Satellite Constellations: Impact, Mitigations, and Industry Engagement

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Connie Walker (NSF’s NOIRLab)

Image credit: Pete Marenfeld (NSF’s NOIRLab)

SATCON1

29 June – 2 July 2020

Report released 25 August 2020

Technical assessment

Four working groups (WG)

- *Observations*
- *Simulations*
- *Mitigation*
- *Metrics*

NOIR Lab
AAS
LOWELL OBSERVATORY
AURA

SATCON1

250 attendees

- *Astronomers*
- *SpaceX (actively participating)*
- *Amazon Kuiper (attending)*
- *NSF and NASA*
- *Industry consultants*
- *Space law*
- *Dark-sky advocates*
- *Parks & public lands*
- *Amateur astronomers*
- *The press were invited to a post briefing*

Motivation for SATCON1 Workshop

Brought together scientists and engineers from astronomy and industry to

- Assess the impact of satellite constellations on optical astronomy;
- Explore solution strategies that can be employed by both the astronomy community and the satellite industry;
- Produce a report with recommendations for observatories, industry and the federal agencies.

SATCON1

Technical focus

SATCON2

Policy & regulation focus

~late Q1 2021

Planning has begun

NOIRLab & the AAS Light Pollution, Radio Interference & Space Debris Committee involved

Principal threats from satellite megaconstellations

We are entering the era of industrialization of space. Proliferation of satellites creates a perfect storm for astronomy along three principal lines:

- Brightness (V = +3 to +4 in parking orbit, +7 to +9 on station)
- Quantity (SpaceX + Amazon + OneWeb possibly > 100K)
- Lack of regulation (no requirement to mitigate, crowded space)

Planned Major Constellations

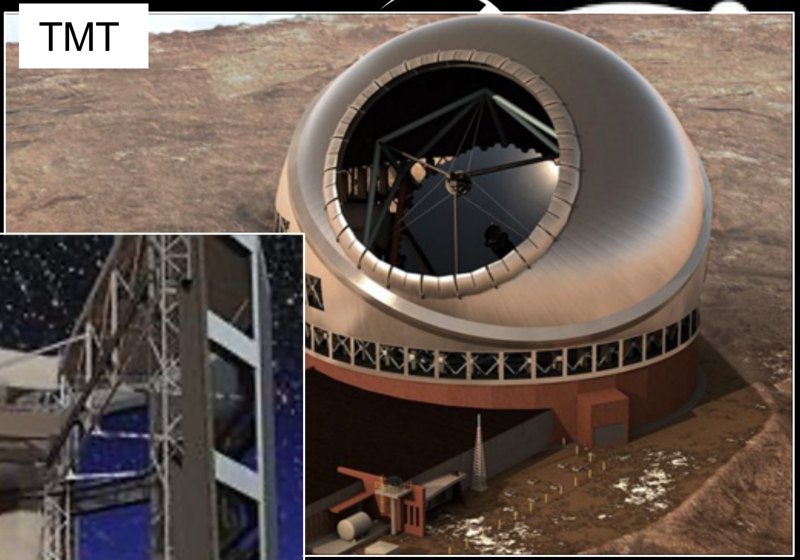
Some large constellations represent > 70% of estimated 107,000 LEOsats planned

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.

