Satellite Constellations: Monitoring and Mitigation

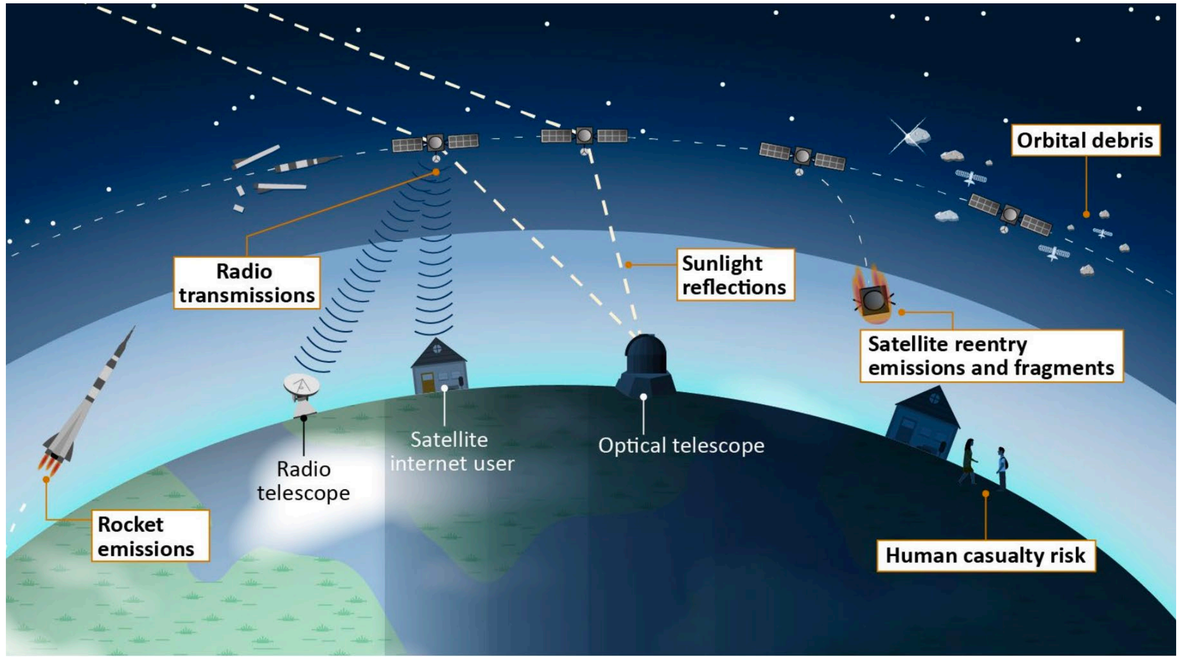
Meredith Rawls | AAAC | Sep 19, 2024

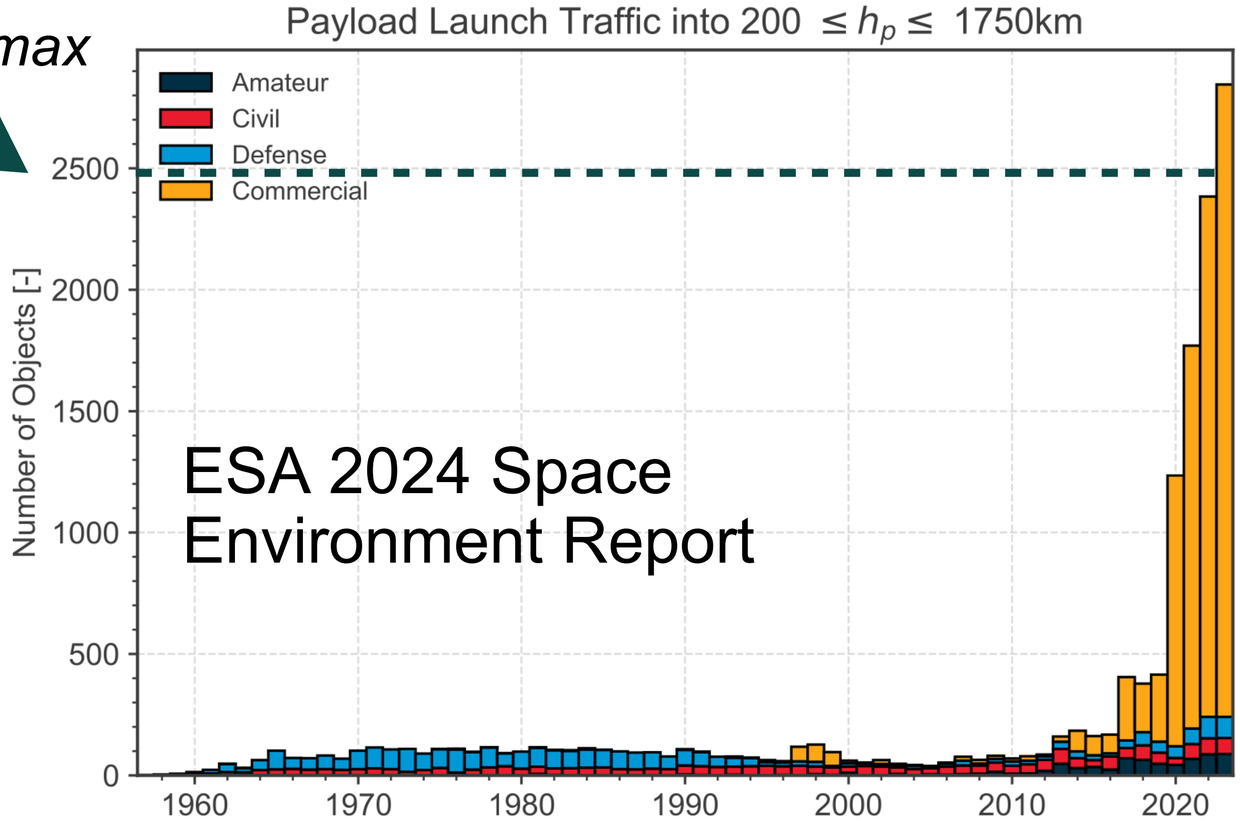
mrawls@uw.edu

A new era for low-Earth orbit (LEO)

