Press Conference: Conclusions from Satellite Constellations 1 (SATCON1) Workshop

NSF’s NOIRLab & American Astronomical Society

Tuesday, 25 August 2020, 2:00 pm US EDT

Rick Fienberg, AAS

Introduction

SATCON1 Report Published

- On the NOIRLab website: https://noirlab.edu/public/news/noirlab2022
- On the AAS website: https://aas.org/satcon1-workshop-report

Also, press release distributed via AAS Press List (etc.) and is online at https://aas.org/news and https://noirlab.edu/public

Ralph Gaume, NSF

Welcome


Phil Puxley, AURA
Welcome

Satellite Constellations 1 (SATCON1) Report Overview

Jeff Hall (Lowell Observatory) & Connie Walker (NSF’s NOIRLab)

Co-chairs, SATCON1 Scientific Organizing Committee (SOC)

Rationale

Vera Rubin Observatory and 30-meter telescopes coming online in the next decade will address fundamental questions and substantially enhance humankind’s understanding of the cosmos.

For reasons of expense, maintenance, and instrumentation, such facilities cannot be launched into, or operated from, space. Ground-based astronomy is, and will remain, vital and relevant.

Ground-based observatories require dark night skies!

About the Workshop

- 250 attendees from astronomy and industry
- Focus on scientific & technical matters, not policy matters
- Four working groups prepared reports in advance
- Summary report + WG reports released today: https://noirlab.edu/public/news/noirlab2022 and https://aas.org/satcon1-workshop-report

Findings

No combination of mitigations will eliminate the impact of satellite constellations on optical-infrared astronomy.

Findings

Options* to reduce impact are:

1. Don’t launch them
2. Keep them low (less than 600 km altitude)
3. Darken them
4. Orient them to reflect less sunlight
5. Remove or mask trails in images
6. Avoid them

*Not all options are viable in all circumstances.

Recommendations

For observatories:

- Support development of improved software tools to predict satellite positions and to mask or remove trails from images.

Recommendations

For satellite operators:

- Meet recommended targets for satellite brightness, absence of flares, and optimal post-launch configuration and attitude.

Recommendations

For observatories and satellite operators collaboratively:

- Develop a comprehensive observing network to monitor satellite constellations and provide data needed to optimize mitigation tools; also greatly improve the precision of publicly available positional information.

Working Group Reports

- Lori Allen (NSF’s NOIRLab) – Observations WG
- Pat Seitzer (U Michigan/AAS LPRISD) – Simulations WG
- Tony Tyson (UC Davis/Rubin Observatory) – Mitigation WG
- Richard Green (U Arizona/Steward Observatory) – Metrics WG

