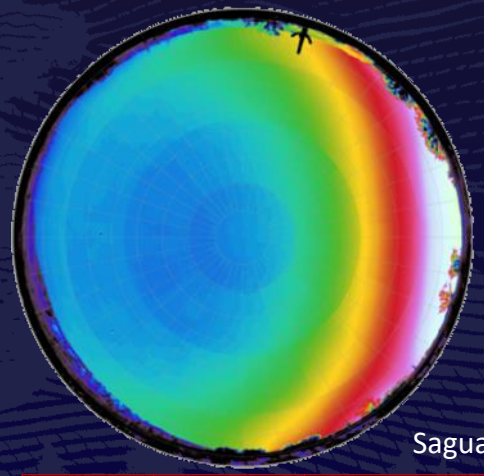
Lake Mead N.R.A
Temple Bar

| zenith | average | maximum |
|---|---|---|
| 0.054 | 0.331 | 22.7 |



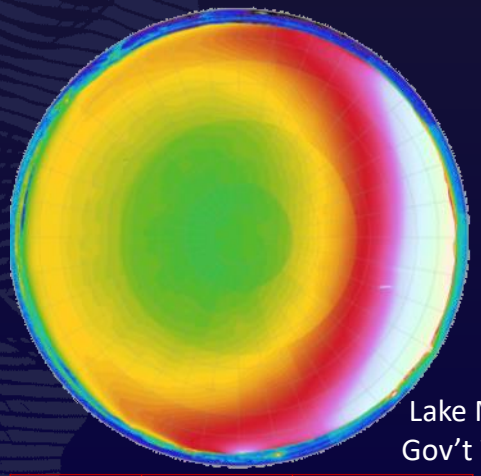
Bandelier N.M.

| zenith | average | maximum |
|---|---|---|
| 0.108 | 0.398 | 23.9 |



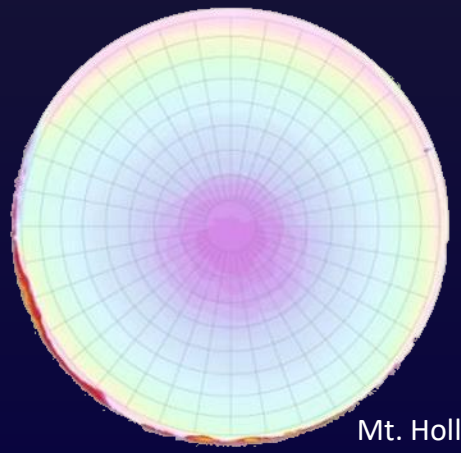
Saguaro N.P.

| zenith | average | maximum |
|---|---|---|
| 0.430 | 1.36 | 31.7 |



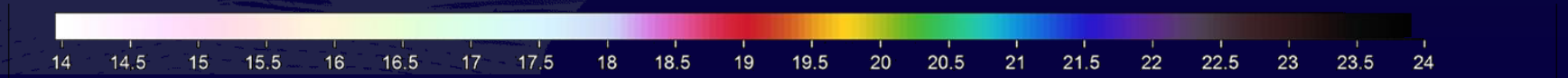
Lake Mead N.R.A
Gov't Wash

| zenith | average | maximum |
|---|---|---|
| 0.853 | 3.17 | 62.8 |



Mt. Hollywood

| zenith | average | maximum |
|---|---|---|
| 5.37 | 20.1 | 123 |

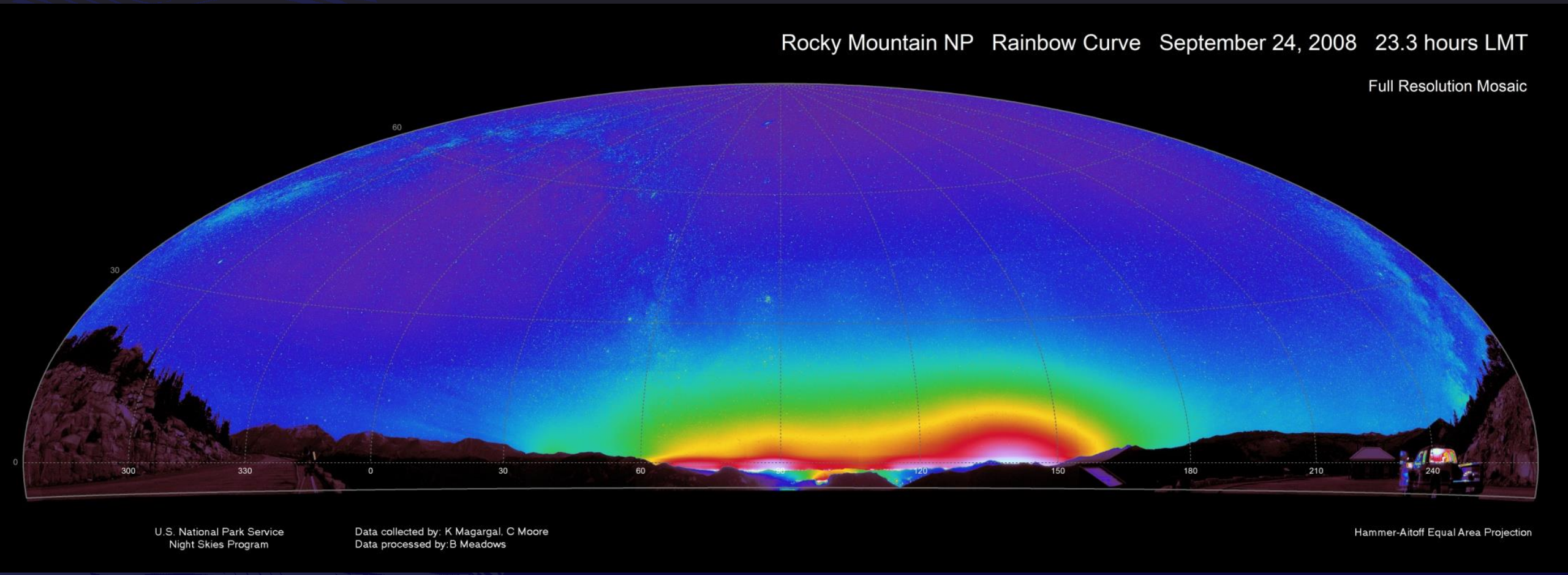



Anthropogenic sky luminance (mcd $m^{-2}$)

| zenith | average | maximum |
|---|---|---|


Duriscoe, Dan M. "Photometric indicators of visual night sky quality derived from all-sky brightness maps." *Journal of Quantitative Spectroscopy and Radiative Transfer* 181 (2016): 33-45.

# Observations – distant cities from a protected area



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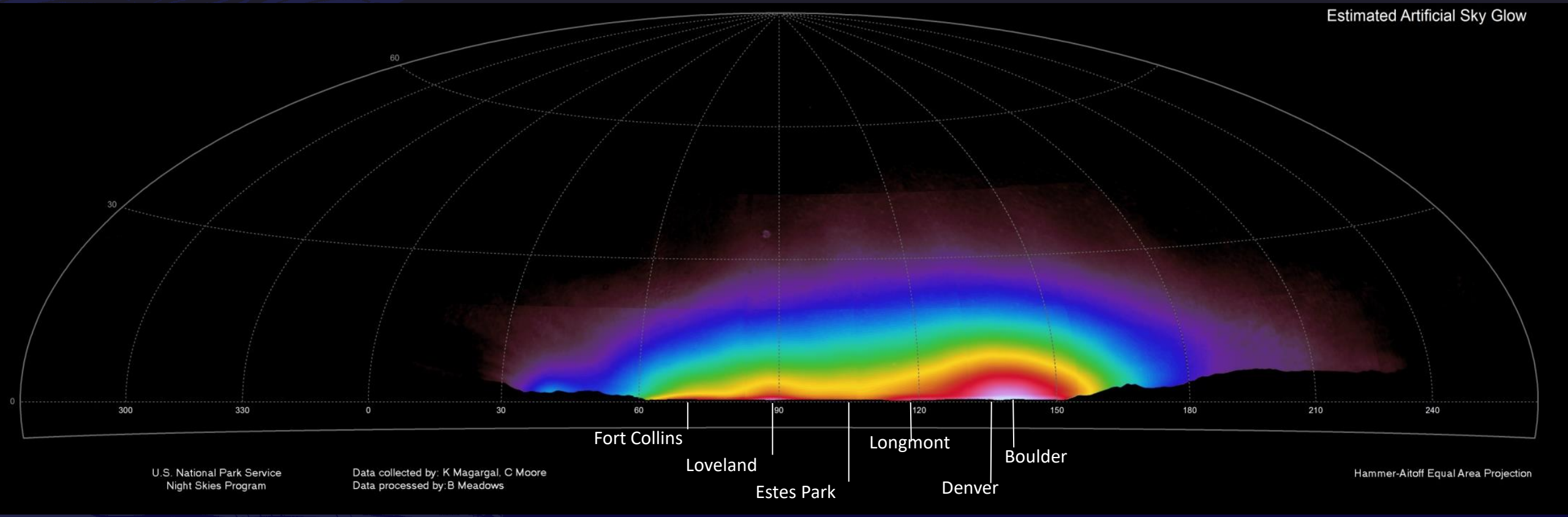
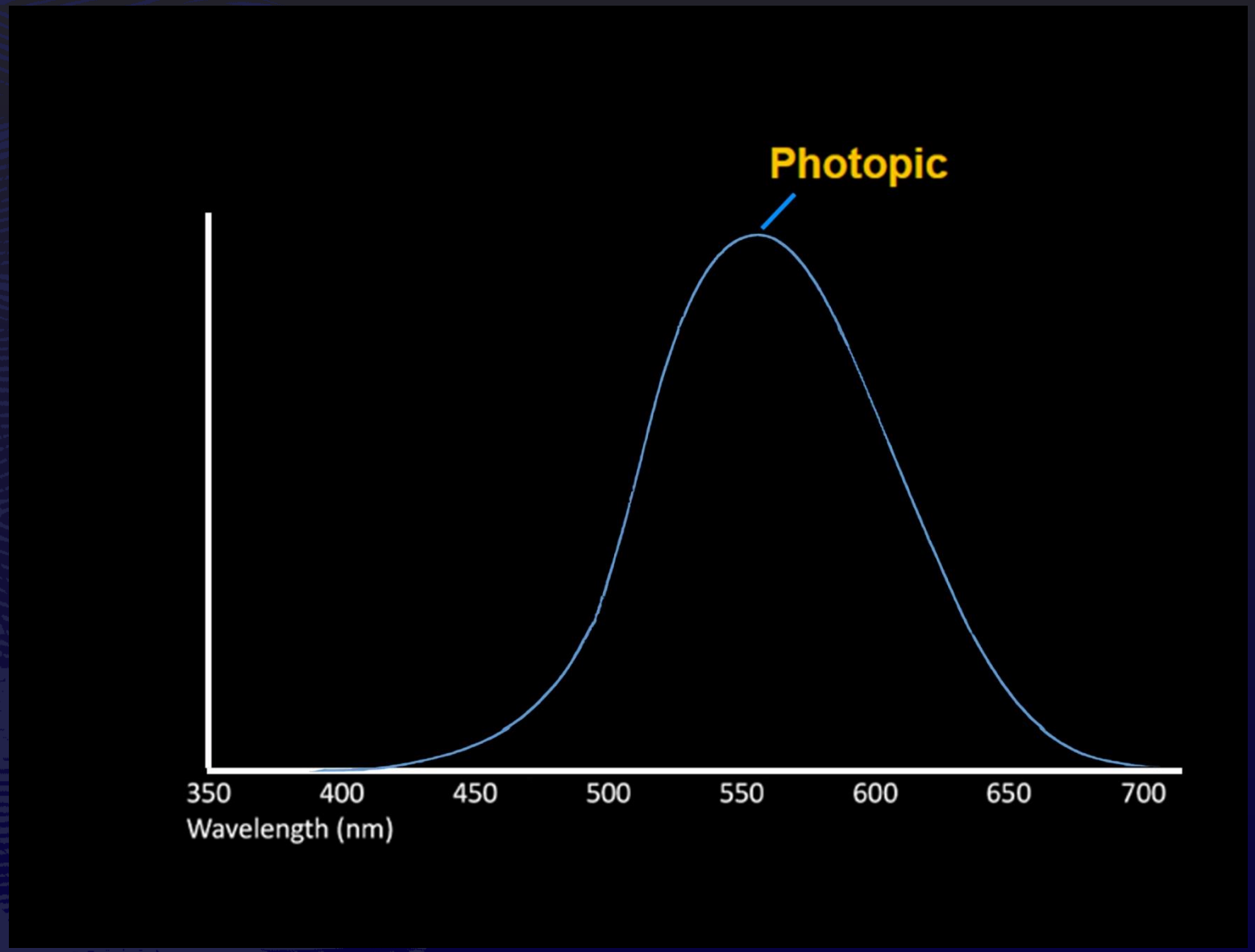


# Calibrated monochrome CCD camera accepts filters

for broadband photometry in different systems

# Spectral Bands, natural sky spectrum, and lighting



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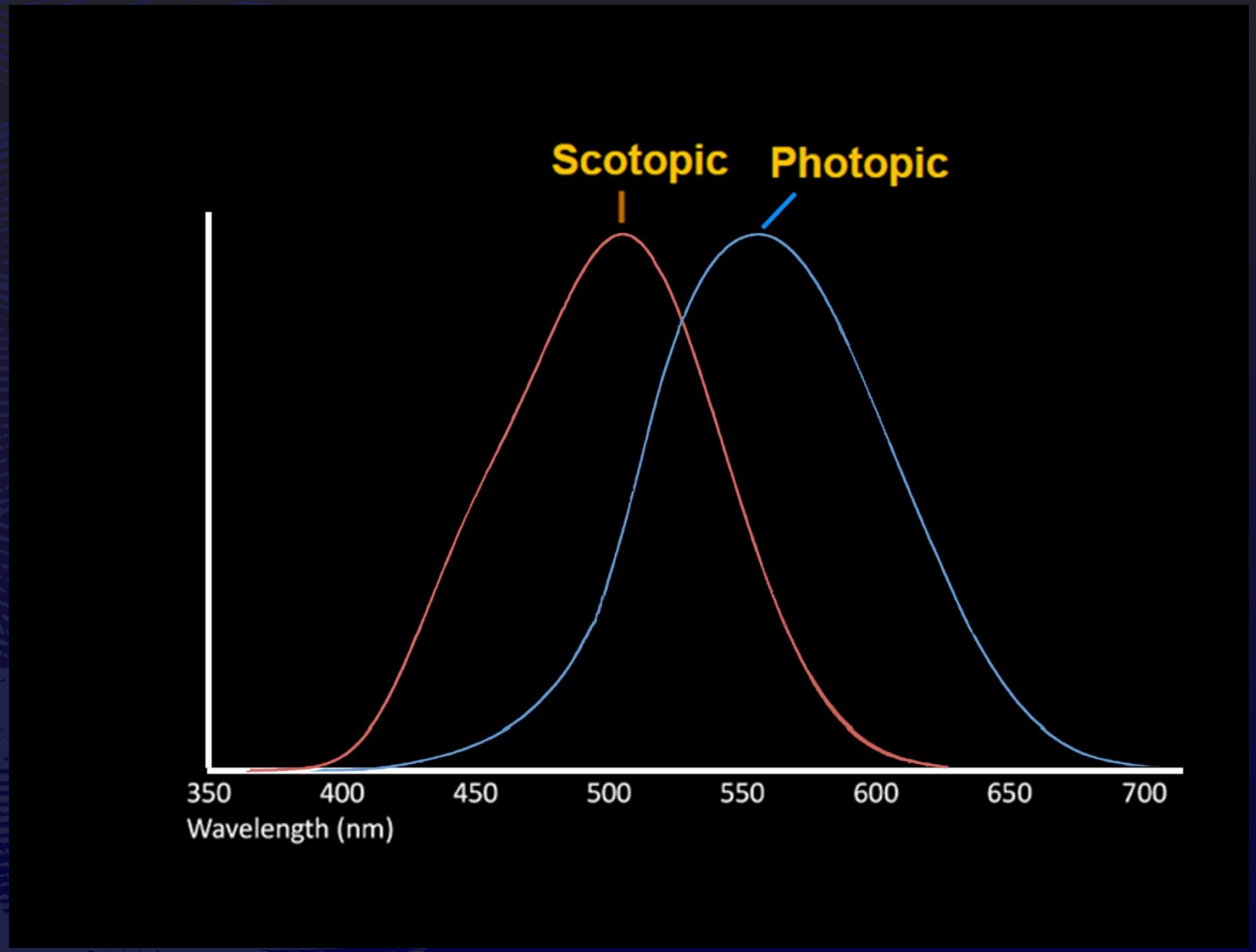

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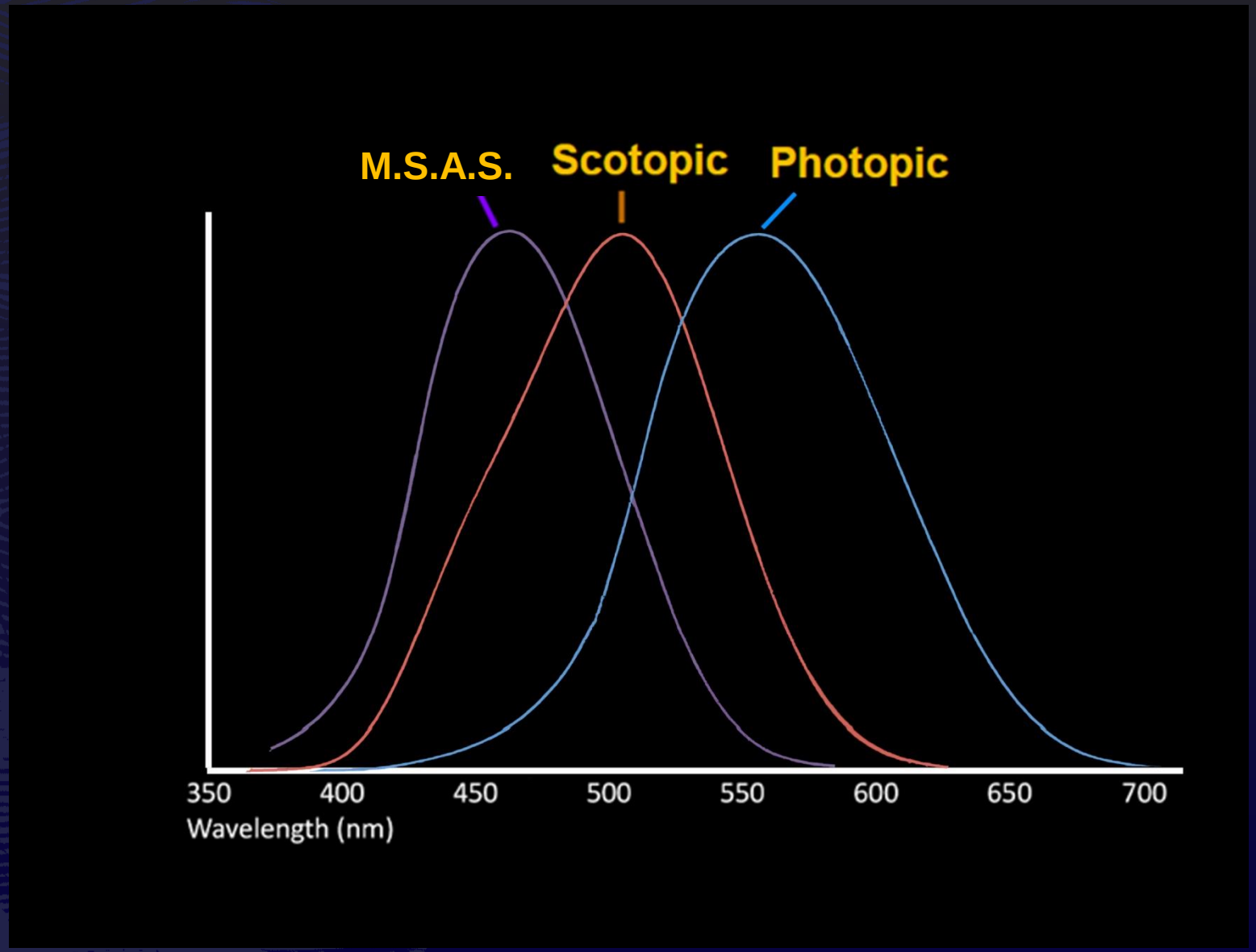

