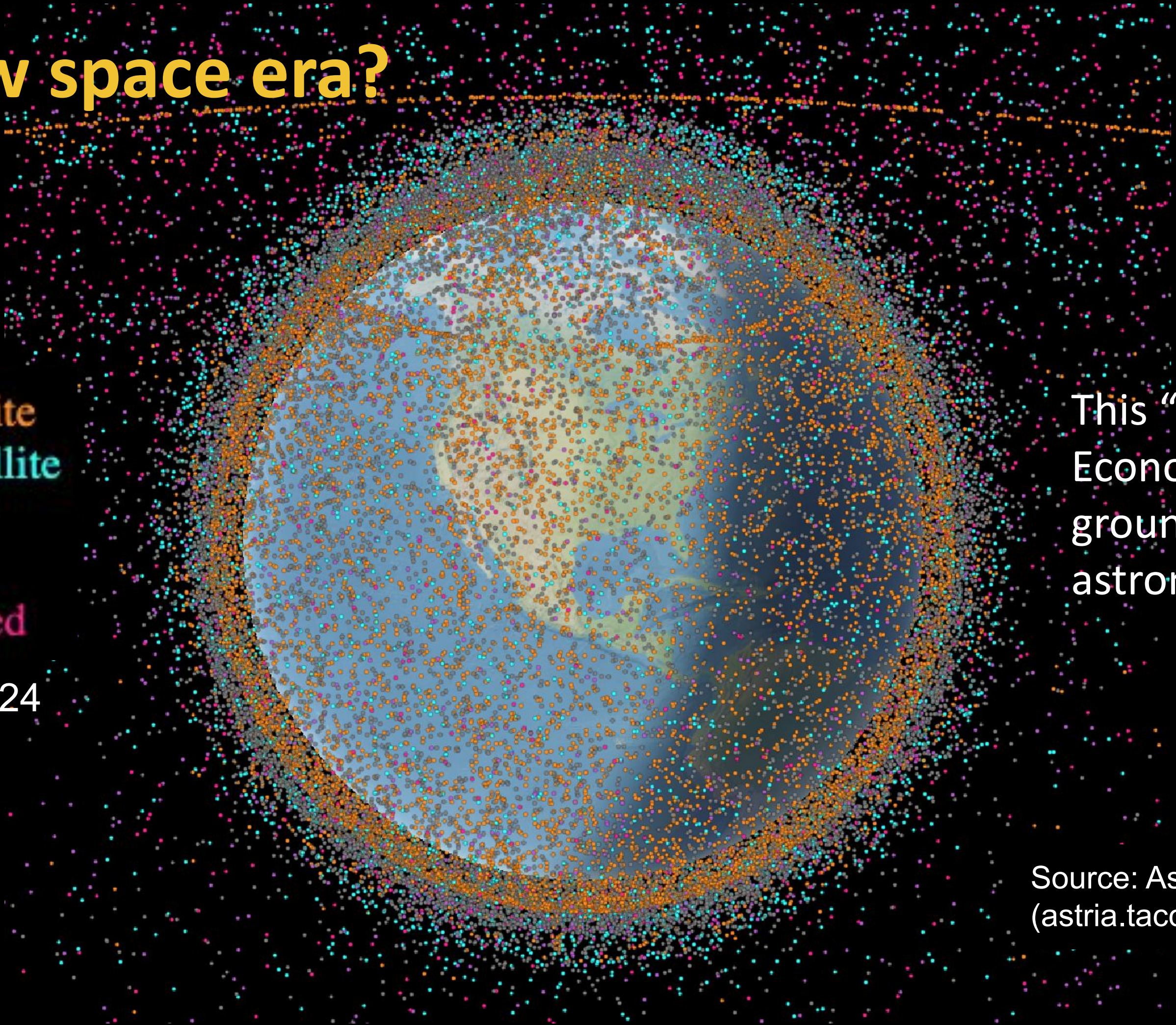
The IAU Centre for the Protection of the Dark and Quiet Skies - achievements and ongoing work

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

(Postdoc, Imperial College London)

A new space era?



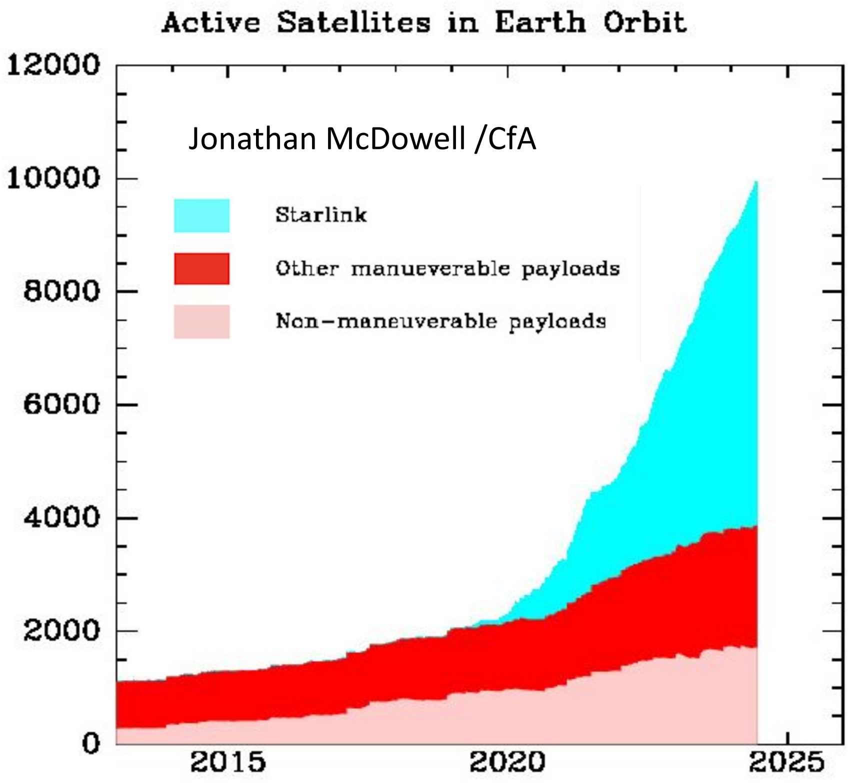
- Active satellite
- Inactive satellite
- Rocket body
- Debris
- Uncategorized

as of 27 July 2024

This “New Space Economy” is harming ground-based astronomy

Source: AstriaGraph (astria.tacc.utexa.edu/AstriaGraph)