Last year's plot y-max

GAO-22-105166

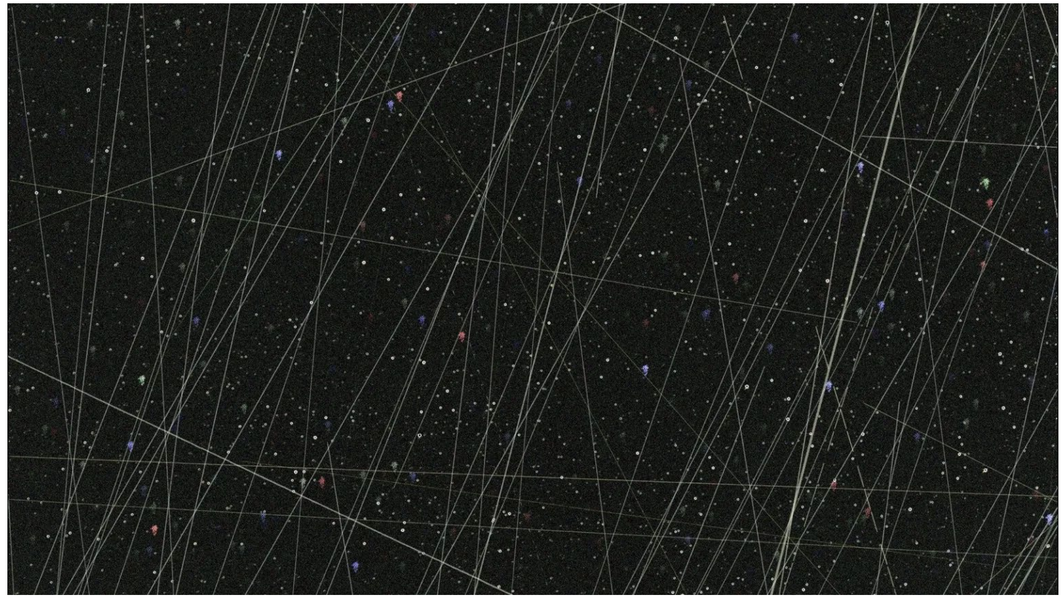




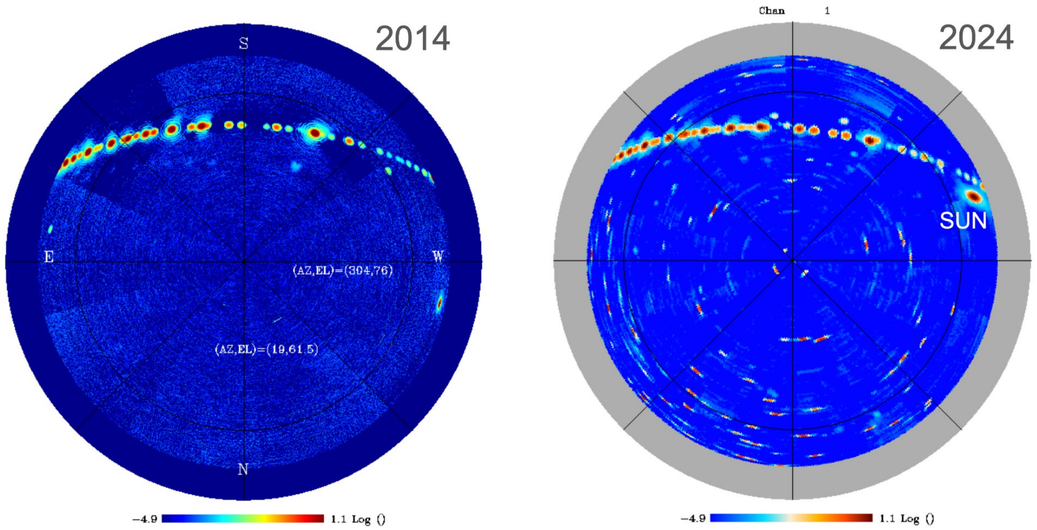
- Commercial LEO satellites reflect the full sunlight spectrum and emit in radio
- Most numerous near twilight but can be visible all night

Satellite streaks across the EM spectrum

- All ground-based astronomy is impacted
- Number of commercial operators is growing: SpaceX Starlink, Amazon Kuiper, OneWeb, AST SpaceMobile, Planet Pelican, SSST Qianfan, and more
- 7000 Starlinks alone launched since 2019



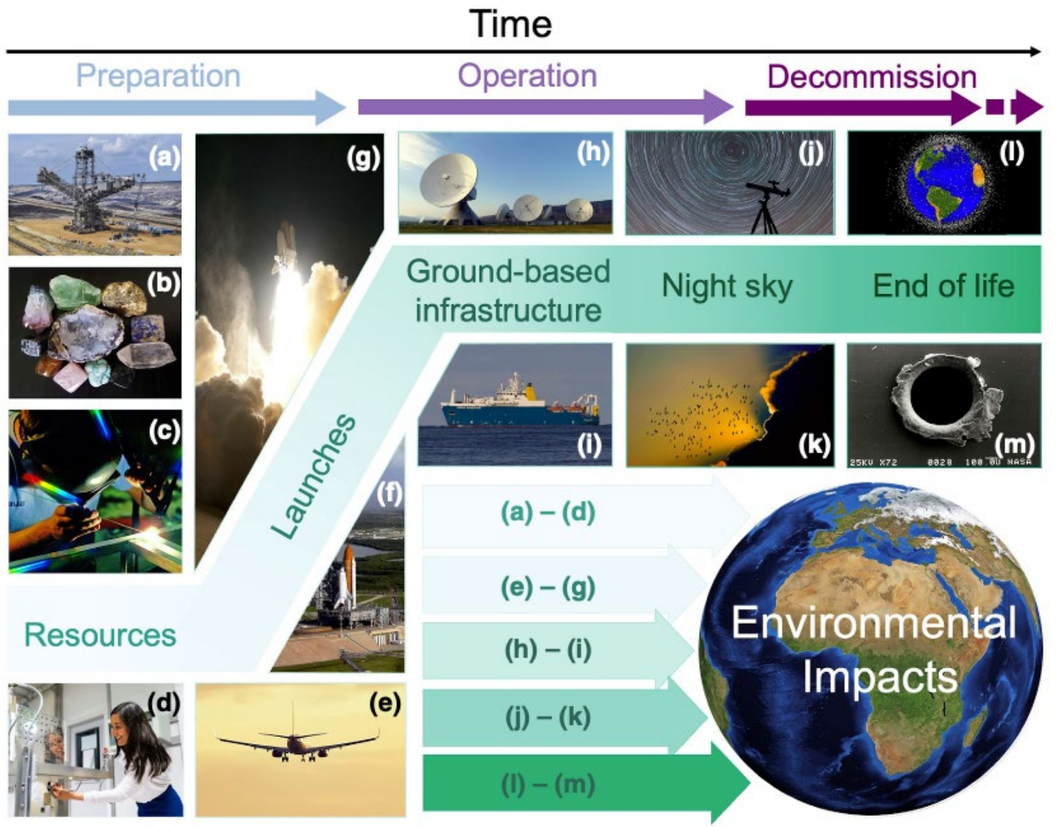
Astrophotographer pixel rejection map (Fegato/Cloudy Nights)
Stacked images from Aug 10, 2022



The difference a decade makes
QUIJOTE at 10–14 GHz, 2014 vs 2024

Orbital space is a human environment

- We rely on the orbital space environment by looking through it and working within it
- Cumulative effects — a critical framework
- **Beyond impacts to astronomy**, we must consider public access to the sky, collision impacts on space operations, atmospheric pollution, ground and airspace collisions, animal and plant ecosystems, and space weather



Gaston et al. 2023

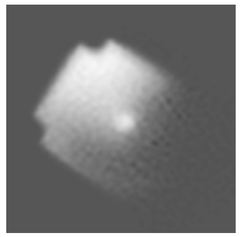
The case for space environmentalism
Lawrence, Rawls, Jah, et al. 2022
Nature Astronomy

What's new: Direct To Cell

- Starlink direct-to-cell, lower altitude and larger, V mag ~4–5 (5x brighter than higher smaller counterparts, despite mitigations)
- AST SpaceMobile, 5 BlueBirds launched Sep 2024, V mag ~7 pre-unfurling
- NASA solar sail demo launched Aug 2024, tumbling, V mag oscillating from ~0 to ~8

Starlink V2.0 direct-to-cell (Tom Williams)

BlueBird rendition (AST SpaceMobile)

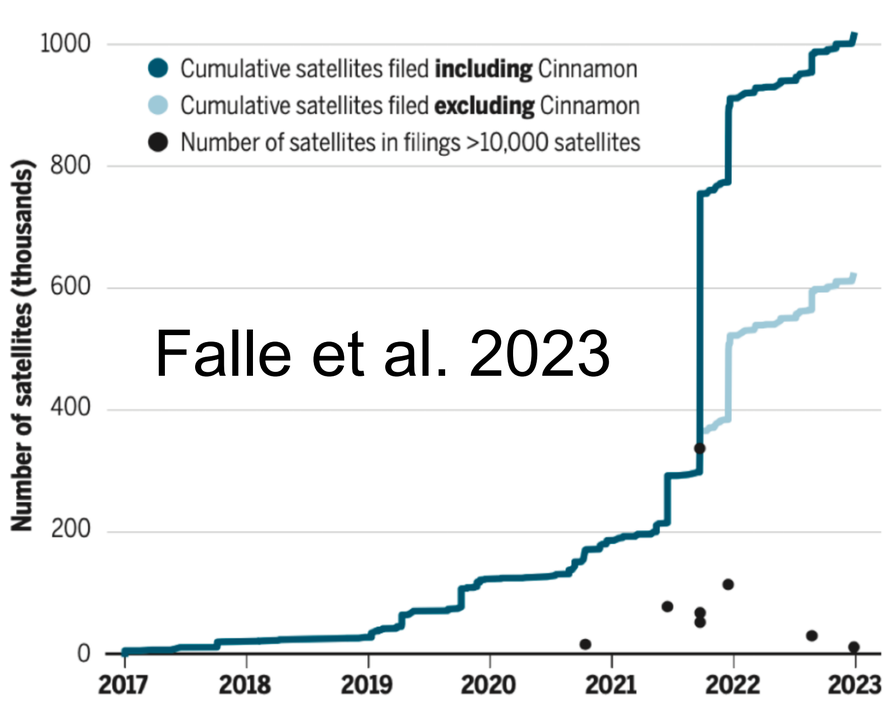


BlueWalker 3 (M. Tzukran)

What's new: Policy etc.