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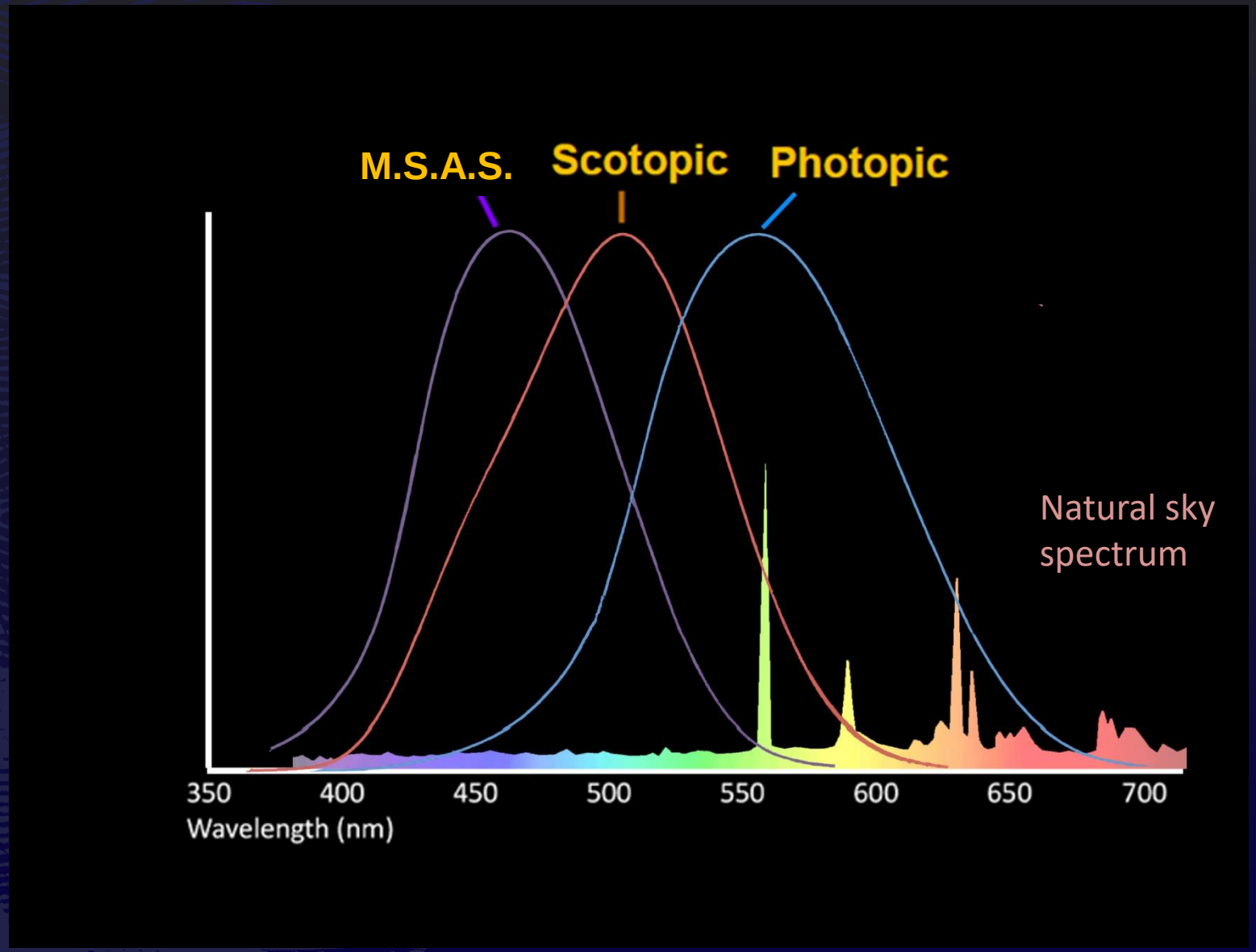

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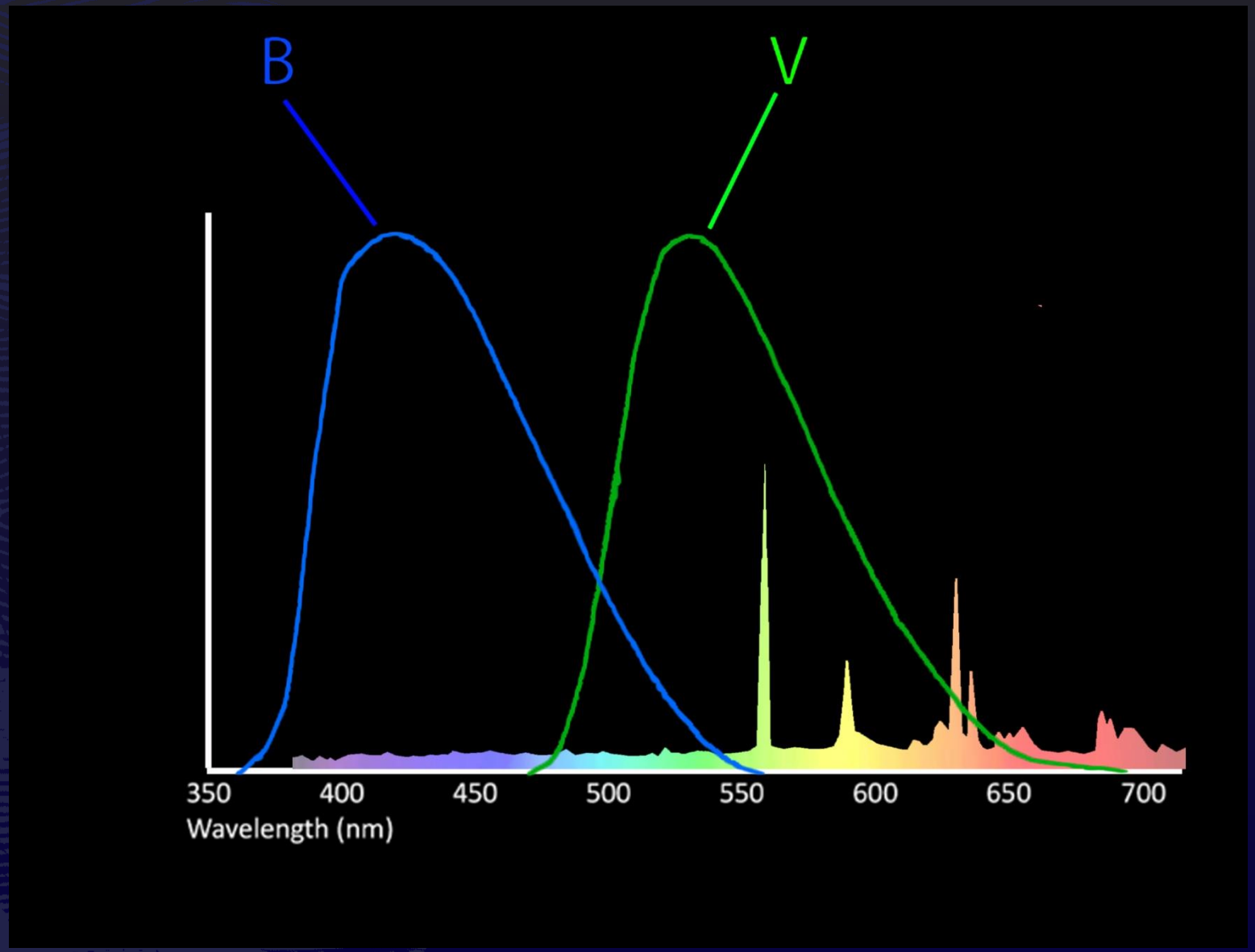

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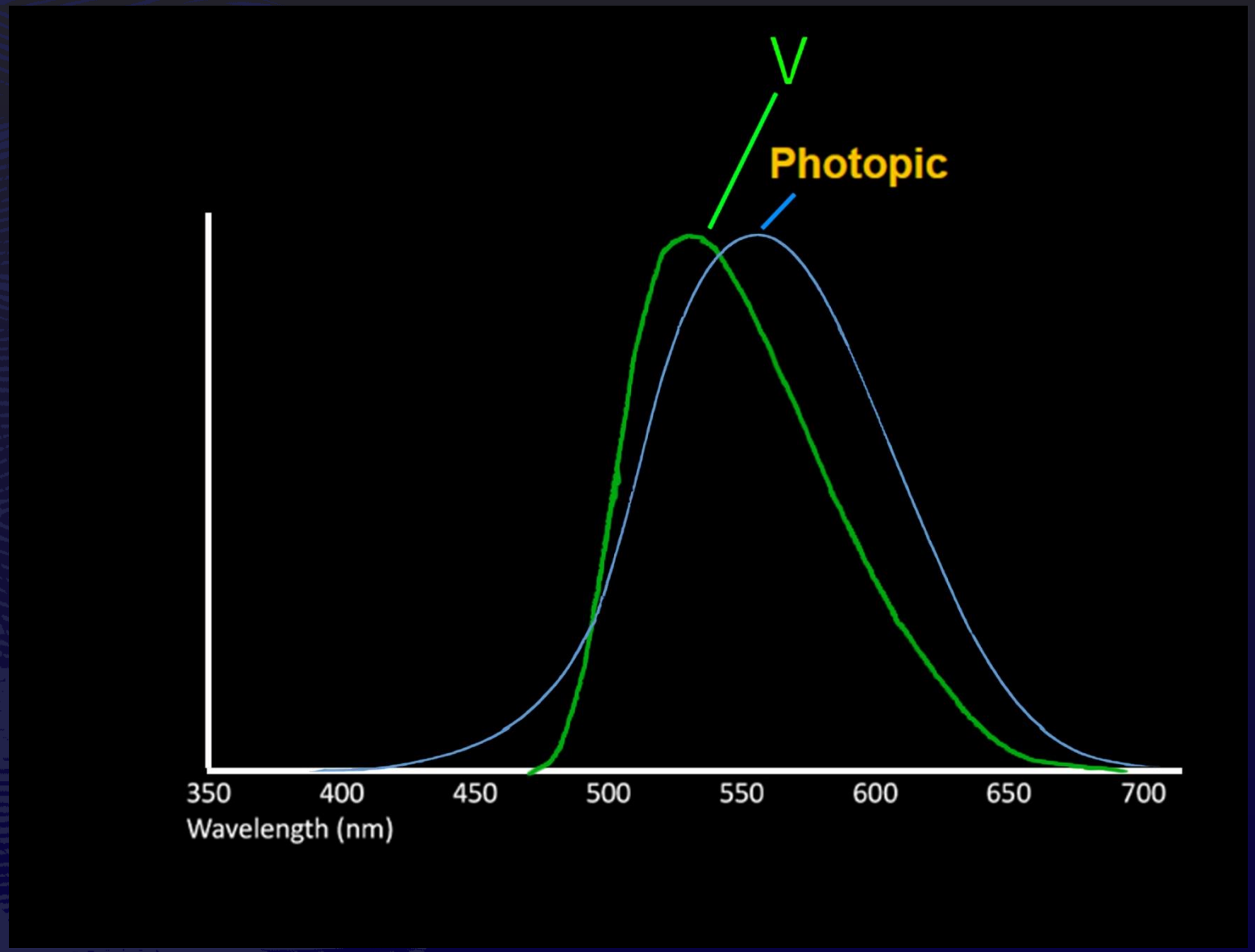
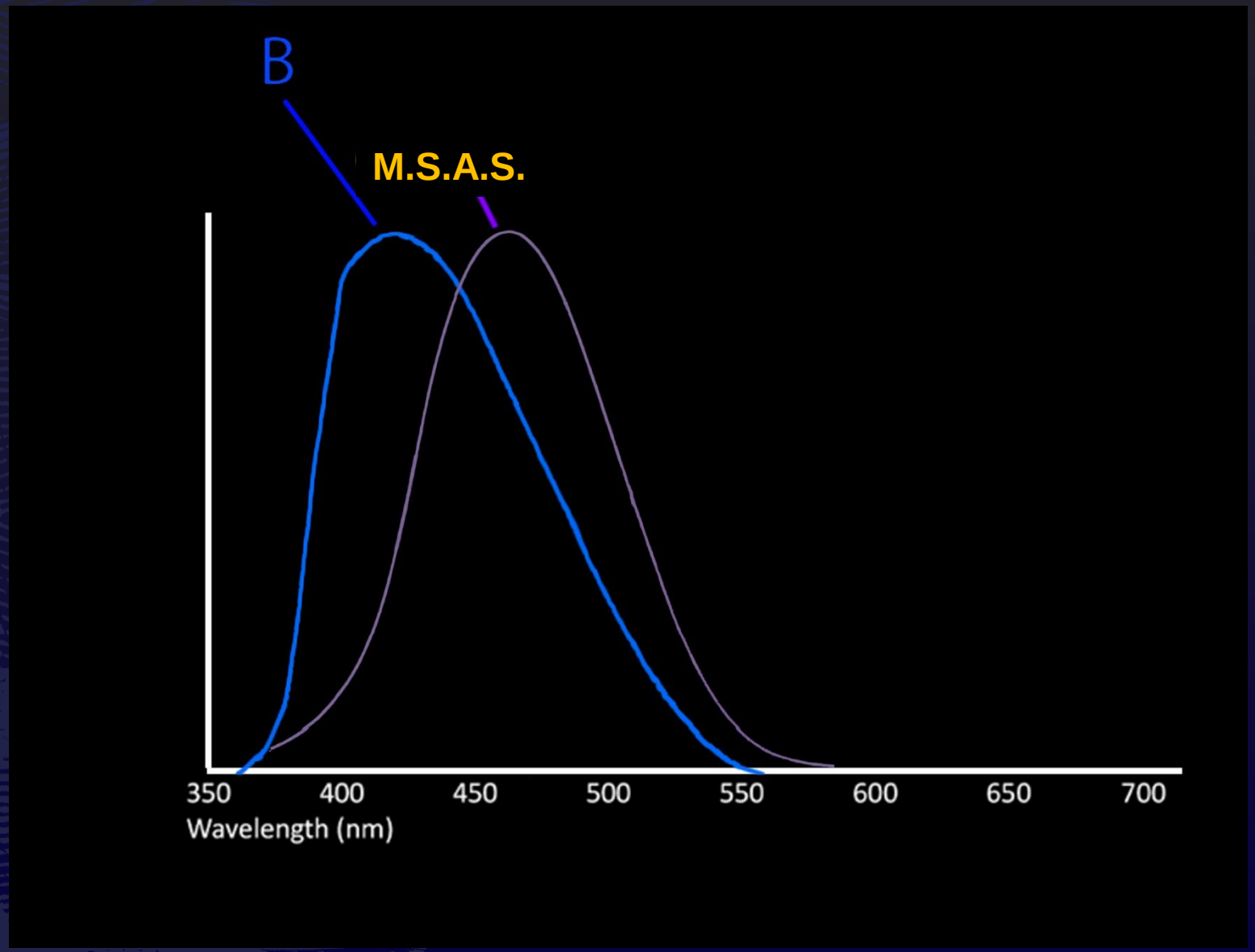


# Spectral Bands, natural sky spectrum, and lighting



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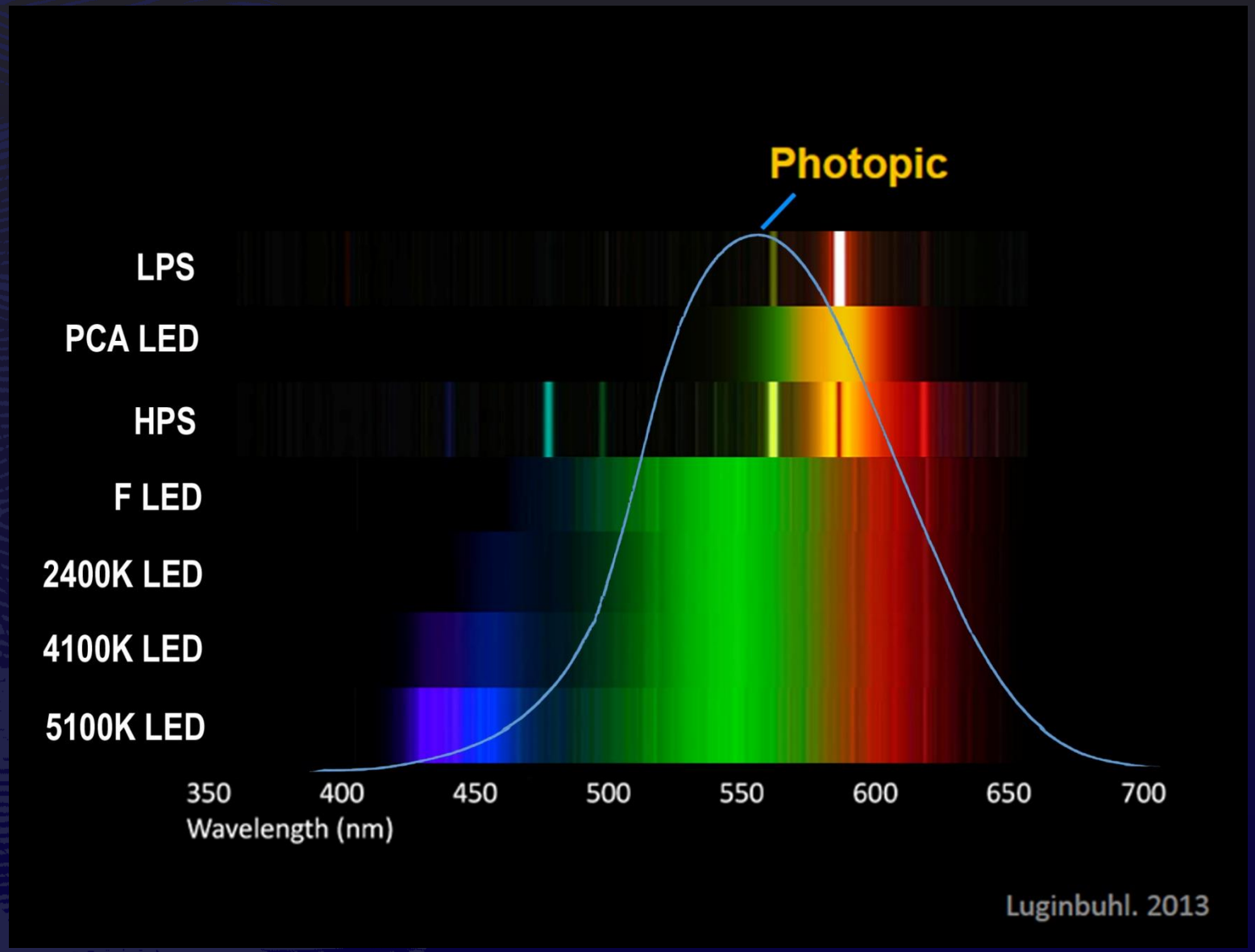
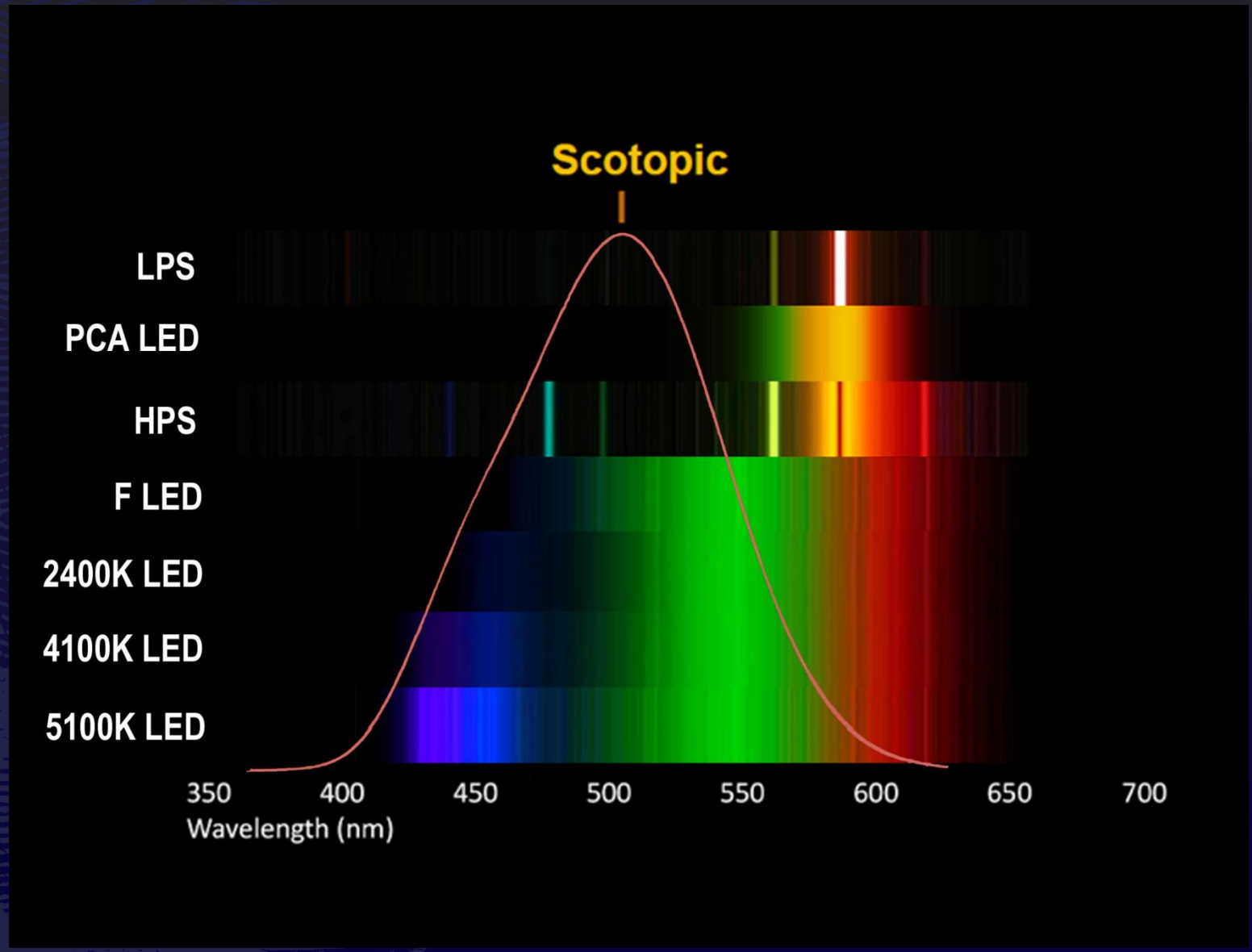


