Dark and Quiet Skies for Science and Society

UNITED NATIONS
Office for Outer Space Affairs

International Astronomical Union

With the support of NOIRLab

Dark and Quiet Skies for Science and Society

Opening Remarks

SOC Member
José Miguel R. Espinosa
Assist. Gen. Secretary,
IAU
& IAC, Spain

UNITED NATIONS
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Opening Remarks
Special Guest
Rafael Rebolo
Director, IAC

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Dark and Quiet Skies for Science and Society

Optical Observatories
15:00 – 17:00 UTC

Notes & Introductions
SOC Member/Moderator
Casiana Muñoz-Tuñon
(WG co-chair)
IAC

DARK & QUIET SKIES

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INSTITUTO DE ASTROFISICA DE CANARIAS · IAC ·

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Dark and Quiet Skies for Science and Society: Draft Reports

Five Draft Reports are available and open for comments until 16 October

- Download them from http://bit.ly/DQS_reports
- Please comment recommendations at http://bit.ly/DQS_comment

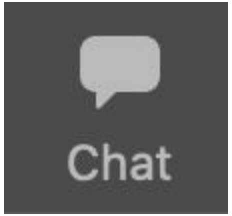
If you registered for today's Workshop then you have received the links on Thursday in an email from UNOOSA-Events@un.org and on Friday in an email from DQSkies@iac.es

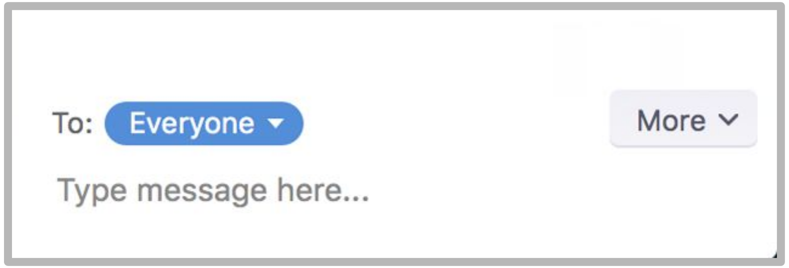
Not received even though you had registered? Please email UNOOSA-Events@un.org

Zoom Meeting Housekeeping

Have a question?

- Use the chat at any time
- Keep it short!





Participants will **not** be unmuted
Q&A monitors will read a subset of questions

Optical Astronomy WG Members

Juan Pablo Armas, Martin Aubé, John Barentine, Zouhair Benkhaldoun, Chris Benn, Peter Blattner, Costis Bouroussis, Javier Diaz Castro, Maurice Donners, Bryan Douglas, Dionýz Gašparovský, ***Richard Green (Chair)****, Jeffrey Hall, John Hearnshaw, Zoltán Kolláth, Casiana Muñoz Tuñon (Co-Chair), Kathryn Nield, Steve Lau, Tomas Novak, Sergio Ortolani, Jose Miguel Rodriguez Espinosa, Pedro Sanhueza, Antonia M. Varela Pérez & Constance Walker.*

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Dark Sky Protection for Optical Observatories

Richard Green, Ph.D.

University of Arizona, Steward Observatory

USA

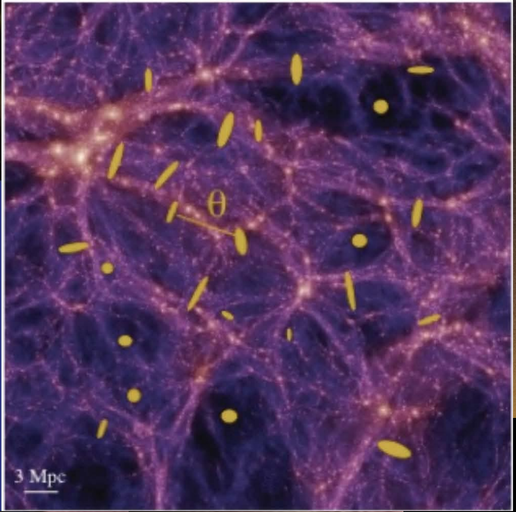
Member of the SOC and Co-Chair Optical Astronomy Working Group

Ground-based Observatories Are Critical to the Mission of COPUOS

- Ground-based optical/IR telescopes can be built at a substantially larger scale and lower cost per unit collecting area than those launched into orbit.
- There are 40 telescopes in the world with mirrors of effective diameter 3 m - 11 m, sited in the U.S., Chile, Spain, South Africa, Russia, China, Australia, and India, constituting a world-wide investment. (None yet in orbit.)
- They support the mission of COPUOS:
    - They directly enable “continued research and the dissemination of information on outer space matters”.
    - They are often essential to interpret observations from space-based telescopes.
    - They provide the critical data for planetary defence and key aspects of space situational awareness.

Ground-based Observatories Remain the Engines of Cutting-Edge Scientific Discovery

- The Vera Rubin Observatory, being constructed in Chile, will provide the shapes for billions of faint galaxies, yielding the distribution and amount of Dark Matter.
- Tracing the filamentary cosmic web of gas requires thousands of blue-green spectra from DESI on Kitt Peak and 4MOST at ESO.



Strong lensing in galaxy cluster Abell 2218 above stretches background galaxy images into long arcs.
The matter in the 'Cosmic Web' (right) creates slight elongations as modeled.

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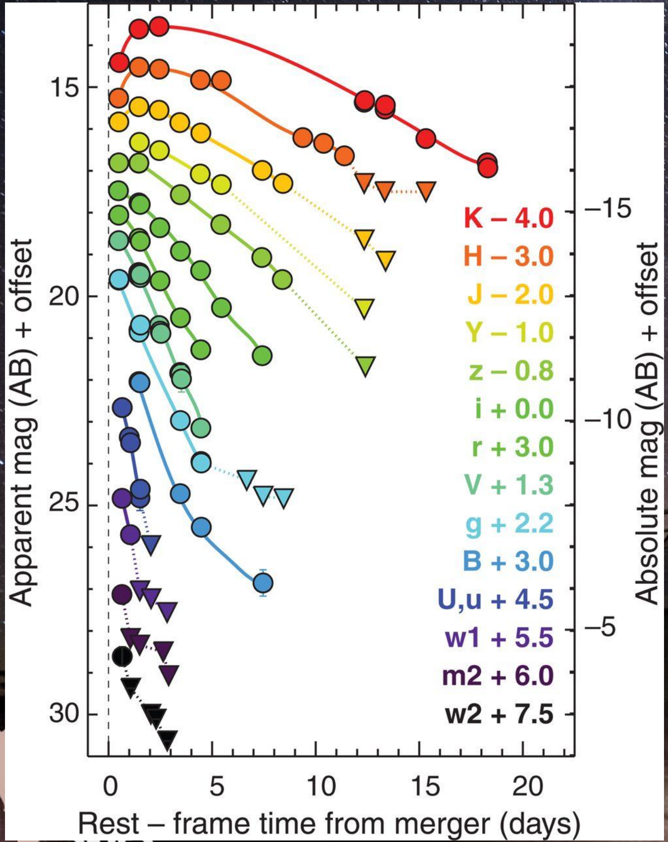
Ground-based Observatories Remain the Engines of Cutting-Edge Scientific Discovery



Capturing the rapidly fading optical transients from the merger of neutron stars generating gravitational waves requires multiple instruments.

The advance detection of small potentially hazardous asteroids is enabled by dark sky backgrounds.