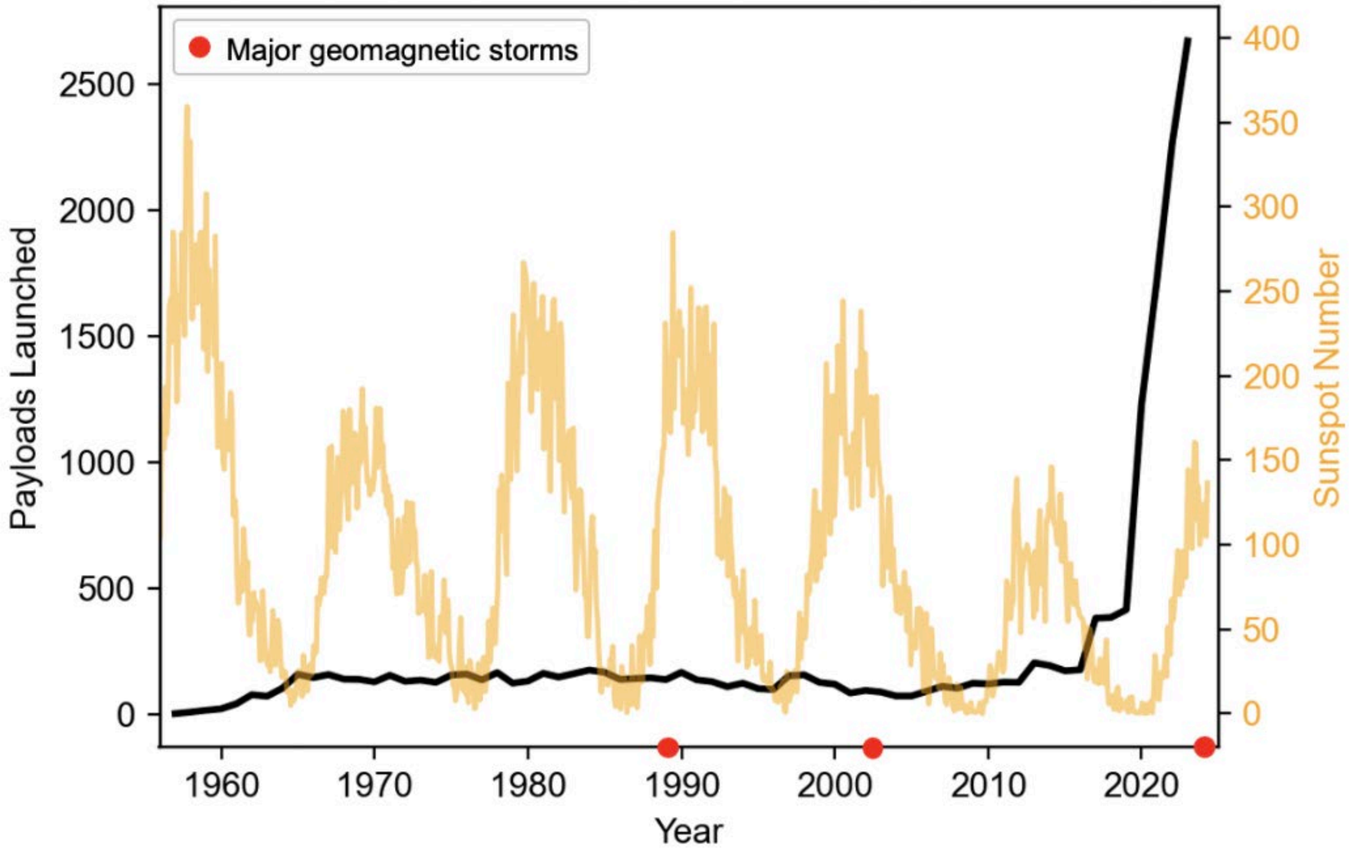
- ESA includes the Dark and Quiet Sky in its Zero Debris Charter, at an **equivalent level** to space safety and debris avoidance
- New IAU GA 2024 **resolution passed** to "include the protection of the Dark and Quiet Sky as part of IAU's mandate"
- Dark and Quiet Skies Act introduced in US Senate
- NSF coordination is usually a condition of FCC licensing for US satellite operators (not ITU) →
- Many conversations are behind closed doors and **limited in scope** — one operator + one country

Join or connect with colleagues who are doing this work!
cps.iau.org and compasse.aas.org



What's new: Space weather

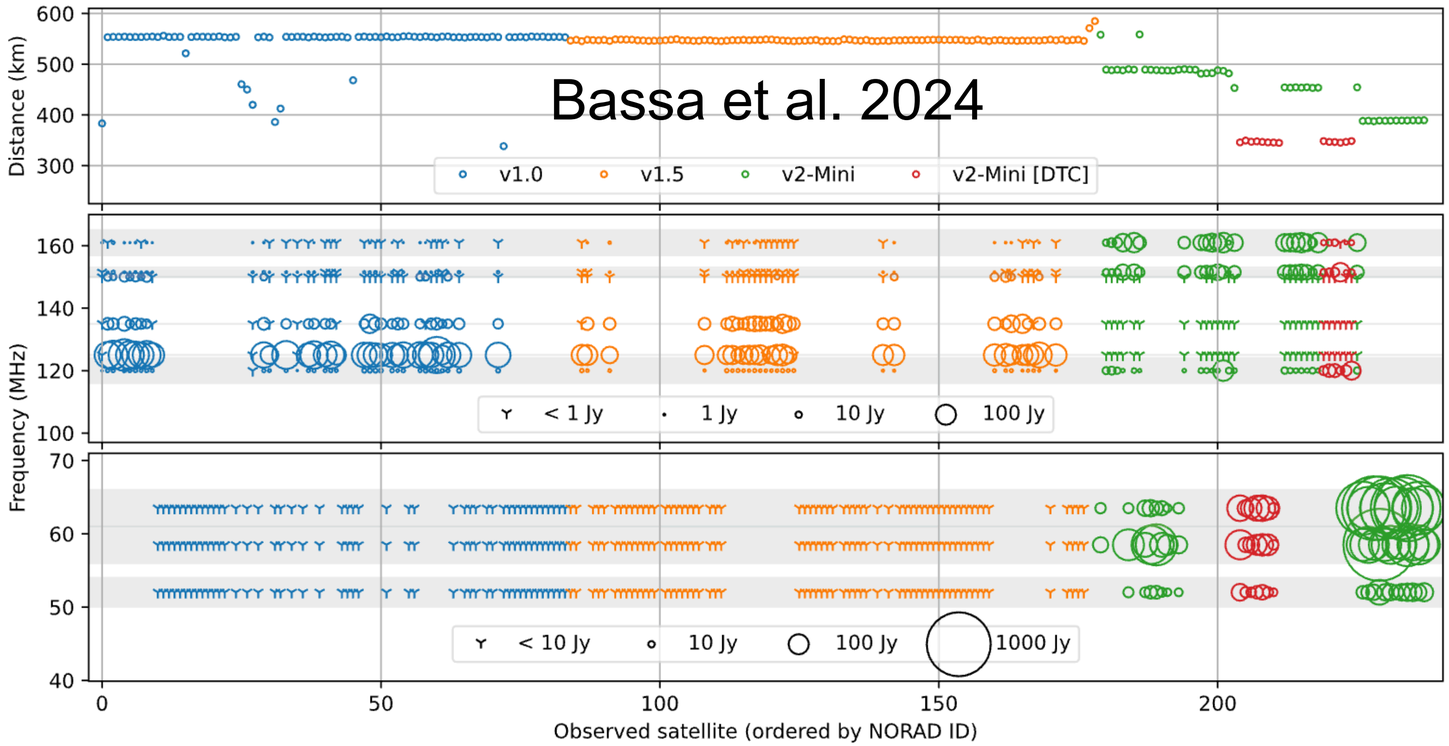
- Satellite position uncertainties increase drastically
- Everyone is maneuvering as hard as possible, all at the same time
- Only sometimes causes deorbit

