Towards a More Comprehensive Bortle Classification System

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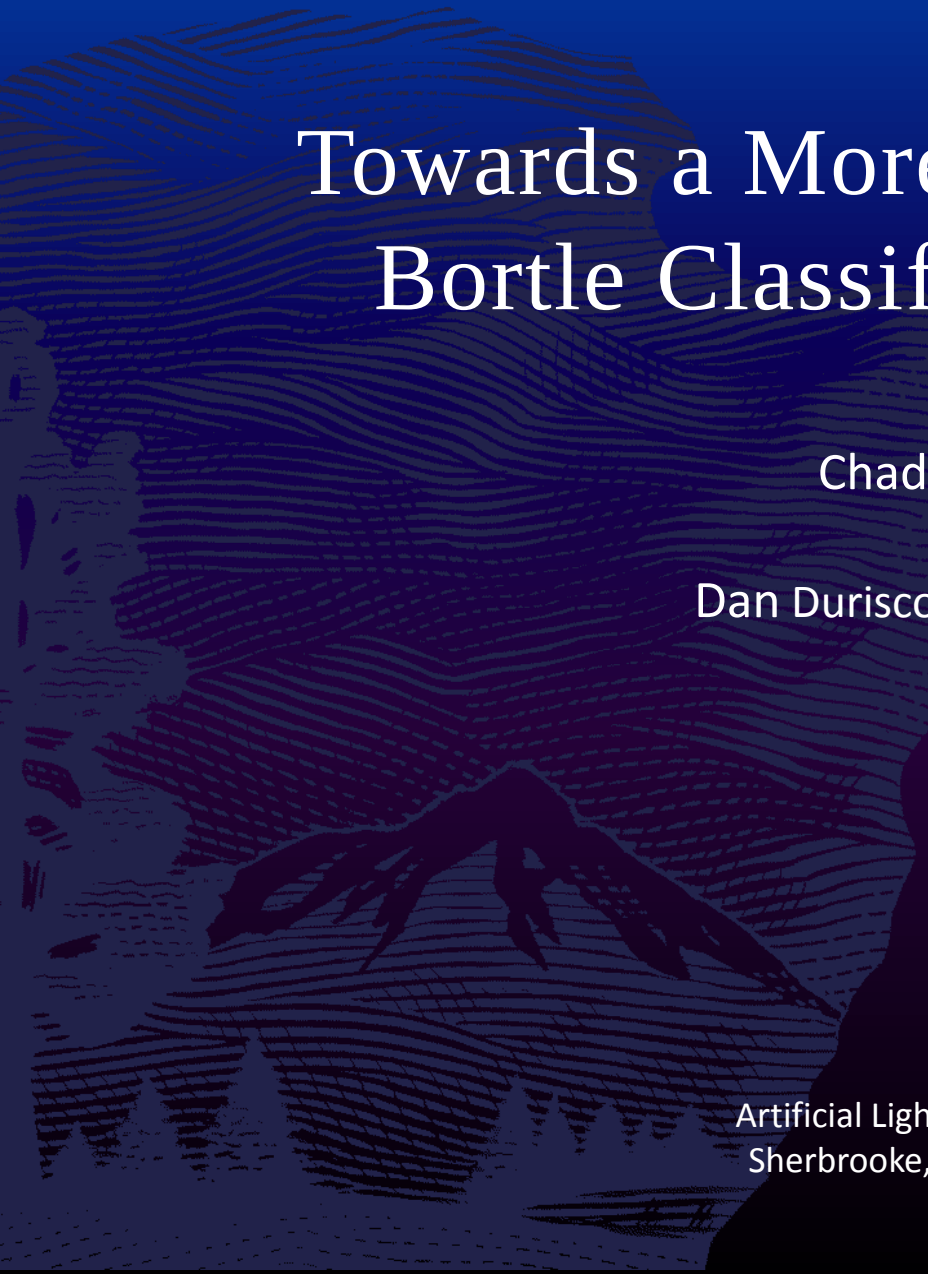
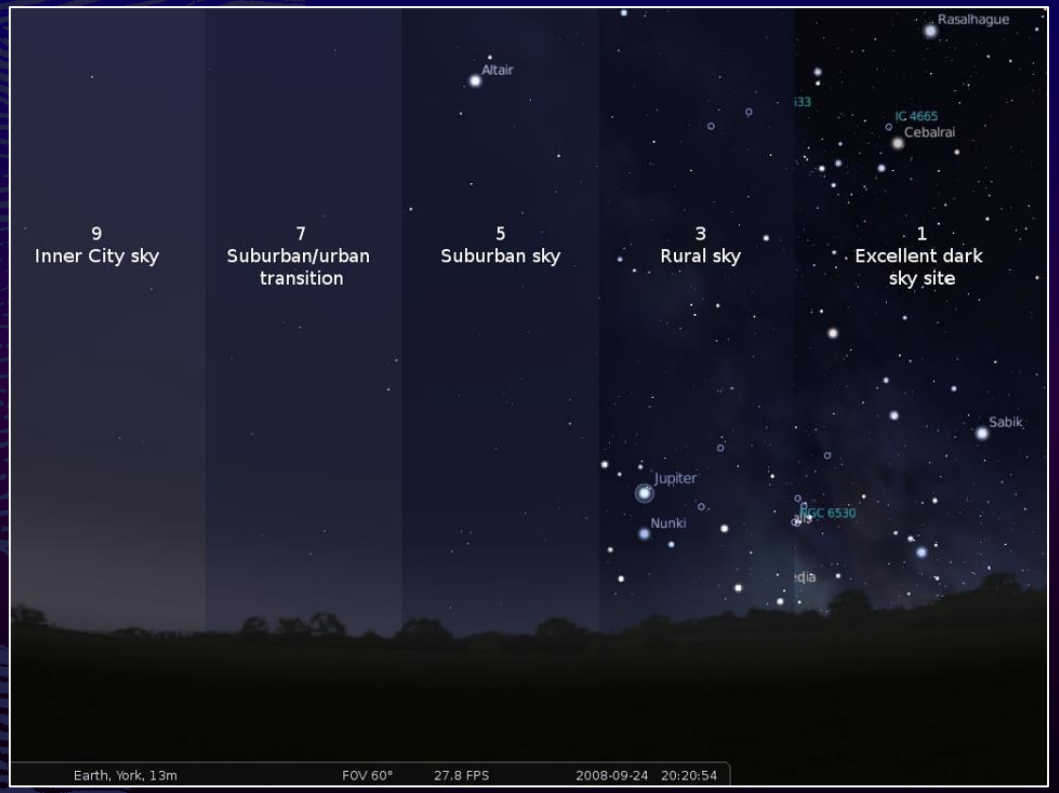