Rapidly Growing Artificial Skyglow Puts World Observatories under Threat

- In the past decade, the globally averaged rate of increase was 2% per year in terms of both lit area and total radiance, roughly double the rate of world population growth during the same period.
- This increase is mainly related to three factors: the increase of the global population, economic growth, and the reduction of illumination costs.
- Population growth and resource development has created measurable artificial light contribution at major professional sites such as those in southern Arizona, California, New Mexico, Texas, north-central Chile, the Canary Islands and southern Spain.

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Light Domes from Distant Cities Can Impact Major Observatories

Light domes from Tucson (120 km - 1 million population) and Phoenix (220 km - 4 million population), Arizona from the summit of Mt. Graham, site of the world’s largest optical telescope. (M. Pedani)

Rapidly Growing Artificial Skyglow Puts World Observatories under Threat

- The International Astronomical Union (IAU) has defined the upper limit of artificial light contribution for a professional site adequate for true dark-sky observing to be <10% at an elevation of 45° in any azimuthal direction.
- Most of those observatories with 4-10-m-diameter telescopes still fall within the IAU definition of dark sites, but many of them require strong cooperation from the surrounding population and regulation and enforcement by government entities to maintain that status.
- The exposure time needed to reach a given signal-to-noise when observing a faint object is typically proportional to the intensity of the sky background. If the artificial contribution reaches 10%, less science can be done with the (expensive) telescope time available, and with further brightening, the faintest objects cannot be observed at all.

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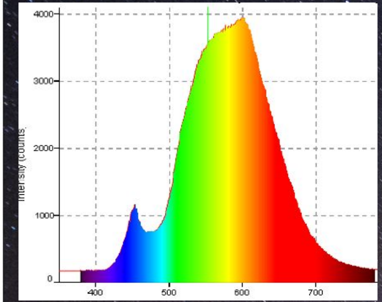
Solid-State Lighting Holds Threats and Benefits



- Solid state LED lighting provides genuine threats to astronomy:
  - Higher blue content of white LED lighting scatters more efficiently in the atmosphere, compared to earlier lighting technologies.
  - The high energy efficiency and relatively low cost of operation of LEDs is fueling elastic demand for the consumption of light, leading to higher overall light emissions.
- Solid state LED lighting can provide genuine benefits to astronomy:
  - LED flux can be easily controlled as a function of the time of night in accordance with the targeted usage.
  - LED luminaires can be better focused on the surfaces that require lighting, with less light spill and no upward light emissions.
  - The spectral energy distribution of LEDs can be chosen to minimize undesired short wavelength emission and limit spectral bandwidth.

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Goal of Recommended Framework

- The newest professional observatories have been located at sites that are significantly below the IAU limit of artificial light contamination.
- Therefore, the goal is defined to slow and reverse the rate of increase of artificial skyglow appropriate to each site.
- **The goal of the model regulatory framework proposed for COPUOS consideration is to reduce the current rate of increasing artificial skyglow at major professional observatories by a factor of two or more over the next decade and to achieve a decreasing rate of additional skyglow in the following decade for these sites.**

Purpose of COPUOS Endorsement

- Major observatories are now typically funded and operated by international consortia, but they are situated in individual countries whose own laws apply to light pollution control.
- The Working Group draft report provides a suite of recommended regulations on regional scale to protect observatory dark skies.
- COPUOS endorsement will provide a strong impetus for national and local governments to provide such protection.

Basis of Recommended Framework

- Take the approach of quality lighting design to match the illumination level to need, to limit unnecessary spectral content, to use precise optics to minimise spill light, and to employ active control to reduce light levels when usage is low.
- Define a near zone in proximity to professional observing sites, within which both lighting levels and color rendition are sharply limited, and beyond satisfying basic safety requirements, must be justified to exceed the tightly prescribed limits. Radius ~30 km.
- For those urban areas for which light domes impact an observatory's skyglow at more than 30^0 above its horizon, invoke the tightest limits on the range of recommended best practice and standards, along with active controls to reduce lighting levels when possible. Radius up to 300 km or more, depending on impact.

Determination of Artificial Skyglow

- A truly dark astronomical site has only a few percent of the natural sky glow at zenith contributed by scattering of artificial sources.
- Finding the contribution of artificial sky glow depends on both measurement and modeling.
- Determination from “top down” (satellite) measurements depends on a spectral source function for aggregate outdoor lighting and radiative transfer model.
- Determination from “bottom up” (sky monitor) measurements depends on accurate removal of celestial sources and natural sky glow, which is impacted by solar activity.

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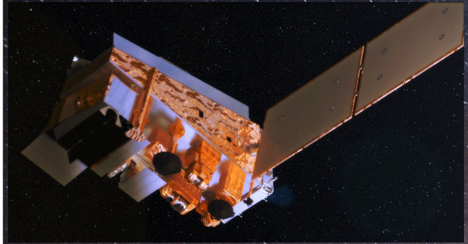
Measurement and Modelling from Orbital Reconnaissance



SUOMI- NPP
NASA/GSFC

- **Strengths**
  - Visible-Infrared Radiometer Suite (VIIRS) on the Suomi NPP down-looking weather satellite data
  - Scanning CCD with broad 500-850 nm bandpass (green through deep red)
  - Similar time of night, clear, no snowpack
  - Uniformly correlated with up-looking Sky Quality Monitors
- **Limitations**
  - Assumption of uniform aerosol content overestimates scattering for most remote dry sites
  - Instrument response cutting on in the green doesn't directly measure impact of white-light LEDs as replacement for low- or high-pressure sodium.

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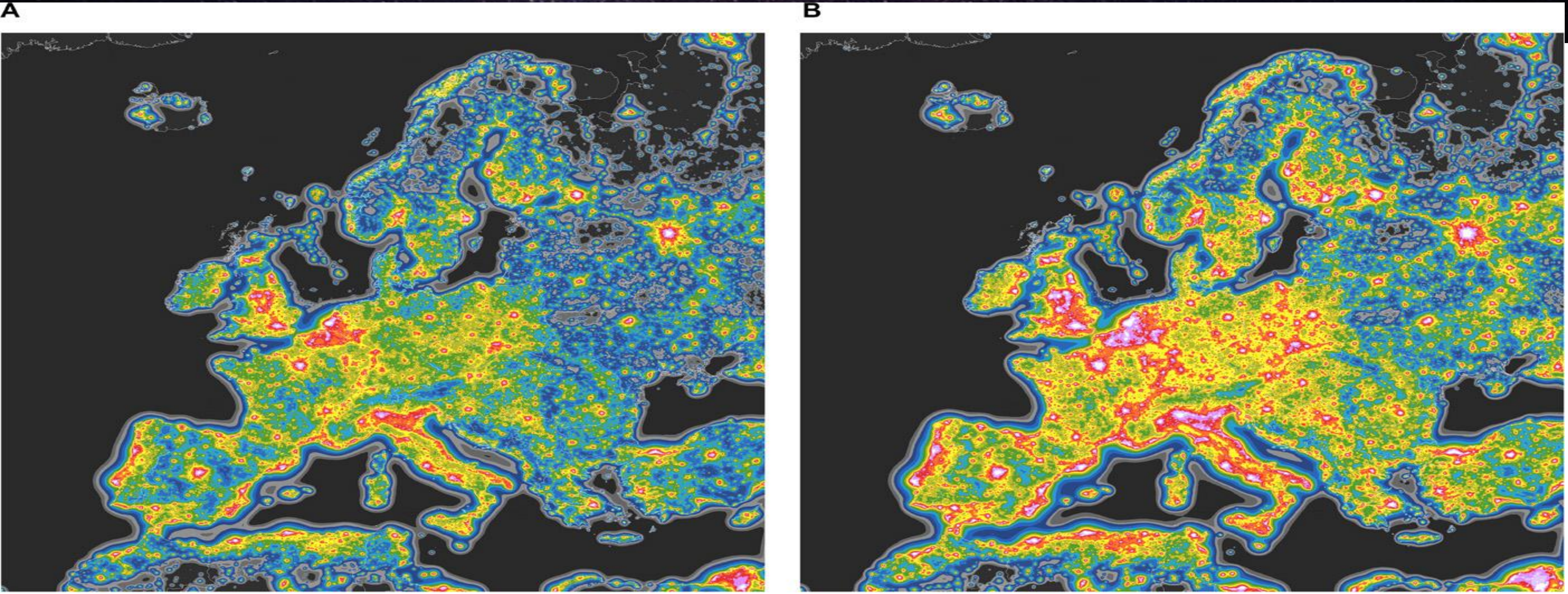
Modeling Artificial Skyglow from Weather Satellite Measurements