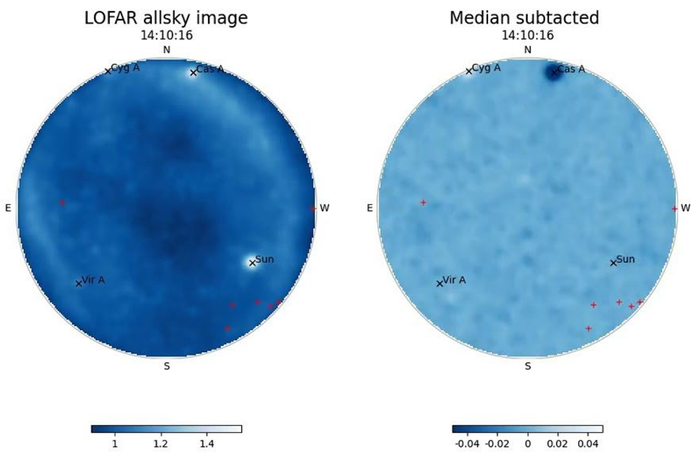


Parker & Linares 2024

What's new: Radio emissions

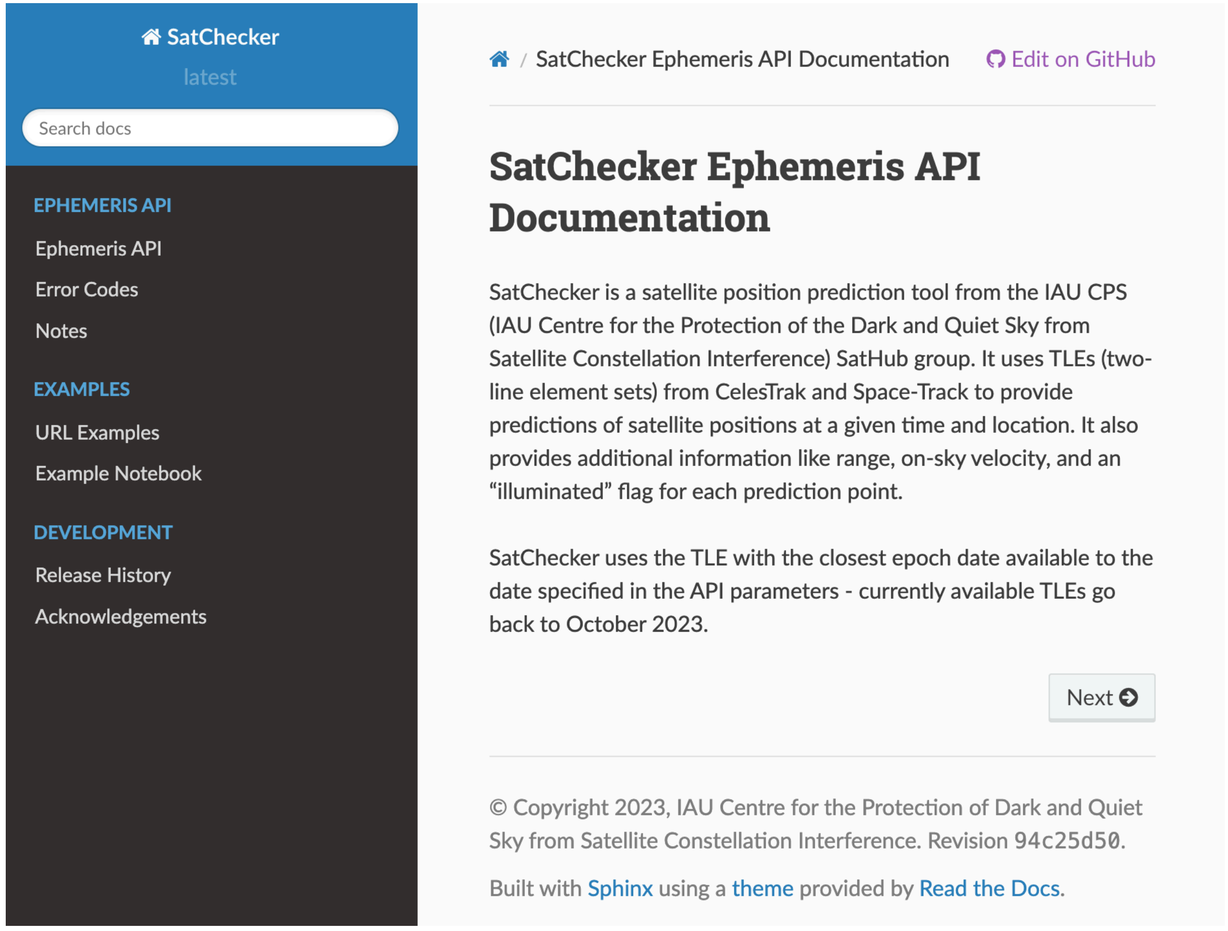
- VLBI using active avoidance scheduling, but can only handle 10k satellites
- NRAO and SpaceX working on Operational Data Sharing (boresight avoidance)
- Unintended RFI is a growing concern — regulatory limits do not apply





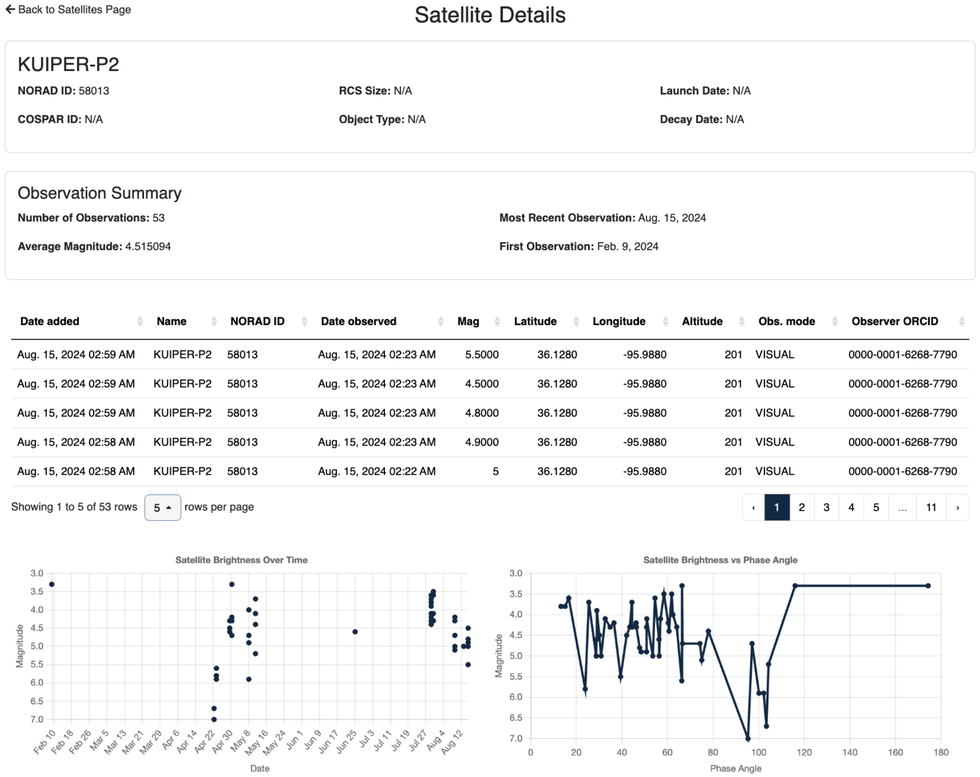
LOFAR observations of Starlink v2-Mini (ASTRON)

What's new: IAU CPS SatHub



Satellite position lookup tool
satchecker.readthedocs.io

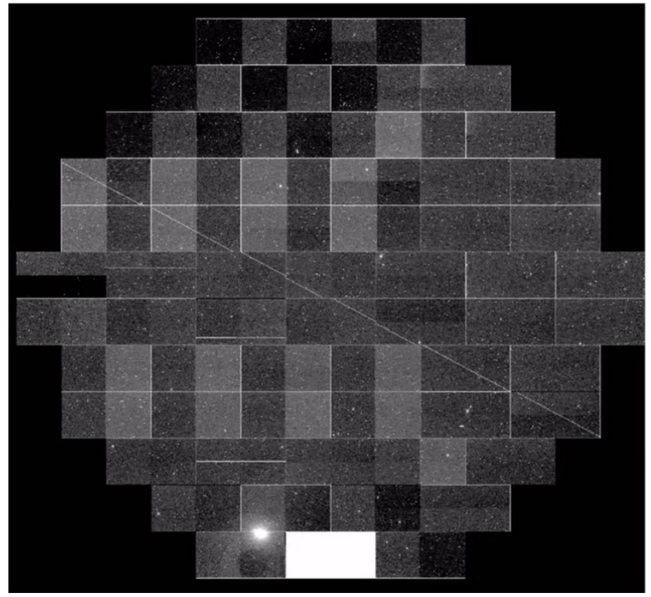
Satellite Constellation Observation Repository (SCORE)



Example SCORE satellite detail page (see Dadighat et al. 2023)

