Recommendations from the UN/Spain/IAU conference on Dark & Quiet Skies for Science & Society

STSC Symposium on Dark Skies

Tuesday, February 15, 3PM– 5PM CET

Findings and recommendations on Artificial Light at Night (ALAN)

Richard Green (*University of Arizona*)

on behalf of the D&QS2 ALAN Working Group

Astronomy is key to the COPOUS mission and requires protection from growing artificial skyglow

- Astronomical observations embody a primary aspect of the COPUOS mission: enabling ***"continued research and the dissemination of information on outer space matters"***.
- Light pollution is ***growing globally at an estimated rate of 2 to 6% per year***, reducing darkness everywhere, even at remote observatory sites.
- This increase is mainly related to three factors: the increase of the global ***population***, ***economic growth***, and the reduction of illumination ***costs*** (e.g., from LEDs).
- Population growth and resource development have created ***measurable light pollution at major professional observatories***, such as those in the southwestern U.S., Hawaii, north-central Chile, the Canary Islands, and southern Spain.
- Light pollution negatively impacts ***human health*** and well-being and ***flora and fauna*** in a sustainable environment***.***
- It is also critical to protect dark skies for associated ***cultural values*** and ***socio-economic development*** of many local communities, especially in rural areas, through ***astro-tourism***.


Chelyabinsk meteor, 2013


Catalina Observatory, USA

David Harvey photo

ALAN recommendations for COPUOS and its member states

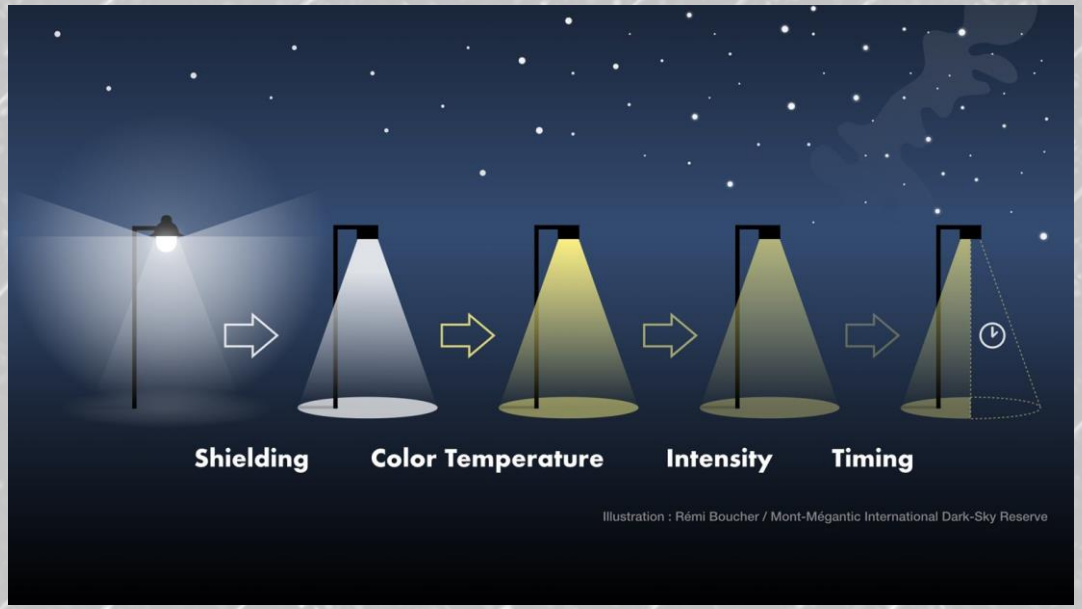
- ***Endorse*** the overarching goal of ***reducing ALAN***:
  - ➤ To ***reduce, stop, and then reverse*** the growth of ALAN on the timescale of a decade.
  - ➤ To keep the total contribution of ALAN substantially ***below the 10% limit*** defined by the IAU for dark sky observatories.
  - ➤ To control and reduce light pollution at its main source: ***human population centers, agricultural and industrial centers***.
- Endorse a ***policy framework*** for controlling ALAN, particular to each member state.
- Encourage UNOOSA to engage in activities to ***raise awareness*** of the harmful impacts of light pollution and to reduce it globally ***in coordination with multiple UN and international parties***: IUCN, UNEP, Convention on the Conservation of Migratory Species, WHO, UNDRIP, etc.

Policy Framework for Controlling Light Pollution

1. Implement control at the level of ***single lighting installations***.
   - ➤ Traditional means of regulation, now enhanced with active control options.
2. Establish regional lighting master plans through ***zonal light output limits*** that protect critical dark sky areas (like air quality zones).
   - ➤ Lighting limits would take priority over development in certain cases.
   - ➤ Cap-and-trade approach can involve incentives such as lighting credits.
   - ➤ Governments with controlling environmental regulations could take top-down approach within existing framework.

Principles for outdoor lighting regulation

1. Light should have a clear and useful purpose, and should be designed and installed to minimize negative effects on the night sky, human health and the environment.
2. Light should be directed only where needed through shielding and careful aiming.



3. Light should be no brighter than the minimum level required for the intended application.
4. Light should be used only when it is useful, dimmed when possible and turned off when not needed.
5. Light should be a warmer color whenever possible, limiting the amount of blue light to the least amount needed.