# Spectral Bands, natural sky spectrum, and lighting



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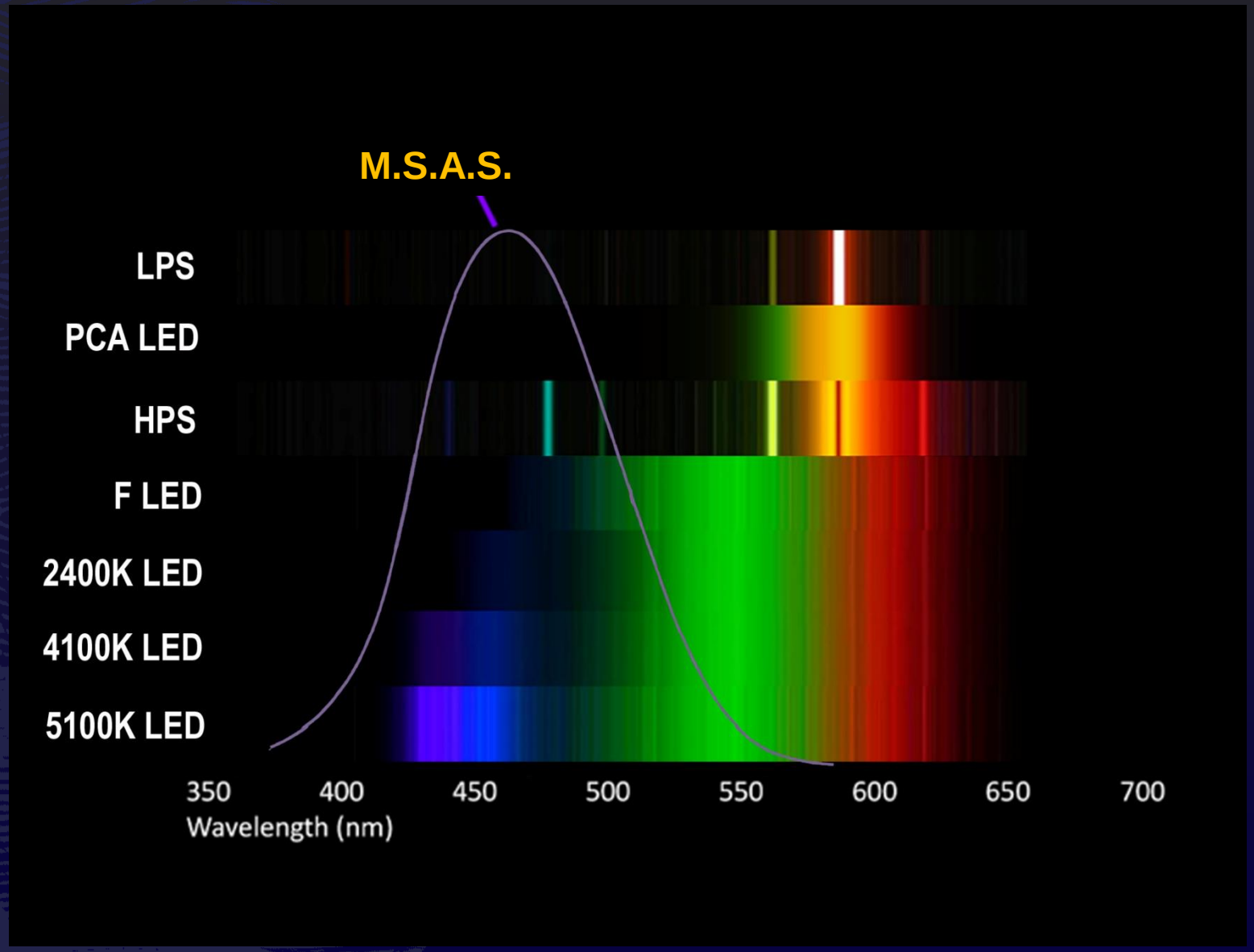
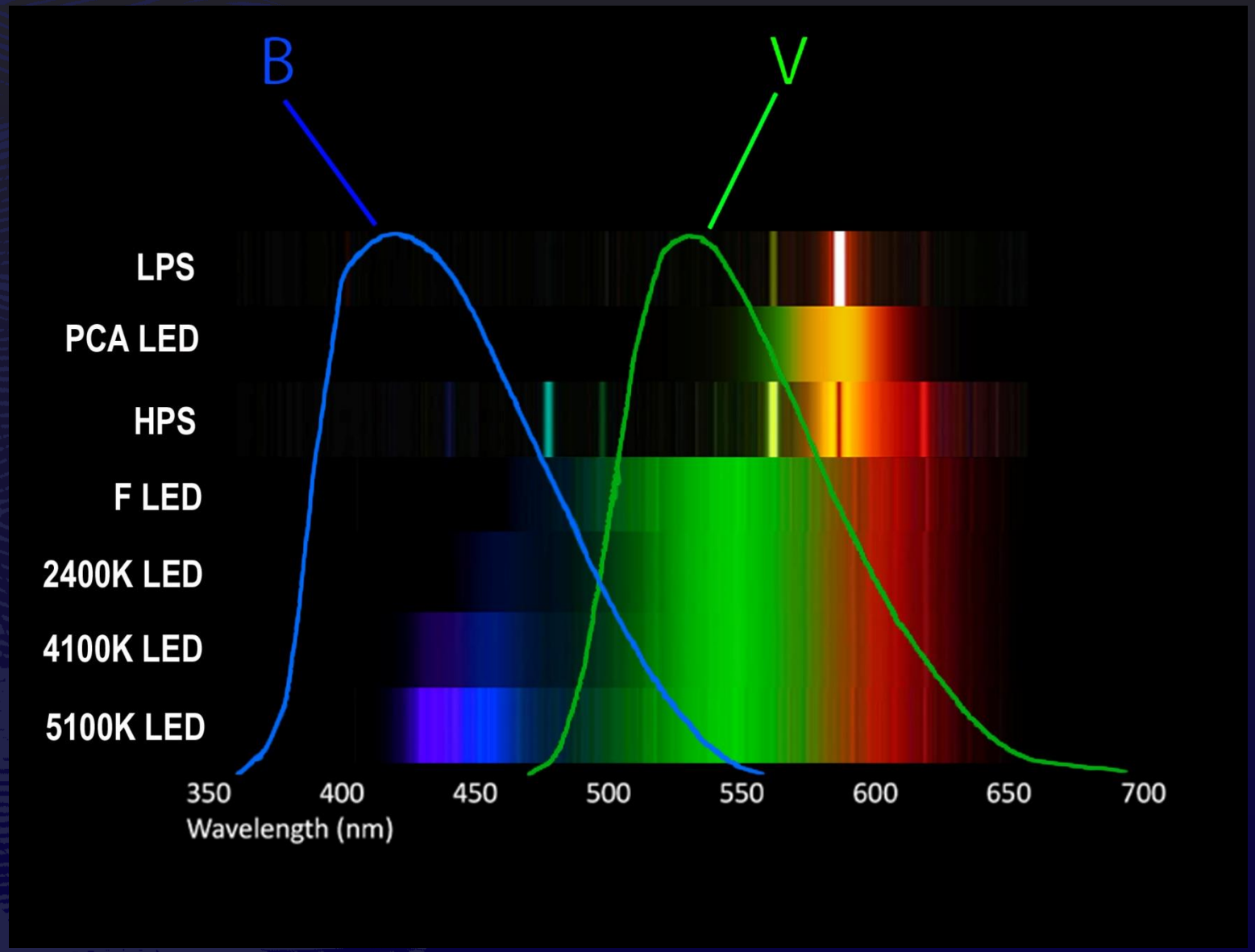
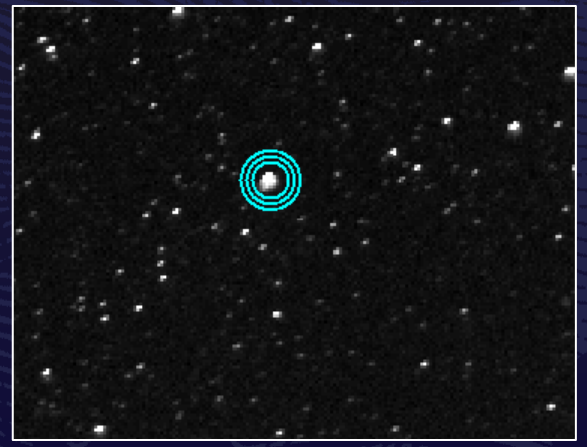


# Spectral Bands, natural sky spectrum, and lighting

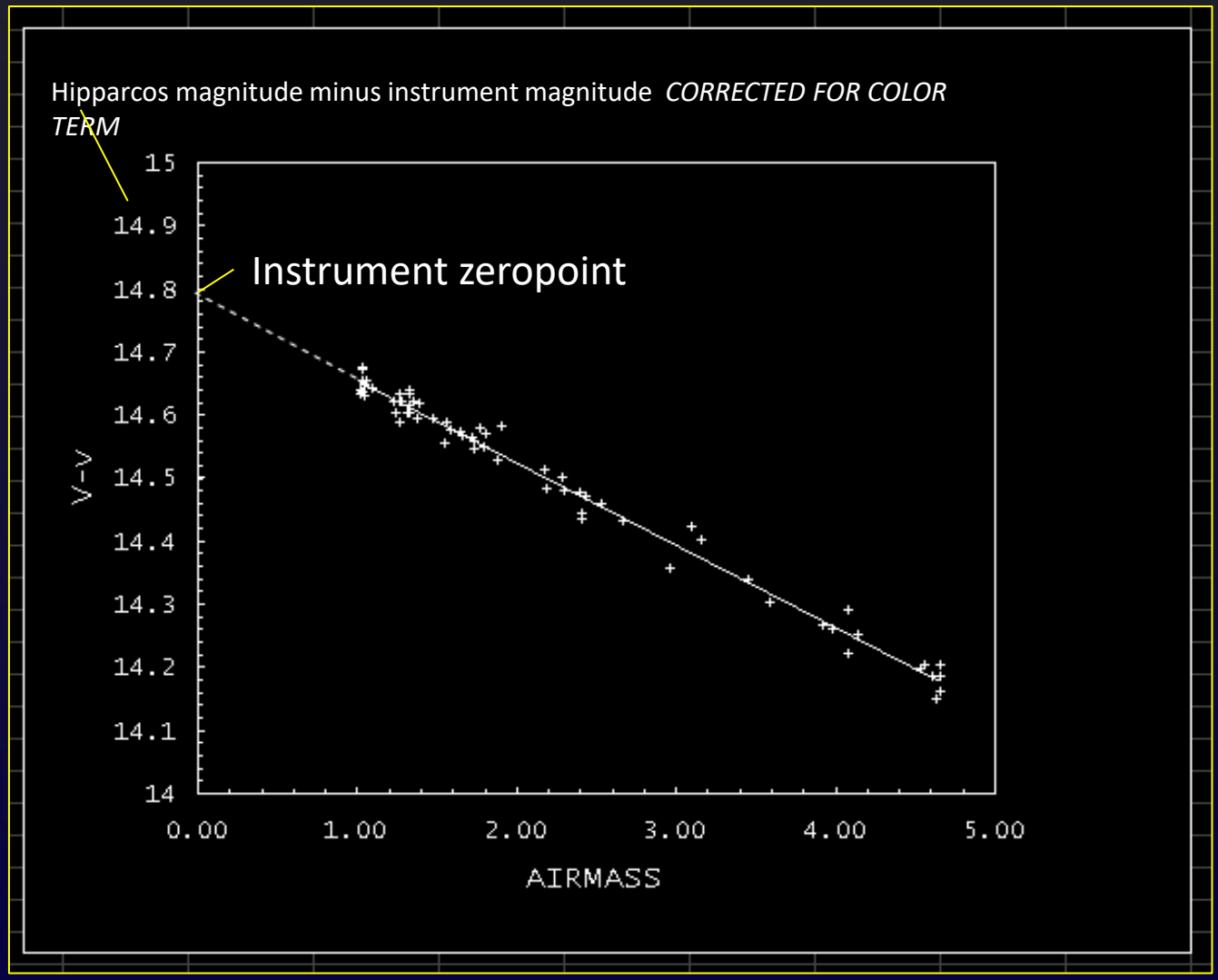


# Calibration with stars (astronomical methods) reliably produces accurate sky background brightness data

Synthetic aperture photometry of standard stars



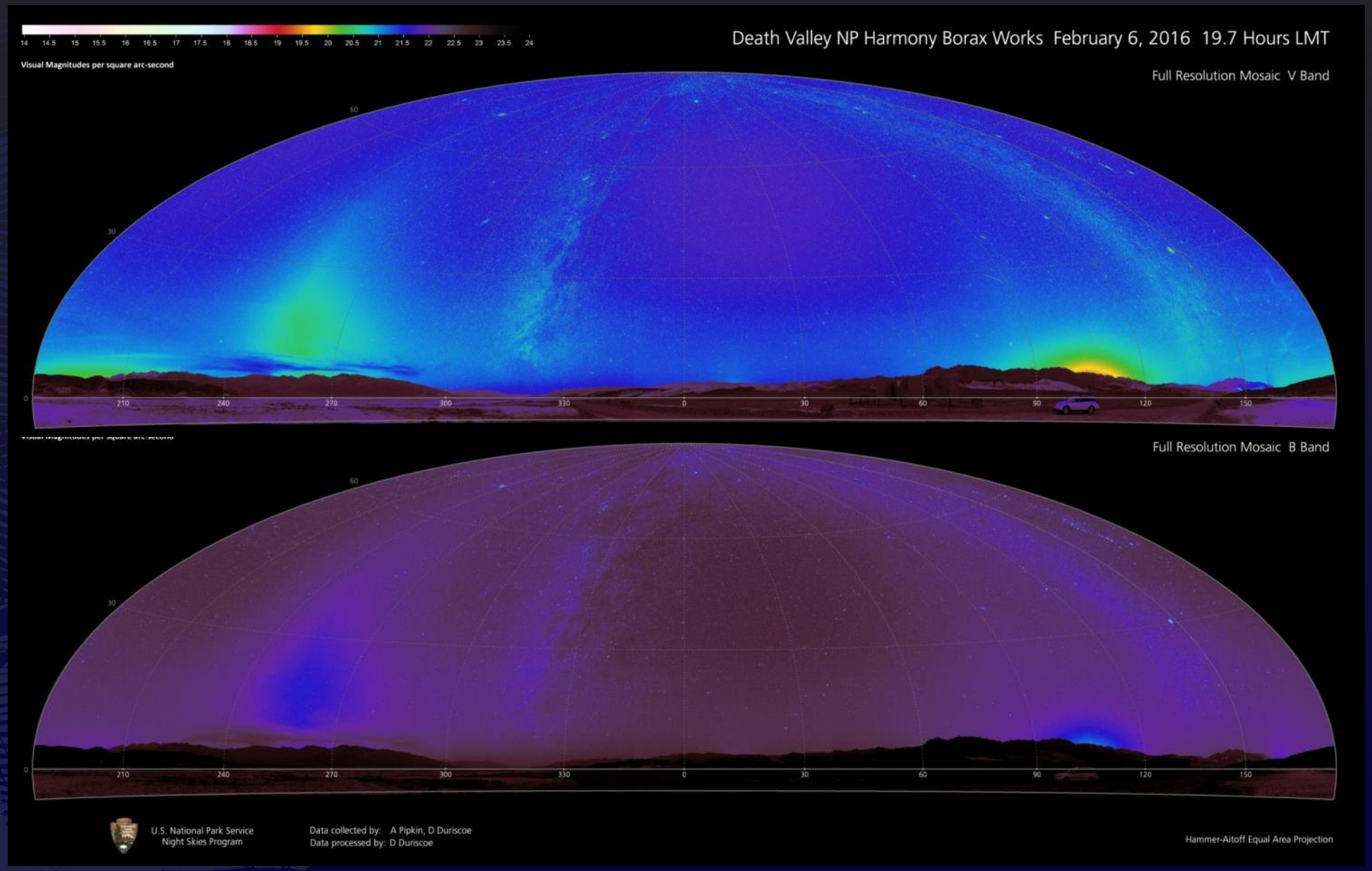
Duriscoe, Dan M., Christian B. Luginbuhl, and Chadwick A. Moore. "Measuring night-sky brightness with a wide-field CCD camera." *Publications of the Astronomical Society of the Pacific* 119.852 (2007): 192.



# Observations – A nearly natural night sky

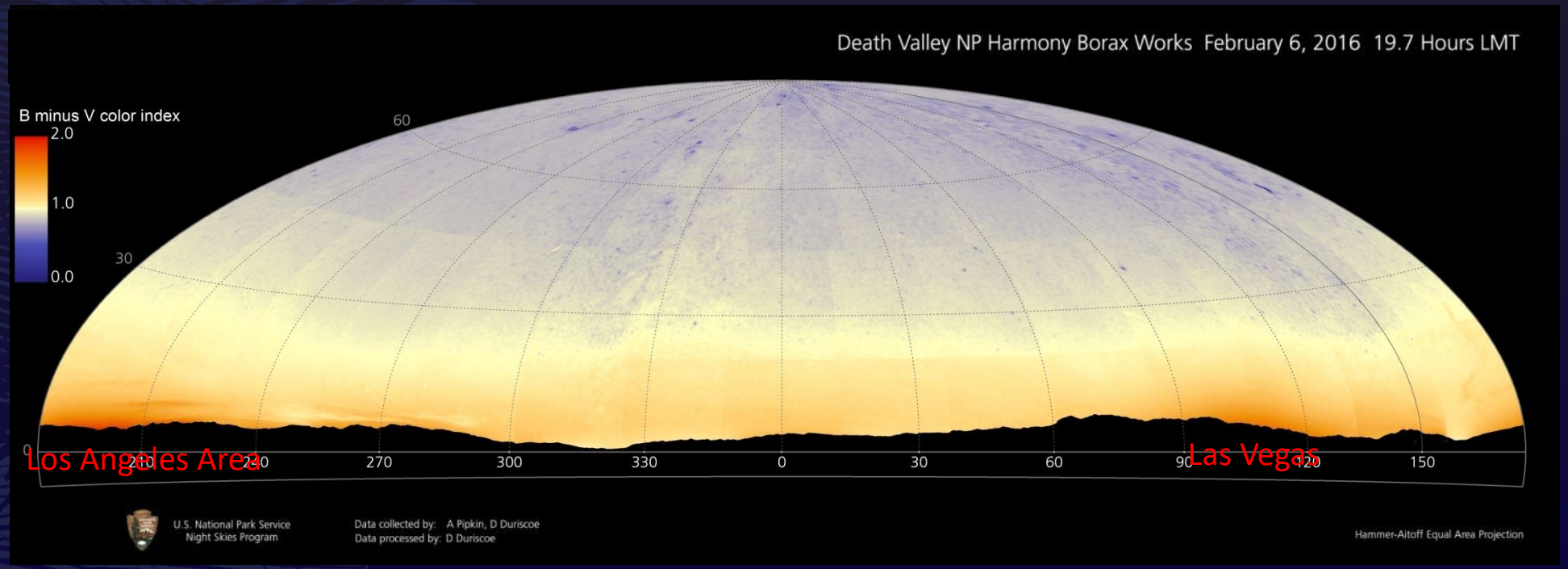
V

B



# Observations – a nearly natural night sky

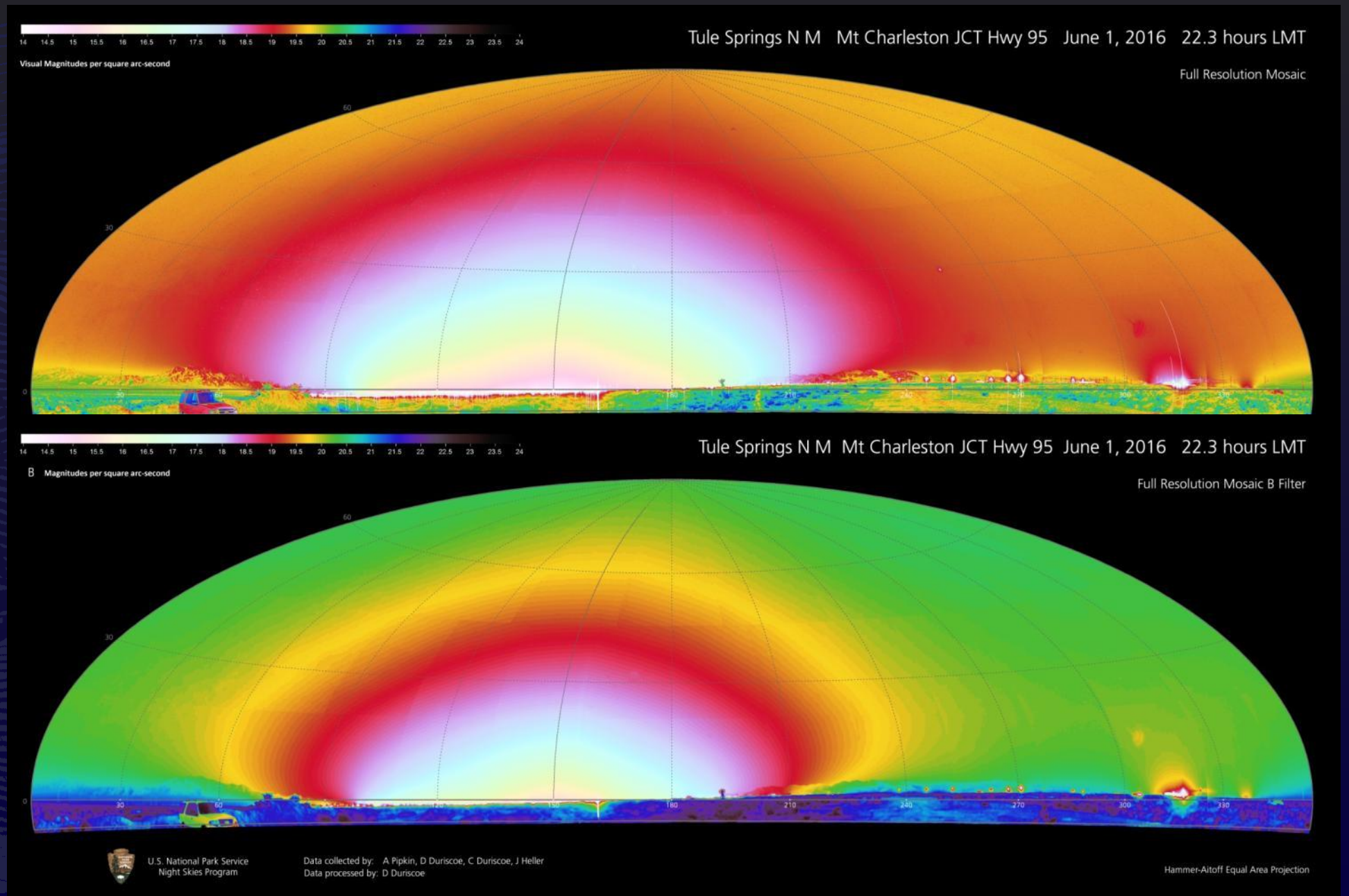
The B minus V color index is a standard method in astronomy to describe the colors of stars. It is similar to scotopic/photopic ratio (B-V in logarithmic units, S/P in linear units)