Future Technology Requires Dark Skies

- A tremendous amount of new technology in astronomy is coming online in the future
  - will substantially increase our understanding of the universe.
- Observatories require a dark night sky to uncover the secrets to some of the most fundamental questions about the nature of our Universe.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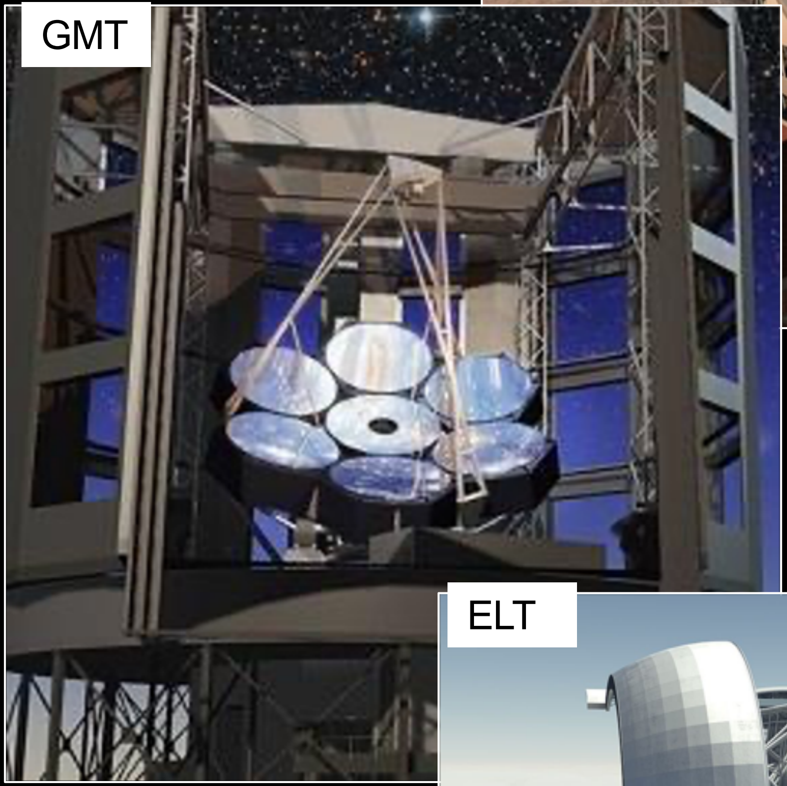
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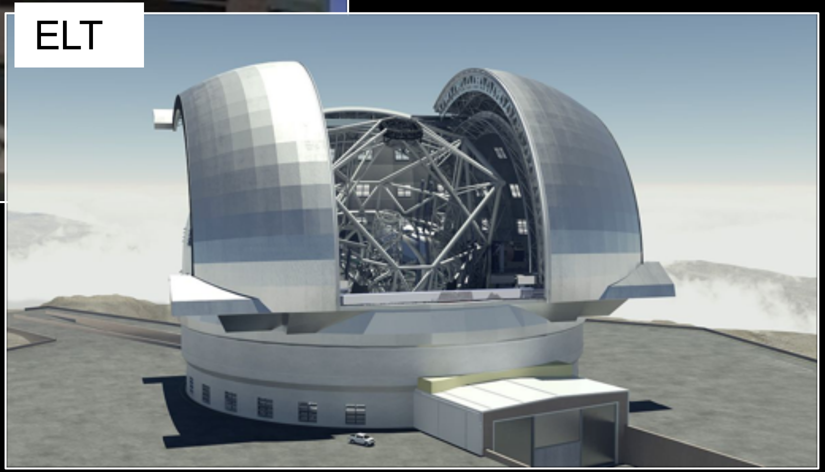
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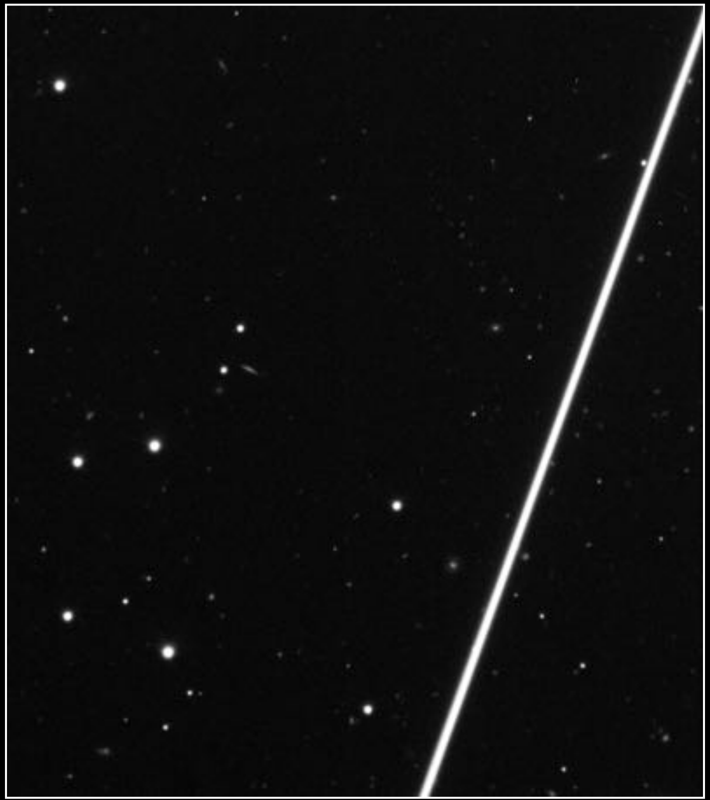
Impact Assessment by Selected Observing Genres & Science Cases



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. Hawai'i), 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