We are facing an exponential increase in space activity



Active Satellites
2019 May: ~2,200
2023 Nov: ~6,800 (3x in 4 years)
2024 Jun: ~10,000 (1.5x in 0.6 year)

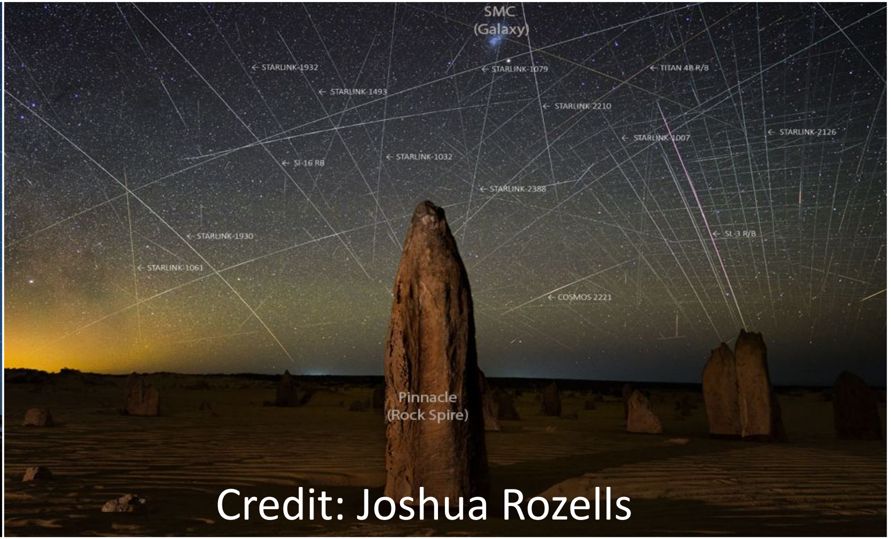
Active+Inactive Satellites ~13,000
Trackable space junk ~30,000

Disturbing Prospect: >1 million constellation satellites are envisioned (according to ITU applications)

Illuminated satellites can affect the Night Sky for:

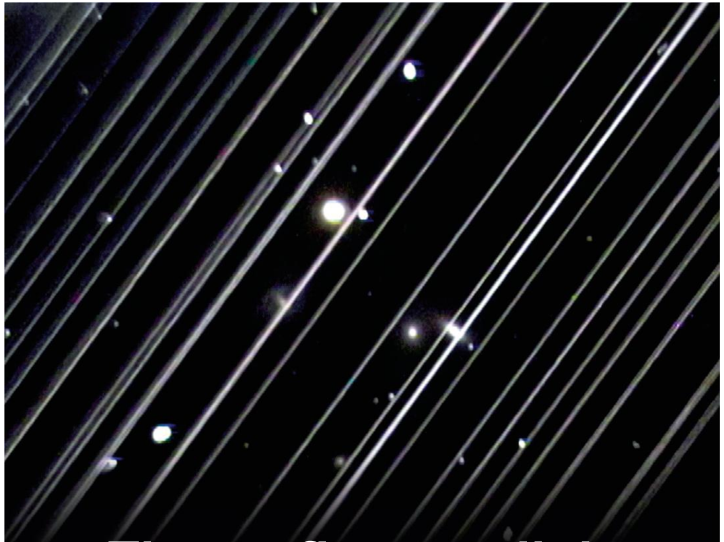
- Professional Astronomy
- Nature
- Tourism/Economy
- Astrophotography
- Amateur astronomy
- Cultural heritage


Credit: Max Alexander “Our Fragile Space”



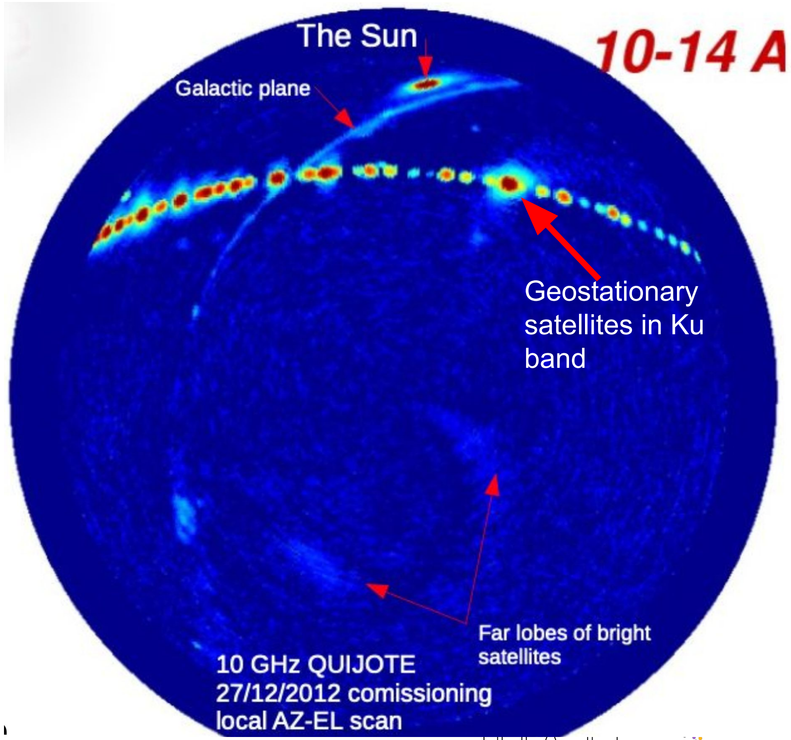
Credit: Joshua Rozells

How do satellites interfere with astronomy?