What's new: Grant awarded to SatHub members

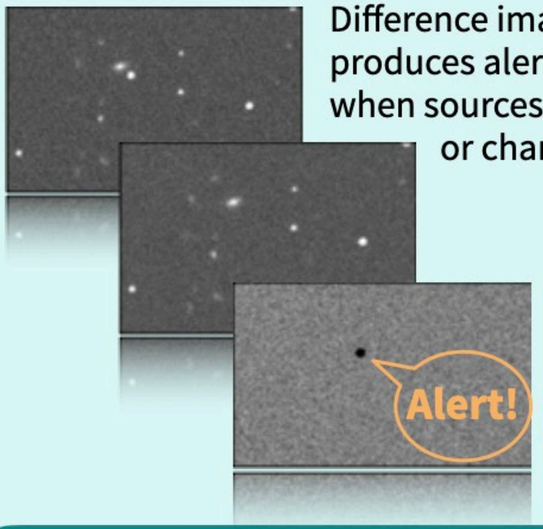
- NSF SWIFT-SAT $750k award funds development of satellite position and brightness forecasting tools and measuring some LSST science impacts (C. Walker, T. Tyson, S. Eggl, M. Rawls, M. Dadighat, w/Aerospace Corp)
  - **Field-of-view pass prediction tool** powered by high accuracy vector covariance messages & brightness models
  - Validate these predictions with real SatHub observations
  - Simulate LSST observations with and without satellite interference to **assess systematic errors** for discovery of Solar System Objects and transients
  - Validate these simulations with real LSST data



Validation of prototype per-satellite SatChecker tool using public TLEs with DECam

Rubin and satellites

Rubin Observatory's potential for discovery is also its vulnerability to satellites



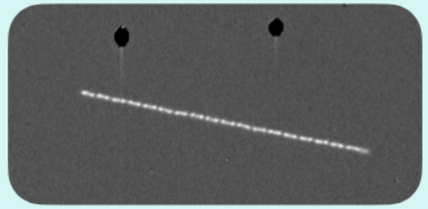
Difference imaging produces alerts when sources move or change

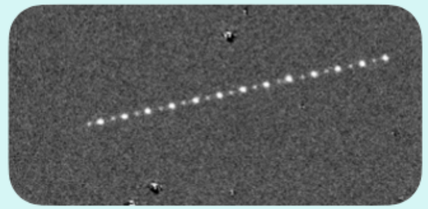
Wide, fast, deep imaging survey will produce 10 million nightly alerts from 2025 as the population of low-Earth orbit (LEO) satellites and debris continues to increase

Mitigations we control include identifying glints and streaks in difference images and an option for avoidance

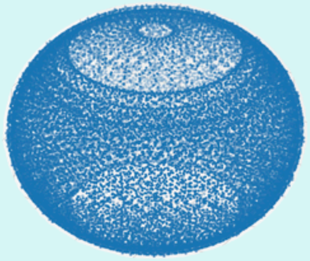
The LSST Science Pipelines will find and label streaks and glints in difference images — without discarding any pixel data — to help distinguish satellites and debris from astrophysical sources

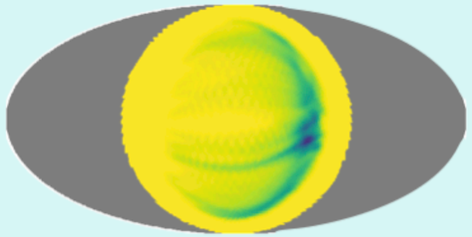
Avoidance uses observing time, and is probably only worthwhile for the brightest satellites





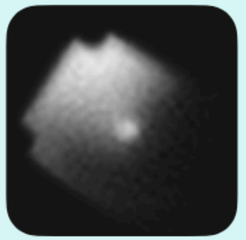
Model Starlink Gen2 satellite population and corresponding sky regions to potentially **avoid** with the scheduler — Hu+2022





Prototype **glint** detection works on ATLAS data — A. Heinze

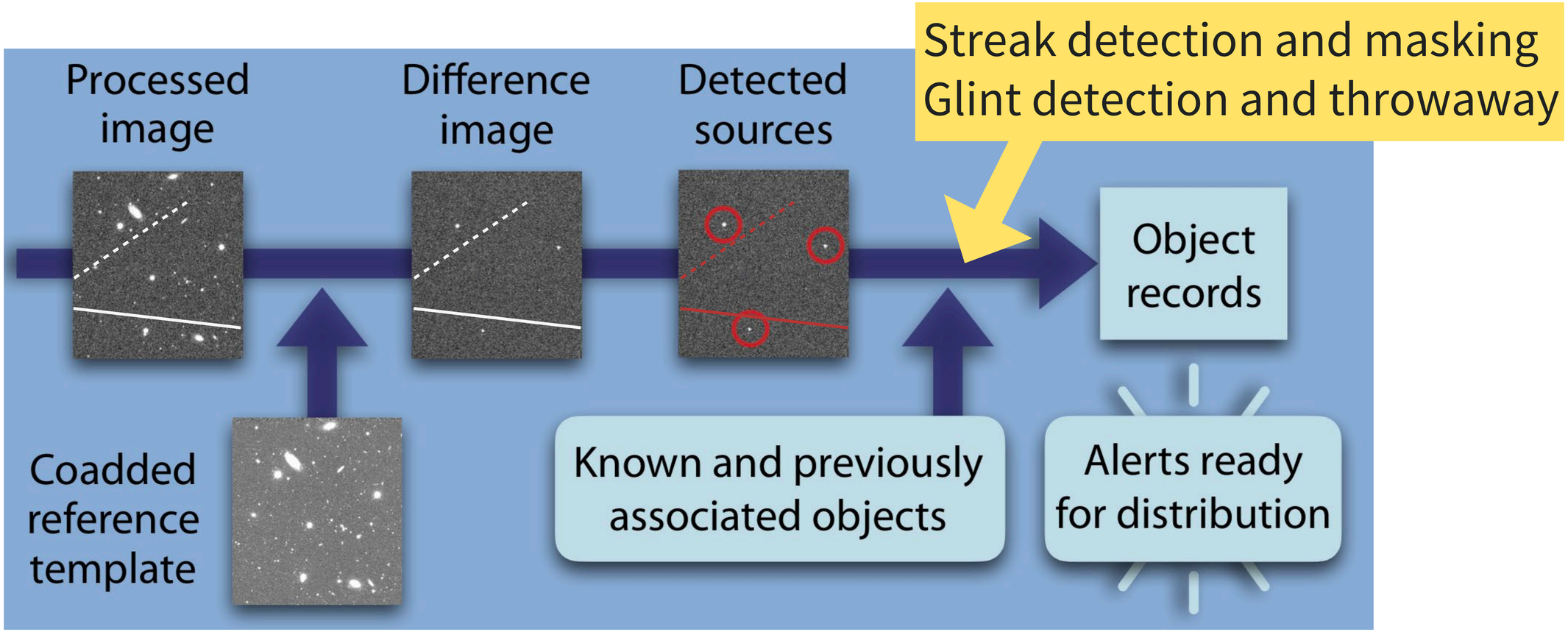
Large satellites like BlueWalker 3 can exceed 0th mag — Nandakumar+2023 (Photo: M. Tzukran)



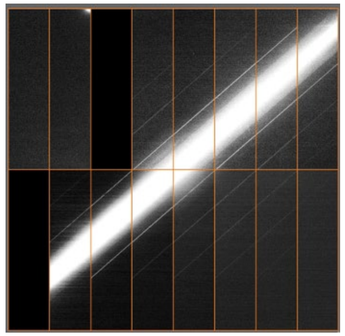
Portion of Ivezić & Rawls IAU GA 2024 poster

