

# Dark and Quiet Skies for Science and Society II



Summary of Conference Held  
3 to 7 October 2021

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# Background



- Starlight Conference: 2007
- SpaceX Starlink: May 2019, first satellites launched
- SATCON1: 29 June - 2 July 2020
- Dark and Quiet Skies for Science and Society I: 5 - 9 October 2020
- SATCON2: 12 - 16 July 2021

# Starlight Conference 2007



- International Conference on Light Pollution: Held on La Palma
- Produced Ten Broad Principles Regarding Light Pollution
- Participating Organizations:
  - UN World Tourism Organization
  - European Landscape Convention
  - International Astronomical Union
  - Ramsar Convention
  - UNEP Convention on Migratory Species
  - Secretariat of the Convention on Biological Diversity
  - Spanish National Commission for UNESCO

# SpaceX Starlink



## 1791 satellites as of September 2021

- **First shell:** 1,440 in a 550 km (340 mi) altitude shell at 53.0° inclination
- **Second shell:** 1,440 in a 540 km (340 mi) shell at 53.2° inclination
- **Third shell:** 720 in a 570 km (350 mi) shell at 70° inclination
- **Fourth shell:** 336 in a 560 km (350 mi) shell at 97.6°
- **Fifth shell:** 172 satellites in a 560 km (350 mi) shell at 97.6°
  
- 30,000 satellites in the Gen2 constellation in orbits ranging from 340 km to 614 km

# SATCON1

## For Observatories



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### **Recommendation 1:**

Support development of a software application available to the general astronomy community to identify, model, subtract, and mask satellite trails in images on the basis of user-supplied parameters.

### **Recommendation 2:**

Support development of a software application for observation planning available to the general astronomy community that predicts the time and projection of satellite transits through an image, given celestial position, time of night, exposure length, and field of view, based on the public database of ephemerides. Current simulation work provides a strong basis for the development of such an application.

# SATCON1

## For Observatories



### **Recommendation 3:**

Support selected detailed simulations of the effects on data analysis systematics and data reduction signal-to-noise impacts of masked trails on scientific programs affected by satellite constellations. Aggregation of results should identify any lower thresholds for the brightness or rate of occurrence of satellite trails that would significantly reduce their negative impact on the observations.

# SATCON1

## For Constellation Operators

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### Recommendation 4:

LEOsat operators should perform adequate laboratory Bi-directional Reflectance Distribution Function (BRDF) measurements as part of their satellite design and development phase. This would be particularly effective when paired with a reflectance simulation analysis.

### Recommendation 5:

Reflected sunlight ideally should be slowly varying with orbital phase as recorded by high etendue (effective area  $\times$  field of view), large-aperture ground-based telescopes to be fainter than  $7.0 V_{\text{mag}} + 2.5 \times \log(r_{\text{orbit}} / 550 \text{ km})$ , equivalent to  $44 \times (550 \text{ km} / r_{\text{orbit}})$  watts/steradian.

# SATCON1

## For Constellation Operators



### **Recommendation 6:**

Operators must make their best effort to avoid specular reflection (flares) in the direction of observatories. If such flares do occur, accurate timing information from ground-based observing will be required for avoidance.

### **Recommendation 7:**

Pointing avoidance by observatories is achieved most readily if the immediate post-launch satellite configuration is clumped as tightly as possible consistent with safety, affording rapid passage of the train through a given pointing area. Also, satellite attitudes should be adjusted to minimize reflected light on the ground track.

# SATCON1

## For Observatories and Operators in Collaboration

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### **Recommendation 8:**

Support an immediate coordinated effort for optical observations of LEOsat constellation members, to characterize both slowly and rapidly varying reflectivity and the effectiveness of experimental mitigations. Such observations require facilities spread over latitude and longitude to capture Sun-angle-dependent effects. In the longer term, support a comprehensive satellite constellation observing network with uniform observing and data reduction protocols for feedback to operators and astronomical programs. Mature constellations will have the added complexity of deorbiting of the units and on-orbit aging, requiring ongoing monitoring.

# SATCON1

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## For Observatories and Operators in Collaboration

### **Recommendation 9:**

Determine the cadence and quality of updated positional information or processed telemetry, distribution, and predictive modeling required to achieve substantial improvement (by a factor of about 10) in publicly available cross-track positional determination.

### **Recommendation 10:**

Adopt a new standard format for publicly available ephemerides beyond two-line-elements (TLEs) in order to include covariances and other useful information.

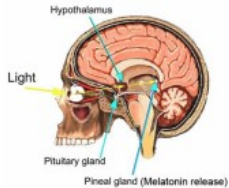
The application noted in Recommendation 2 should be compatible with this format and include the appropriate errors.

# Dark and Quiet Skies for Science and Society I

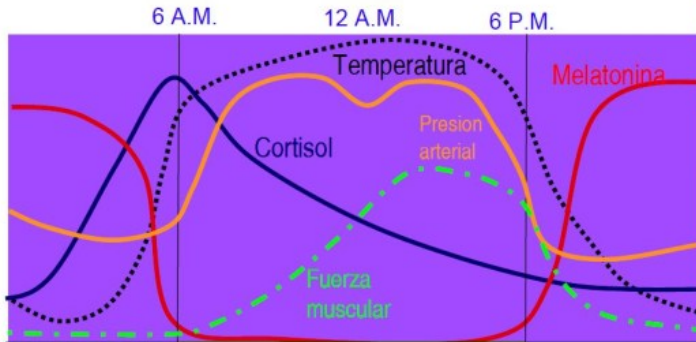
**DARK  
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- Describe what measures governments and private enterprises can adopt to mitigate the negative impact of technological implementations on astronomy without diminishing the effectiveness of the services they offer to citizens.
- Final document presented to the intergovernmental Committee on the Peaceful Uses of Outer Space (COPUOS) for consideration.  
<https://www.iau.org/static/publications/dqskies-book-29-12-20.pdf>
- Divided into three parts:
  - Artificial Light at Night (ALAN)
  - Satellite Constellations
  - Radio Astronomy

# Human Health Impacts of ALAN



Too much light can affect people's health, by changing circadian rhythms.