SATCON1
Observations Working Group

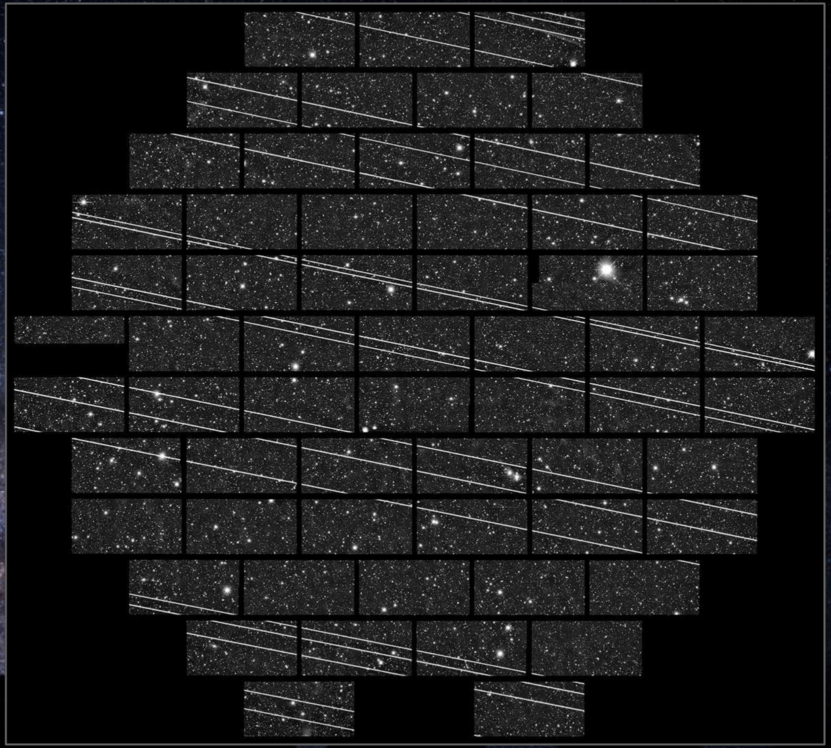
Lori Allen, Chair

NSF's NOIRLab

Observations of LEO satellites

Why observe LEO satellites?

- Tens of thousands may be launched in the next decade
- Even with mitigations, they will land in our data
- Predict their impact on astronomy now
- Quantify ways to minimize satellite impacts
- Develop, test, and refine solutions



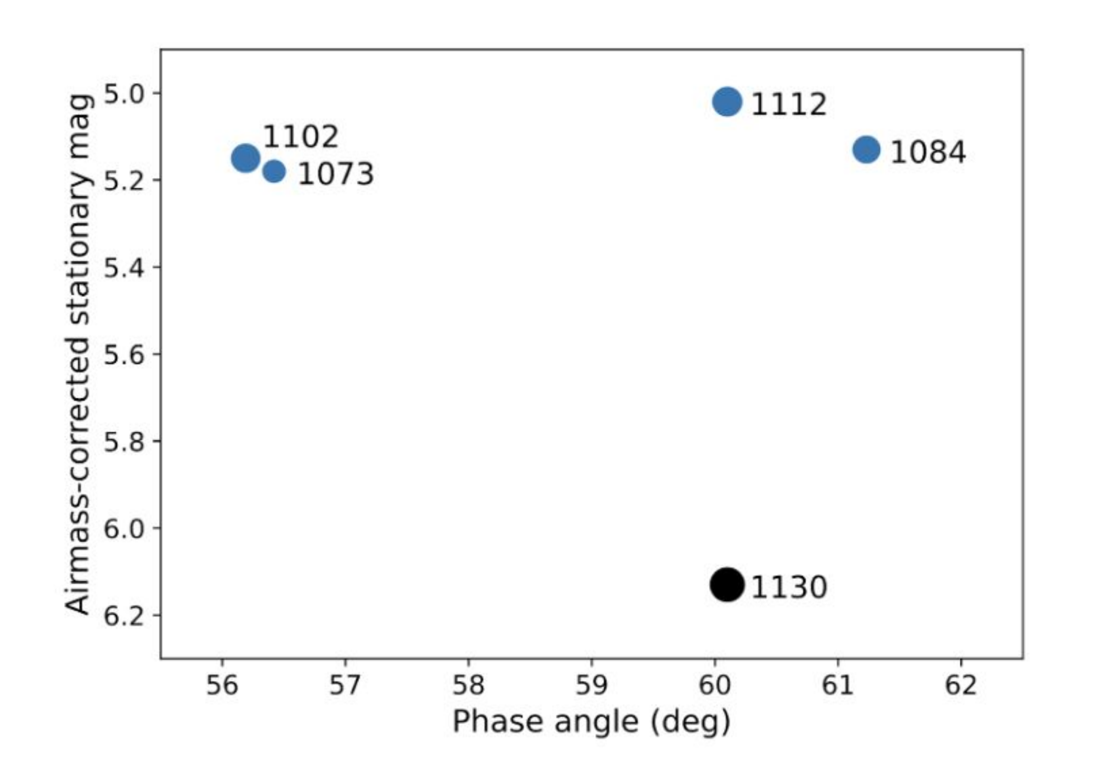
A wide-field image (2.3 degrees across) from the Dark Energy Camera on the Víctor M. Blanco 4-meter telescope at the Cerro Tololo InterAmerican Observatory, on 18 November 2019. Several Starlink satellites crossed the field of view.
Image credit: CTIO/NOIRLab/NSF/AURA/DECam DELVE Survey

Findings

1) Observing LEOsats has its challenges
   - Accuracy of predicted position and timing
   - Fast motion of satellites