Rubin operations alert production

- Satellites, debris, etc. may appear as false (non-astrophysical) sources



Total impact to science depends on several imperfectly known quantities

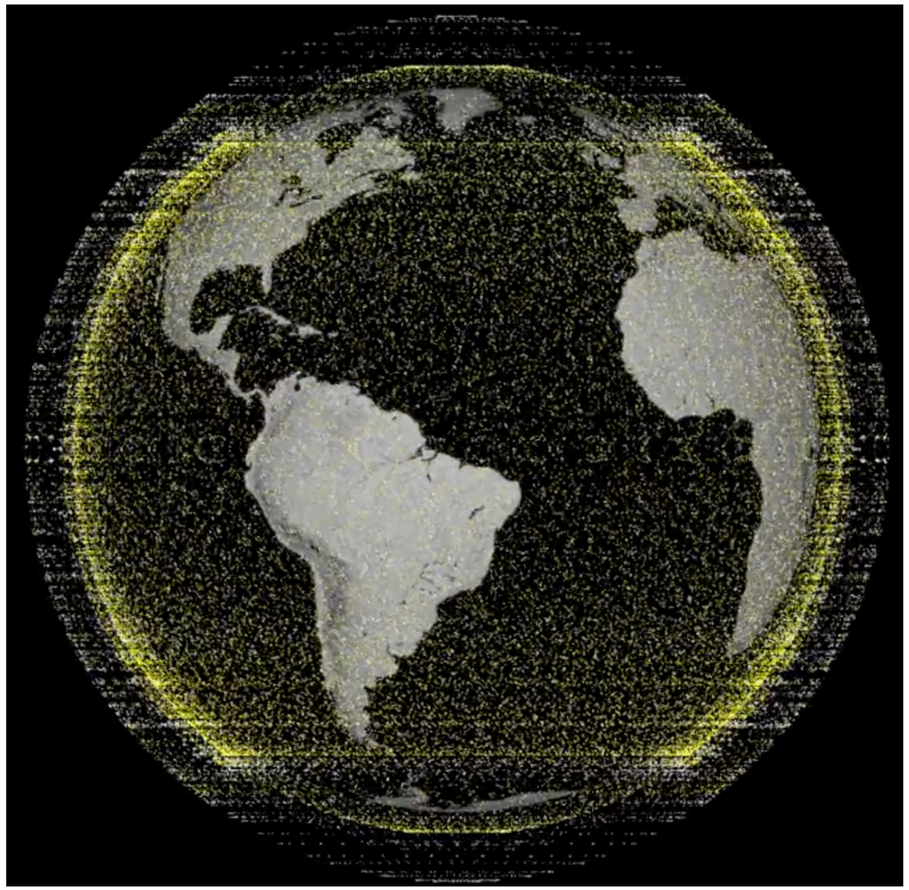


1. Number of satellites and their orbits
2. The satellite brightness distribution
3. How the LSST Camera responds
4. Image processing algorithms and pipelines

Summary of Rubin and satellites (largely written by me): **ls.st/satcon**

1. Number of satellites and their orbits

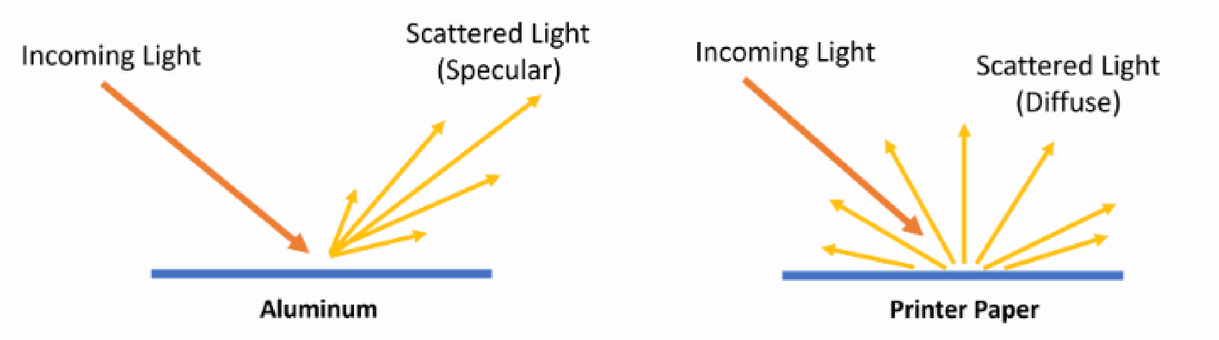
- Low-Earth orbit period ~90 minutes
- At any time:
  - ~4% of LEO sats above the horizon
  - ~0.6% of LEO sats above 30 deg
- **In the next decade: 50,000 – 500,000**
- Depends on economics & regulations
- Physical carrying capacity unknown



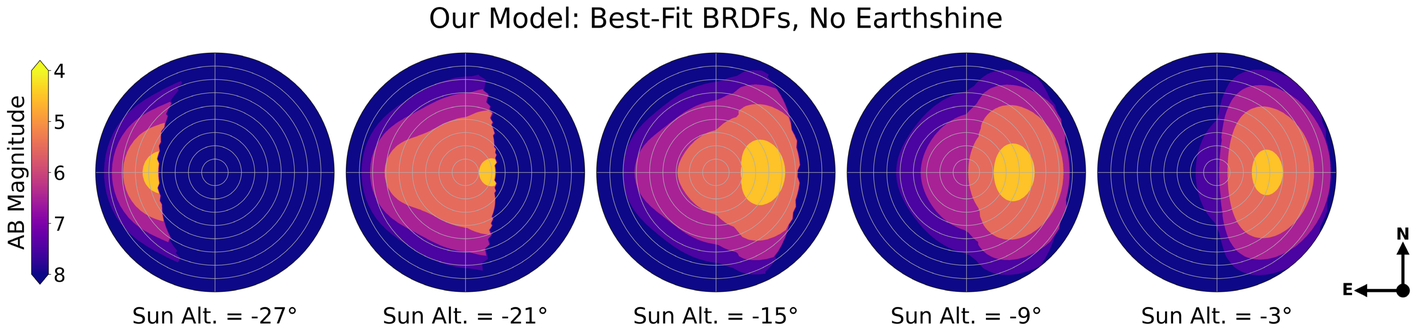
René Schulze via NYTimes, based on filings from Starlink, OneWeb, Kuiper, Telesat, Guowang, Astra, and Globalstar

2. Satellite brightness distribution

- Work underway via SatHub to incorporate brightness predictions into a field of view forecasting service