Artificial Light at Night — 2015
Sherbrooke, Québec, Canada

Bortle Dark Sky Scale

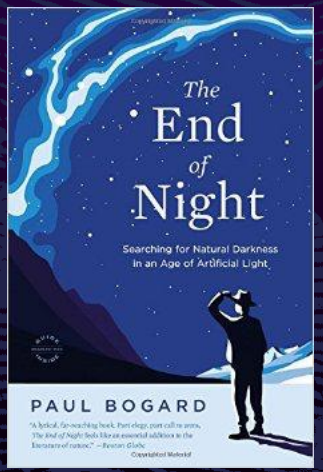
- Published in 2001 (Sky & Telescope)
- Based on lifelong experience of amateur comet hunter John Bortle
- Qualitative visual assessment of sky and terrain — a holistic assessment of lightscape
- 9 Classifications

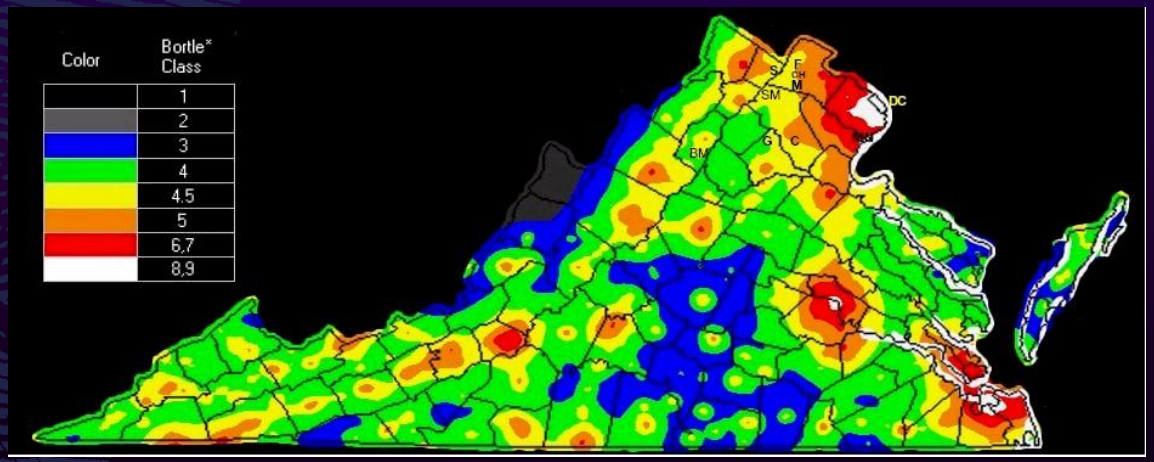


International Dark-sky Association

Utility

- Public Relations
  (e.g. chapters in End of Night)
- Recording of Visual Observations
  (e.g. a 6” telescope shows spiral structure under Bortle Class 3 skies)
- Resource condition assessments and targets
  (e.g. IDA Gold Tier ~ Bortle 3)
- Communicating functional consequences of artificial light
  (e.g. modeling)





NOVAC

A Charismatic Description to Compliment Quantitative Data

Rural/Dark Skies

Class 1

Gegenschein and zodiacal band are visible

Milky Way cast obvious shadows

Many Messier objects are visible with unaided eye (e.g. M33 is easily seen)

NELM 7.6-8.0

Class 2

Clouds are only visible as dark holes against the sky

Surroundings are barely visible silhouetted against sky

Milky Way is highly structured, airglow often seen

NELM 7.1-7.5

Class 3

Some light pollution evident along horizon

Clouds are illuminated near horizon, near surroundings are vaguely visible

Brighter globular clusters are visible

NELM 6.6-7.0

A Charismatic Description to Compliment Quantitative Data

Suburban/Transition Skies

Class 4

Zodiacal light is still visible, less than 45 degrees extent

Milky Way lacks detail

Terrestrial objects clearly visible, clouds illuminated except at zenith

NELM 6.1-6.5

Class 5

Only hints of zodiacal light are seen in autumn and spring

Light pollution in most or all directions, bright clouds

Milky Way is weak or invisible near horizon, washed out overhead

NELM 5.6-6.0

Class 6

Light pollution extends up to 35° above horizon

Clouds are fairly bright, surroundings easily visible

Milky Way only visible near zenith

NELM 5.1-5.5

A Charismatic Description to Compliment Quantitative Data

Urban/Bright Skies

Class 7

Entire sky gray with light pollution, in every direction

Clouds are brightly lit

M31 and M44 may be glimpsed

NELM 4.6-5.0

Class 8

Light pollution has color, read print under skyglow

Many constellation stars lost

M31 or M44 may be glimpsed by experienced observer

NELM 4.1-4.5

Class 9

Sky is brilliantly lit with colors of artificial lamps

Many constellations are invisible

M45 the only Messier object visible

NELM 4.0

Our Experience Making Bortle Qualitative Assessments

- 330 nights of observation with all-sky photometric data to complement
- Even trained observers have different interpretations of criteria
- Targets such as M33 or Sagittarius Milky Way not always visible, or viewed through high airmass distance
- Bortle's original Naked Eye Limiting Magnitude ranges overly simplified

Our Experience Making Bortle Qualitative Assessments *Cont'd*

•Only 8 Class 1 nights observed (very rare), and 7 had outstanding extinction < 0.15

- Visibility of light domes and terrestrial features is highly dependent on local factors — soil color, foliage, horizon blocking

- Nightly variability in airglow brightness and seasonal variability in zodiacal light brightness sometimes makes them poor benchmarks

- The presence or absence of sky glow is easily detected by the unaided eye, not so easily quantified (absolute brightness)

- The gradient in sky brightness to the zenith is a good indicator of presence or absence, is there an area near the zenith that is dark?

Key questions with Bortle Classification

- Do all features of a sky have to be present in class, a majority, or only a few features?
- How do classes relate to quantitative measures (Sky Quality Meter, Sky Quality Index, illuminance, sky luminance)?
- Can this system be modified to be more repeatable and have less individual bias? Can it be made more user friendly?
- How to classify “split personality” skies?
- How to handle blocking of light near horizon? For Class 1 and 2, absolutely no evidence of sky glow taken literally?