2) Mitigation attempts are measurable
   - DarkSat (Starlink-1130) is about 2x fainter

3) Large telescopes are not required
   - Many can participate



Apparent stationary g band magnitude of five recent Starlink satellites in the "on station" main operational phase extrapolated to zenith as a function of solar phase angle. DarkSat (black) was measured to be 1 magnitude fainter than its four bright siblings launched in January 2020 (blue), which are in turn about 0.5 magnitude fainter than the older v0.9 Starlinks. Measurement errors are the symbol sizes. (Tyson et al. 2020)

Recommendations

1) A coordinated effort to observe LEOsats now, for characterization and understanding of their impacts
   - Multiple measurements of satellite brightness at a range of deployment stages and illumination angles and in multiple filters
   - Measurements of flare and glint behavior
   - Measurements over satellite life cycles

Left: Two Starlink satellites, launched together. Difference in brightness is likely due to different orientations with respect to the Sun.

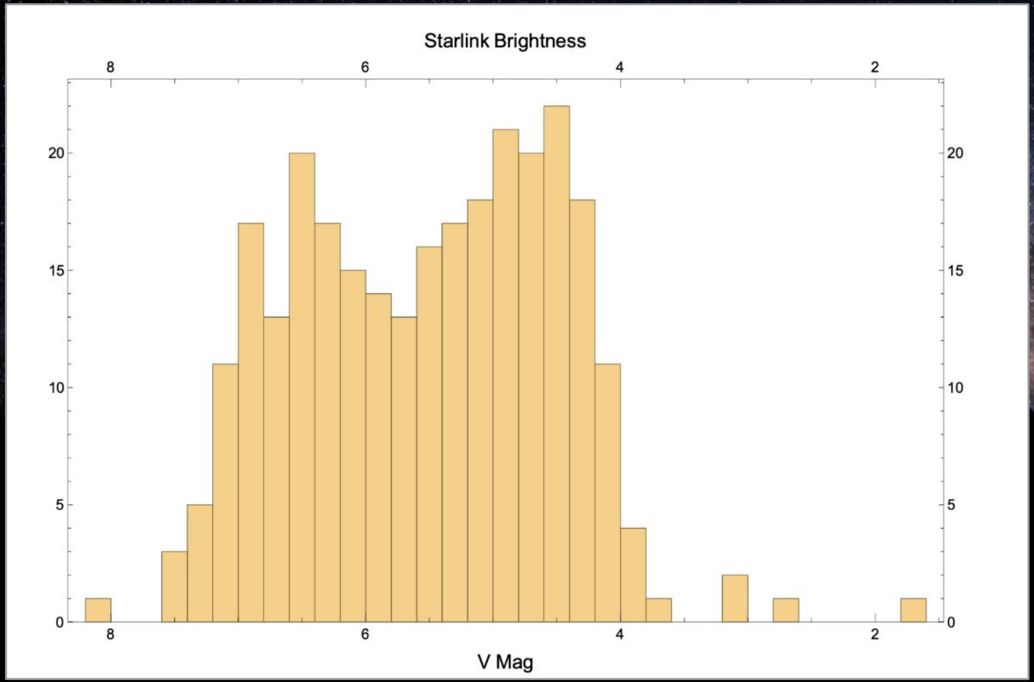
Right: Starlink-1352 in flare on 7 June 2020.

Images from Pomenis Observatory

Recommendations

2) A comprehensive satellite constellation observing network

- Connect observers with telescopes
- Provide coordinated observing protocols and data analysis standards
- Coordinate ongoing observations of satellite constellations
- Prepare for the next generation of LEOsats



281 measurements of Starlink visual magnitudes (left), imaged by the Pomenis Telescope (right).

Credit: Harrison Krantz (U. Arizona)

SATCON1
Simulations Working Group

Patrick Seitzer, Chair

University of Michigan
&
AAS Committee on Light Pollution, Radio Interference, and Space Debris

Some large constellations represent > 70% of estimated 107,000 LEOsats planned

Constellation	Altitudes (km)	Inclinations (deg)	# of satellites
Amazon/Kuiper	590 - 630	33.0 - 51.9	3,236
OneWeb	1200	40.0 - 87.9	47,844
SpaceX (Starlink)	328 - 614	30.0 - 148.0	34,408

Data from public FCC filings.

