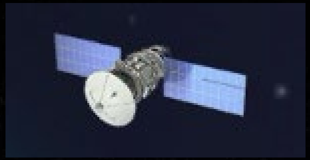
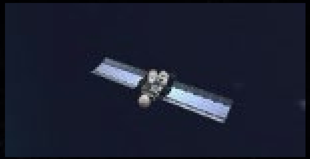



Update on
Dark & Quiet Skies Initiative



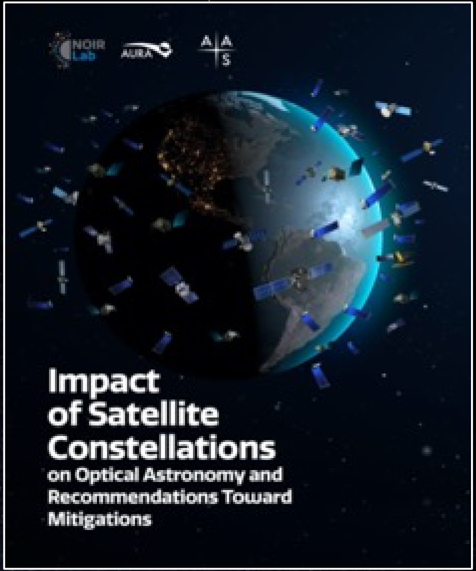
Connie Walker (NSF's NOIRLab), Joel Parriott (AAS)
& Phil Puxley (AURA)

(noting the Working Group Members of the SATCON1 and D&QS Workshops)

Two Workshops in 2020

SATCON1: June 2020, NSF-funded, NOIRLab & AAS hosted

- Impact of satellite constellations to astronomy & recommended mitigations
- Download the reports a BAAS article:
  https://noirlab.edu/public/news/noirlab2022/
  https://doi.org/10.3847/25c2cfeb.346793b8



Slides 16-31

Dark and Quiet Skies: Oct. 2020, sponsored by IAU, UN & IAC

- Recommendations to the UN Science & Technology Sub-Committee on Satellite Constellations, Protection of Optical & Radio Observatories, Dark Skies Oases & Bio-Environment
- Download the reports at:
  https://www.iau.org/publications/iau/wg_reports/

SATCON1 Working Group Members (80% from USA)

Constance	Walker	NSF's NOIRLab	Jared	Greene	SpaceX
Jeffrey	Hall	Lowell Observatory	Flynn	Haase	NSF's NOIRLab
Lori	Allen	NSF's NOIRLab	Olivier	Hainaut	ESO
Richard	Green	U. Arizona	Steve	Heathcoat	NSF's NOIRLab
Patrick	Seitzer	U. Michigan	Moriba	Jha	U. Texas at Austin
Tony	Tyson	UC Davis/Rubin Observatory	Harrison	Krantz	U. Arizona
Amanda	Bauer	Vera C. Rubin Observatory	Daniel	Kucharski	U. of Texas at Austin
Kelsie	Krafton	AAS	Jonathan	McDowell	CfA
James	Lowenthal	Smith College	Przemek	Mróz	Caltech
Joel	Parriott	AAS	Angel	Otarola	ESO
Phil	Puxley	AURA	Eric	Pearce	U. Arizona
Tim	Abbott	NSF's NOIRLab	Meredith	Rawls	U. Washington/Rubin Observatory
Gaspar	Bakos	Princeton	Clare	Saunders	Princeton
John	Barentine	IDA	Rob	Seaman	Catalina Sky Survey
Cees	Bassa	ASTRON	Jan	Siminski	ESA Space Debri Office
John	Blakeslee	Gemini Observatory/NSF's NOIRLab	Adam	Snyder	Stanford
Andrew	Bradshaw	SLAC	Lisa	Storrie-Lombardi	Las Cumbres Observatory
Jeff	Cooke	Swinburne University	Jeremy	Tregloan-Reed	U. Antofagasta
Patricia	Cooper	SpaceX	Richard	Wainscoat	U. Hawaii
Daniel	Devost	Canada-France-Hawai'i Telescope	Andrew	Williams	ESO
David	Galadí	Icosaedro working group of the Spanish Astronomical Society	Peter	Yoachim	U. Washington/Rubin Observatory

D&QS Working Group Members (40% from USA)

Slides 32-35

Constance	Walker	Chris	Hofer	Kathy	Nield	Paul	Gard
Simonetta	Di Pippo	Daniel	Kucharski	Kelsie	Krafton	Pedro	Sanhueza
Andrew	Williams	Daniel	Devost	Kevin	Wu	Peter	Blattner
Angel	Otarola	Diane	Paulson	Liese	Van Zee	Rachel	Street
Antonia	Varela	Dionýz	Gašparovský	Lori	Allen	Richard	Wainscoat
Casiana	Muñoz-Tuñon	Doug	Knox	Luc	Schlangen	Robert	Seaman
Costis	Bouroussis	Eduardo	Unda-Sanzana	Mario	Motta	Robert	Massey
David	Galadí-Enríquez	Eric	Pearce	Markus	Duelli	Roger	Davies
Genoveva	Micheva	Federico	DiVruno	Martin	Barstow	Salvador	Bará
Harvey	Liszt	Giuliana	Rotola	Martin	Aubé	Sergio	Ortolani
James	Lowenthal	Harrison	Krantz	Masatoshi	OHISHI	Sibylle	Schroer
John	Hearnshaw	Jan	Siminski	Maurice	Donners	Steve	Lau
Piero	Benvenuti	Javier	Diaz Castro	Meredith	Rawls	Steve	Heathcote
Richard	Green	Jeffrey	Hall	Michael	Lindqvist	Tasso	Tzioumis
Sara	Lucatello	Jeremy	Tregloan-Reed	Michele	Bannister	Tim	Deck
Adrian	Tiplady	Joel	Parriott	Moriba	Jah	Tim	Maclay
Andreas	Jechow	John	Barentine	Nathalie	Ricard	Tomas	Novak
Anika	Jäggerbrand	John	Hearnshaw	Olga	Zamora	Tony	Tyson
Bryan	Douglas	Jonathan	McDowell	Olivier	Hainaut	Travis	Longcore
Cees	Bassa	José Miguel	Rodriguez	Patricia	Cooper	Vlad	Pashkovsky
Charles Lee	Mudd Jr	Juan Pablo	Armas	Patrick	Seitzer	Zouhair	Benkhaldoun
Chris	Benn						

Principal factors of impacts on astronomical observations from satellite constellations

Slides 36-39

The number of visible satellites

- Increasing from a few hundred up until 2019 to tens of thousands in the next few years

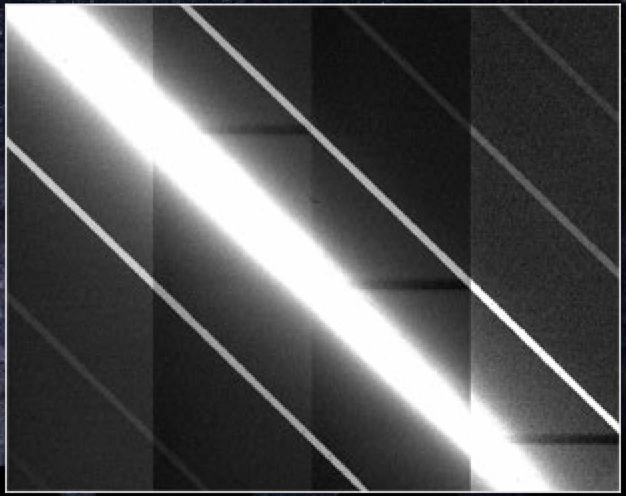
The orbital altitude of the satellites

- At any altitude, the projected surface density of bright satellites is greatest near the horizon and during twilight
- Increasingly visible all night long with increasing altitude over 600 km