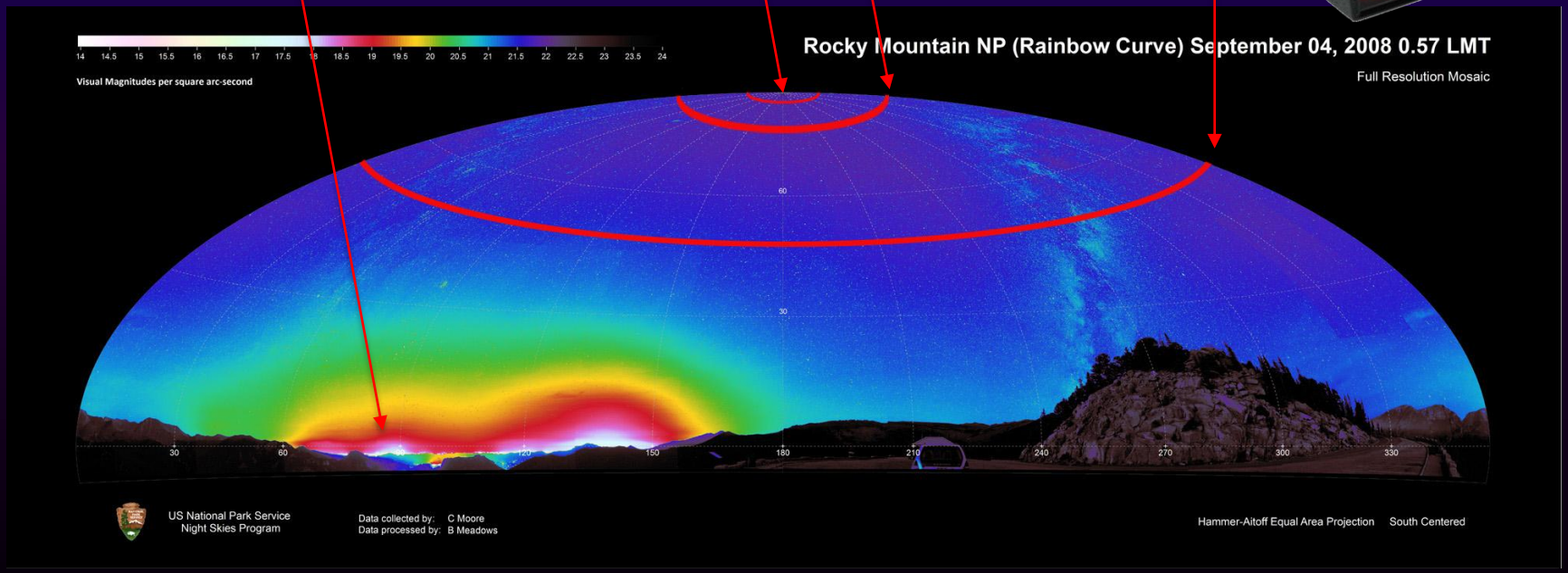
Split Personality Sky — Bortle Class 4, or Bortle Class 2?

Zenith= 21.90 msa

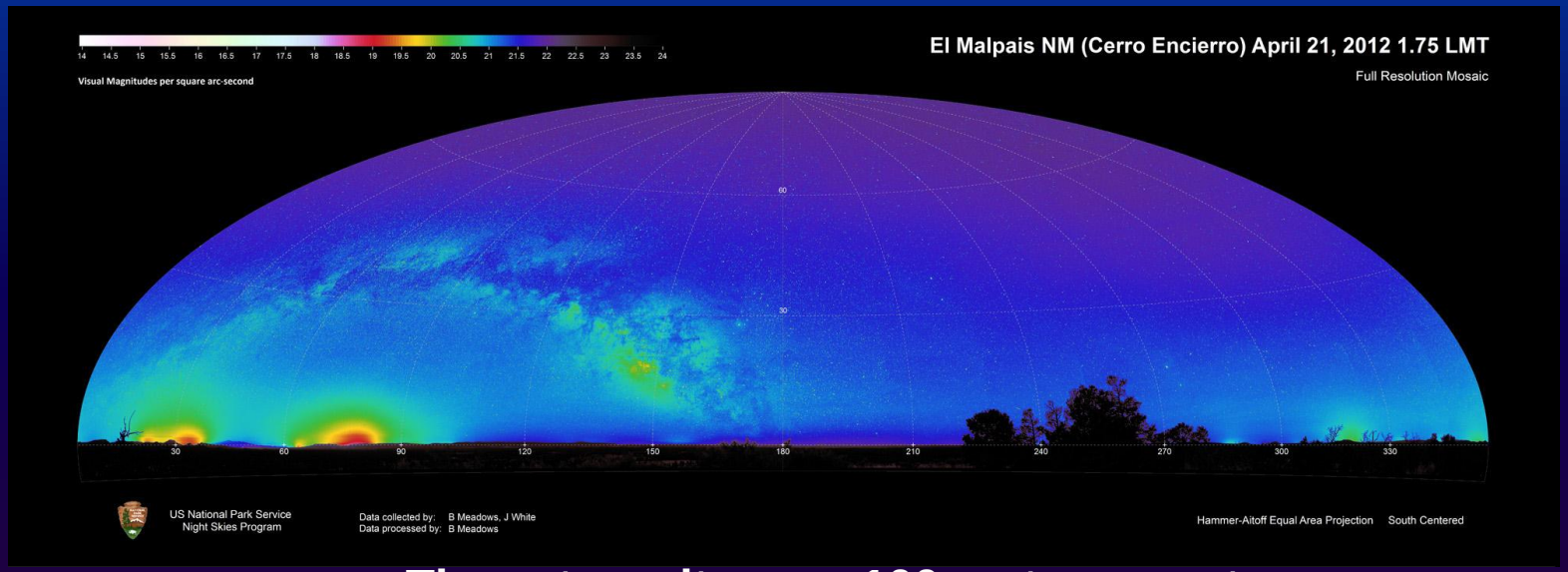
SQM-L= 21.85 msa

SQM= 21.75 msa

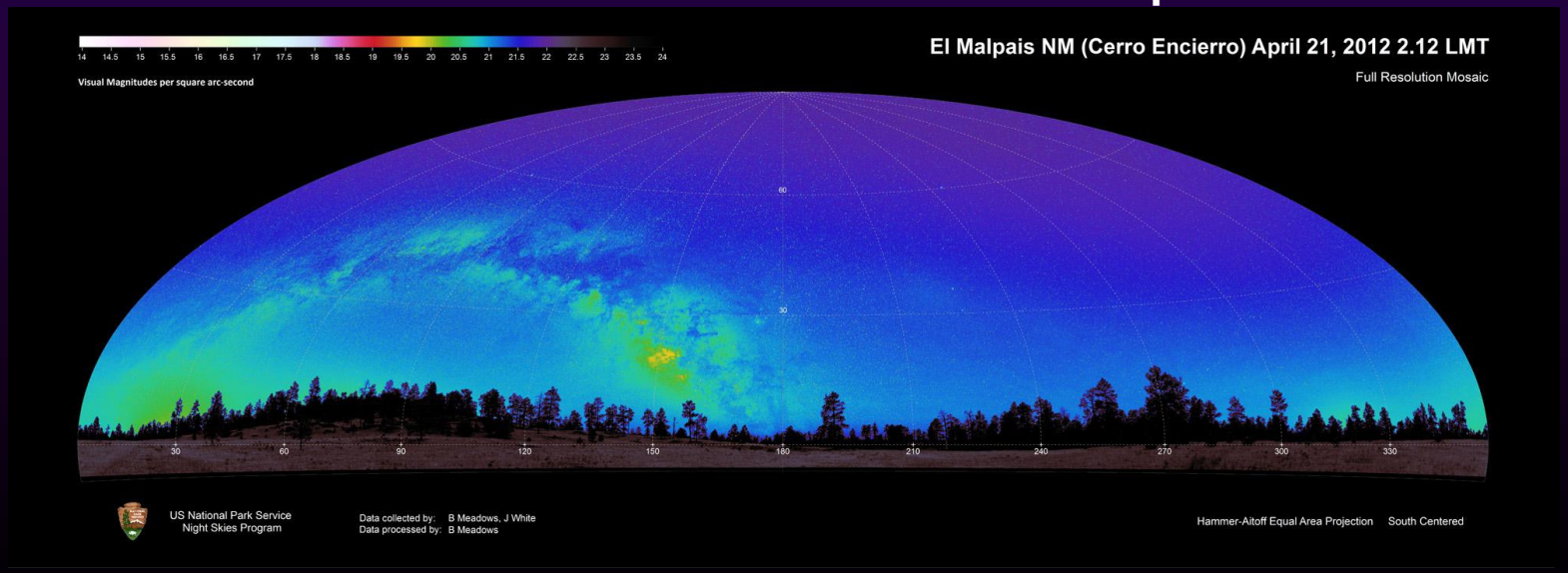
Dome= 17.00msa



Terrain Blocking— Bortle Class 3, or Bortle Class 2?