# Observations – just outside a large metro area

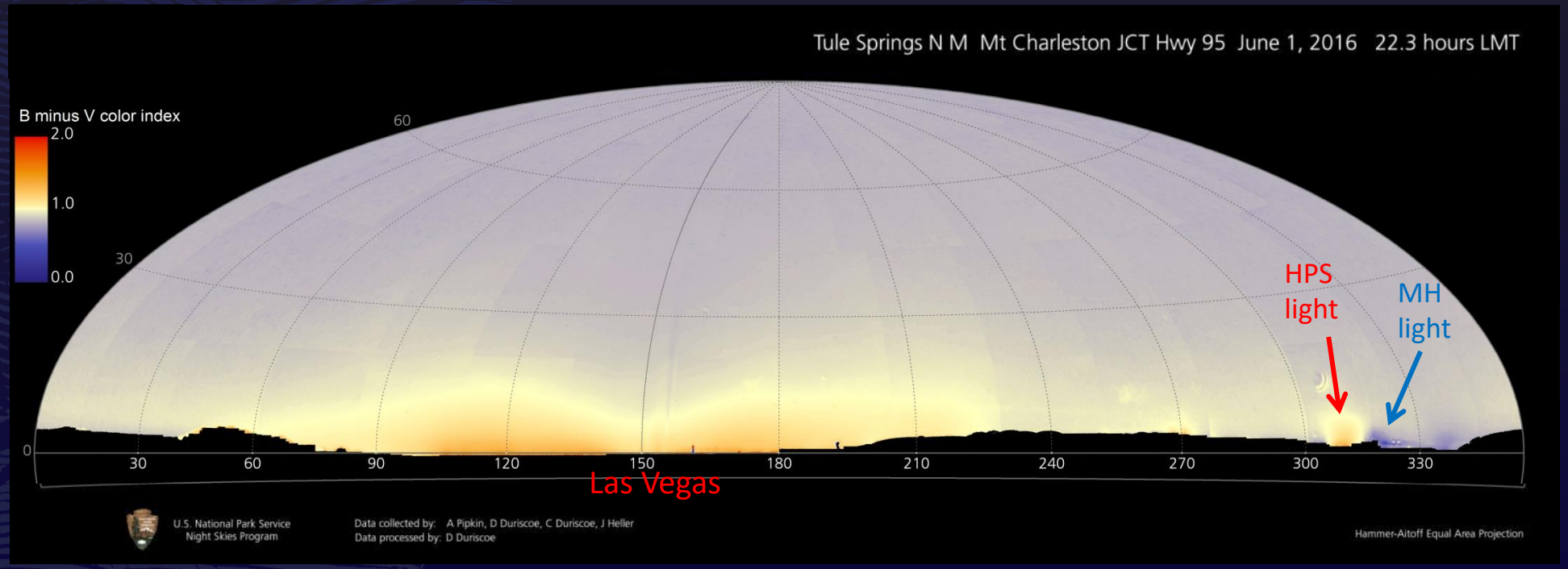
V

B

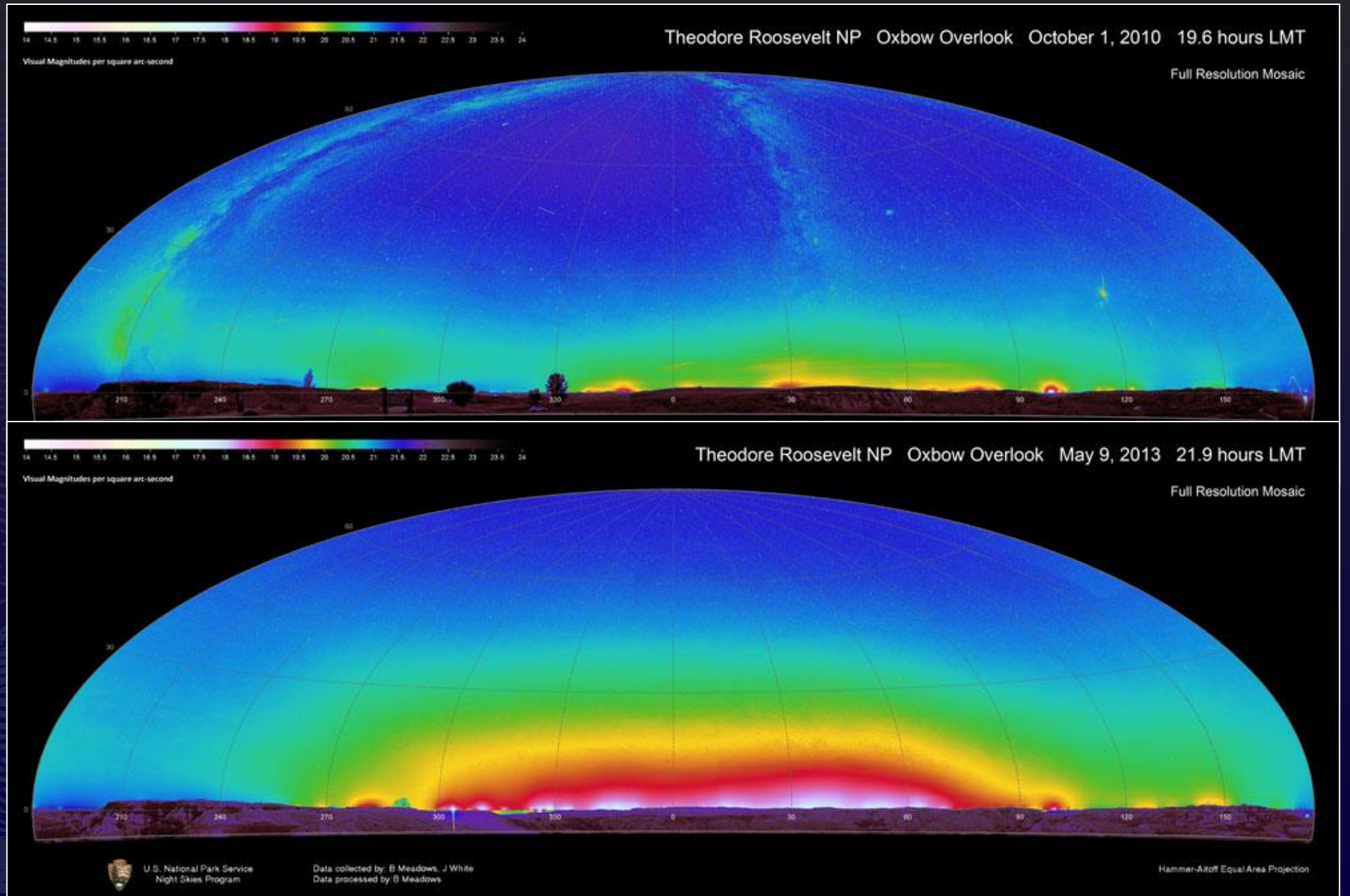


# Observations – just outside a large metro area

The color of sky glow from large cities may be changing. Notice the blue "dip" near the center of Las Vegas.



# Observations – change over time



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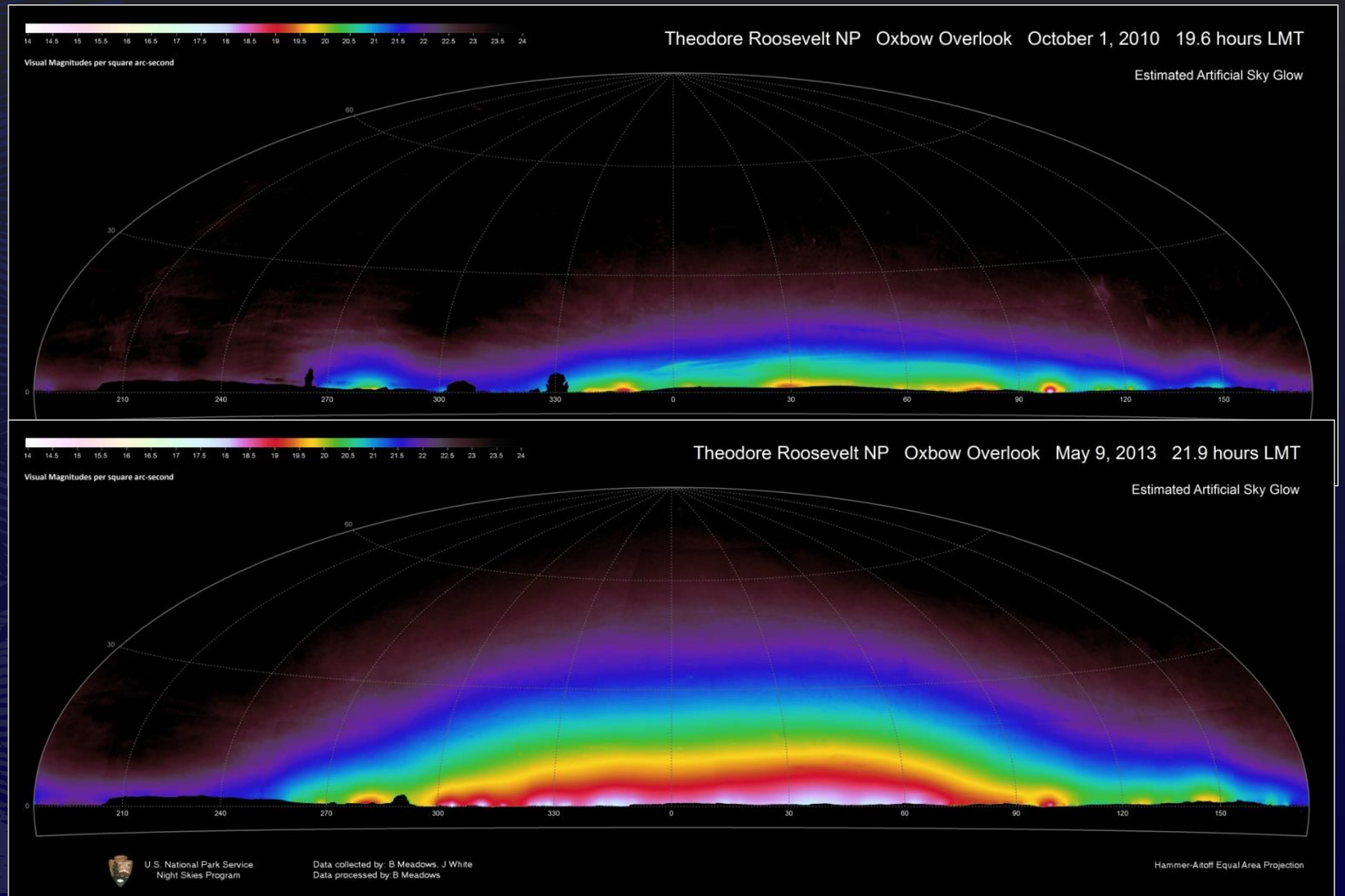
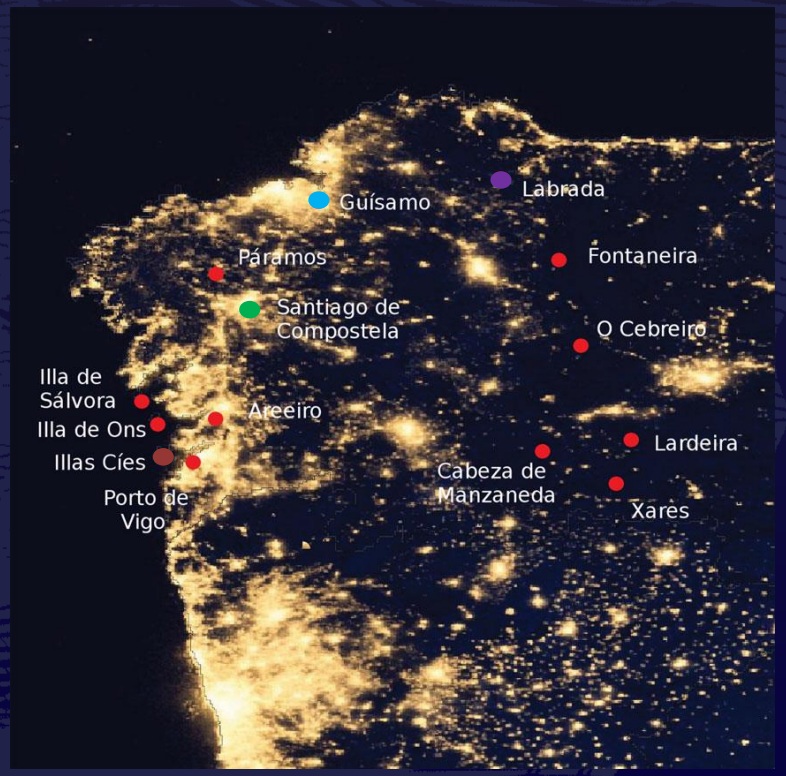


# Long Term Monitoring Example

A regional (northwest Iberian peninsula) monitoring network of single-channel photometers measuring zenith sky brightness every minute



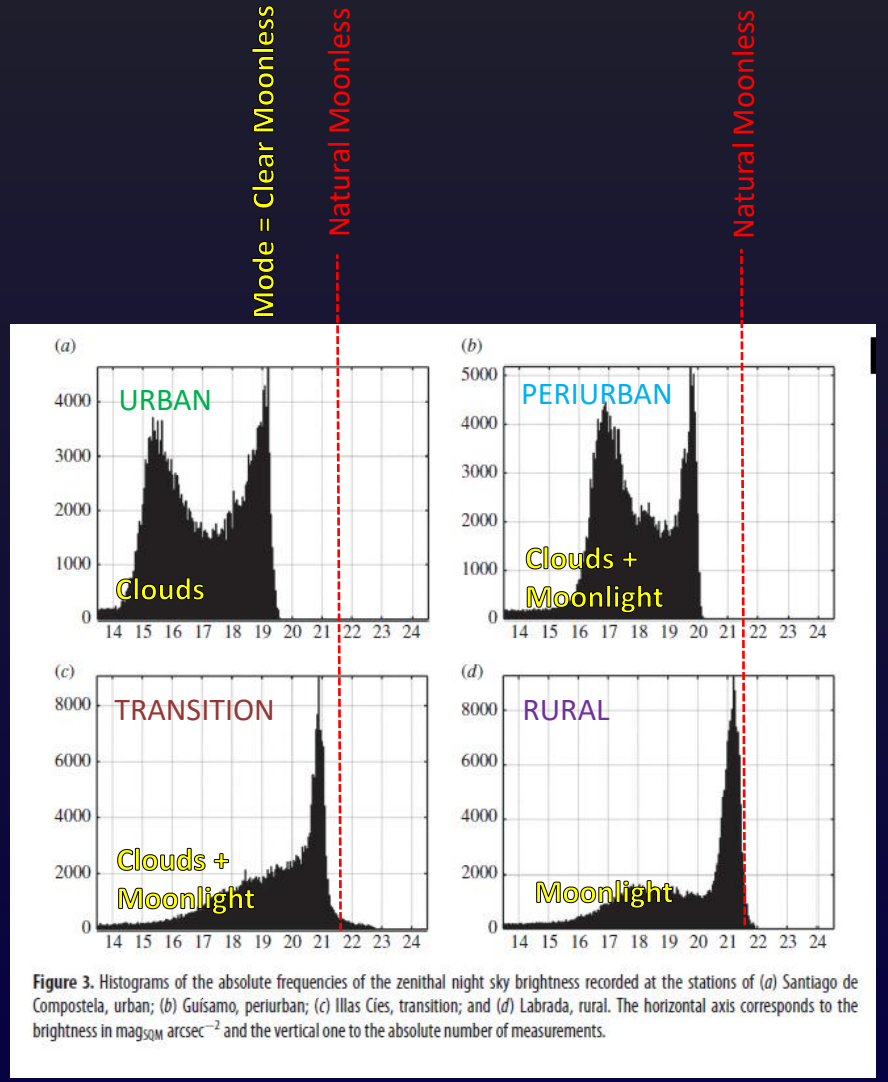




**Figure 3.** Histograms of the absolute frequencies of the zenithal night sky brightness recorded at the stations of (*a*) Santiago de Compostela, urban; (*b*) Guísamo, periurban; (*c*) Illas Cíes, transition; and (*d*) Labrada, rural. The horizontal axis corresponds to the brightness in $mag_{SQM}$ $arcsec^{-2}$ and the vertical one to the absolute number of measurements.

Bará S. 2016 Anthropogenic disruption of the night sky darkness in urban and rural areas. R. Soc. open sci. 3: 160541. http://dx.doi.org/10.1098/rsos.160541

# Cameras --modern digital RGB cameras

Provide a quantitative and qualitative measure, may be calibrated (green channel) in luminance units

# Anti-blooming technology clips bright sources – loss of calibration unless HDR stack is used

Natural night sky imaged with monochrome CCD camera, 45 image mosaic

RGB image of Page, Arizona, industrial developments have many unshielded lights

# Artificial and natural sources have many different colors

# Use caution in interpreting color images

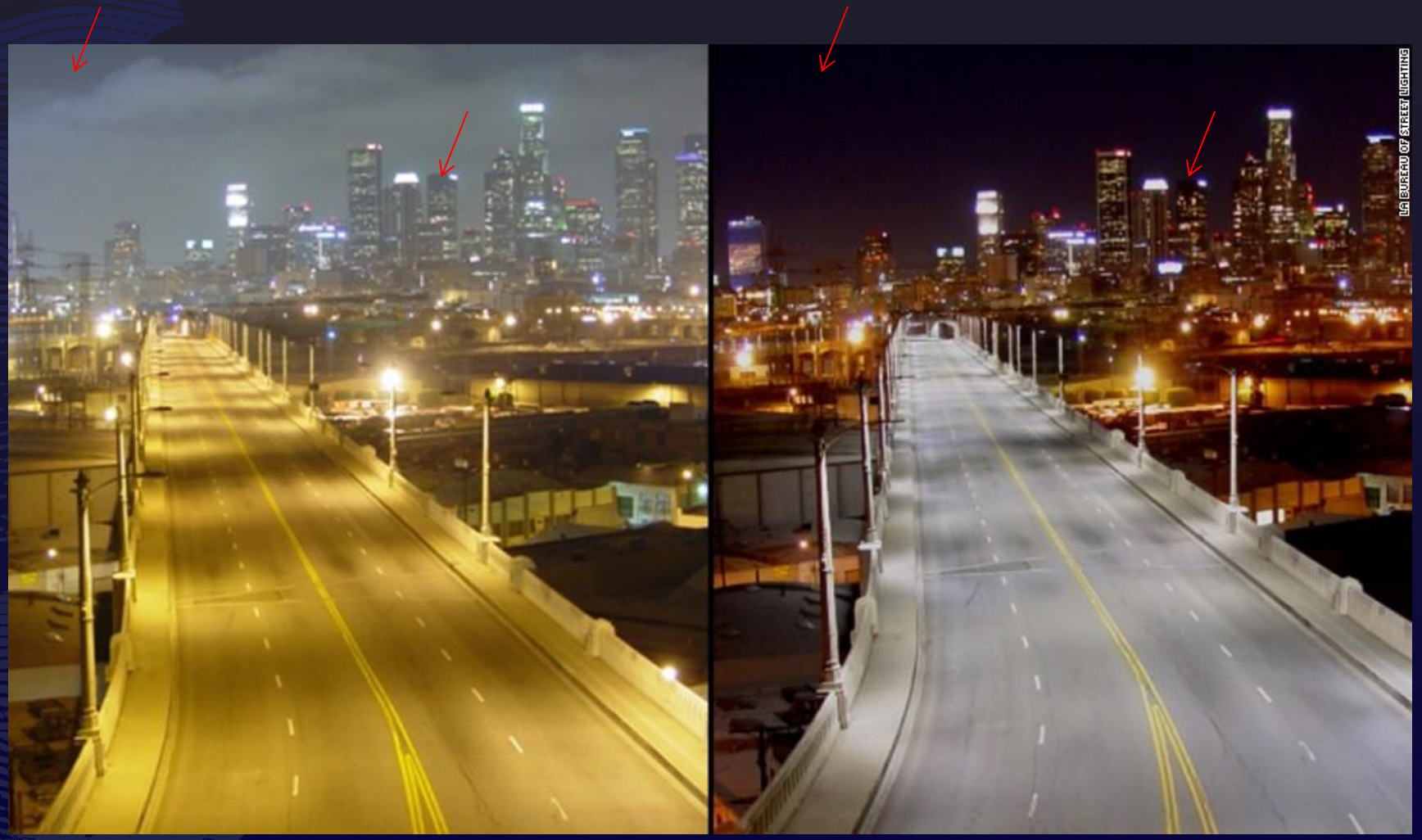
Dynamic range stretch and color enhancement

A linear stretch of the full dynamic range of an image is usually the most realistic

# The dark-adapted human eye does not see color

# Use caution in interpreting color images

Weather and atmospheric conditions , setting of black point




IF the same camera, exposure, ISO, and f/stop are used AND the results are show with the same dynamic range stretch and black set point

The effect of human vision must be considered. The dark adapted eye is more sensitive to blue and green, and the rods have a higher “gain”.