Impacts on Scientific and Observational Programs

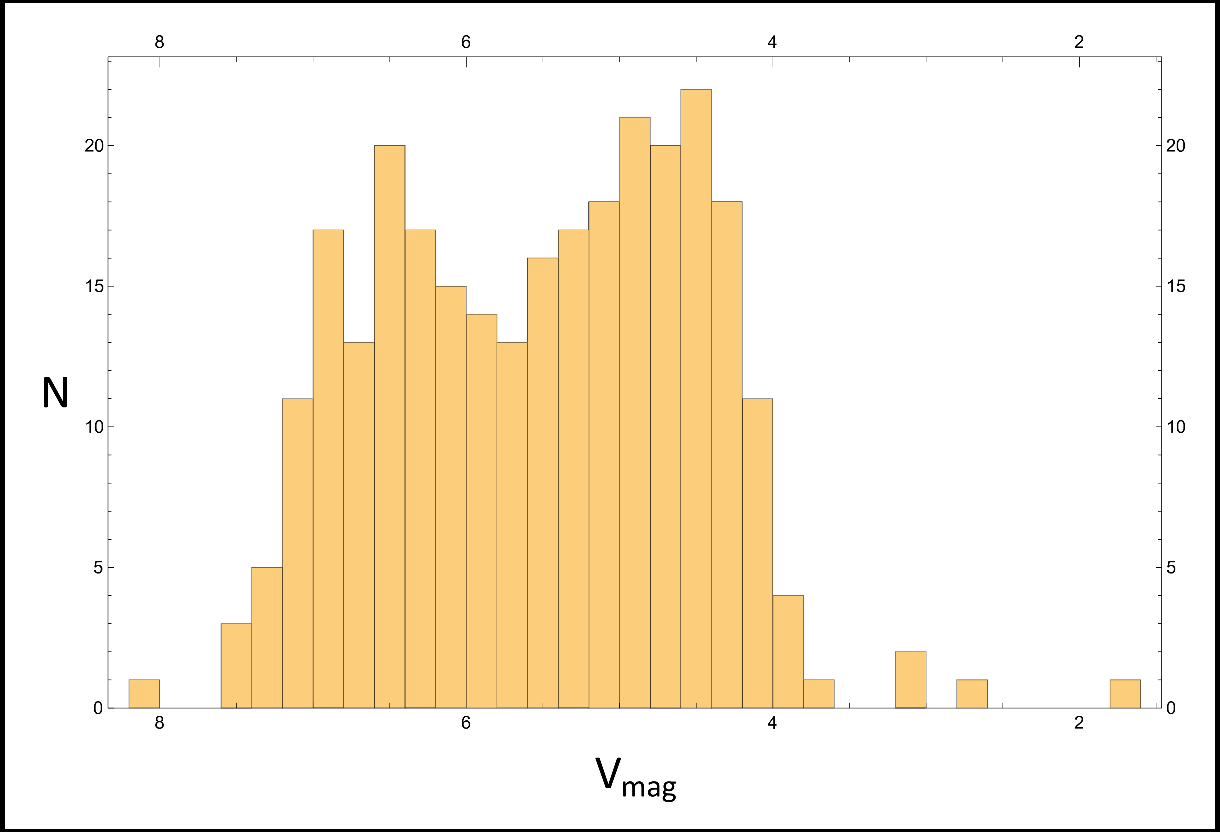
Rare Transients

- 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.
- With 107,000 new satellites to be launched in the next decade….

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

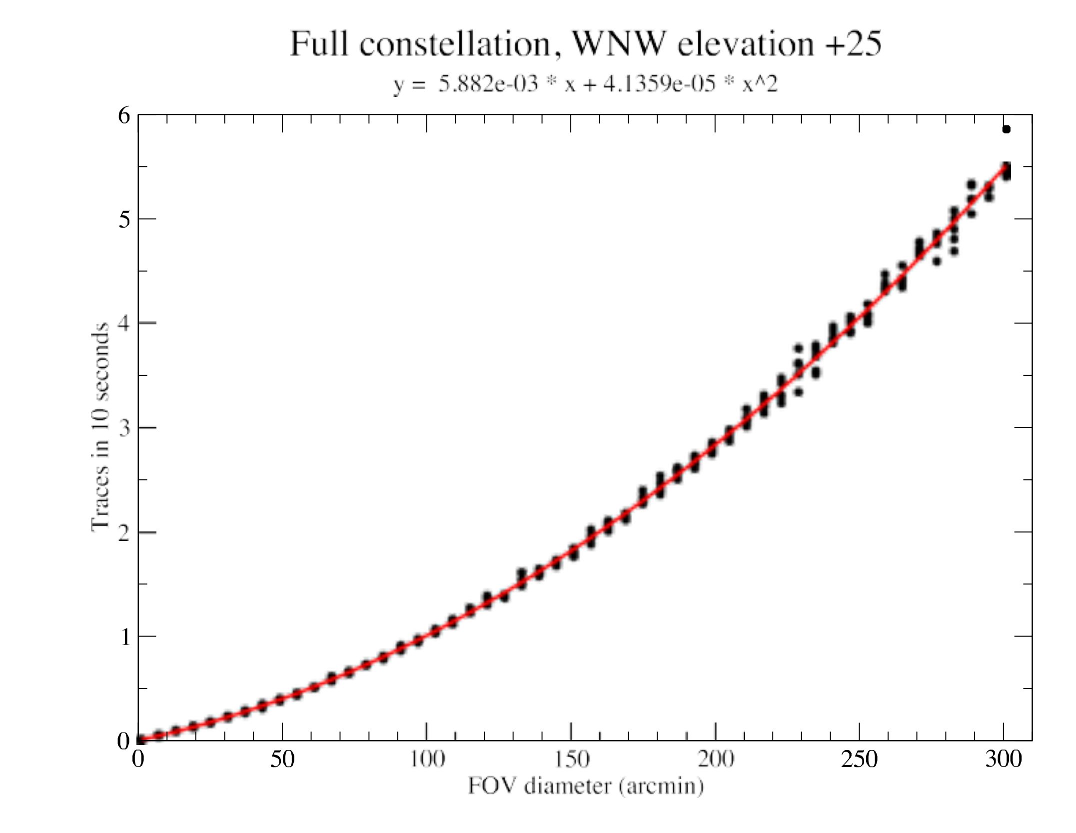
Deep Wide-field NIR Imaging

- 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 .