The apparent brightness and attitude of the satellites

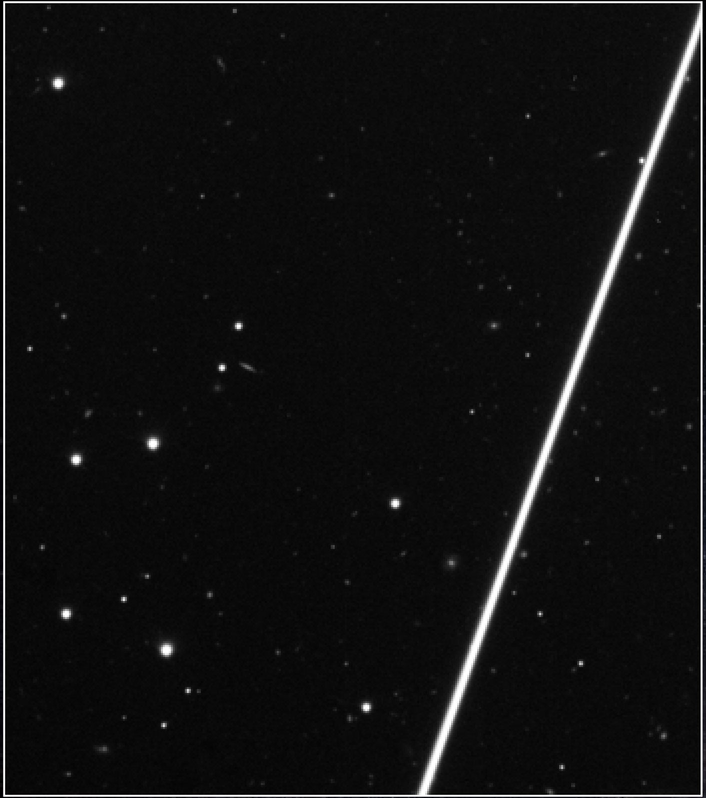
- Are they visible and bright enough to saturate detectors?

Lack of regulation (no requirement to mitigate, crowded space)



Impact Assessment by Selected Observing Genres & Science Cases

Slides 40-49



A LEOsat trail in a portion of a Subaru Telescope CCD image, as an example of a LEOsat trail in a wide-field image. This serendipitous observation of FUSE1 was done in morning twilight (4:33 am local time on 28 May 2020). The low surface brightness fuzz extends to 15 arcseconds. Credit: R. Wainscoat (U. Hawaiʻi), private communication

- Rare transients
- Deep, wide, extragalactic imaging
- Near-Earth objects (NEOs)
- Deep multi-object spectroscopic surveys
- Deep wide-field near-infrared (NIR) imaging
- Imaging of large extended low surface brightness targets
- Exoplanet transits in wide-field surveys
- Discovery of new phenomena
- Citizen science, amateur astronomers, and stargazers worldwide

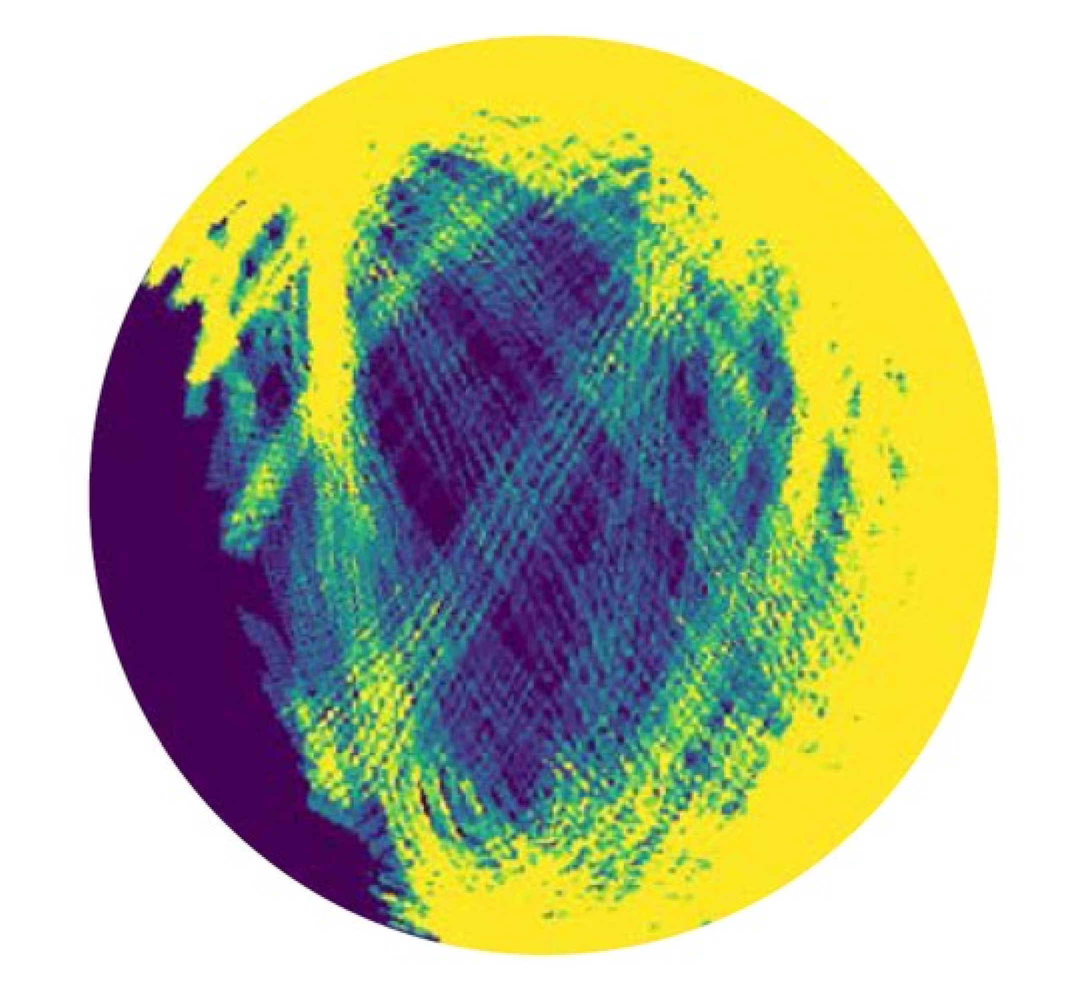
Discovering Our Universe Together

A Primary Finding

Wide-field and twilight programs will be critically affected.

High-etendue facilities like Rubin will severely impacted if numbers of satellites reach the tens of thousands.

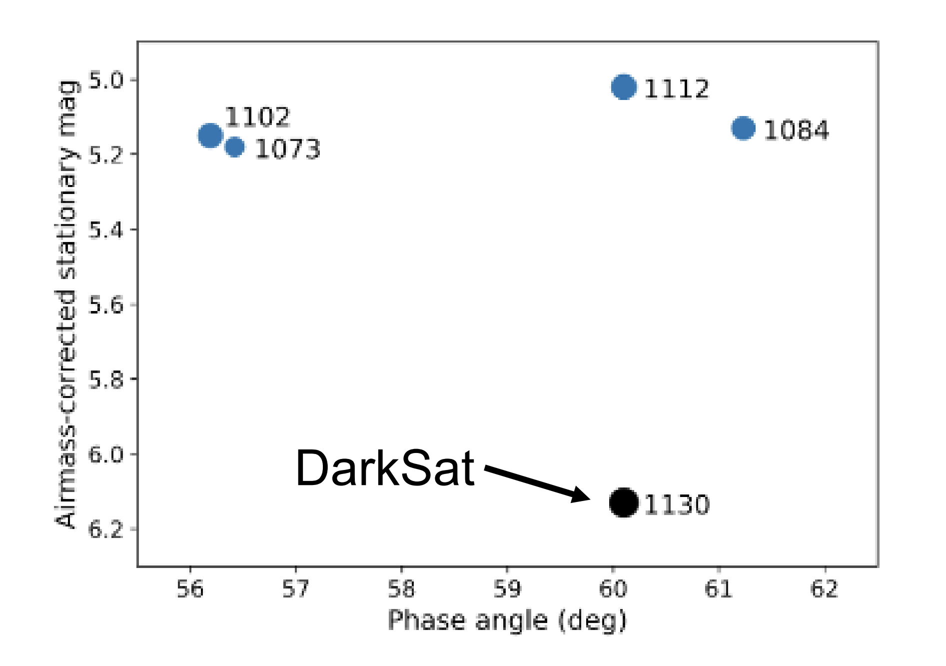
Low-elevation studies (e.g., NEO searches) will be heavily impacted as well.



