The IAU CPS SatHub: Updates on observation campaigns, services and software to mitigate satellite constellation interference

Mike Peel, on behalf of the IAU CPS | ESA Clean Space Days | Oct 5, 2024

(Postdoc, Imperial College London)

IMPERIAL

The IAU CPS SatHub

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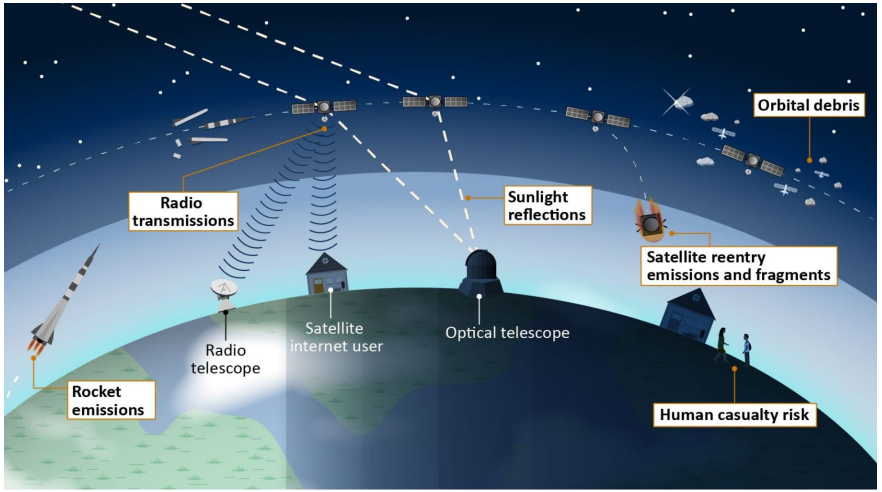
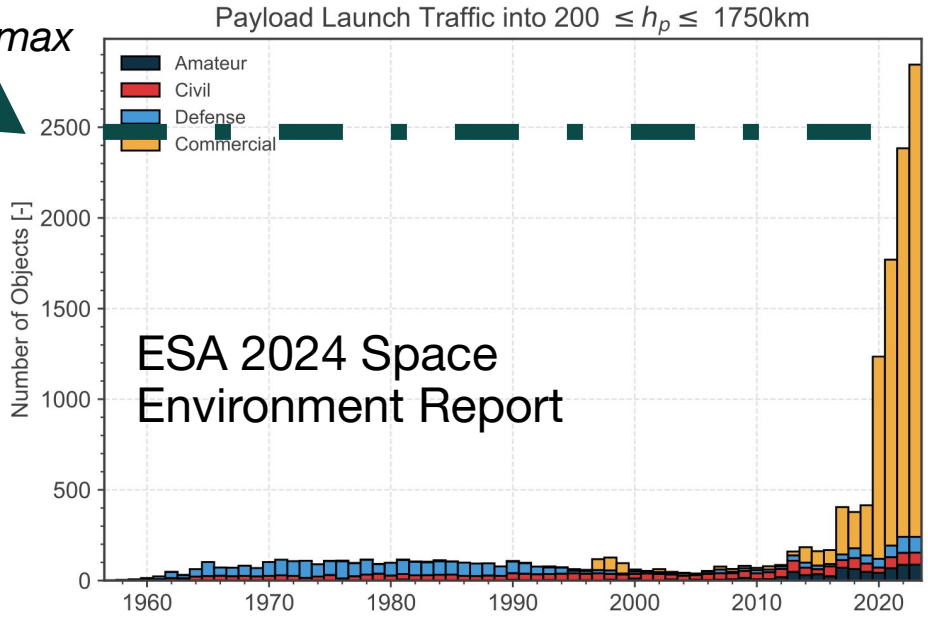
A new era for low-Earth orbit (LEO)