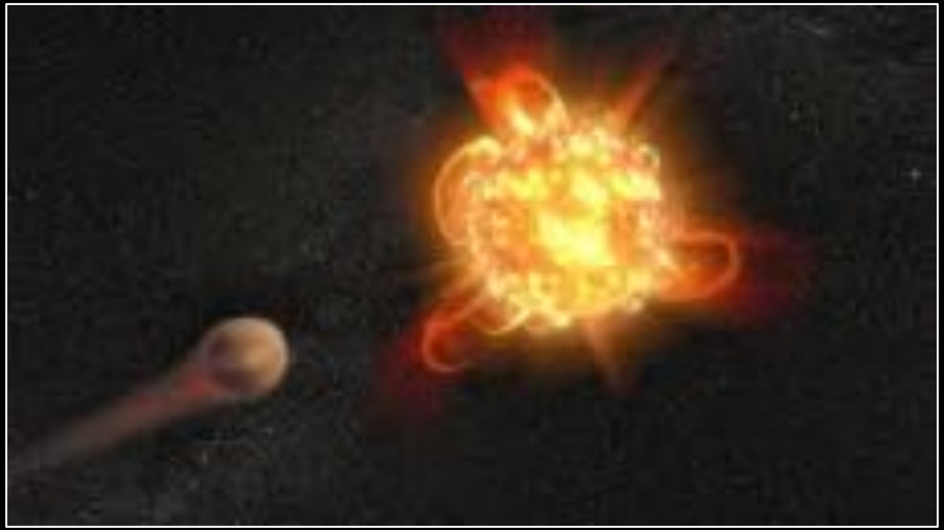


Count of the number of satellite trails affecting a 10-second exposure for increasing field of view (FOV). The dots represent a series of direct simulations of observations, while the line shows a model fit. Credit: Galadi, private communications

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.



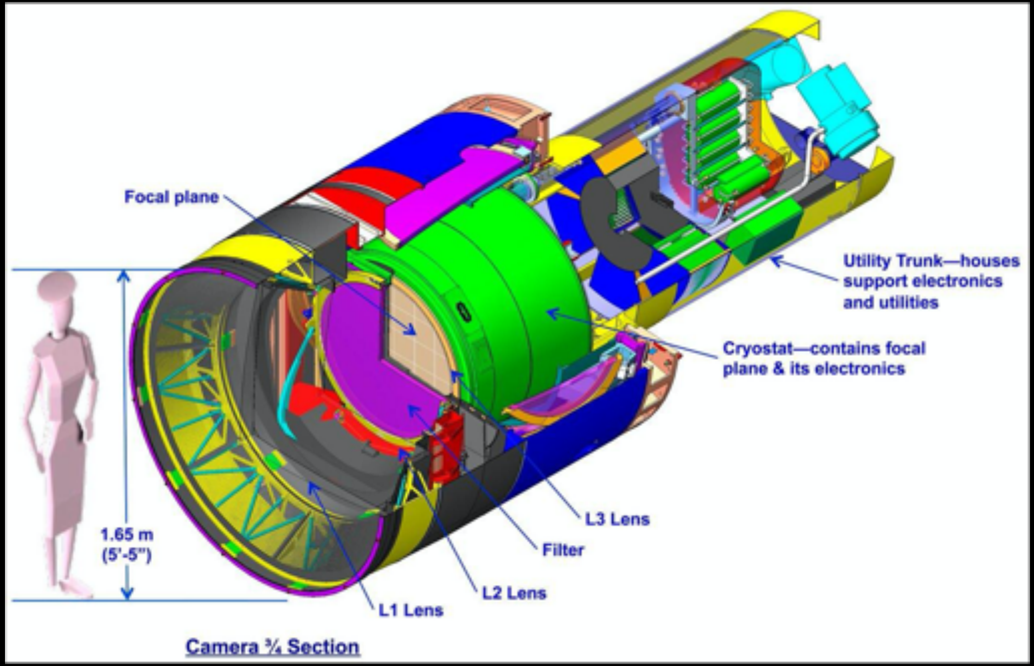
Impacts on Scientific and Observational Programs

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

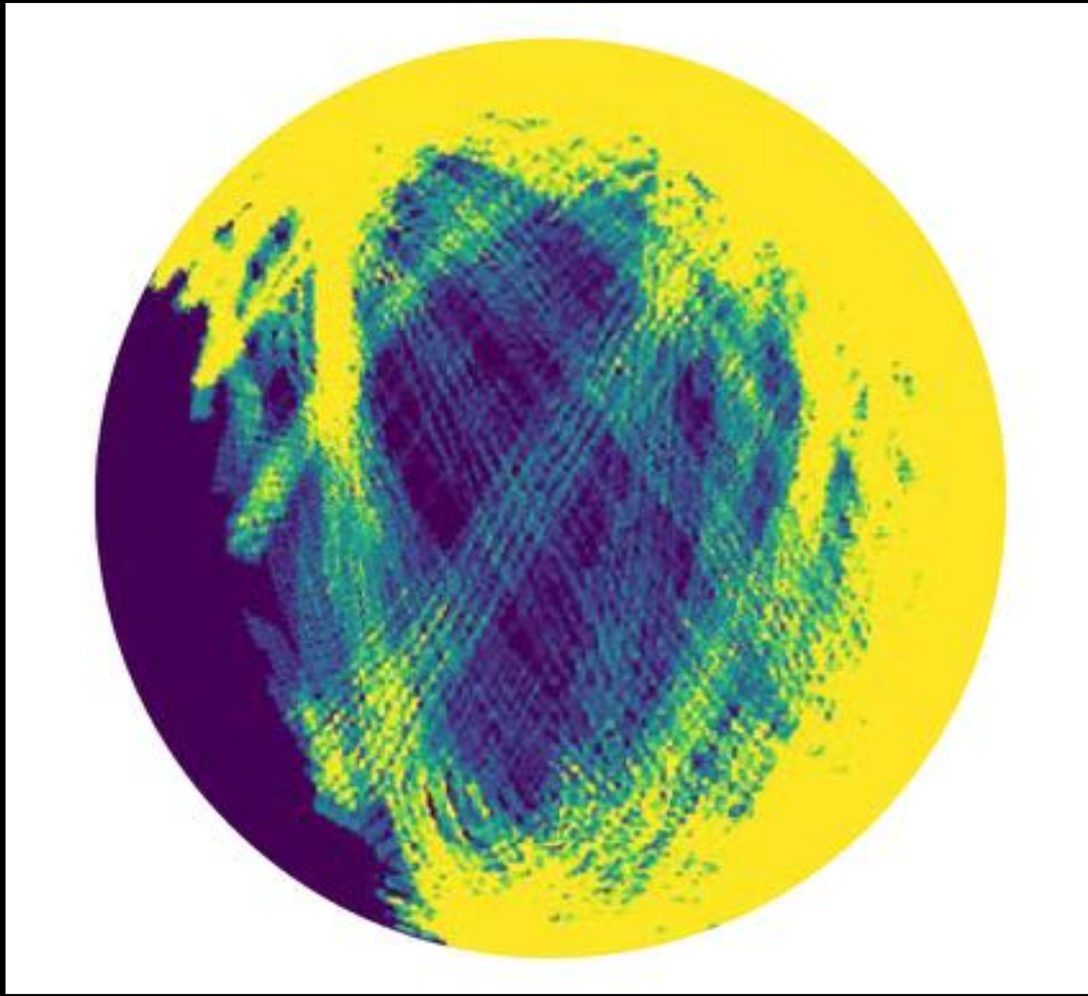
- *To casual observers, mobile-phone astrophotographers, narrow-field photographers.*