Satellite visibility from Rubin Observatory
P. Yoachim (U. Washington)

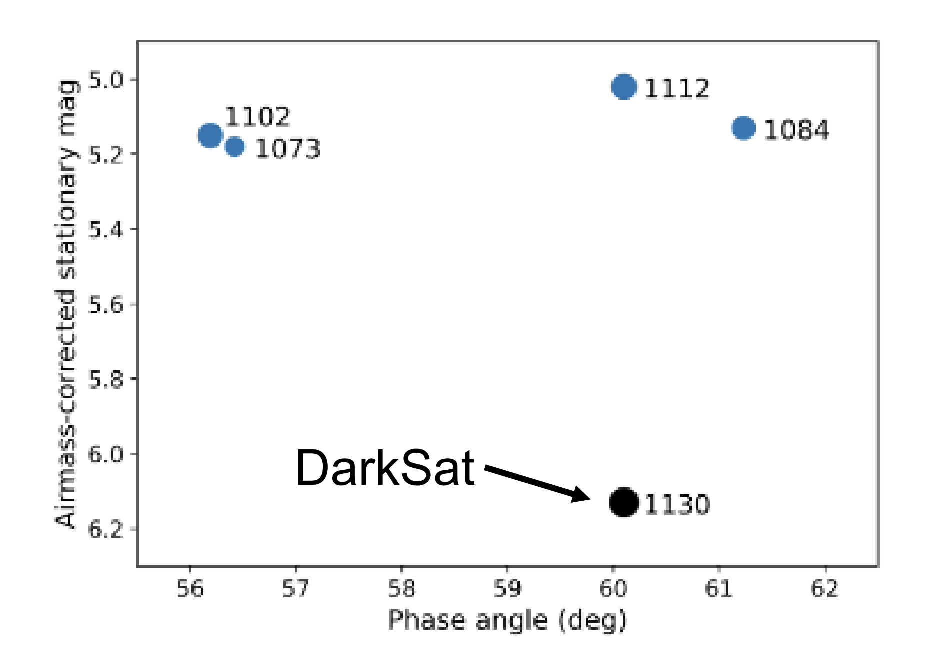
D&QS Satellite Constellations WG: Main Recommendations

- Encourage awareness raising, transparency, & collaboration in stewardship of the night sky.
- Design missions to minimize negative impacts on astronomical observations
  - Minimize operational altitudes
  - Number of satellites
  - Time spent in orbit



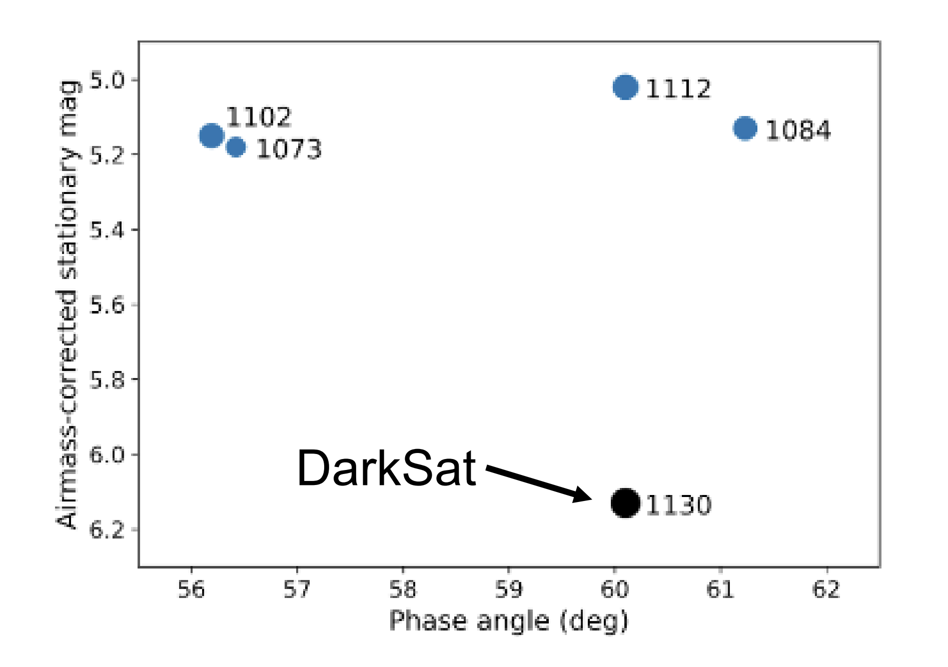
D&QS Satellite Constellations WG: Main Recommendations

- Design satellites to minimize negative impacts on astronomical observations and the pristine night sky
  - To be fainter than 6th mag to naked eye and 7th mag at 550km for observaotries,
  - Incorporating dynamic orientation adjustments
  - Minimize sidelobe emissions
  - Prevent direct illumination of radio observatories



D&QS Satellite Constellations WG: Main Recommendations

- Conduct operations to minimize the impacts on astronomical research.
- Formulate satellite licensing requirements, guidelines and operational standards that take into account the impact on stakeholders.
- Support and expand the development of space domain decision intelligence



- Provide funding for understanding & mitigating impacts on astronomy & the increased overheads (e.g., more observing time or science losses).

D&QS: Moving Forward…

- The 280 page full report is almost ready for a second release.
- A “glossy” version for the public is being written.
- Support is being requested of UN delegates for the Conference Room Paper (CRP).
- CRP & technical presentations to be made at the UN Science & Technology Sub-Committee (STSC) meeting April 21 & 22.
- If successful, the CRP will be raised to a “Working Paper” for the full COPUOS meeting in August.
- The D&QS Conference will take place (in person?) Oct 4-8 in La Palma.

E-Institute – A Path Forward

Explore ways astronomers, satellite operators, and a broad set of stakeholders can collaborate on the highest-priorities or most feasible recommendations and consider the resources required to do so.

- A network of observatories to coordinate observations to check on decrease in satellite brightness.
- Tools for highly accurate position-time information on LEOsats, including real time prediction software for observers.
- Advanced pointing algorithms for avoidance of bright satellites (e.g., optimize observing scheduler)
- Predictive models for satellite brightness vs orbit relative to observatory.
- Lab investigations of sensor response to bright satellite trails.
- Pixel processing software for suppression of these effects.
- Measures to darken LEO satellites to meet the brightness goal.
- Full simulations of science impact by research community.

Disc

- Thought leadership on the policy, regulatory, and standards-setting environment

Bottom Line Now & Looking to the Future

- *No combination of mitigations able to completely avoid the impacts of Low-Earth Orbit satellite trails on science programs of the coming generation of optical astronomy facilities.*
- All optical astronomy observatories will be affected to some degree.
- If operators cannot or will not implement successful mitigation strategies, then many of the observing modes of the new technology telescopes coming out in the next decade will be endangered.
- If satellite operators launch > tens of thousands, at 1200km altitude, every 30-second exposure taken at the optimal observing time (summer) in the southern hemisphere will be impacted.
- With tens of 1000s of satellites planned to be launched in the next decade, mitigating that many, will be a challenge that few observatories will be able to fully handle.