Last year's plot y-max

GAO-22-105166

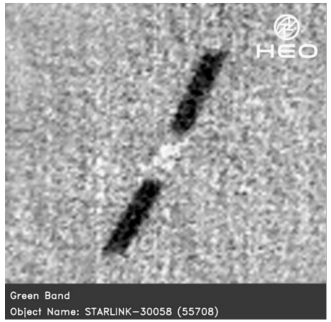


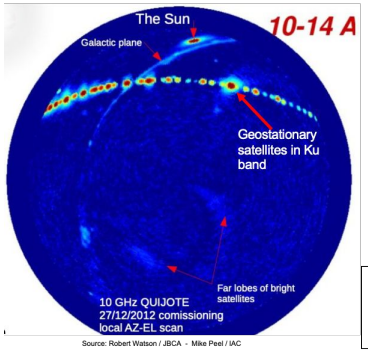


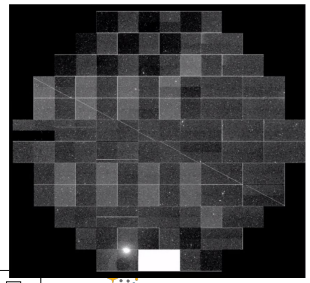
- Commercial LEO satellites reflect the full sunlight spectrum and emit in radio
- Most numerous near twilight but can be visible all night

The IAU CPS SatHub

- **Collaborate** among astronomers, experienced amateurs, policymakers, industry experts, satellite operators, government agencies and more.
    - International community with over 200 members.
- **Promote** open source **software development** and curate **data repositories.**
- **Coordinate** observation campaigns to measure satellite brightness and provide feedback to operators and industry **across the electromagnetic spectrum.**
- **Share** technical expertise and develop **recommendations.**

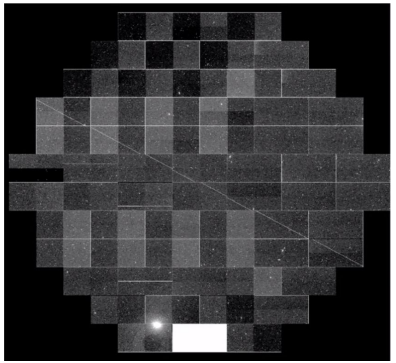






IAU CPS SatHub Aims

- **Assess constellation impact on optical and radio astronomy** via independent observation campaigns and peer reviewed publications
    - Starlink/SpaceX, Kuiper/Amazon, Pelican/Planet Labs, BlueWalker 3/AST Space Mobile, SSST Qianfan, Unintended Radio Emissions/LOFAR, etc.
- **Develop mitigation tools for astronomers**/observatories
    - SatChecker satellite position prediction service
    - Satellite Constellation Observation REpository (SCORE)
    - **NSF SWIFT-Sat: Field-Of-View / active satellite avoidance service**
    - Radio astronomy impact modeling (SCEPTER)
- **Coordinate mitigation efforts** with all stakeholders



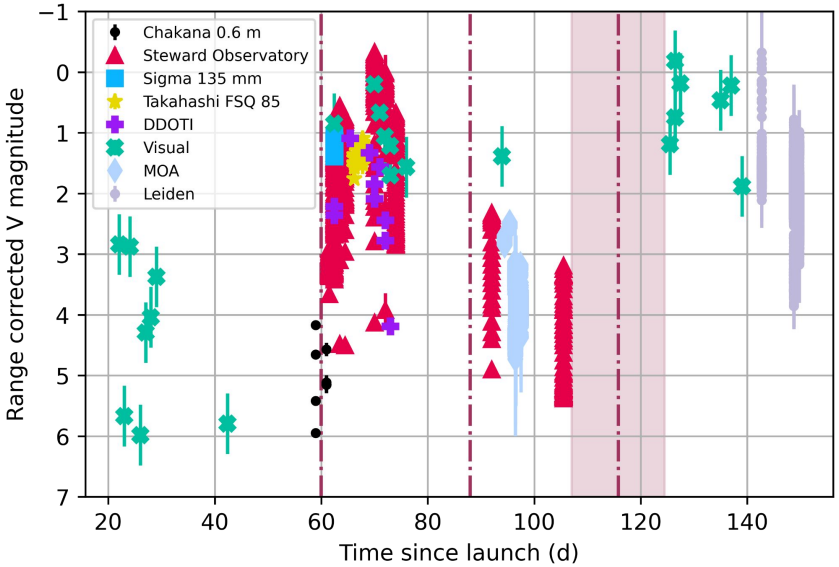
New types of satellites continually launched