Simulations: How many of these satellites will be visible? How bright will they be? Are some constellation architectures more challenging for astronomy?

Individuals and Groups Undertaking Simulations

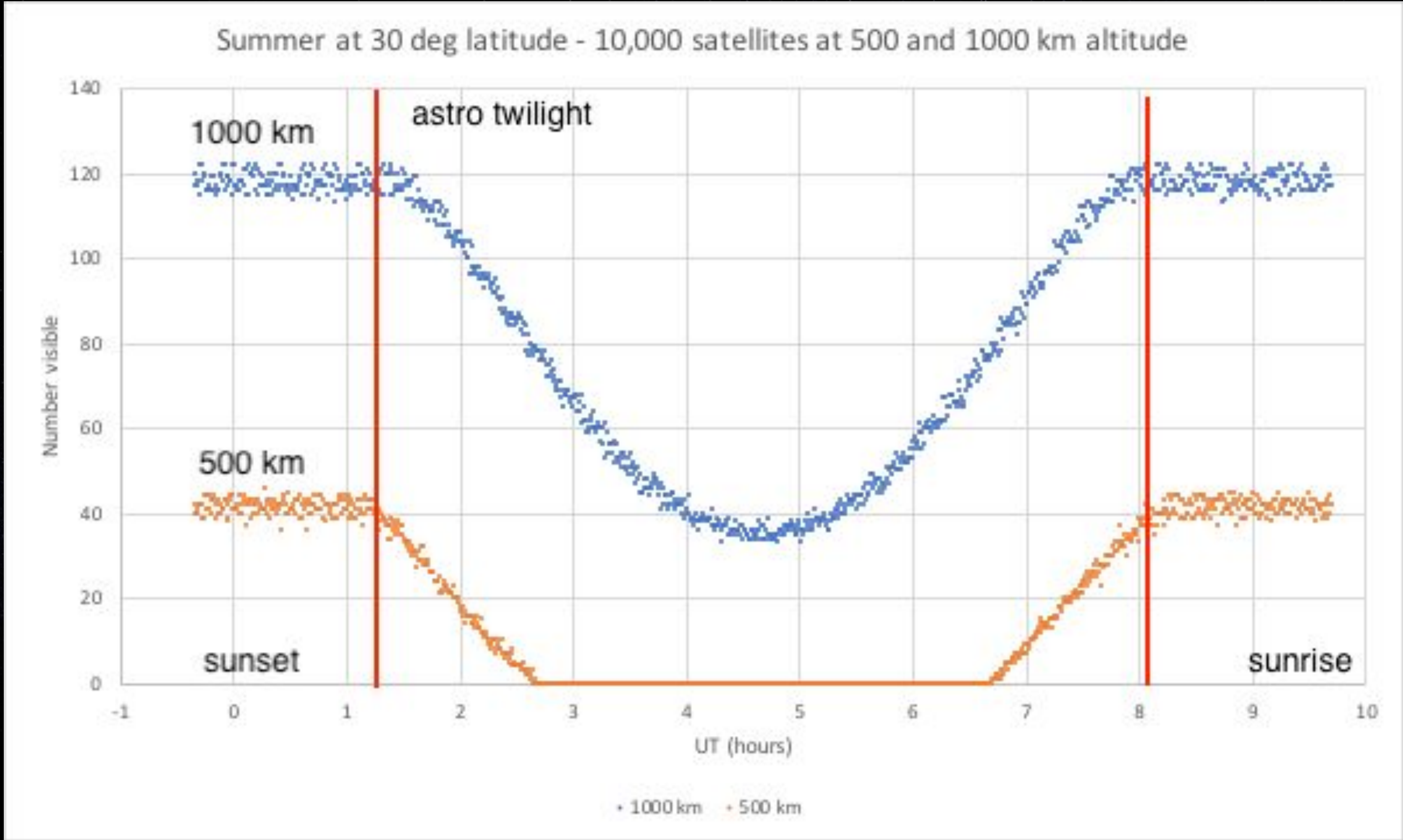
- Cees Bassa (ASTRON Netherlands Institute for Radio Astronomy)
- David Galadí (Icosaedro working group of the Spanish Astronomical Society SEA)
- Olivier Hainaut (European Southern Observatory)
- Jonathan McDowell (Center for Astrophysics | Harvard & Smithsonian)
- Patrick Seitzer (University of Michigan)
- Jan Siminski (European Space Agency Space Debris Office)