Star Light Index maps from Falchi et al. (2016) showing how heavily the night sky will be polluted in the scotopic band. The step from one colour to the next is a doubling of the sky brightness. The right side shows the impact of bluer LEDs compared to the satellite bandpass (>500 nm) on the left.

Uniform Protocol for Ground-based Upward Measurement

To establish the contribution of artificial skyglow and rate of change, professional observatories are urged to begin/continue campaigns of systematic monitoring, with a uniform protocol and calibration.

- Moon at least ten degrees below the horizon.
- No clouds, fog, high aerosol content, or auroral activity.
- The Sun is at least 18 degrees below the horizon (astronomical twilight).
- Consistent set of spectral bandpasses and altitude-azimuth range.
- No direct light from artificial sources reaching the detector or the camera.
- High Galactic latitude and high ecliptic latitude (if pointed as opposed to all-sky).

Ground-based Measurement Contains Natural Diffuse Sources to be Removed to Determine Artificial Skyglow

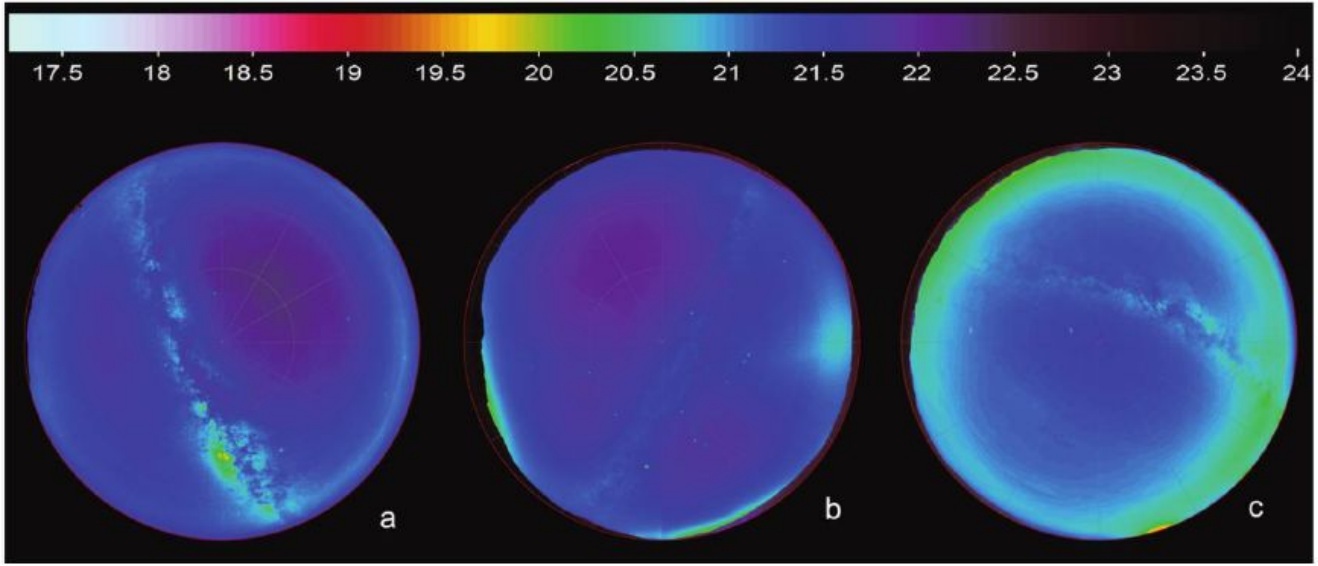


FIG. 1.—Panels (*a*), (*b*), and (*c*) illustrate the brightness of the night sky in false color in a fisheye projection from three different locations remote from anthropogenic skyglow: Mauna Kea, Hawai'i, Death Valley National Park, California, and Great Sand Dunes National Park, Colorado. These maps illustrate different appearances of the night sky including: when the northern hemisphere summer Milky Way is dominant, when the northern hemisphere winter Milky Way is overhead and the Zodiacal Light is prominent, and where the natural airglow is dominant. Each image was created by the sky brightness camera of the NPS all-sky mosaicking system. The color map scale at top, in V mag arcsec^{-2}, applies to all figures which display sky brightness in this paper.

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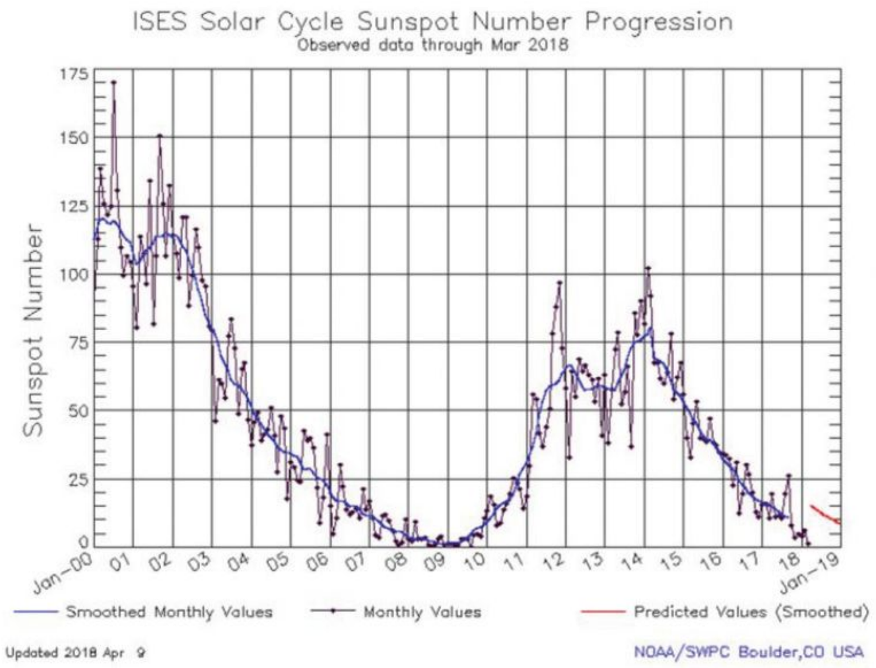
- Sources include natural air glow, starlight and the Milky Way, Zodiacal light, and multiple scatterings, which must all be modelled. (Duriscoe 2013)

Natural Skyglow has long-term variations from Solar Activity

- Most of the natural sky glow is from excitation of molecules in the Earth's atmosphere.
- The level can vary by as much as 0.4-0.5 mag in V-band from solar maximum to solar minimum.
- Sunspot number is a proxy for that activity; the skyglow is directly correlated with 10.7 cm solar radio flux variation on long timescales.