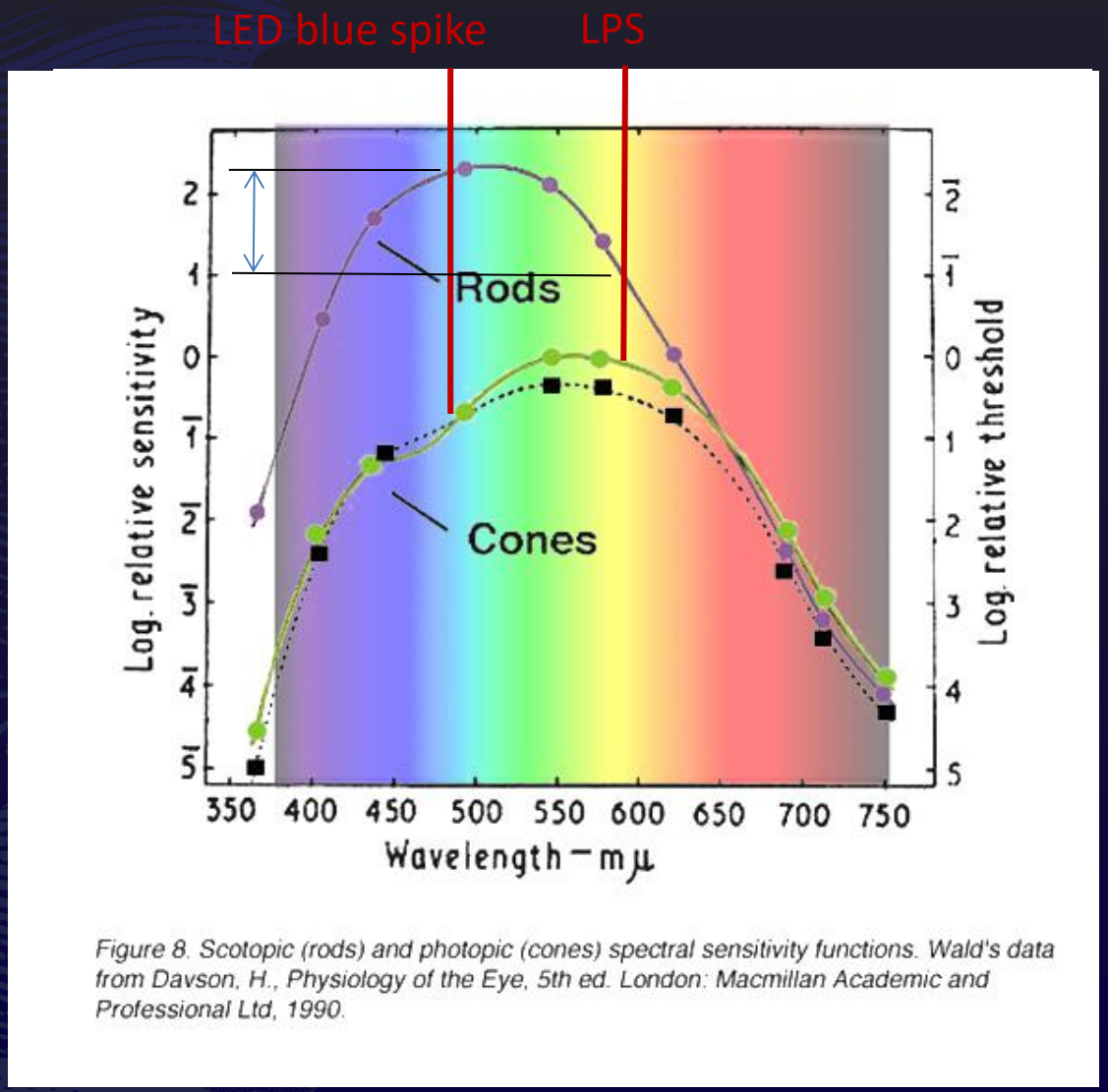
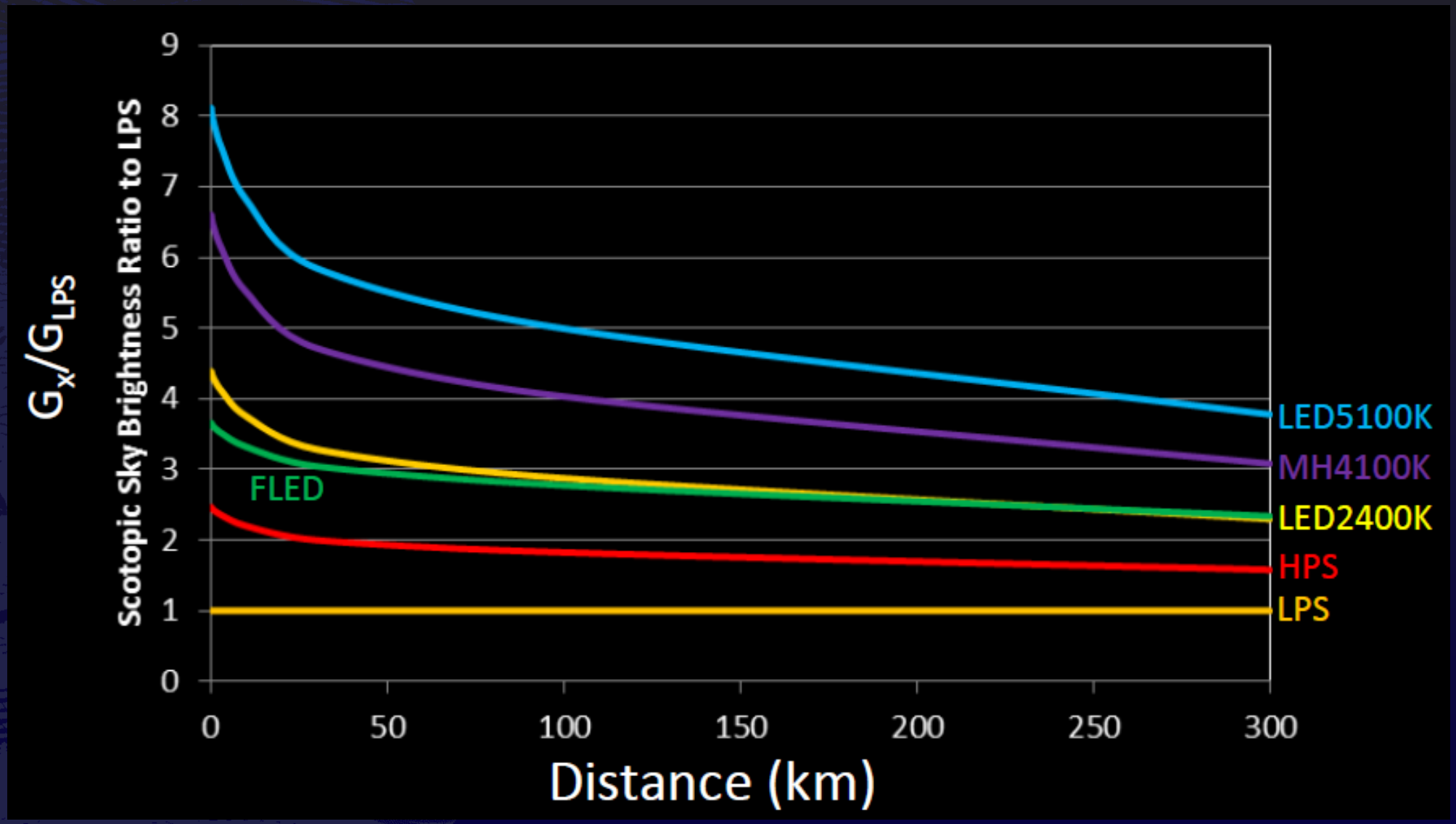
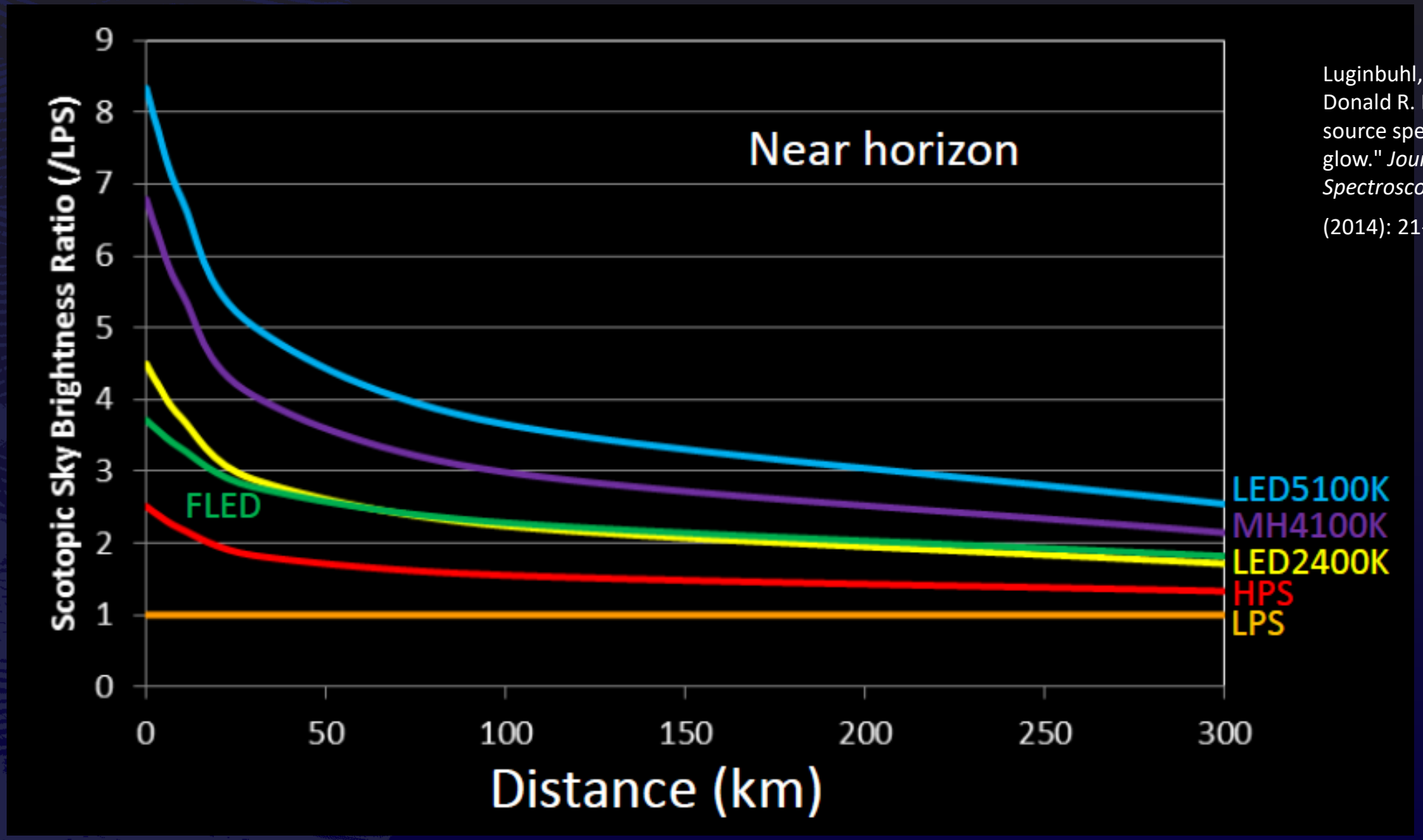



*Figure 8. Scotopic (rods) and photopic (cones) spectral sensitivity functions. Wald's data from Davson, H., Physiology of the Eye, 5th ed. London: Macmillan Academic and Professional Ltd, 1990.*

When observed at various distances, the apparent brightness of the scattered sky glow from most LED lights is brighter than HPS or LPS

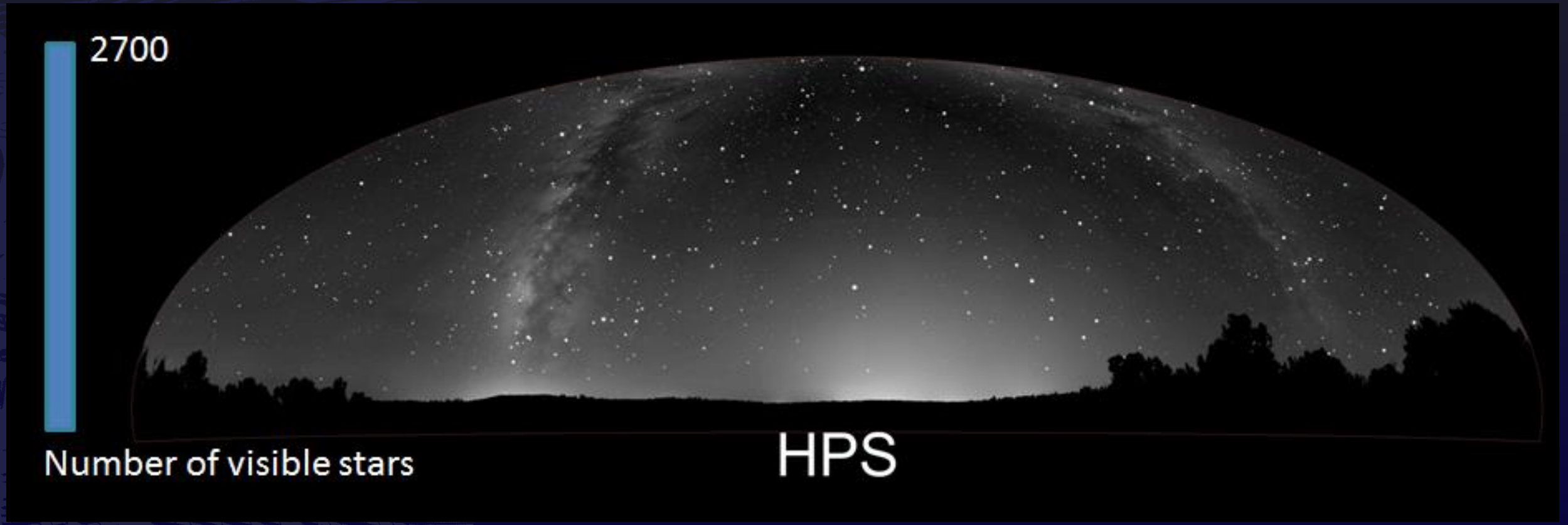


The effect is somewhat mitigated near the horizon because of absorption of the blue through the denser air column




Luginbuhl, Christian B., Paul A. Boley, and Donald R. Davis. "The impact of light source spectral power distribution on sky glow." *Journal of Quantitative Spectroscopy and Radiative Transfer* 139 (2014): 21-26

A brighter apparent sky background results in the number of visible stars to be reduced and loss of fainter features in the Milky Way, especially when the observer is near the source, compared to redder sources such as HPS



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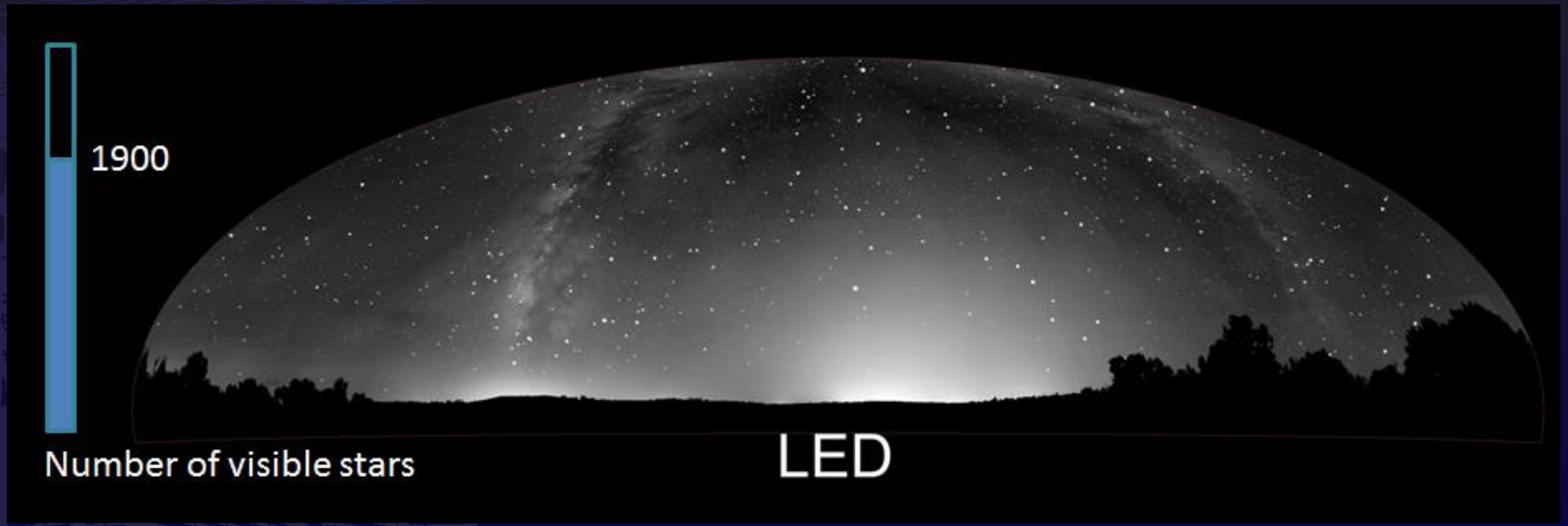
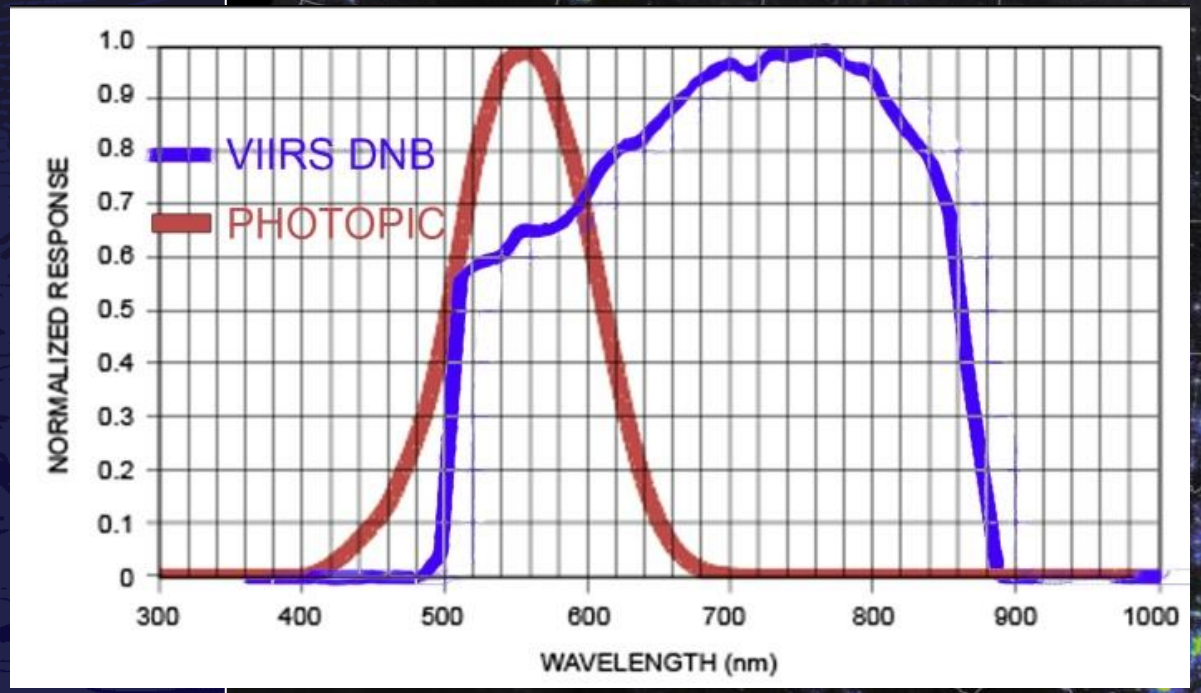
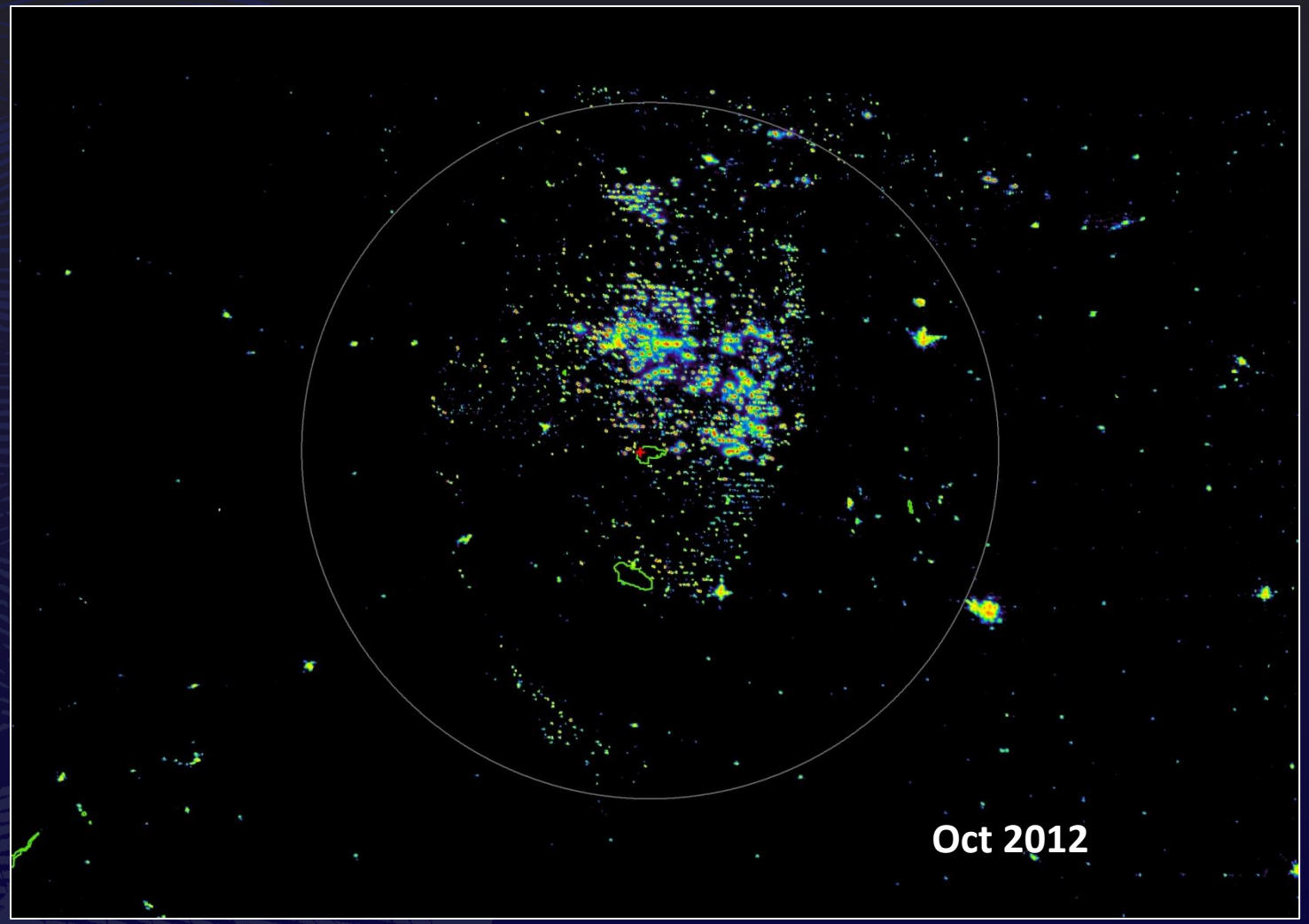