Findings

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.



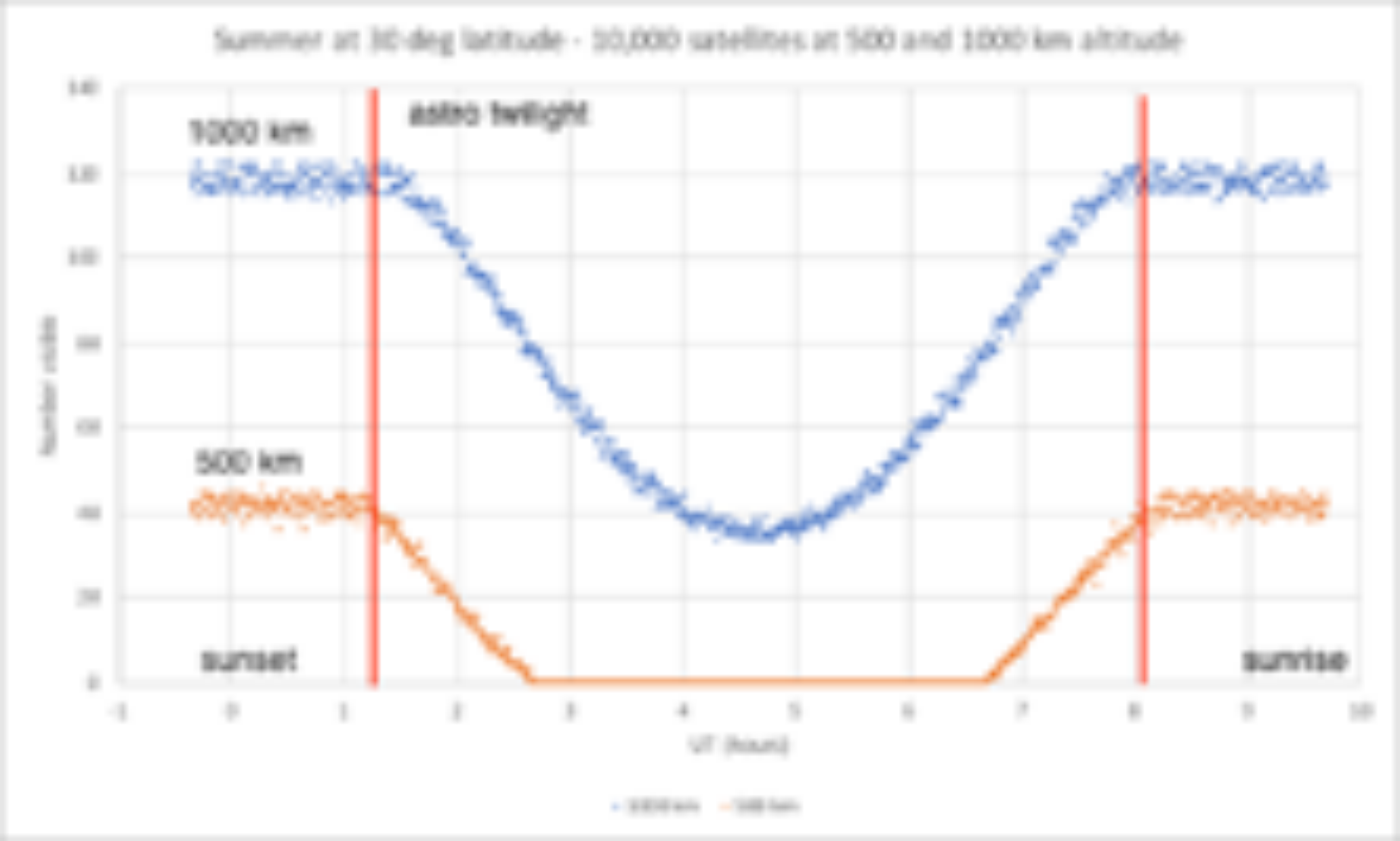
Satellite visibility from Rubin Observatory
P. Yoachim (U. Washington)

Findings

Fly Low.