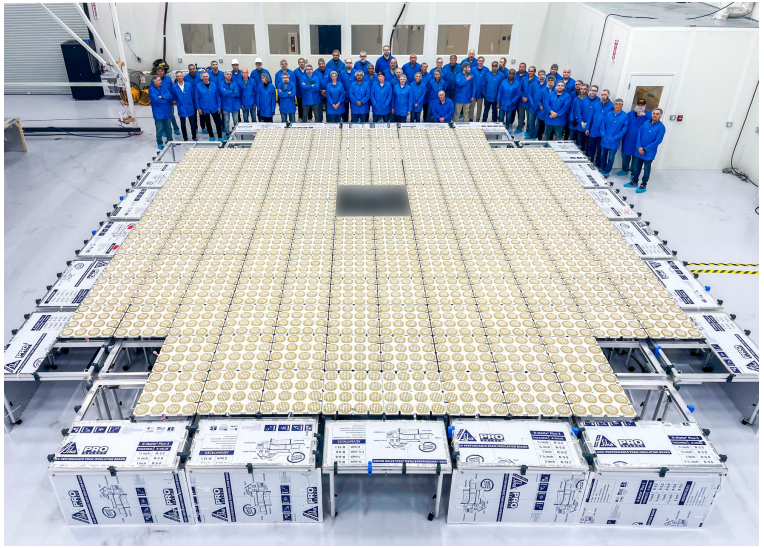
- Starlink direct-to-cell, lower altitude and larger, V mag ~4–5 (5x brighter than higher smaller counterparts, despite mitigations)
- AST SpaceMobile, 5 BlueBirds launched Sep 2024, V mag ~7 pre-unfurling
- NASA solar sail demo launched Aug 2024, tumbling, V mag oscillating from ~0 to ~8 (drag devices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

Starlink V2 mini direct-to-cell (Tom Williams)

BlueBird rendition (AST SpaceMobile)

BlueWalker 3



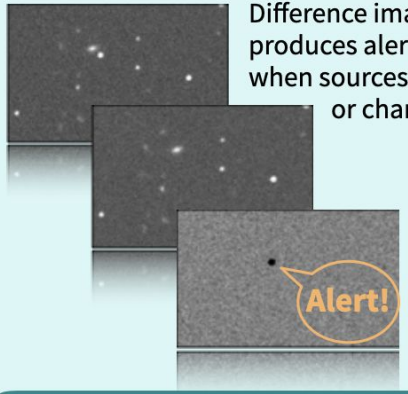


- 64m^2 phased array, prototype for mobile phone connections using standard phones + satellite
- Optically brighter* than Vega and all except top 10 stars (~99% of >mag6) (Nandakumar et al., Nature, 2023)
- (+ launch vehicle adapter bright & untracked for first few days, + position predictions degrade over time)
- Thermal brightness unknown: have SCUBA2/JCMT time to observe ISS + BW3, observations later this year
- 5 Bluebirds now launched, V mag ~7 pre-unfurling...

(* apparent magnitude)

Rubin and satellites

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



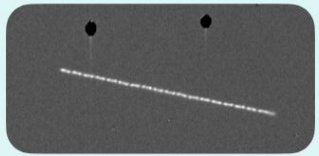
Difference imaging produces alerts when sources move or change

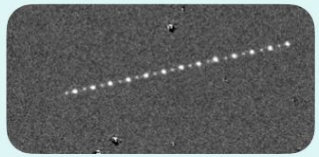
Wide, fast, deep imaging survey will produce 10 million nightly alerts from 2025 as the population of low-Earth orbit (LEO) satellites and debris continues to increase

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

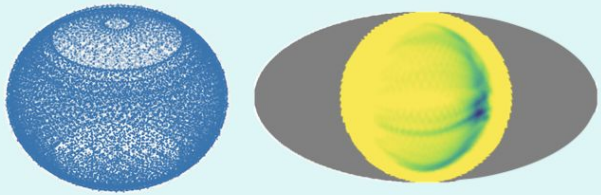
The LSST Science Pipelines will find and label streaks and glints in difference images — without discarding any pixel data — to help distinguish satellites and debris from astrophysical sources

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



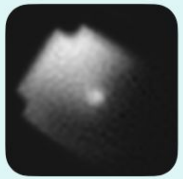


Model Starlink Gen2 satellite population and corresponding sky regions to potentially **avoid** with the scheduler — Hu+2022