# Remote sensing methods allow wide geographic scope

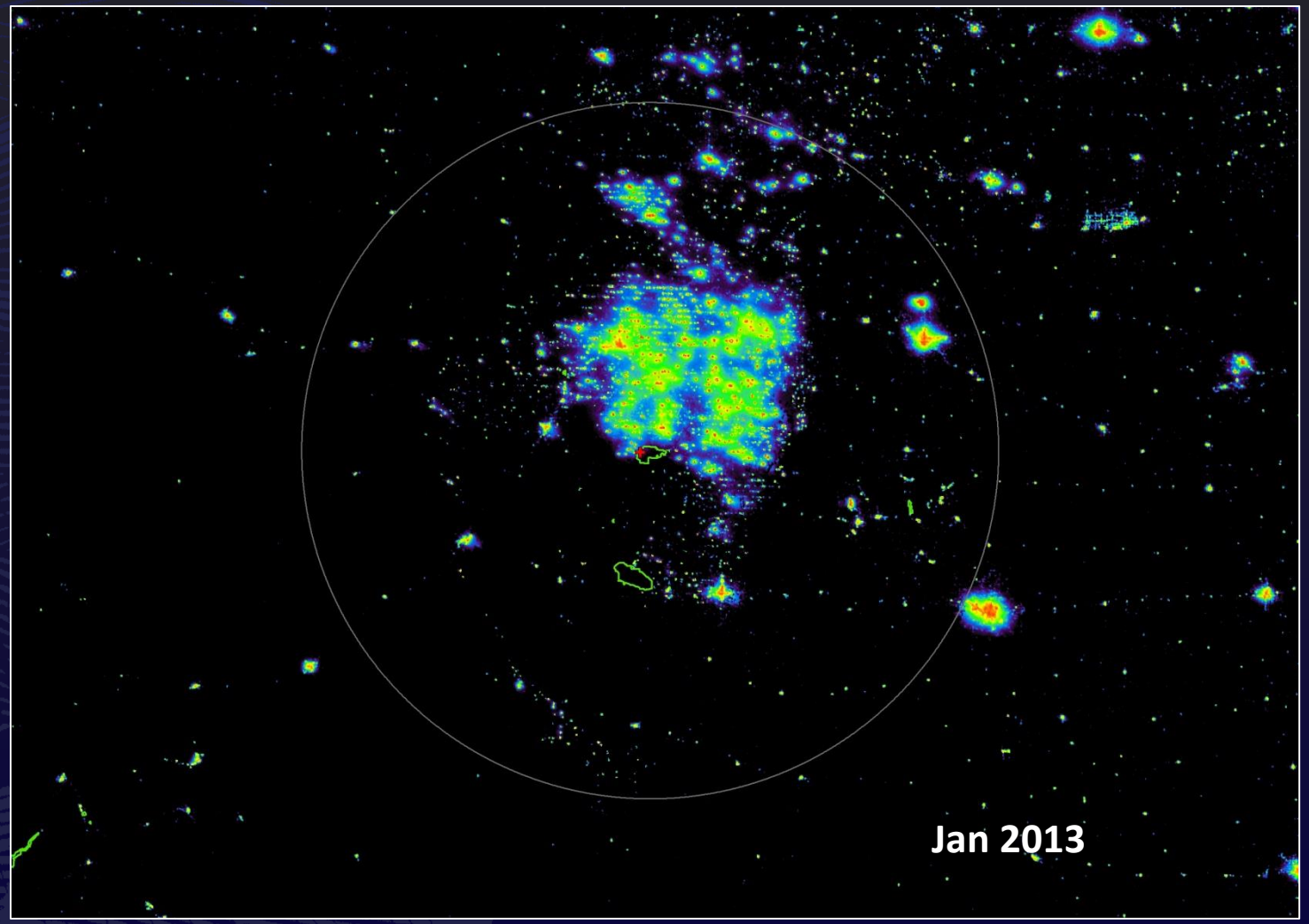



VIIRS Day / Night Band Radiance Data

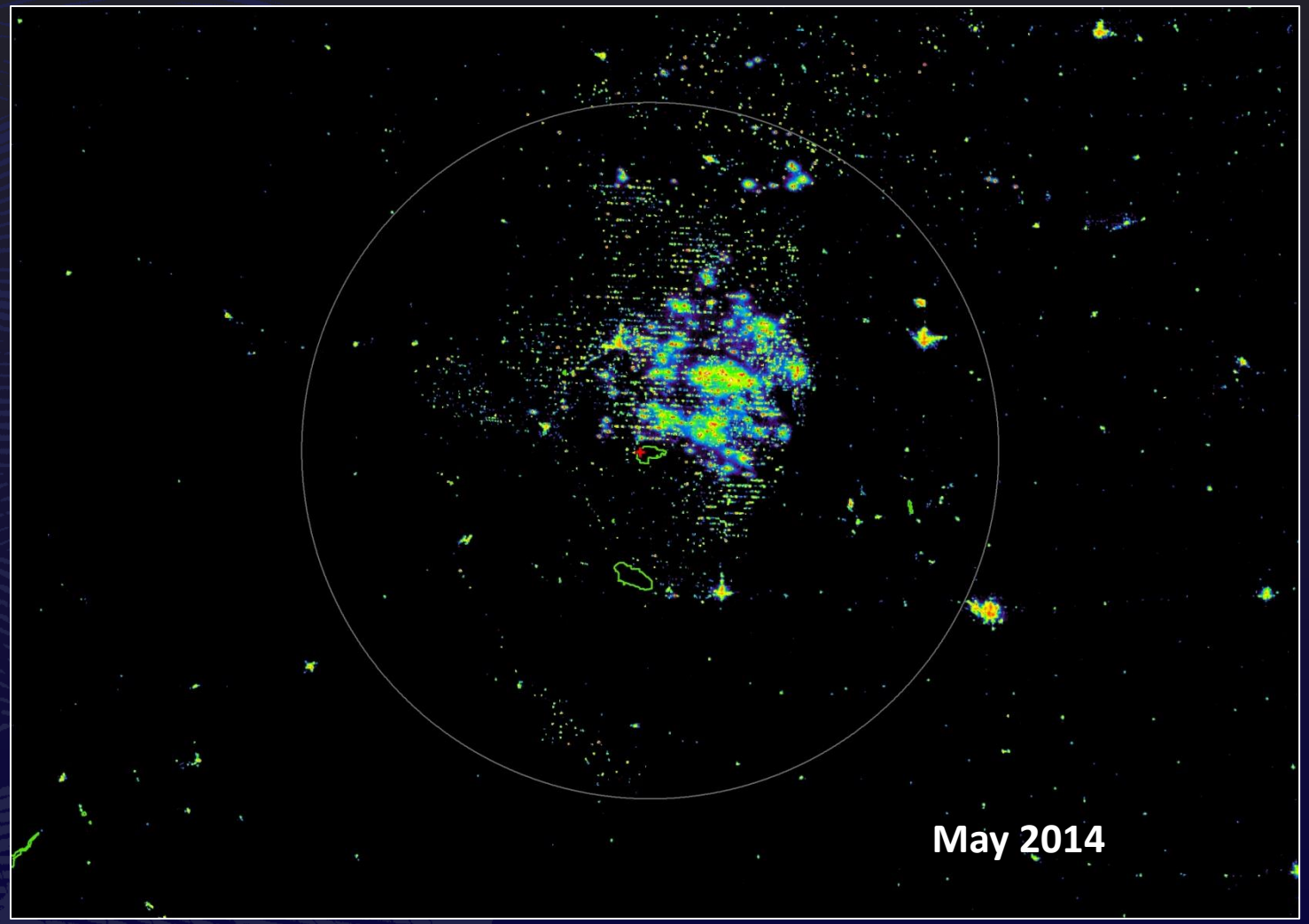
# Monthly products since 2014 allow monitoring over time



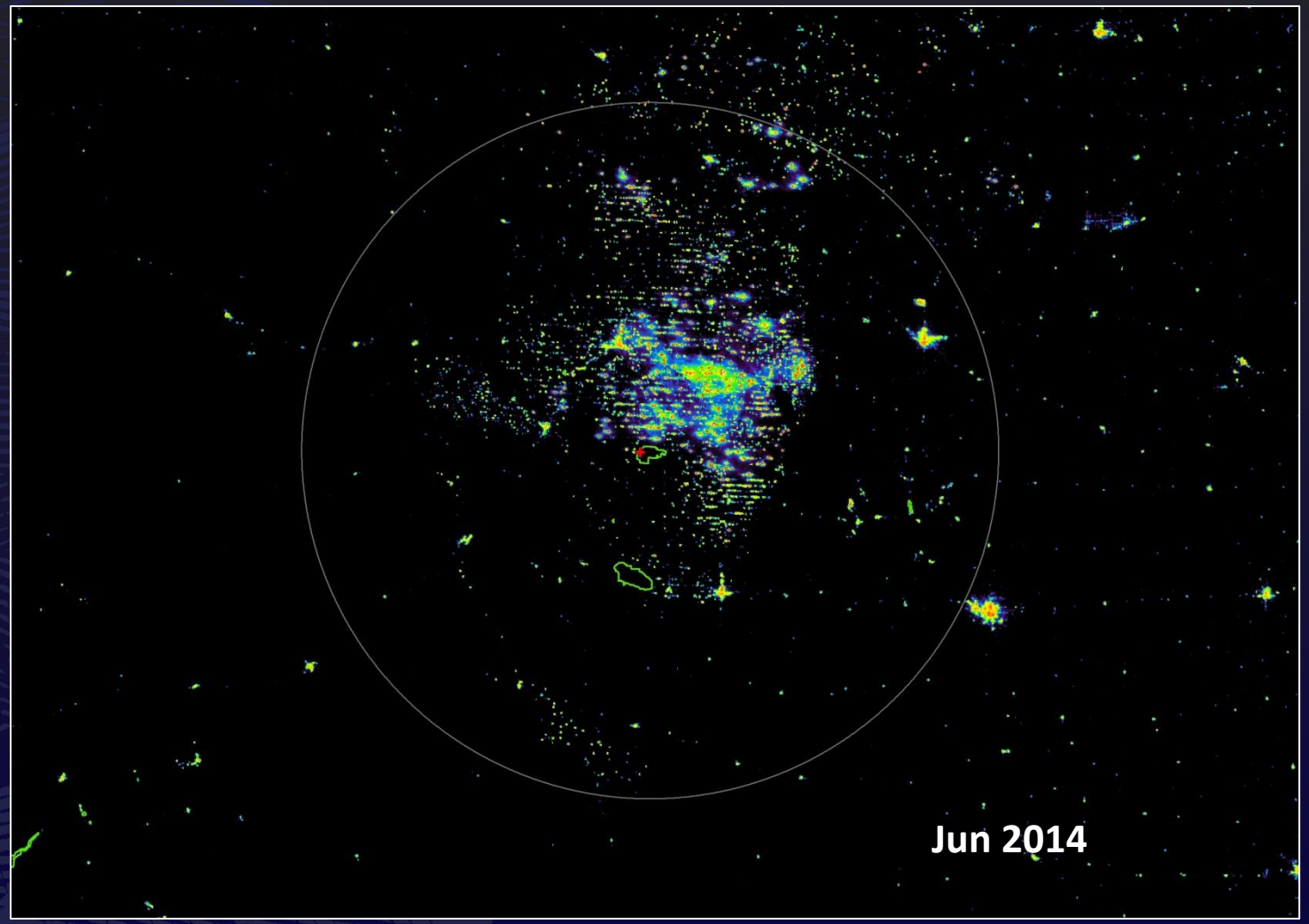
# VIIRS day/night Band data – Theodore Roosevelt NP



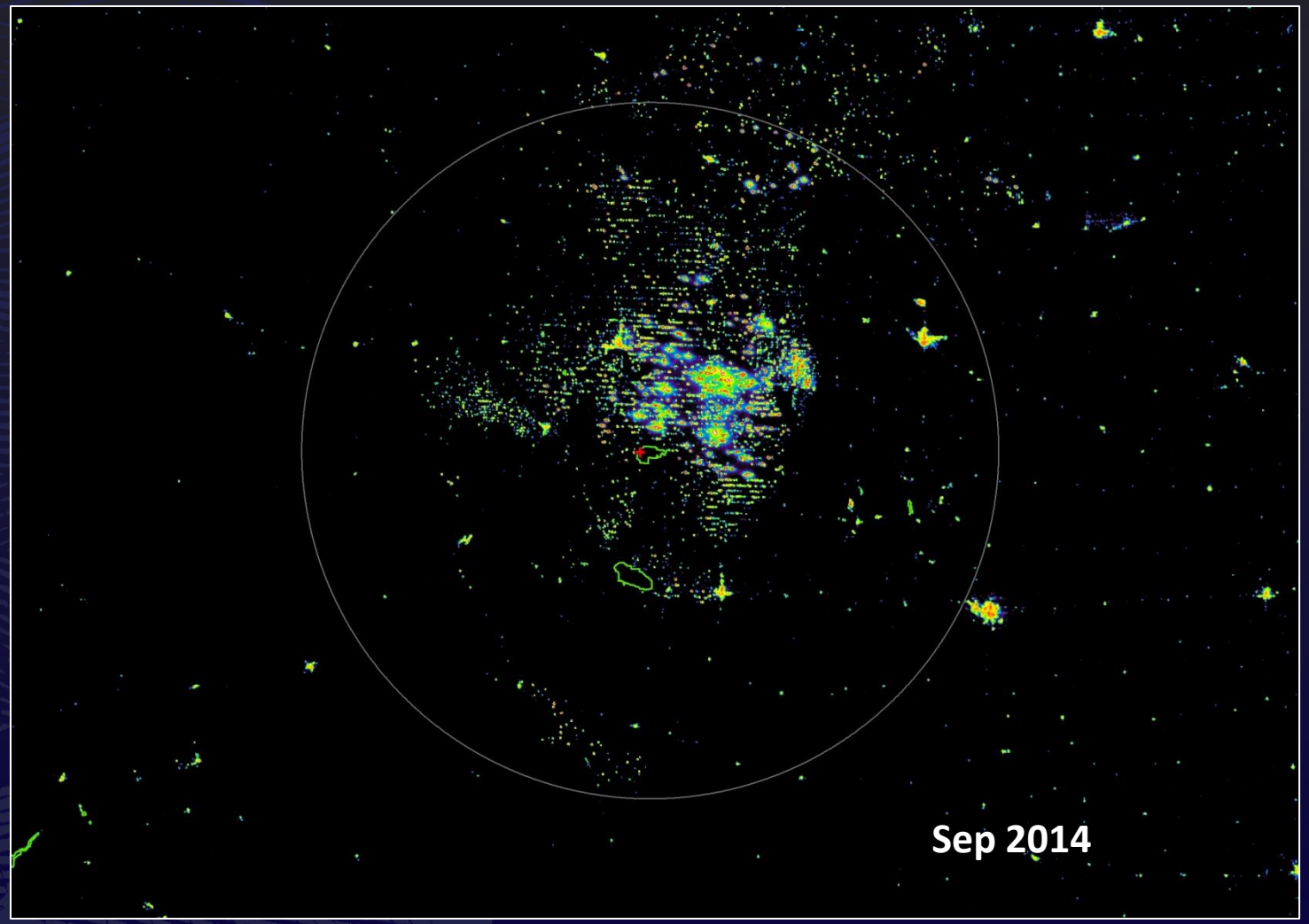
# VIIRS day/night Band data – Theodore Roosevelt NP