- They reflect sunlight
- They emit microwave radiation

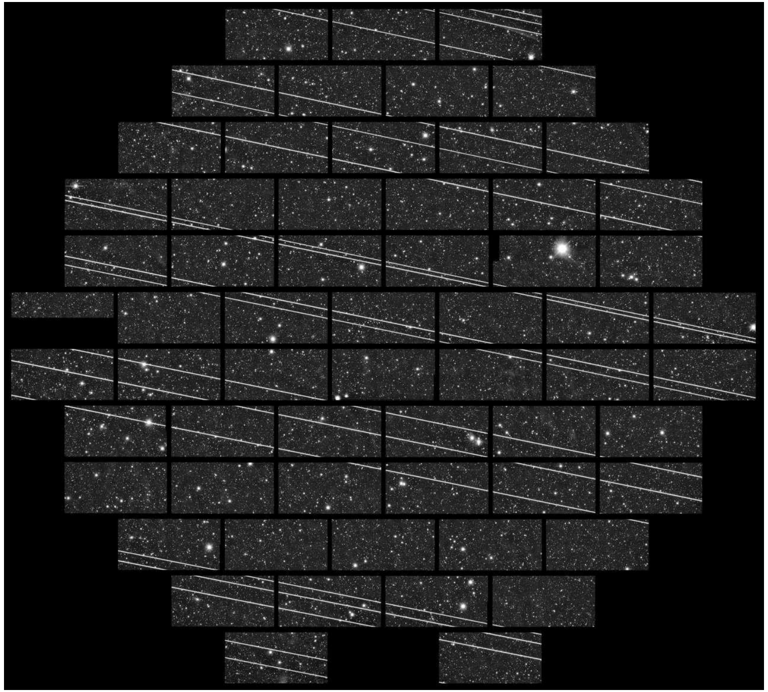
Source: Victoria Girgis/Lowell Observatory



Source: QUIJOTE collaboration, Tenerife

Satellites’ Impact on Astronomical Observatories

- **Narrow field** (Gemini, Keck, ESO’s VLT, ELT): **~10% of frames** (twilight)
- **Wide-field** (Blanco, VST): **50% of frames** (twilight)
- **Super-Wide-field:** (Rubin Observatory)
  - **~ all image frames** (twilight)
  - Many frames - during whole nights

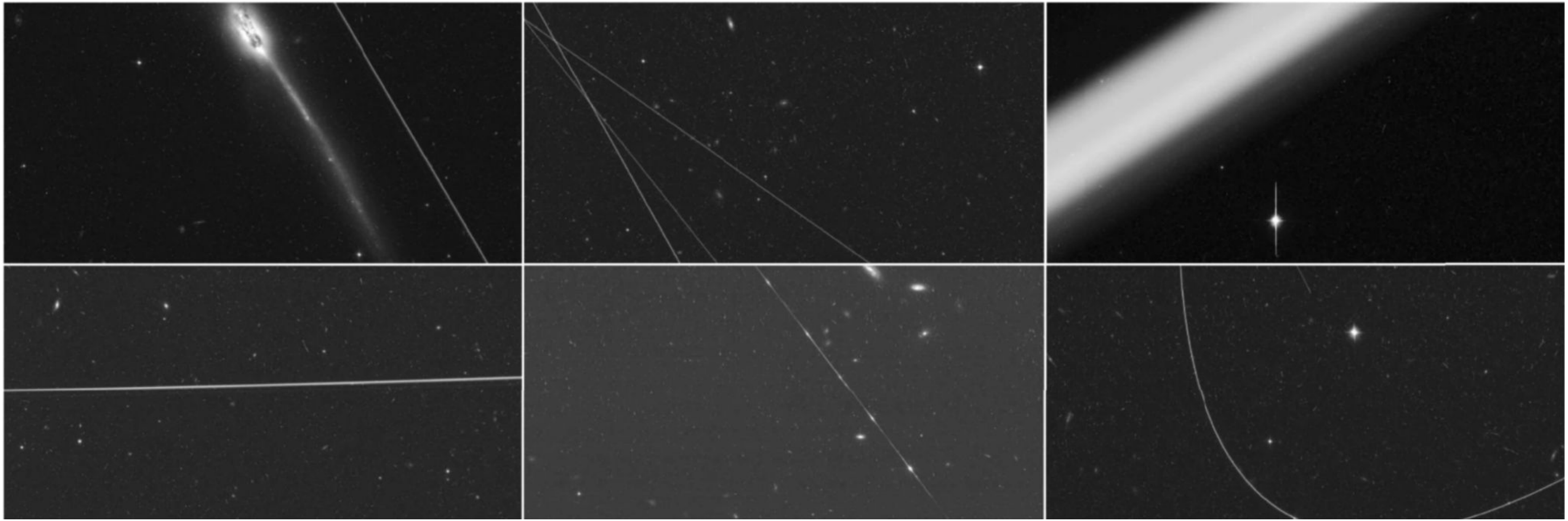


Credit: CTIO/NOIRLab/NSF/AURA/Decam DELVE Survey

IAU NOIRLab SKAO

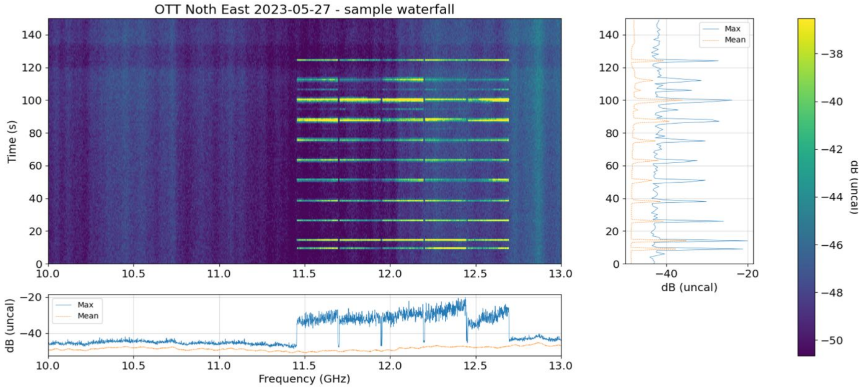
Satellites’ Impact on Space-based Astronomy

Satellite trails in HST individual exposures (Kruk et al. 2023, NatAs, 7, 262)

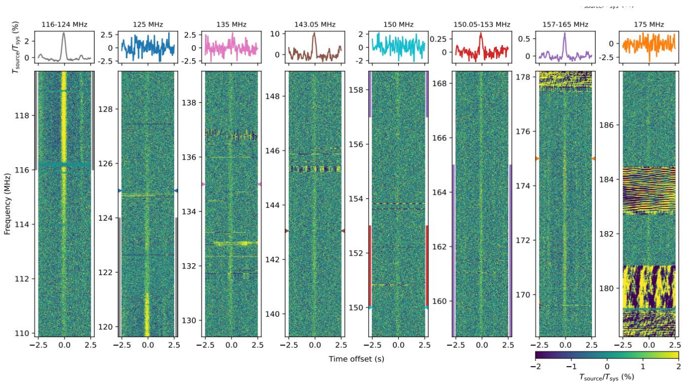


Radio Frequency Interference by Satellites

- ***Ultra-bright beams*** from satellite downlinks
- Unintended ElectroMagnetic Radiation (***UEMR***)
- LOFAR detected UEMR radiation between 110 and 188 MHz