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

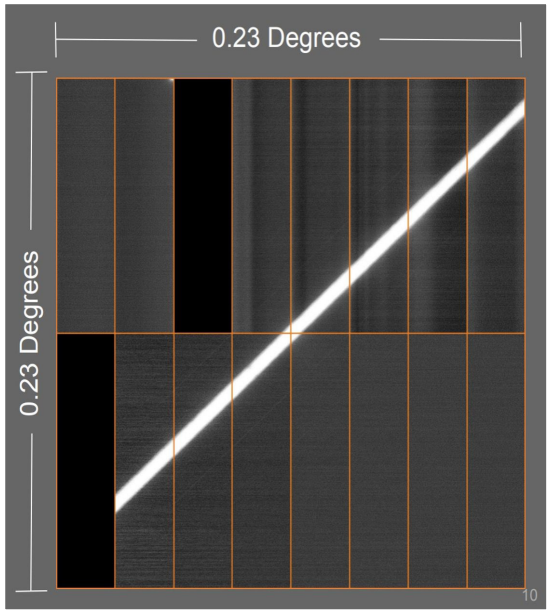
Large satellites like BlueWalker 3 can exceed 0th mag — Nandakumar+2023 (Photo: M. Tzukran)



Portion of Ivezić & Rawls IAU GA 2024 poster

Rubin Observatory CCDs

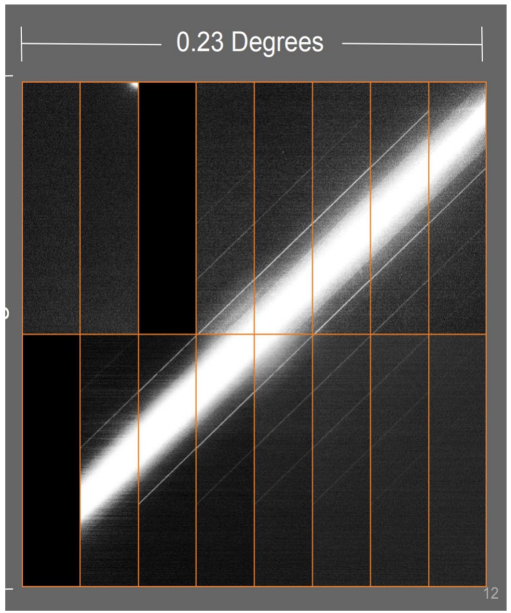
IAU CPS recommendation



Crosstalk Correctable with <10%
Error = 5,000 peak electron count
= 7-8th magnitude*