World Health Organization 2007 and US Medical Association 2012

CIRCADIAN RHYTHMS OF HORMONES AND BIOLOGICAL VARIABLES

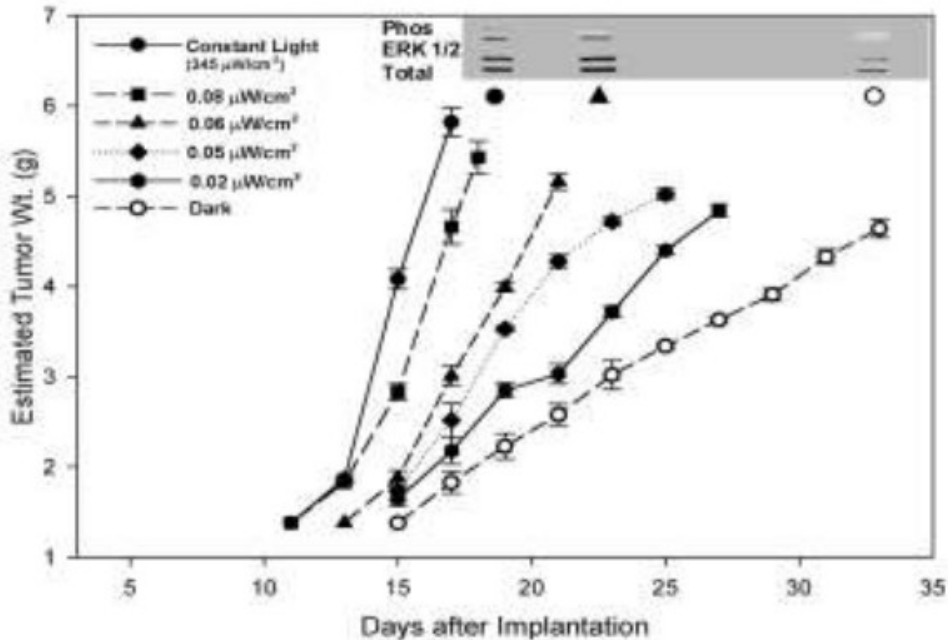
Melatonin  
Cortisol  
Immunosuppressants  
Temperature  
Muscular strength, ...

Regulate circadian cycles  
And annual cycle

DISEASES

Insomnia  
Obesity  
High cholesterol  
Diabetes  
Cardiovascular diseases  
Cancer, ...

# Human Health Impacts of ALAN



Blask et al, 2003

# Impacts of ALAN on Flora & Fauna



## Nocturnal Fauna:

- Vertebrates 28%
- Invertebrates 64%
- Bats 100%
- Non flying mammals 63%
- Amphibia 93%
- Insects 49%

Hölker et al. 2010 Trends Ecol. Evol.

# Impacts of ALAN on Flora & Fauna

## Migratory Bird Routes



# Impacts of ALAN on Flora & Fauna

## Timing and Quantity of Reproduction



**Mammals:** expanded timing of birth  
Le Tallec et al. 2013; Robert et al. 2015

**Fishes:** reduced follicle-stimulating and luteinizing hormone mRNA expression  
Brüning et al. 2018

**Birds:** 0.3 lx can move reproductive seasonality of songbirds by a month and cause irregular molt progression  
Dominoni et al. 2013

**Insects:** reduced pheromone quality and quantity in moths  
van Geffen et al. 2014

**Plants:** early bud burst, unrelated to temperature  
ffrench-Constant et al. 2016

# Impacts of ALAN on Flora & Fauna

## Immune Responses



**Mammals:** impact on circadian rhythms, physiological functions and immune response  
Bedrosian et al. 2011, Fonken et al. 2013

**Birds:** higher probability of malaria infection and increased bactericidal activity  
Quyung et al. 2017; Saini et al. 2019

**Plants:** accumulation of superoxide radicals, triggered stress responses  
Nitschke et al. 2016; Kwak et al. 2017; Meravi et al. 2020

# Dark and Quiet Skies for Science and Society I

## Artificial Light at Night: Recommendations to COPUOS

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SKIES**

### Dark Sky Oases

- DS\_Oas 1.** Dark Sky Astronomy Site, DSAG class 1:  $<260 \mu\text{cd m}^{-2}$  ;  $>21.7 \text{ mag arcsec}^{-2}$  . 10% more than airglow
- DS\_Oas 2.** Dark Sky Park, DSAG class 2: no more than 50 % more than the natural airglow, or  $<360 \mu\text{cd m}^{-2}$  ( $>21.4 \text{ mag arcsec}^{-2}$ )
- DS\_Oas 3.** Dark Sky Heritage Site, DSAG class 3: No more than 2.75 times the natural airglow, or  $<660 \mu\text{cd m}^{-2}$  ( $>20.7 \text{ mag arcsec}^{-2}$ )
- DS\_Oas 4.** Dark Sky Outreach Site, DSAG class 4: given that astro-tourism and amateur astronomy often happen at these places, the recommended limit is 2.0 times the airglow, or  $<480 \mu\text{cd m}^{-2}$  ( $>21.0 \text{ mag arcsec}^{-2}$ )

# Dark and Quiet Skies for Science and Society I

## Artificial Light at Night: Recommendations to COPUOS

**DARK  
& QUIET  
SKIES**

### Dark Sky Oases

- DS\_Oas 5.** Dark Sky Reserves, DSAG class 5: similar to outreach sites,  $<480 \mu\text{cd m}^{-2}$  ( $>21.0 \text{ mag arcsec}^{-2}$ )
- DS\_Oas 6.** Dark Sky Community, urban, DSAG class 6a: The recommended limit is 4 times the airglow for protected sites in more urban areas, giving sky brightness  $<1000 \mu\text{cd m}^{-2}$  ( $>20.3 \text{ mag arcsec}^{-2}$ )
- DS\_Oas 7.** Dark Sky Community, rural, DSAG class 6b: The recommended limit is 3 times the airglow for protected sites in more rural areas, giving sky brightness  $<750 \mu\text{cd m}^{-2}$  ( $>20.6 \text{ mag arcsec}^{-2}$ )
- DS\_Oas 8.** In all protected Dark Sky Oases the default condition should be no artificial light. Specific uses justifying light should then be additive once other non-lighting interventions are exhausted

# Dark and Quiet Skies for Science and Society I

## Artificial Light at Night: Recommendations to COPUOS

**DARK  
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SKIES**

### Dark Sky Oases

- DS\_Oas 9.** In ecological reserves and similarly sensitive sites with little or no human presence at night, generally speaking, artificial light should not be used. If it is used, it should be a narrowband amber LED or equivalent emitting no light at  $\lambda < 500$  nm. Lighting should be strictly controlled and switched on only when it is needed.
- DS\_Oas 10.** If phosphor-converted amber LED lights are used, the amount of blue light ( $\lambda < 500$  nm) should be below 5 per cent of the total spectral power. Generally this requires using LED luminaires with a corresponding color temperature of 2200 K or less.
- DS\_Oas 11.** All exterior lights should only distribute light below the horizontal, and the upward light output ratio (ULOR) should be no more than 0.5 per cent. This requires luminaires to be mounted horizontally and have flat optics below the light source.