Technical implementation of outdoor lighting regulation

- Lighting master plan requires ***modeling and assessment through measurement and monitoring***, with stakeholder agreement on ***skyglow limits*** and ***rate of reduction***.
- ***Active control*** of solid-state lighting (LEDs) allows dynamic definition of lighting zones based on usage (traffic) or time of night.
- Near zones for specially protected areas (observatories, nature preserves) start from the ***assumption of no artificial light***; if demonstrated need, monochromatic strongly preferred (narrow-band amber). Color rendition (more blue – red spread) only if absolutely required for safety.
- Design for the ***minimum lighting level required for safety*** (even in urban core), with only 20% margin.
- Increase ***support for research*** on the impact of ALAN on visibility levels and public safety, on human health, and on flora and fauna.

Casiana Muñoz-Tuñón

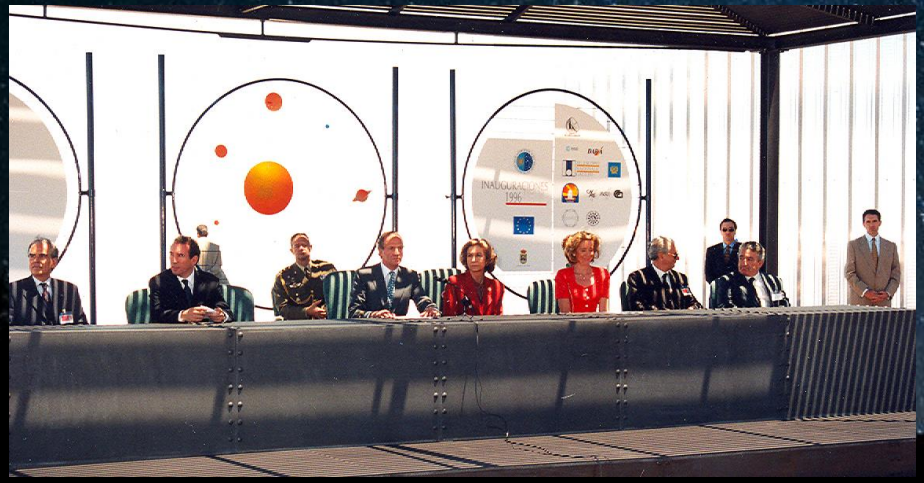
COPUOS STSC, Symposium 15 February 2022

International Agreements

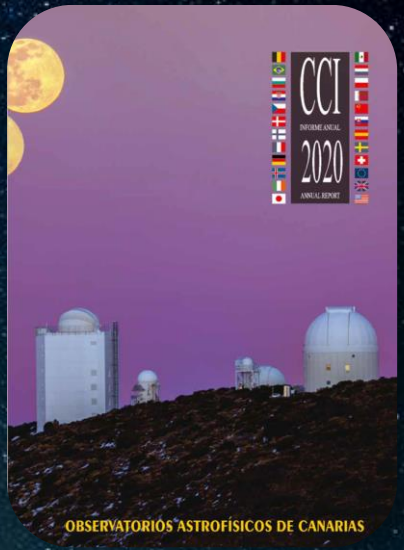
1979

INTERNATIONAL SCIENTIFIC COMMITEE (CCI)

Strong political support- 1985 official innauguration



- Belgium
- Brasil
- Bulgaria
- China
- Croatia
- Czech Republic
- Denmark
- Finland
- France
- Germany
- Hungary
- Iceland
- Italy
- Japan
- Mexico
- Netherlands
- Poland
- Qatar
- Russia
- Spain
- Sweden
- Switzerland
- United Kingdom
- United States



Other International organizations

- European Space Agency
- MAGIC Consortium
- 4LST Consortium
- CTA Observatory

1988 Sky Law

Law 31/1988 and Regulation R.D. 243/1992

La ley del cielo is the first law at a national level (Kingdom of Spain).

Earth at Night
More information available at:
http://apod.nasa.gov/ap081005.html

Astronomy Picture of the Day
2008 October 5
http://apod.nasa.gov/

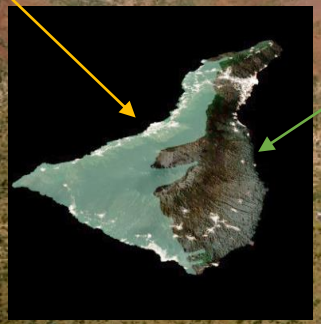
Canary Islands Observatories

Excellent astronomical sky quality // Internationally recognized

OT - Teide Observatory

PROTECTED AREAS

AREAS "WITHOUT PROTECTION"
(But under agreements with local administrations)



ORM - Roque de los Muchachos Observatory

Statutory regulation - The OTPC monitors law compliance.

Light pollution
Regulates outdoor lighting.

Radioelectric contamination
It establishes the levels of electromagnetic radiation so that it does not interfere with the observations.

Atmospheric pollution
Controls the activities that may degrade the quality of the atmosphere in the Observatories.

Air routes
Regulates air traffic over the Observatories, avoiding overflights.

The Law and the Technical Office of Sky Quality have become models followed by others such as Chile, Hawaii and Italy.

HOW DO WE ENSURE COMPLIANCE WITH THE LAW?

The OTPC is the technical office in charge of ensuring law compliance. To do so, the office:

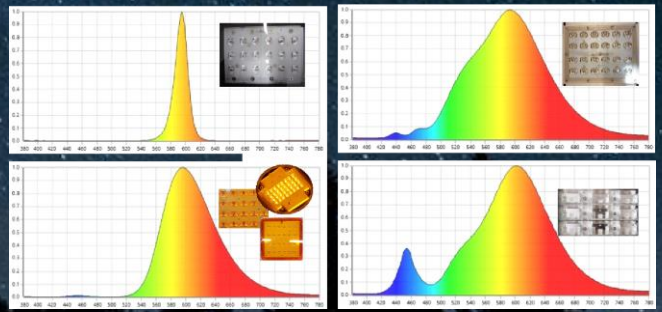
1) <u>Has an important proactive role:</u>

Gives free advice to municipalities and organizations entrusted with installing the new lighting, so that the new hardware is law-compliant.