Thank you for your kind attention.

Connie Walker: connie.walker@noirlab.edu

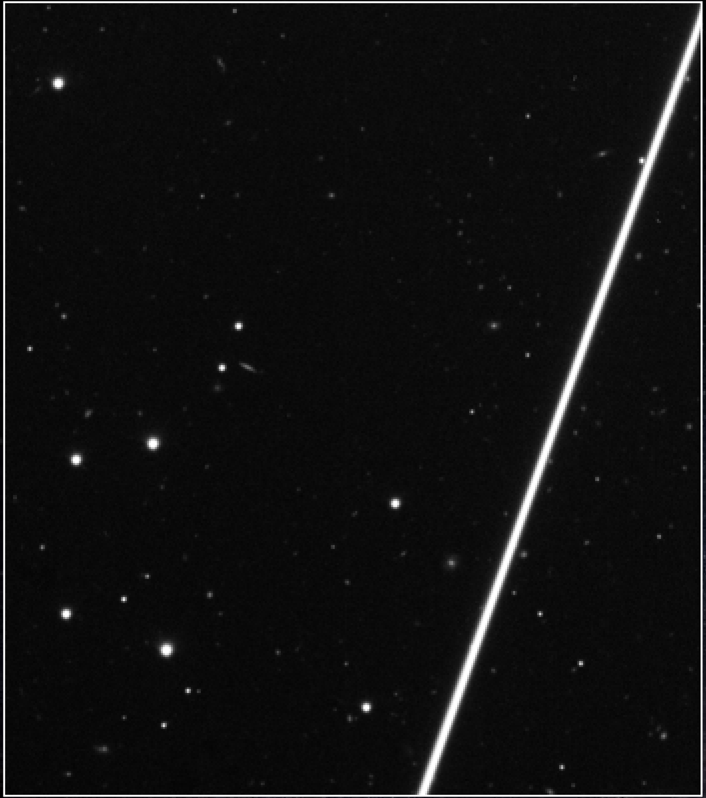
EXTRA SLIDES

Protection of Ground-Based Optical Observatories

(Dark & Quiet Skies Workshop)

Richard Green, WG Co-Chair
Casiana Muñoz-Tuñón, WG Co-Chair

Impact Assessment by Selected Observing Genres & Science Cases



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Discovering Our Universe Together

D&QS Optical Observatories WG: Overaching Goal/Recommendation

- The goal of the model regulatory framework proposed for the UN is to slow, stop, and reverse the rate of increasing artificial skyglow at major professional observatories in no more than a decade and on shorter timescales wherever possible.

- Other D&QS working groups protection:
  - Dark skies Oases
  - Bio-Environment
  - Radio Observatories

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.
- Special circumstances for even the darkest remote observatory sites include mines, wind farms, military installations, border control

Recommended Regional Framework

- Each major observatory site has its own circumstances of current artificial light contribution, topography, and pattern of development.
- Achieving the goal will require a regional lighting plan with a specific approach based on detailed modelling.
- Protection of the site may entail land-use zoning that restricts development and the ultimate tightening of regulations with time.
- A key first step is dynamic definition of usage zones, depending on traffic, activity, and time of night to set the safety-based lighting levels.

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 30º 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.

Protection of Radio Observatories

(Dark & Quiet Skies Workshop)

Harvey Liszt, WG Chair

2020 in Radio Astronomy Spectrum Management

- Summer prelude
  - Aeronet Global air-air 70/80/90GHz mesh network
- Autumnal horror
  - AST&Science satellite network
- December surprise
  - ESA-IUCAF agreement to avoid illumination of RAS sites by EarthCare 94 GHz cloud-profiling radar
- January illumination
  - But yuck, 63 new C-band (5.5 GHz) Radars

https://tinyurl.com/yyumnr2r

Harvey Liszt

NRAO Spectrum Manager (www.nrao.edu)

&

Chair, IUCAF (www.iucaf.org)

Radio Astronomy: Satellite Constellations

- Observations conducted by radio and mm-wave observatories will also be substantially affected.
- Radio observatories have relied on local radio quiet zones to allow observations outside the limited set of frequency bands allocated to radio astronomy.
- With the advent of substantial numbers of space-based transmitting objects above the horizon, radio astronomy faces a substantial loss unless preventative action is taken.

Dark Skies Oases

(Dark & Quiet Skies Workshop)

John Hearnshaw, WG Co-Chair

Antonia Varela, WG Co-Chair

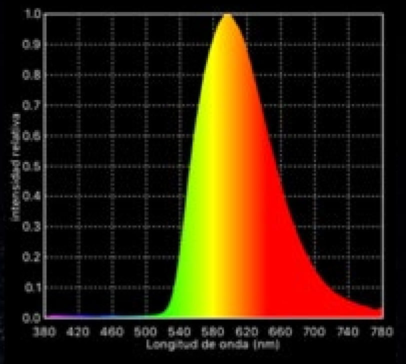
Dark Skies Oases (Places) WG

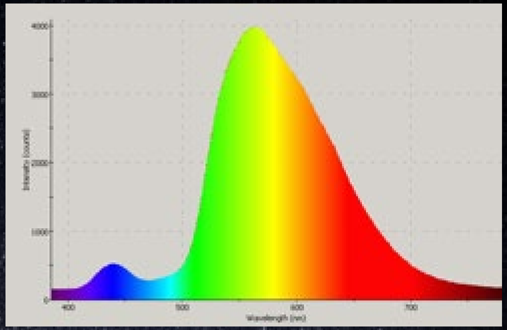
What is a dark sky oasis?

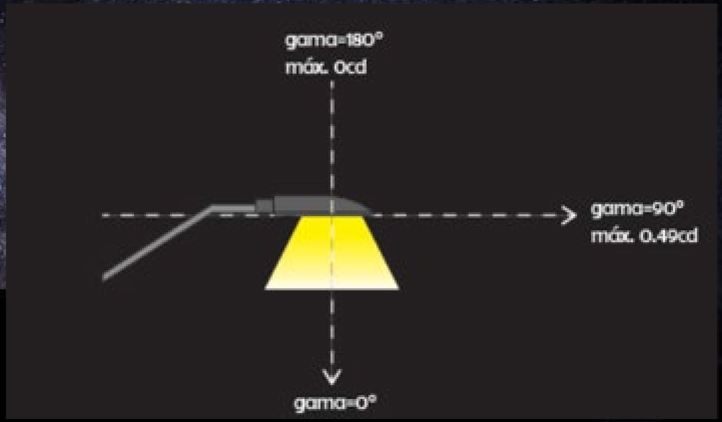
- A **dark sky oasis** (also often referred to as a ‘**dark sky place**’) is a location where the night sky is protected by an outdoor lighting policy, or in legal terms, by *a lighting ordinance.*
- This limits the amount and the wavelengths of light that shine upwards into the sky. Blue light (λ < 500 nm) is especially harmful, as it scatters the most.

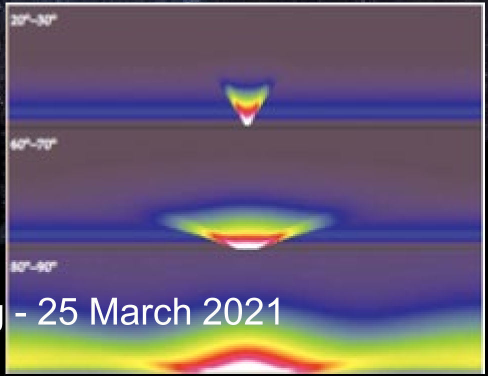
Recommendations to COPUOS

- Default condition: No artificial light.
- In ecological reserves, artificial light should not be used and if needed, it shall be narrow band amber LED or equivalent emitting no light below 500 nm. Lighting should be strictly controlled and switched on only when it is needed.
- If phosphor - converted amber LED lights are used, the amount of blue light should be below 5% of the total power distribution. 2200 K or less.
- All exterior light should only distribute light below the horizontal, and upward light output ratio (ULOR) should be no more that 0.5%: fully shielded luminaires, horizontally installed and having flat screen glass below the light source.