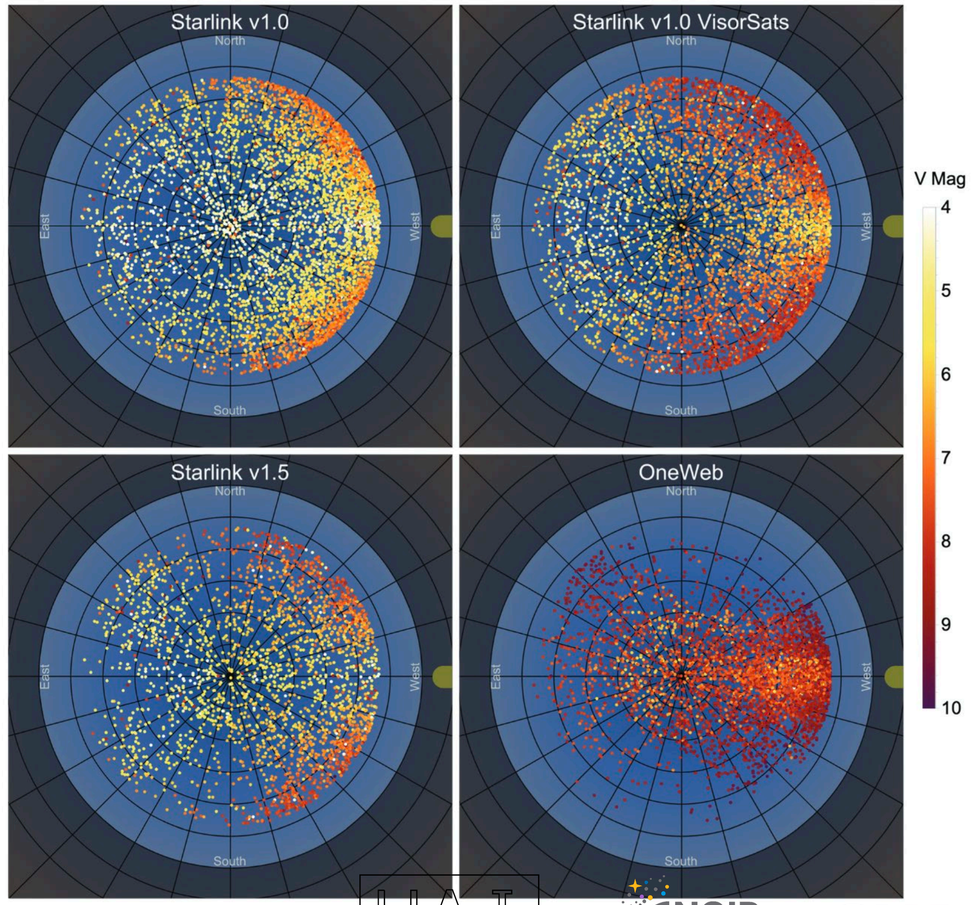


Lumos-Sat brightness modeling tool



Fankhauser et al. 2023

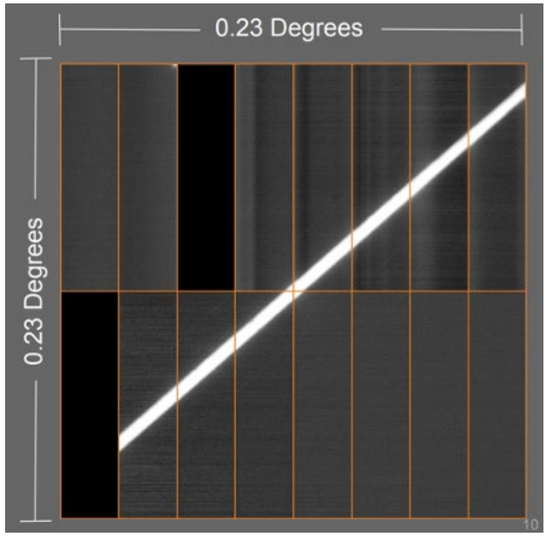
Krantz et al. 2023



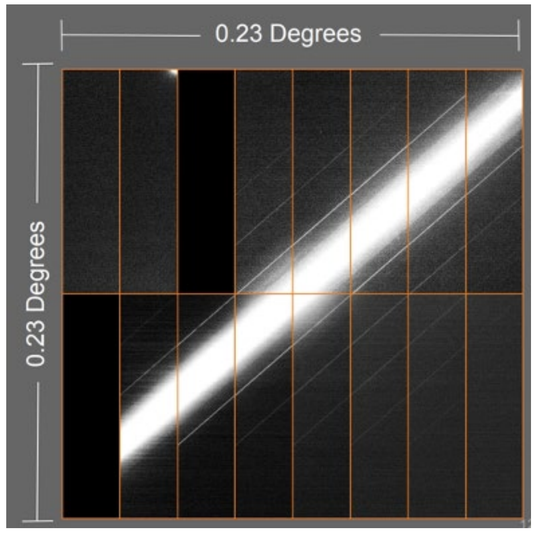
3. How the LSST Camera responds

- Bright satellite trails in the sensitive LSST Camera can induce image artifacts
- Electronic crosstalk between output amplifiers (scales non-linearly with intensity!), and determining an appropriate mask width is tricky
- Paper coming soon from Tony Tyson's group on trailed charge challenges

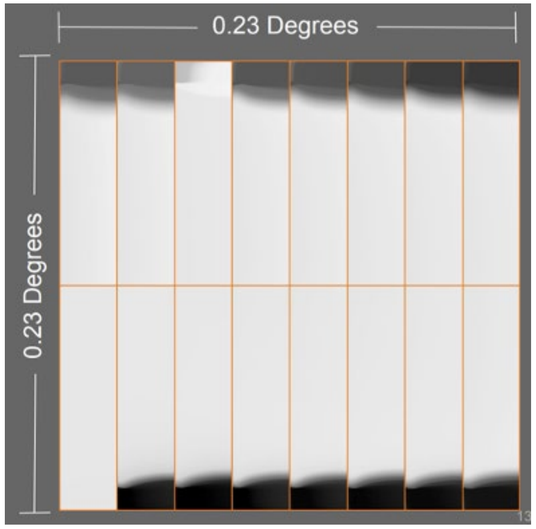
Simulated streak images courtesy Dan Polin