# Dark and Quiet Skies for Science and Society I

## Artificial Light at Night: Recommendations to COPUOS

### Dark Sky Oases



- DS\_Oas 12.** LED lights should have a central management system (CMS) to reduce or extinguish light output in off-peak hours.
- DS\_Oas 13.** No commercial development in or near highly ecologically sensitive sites should be permitted.
- DS\_Oas 14.** Monitoring of nighttime conditions in/near Dark Sky Oases is encouraged through a combination of ground-based and remote sensing methods.
- DS\_Oas 15.** Active management of natural nighttime darkness as a pristine resource is encouraged through recognized conservation best practices.
- DS\_Oas 16.** Restoration plans should be implemented when sky brightness thresholds are routinely exceeded.

# Dark and Quiet Skies for Science and Society I

## Artificial Light at Night: Recommendations to COPUOS

### For Observatories and Their Extended Protected Zones



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- Opt\_Ast 1.** Each professional observatory with programmes requiring limiting darksky data for which regulation of artificial skyglow is critical should obtain a current baseline and well-sampled time series of night-sky brightness measurements.
- Opt\_Ast 2.** 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.
- Opt\_Ast 3.** Such sky-monitoring data should be collected under uniform protocols with standard calibration traceable to the SI system of dark sky units.
- Opt\_Ast 4.** Each major professional observatory and controlling governmental body should undertake a modeling exercise to determine the total amount of fully shielded outdoor lighting allowable, as well as the extent of the area of protection.

# Dark and Quiet Skies for Science and Society I

## Artificial Light at Night: Recommendations to COPUOS & QUIET SKIES

### For Observatories and Their Extended Protected Zones

- Opt\_Ast 5.** The zone in the immediate vicinity of the observatory in which all outdoor lighting is prohibited should be made as large as possible.
- Opt\_Ast 6.** All luminaires must provide no direct illumination above horizontal.
- Opt\_Ast 7.** No architectural lighting, or electronic message displays with light emitted above horizontal be permitted in Zones E0, E1, or E2 within the extended protected area (see Table B.3 in Appendix B for the definition of Zones).
- Opt\_Ast 8.** The Blue Light Content (percentage of light emitted below 500nm over the total light emitted) should be zero. 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 ~100 nm can be used in those exceptional cases.

# Dark and Quiet Skies for Science and Society I

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## Artificial Light at Night: Recommendations to COPUOS

### For Observatories and Their Extended Protected Zones

- Opt\_Ast 9.** The maintained average illuminance for periods of active use should not be higher than 20% above the minimum maintained average illuminance suggested in technical norms/recommendations published by CIE or IES (i.e. 1.2 times the minimum maintained illuminance prescribed by the norm/recommendation) and this high-side deviation must be kept at the lowest possible level by proper lighting design and employing suitable lighting controls.
- Opt\_Ast 10.** Avoid exceeding luminance or illuminance limits by more than 20% in design, and plan on active control and maintenance to achieve nearly constant light output.

# Dark and Quiet Skies for Science and Society I



## Artificial Light at Night: Recommendations to COPUOS

### For Observatories and Their Extended Protected Zones

- Opt\_Ast 11.** A maximum possible reduction of the total 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.
- Opt\_Ast 12.** The utilisation ratio should be at least 75%.
- Opt\_Ast 13.** Luminaires should be designed and mounted to minimise direct and reflected light propagating in the direction of observatories.

# Dark and Quiet Skies for Science and Society I

## Artificial Light at Night: Recommendations to COPUOS

### For Observatories and Their Extended Protected Zones

The background of the slide is a night sky featuring the Milky Way galaxy. In the lower-left foreground, the top of a telescope dome is visible. On the right side, there is a blue silhouette of the continent of Africa, with the text 'DARK & QUIET SKIES' written in white, bold, sans-serif capital letters over it.

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- Opt\_Ast 14.** Special use cases in remote areas, such as open-pit mines, should employ fixtures consistent with the near-zone regulations to the maximum degree possible, consistent with safety and national and local regulations.
- Opt\_Ast 15.** Civilian regulators and military flight planners should keep approved flight paths as far from observatories as practicable.

# Dark and Quiet Skies for Science and Society I

## Artificial Light at Night: Recommendations to COPUOS

### For More Distant Urban Areas Impacting Observatories



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- Opt\_Ast 16.** Follow (and minimize high-side deviation to no more than 20% from) the lowest luminance and illuminance levels for road lighting of the appropriate lighting class according to CIE 115, but whenever possible, dynamically reduce the levels 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.
- Opt\_Ast 17.** Follow (and minimize high-side deviation to no more than 20% from) CIE guidance for illumination levels and colour rendition of pedestrian areas and actively adjust by usage class with time of night or by motion sensing.
- Opt\_Ast 18.** Observe (and minimize high-side 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.

# Dark and Quiet Skies for Science and Society I

## Artificial Light at Night: Recommendations to COPUOS

### For More Distant Urban Areas Impacting Observatories

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- Opt\_Ast 19.** Adhere to the zone-appropriate limits by CIE environmental zone for lighting levels, with a minimum Upward Flux Ratio (UFR) and a null Upward Light Ratio (ULR = 0), with application of curfew-time reductions in lighting levels.
- Opt\_Ast 20.** For Zones E2 and E3 impacting observatories, do not exceed ANSI/IES recommendations for maximum luminances for illuminated signs. Take all recommended measures to reduce sky glow from internally illuminated signs and electronic message displays. For E3 Zones, do not exceed the CIE maximum standard permitted luminance levels for building façades; in E0, E1, and E2 Zones in the extended area impacting observatories, façade lighting is not Permitted.

# Dark and Quiet Skies for Science and Society I

## Artificial Light at Night: Recommendations to COPUOS & QUIET SKIES

### For More Distant Urban Areas Impacting Observatories

- Opt\_Ast 21.** Employ adaptive lighting technology in new installations and major renovations to minimize illumination when there is minimal demand.
- Opt\_Ast 22.** Develop and follow lighting master plans that govern the planning, installation and maintenance of outdoor lighting, especially for urban and suburban areas.
- Opt\_Ast 23.** Use fully shielded lighting and/or other techniques to assure that no light is directly projected above horizontal. Minimize the impact of unshielded lighting like electronic message displays and older sports lighting by imposition of curfews and limitations by usage zone.
- Opt\_Ast 24.** Sharply limit any blue and near-ultraviolet (UV) (<500 nm) spectral content of luminaries. Employ sources with the narrowest possible band-passes, based on the actual need for color rendition, and use light sources with the lowest blue-UV content available (color index  $G > 2$ )  
When color rendition is necessary.

# Dark and Quiet Skies for Science and Society I

## Artificial Light at Night: Recommendations to COPUOS

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SKIES**

**Bio\_Env 1.** Establish specific regulations for outdoor lighting within each country.

**Bio\_Env 2.** Establish an accreditation system for outdoor lighting installations.

**Bio\_Env 3.** Ensure that new installations and renovations follow the relevant regulations.

**Bio\_Env 4.** Review and revise the requirements for illuminating roads and highways and the lighting legislation to consider environmental effects of ALAN.