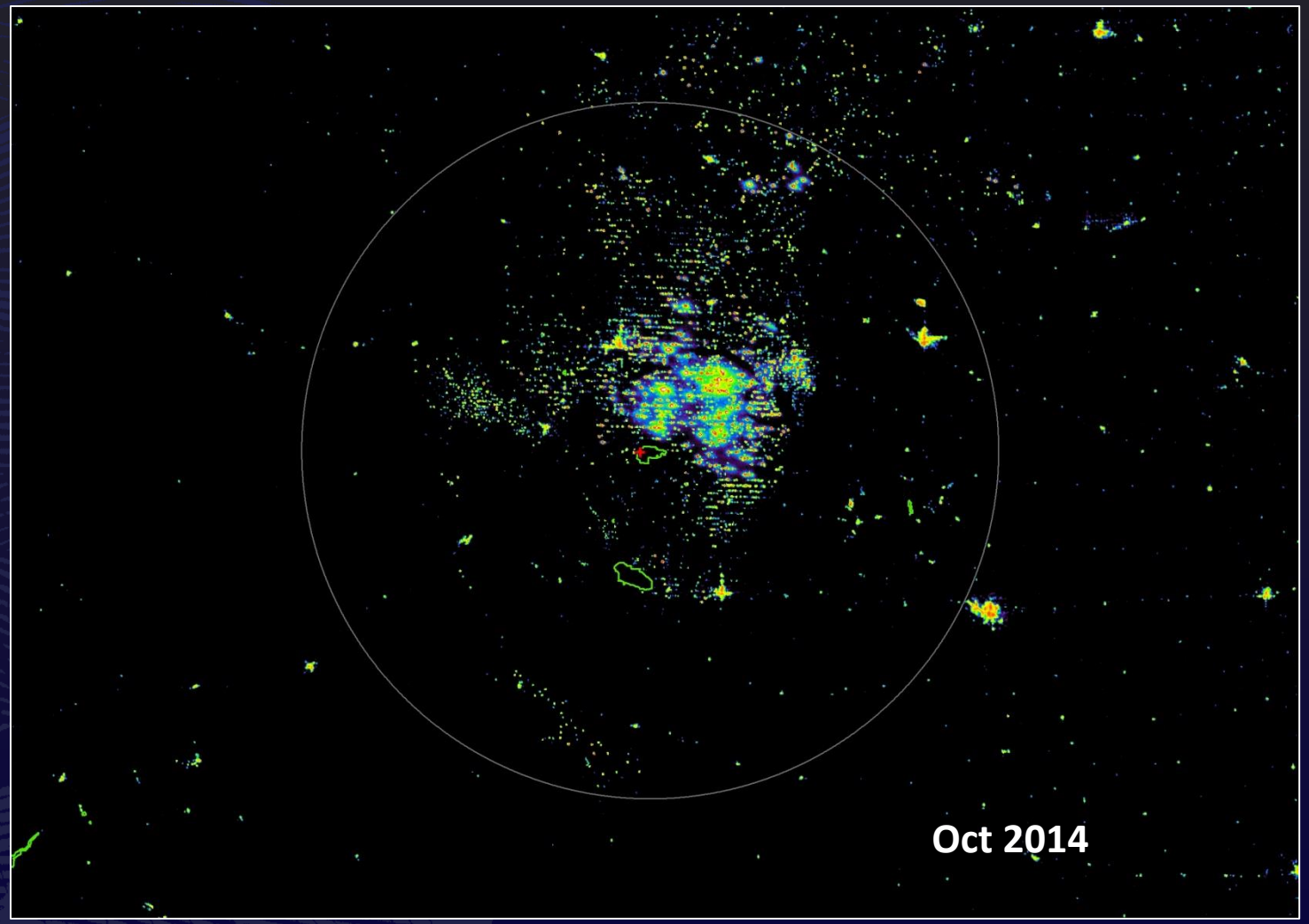
# VIIRS day/night Band data – Theodore Roosevelt NP



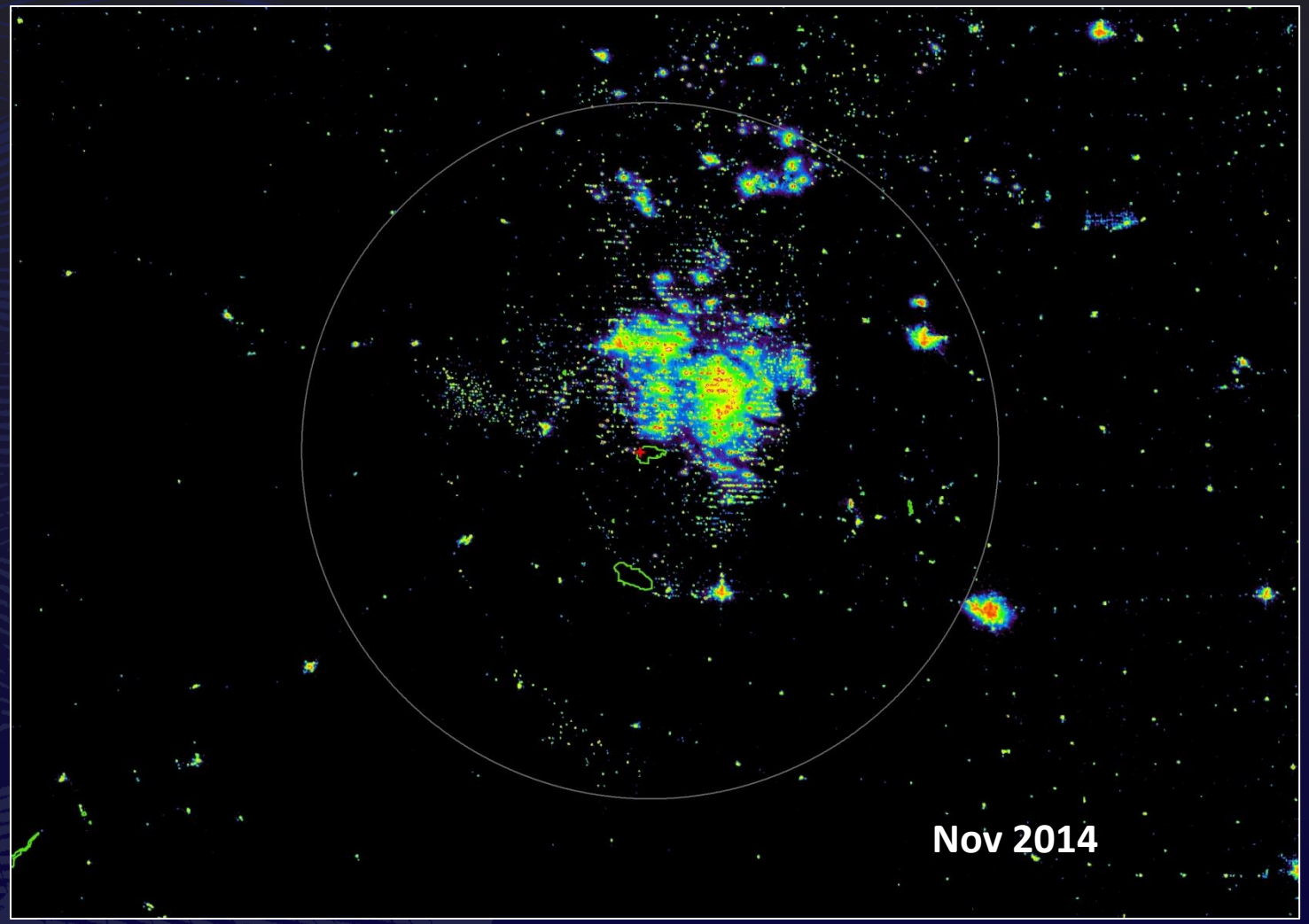
# VIIRS day/night Band data – Theodore Roosevelt NP



# VIIRS day/night Band data – Theodore Roosevelt NP



# VIIRS day/night Band data – Theodore Roosevelt NP



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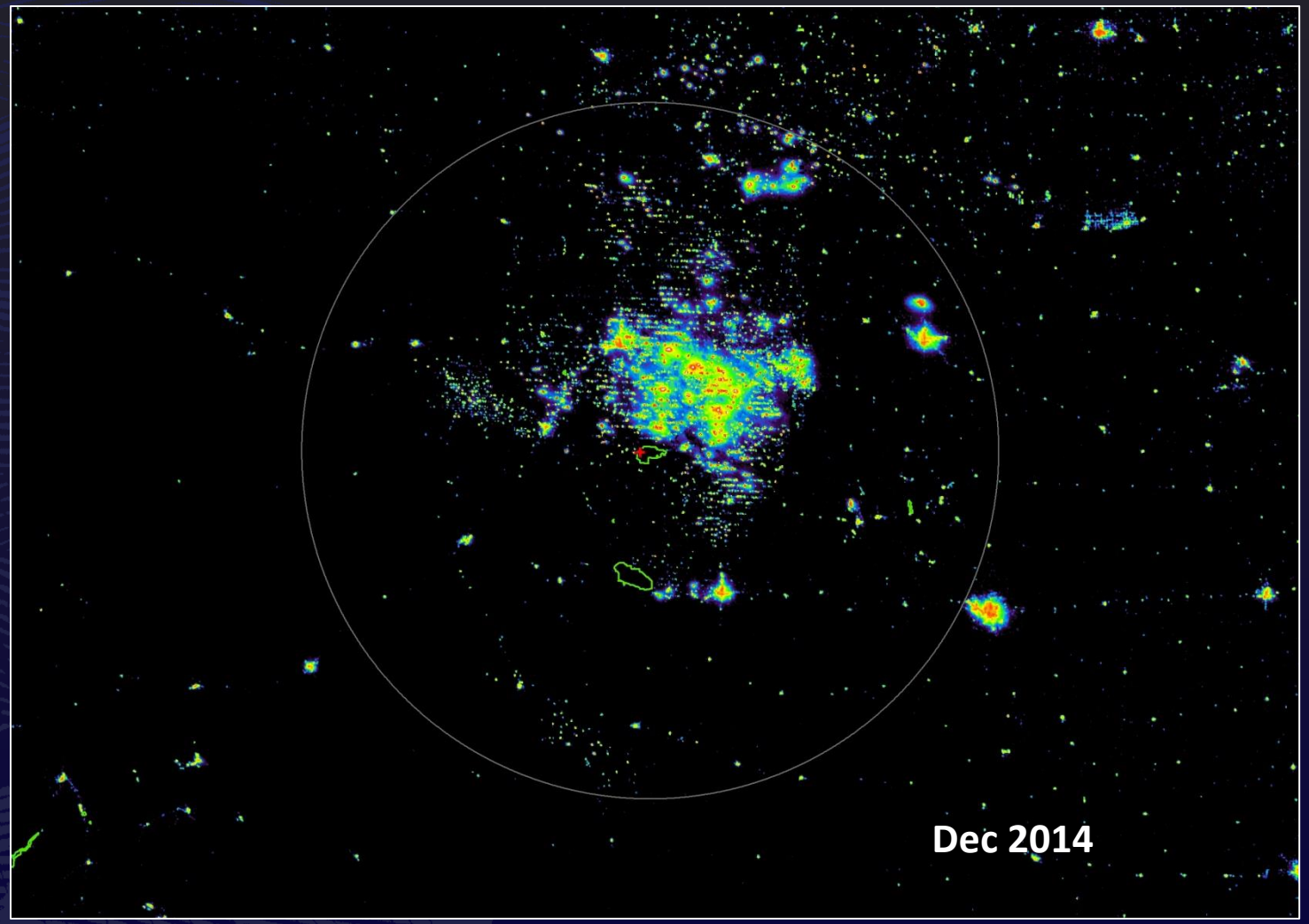

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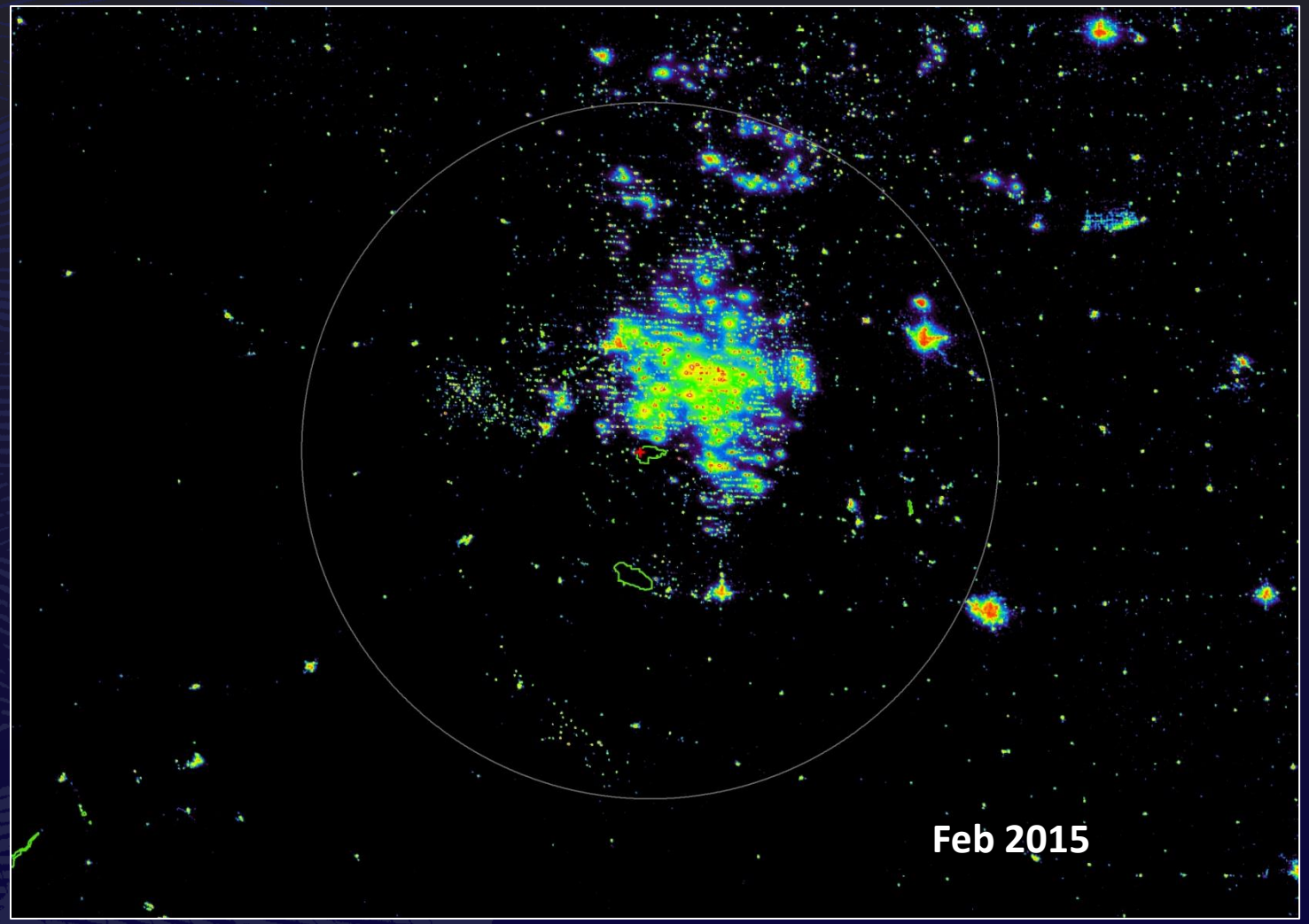
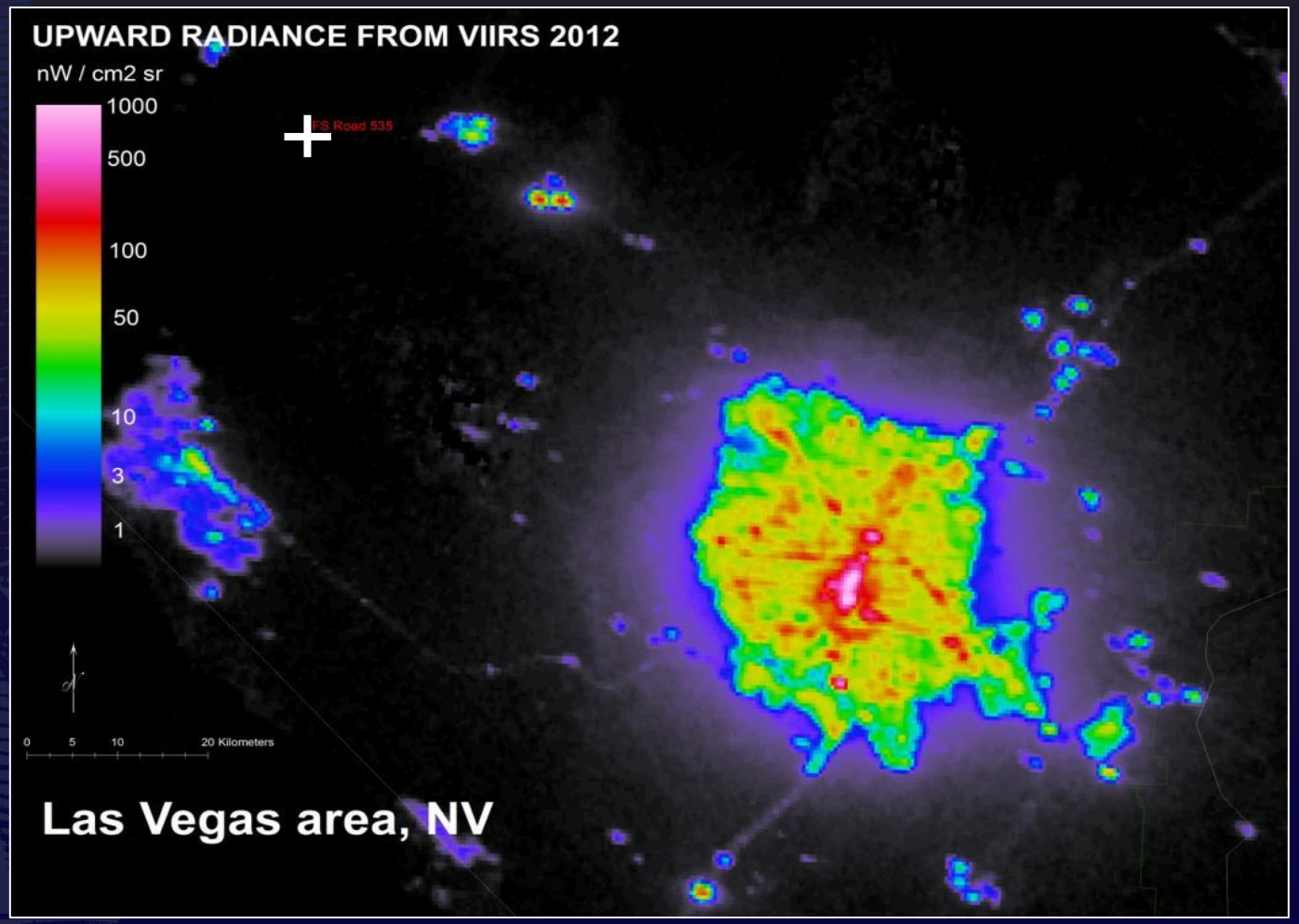
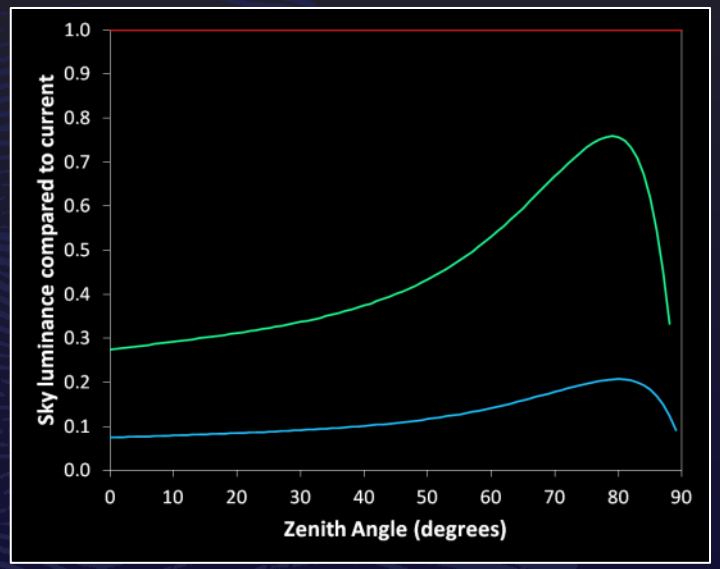


Upward radiance measures, when calibrated with ground based observations of outdoor lighting and sky glow, may be used used as input to atmospheric scattering model and to estimate lumens per capita use in cities



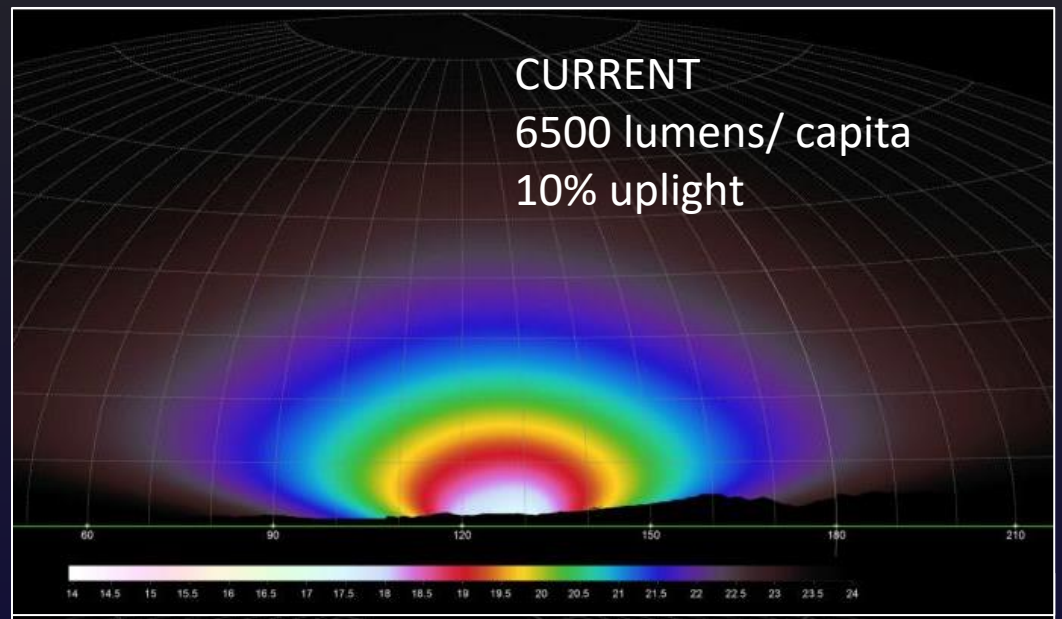
# Reductions in lumens per capita (or per acre) may be the only path to restoration