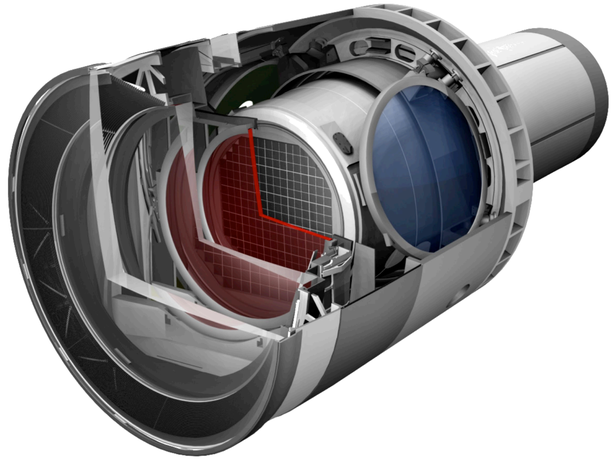
CPS rec 😐



Current Starlinks 😬

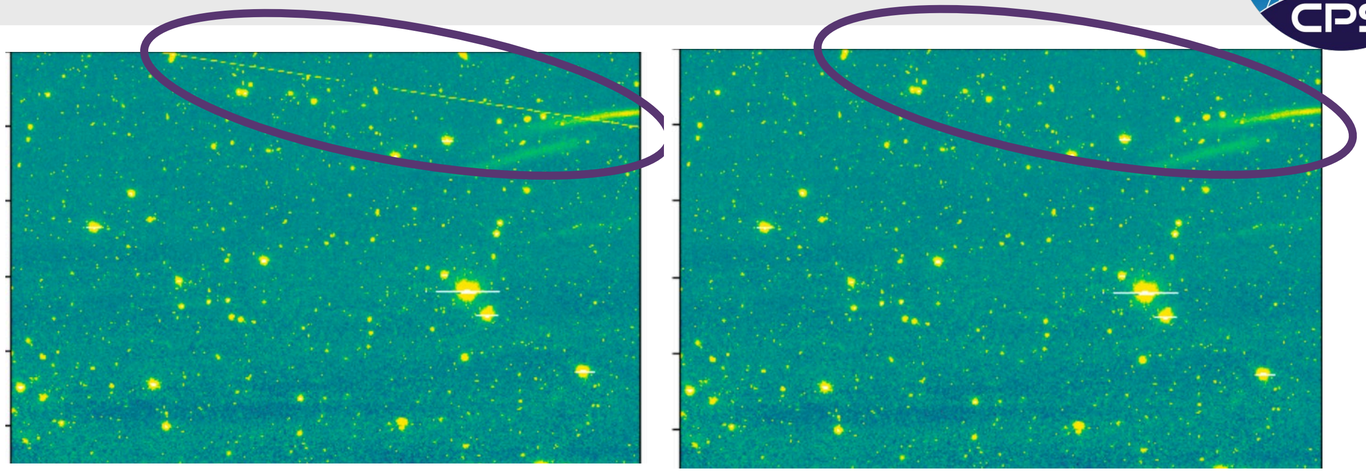


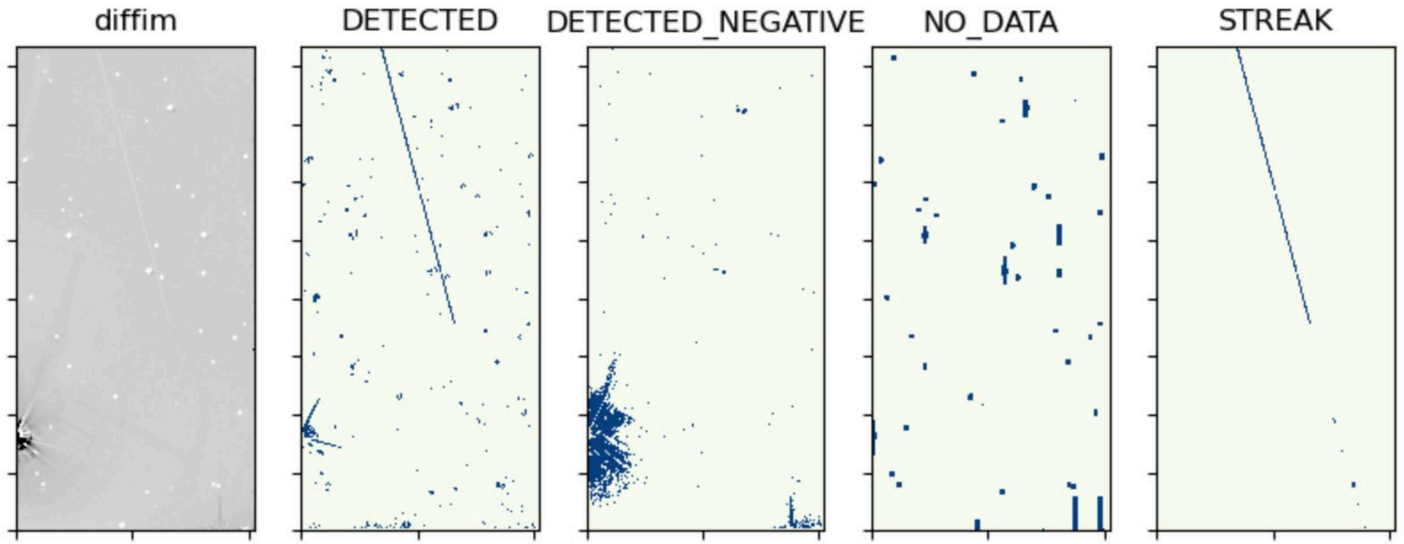
BlueWalker 3 😭



4. Image processing algorithms

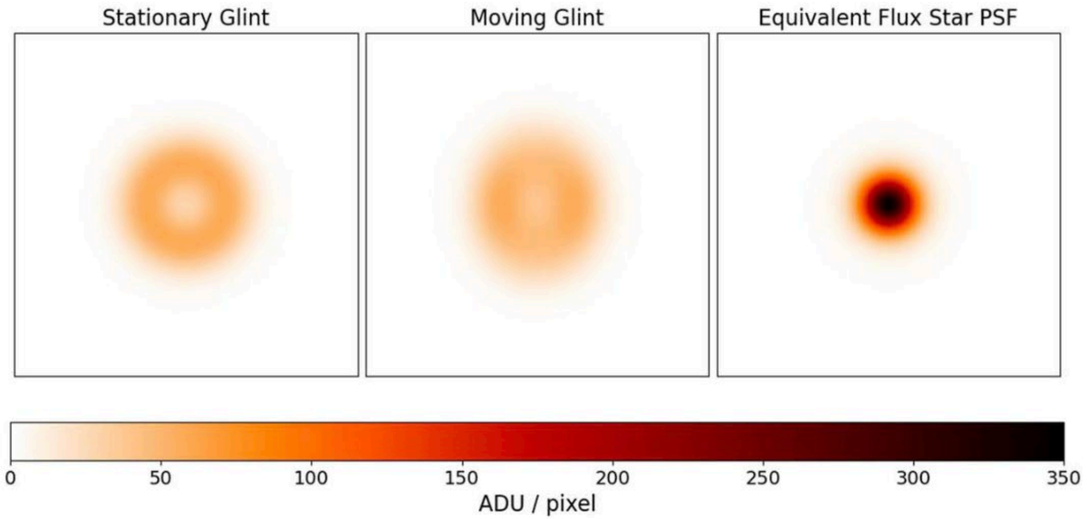
- We will detect and mask streaks during coadd assembly and difference imaging
- Working on adding glint detection also (tumbling debris)
- Pixel data is never discarded
- Goal is no artificial signals in the final difference image source catalog (or the alerts)
- Future: use real streaks in Rubin data to measure impacts of optical satellite interference on science and make decisions about avoidance

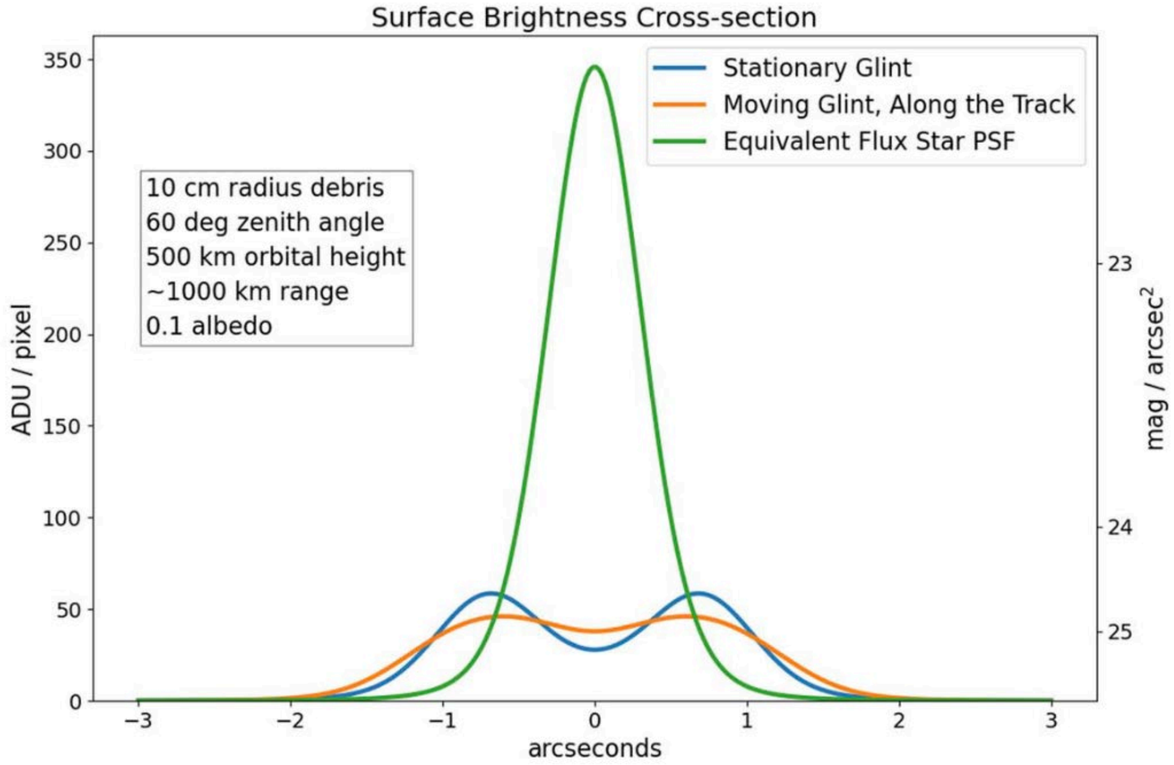




Debris and LSST

- 10 cm and smaller debris should not typically* be detected or cause problems
- Need to account for defocus (primary effec and motion (secondary effect)
- Still a problem: **gradually increasing sky background brightness** from growing population of very small debris





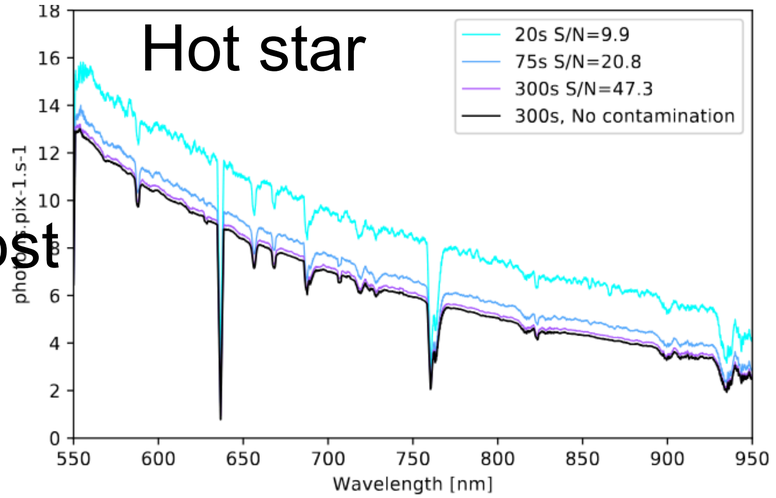
Tyson et al. 2024

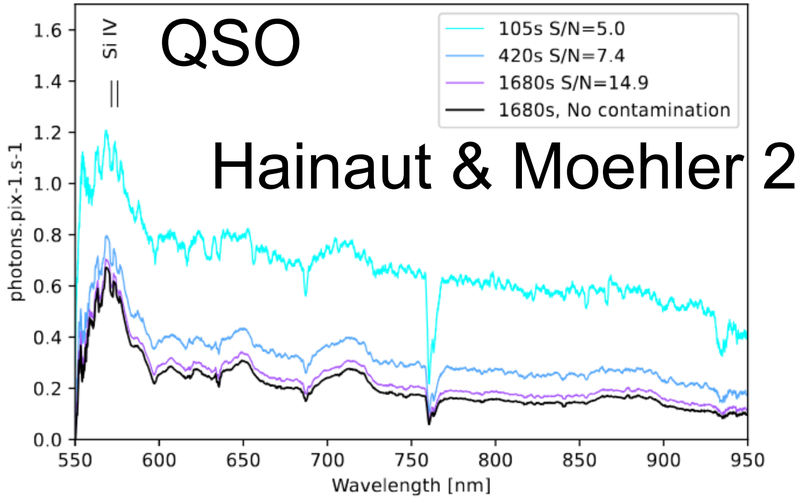
*unless it's super shiny

Wider challenges: flares, spectroscopy

- Specular reflection mitigations reduce average brightness, but increase flares or glints
  - Can be predicted if satellite attitude is known (most companies consider this proprietary)
- Contaminated spectra can be identified with simultaneous imaging, but not “repaired”

Starlink cluster flare
(Nick Hartman)





Hainaut & Moehler 2024

The state of satellite constellations

- Problem is still exponentially increasing — expect **50k–500k** LEO satellites in the next decade
- Even when companies listen and cooperate, they have **no obligation** to protect the sky
- Coordination agreements, charters, resolutions, etc. are great, but no substitute for int'l regulations
- Astro community **needs to know** when closed-door discussions are happening (even when details cannot be disclosed) to coordinate our own mitigations
- Rubin is working to effectively identify satellite streaks so we can **minimize impacts to LSST science**, and will need to proactively avoid the brightest satellites