# Dark and Quiet Skies for Science and Society I

## Artificial Light at Night: Recommendations to COPUOS

**DARK  
& QUIET  
SKIES**

- Bio\_Env 5.** Minimize the negative effect of outdoor lighting on vision, human health and natural species.
- Bio\_Env 6.** Restore and protect affected existing ecosystems by implementing environmentally conscious lighting technology, and establishing definite and verifiable transition plans to reduce the light emissions where required.
- Bio\_Env 7.** Promote education about lighting and the effects of ALAN on human health and the environment among research communities, decision makers, and society at large.

# Dark and Quiet Skies for Science and Society I

**DARK  
& QUIET  
SKIES**

## Artificial Light at Night: Recommendations to COPUOS

- Bio\_Env 8.** Develop a scale of ecological classes of dark skies to show the differential impact of light over ecosystems and species across the territory.
- Bio\_Env 9.** Establish evidence-based thresholds for lighting levels that should not be exceeded in various environmental zones where there are negative effects of lighting on human health and on species and habitats.
- Bio\_Env 10.** Develop standardized methods for measuring ALAN and skyglow and establish them in the relevant national or international standards.

# Satellite Constellations

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- **Starlink (SpaceX)** – up to 12,000 satellites with orbit altitudes ranging from 328 km to 614 km. Up to 30,000 satellites planned for the Gen2 constellation
- **Kuiper (Amazon)** - 3,236 satellites that will have orbit altitudes ranging from 590 km to 630 km
- **OneWeb (Airbus and OneWeb)** - 47,844 satellites in orbits with altitudes of 1,200 km
- Constellations by other operators are planned

# Satellite Constellations

## Impacts

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- Hundreds to thousands of satellites will be visible after sunset
- NEO asteroid search programs – operate in twilight hours when impact is the worst
- Deep wide field extra-galactic surveys
- Transient programs
- Deep multi-object spectroscopic surveys
- Deep wide-field NIR imaging

# Satellite Constellations

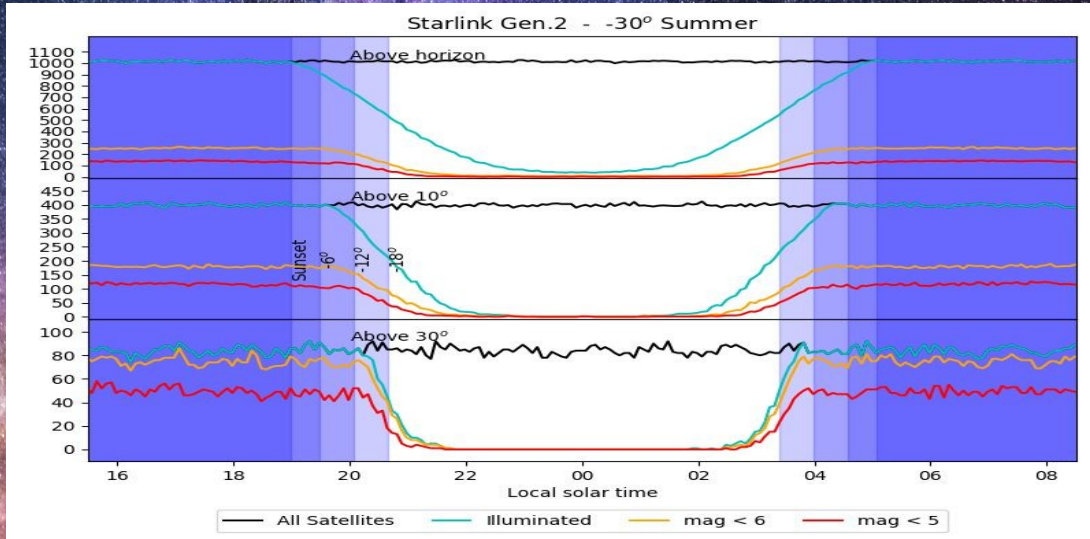
## Impacts

- Imaging of large extended low surface brightness targets
- Exoplanet transits in wide-field surveys
- Hubble Space Telescope (impacted by OneWeb satellites)
- Discovery of new phenomena
- Citizen science, amateur astronomers, and stargazers worldwide
- Environmental impact – migratory birds that use stellar navigation

**DARK  
& QUIET  
SKIES**

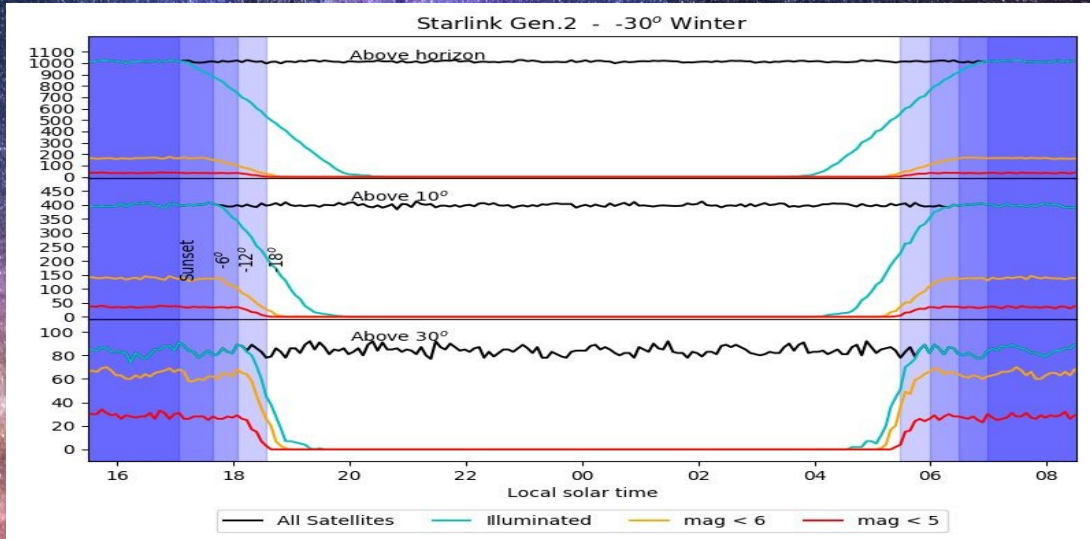
# Impact of Starlink Satellites (550 km Orbit)