Makes a very good use of the argument of environmental biodiversity protection and energy (and money) saving as "corollary" of applying the law.

Seeks financing for the new lighting, suitable for the energy saving instructions, and communicates those resources to the relevant state, regional and local public institutions.

For lighting manufacturers, the OTPC certifies free of charge light fixtures and light sources suitable to be used in protected areas.



HOW DO WE ENSURE COMPLIANCE WITH THE LAW?

2) Legally, any new construction site with exterior lighting has to be reviewed before the building permit is granted and, among the things to be checked is the compliance with the ley del cielo.

The office does routine follow-ups of the lightning in the different municipalities searching for eventual public or private new lighting (such as advertising lighting) to ensure they have followed the requirements. When this is not the case, they start up the fining process through the regional Ministry of Industry of the Canarian Government.

3) The development of new lightning systems —e.g. the more recent LED technology— implies adapting the law. For this, new regulations have to be drafted. The OTPC also takes care of this, proposing to the Spanish Government changes to the legislation.

4) The OTPC is headquartered in the IAC, the institution that owns the Astronomical Observatories. The IAC has a proactive role in disseminating, educating and communicating to the various strata of society to inform and convince about the importance of preserving the sky as a natural resource.

This law is possible thanks to...

Excellent sites for science

State support

Communication and awareness

Strong local support


THE SKY,
THREATENED
International Agreements
1979
“UNIVERSAL” LAWS/AGREEMENTS-UN
OTIPC
(OFICINA TÉCNICA INTERNACIONAL DE
PROTECCIÓN DEL CIELO)
SKY
LIVE.TV

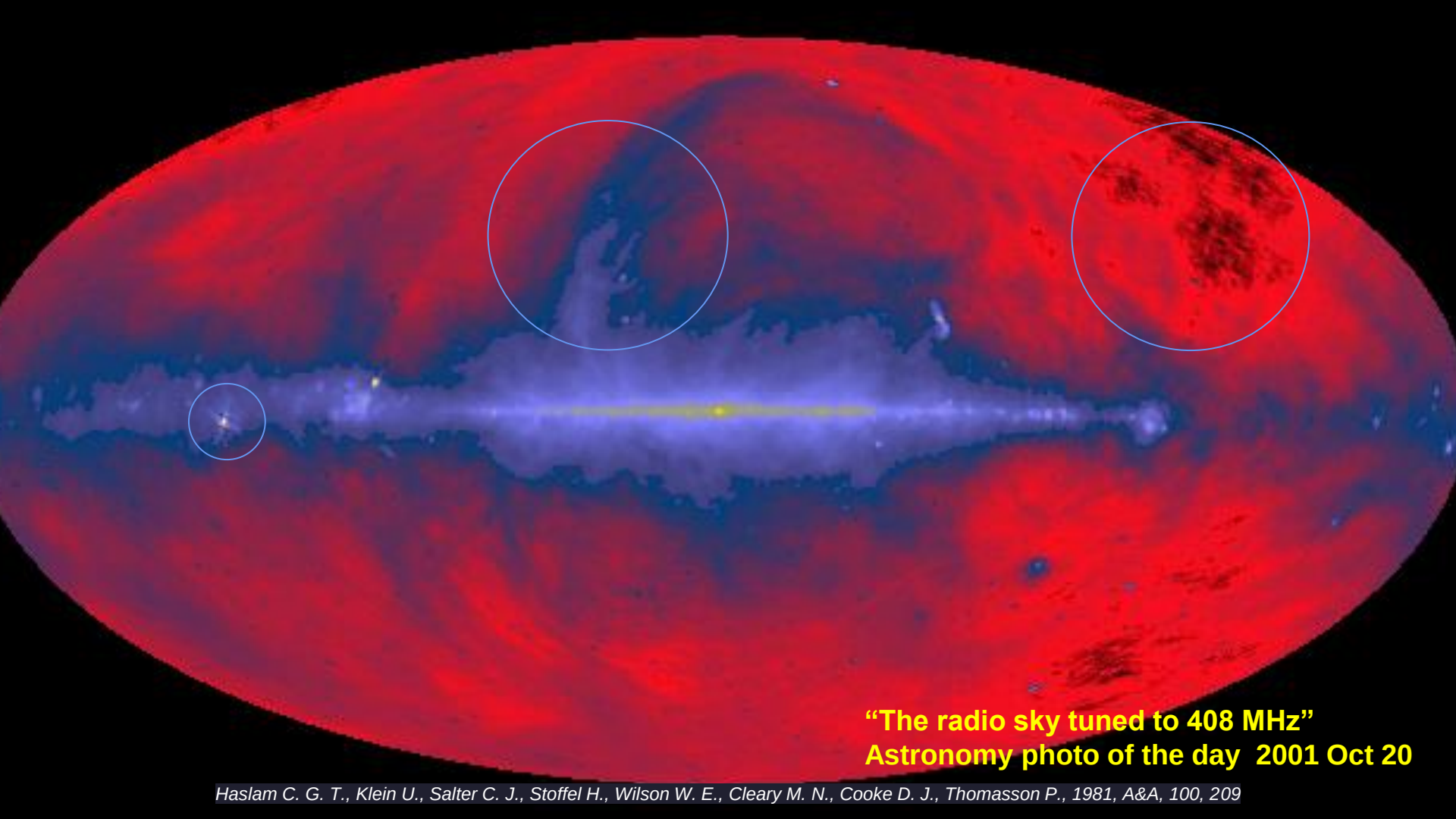
Casiana Muñoz-Tuñón

Radio astronomy

Federico Di Vruno (*SKA Observatory/ IAU Centre*)