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Adopt System of Calibration to SI Units

- Astronomers gauge a pristine dark site in their measured units of mag / sq arcsec; in V band, that is around 22.0.
- In engineering units, that is 174 micro-candela / m^2.
- For matters requiring a decision process and the influence of stray optical radiation on astronomical observations, it is worthwhile to establish a common standard that is compatible with standards definitions and traceable to SI units.
- The ‘continuous’ component of the natural sky (zodiacal light, scattered starlight and airglow pseudo-continuum) is nearly constant at all visible wavelengths and has a spectral radiance of ~2 nW m^{-2} sr^{-1} nm^{-1}, or 2 *dsu* (dark sky units).

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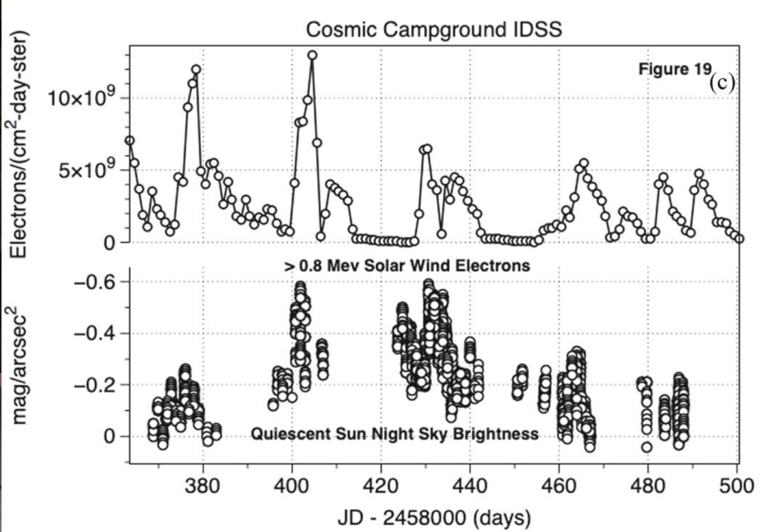
Adopt System of Calibration to SI Units

- Because of the relatively limited range of broad-band color variations of skyglow under clear, moonless conditions, digital camera-based, three-colour (RGB) radiance measurements in dsu give a usable sky brightness measurement.
- The hourly and nightly variations in natural skyglow can be > 10 %. Therefore, an accuracy of 5 % or better for long-term characterization of an astronomical site is sufficient. High-quality cameras can provide ~2 % accuracy, more than adequate for the task.
- Major observatories are urged to adopt the dsu as standard calibration for skyglow measurements.



Grauer+ (2019) PASP, 131.

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Recommended Skyglow Monitoring and Data Aggregation

- **Each professional observatory with programmes requiring limiting dark-sky data for which regulation of artificial skyglow is critical should obtain a current baseline and well-sampled time series of night sky brightness measurements.**
- That information is critical for objective assessment of the efficacy of regulation and for demonstrating to policy makers and implementers that the astronomers value and need their efforts.
- **International astronomical organisations are advised to form and support a data repository with consistent formatting to aggregate and make publicly available the sky monitoring data collected.**

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Special Circumstances for Remote Observatory Sites

- Mines, wind farms, military installations, border control
  - All with lighting guidance and regulation typically beyond local control
- **Recommendation: Special use cases in remote areas to employ fixtures consistent with the near-zone regulations to the maximum degree possible, consistent with safety and national and local regulations. Direct uplight and colour rendition should be employed if and only if absolutely necessary as required by safety or regulatory requirements.**
- **Recommendation: Civilian regulators and military flight planners should exclude the observatory near zones from approved flight paths, and keep those paths as far from observatories as practicable.**

Other Incentives for Protection of Observatory Dark Skies

- In promoting the adoption of regulations protecting the dark skies of observatories, local governments can be incentivised by corollary benefits.

- Sustainability
  - Protection of dark skies is an environmental goal per se.
  - Consider total cost of lighting to include impact as well as production.
  - Bank reduced costs of Solid State Lighting for other public good rather than providing more public lighting at the same cost.

- Observatories are sometimes co-located with designated natural areas, creating synergies for mutual dark sky protection.

- The WG hypothesises that the same quality lighting design that is best for minimizing light pollution is also most conducive to public safety, by carefully targeting light to outdoor task performance at night.

Recommendations for Urban Areas and Near Zones

- Following are the two suites of recommendations to limit artificial skyglow at professional observatories.
- The first, by Dionýz Gašparovský of CIE, concentrates on the best practices for urban lighting, in the specific case where the light dome impacts a nearby observatory. Although cast in terms of current documented standards and recommendations, the intention is for model regulations to be based on the most up-to-date versions.
- The second, by Martin Aubé, concentrates on the near zones around observatories and on the particular requirements for spectral control and shielding.

Thanks

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Outdoor lighting recommendations and protection of observatories

Dionýz Gašparovský

Slovenská technická univerzita v Bratislave, Slovakia; CIE

Optical Astronomy Working Group

Outdoor lighting recommendations and protection of observatories

1. <u>International Commission on Illumination (CIE)</u>

- At the international level, recommendations for various lighting applications are developed and provided by the CIE
- Independent, non-profit organization with strong technical, scientific and cultural foundation
- Recognized by CIPM, ISO and IEC as a standardization body across its scope , publishing international standards for basic research on light and lighting
- Many national and regional regulations and norms are based on or refer to CIE publications

cie
International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

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Outdoor lighting recommendations and protection of observatories

1. International Commission on Illumination (CIE)

Overview of selected CIE publications on lighting recommendations:

CIE 115:2010 Lighting of Roads for Motor and Pedestrian Traffic

CIE 236:2019 Lighting for Pedestrians: A Summary of Empirical Data

CIE S 015/E:2005 Lighting of Outdoor Workplaces

CIE 083:2019 Guide for the Lighting of Sports Events for Colour Television and Film Systems, 3rd Edition

CIE 234:2019 A Guide to Urban Lighting Masterplanning

CIE 094-1993 Guide for Floodlighting

Outdoor lighting recommendations and protection of observatories

1. International Commission on Illumination (CIE)

Overview of CIE publications on obtrusive light:

CIE 001-1980 Guidelines for minimizing urban sky glow near astronomical observatories

CIE 126-1997 Guidelines for minimizing sky glow

CIE 150:2017 Guide on the Limitation of the Effects of Obtrusive Light from Outdoor Lighting Installations, 2nd Edition

Outdoor lighting recommendations and protection of observatories

1. International Commission on Illumination (CIE)

Current CIE works related to obtrusive light problems:

TC 4-58 Obtrusive Light from Colourful and Dynamic Lighting and its Limitation

TC 4-61 Artificial Lighting and its Impact on the Natural Environment

TC 4-62 Adaptive Road Lighting

DR 4-53 Environmental Aspects of Obtrusive Light from Outdoor Lighting Installations

Outdoor lighting recommendations and protection of observatories

1. <u>International Commission on Illumination (CIE)</u>

Terminology according to CIE S 017 International Lighting Vocabulary (ILV):

- Light pollution: generic term indicating the sum total of all adverse effects of artificial light
- Obtrusive light: spill light which, because of quantitative or directional attributes, gives rise to annoyance, discomfort, distraction, or a reduction in ability to see essential information such as transport signals
- Spill light: light emitted by a lighting installation which falls outside the boundaries of the property for which the lighting installation is designed