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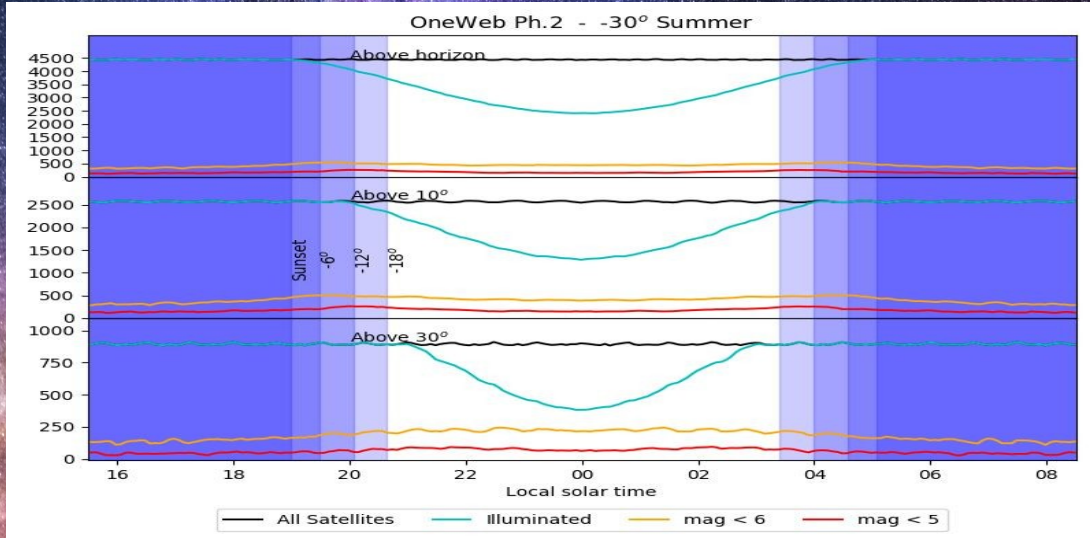
# Impact of Starlink Satellites (550 km Orbit)

**DARK  
& QUIET  
SKIES**



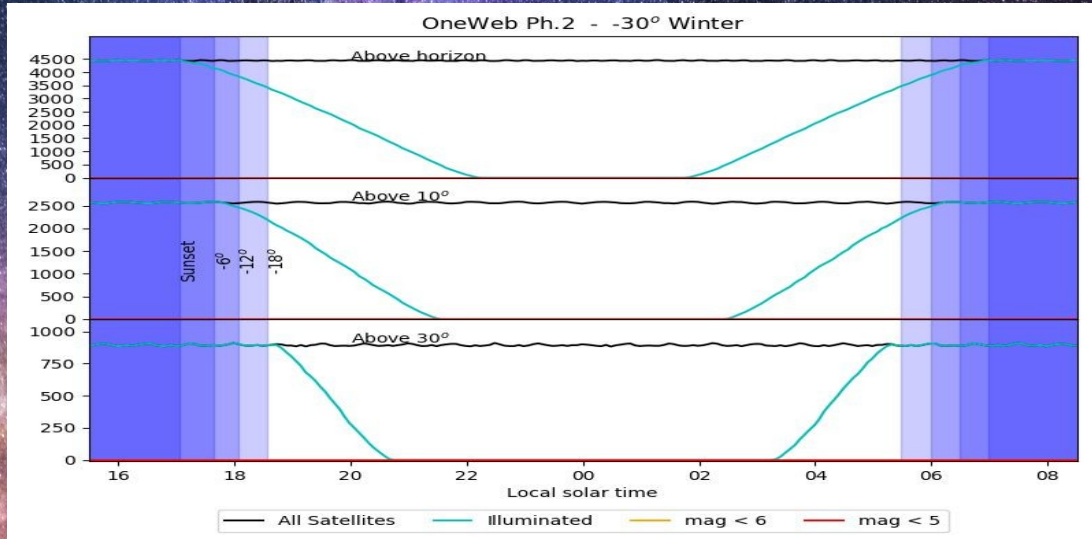
# Impact of Starlink Satellites (550 km Orbit)

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SKIES**



# Impact of Starlink Satellites (550 km Orbit)

**DARK  
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SKIES**



# Dark and Quiet Skies for Science and Society I

## Satellite Constellations: Recommendations to COPUOS

**DARK  
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SKIES**

### Recommendations for Observatories

- Sat\_Con 1.** Support the development of software applications to conduct long term planning and simulations of observations, scheduling, and to identify and remove satellite-induced artifacts from data. This requires a range of data from industry on satellite reflectance, antenna parameters, and predicted and real-time ephemerides. Observatories will also require additional funding for development and to assess overall impacts on science programmes.
- Sat\_Con 2.** Plan for more stringent requirements on future designs of observing facilities to account for the additional losses from satellite constellations, including additional telescopes, increased apertures, additional tools for image processing, higher robustness receivers, and enhanced detector technologies. These measures require additional funding.

# Dark and Quiet Skies for Science and Society I

## Satellite Constellations: Recommendations to COPUOS

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SKIES**

### Recommendations for Satellite Operators

- Sat\_Con 3.** Raise awareness of the impacts on astronomy amongst designers, investors, regulators, manufacturers and operators, and include impact mitigations as a core component of corporate social responsibility and sustainability strategies.
- Sat\_Con 4.** Design missions to minimize negative impacts on astronomical observations by: a) minimising operational altitudes — satellites in constellations with higher orbital shells are illuminated by the sun for longer during the night and appear more 'in focus' to telescopes; in general, the impact on astronomy increases with constellation altitude. Scientific analysis shows that orbits on the order of 600km or below offer a compromise between brightness and the length of time satellites are illuminated during the night; b) minimizing the number of satellite units as second priority to altitude while maintaining safe operational practices; c) minimising the time spent in orbit when not in service.

# Dark and Quiet Skies for Science and Society I

## Satellite Constellations: Recommendations to COPUOS

**DARK  
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SKIES**

### Recommendations for Satellite Operators

- Sat\_Con 5.** Design satellites to minimize negative impacts on astronomical observations by:
- a) guaranteeing that all satellites appear fainter than  $7.0 V_{\text{mag}} + 2.5 \times \log(\text{SatAltitude} / 550 \text{ km})$  with a minimum value - corresponding to maximum brightness - of visual magnitude ( $V_{\text{mag}}$ ) 7 during all flight phases, which makes them undetectable to the unaided eye;
  - b) minimizing antenna sidelobe emissions such that their indirect illumination of radio observatories and radio quiet zones do not interfere, individually or in the aggregate;
  - c) preventing direct illumination of radio observatories and radio quiet zones with a satellite's main antenna beam.
- Sat\_Con 6.** Provide timely, transparent and reliable data to the astronomy community and observatories to allow sufficient planning to avoid impacts and post-hoc analysis of incurred impacts. Data required include: spacecraft design, brightness data, mission designs and orbital profiles, attitude control, and predicted and real-time orbital elements.

# Dark and Quiet Skies for Science and Society I

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## Satellite Constellations: Recommendations to COPUOS

### Recommendations for the Astronomy Community

- Sat\_Con 7.** Raise awareness of the impacts of satellite constellations and possible mitigation strategies and their costs and requirements amongst key astronomy stakeholders. Develop mechanisms to coordinate approaches across communities and countries and share information on industry interactions, mitigation solutions and observational data.
- Sat\_Con 8.** Conduct outreach and advocacy campaigns with policymakers, regulators, funders and industry, and represent astronomy interests in satellite industry and professional working groups.