“The deep Sky” by Axel Mellinger (2000)

*Axel Mellinger, A Color All-Sky Panorama Image of the Milky Way, Publ. Astron. Soc. Pacific **121**, 1180-1187 (2009).*



“The radio sky tuned to 408 MHz”
Astronomy photo of the day 2001 Oct 20

Haslam C. G. T., Klein U., Salter C. J., Stoffel H., Wilson W. E., Cleary M. N., Cooke D. J., Thomasson P., 1981, A&A, 100, 209

Threats to the radio sky

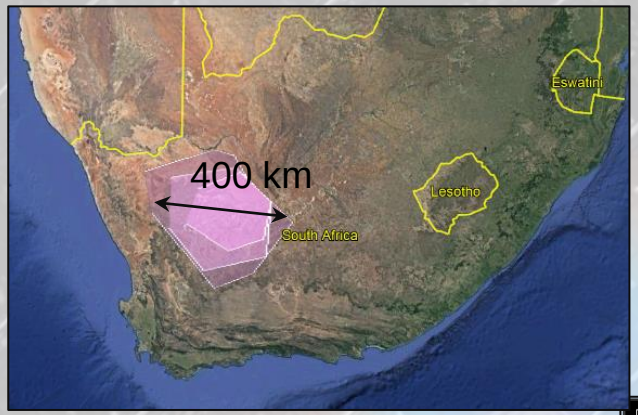
- Continuous increase in the use of the radio spectrum by terrestrial and airborne systems (Communications, ultra wide-band devices)
- Increase in the number of high-power space radars, that can damage radio telescope receivers
- New large LEO constellations:
  - Potential impact on **radio astronomy protected bands** close to downlinks (out of band emissions)
  - Wideband observations will be affected
  - Potential interference owing to **electromagnetic radiation** (not related to downlinks)

Mitigations by Regulation

- **Frequency bands**: primary or secondary status in the Radio Regulations, passive bands (RR5.340) and urging protection to radio astronomy (RR 5.149)
- Recommendations for high-power radars to coordinate with radio astronomy
- Protection from adjacent or in-band signals
- National/Regional Coordination zones

National **Radio Quiet Zones:**

- Australia
- United States
- China
- South Africa
- Chile
- Mexico
- Spain
- Brazil
- Canada
- Russia
- Puerto Rico



South African RQZ

Mitigations by national regulators
Radio Quiet Zones

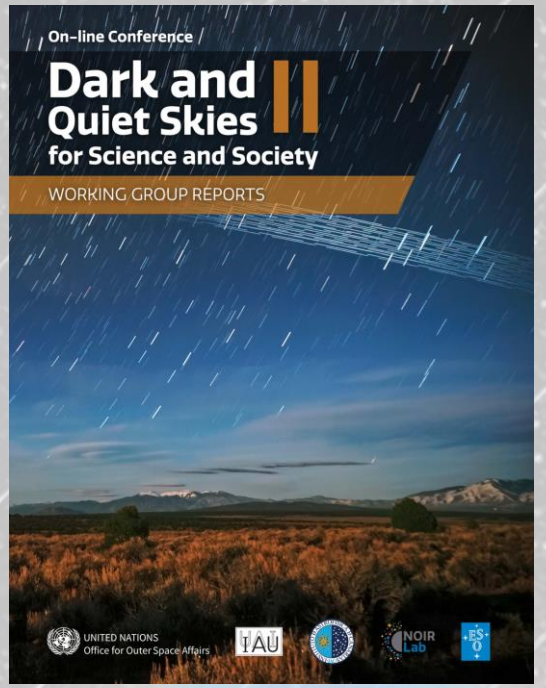
Sign entering the Western Australia RQZ. Credit:CSIRO

- Geographical areas where the radio spectrum is **specially managed to avoid interference** to radio telescopes
- Different frequency ranges and protection limits
- Mostly acting on terrestrial transmitters
- Some also coordinate airborne transmitters
- RQZ regulations **don't apply to spaceborne transmitters**

Report ITU-R RA.2259-1: "Characteristics of Radio Quiet Zones"

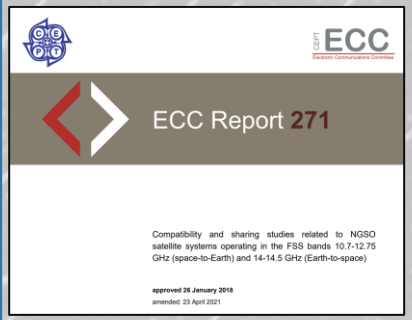
Recommendations from D&QS II
Satellite Constellations

I. Be able to avoid pointing at radio telescopes and Radio Quiet Zones
II. Minimize antenna sidelobes and out-of-band emissions
III. Characterize radio noise* in large constellations



* Not related to downlink radio transmissions

Mitigations by national regulators



- Large LEO constellations:
  - Studies of protection of radio astronomy bands (e.g. ECC report 271[1], JASON report[2])
  - Some protections in national radio licenses:
    - **USA** has coordination requirements with radio astronomy sites in their national frequency plan for satellite downlinks at certain frequencies, also for terrestrial transmitters near radio telescopes
    - **Germany** and **Spain** have introduced conditions to protect telescopes from constellations in radio licenses (in some frequencies).