Faith brightness science affected

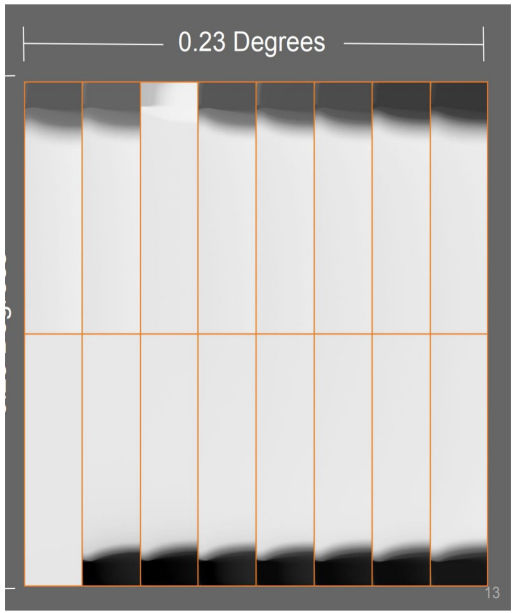
Current Starlinks



Saturation/ “Correctible” with large
Error = 100,000 electrons =
4th mag

Most science programs affected

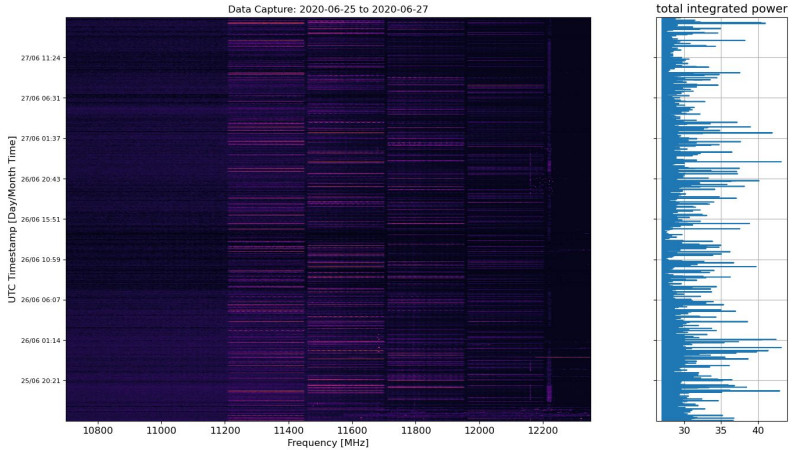
BlueWalker 3

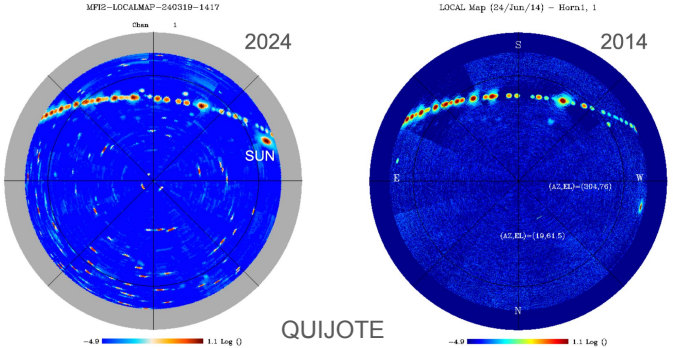


Blooming/ Not Correctable =
1 Million electrons = 0-1 Mag

Potential impact at radio frequencies

- Active 10-20GHz transmissions - plus 40GHz soon? (and octaves!)
  - (Latest Starlink filing of ~30k satellites from Tonga is 120-180GHz!)
  - Each satellite constellation using different frequencies? Important to minimise frequency use...
- Sidelobe coupling also a concern, particularly for CMB experiments
- Difficult to filter out with broadband detectors, unless using FPGAs
- Satellites highly variable - need to accurately know positions, or see as transients?
- Protected radio bands v. narrow - observations normally use broader unprotected bandwidths