# Dark and Quiet Skies for Science and Society I

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SKIES**

## Satellite Constellations: Recommendations to COPUOS

### Recommendations for the Astronomy Community

- Sat\_Con 9.** Develop the skill base to operate in the satellite constellation era by: supporting the development of educational material on how to conduct astronomy in the context of high numbers of satellite interferences; organising professional development opportunities, workshops and symposia.
- Sat\_Con 10.** Include considerations of satellite constellations in strategic planning for future observatories and understand impacts on science cases of existing observatories. Improve simulations of the impact of satellite constellations, providing more accurate estimates of apparent brightness, a more detailed consideration of trails due to not point-like sources (spatially resolved and/or out of focus), a better assessment of transitory orbital phases and a quantitative study of the impact on astrophotography.

# Dark and Quiet Skies for Science and Society I

**DARK  
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SKIES**

## Satellite Constellations: Recommendations to COPUOS

### Recommendations for the Astronomy Community

**Sat\_Con 11.** Support the collection and coordination of multispectral observational data, in partnership with industry and observatories, and citizen-scientists and amateur astronomers.

# Dark and Quiet Skies for Science and Society I

**DARK  
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SKIES**

## Satellite Constellations: Recommendations to COPUOS

### Recommendations for Science Funders

**Sat\_Con 12.** Provide support for understanding impacts on astronomy and the increased overheads in terms of additional observing time or science losses. This includes provision of specific funding instruments for development of software, hardware and facility mitigations, technology developments in detectors and receivers, and taking steps to evaluate, formalise and report to governments the overall impacts on science research and capital investments.

# Dark and Quiet Skies for Science and Society I

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SKIES**

## Satellite Constellations: Recommendations to COPUOS

### Recommendations for National Policymakers and Regulatory Agencies

- Sat\_Con 13.** Formulate satellite licensing requirements and guidelines that take into account the impact on stakeholders, including astronomical activities, and that coordinate with existing efforts in relation to radio astronomy and space debris mitigation.
- Sat\_Con 14.** Develop inquiries and recommendations that encourage flexible technology that can better share spectral resources while ensuring protection of sensitive radio astronomy operations.
- Sat\_Con 15.** Develop spacecraft systems and operational standards that take into account the impacts on astronomical science. Areas include reflectivity of surface materials, brightness of space objects, telemetry data, and spurious antenna emissions.

# Dark and Quiet Skies for Science and Society I

**DARK  
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SKIES**

## Satellite Constellations: Recommendations to COPUOS

### Recommendations for National Policymakers and Regulatory Agencies

- Sat\_Con 16.** Support the development of space domain decision intelligence collecting data of proposed satellite constellations and existing orbiting space objects, modeling satellites, their operations in the space environment, and estimate uncertainties to assess the impact of satellite constellations on ground-based astronomical observations.
- Sat\_Con 17.** Investigate policy instruments that account for negative externalities of space industrial activities, including on astronomical activities, and develop incentives and inducements for industry and investors.

# Dark and Quiet Skies for Science and Society I

**DARK  
& QUIET  
SKIES**

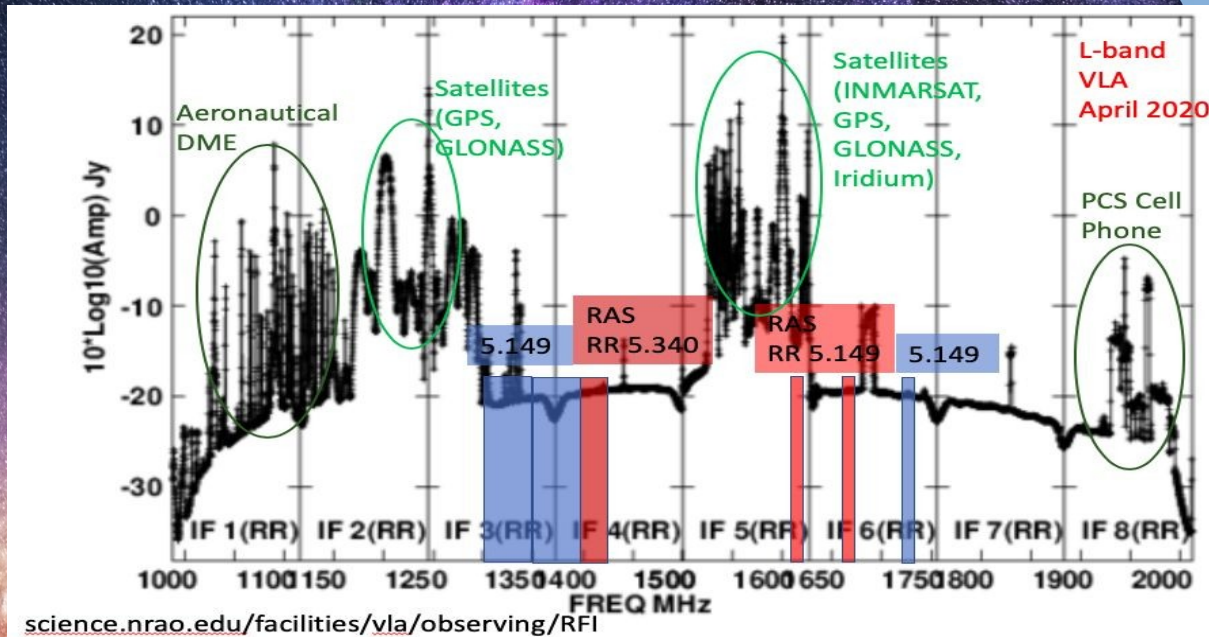
## Satellite Constellations: Recommendations to COPUOS

### Recommendations for International Policymakers

- Sat\_Con 18.** Policymakers are encouraged to contemporaneously develop international agreements, on the one hand, and national laws within their respective legal frameworks, on the other hand, relating to reflected or emitted electromagnetic radiation from satellites, its impacts on science (particularly, but not exclusively, astronomical science), and efforts to mitigate (if not eliminate) the deleterious aspects of such impacts.
- Sat\_Con 19.** At both international and national levels, efforts can build upon frameworks in radio astronomy and space debris, informed by this report and by capacity-building and outreach efforts that bring stakeholders together for purposes of discussion and moving policy development forward, such as this international workshop.