- Brightness simulations by Daniel Kucharski and Moriba Jah (University of Texas)

Each group or individual worked completely independently — no sharing of algorithms and/or software. Test constellation of 10,000 satellites at 1,000 km and 53 degree inclination — 100 planes with 100 satellites each. Results agreed very well.

Standard Test Constellation— 10,000 Satellites

100 planes with 100 satellites per plane — inclination = 53 deg



Satellite elevation > 30 deg.

Results from all groups agreed very well.

Astro twilight – Sun 18 degrees or more below horizon: darkest part of the night.

Extensive simulations of real constellations in WG report.

Simulations Summary

- The fraction of satellites of each constellation that will be visible at any observatory at any one time is typically around 5%.
    - Higher altitude constellation shells will have a greater fraction visible (7-8%), lower altitude constellations a smaller fraction (<4%).
    - Most of these satellites appear at low elevation over the horizon (typically 50% below 10 degrees).
- The number of satellites visible is a function of their orbital inclination, peaking at a latitude close to the inclination.
- The constellation with the greatest impact for any observatory in terms of the number of satellites visible will be one at higher altitude and with an orbital inclination close to the latitude of the observatory.

Large Magellanic Cloud (LMC)

Largest satellite galaxy of our own Milky Way Galaxy

Eckhard Slawik via ESA

Optimal observing time: Summer in south.

If large constellations like OneWeb (47,844 satellites at 1,200 km) launched:

Every 30-second exposure will have at least one satellite trail!

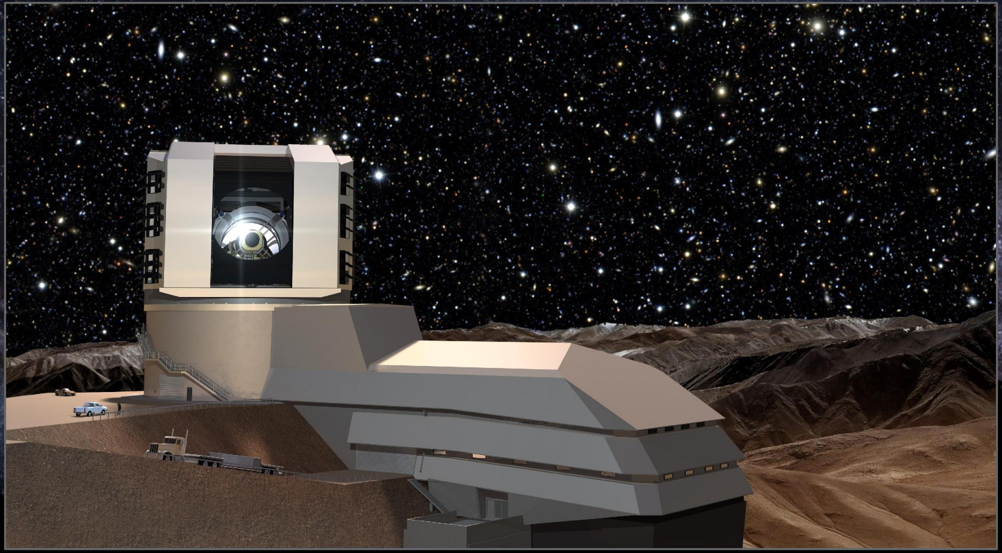
Recommendations

1. Simulate the impact on science of these constellations: how often will a specific observation of an astronomical object be lost due to a satellite trail.
2. Simulate the other two phases of a constellation lifetime:
   - Initial mission phase: parking orbit and orbit raise.
   - Deorbit phase.
3. High fidelity simulations of the observed brightness including the defocus expected for satellites at small ranges.