Recommendations to COPUOS

- No development in or near highly ecologically sensitive sites should be permitted. (roads, industries, urbanizations)
- Monitoring of night-time conditions in/near dark sky oases is encouraged through a combination of ground-based and remote sensing methods.
- Active management of natural night-time darkness as a natural resource is encouraged through recognized conservation best practices.
- Restoration plans should be implemented when sky brightness thresholds are routinely exceeded.

Bio-Environment

(Dark & Quiet Skies Workshop)

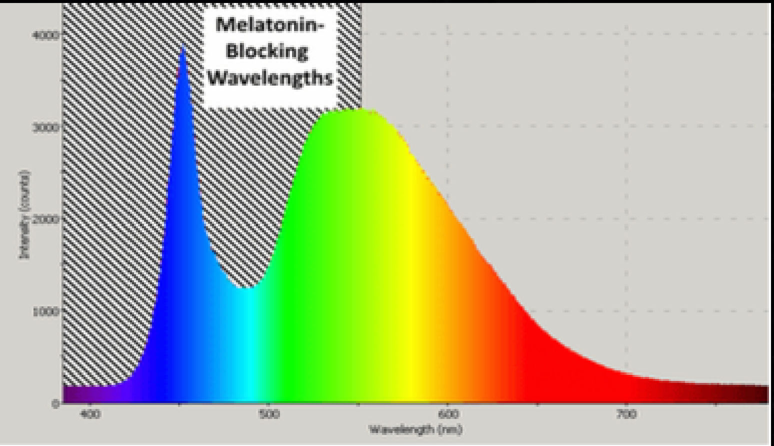
James Lowenthal, WG Co-Chair

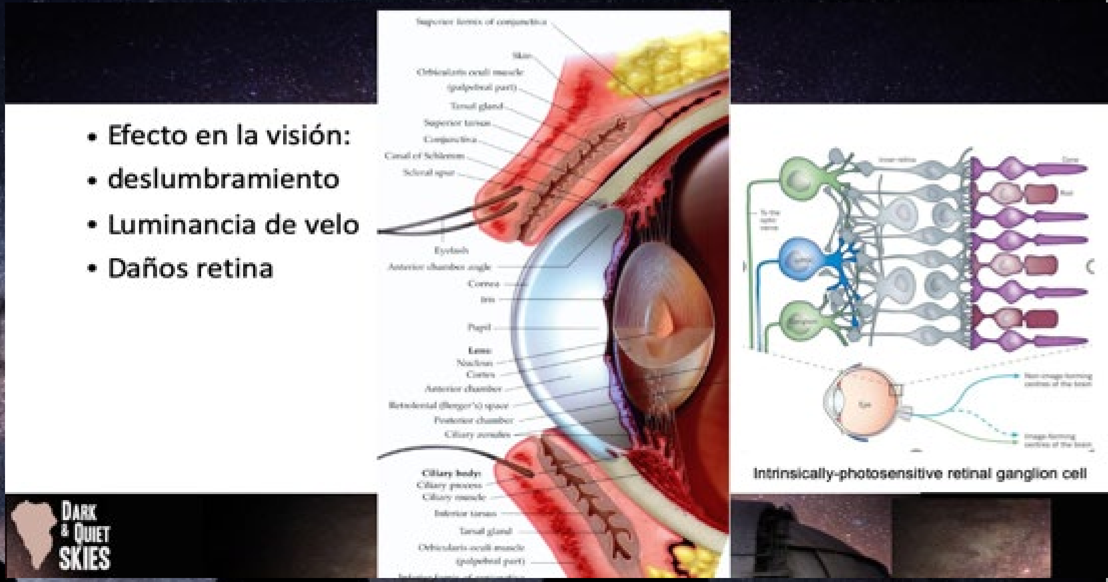
Costis Bouroussis, WG Co-Chair

Bio-Environment WG

Blue-Rich Light: A Health Risk?

- Blue light suppresses melatonin, a hormone that influences circadian rhythms
- Even dim light can interfere with a person´s circadian rhythm and melatonin secretion.
- Eyes exposed to blue light experience decrease in visual acuity since blue light scatters in eye.
- Disrupt circadian rhythm of wildlife.





General recommendations should enable:

- Regulations for environmentally friendly lighting for countries, regions, municipalities, and communities.
- Implementation of the lighting scheme: The right light, at the right place, at the right amount, for the right duration.
- Even the option of no use of light.
- Coverage of most of the environmental aspects of ALAN or Light Pollution.

Satellite Operators
(involved in D&QS Working Groups)

STARLINK BRIGHTNESS REDUCTION EFFORTS

Objectives

- Make the satellites generally invisible to the naked eye within a week of launch.
- Minimize Starlink's impact on astronomy by darkening satellites so they do not saturate observatory detectors.

Mitigations

VISORSAT

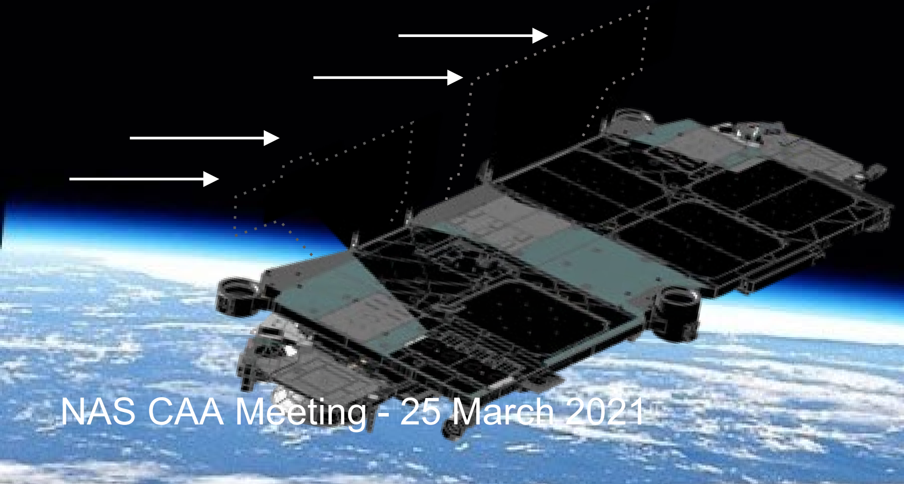
ANTENNAE MITIGATION ON STATION

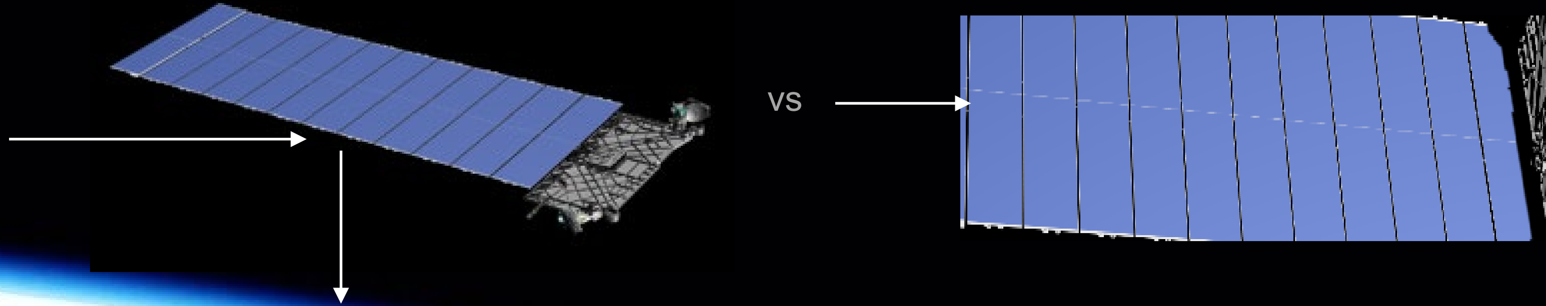
On station, the sun shade blocks sunlight from reaching the antennas, preventing reflection.