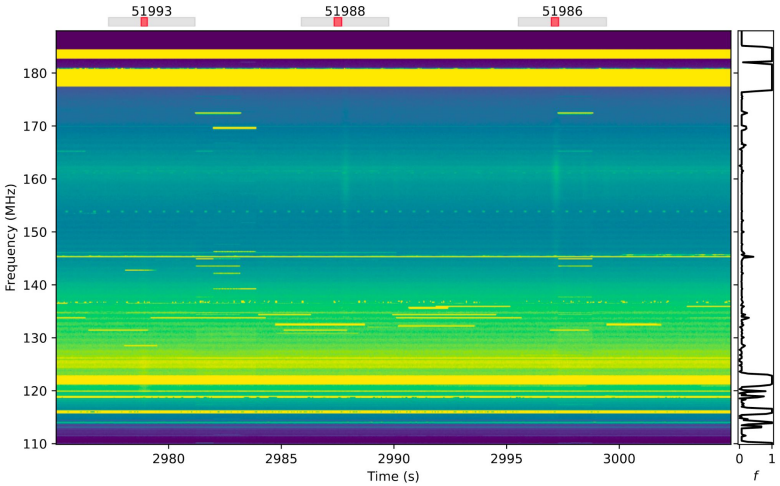


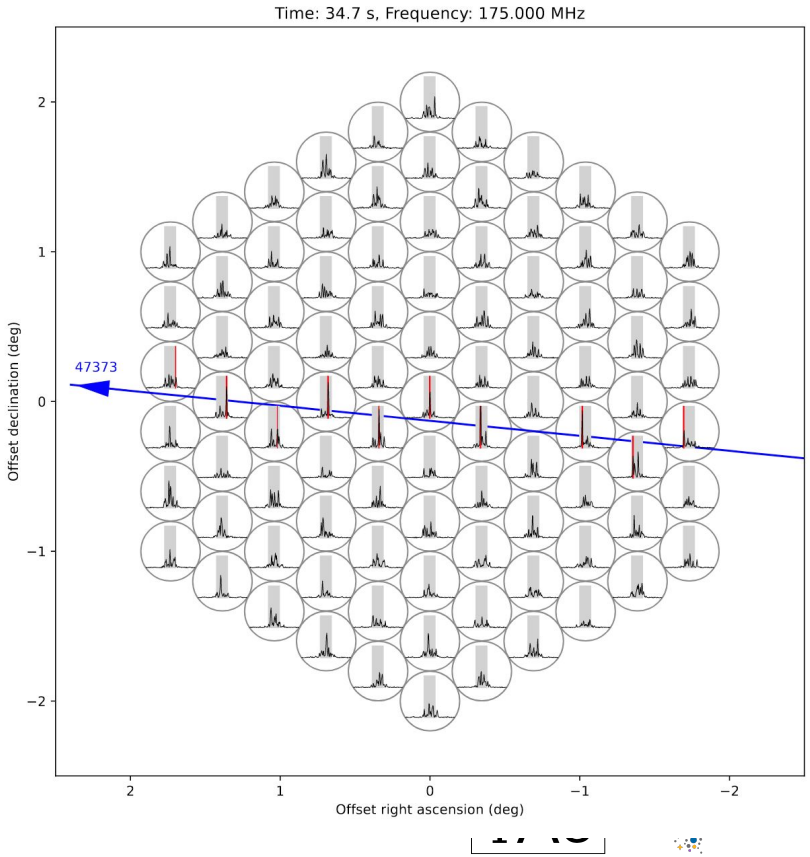


Above: QUIJOTE 10-14GHz observations from Tenerife in 2014 and 2024
Left: satellite dish observations, F. Di Vruno

Unintended emission at low frequencies

- LOFAR sees Starlink passing overhead!
- Unintended emission from back-end electronics seen at ~150-180MHz
- Not permitted bands for transmitting...
- Di Vruno et al. (2023), A&A (published), arXiv:2307.02316
- (Also Grigg et al., 2023, 2309.15672)
- Gen2 mini 32x worse!

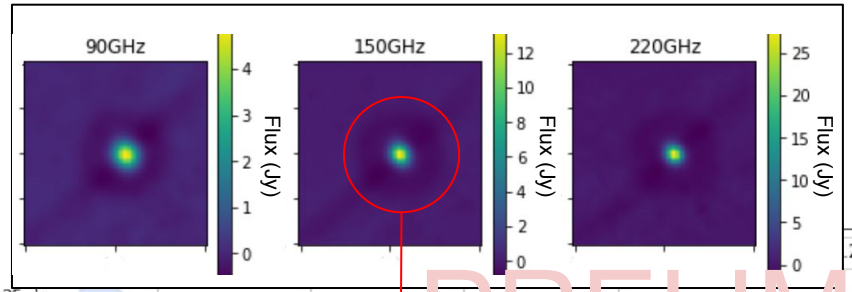


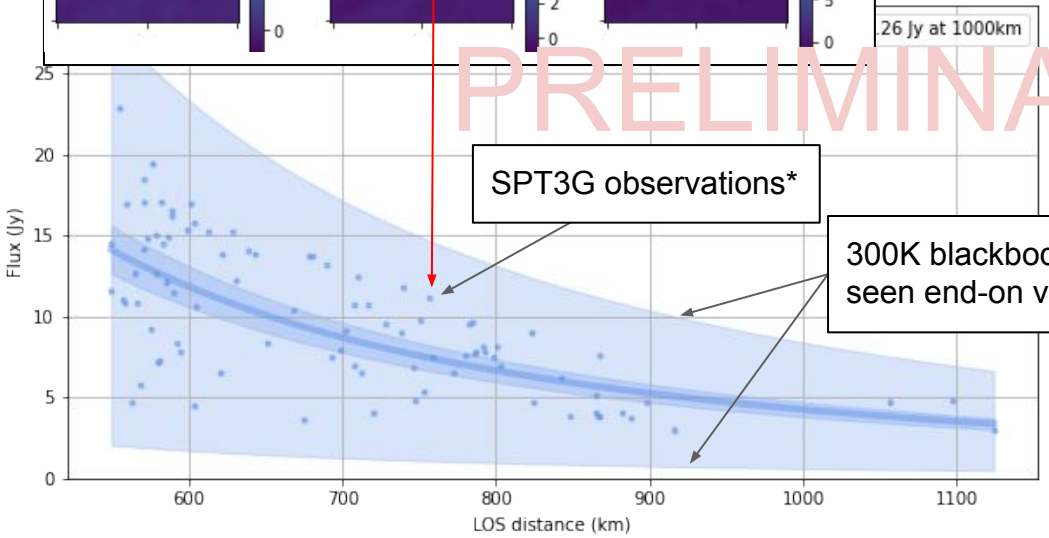


Thermal Emission

(with thanks to Allen Foster, paper in prep.)