# Satellite Impacts to Radio Astronomy

DARK  
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SKIES



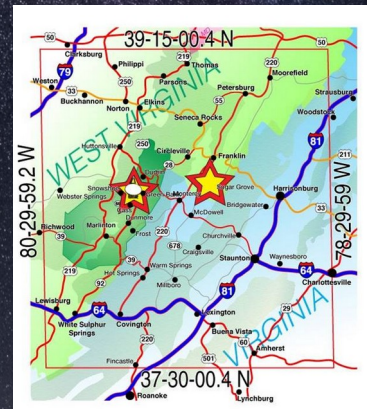
# Satellite Impacts to Radio Astronomy

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## US Radio Quiet Zones

- National Radio Quiet Zone in West Virginia: 13,000 square miles
- West Virginia Radio Astronomy Zone: 315 square miles
- Puerto Rico Coordination Zone: 100 mile radius extending out from the site of the Arecibo dish.

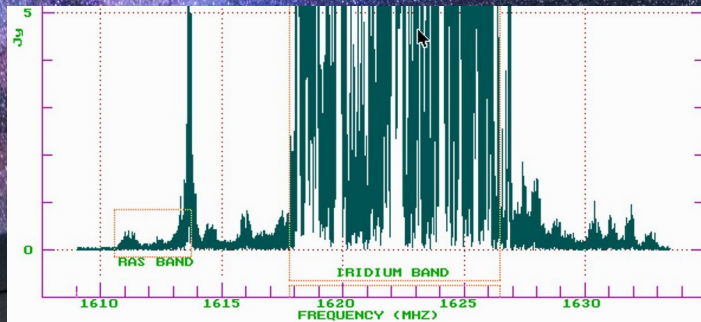
\* The VLA in New Mexico is not protected by a radio quiet zone.



# Satellite Impacts to Radio Astronomy

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- Spillover from satellite antennae side-lobes that intrude upon the spectrum reserved for astronomy



- Direct illumination of radio telescopes by satellite radar that can burn out the receivers
- All satellites visible to a radio telescope can contribute to interference

# Satellite Impacts to Radio Astronomy

**DARK  
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## Radio Astronomy: Recommendations to COPUOS

**Rad\_Ast 1.** Non-GSO satellites should be required to be able to avoid direct illumination of radio telescopes and radio quiet zones, especially the radar and other high-power satellite applications that are capable of burning out radio astronomy's receivers.

**Rad\_Ast 2.** Non-GSO satellites should be required to have sidelobe levels that are low enough that their indirect illuminations of radio telescopes and radio quiet zones do not interfere, individually or on aggregate.

# SATCON2

## Observations Working Group

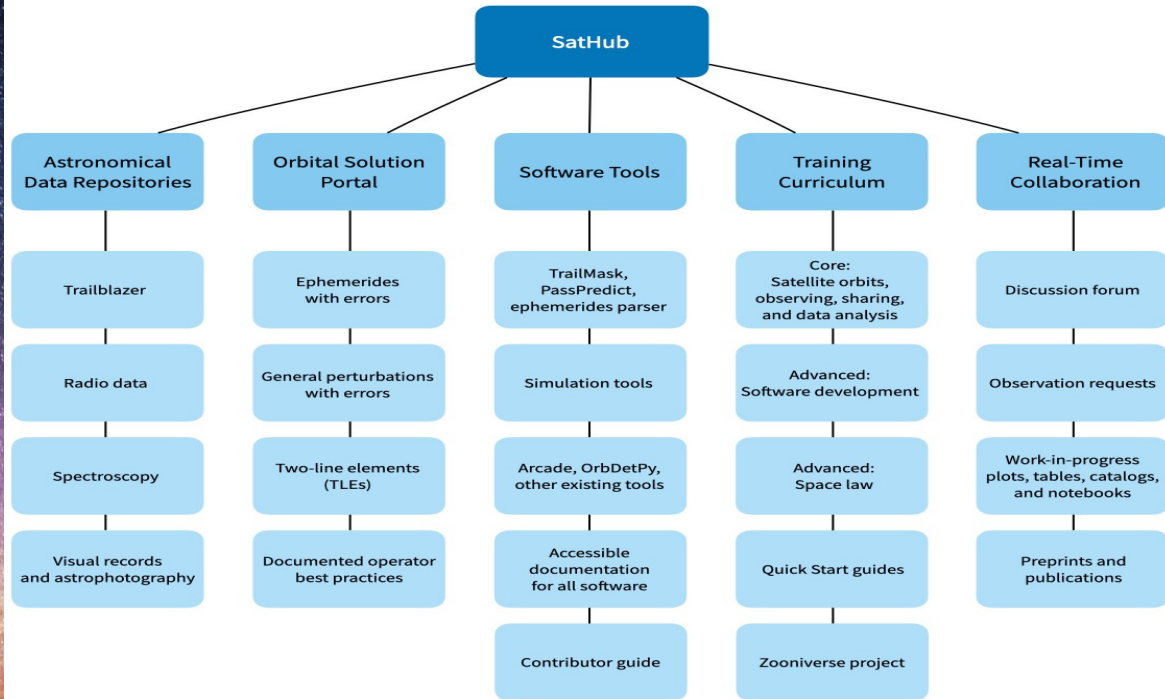


**SatHub:** a one-stop shop for training, outreach, and collection & analysis of LEO satellite observations

- Coordinated observation-focused hub enabling astronomers, community members, and operators to work together
- Primary goal: inform and enable timely LEO satellite observing
- Secondary goal: host software, tutorials, ephemerides, images+
  - Software with documentation and tutorials
  - Instructions for specific observer setups, including unaided eye
  - Lesson plans and citizen science projects for educators
  - Connections to queryable affected data products
- Funding model TBD

# SATCON2

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# SATCON2

## Algorithms Working Group



### 1. Re-emphasize SATCON1 recommendations 1 to 3

New tools are critical to partially mitigate impacts on astronomy:

- Will my observation be affected? **PassPredict**
- PassPredict and simulation software will also enable quantification of the predicted degradation of science data in a particular situation
- Can I salvage useful science from affected data? **TrailMask**
- Astronomers also need a large simulation and modeling effort to assess impacts of current and future constellations on both ground-based and space-based observations

### 2. The working group has carried out a study of the algorithms and interfaces needed for these software tasks; this will be included in the report .

# SATCON2

## Policy Working Group



- Encourage operators to consider effects on astronomy early in constellation development
  - Preferable to test/model prior to production vs observing/mitigating after launch
- Pre-launch:
  - Build accurate, cost effective and readily available testing and modeling during early stages of constellation design
  - Share mitigation approaches and lessons learned
- Post-launch:
  - Routinize observational data and expand transparency from satellite location data
- Best practices, guidelines should focus on clear outcomes and performance based metrics, not proscriptive approaches
  - Foster ongoing innovation in mitigation and voluntary measures

# SATCON2

## Conclusions and Emerging Policy Gaps



- Lack of clear protections for the orbital environment and gaps exist for on-orbit impact assessments, with direct impacts on astronomical observations
- The effects of satellites on the human and outer space environment cannot be considered in isolation. A cumulative analysis of satellite influence needs to be performed.
- Critical need for discussion in multilateral fora to increase actions at the international and national levels for the reduction of environmental impacts and interference with astronomy.