ORIENTATIONAL ROLL

ANTENNAE MITIGATION DURING ORBIT RAISE

Rolling the satellite makes sunlight bounce off the smaller ‘knife edge’ of array, reducing reflection.





Protecting astronomical observations

Reflectivity is a key consideration in our design and development process, and we are taking steps to minimize our impact on radio and optical astronomy.

System design

Project Kuiper is 3,236-satellite constellation operating between 590 and 630 km, helping reduce reflectivity compared to larger constellations or those operating at higher altitudes (over 1,000 km). As an all Ka-band system, we avoid potential interference issues with radio astronomy in Ku-band.

Deployment and operations

Maneuvering capabilities enable us to reduce earthward reflectivity during propulsive operations (orbit raise and lower), and steering capabilities allow us to minimize reflections during mission operations.

Collaboration

Amazon is committed to working with the astronomical community to find shared solutions, and will share ephemeris data throughout operations to help protect and preserve scientific research.

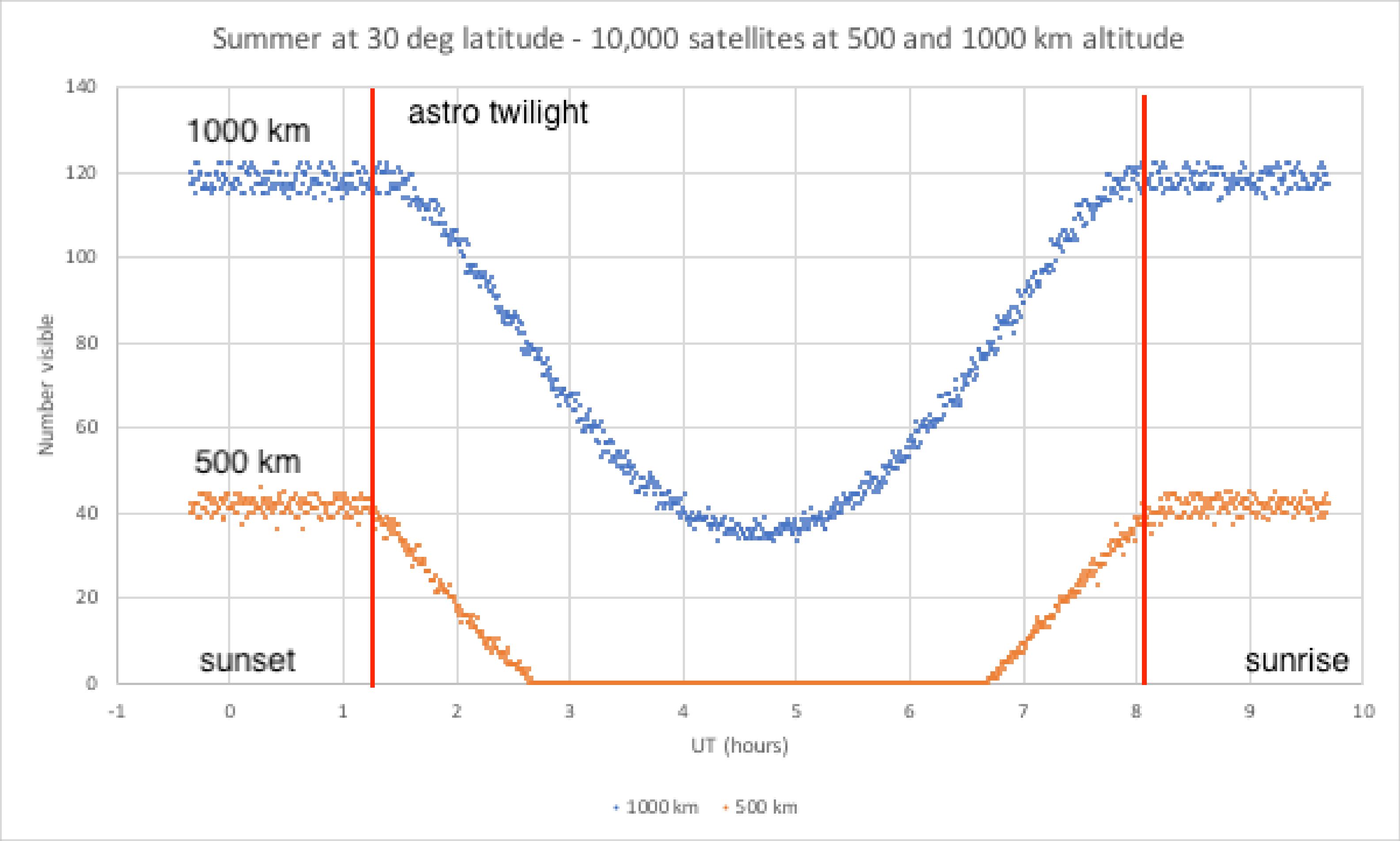
OneWeb Streamlines Constellation

OneWeb

- OneWeb's FCC filing streamlines our constellation: *47,884 to 6,372 satellites*.
- Demonstrating the commitment and vision from OneWeb's new owners, UK Gov and Bharti Global, to deploying a cost effective, responsible, groundbreaking satellite network for global broadband.
- OneWeb's top priority is deploying our first generation of 648 satellites.
- OneWeb is committed to #ResponsibleSpace: design, deployment and operations.

Principal factors of impacts on astronomical observations from satellite constellations

Numbers



10,000 satellites @ 500 km

10,000 satellites @ 1000 km

100 planes
100 satellites/plane

orbital inclination = 53 deg

elevation > 30 deg

Brightness

For detection by unaided eye in excellent conditions,

- Goal is V = 7.0 or fainter in all phases of satellite lifetime.

At operational altitude:

- Starlink Visorsat - median V magnitude ~ 6.5
  - Original Starlink 0.9 - median V magnitude ~ 5.0
- OneWeb - median V magnitude ~ 7.9

but….

Altitude

Objects further away are fainter to the eye, but to large, fast telescope:

- objects at 600 km are out of focus
- objects at 1200 km are more in focus - more concentrated trail!
- objects at 1200 km travel slower across detector than one at 600 km, so effective exposure time greater, so not as faint as expected originally

Combination of effects: objects at 1200 km are not as faint as 1/r squared law predicts. It is the surface brightness which matters to the telescope.