SATCON1
Mitigations Working Group

Anthony Tyson, Chair

University of California, Davis
& Vera C. Rubin Observatory

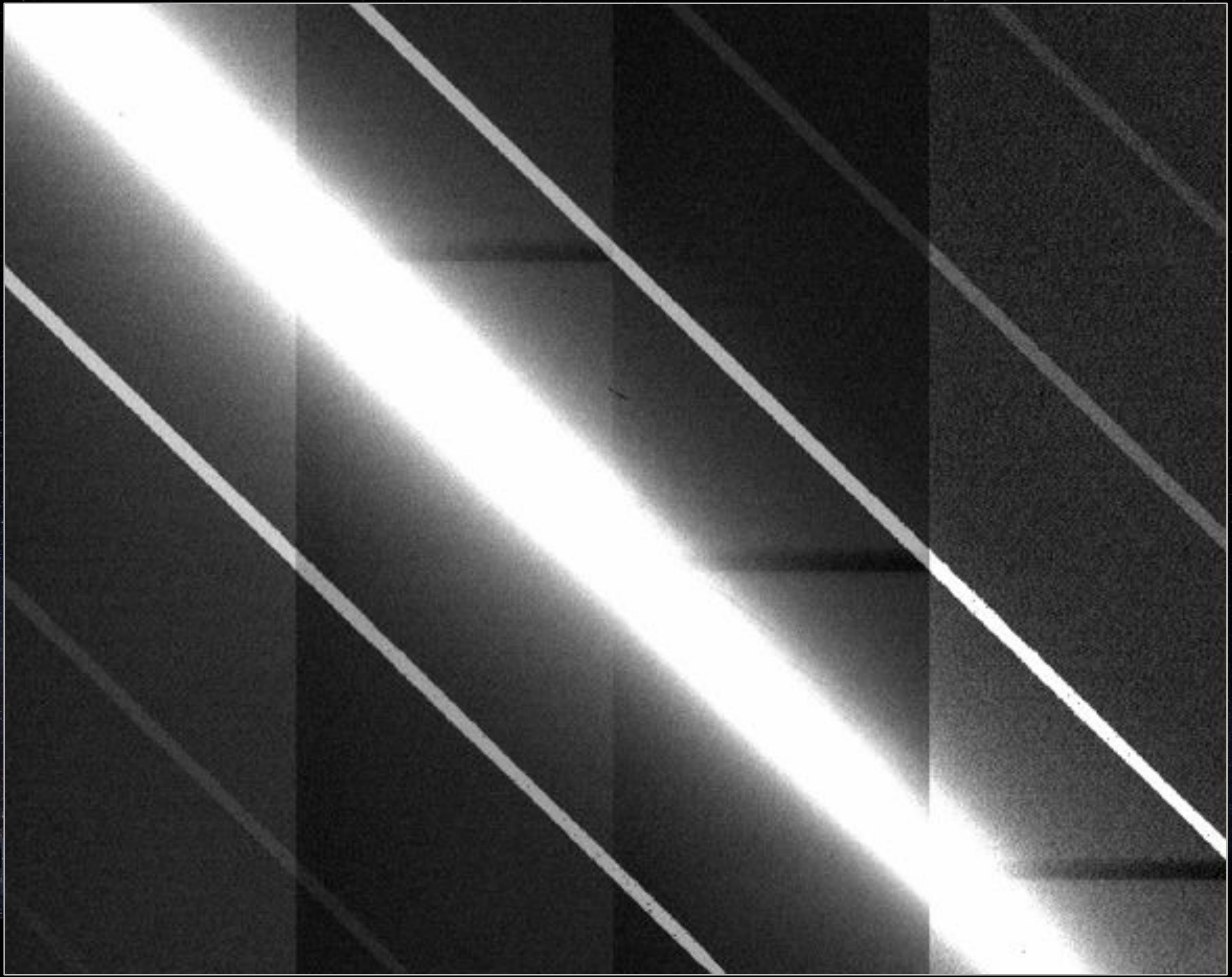


All optical-infrared observatories and their science will be impacted by tens of thousands of bright LEOsats.