Even if not actively emitting RF signal, satellites can be millimeter bright!



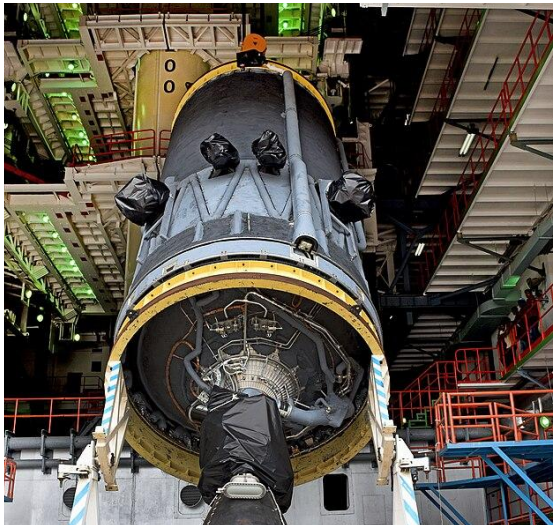


PRELIMINARY

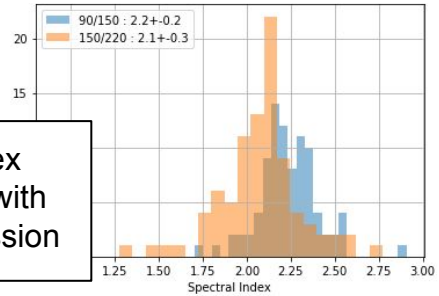
SPT3G observations*

300K blackbody LVM3 seen end-on vs side-on

* observed both in direct sunlight and in Earth's shadow

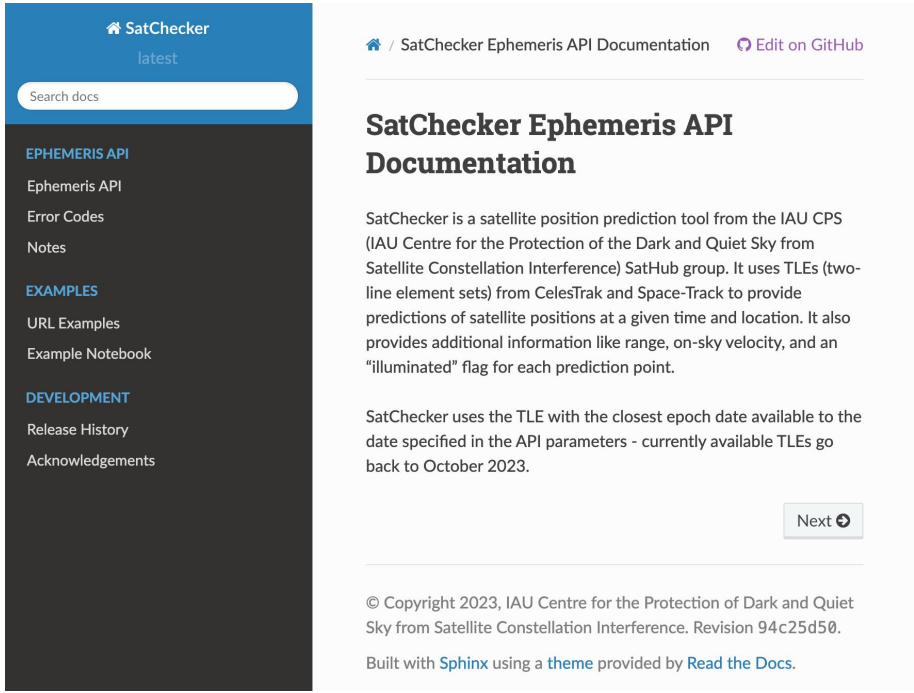


LVM3 Upper stage : 4m diam. x 13.5m long



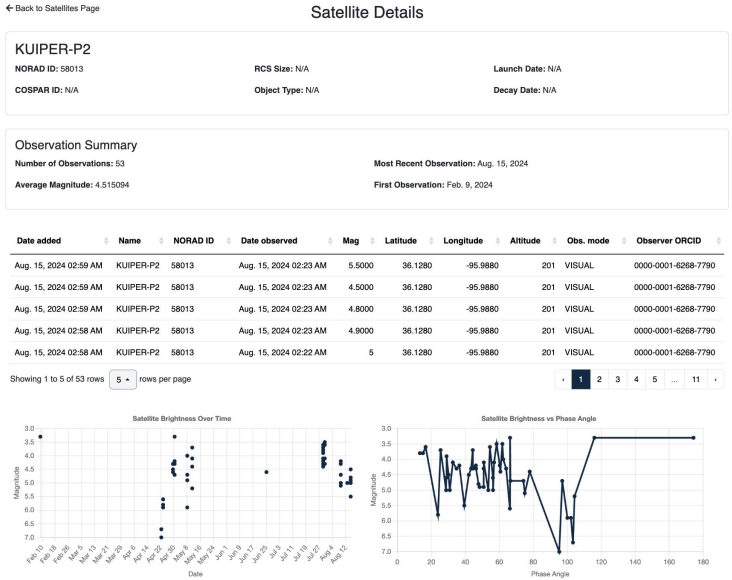
Spectral index ~consistent with thermal emission

Software development



Satellite position lookup tool
satchecker.readthedocs.io

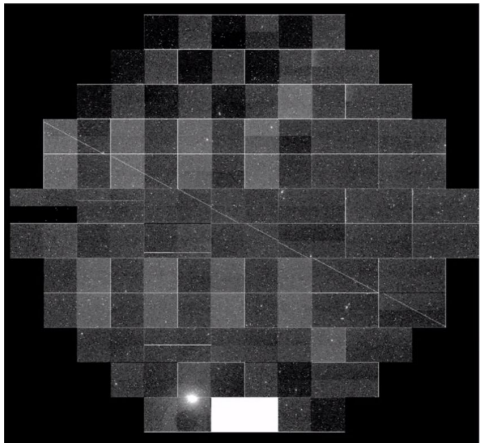
Satellite Constellation Observation Repository (SCORE)



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

SWIFT-SAT software development

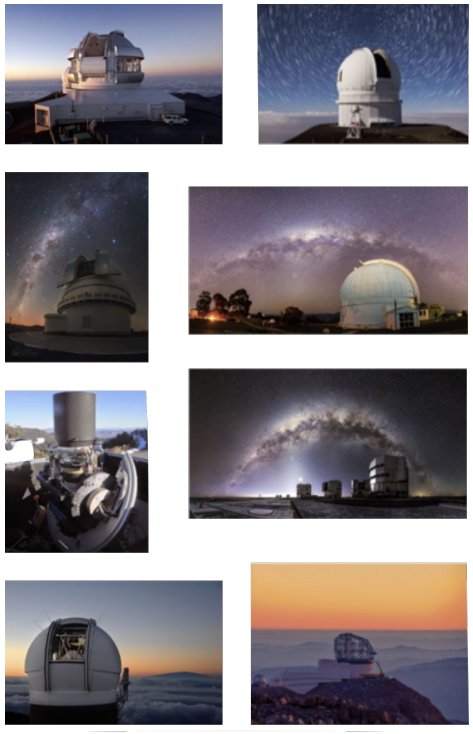
- NSF SWIFT-SAT $750k award funds development of satellite position and brightness forecasting tools and measuring some LSST science impacts (C. Walker, T. Tyson, S. Eggl, M. Rawls, M. Dadighat, w/Aerospace Corp)
  - **Field-of-view pass prediction tool** powered by high accuracy vector covariance messages & 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

How you can get involved!

- **Join:** Apply for SatHub affiliate membership at cps.iau.org, and receive an invitation to our Slack Workspace
- **Contribute:** Develop software at github.com/iausathub, upload observations to SCORE, or pitch a webinar
- **Collaborate:** Use our #sathub or related Slack channels (preferred), or email sathub@cps.iau.org
- SatHub's success depends strongly on contributions from volunteer members, as well as opportunities for funding.
- Anyone observing/simulating/gathering data on satellites, in any context, is welcome!
  (e.g., active collaborations with industry observers)
- **We need your support** to preserve our dark and quiet skies!



Thanks for listening!

Questions?

Join CPS!

https://cps.iau.org