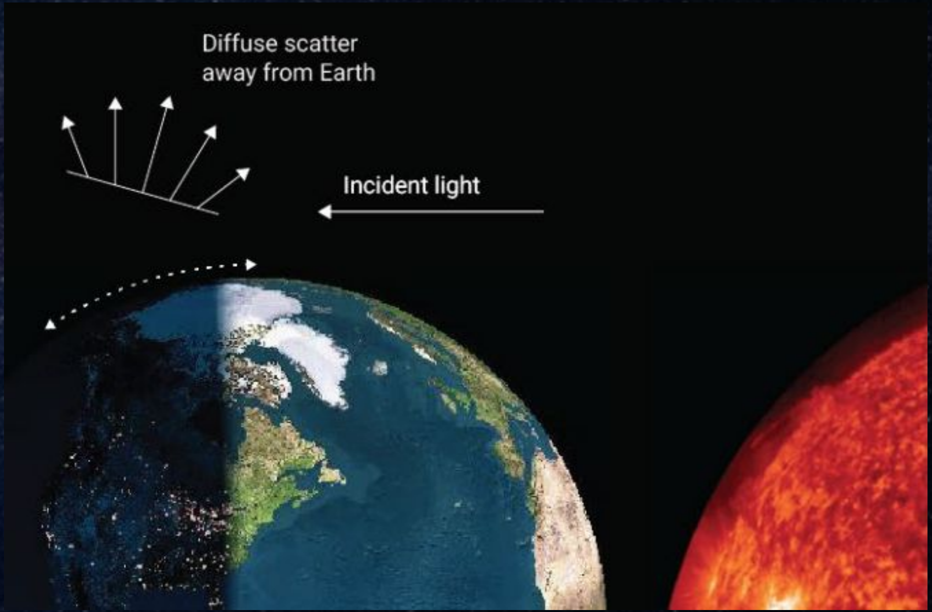


Top: Communication downlinks from satellites observed with Onsala Twin Telescopes (Hovey et. al.)



Left: Unintended Electromagnetic Radiation (UEMR) from satellites observed with LOFAR at 110-188MHz (Di Vruno et al.)

Mitigations by the Satellite Operators



- Fewer satellites
- Lower satellites
- Darker materials
- Directionally reflective coatings
- Attitude adjustment
- Sharing position data

The IAU response

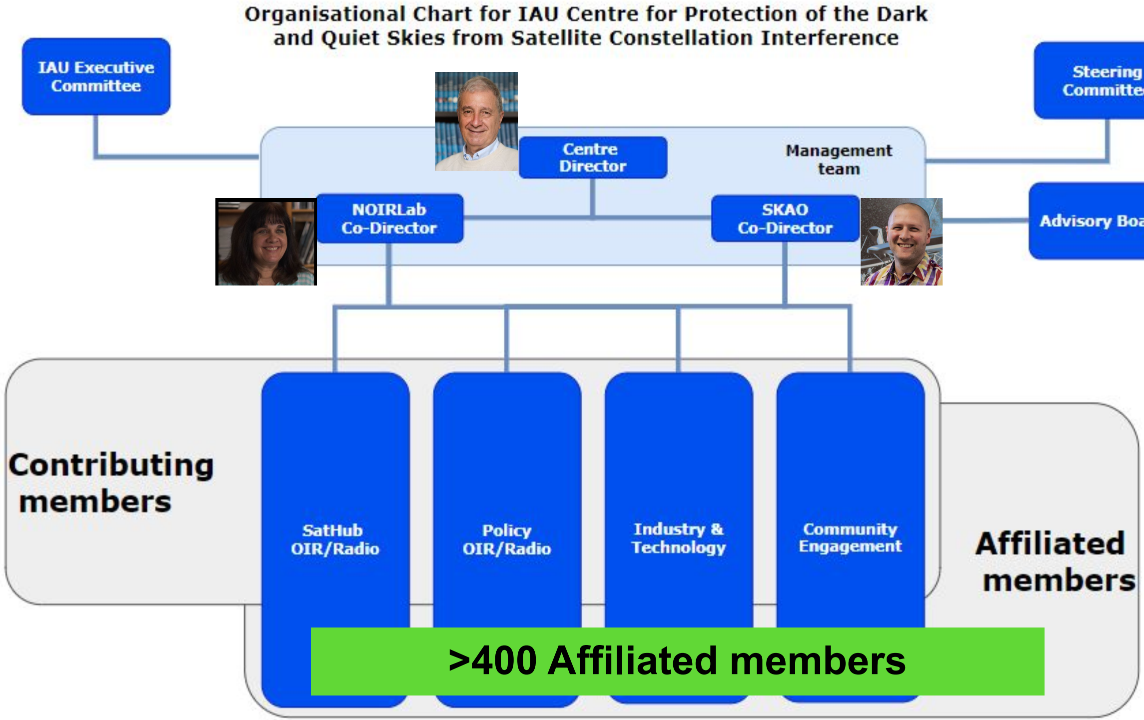
Promoting guidelines and regulations at the UN COPUOS level

Creation of the "IAU Centre for the Protection of the Dark and Quiet Skies from Satellite Constellation Interference (IAU CPS)"

Led by SKAO and NSF's NOIRLab:
Director Piero Benvenuti,
Co-directors: Connie Walker & Federico Di Vruno.

CPS organizes the energy of >400 members and the cooperation of industry through four Hubs.