Recommendation: Stay 600 km or below. Goal is fainter than V = 7 @ 550 km

Impact Assessment by Selected Observing Genres & Science Cases

(Mostly from SATCON1)

Impacts on Scientific and Observational Programs

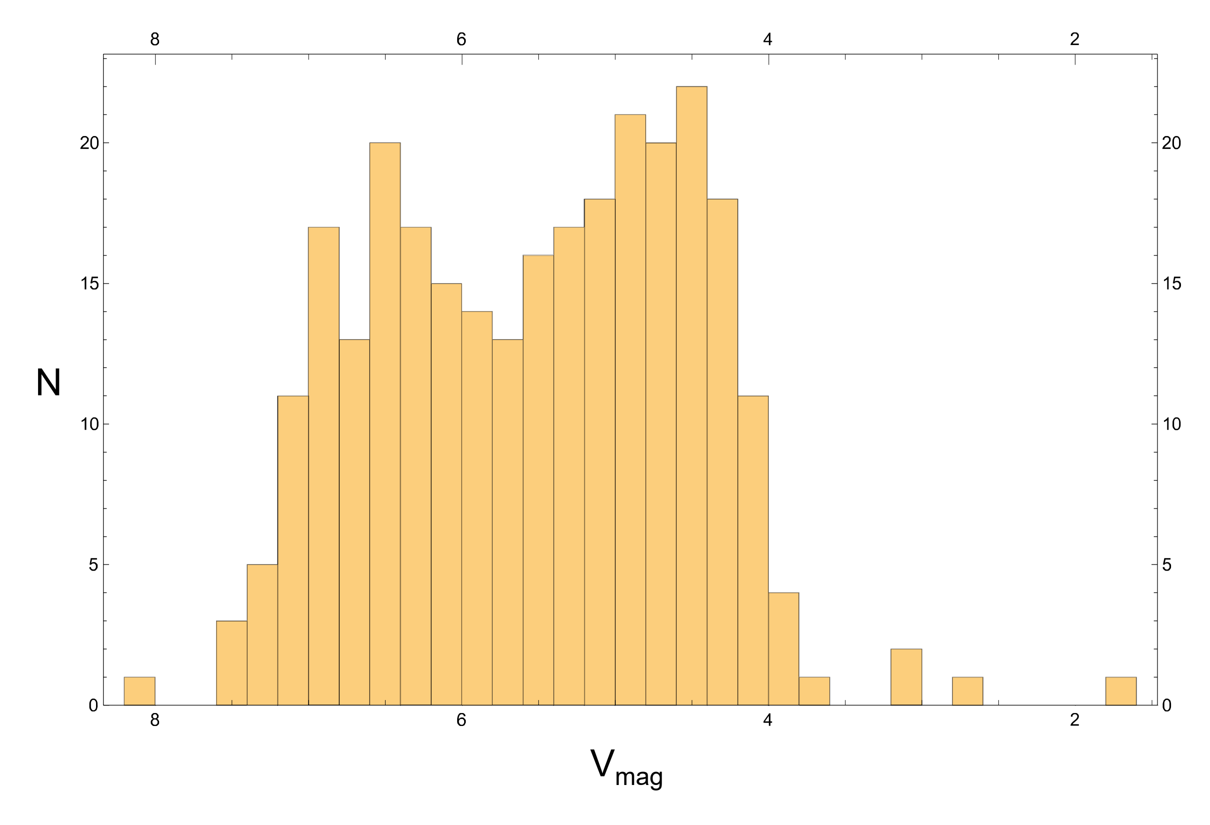
Rare Transients

- Fast Transients
  - *Searches for optical or infrared counterparts to fast transients require rapid responses. (Rubin LSST, ZTF, Pan-STARRS)*
  - *Satellites can ruin detections of these events. As they fade very rapidly, the ability to re-acquire the data is lost.*
- Optical Gravitational Wave Follow-Up
  - *Simultaneous data from optical/IR observatories and detectors, such as neutrinos or gravitational waves, represent a unique multi-messenger science opportunity in the next decade.*
  - *Satellite trails interfere with algorithms developed to distinguish real transient events from false detections.*
- Rapid Contiguous Monitoring of Special Sky Areas
  - *Several LSST science programs involve rapid contiguous monitoring of special fields.*
  - *This precludes satellite avoidance strategies where one moves to an adjacent field.*

Impacts on Scientific and Observational Programs

Deep, Wide, Extragalactic Imaging

- Low surface brightness imaging surveys over wide areas enable unprecedented probes of cosmology and galaxy evolution.
- For the Rubin LSST, measuring the physics of dark matter & dark energy requires billions of extremely faint galaxies for which the shape must be accurately known to 1 in 10,000.
- Science discoveries from these measurements will be more affected by systematics than by sample size.
- Masked trails can potentially produce cosmic shear bias (e.g., residual noise).
- Virtually the entire astronomical community will rely on the released LSST data products.



A histogram of 281 visual magnitude measurements of Starlink satellites imaged by the Pomenis Observatory in late May and early June 2020. The mean of all 281 measurements is Vmag = 5.5 with a standard deviation of 1.0. This broad distribution of values demonstrates the varied brightness of Starlink satellites which depends on numerous geometric factors. Credit: H. Krantz (U. Arizona), private communication

Impacts on Scientific and Observational Programs

Near-Earth Objects (NEOs)

- The most direct motivation for discovering and characterizing NEOs is their potential to collide with the Earth and cause catastrophic damage.
- NEO detection and characterization has a US congressional mandate, supported by the United Nations Office for Outer Space Affairs.
- These surveys operate in twilight hours when targets are visible but also when satellite interference is worst. Need more than 1 observation to show movement.
- For the Catalina Sky Survey, a rough estimate of the fractional loss of pixel area from satellite trails is that a satellite trail in every image will cost a few tenths of a percent in detection efficiency. Perhaps “negligible,” but bright trails from satellites not yet on-station or brightly illuminated without mitigations may have more impact.

Impacts on Scientific and Observational Programs

Deep Multi-object Spectroscopic Surveys

- Spectroscopic observations generally cover smaller fields of view than imaging programs. However, exposure times can be much longer for spectroscopy.
- It is not known a priori which observations are contaminated, forcing a repeat exposure or possible loss of science opportunity.
- There are several large spectroscopic facilities nearing operation or in advanced planning that are all vulnerable to LEOsat trails. (DESI, MSE)
- LEOsats leave a much wider trail than the effective size of low surface brightness objects. This impacts the necessarily long integration times for these faint objects.
- Owing to the long exposure times, there is no mitigation for the next generation of large spectroscopic facilities. Control of mid-exposure shuttering is not possible.
- Need to develop the ability to access the positions of the satellites with a precision comparable to a fiber diameter, and with a timing accuracy of ~1 second.

Impacts on Scientific and Observational Programs

Deep Wide-field NIR Imaging

- Wide-field large-aperture surveys are especially vulnerable to satellite trails; WFCAM = Wide-Field Near-IR Camera at the 4m UKIRT
- Impossible to determine if LEOsat trails can be handled in its images
- The default pipeline stacking will remove short obvious satellite trails. However, LEOsats generally leave longer and lower surface brightness tracks, which are much harder to get rid of.
- Need to create custom software that uses the longer track signatures of LEO satellites to identify affected pixels in the images.