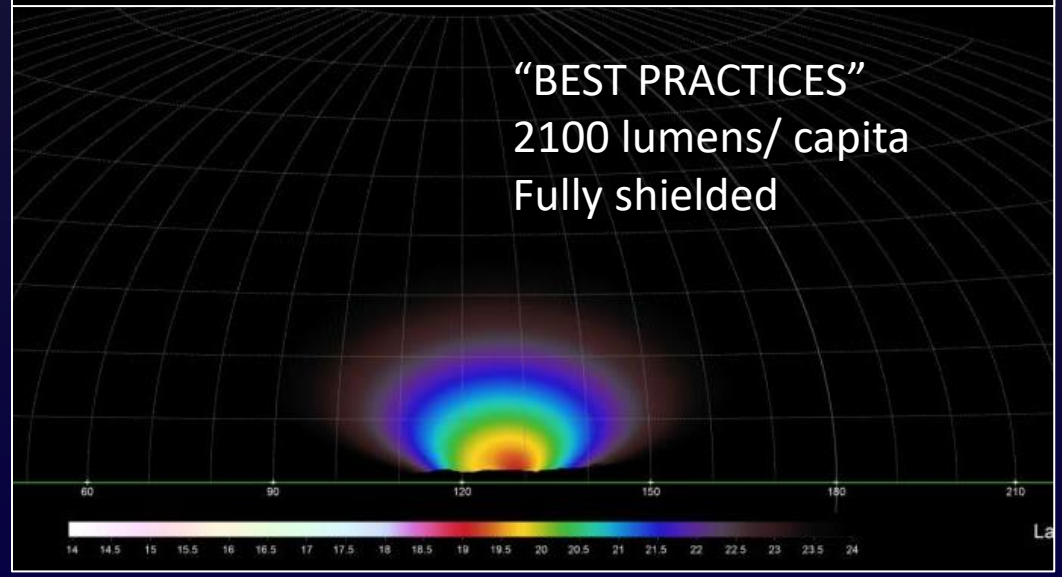



All-sky average luminance

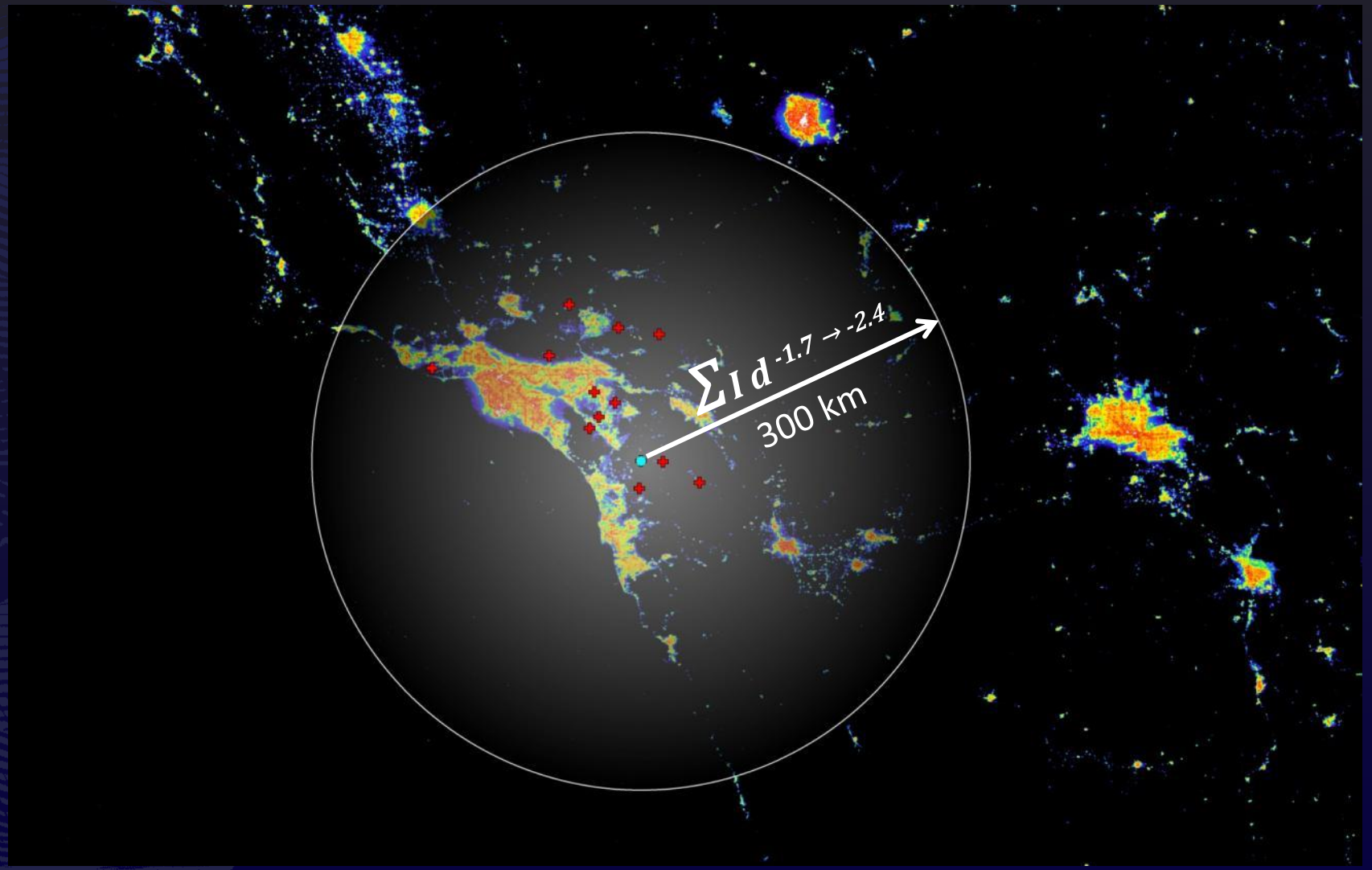
| Current | Best Practices | Ratio |
|---|---|---|
| 75.2 nL | 8.9 nL | 0.14 |

Duriscoe, D. M., C. B. Luginbuhl, and C. D. Elvidge. "The relation of outdoor lighting characteristics to sky glow from distant cities." *Lighting Research and Technology* 46.1 (2014): 35-49.



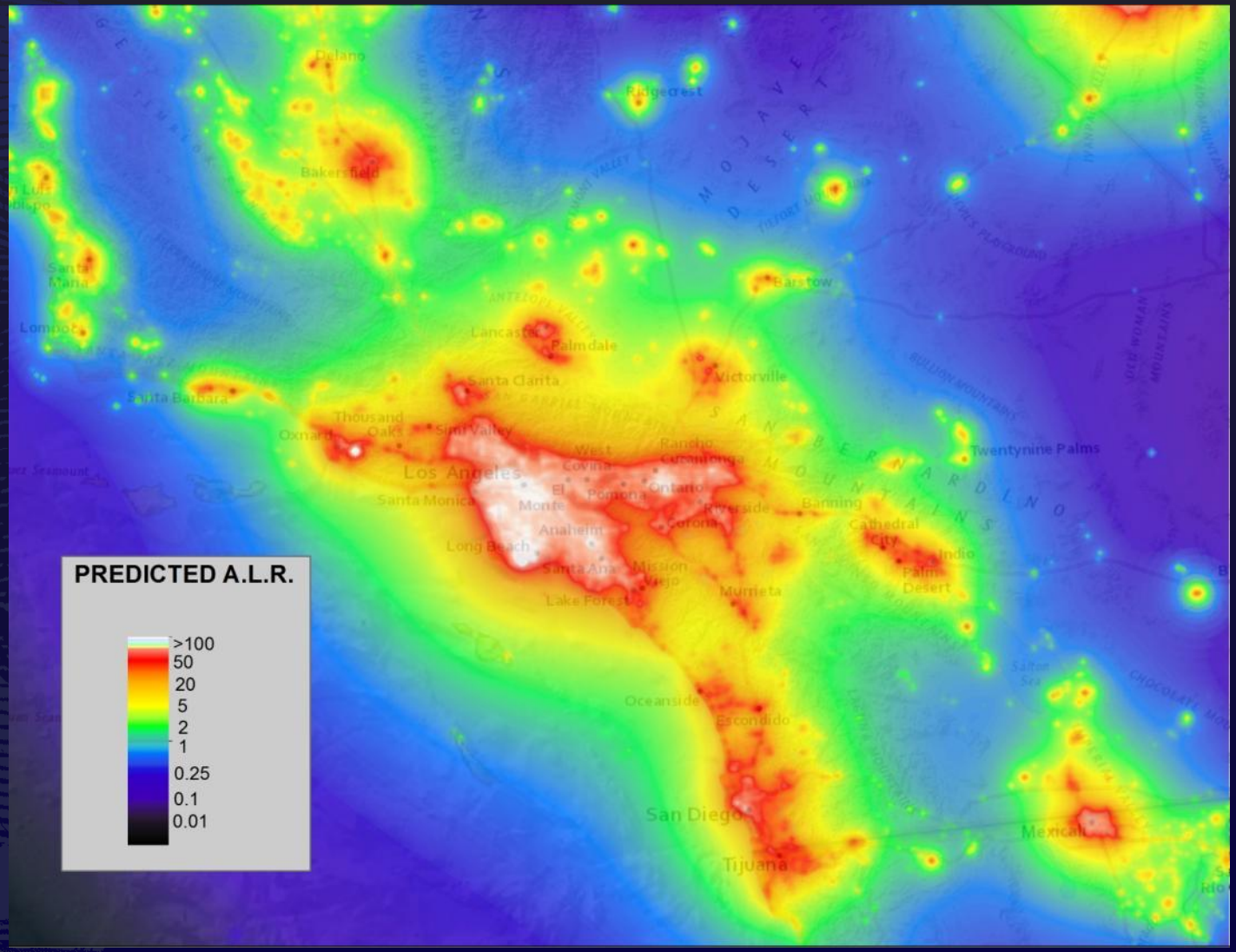



# Measurements and remote sensing combine to create an empirical landscape scale model



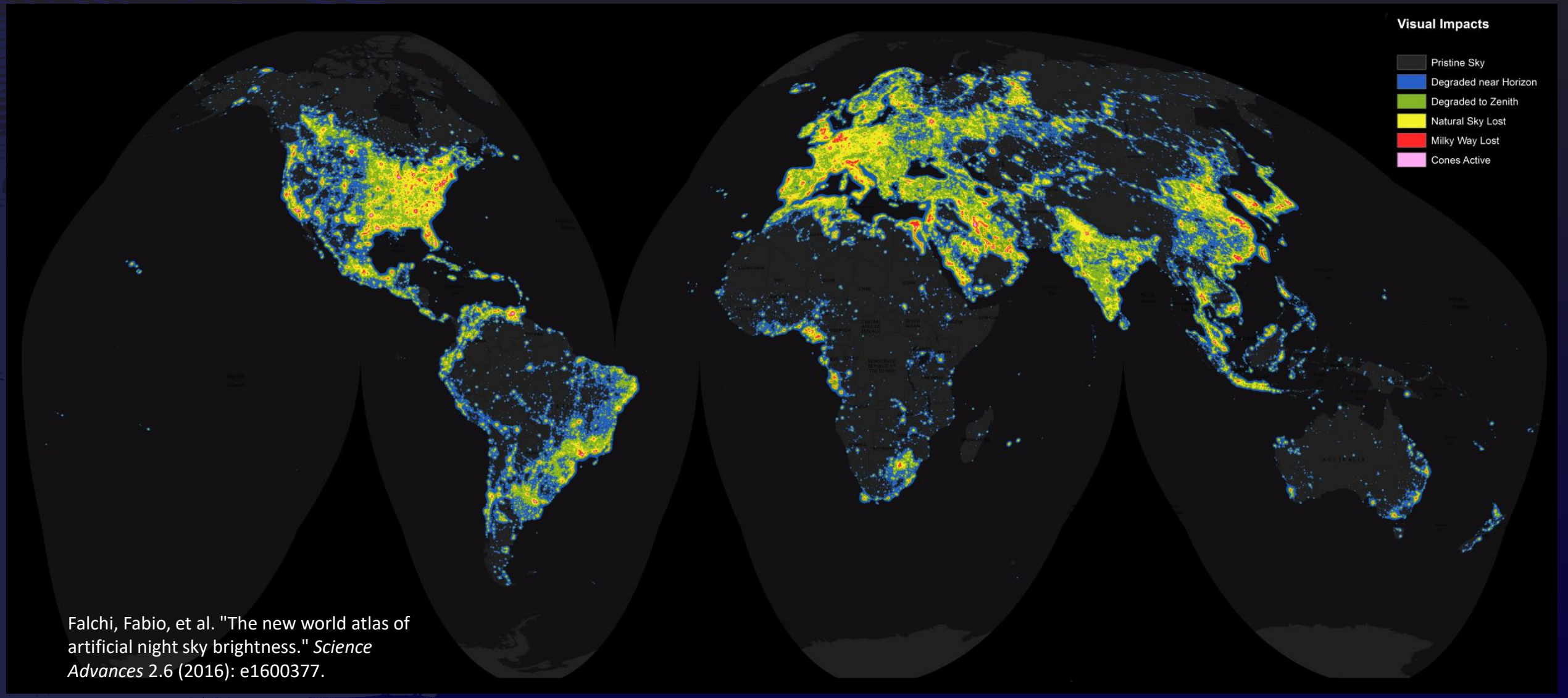
# Modeling provides valuable predictive tools

Empirical landscape scale model



# The New World Atlas of Artificial Sky Brightness

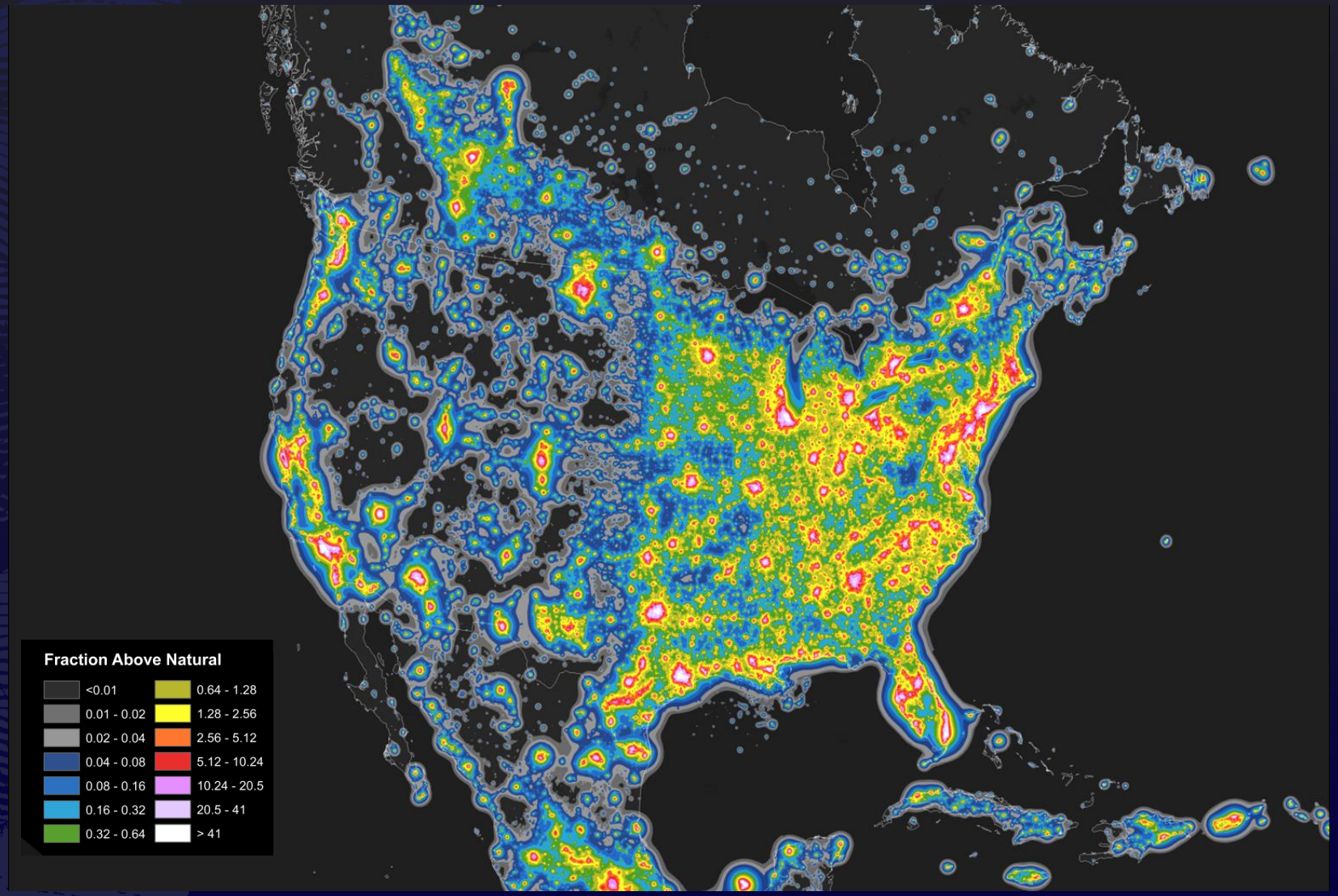
A hybrid -- combines physical model using remote sensing input with ground observation calibration of the output




Falchi, Fabio, et al. "The new world atlas of artificial night sky brightness." *Science Advances* 2.6 (2016): e1600377.

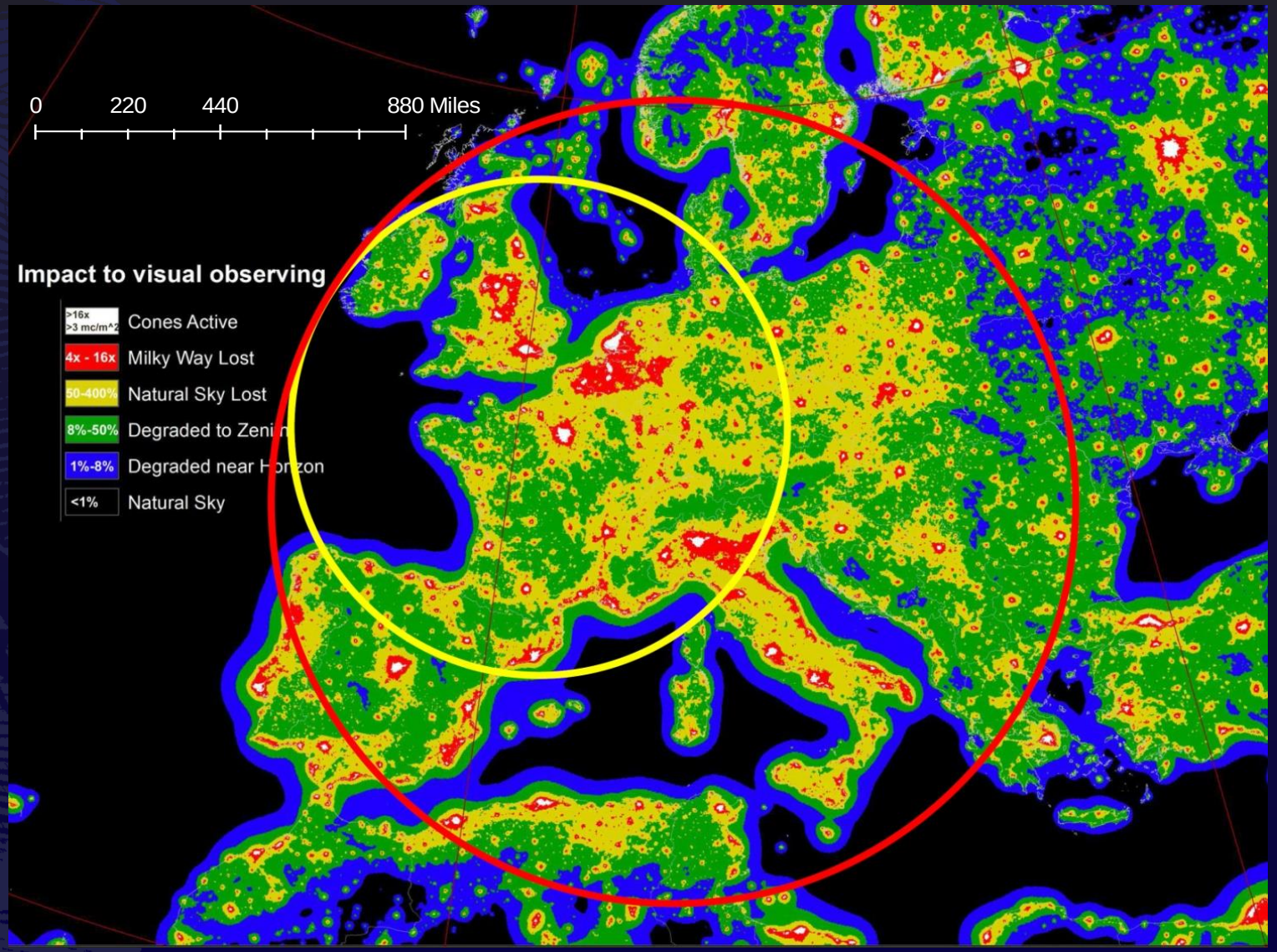
# The New World Atlas of Artificial Sky Brightness

Identify areas of pristine nights skies remaining in the western U.S.



# The New World Atlas of Artificial Sky Brightness

Residents of central Europe have to travel long distances to a good observing site.



# Thank you