IAU CPS Organization



Piero Benvenuti (Director)
Connie Walker (Co-Director)
Federico Di Vruno (Co-Director)
Meredith Rawls (SatHub)
Mike Peel (SatHub)
Siegfried Eggl (SatHub)
Chris Hofer (InTech Hub)
Tim Stevenson (InTech Hub)
Patricia Cooper (InTech Hub)
Jessica Heim (CE Hub)
John Barentine (CE Hub)
Andrew Williams (Policy Hub)
Aaron Boley (Policy Hub)
William McGinn (Project Manager)
Carolyn Crichton (Governance support)
Charles Mudd (Legal advisor)

SatHub: Satellite observation and data analysis hub

- Open source **software development and data repositories**, with substantial contributions from NOIRLab, SKAO, and others
- Volunteer-led **observations and research projects** on satellite constellation interference and mitigation **across the electromagnetic spectrum**
- A collaboration among pro astronomers, experienced amateurs, policymakers, industry experts, satellite operators, and more

Community Engagement Hub

IAU CPS’ bridge to the community of night sky users beyond professional astronomers.

Ensures all stakeholders’ voices are part of the broader discussion.

Objective 1

Create a venue in which all stakeholders may be heard and feel safe expressing their opinions and views

Objective 2

Manage that venue in a way that fosters respectful dialog among participants to promote the understanding of different and potentially opposing viewpoints

Objective 3

Over time, amass a set of stakeholder opinions as primary sources that we compare critically to find common themes

Objective 4

Use the materials, and the conclusions we draw from them, to inform the activities of the other CPS hubs and our communications with the public on relevant issues

Industry and Technology Hub

IAU CPS' arm to engage the technical insights of both satellite stakeholders and astronomers to build the tools and resources to spur voluntary adoption of mitigations

ENLIST

- **Recruit** satellite constellation operators, manufacturers, other stakeholders to participate and collaborate in the Hub to **develop and adopt solutions**

INFORM

- **Provide a flow of references** to the latest technical concerns, recommendations and best practices, and **identify available tools and resources** to assess and adopt mitigations

EXCHANGE

- **Facilitate dialogue among industry stakeholders** on mitigation techniques and their efficacy, and **promote innovative approaches and tools** that are accessible, affordable and effective

IAU NOIRLab SKAO

Policy Hub: Goals & Strategic Outcomes

1. **Raise awareness** of astronomy requirements in space policy-making circles
2. **Coordinate policy work** conducted by national societies and observatories
3. **Foster the development of better regulation**, in coordination with national points of contact
4. **Coordinate spectrum management processes,** along with emerging optical-related issues
5. Identify **future threats**

Astronomy community acts together with aligned messages

We produce policy outputs and contribute to policy change

Industry is aware of the issue and of the solutions

Policy makers are aware of the issue and of the solutions

Establishment of Group of Friends (GoF) of DQS

- UN COPUOS Delegations and Observers:
  - Belgium, Bulgaria, Chile, Colombia, Germany, Italy, Luxembourg, Mexico, New Zealand, Rumania, Slovakia, South Africa, Spain, Switzerland, UK, USA
  - COSPAR, EAS, ESO, IAA, IAU, SKAO

- Aims of the Group of Friends:
  - Promote awareness
  - Support/Review best practices and mitigation suggestions
  - Discuss the overall implications of the adoption of mitigating measures
  - Discuss approaches for coordination between the various stakeholders

- CPS serves as the secretariat and provides astronomy input
- GoF webpage: https://cps.iau.org/group-of-friends/

UN Committee on the Peaceful Use of Outer Space (COPUOS)

- In June 2024, UN COPUOS agreed to include the item "Dark and Quiet Skies, Astronomy and Large Constellations: addressing emerging issues and challenges" on the agenda of its Science and Technology Subcommittee (STSC) from 2025 to 2029.
- IAU CPS, GoFs, and many sponsors were behind this achievement


United Nations Agrees to Address Impact of Satellite Constellations on Astronomy

2024년 2월 15일

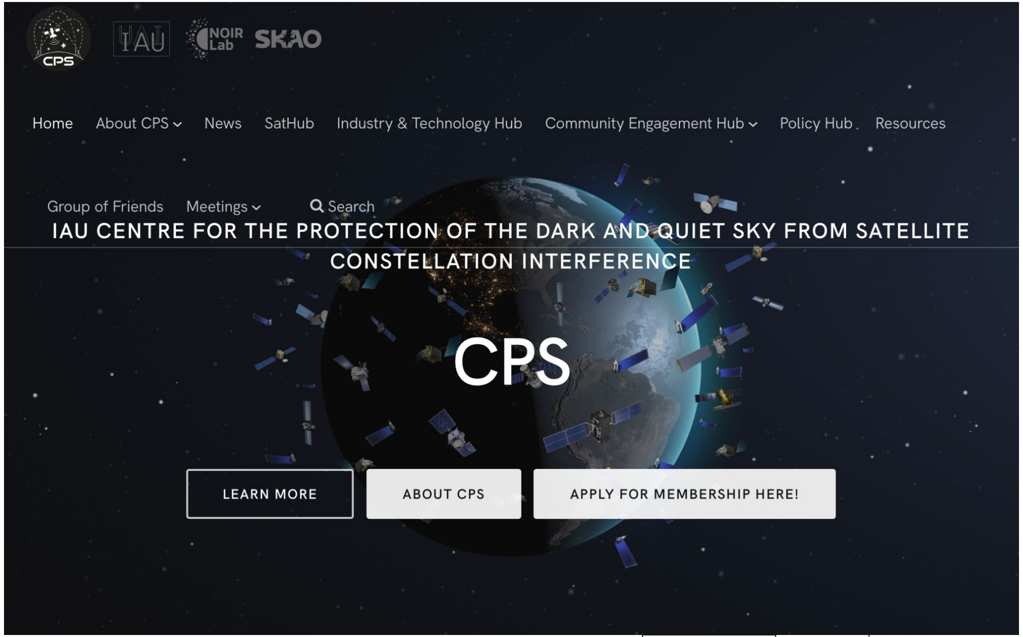
After several years' work by astronomers affiliated with the IAU CPS, a key UN body agreed last week to put on their agenda the issue of satellite constellations' impact on astronomy.