1. https://docdb.cept.org/download/3ab9e6bc-0afd/ECC%20Report%20271.pdf
2. https://www.nsf.gov/news/special_reports/jasonreportconstellations/

Mitigations by national regulators

- **Germany**
  - No downlink beams in 12.5 km radius in Effelsberg and Wetzell Telescopes for **10.95-12.75 GHz**
  - Prohibit the use of **14.47 - 14.5 GHz** within the zone marked in black

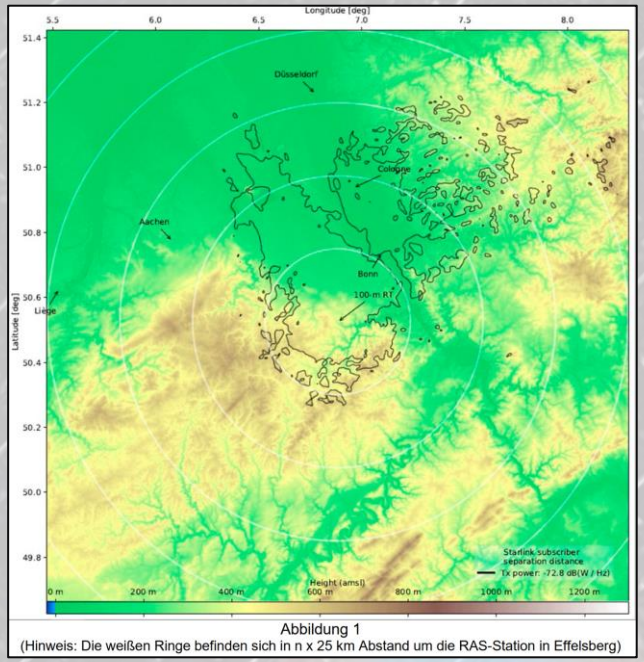


Abbildung 1
(Hinweis: Die weißen Ringe befinden sich in n x 25 km Abstand um die RAS-Station in Effelsberg)

Protection zone around Effelsberg for 14.47-14.5 GHz

1. https://www.bnetza-amtsblatt.de/download/73

Mitigations by Industry

- Operators are sharing ephemerides, enough accuracy?
- Antenna technology moving towards small-footprint, steerable beams
- Guard-bands around RAS bands (e.g. 10.6-10.7 GHz band)
- Wishlist:
  - Minimize out-of-band emissions and sidelobes to avoid interference into RAS bands
  - Characterization of radio noise (non-communication signals) in RAS bands?

Mitigation by radio observatories

- Radio Frequency Interference mitigation work for more than 3 decades
- Simulations to assess the issues
- Measurement campaigns (requires transmitting spacecraft)
- The community is willing to put **even more resources** on hardware and software to mitigate these effects (no combination can make them disappear)

ATCA radio telescope – Credit: CSIRO

Next Steps in Implementing Mitigations for Satellite Constellation Impact on Optical/Infrared Astronomy

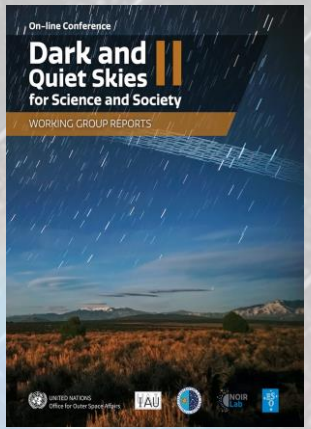
Connie Walker (NSF's NOIRLab/ IAU Centre)

on behalf of the Dark & Quiet Skies Sat Con Observatories Working Group

Acknowledgement to Meredith Rawls, Richard Green, Andy Williams and Federico Di Vruno for input on slides.

Addressing the impact of satellite constellations on optical astronomy

- Described here are efforts the astronomical community is taking to **characterize and mitigate the impact of reflected sunlight** from constellations of commercial communications satellites in Low Earth Orbit (LEO).
- These efforts are built on the **series of workshops**[1] starting with the US NSF sponsored SATCON1, followed by the first UN/IAU/IAC-sponsored Dark & Quiet Skies Workshop, then SATCON2, and the current Dark & Quiet Skies Workshop II.
- The **focus is on next steps and implementation strategies**.
- Reflected sunlight is only one of the impacts on astronomy, with radio interference and sustainable scientific use of increasingly crowded LEO space among the other concerns.



[1] *All four reports at https://noirlab.edu/public/products/techdocs/*

Impacts to optical/IR astronomy from satellite constellations

Brightness

V ~ +3 to +4 in parking orbits, +6.5 to +9 on station (smaller numbers = brighter)

Number

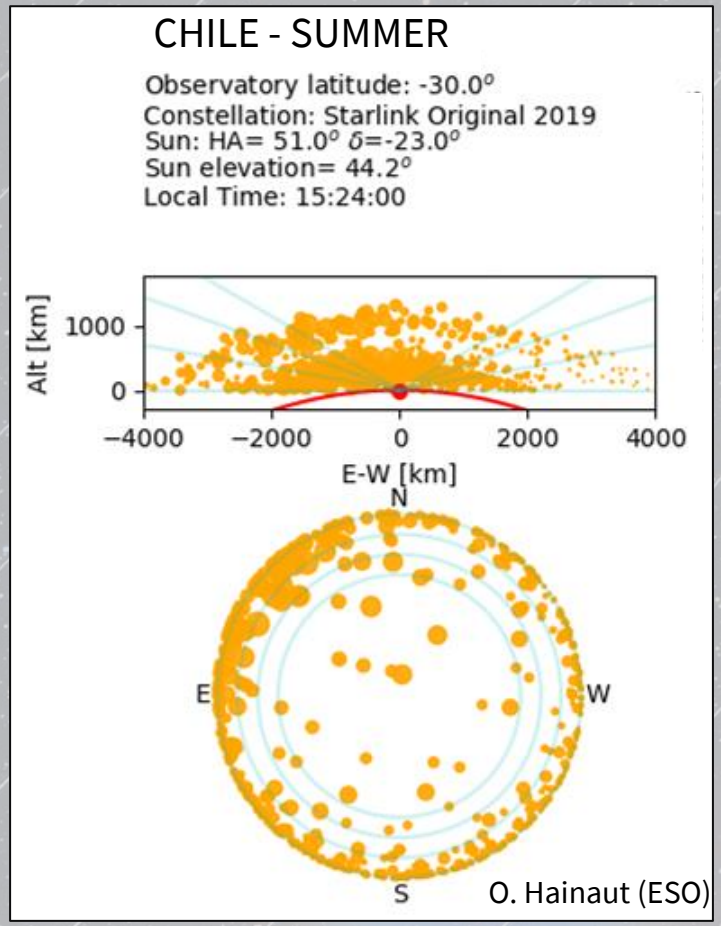
Hundreds of thousands proposed in FCC & ITU filings