- All optical astronomy observatories will be affected to some degree by the light pollution generated by LEO satellites. The issue is frequency of LEOsat trails in their data and their brightness.
- Rubin Observatory will be particularly impacted because of its unprecedented product of its light collection and its wide field of view per exposure.

Bright satellite trail in the Rubin Observatory camera induces image artifacts.

If LEOsat darkened to 7th magnitude, special pixel processing can remove the “ghost” trails.



- SpaceX is working with us to address mitigation

- Making Starlinks 10 times darker than v0.9 may remove some satellite trail artifacts in LSSTCam.

- However, *even if that works*, the satellite trails themselves will clearly be in the data — complicating data analysis and limiting discoveries.

- With tens of thousands of LEOsats, we find that *generally no combination of mitigations can completely avoid the impacts of LEO satellite trails on the science programs of the coming generation of optical astronomy facilities.*
- These facilities are designed to probe the dark sky in new ways for dynamic events to unprecedented faintness. They will require fewer and fainter LEOsats to realize their scientific potential.
- Rubin Observatory's LSST opens the prospect of discovering the unexpected, especially in the time domain. It is precisely this discovery space that is most at risk from artifacts arising from tens of thousands of LEOsats.

Recommendations

- Darken satellites in all phases of the orbit, including launch, parking orbit, final orbit, and decay.
- Darken satellites on station to fainter than 7th mag. Incorporate corresponding 44 W/sr radiance in the satellite design process.
- Fewer satellites.
- *No satellites far above 600 km.*
- High accuracy orbit position-time data. App for LEOsat position-time prediction for observers.
- Advanced pointing algorithms for avoidance of bright satellites.
- Predictive model for satellite brightness vs orbit relative to observatory.
- Support for full simulations of science impact by research community.

SATCON1
Metrics Working Group

Richard Green, Chair

Steward Observatory, University of Arizona

Metrics Working Group Purpose & Outcomes

- Context: Nighttime images without the passage of a Sun-illuminated satellite will no longer be the norm.
- The Metrics Working Group distilled the proposed mitigations and findings from the other Working Groups into a set of specific recommendations.
- They fall into three general categories:
    - Astronomers will need software tools to handle data with satellite trails and provide options for dynamical scheduling for pointing avoidance and shuttering when possible.
    - Operators are strongly encouraged to design and operate to keep reflected sunlight onto telescopes below a specified limit and lower if possible.
    - Operators and astronomers will need to collaborate to improve the predictions of positions and reflections.

For Astronomers & Funding Sources

Recommendation 1

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

Recommendation 2

Support development of an 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.

Recommendation 3

Support selected detailed simulations of the effects on data analysis systematics and data reduction 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.

For Constellation Operators

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 × field of view), large-aperture ground-based telescopes to be fainter than $7.0\ V_{mag} + 2.5 \times \log(r_{orbit} / 550\ \mathrm{km})$, equivalent to $44 \times (550\ \mathrm{km} / r_{orbit})$ watts/steradian.

Recommendation 6

Operators must make best effort for no 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.

For Constellation Operators

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.

For Astronomers & Operators in Collaboration

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.

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 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.

Findings

For all orbital heights, the visibility of sunlit satellites remains roughly constant between sunset and astronomical twilight (Sun 18 degrees below horizon). The key difference between lower (~600 km) and higher (~1,200 km) orbits is the visibility in the dark of night between astronomical twilights: higher altitude constellations can be visible all night long during summer, with only a small reduction in the number visible compared to those in twilight.

Mitigation of the most damaging impacts on scientific programs is now being actively explored by the professional astronomy community worldwide. These investigations have benefited from collaboration with SpaceX.

If the 100,000 or more LEOsats proposed by many companies and many governments are deployed, no combination of mitigations can fully avoid the impacts of the satellite trails on the science programs of current and planned ground-based optical-NIR astronomy facilities.

The organizers hope that the collegiality and spirit of partnership between these two communities will expand to include other operators and observatories and continue to prove useful and productive.

SATCON2

Satellite Constellations 2 (SATCON2), which will tackle the significant issues of policy and regulation, is tentatively planned for early to mid-2021.

Watch for announcements from NOIRLab and the American Astronomical Society.

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And now...Q&A

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