These two sites are 100 meters apart



Other Thoughts

- System should retain holistic focus — sky and landscape

- Difference between Class 1 & 2 is predominantly due to transparency and airglow — same site can have different class determination on different nights

- System should retain this incorporation of atmospheric clarity

- System should retain scotopic adaptation (for far sources, near sources should be blocked)

- NELM alone should not be used to determine Bortle Class — too dependent on observers' visual acuity and training

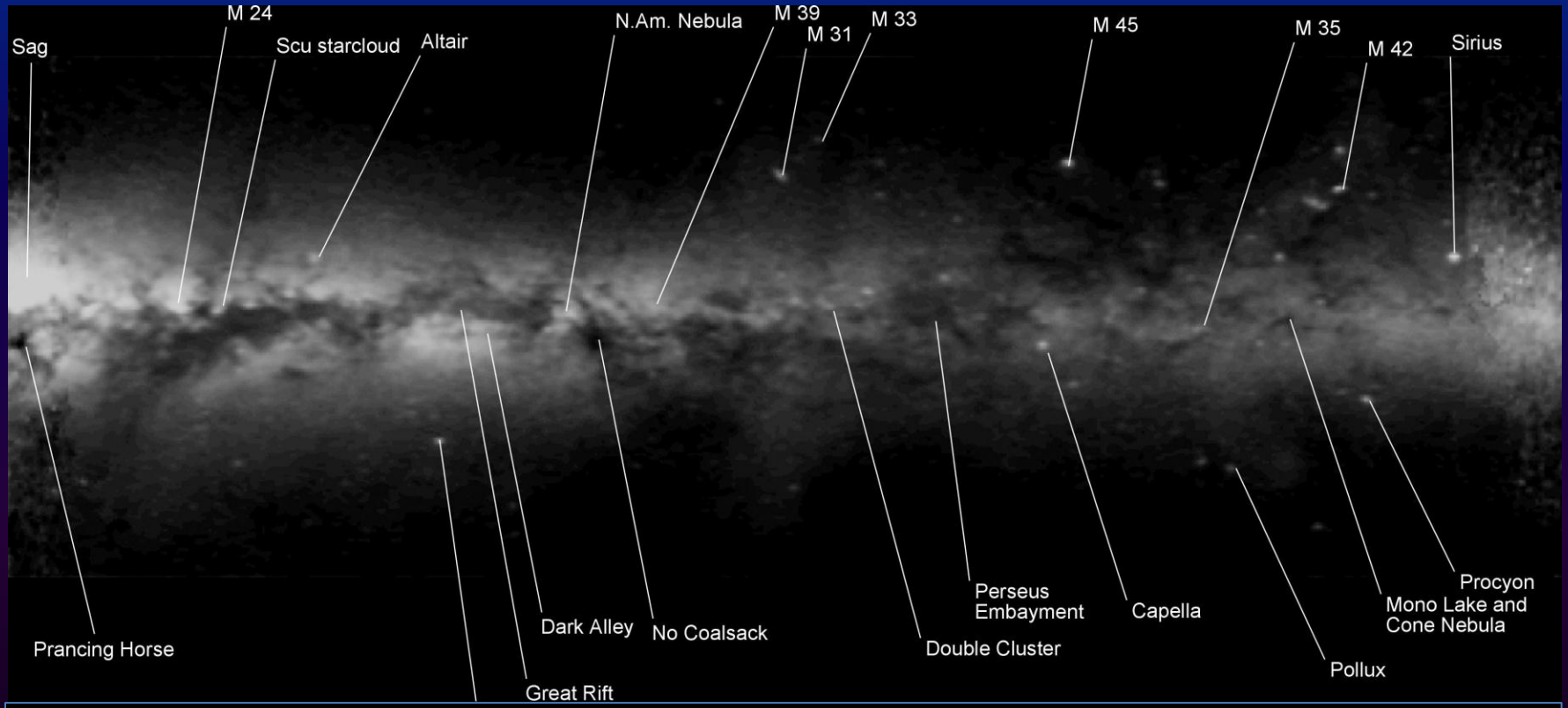
- Estimating amount of sky glow is much easier than locating the challenge objects, but Bortle class is not just about sky glow

Approaches

1. Dichotomous Key
2. Photometric Correlations
3. Expanded Palette of Benchmarks
4. Resolution of “Problem Skies”

Approach — 1. Dichotomous Key

- Tested with trained observers and citizen scientists past two years
- Experience indicates that 4 to 6 different keys will have to be developed for different local sidereal times so that benchmark objects are near zenith
- Likewise would require different keys for different latitudes
- First attempted without illustrations or photos, future needs include a diagrammatic “field guide”



Sample Milky Way Diagram for Training

Sample Key using Milky Way Visibility

Bortle Dark-Sky Scale

Key for the Summer Sky— Latitudes 30° to 50° N

The Milky Way is not visible and sky glow extends above 35 degrees. Little to no dark adaptation is possible. Ground texture is easily seen, and artificial light dominates the landscape. Visible constellations are limited to the very brightest if any. The sky has a uniform washed out appearance.[1]

If this describes your nighttime environment, continue below

If the nighttime environment appears darker than this description, jump to the next section

Sky appears nearly completely washed out, and is luminous. Dark adaptation is not possible, ground is brightly illuminated and fewer than 200 stars are visible. Only the most major constellations are identifiable. For instance, the entire keystone of Hercules or the five stars of Delphinus are not completely visible.

this is accurate **Bortle Class 9** if darker—proceed below

Constellations are visible but may be missing key stars, sky background has a uniform washed out glow with light domes reaching 60 degrees above the horizon. Stars such as the tip of Sagitta or epsilon Lyrae are not visible. If clouds are present they are brilliantly lit.

this is accurate **Bortle Class 8** if darker—proceed below

Brighter constellations are easily seen in full, yet sky background has greyish or yellow background. Milky Way may be just barely seen near the zenith. The Scutum and Cygnus star clouds are not visible.If clouds are present they are brilliantly lit. Ground texture is still visible.

this is accurate **Bortle Class 7**

The Milky Way is visible but discontinuous, and lost to light domes near the horizon. Fine details and structure are not easily visible, if at all. Ground texture is still visible, and shadows are cast from light pollution. Light domes are clearly visible along the horizon and appear brighter than any portion of the visible Milky Way.[2]

If this describes your nighttime environment, continue below

If the nighttime environment appears darker than this description, jump to the next section