Diffuse sky brightening

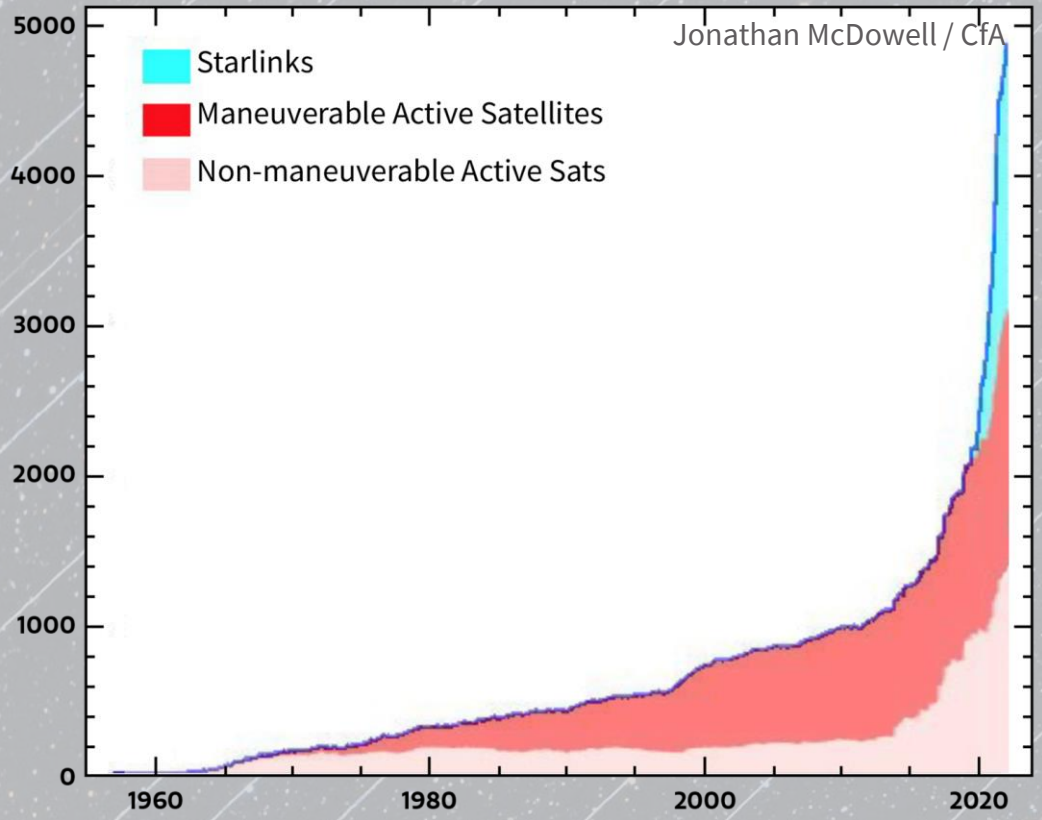
Scattering of reflected sunlight from satellite debris (<10cm)

"Wild West" or "Far West"

No protection for optical astronomy; limited protections for radio.



Number of Active Satellites (1957–2022)



Active satellites

2019 May 1: ~2,200

2022 Jan 1: ~5,000

Active + inactive satellites

~8,000

Trackable space junk

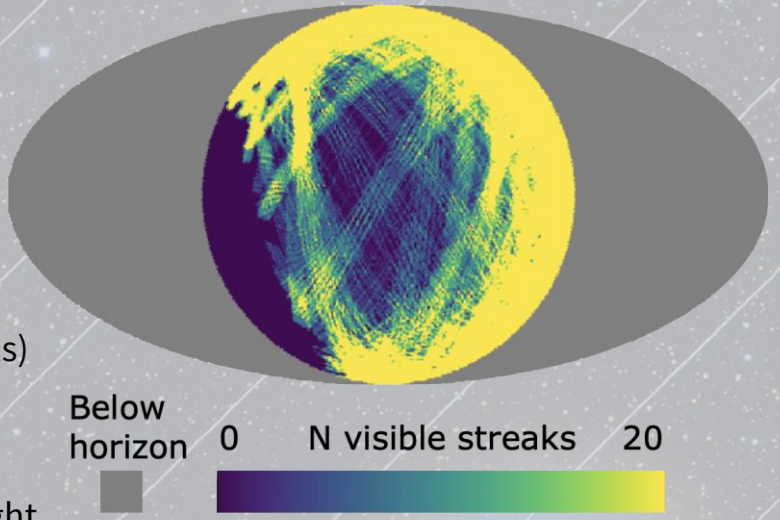
~~~38,000~~ (~41,000!)

Small (1-10 cm) debris

~600,000
~~~