Take Home Messages

- Sustainable use of outer space is a key to the future
- Reducing the visibility of satellites is an integral part of sustainable use of the outer space
  - For the benefit of Astronomy and Space Science
  - For the benefit of Cultural Heritage of Humanity
  - For the benefit of Space Environment
- Careful control of radio frequency emissions and projection is essential for preserving a vital radio astronomy enterprise
- Technical innovation to reduce the visibility, and to control the radio frequency interference of satellites may contribute to the space technology development

IAU CPS Welcomes Your Participation

- Contact us via info@cps.iau.org



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)

The IAU CPS SatHub

IAU CPS SatHub co-leads:

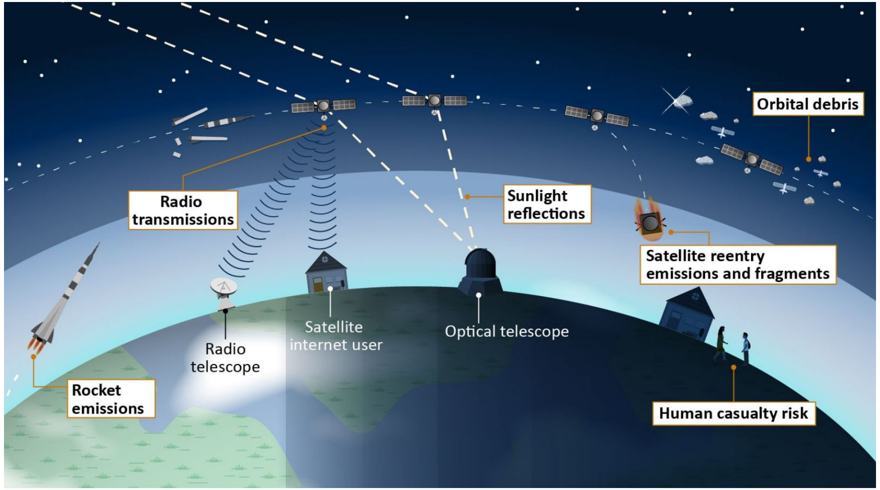
Meredith Rawls
U. Washington

Mike Peel,
Imperial College
London

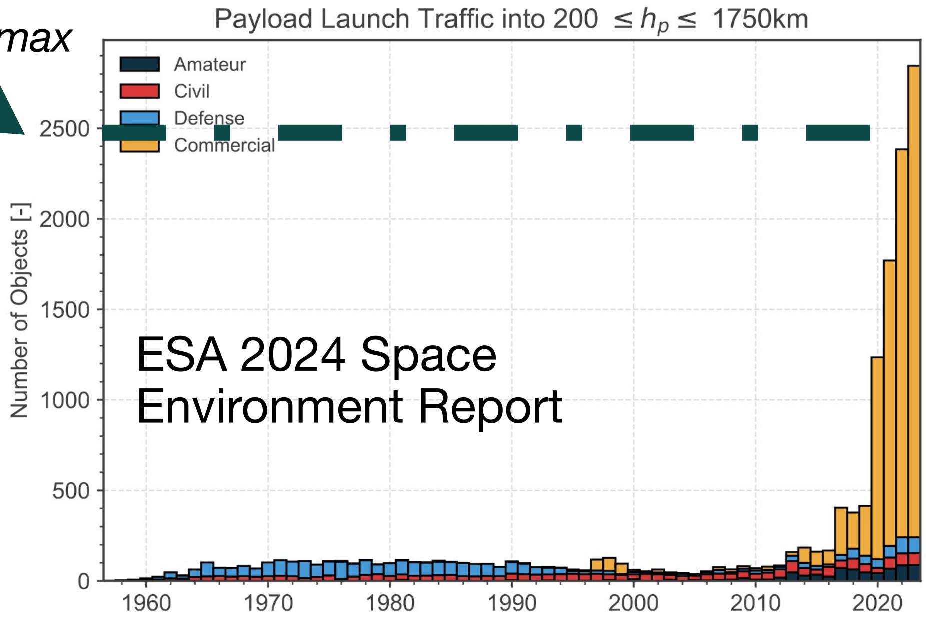
Siegfried Eggl,
U. Illinois

A new era for low-Earth orbit (LEO)

GAO-22-105166



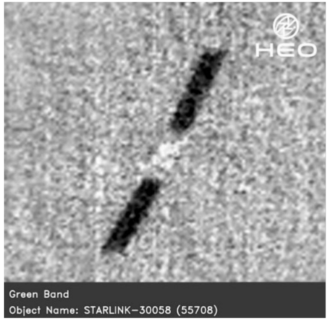
Last year's plot y-max

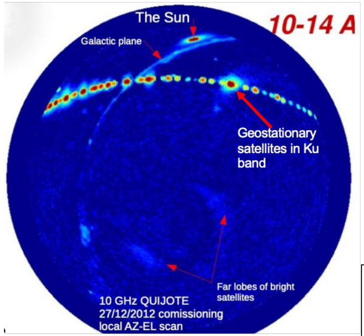


- Commercial LEO satellites reflect the full sunlight spectrum and emit in radio
- Most numerous near twilight but can be visible all night

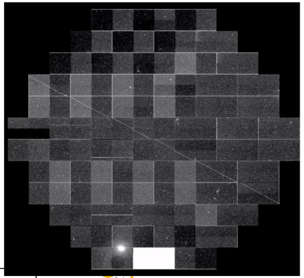
The IAU CPS SatHub

- **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.**



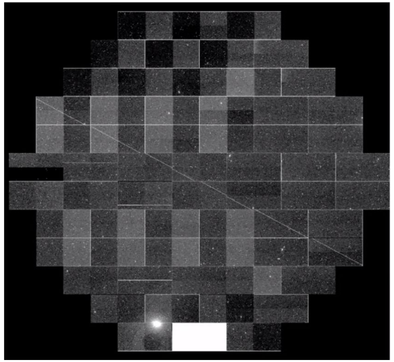


Source: Robert Watson / JBCA - Mike Peel / IAC



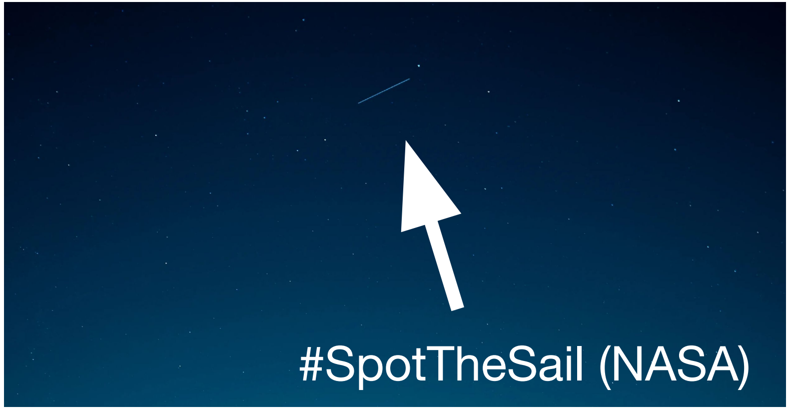
IAU CPS SatHub Aims

- **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?)