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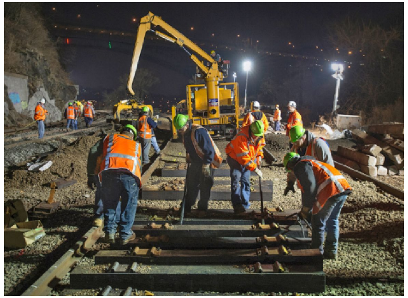
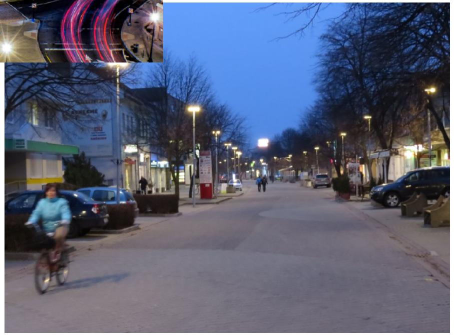
Outdoor lighting recommendations and protection of observatories

2. Diversity of outdoor lighting applications


ROADWAYS


MEANS OF TRANSPORTATION


OUTDOOR WORKPLACES


PEDESTRIANS & CYCLISTS


FLOODLIGHTING


SPORTS LIGHTING

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Outdoor lighting recommendations and protection of observatories

3. Road lighting recommendations

Table: Lighting levels for motorized traffic (based on road surface luminance)

Lighting class	L_{av} (cd.m^{-2})	U_o	U_l	f_{TI} (%)	R_s
M1	2,0	0,40	0,70	10	0,5
M2	1,5	0,40	0,70	10	0,5
M3	1,0	0,40	0,60	15	0,5
M4	0,75	0,40	0,60	15	0,5
M5	0,50	0,35	0,40	15	0,5
M6	0,30	0,35	0,40	20	0,5

Luminance levels

Other parameters

- Overall uniformity
- Longitudinal uniformity
- Threshold Increment
- Surround Ratio / Edge Illuminance Ratio

Outdoor lighting recommendations and protection of observatories

3. Road lighting recommendations

Table: Lighting classes for pedestrian and low-speed traffic areas

Lighting class	$E_{h,av}$ (lx)	$E_{h,min}$ (lx)	$E_{v,min}$ (lx)	$E_{sc,min}$ (lx)
P1	15	3,0	5,0	3,0
P2	10	2,0	3,0	2,0
P3	7,5	1,5	2,5	1,5
P4	5,0	1,0	1,5	1,0
P5	3,0	0,6	1,0	0,6
P6	2,0	0,4	0,6	0,4

Horizontal illuminance levels

Additional requirement if facial recognition is necessary

- Vertical illuminance
- Semicylindrical illuminance

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4. Recommendations on lighting of outdoor workplaces and area lighting

Wide range of applications:

- building sites
- parking lots
- farms
- industrial yards and storage areas
- petrochemical and other hazardous industries
- water and sewage plants
- saw mills
- power plants
- railway areas
- harbours
- shipyards and docks
- airports
- etc.

4. Recommendations on lighting of outdoor workplaces and area lighting

Table: Recommended lighting requirements for safety and security

Risk level	E_m (lx)	U_o	GR_L	R_a
Very low risk	5	0,25	55	20
Low risk	10	0,4	50	20
Medium risk	20	0,4	50	20
High risk	50	0,4	45	20

Illuminance levels

Other parameters

- Overall uniformity
- Glare Rating (limit)
- Colour Rendering Index
- Additional remarks

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Outdoor lighting recommendations and protection of observatories

4. <u>Recommendations on lighting of outdoor workplaces and area lighting</u>

- to provide appropriate visual conditions, the values of illuminance can be considerably higher, in the most visually demanding applications even up to 300 lx (compare to road lighting!)
- outdoors usually large areas are illuminated
- careful lighting design is very important to focus the lighting onto clearly demarcated target area – consisting of the task area and surrounding area as specified in the standard

Lighting of outdoor workplaces is major contributor to obtrusive light!

4. Recommendations on lighting of outdoor workplaces and area lighting

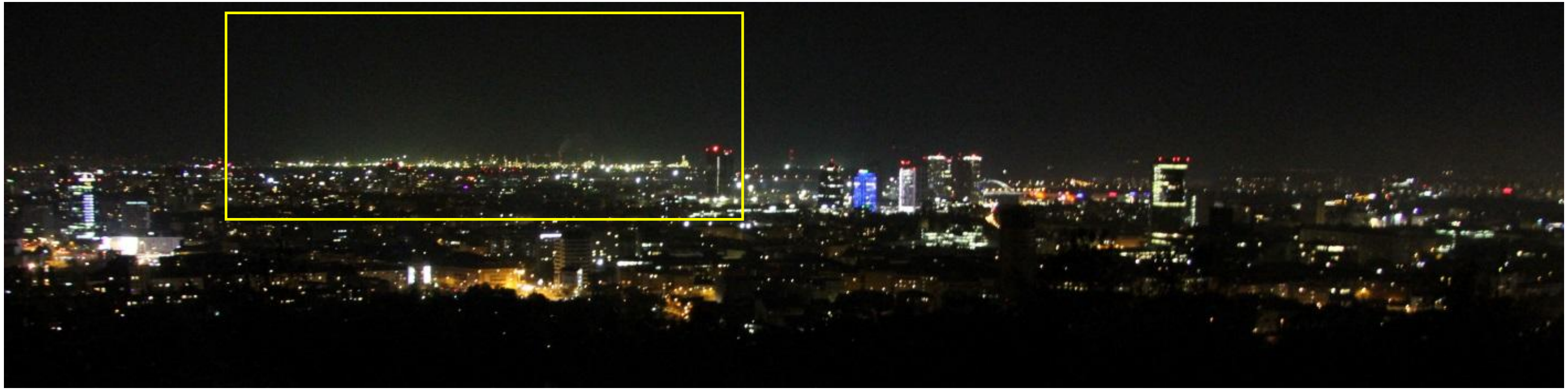

Figure ALAN in Bratislava (Slovakia) visible from the Mt. Koliba with contributions from interior lighting, floodlighted and luminous facades of buildings, intensively illuminated squares; light dome is well visible over the citie’s industrial zone Vlcie Hrdlo with a large refinery yard in the background

Outdoor lighting recommendations and protection of observatories

5. <u>Limiting the obtrusive light from outdoor lighting installations</u>

Recommended maximum values of luminous parameters to control obtrusive light:

- Limitation of illumination on surrounding properties (light intrusion) – vertical illuminance on properties
- Limitation of bright luminaires in the field of view – luminous intensity of luminaires in designated directions
- Limitation of the effects on transport systems – threshold increment and veiling luminance from non-road lighting installations
- Limitation of sky glow – ULR of luminaires and UFR of lighting installations
- Limitation of the effects of over-lit building façades and signs – surface luminance

Outdoor lighting recommendations and protection of observatories

5. Limiting the obtrusive light from outdoor lighting installations

Table: CIE Environmental zones

Zone	Lighting Environment	Examples	Additional recommendations
E0	Intrinsically dark	UNESCO Starlight Reserves, IDA Dark Sky Parks, Major optical observatories	All locations within 100 km of a major optical astronomy observatory regardless of the level of urban development
E1	Dark	Relatively uninhabited rural areas	
E2	Low district brightness	Sparsely inhabited rural areas	Locations within 30 km of an operating urban optical astronomy observatory and locations between 100 km and 300 km from a major optical astronomy observatory regardless of
E3	Medium district	Well inhabited rural and urban settlements	
E4	High district bightness	Town and city centres and other commercial areas	