Impact Assessment on Optical/Infrared Astronomy

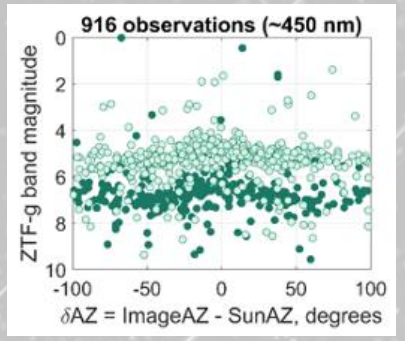
- **Low-elevation (twilight)** studies
  - ➤ Potentially Hazardous Asteroid missions will have fewer discoveries and orbit determinations
- Observatories with **wide fields of view**
  - ➤ Wide-field (e.g., VLT Survey Telescope): **50% of frames - *several satellites per frame*** at twilight
  - ➤ Super-Wide-field on large telescope (e.g., Vera C. Rubin Observatory)
    - ■ ***Every other*** frame affected at twilight (tens of trails)
    - ■ *Many during whole summer night by high altitude*
- Observatories with **narrow fields of view**
  - ➤ (ESO's VLT, ELT etc.): **~% - *~10%*** frames affected at twilight
- Other areas impacted:
  - ➤ Extended objects, such as galaxies, or image arcs from strong gravitational lensing; systematic analysis of weak lensing distortions; spectroscopy; and occultations

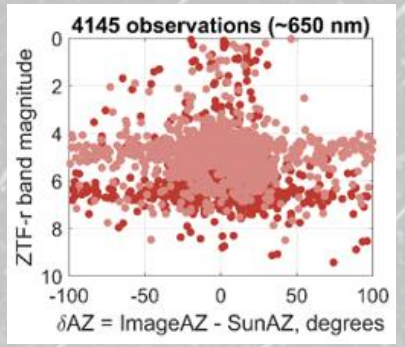


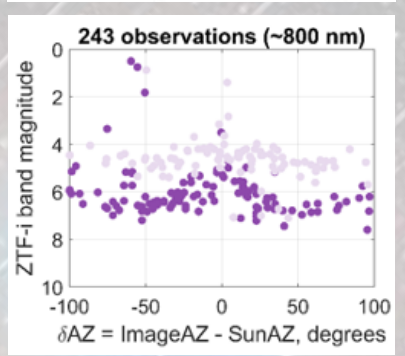
Satellite visibility from Rubin Observatory
P. Yoachim (U. Washington)
from Tyson et al. 2020

Major needs identified for the community

- **Coordinated observations of individual satellites** from multiple sites to map the reflection of sunlight in multiple colors as a function of orbital phase angle and other parameters. This activity is critical for the prediction of apparent brightness.
- **Development of algorithms** with robust implementation for
  - ➤ predicting satellite passages through specific planned observational pointings (PassPredict);
  - ➤ identifying and masking streaks (TrailMask);
  - ➤ simulating streaks in images and addition of solar spectra to spectral data to test detection, masking and removal approaches;
  - ➤ developing current probabilistic predictions and visualization in all-sky mode for general observational planning.
- One or more **image data repositories** for the testing of algorithms for sunlight streak identification and masking.







A pathway to be provided by the IAU Centre

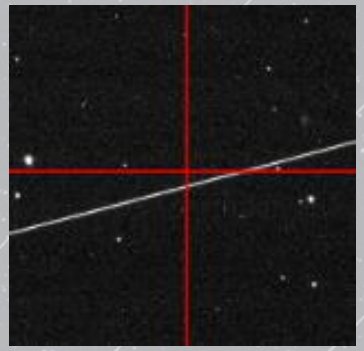
SatHub:

a one-stop shop for training, outreach, collection and analysis of satellite observations

M. Rawls, U. Washington

Orbital solution portal

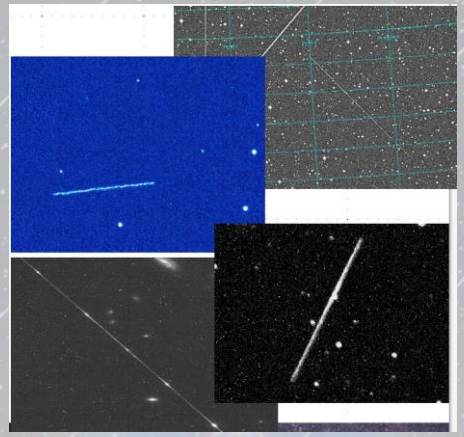
- Provide **public access to orbital solutions** every 8 hours or immediately following a maneuver, whichever is first, with **error bars**
- Ephemerides-style **and** general perturbation-style (“TLE”) solutions
- Automatic synchronization with complementary services



Jeremy Tregloan-Reed

Software tools

- A home for PassPredict, TrailMask, Simulations & Modeling, etc.
- **User-friendly documentation**, support, and maintenance
- Standard **test suite** supporting a wide range of instrument and satellite signature properties to support software development