Orbits < 600km are strongly desirable to reduce satellite visibility.

Lower orbits will also increase de-orbit efficiency and timescale.

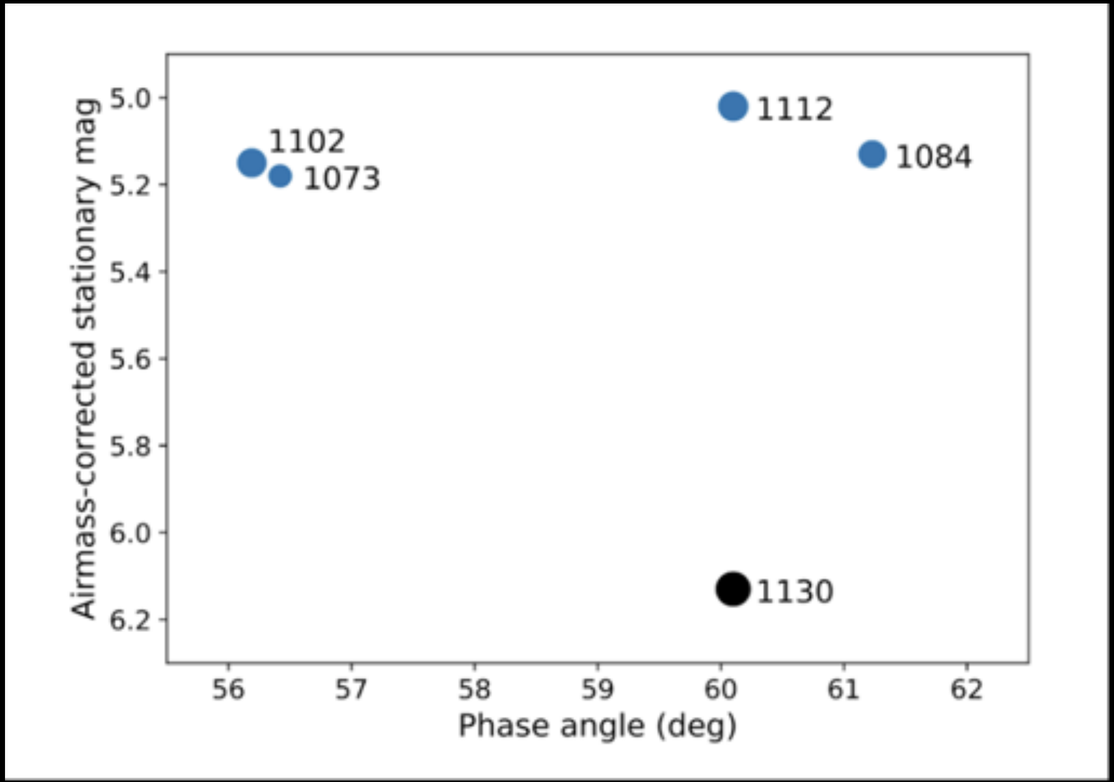


P. Seitzer (U. Michigan)

Findings

Mitigations fall into six categories.

1. Don't launch.
2. Orbits <= ~600 km.
3. Reduce albedo.
4. Minimize reflective area via attitude control.
5. Remove and/or mask trails in images.
6. Improve ephemerides.

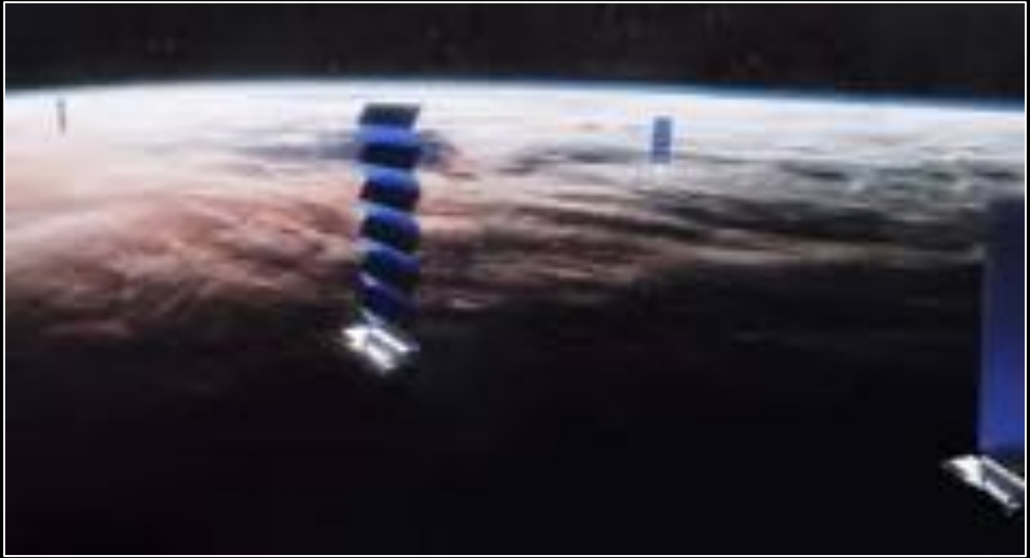


Apparent stationary g band magnitude of five recent Starlink satellites in the "on station" main operational phase extrapolated to zenith as a function of solar phase angle. DarkSat (black) was measured to be 1 magnitude fainter than its four bright siblings launched in January 2020 (blue), which are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

Recommendations

We established recommendations in three categories.