Environmental zones:

area where specific activities take place or are planned and where specific requirements for the restriction of obtrusive light are recommended

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Outdoor lighting recommendations and protection of observatories

5. Limiting the obtrusive light from outdoor lighting installations

Table: Maximum values of Upward Light Ratio (ULR) of luminaires and Upward Flux Ratio (UFR) of lighting installations

Light Technical Parameter	Type of installation	Environmental Zone				
		E0	E1	E2	E3	E4
Upward Light Ratio (ULR)		0 %	0 %	2,5 %	5 %	15 %
Upward Flux Ration (UFR)	Road	N/A	2 %	5 %	8 %	12 %
	Amenity	N/A	N/A	6 %	12 %	35 %
	Sports	N/A	N/A	2 %	6 %	15 %

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Outdoor lighting recommendations and protection of observatories

5. <u>Limiting the obtrusive light from outdoor lighting installations</u>

- Upward Light Ratio (ULR): proportion of the flux of a luminaire or installation that is emitted, at and above the horizontal, when the luminaire(s) is (are) mounted in its (their) installed position – for comparison of luminaires
- Upward Flux Ratio (UFR): ratio of the luminous flux above the horizon resulting from all the luminaires, reflected from the surface area intentionally lit, and reflected from the surrounding surface areas lit unintentionally because of spill light, to the luminous flux above the horizon in the hypothetical ideal situation where the luminaires have no direct light radiated above the horizon, and all their light is is concentrated only to the surface area lit intentionally and that area has exactly the required lighting level – for comparison of lighting installations

5. Limiting the obtrusive light from outdoor lighting installations

Table: Maximum permitted values of average surface luminance

Environmental zone	Building facade L_b (cd.m^{-2})	Sign L_s (cd.m^{-2})
E0	< 0,1	< 0,1
E1	< 0,1	50
E2	5	400
E3	10	800
E4	25	1 000
The values apply for both pre- and post-curfew, except that in Zones 0 and 1 the values shall be ZERO post-curfew		
The values for signs do not apply to signs for traffic control purposes		

BUT:
large areas

BUT:
small areas

5. <u>Limiting the obtrusive light from outdoor lighting installations</u>

Urban lighting:

- avoiding light trespass into interiors
- following the lighting masterplan (CIE 234)
- avoiding ratcheting (continuous increase of the lighting levels)

5. Limiting the obtrusive light from outdoor lighting installations

Lighting of outdoor workplaces:

- focus the lighting only to the area where it is needed (conforming to the normative requirements in relation to the task area and its surrounding area)
- time management is crucially important
- lighting control techniques similar to road lighting can be implemented to prevent from unnecessary lighting

5. Limiting the obtrusive light from outdoor lighting installations

Floodlighting:

- appropriate lighting techniques might help to significantly reduce light pollution
- light from luminaires should be directed downwards (uplighting should be avoided)
- If this is not possible (e.g. monument up on a hill), light beam from luminaires must be narrow enough so that no light is missing the object
- shields and baffles can be used to fine-restrict the angular beam range
- rigorous adherence to curfew times must take place
- following the lighting masterplan (CIE 234)

6. <u>Adaptive lighting as powerful tool to reduce light pollution</u>

Role of adaptive lighting:

- to balance in a holistic way the whole set of luminous parameters to dynamic changes of the current needs of users depending on current conditions and other influencing factors
- to provide proper lighting for different user groups and user patterns sharing the same outdoor space and having different (sometimes contradictory) requirements
- to minimize adverse effects of lighting to all affected subjects (astronomers, inhabited humans, fauna and flora)

Adaptive road lighting incorporating system of sensing devices and smart controllers is capable to considerably reduce unnecessary illumination!

6. Adaptive lighting as powerful tool to reduce light pollution

Maintained lighting levels:

- lowest lighting level when there is no user present (driver, cyclist, pedestrian, worker)
- necessary to safeguard basic visual functions for safety reasons such as surveillance of outdoor space through windows or distant views of users occupying nearby zones
- the lowest lighting class for pedestrians P6 with 2.0 lx minimum illuminance can be appropriate for this purpose
- in such case the provided lighting, however, cannot be deemed as road lighting!

Adoption of the minimum maintained level approach can lead to huge reduction of obtrusive light!

Outdoor lighting recommendations and protection of observatories

6. <u>Adaptive lighting as powerful tool to reduce light pollution</u>

Immediate vicinity of astronomical observatories: full switch-off of some lighting installations can be considered in quiet hours

- if safety level remains unaffected and other measures will compensate for loss of lighting (e.g. temporal reduction of speed limit and/or warning signs are activated by means of interoperating smart traffic systems)
- if lighting is switched on again once sensors detect incoming vehicles or persons (question of reliability)
- if this is deemed as loss of function (no road lighting provided)

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7. Conclusions and outlook

- obtrusive light is still separately addressed within different disciplines, e.g. ecology, astronomy, and illuminating engineering
- different methods used for the assessment of lighting installations
- joint effort of CIE, IAU and other interested organizations is supposed to find a common language and to improve the balance between lighting needs and obtrusions

Recommendations to be applicable to urban lighting

1. Follow (and minimize upward deviation to no more than 20% from) the luminance and illuminance levels for road lighting of the appropriate lighting class according to CIE 115*.
2. Whenever possible, dynamically reduce roadway lighting level under low traffic conditions to the appropriate lower lighting class, and down to M6 or even below if the lighting is not immediately needed by any user.
3. Follow (and minimize upward deviation to no more than 20% from) CIE guidance for illumination levels and colour rendition of pedestrian areas by class.
4. Observe (and minimize upward deviation to no more than 20% from) CIE International Standard S 015/E:2005 for illumination of outdoor workplaces, carefully limiting the illuminated area to avoid spill light.

Recommendations to be applicable to urban lighting

5. Adhere to the zone-appropriate limits by CIE environmental zone for lighting levels, Upward Flux Ratio (UFR) and Upward Light Ratio (ULR), with application of curfew-time reductions in lighting levels.
6. For Zones E2 and E3 impacting observatories, do not exceed the CIE maximum standard permitted luminance levels for building façades and do not exceed ANSI/IES standards for maximum luminances for illuminated signs.
7. Employ adaptive lighting technology in new installations and major renovations to minimise illumination when there is minimal demand.
8. Develop and follow lighting master plans that govern the planning, installation and maintenance of outdoor lighting, especially for urban and suburban areas.