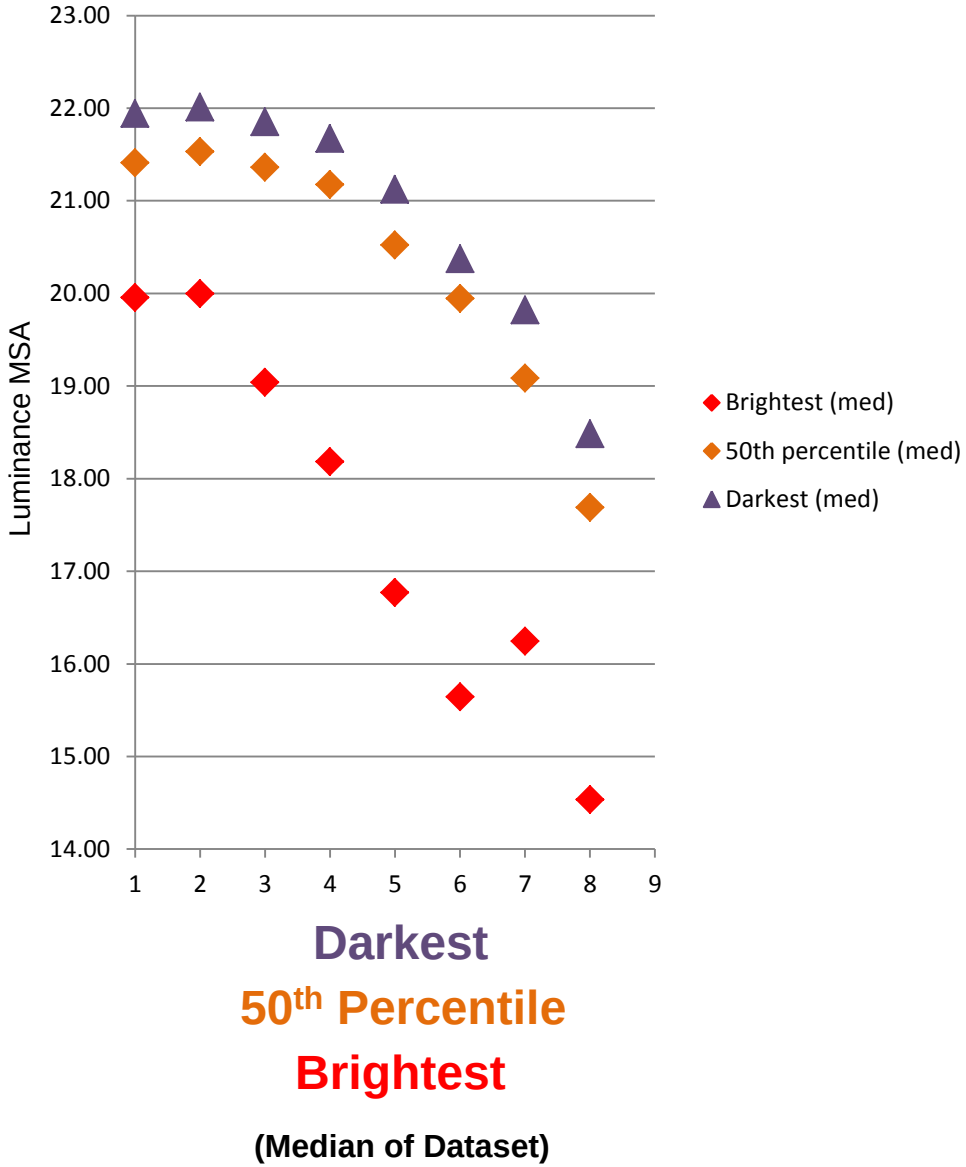
The Milky Way is just visible overhead, but is not continuous and is diminished to obvious skyglow. Cygnus ,Scutum, and Sagittarius star fields just visible. If clouds present they are illuminated and reflecting light. Ground texture is seen with difficulty.

this is accurate **Bortle Class 6** if darker—proceed below

Milky Way is faintly present, but may have occasional gaps and is lost to skyglow near the horizon. Great rift in Cygnus is just visible. Any clouds present are brighter than the background sky and reflect light back. Zodiacal light may be glimpsed, but is difficult to see amidst the light pollution.

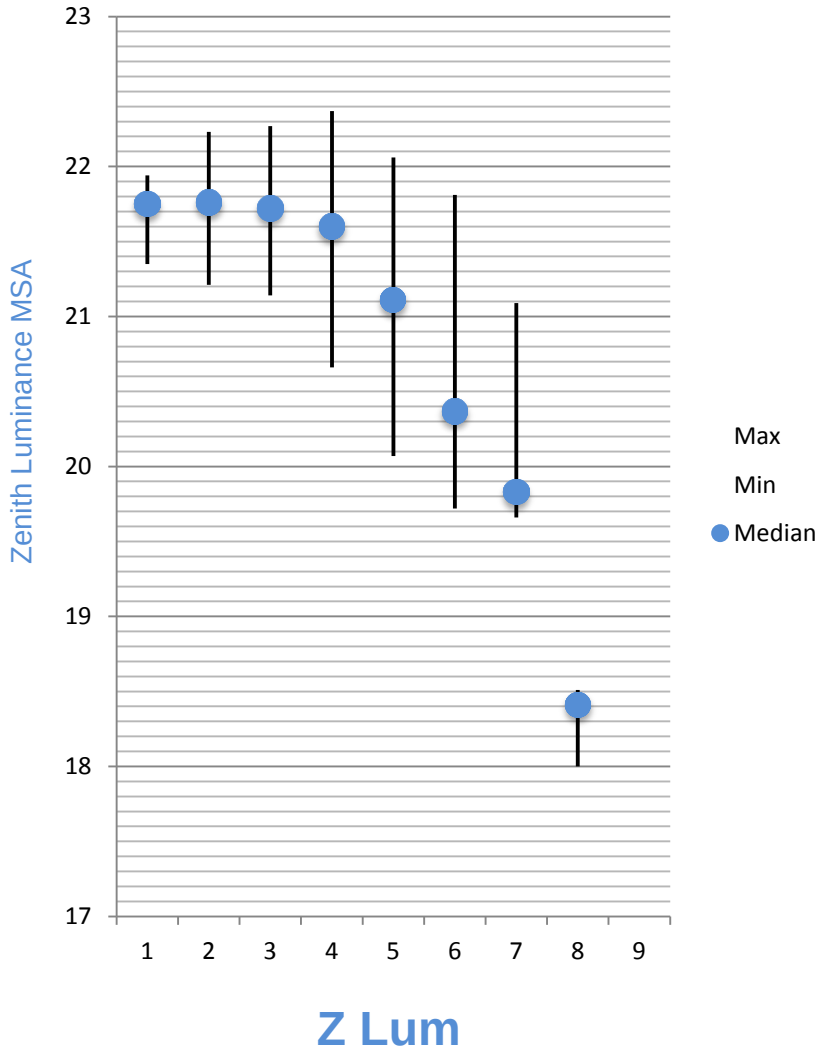
Approach — 2. Photometric Correlations

- Analysis of 340 nights show some metrics grade nicely between classes while others do not
- Bortle 1-3 difficult to determine based on photometrics alone
- Results can be used to improve dichotomous key and training techniques
- Best Correlations with Sky Quality Index, NELM