1. *For observatories*
2. *For satellite operators*
3. *For observatories and operators in collaboration*

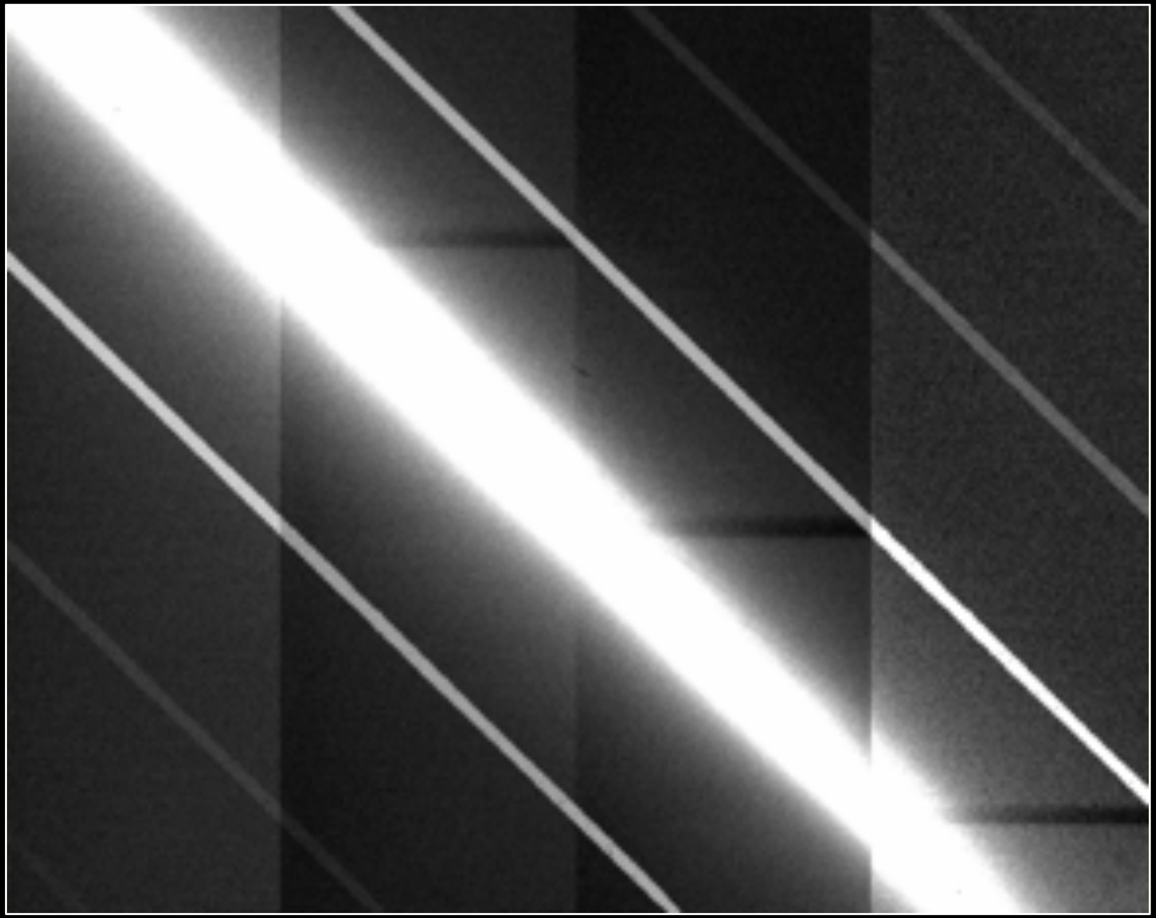


Recommendations 1-3: For Observatories

1. *Create more robust software tools for trail masking and removal.*

2. *Create more robust predictive tools for satellite transits.*

3. *Better understand systematics of trail-masking on resultant images.*

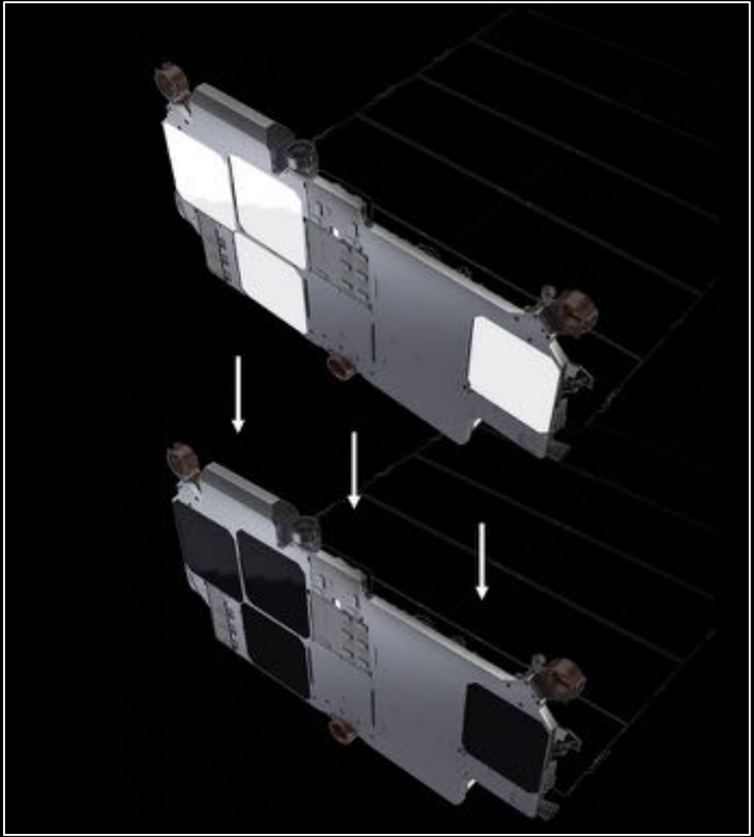


T. Tyson, Rubin Obs.

Recommendations 4-7: For Operators

4. *Incorporate thorough Bidirectional Reflectance Distribution Function measurements in satellite design.*