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Thanks

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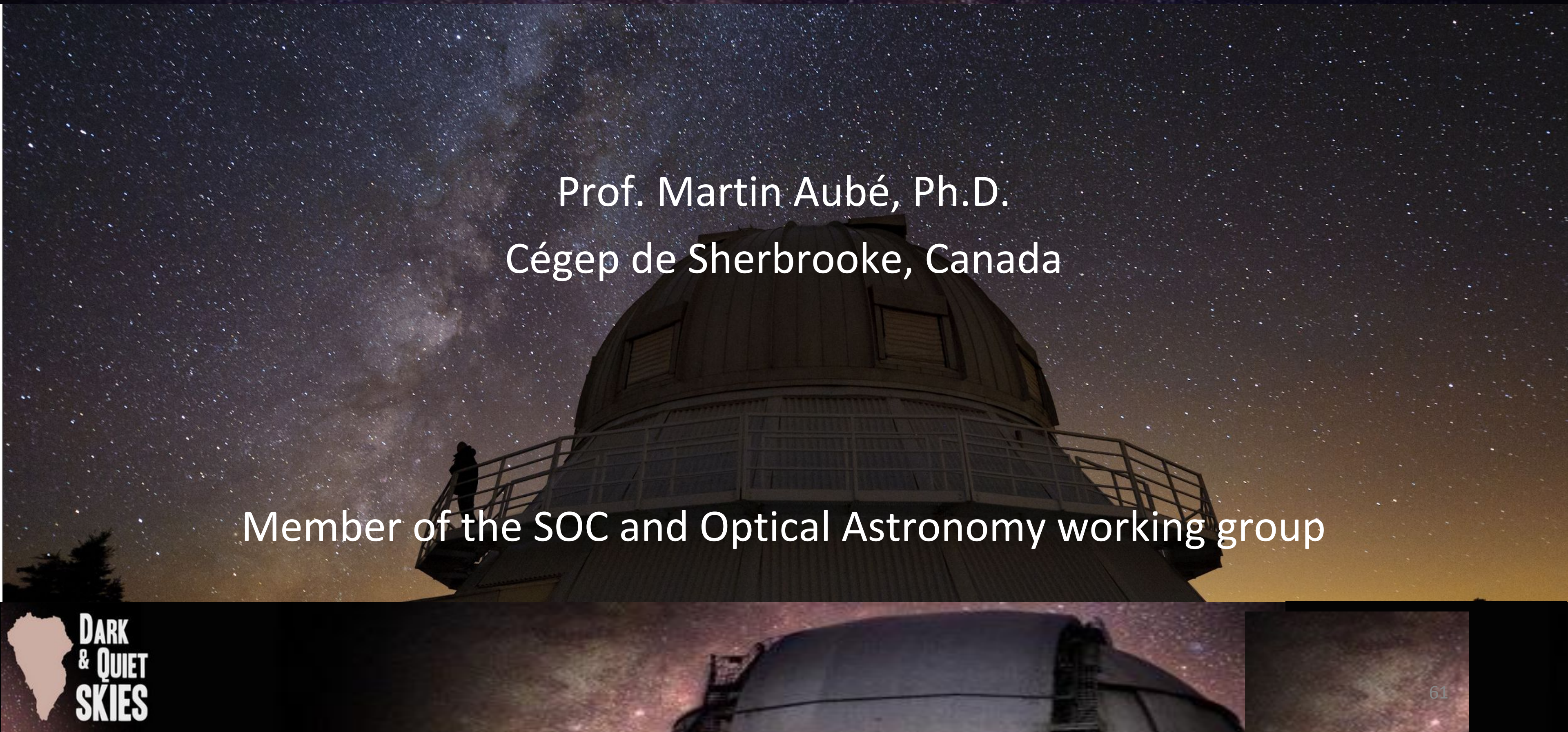
Dark sky protection measures near optical observatories



Prof. Martin Aubé, Ph.D.

Cégep de Sherbrooke, Canada

Member of the SOC and Optical Astronomy working group

What are near the optical observatories zones?

CIE zones

Table 2: Environmental zones

Zone	Surrounding	Lighting environment	Examples
E0	Protected	Dark (SQM 20.5+)	Astronomical Observable dark skies, UNESCO starlight reserves, IDA dark sky places
E1	Natural	Dark (SQM 20 to 20.5)	Relatively uninhabited rural areas, National Parks, Areas of Outstanding Natural Beauty, IDA buffer zones etc.
E2	Rural	Low district brightness (SQM ~15 to 20)	Sparsely inhabited rural areas, village or relatively dark outer suburban locations
E3	Suburban	Medium district brightness	Well inhabited rural and urban settlements, small town centres of suburban locations
E4	Urban	High district brightness	Town/city centres with high levels of night-time activity

Region with a physical radius of approximately 30 km centered at the observatory

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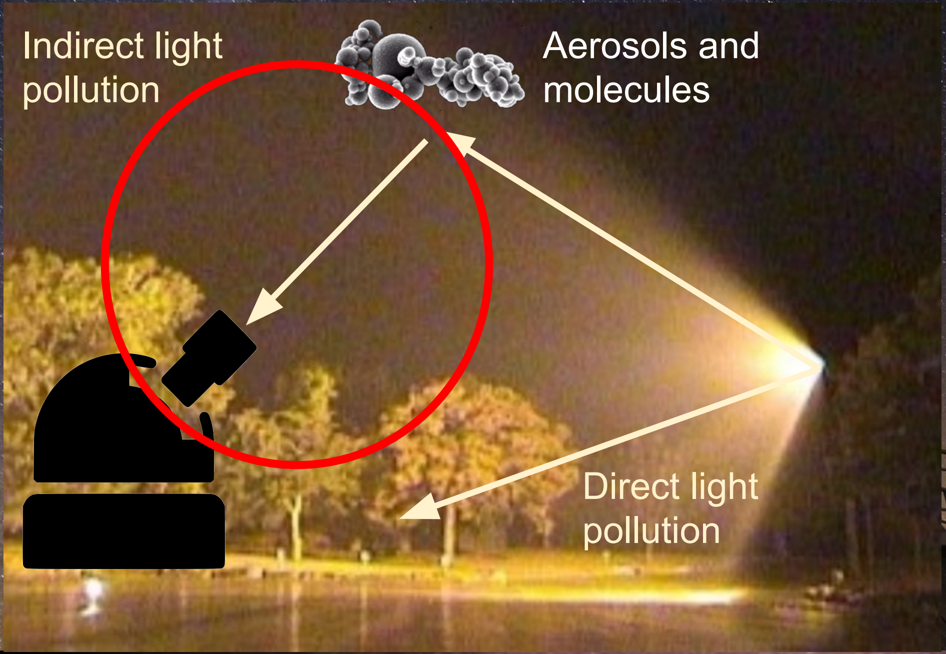
What kind of light pollution matters for optical observatories?

The two main components of light pollution



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Pic du Midi
PYRÉNÉES FRANCE

Near sources are dominant

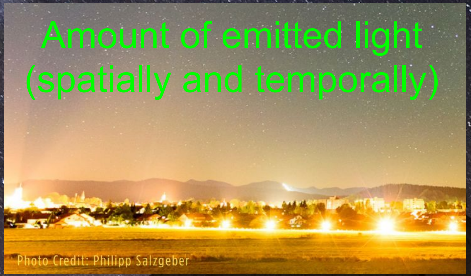
Lights from distant cities are dominant

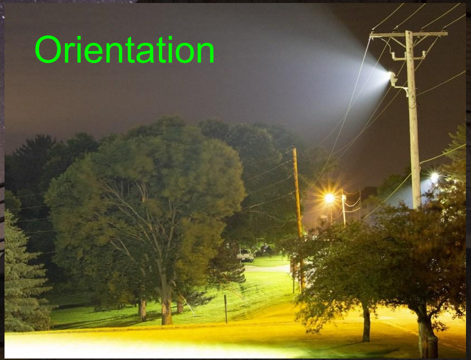
Pau @ 55km
masked
Pop. 77k

Tarbes @ 30km
masked
Pop. 41k

Toulouse @ 130km
direct sight
Pop. 470k

What are the driving parameters ?