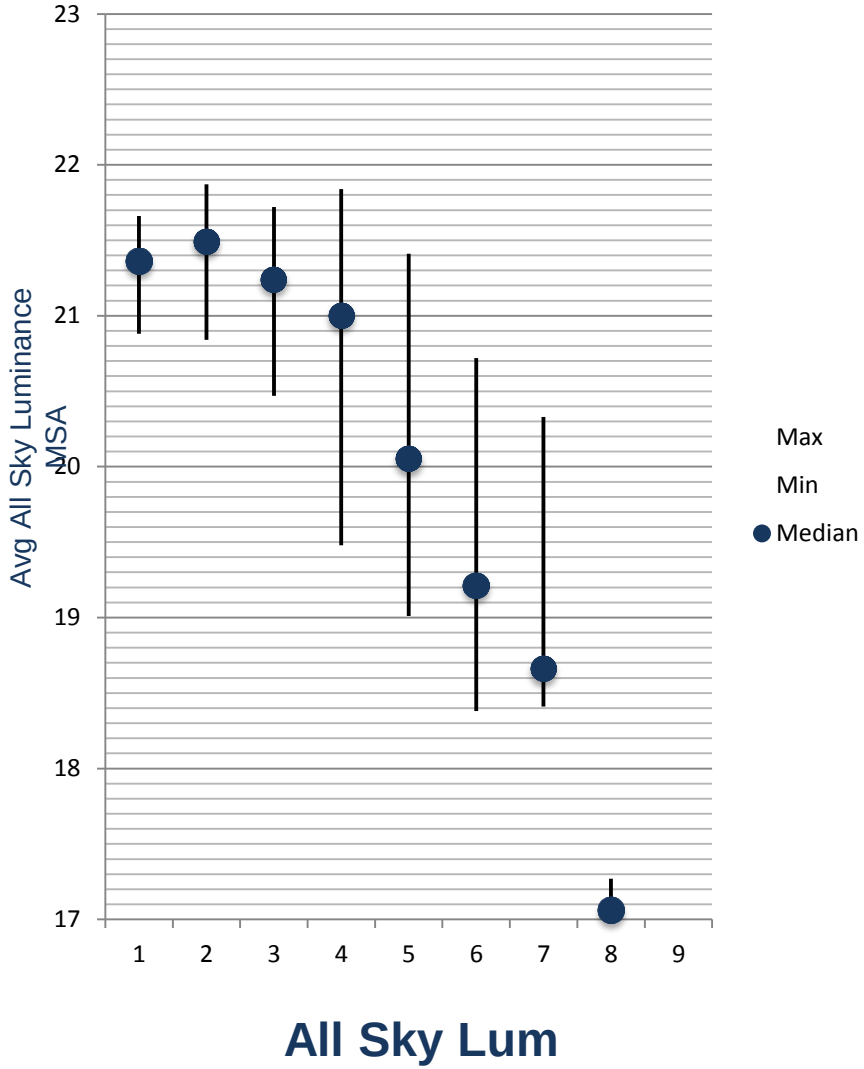


Number of Observations by Class

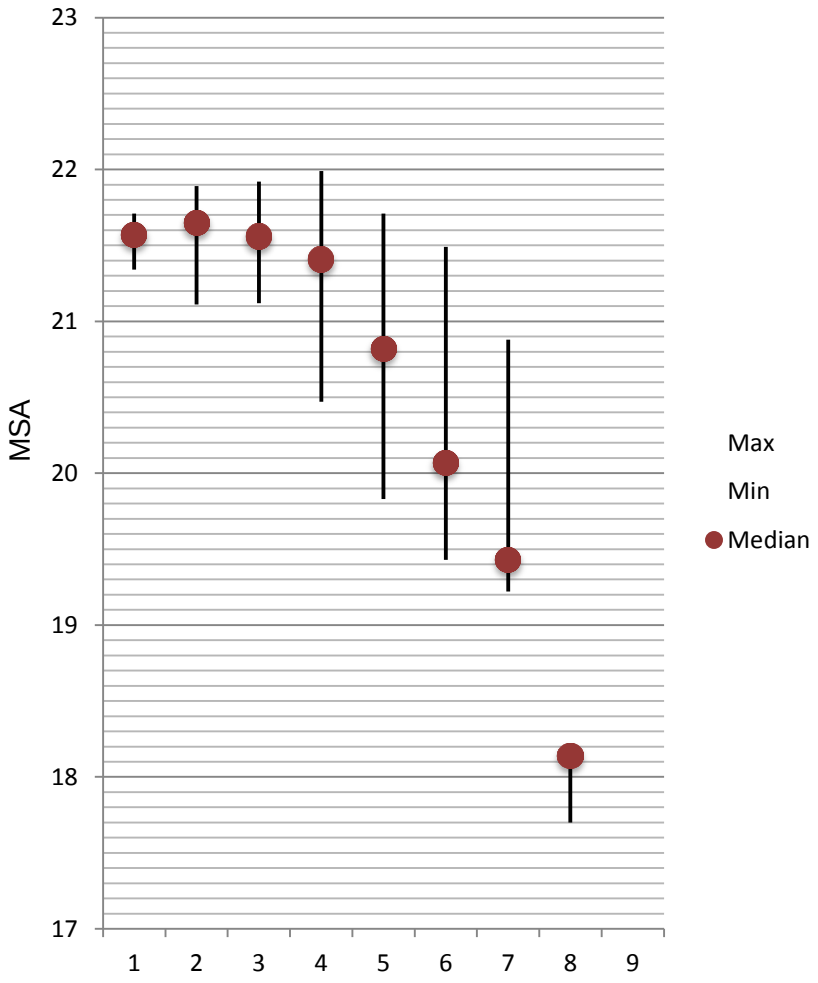
1	8
2	51
3	121
4	83
5	44
6	14
7	6
8	3
9	0