<https://noirlab.edu/public/products/techdocs/techdoc031/>

# Dark and Quiet Skies for Science and Society II

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- Originally scheduled to be held on the island of La Palma, Canary Islands
- Cumbre Vieja eruption necessitated virtual meeting



# Dark and Quiet Skies for Science and Society II

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- Response from COPOUS to Dark and Quiet Skies for Science and Society I report.
  - ALAN recommendations: too much detail
  - ALAN does not fall under mission of COPOUS
- Background material on ALAN, satellite constellations and radio astronomy
- A number of use-cases presented
- Policy discussions

# Dark and Quiet Skies for Science and Society II

**DARK  
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SKIES**

## ALAN

- Convince COPOUS that astronomy is part of the peaceful use of outer space since access to the skies promotes interest in space. This will be a hard sell.
- Reduce ALAN on a one decade time scale
- IDA five principles: **useful, targeted, low light levels, controlled, color**
- Tax ALAN
- Nationalism is a barrier to light pollution regulation by the UN: bottom up approach may be better
  - Cost savings
- ALAN needs to be treated as a pollutant like noise, water, and air
- There is no wildlife friendly light
- ALAN may be best handled by the un environment programme
- Astronomers need to work more closely with the CIE (International Commission on Illumination)

# Dark and Quiet Skies for Science and Society II

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SKIES**

## Satellite Constellations

- Operators responded with "What?" At SATCON2 when asked how they plan to account for the solar cycle impact to their satellites
- Satellite designs not readily shared with astronomers
- Astronomers have been donating their time to develop SatHub and TrailMask. Operators should be footing the bills.
- High latitude observatories such as those in Canada effected more
- Space traffic management has not been a topic of concern
- General public not aware of the problem facing astronomers
- Professional and amateur astronomers needed to submit observations to SatHub

# Dark and Quiet Skies for Science and Society II

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## Satellite Constellations

### Policy Discussions

- Article IX of the Outer Space Treaty is being invoked to argue that COPOUS needs to respond to the impact of satellite constellations to astronomy
  - **Near Earth asteroid detection**
  - Economic considerations – invested amounts in observatories
  - Astronomy is vital as a support for other outer space activities
  - Reentered satellites will contribute to environmental pollution leading to ozone depletion
  - Launch Issues: propellant byproducts could also damage ozone
  - Crowded LEO could raise the probability of major collision events

# Dark and Quiet Skies for Science and Society II

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## Satellite Constellations

### Article IX

In the exploration and use of outer space, including the moon and other celestial bodies, States Parties to the Treaty shall be guided by the principle of co-operation and mutual assistance and shall conduct all their activities in outer space, including the moon and other celestial bodies, with due regard to the corresponding interests of all other States Parties to the Treaty. States Parties to the Treaty shall pursue studies of outer space, including the moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose. If a State Party to the Treaty has reason to believe that an activity or experiment planned by it or its nationals in outer space, including the moon and other celestial bodies, would cause potentially harmful interference with activities of other States Parties in the peaceful exploration and use of outer space, including the moon and other celestial bodies, it shall undertake appropriate international consultations before proceeding with any such activity or experiment. A State Party to the Treaty which has reason to believe that an activity or experiment planned by another State Party in outer space, including the moon and other celestial bodies, would cause potentially harmful interference with activities in the peaceful exploration and use of outer space, including the moon and other celestial bodies, may request consultation concerning the activity or experiment.

# Dark and Quiet Skies for Science and Society II

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SKIES**

## Satellite Constellations

### Problems

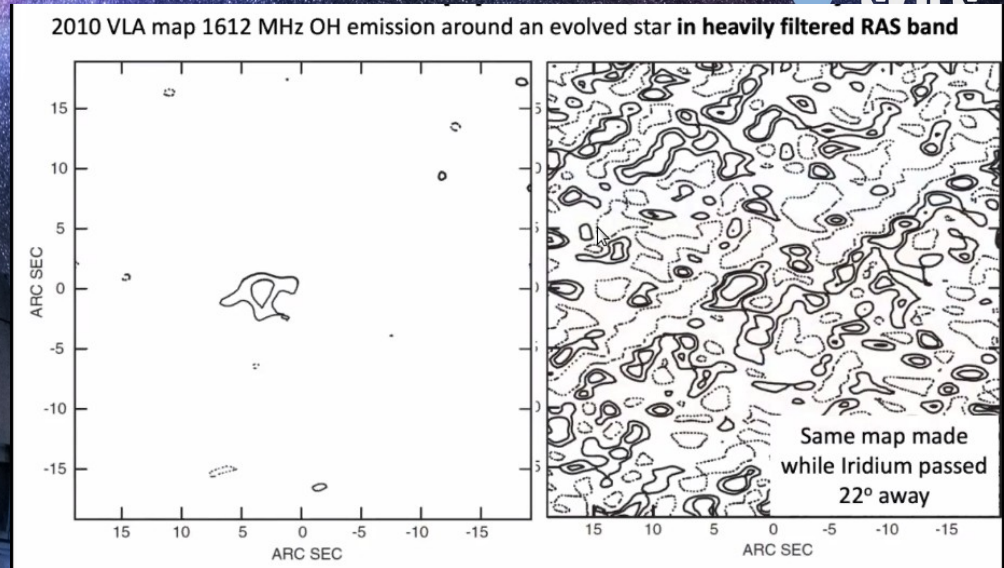
- National legislation may be the only practical problem of space sustainability
  - Drawback: regulation shopping
- Emerging nations may view the motives of developed nations with suspicion
- UN has no guidelines on space sustainability which needs to be addressed

# Dark and Quiet Skies for Science and Society II

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## Radio Astronomy

- Satellite phones forbidden within 160 km of RQZ
- Interference from satellites not forbidden



# Dark and Quiet Skies for Science and Society II

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SKIES**

## Radio Astronomy

- Microwave background polarization measurements will be ruined by satellite constellations
- Previously it was not a problem of satellite numbers but one of design and operation
  - Proposed numbers may overwhelm the best engineering and operational practices
- General Principle: Artificial radiation of whatever kind, including from satellites, should not be produced if it isn't needed and it shouldn't be detectable where it isn't used

# Dark and Quiet Skies for Science and Society II

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## Going Forward

- IAU has announced an new center for the protection of Dark and Quiet Skies from Satellite Constellation interference in both the optical and radio
- A working paper by a number of states will have more weight than the conference report. There were a number of states that expressed support after Russia objected to the recommendations of the first conference.

# Dark and Quiet Skies for Science and Society II

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SKIES**

Questions?