Provisions for the recommended regulatory framework

1. Exclusive use of luminaires with no light above horizontal;

2. Limiting lamps' spectral content in the blue region;

3. Limiting the maintained average illuminance;

4. Implementing curfews and light level controls;

5. Defining minimum utilance ratio;

6. Designing lighting to minimise light propagating toward observatories;

7. Lumen Caps

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1. Exclusive use of luminaires with no light above horizontal

Orientation

Removing the upward emissions can reduce the sky radiance by at least a factor of 2. Typically, when the Upward Light Ratio (ULR) is reduced, the luminous flux can also be reduced if one wants to keep the same illuminance on the ground level. The result is that the reduction factor is generally larger than 2.

All luminaires must provide no direct illumination above horizontal.

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2. Limiting lamps' spectral content in the blue region

The blue light content should be null. The lighting devices should be quasi monochromatic sources with maximum radiant flux (in Watts per nm) lying within the 585-605 nm spectral range and having Full Width Half Maximum (FWHM) smaller than 18 nm. If modest color rendition is approved as a necessity, spectra with broader FWHM of 110 nm can be used.

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3. Limiting the maintained average illuminance

The maintained average illuminance should not be higher than 20% above the minimum maintained average illuminance suggested in technical norms/recommendations published by CIE or IESNA (i.e. 1.2 times the minimum maintained illuminance prescribed by the norm/recommendation) and this upward deviation must be kept at the lowest possible level by proper lighting design and employing suitable lighting controls.

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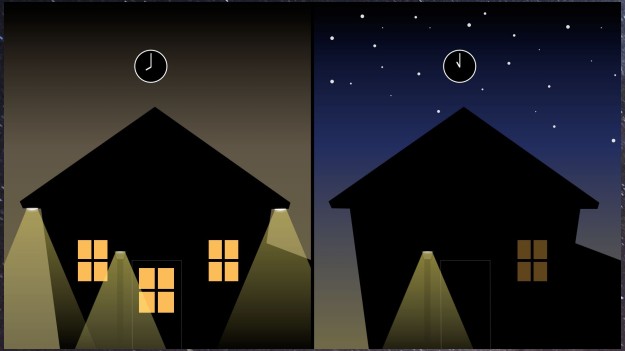
4. Implementing curfews and light level controls



A maximum possible reduction of the light levels, with a target of at least 66%, should be applied after curfew (or before that time whenever possible). Any lighting installation that is not needed for public safety reasons should be switched off at curfew. For isolated areas or hours of low traffic, sensors should be used to increase the light level as needed when any activity is detected. Without detection, the light level should be set down to 10% or less of the maintained average luminance or illuminance.

5. Defining minimum utilance ratio

Pedestrian crossing with high U value

Orientation

Utilance (U) of an installation is the ratio of the luminous flux received by a defined reference surface to the sum of the individual output fluxes of the luminaires of the installation. Utilance should be higher than 75% (U > 0.75), but any higher value is better.

6. Designing lighting to minimise light propagating toward observatories

Luminaires should be designed and mounted to minimise direct and reflected light propagating in the direction of observatories. Approaches include optical beam forming, directional shielding on the luminaire, and taking advantage of natural shadowing by buildings and topological features when possible.

7. Lumen Caps

Each major professional observatory and controlling governmental body undertake a modeling exercise to determine the total amount of fully shielded outdoor light allowable to slow the rate of growth of artificial sky glow to within the stated goal and to keep the total contribution substantially below the 10% dark site limit. Local pressure for development, topography, marine layer prevalence and other local factors motivate the need for individual studies rather than a global prescription.

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Some words about distant urban light domes up to ~300km

Light dome of Berlin masking the Milky Way from 30km away…

Credit: Andreas Jechow

Limiting the growth of urban light domes impacting professional observatories

Importance of fully shielded luminaires

© picture-alliance/dpa/Imaginechina/S. Xiaoming

Urban light domes from distant sources (up to 300 km) can represent a threat to astronomical

like electronic message boards and older sports lighting

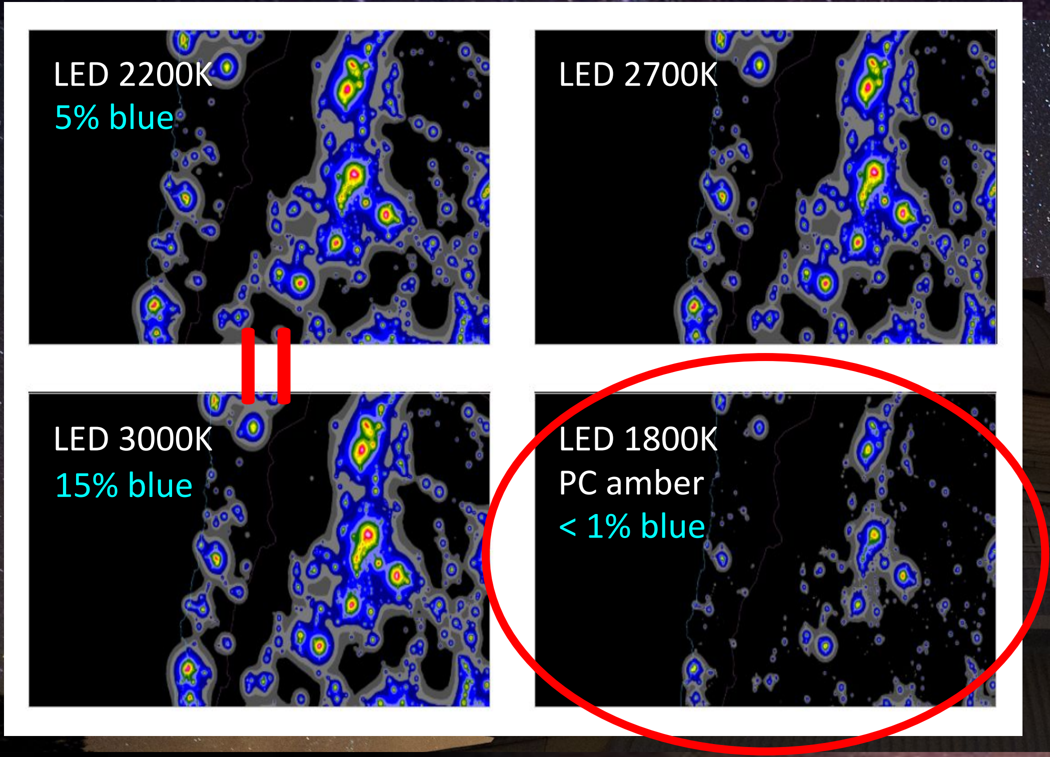
Ensure that no light is directly projected above horizontal

Minimise the impact of unshielded lighting by imposition of curfews

Dark & Quiet Skies

Limiting the growth of urban light domes impacting professional observatories

Importance of limitations on blue spectral content



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Thanks

Dark and Quiet Skies for Science and Society

Discussion Session:

To ask questions, please use the chat tool.

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With the support of NOIRLab

Dark and Quiet Skies for Science and Society

Closing Remarks
By the SOC member
José Miguel R. Espinosa
Assist. Gen. Secretary, IAU

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Dark and Quiet Skies for Science and Society: Draft Reports

Five Draft Reports are available and open for comments until 16 October

- Download them from http://bit.ly/DQS_reports
- Please comment on recommendations at http://bit.ly/DQS_comment

If you registered for today's Workshop then you have received the links on Thursday in an email from UNOOSA-Events@un.org and on Friday in an email from DQSkies@iac.es

Not received even though you had registered? Please email UNOOSA-Events@un.org

Thank you!