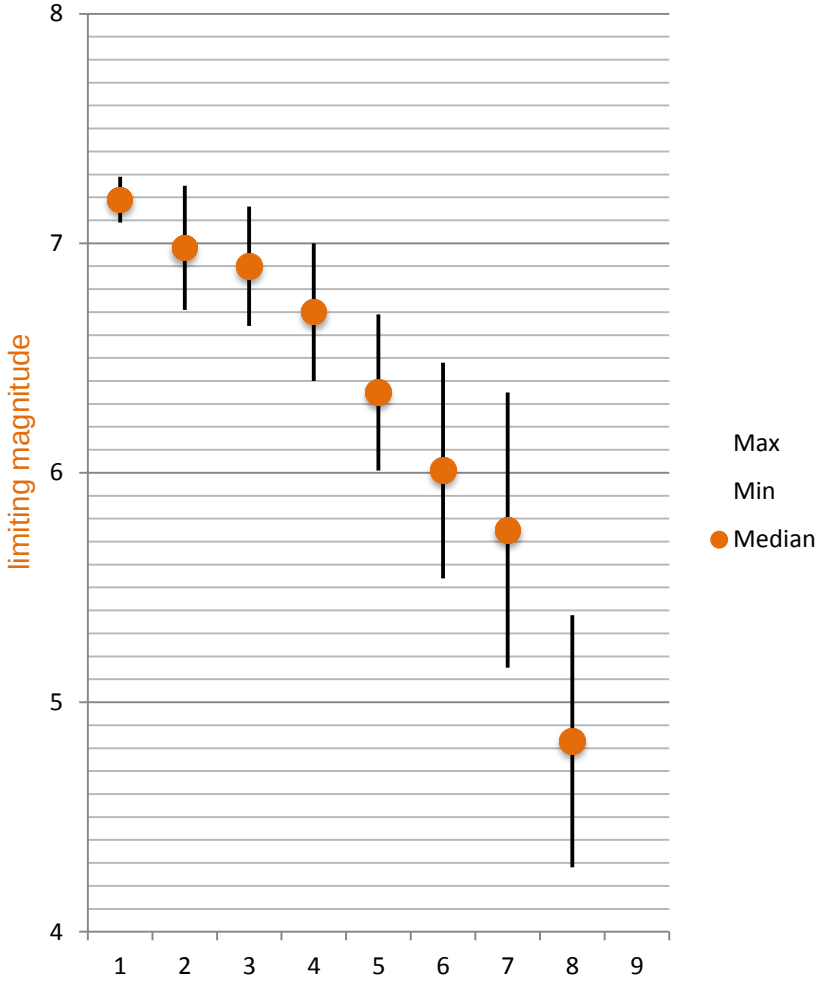
Z Lum



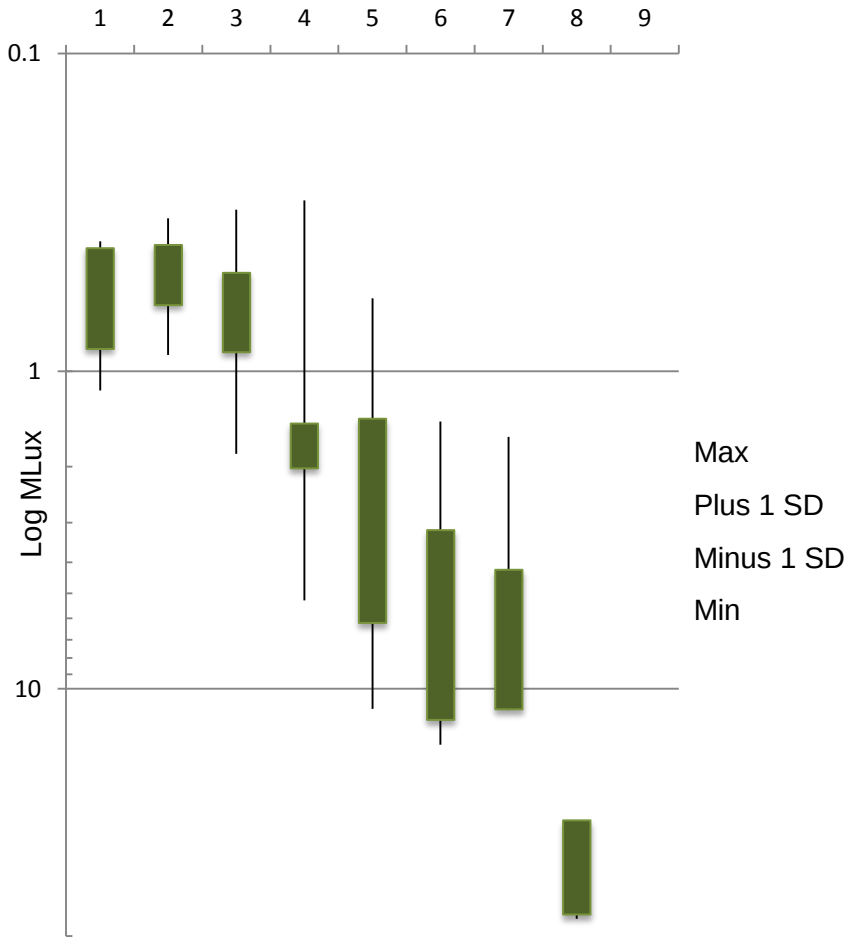
All Sky Lum



Synthetic SQM (wide)