Impacts on Scientific and Observational Programs

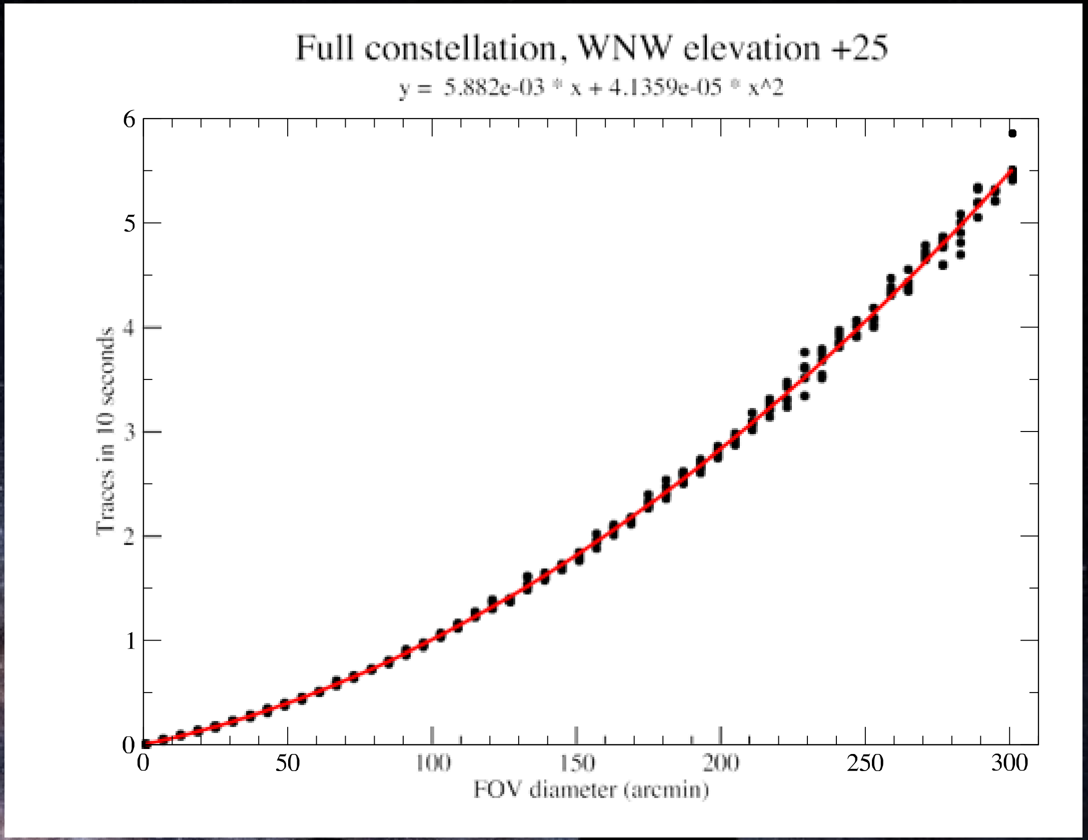
Imaging of Large Extended Low Surface Brightness Targets

Galaxy surveys require very deep imaging consisting of long exposures & stacking those for the required depth.

High-redshift galaxies are 2–100 million times fainter (V_{mag} ~ 23–27) than a V_{mag} = 7 satellite.

Satellites can affect images up to 60 or more pixels away from the trails (or +/- 15 arcsecs).

Bright (V_{mag} < 12) image artifacts can make it difficult to detect faint galaxies .

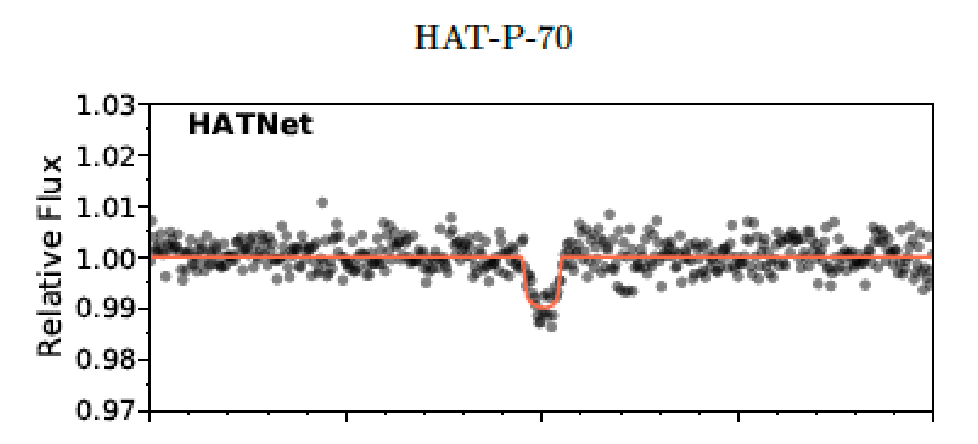


Count of the number of satellite trails affecting a 10-second exposure for increasing field of view (FOV). The dots represent a series of direct simulations of observations, while the line shows a model fit. Credit: Galadi, private communications

Impacts on Scientific and Observational Programs

Exoplanet Transits in Wide-field Surveys

- LEOsat constellations will impact exoplanet surveys (e.g., at HATNet)
- Stars that fall near satellite trails will suffer from skewed and less precise photometry, as well as added noise.
- Exoplanet detection will be impossible for stars that fall directly under a trail.
- Some of the most severely affected targets will be the M dwarfs (cooler stars).
- With the full constellations deployed, it will be impossible to detect super-Earth planets around M dwarf stars crossed by satellites.



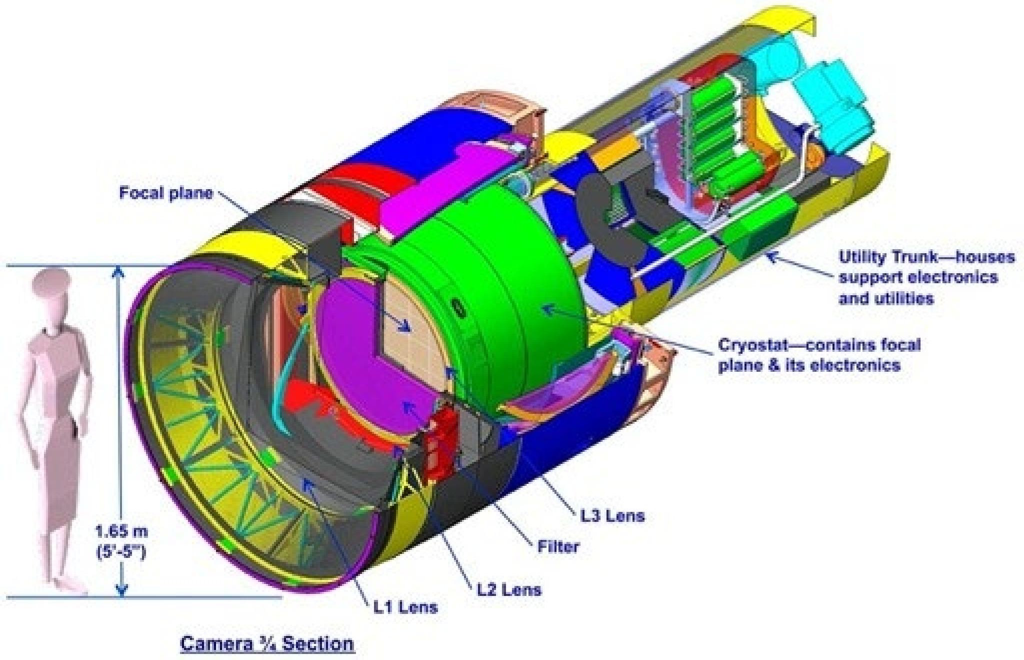
Impacts on Scientific and Observational Programs

Discovery of New Phenomena

“Astronomy is still driven by discovery.”

(New Worlds, New Horizons — 2010 Decadal Survey of Astronomy and Astrophysics)

- The most exciting and important science to come out of current and planned astronomical facilities will be the discoveries of types of objects and phenomena not yet observed nor predicted by theorists.
- Those discoveries have the potential to revolutionize our understanding of every field from exobiology to cosmology.
- For Rubin and other observatories, it is precisely this discovery space that is most at risk from artifacts arising from tens of thousands of LEOsats.



Vera C. Rubin LSST Camera

Impacts on Scientific and Observational Programs

Citizen Science, Amateur Astronomers, and Stargazers Worldwide

Severe impact potential

- *No barrier to building satellite constellations visible to the unaided eye.*
- *Simulation indicate two satellite trails per square degree per 60 sec exposure near the horizon. Wide-field astrophotography would be severely impacted by the fully-deployed Starlink Generation 2 and OneWeb constellations.*

Moderate impact potential

- *Based on current deployment strategies, hundreds of satellites will be on their way up or down at any given time. These may be brighter than magnitude 7, mostly noticeable during twilight. Starlink alone will double the number detectable by eye.*
- *A cultural resource, with significance ranging from practical benefits to religious.*

Minor impact potential

- *To casual observers, mobile-phone astrophotographers, narrow-field photographers.*