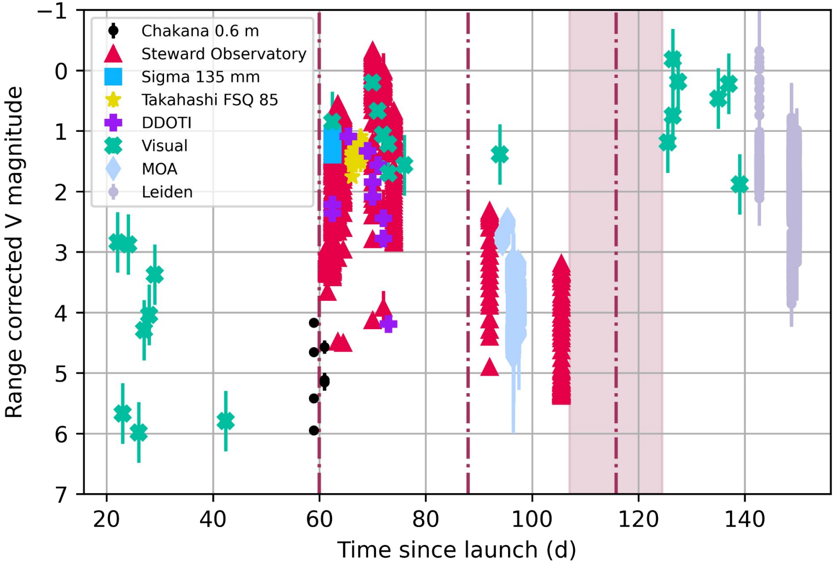
#SpotTheSail (NASA)

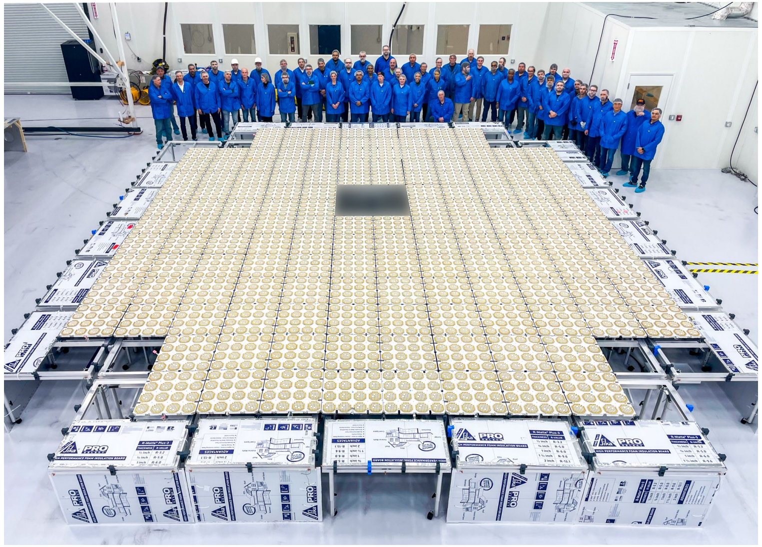
Starlink V2 mini direct-to-cell (Tom Williams)

BlueBird rendition (AST SpaceMobile)

IAU NOIRLab SKAO

BlueWalker 3



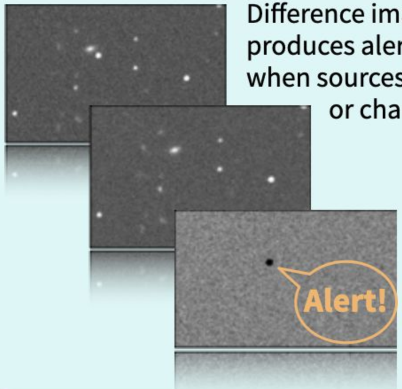


- 64m^2 phased array, prototype for mobile phone connections using standard phones + satellite
- Optically brighter* than Vega and all except top 10 stars (~99% of >mag6) (Nandakumar et al., Nature, 2023)
- (+ launch vehicle adapter bright & untracked for first few days, + position predictions degrade 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



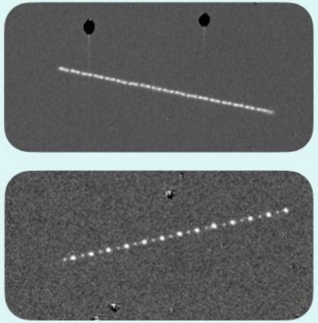
Difference imaging produces alerts when sources move or change

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

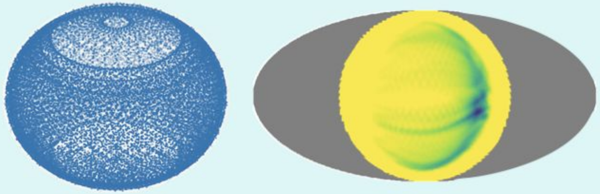
The LSST Science Pipelines will find and label streaks and glints in difference images — without discarding any pixel data — to help distinguish satellites and debris from astrophysical sources

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

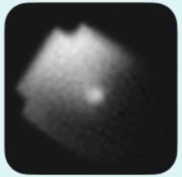


Prototype glint detection works on ATLAS data — A. Heinze

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



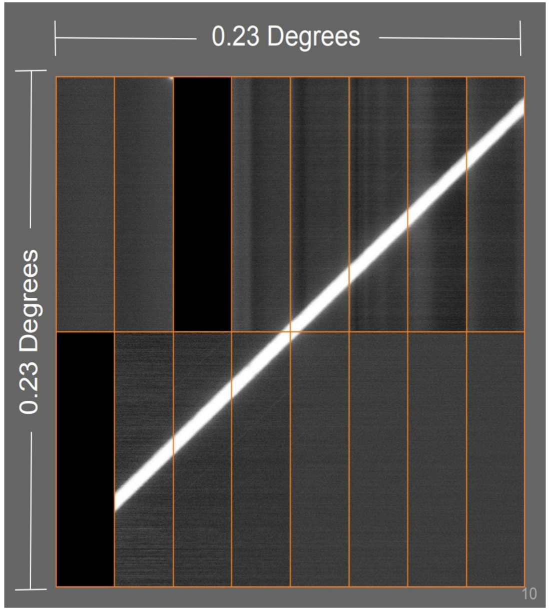
Large satellites like BlueWalker 3 can exceed 0th mag — Nandakumar+2023 (Photo: M. Tzukran)