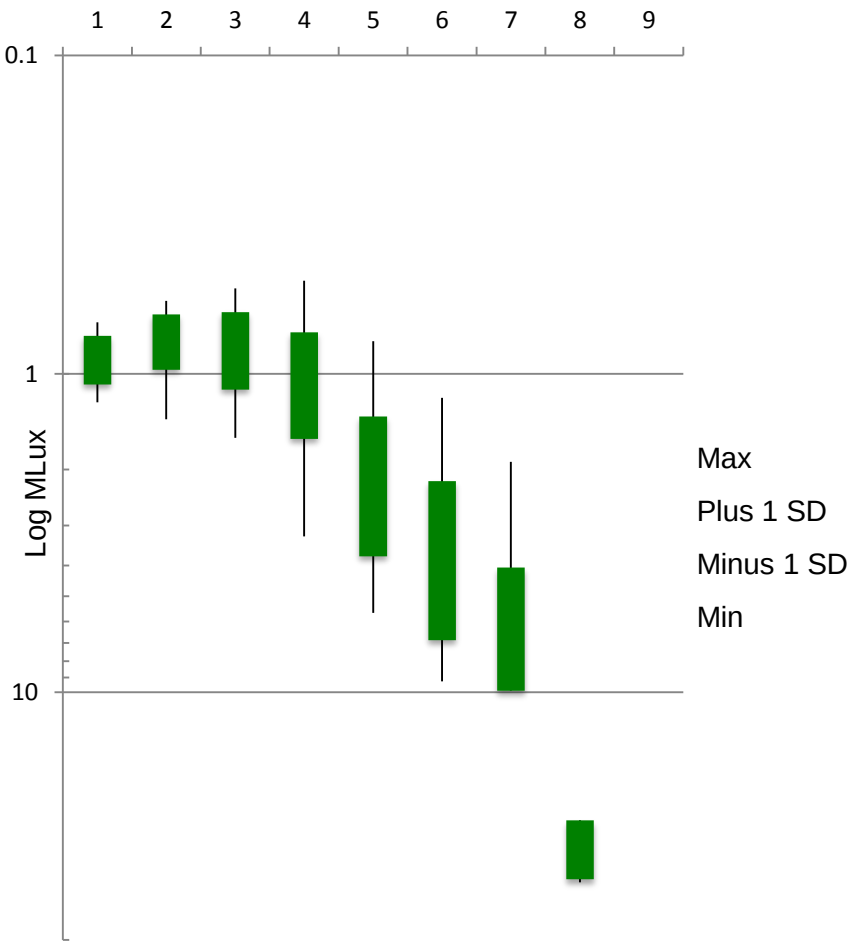


NELM



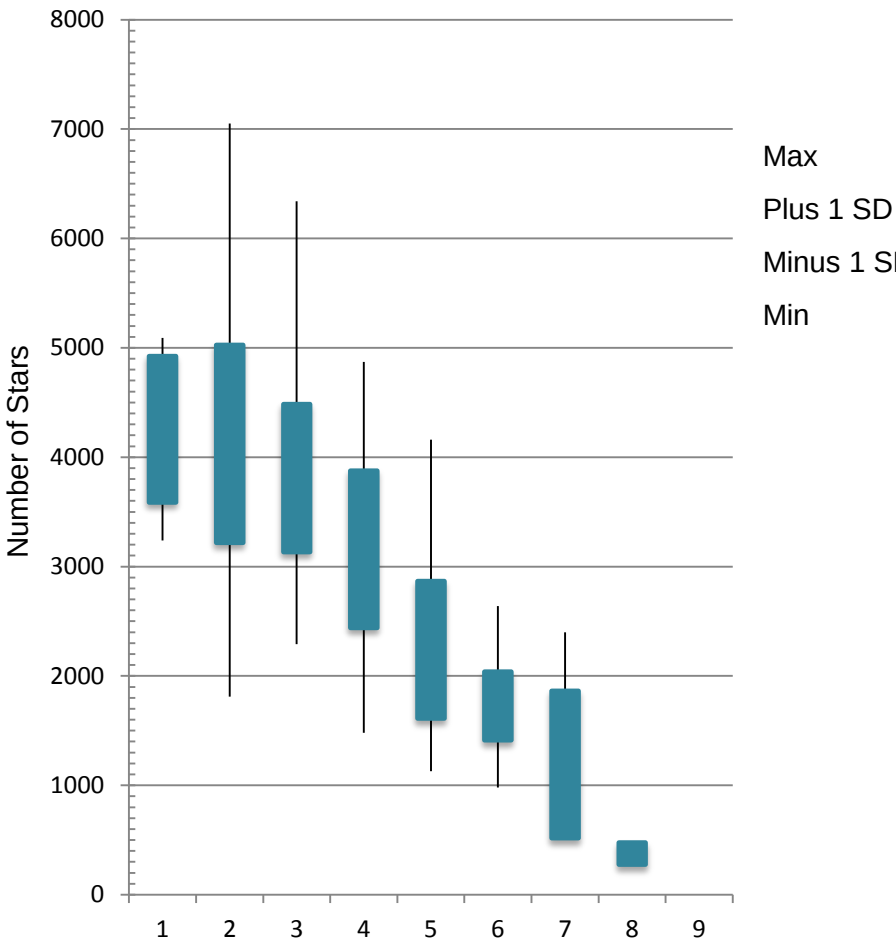
Vertical Illuminance

(MilliLux)



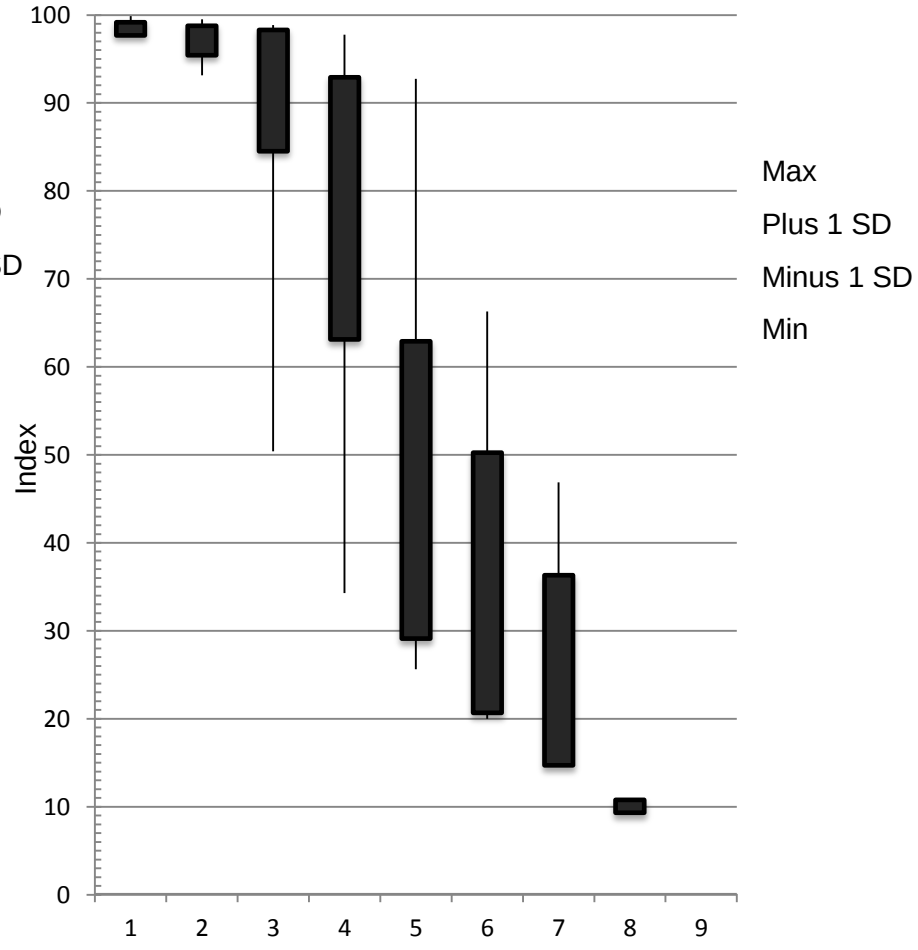
Horizontal Illuminance

(MilliLux)



Number Stars Visible

Synthetic Measure



Sky Quality Index

(Synthetic Index of 4 parameters)

Approach — 3. Expand Palette of Benchmark Objects

- Testing of several Messier objects in winter sky showed that better fidelity between classes can be achieved and multiple objects can be used as a benchmark — diffuse objects less affected by seeing and observer's visual acuity

- Need to identify more features of the Milky Way as benchmarks — for example Prancing Horse (i.e. Pipe Nebula) is marker for Bortle 3 when >20° above horizon

- Brian Skiff's online observations are another source of benchmarks

- Much work to do, possibly crowd source with amateur astronomy community

- Due to rarity, difficulty in developing palette for Class 1 & 2

Approach — 4. Resolution of "Problem Skies"

- Multiple criteria would best differentiate classes and address split personality skies — a lightscape need not have ALL the features, but should have most of the features of a class

- Suggest "What you see is what you get" for classification — an open field will classify differently than a nearby field with high trees, with allowances for nearby glare sources

- For each class, we can publish a range of values for other parameters (e.g. NELM, SQM, SQI) that will allow a cross-walk between systems

- Input appreciated!

Summary

- Bortle Class is a synthesis of visual effects of artificial light at night, atmospheric conditions, and observer skill upon the aesthetic quality of the night sky

- For the darker classes, visual observations are much better at resolving the classes than simple photometric methods

- The challenge objects take time, skill, and patience to find, as well as NELM

- The NPS Sky Quality Index appears to correlate well with Bortle class if photometric measures of artificial sky glow are to be used alone.

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