5. *Design for fainter than 7.0 V mag +2.5 × log(r_{orbit} / 550 km), equivalent to 44 x (550 km / r_{orbit}) watts/steradian.*

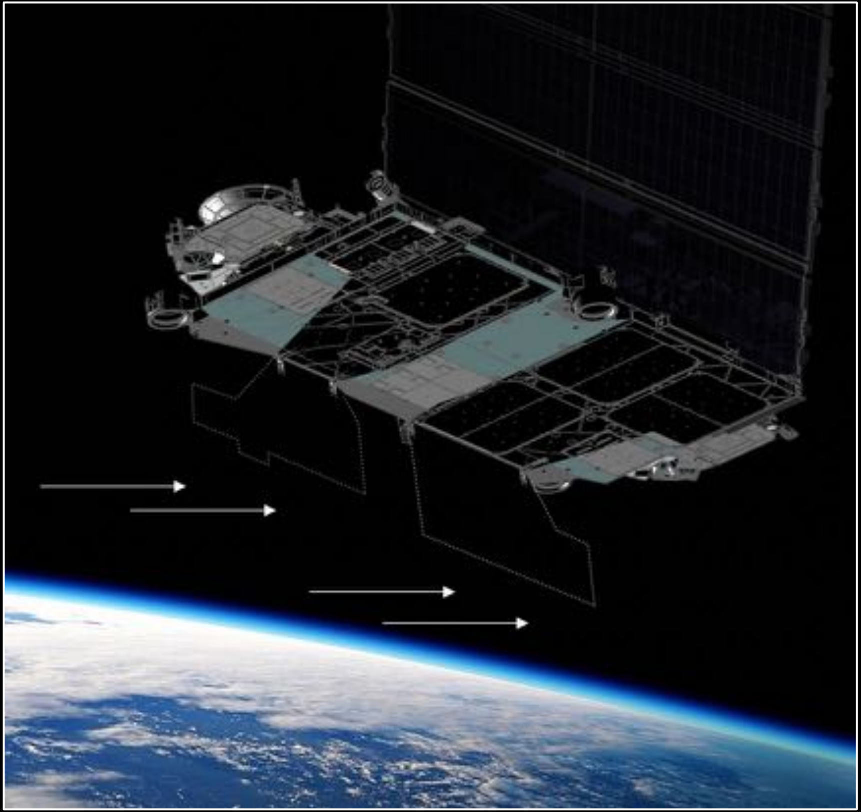


DarkSat (SpaceX)

Recommendations 4-7: For Operators

4. *Incorporate thorough BRDF measurements in satellite design.*

5. *Design for fainter than 7.0 V mag $+2.5 \times \log(r_{orbit} / 550\ km)$, equivalent to $44 \times (550\ km / r_{orbit})$ watts/steradian.*



VisorSat (SpaceX)

Recommendations 4-7: For Operators

6. *Minimize specular reflection in the direction of observatories. Provide accurate timing guidance for flares that may occur.*

7. *Clump satellites post-launch while in parking orbits. Use attitude adjustment to minimize reflecting surface area as seen from ground tracks.*

Victoria Girgis (Lowell Observatory)

Recommendations 8-10: For Observatories and Operators Collaboratively

8. *Create a comprehensive satellite observing network (incl. citizen science).*

9. *Greatly improve (~10X) publicly available positional information.*

10. *Adopt a new standard format for ephemerides beyond present Two-Line Elements.*

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 the companies cannot meet astronomers even part way, then all of the new technology telescopes coming out in the next decade will be endangered
- Especially if satellite companies launch tens of thousands, at 1200km altitude, every 30-second exposure taken at the optimal observing time (summer) in the southern hemisphere (where all the major observatories are in Chile).
    - All images will show a satellite streak.
- With over 100,000 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.

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!

Comments and thoughts

1. The industrialization of space is here.
2. Kudos to SpaceX.
3. Amazon and OneWeb also getting positively engaged.
4. Collaborative development of policy is imperative.
    - *What of a "rogue operator," and what of other countries?*
    - *What of many voices not yet at the table?*

The Request

- How can AAAC help?
  - Close to 100 people involved with working groups in SATCON1 and the Dark & Quiet Skies Workshop. Soon more with SATCON2.
  - We are interested in forming an “e-institute” to work on problems together and share results. Need endorsement for funding to address the problem through:
    - A network of observatories to coordinate observations.
    - An app for LEOsat position-time prediction for observers.
    - Advanced pointing algorithms for avoidance of bright satellites.
    - Predictive models for satellite brightness vs orbit relative to observatory.
    - Full simulations of science impact by research community.
    - Continued collaboration with industry.
- What can we do to help AAAC?