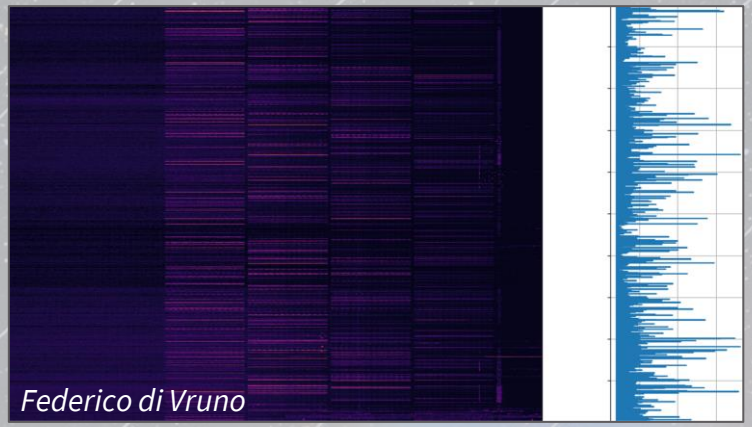


Jonathan McDowell

Astronomical data repositories

Publicly available, easily accessible, user-friendly, documented

- Collection of optical/near-IR images with satellite streaks (e.g., **Trailblazer**)
- Spectra contaminated with reflected solar spectrum
- Space-based observations from low-Earth orbit (e.g., Hubble)
- Radio data affected by satellite interference
- DSLR images, visual sightings, other formats



Research topics identified for the community

- **Research on the impacts of satellite trails on scientific analysis**, in cases such as filtered measures of weak gravitational lensing, determination of orbital parameters for near-Earth objects, or analyzing continuous diffuse objects such as emission nebulae.
- **Research on the aggregate impact of the increasing number of objects** in near-earth space on diffuse sky brightness, with particular emphasis on increased atmospheric aerosols and the small particle distribution in LEO.
- **Research on the impacts of satellite trails on other astrophysical subfields** not mentioned above, including spectroscopic and radio studies, with a particular focus on how this impact is changing as a function of time and frequency/color/bandpass. (Image data repositories will be crucial for these studies.)
- **Development of strong education and outreach materials** (e.g., the SatHub Training Curriculum) for the general public, amateur, and professional astronomers.

Training curriculum for observers worldwide

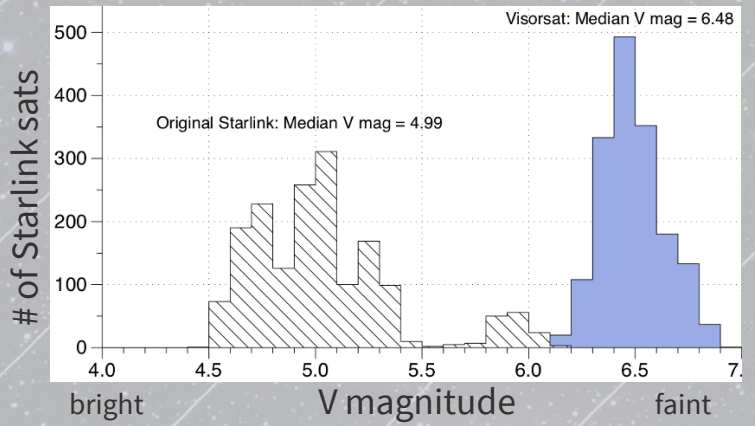
- A crucial part of SatHub — a global LEO satellite monitoring campaign plus shared data and software are insufficient
- Outline of a training curriculum for observers of all kinds
  - ➤ **Core curriculum** (introduction, observing satellites, reporting observations, image and data analysis)
  - ➤ **Advanced modules** (software development, radio astro, space law)
  - ➤ **Quick start recipes** (for different observer hardware scenarios)

We want everyone to interface with SatHub

Sky observers, data analysts, software developers, industry experts, students…

- As the satellite population changes, evolving impacts require **observer-operator dialogs**
- Information in SatHub will be **public**, open, and accessible to support real-time collaboration
- We aim to join innovation with existing solutions, prioritize **ease of use**, and enable **coordination among multiple stakeholders**

Pat Seitzer



There will be many opportunities for individuals and organizations to contribute to SatHub!

Forward look towards policy and regulatory measures

Findings from the Dark & Quiet Skies SATCON WG

Andrew Williams (ESO)

Dark & Quiet Skies SATCON WG aims

National policy working group:

- Reviewed existing space policy and regulations
- Identified where existing regulatory instruments can be adapted to take account of astronomy, or which new instruments are needed

International Legal Working Group:

- Reviewed the applicability of the international legal framework for the protection of dark and quiet skies
- Identified other international instruments that have similar objectives to those of the astronomy community, with particular regard to the impact of space activities and satellite constellations on astronomical observations.

Current Situation for Dark Skies / Optical Astronomy

startup wants to put huge ads in space. Not everyone is on board with the idea.

Swarms of tiny, light-reflecting "cubesats" would come together to form luminous words or logos.

Other than a US Law regulating Space Advertising…

No regulation governing:

- the visual appearance of the night sky
- Reflected sunlight from anthropogenic space objects

Satellite operators only beginning to grapple with brightness as a design requirement

Future directions for Policy and Regulatory measures

Future regulatory requirements could consider:

- A quantitative impact assessment of:
  - Brightness of satellites in context of operational profiles
  - Cumulative radio emissions
  - Strategies to avoid radio quiet zones.
- Requirements for operational data sharing to mitigate impacts on astronomy;

Further regulatory measures should be implemented in coordination with other space policy issues (E.g. space traffic management, environmental issues, space debris, spectrum management)

Other measures (jointly with industry, astronomy, government)

- Development of industry standards
- Development and implementation of coordination mechanisms
- Support for mitigation measures in national science policies and funding instruments
- Incentives for corporate social responsibility

Contact Information

- Richard Green: rgreen@arizona.edu
- Casiana Muñoz-Tuñón: cmt@iac.es
- Federico Di Vruno: Federico.DiVruno@skao.int
- Connie Walker: connie.walker@noirlab.edu
- Andrew Williams: awilliam@eso.org>