Portion of Ivezić & Rawls IAU GA 2024 poster

Rubin Observatory CCDs

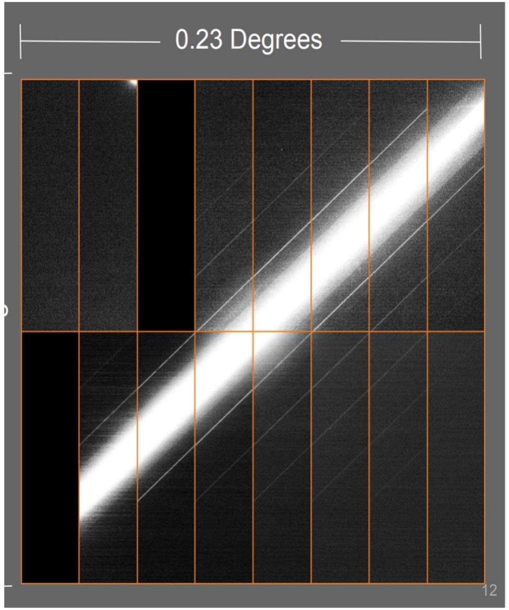
IAU CPS recommendation



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

Faint brightness science affected

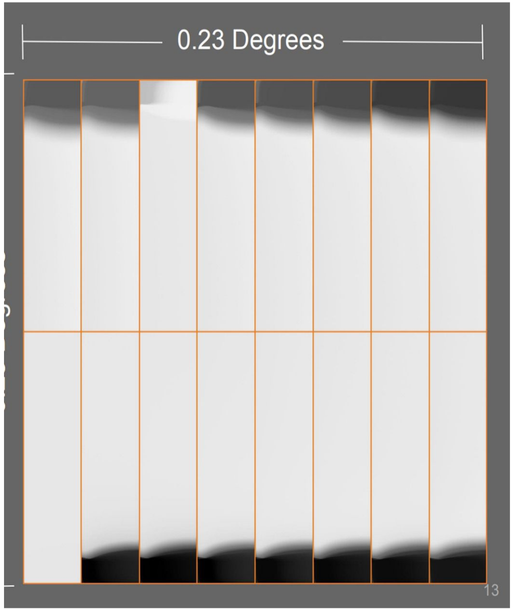
Current Starlinks



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

Most science programs affected

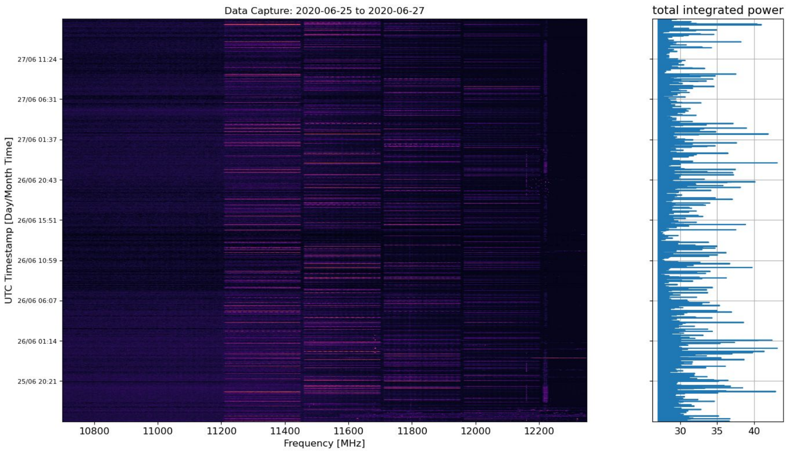
BlueWalker 3

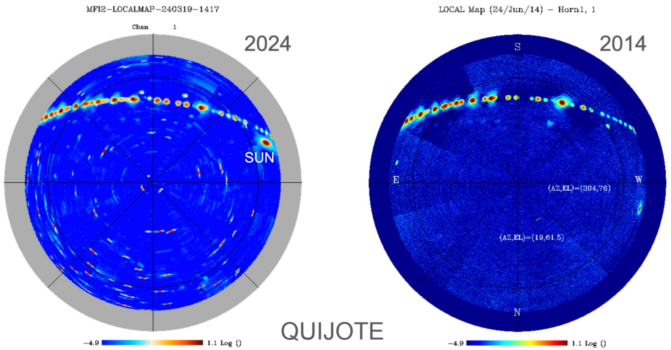


Blooming/ Not Correctable =
1 Million electrons = 0-1 Mag

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

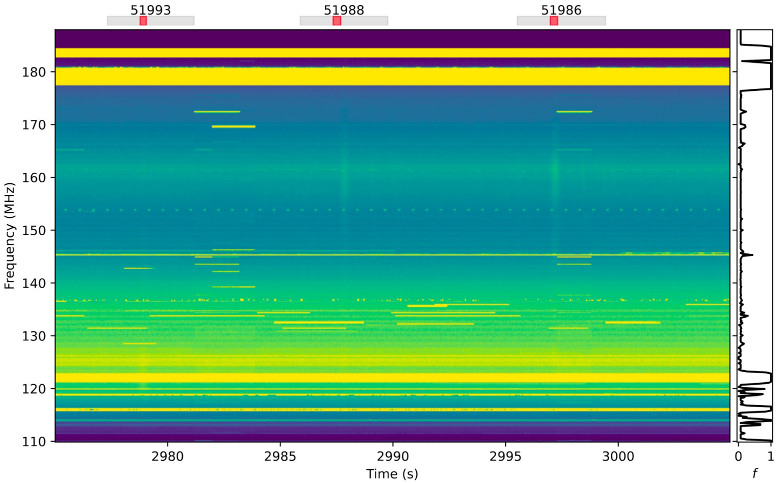


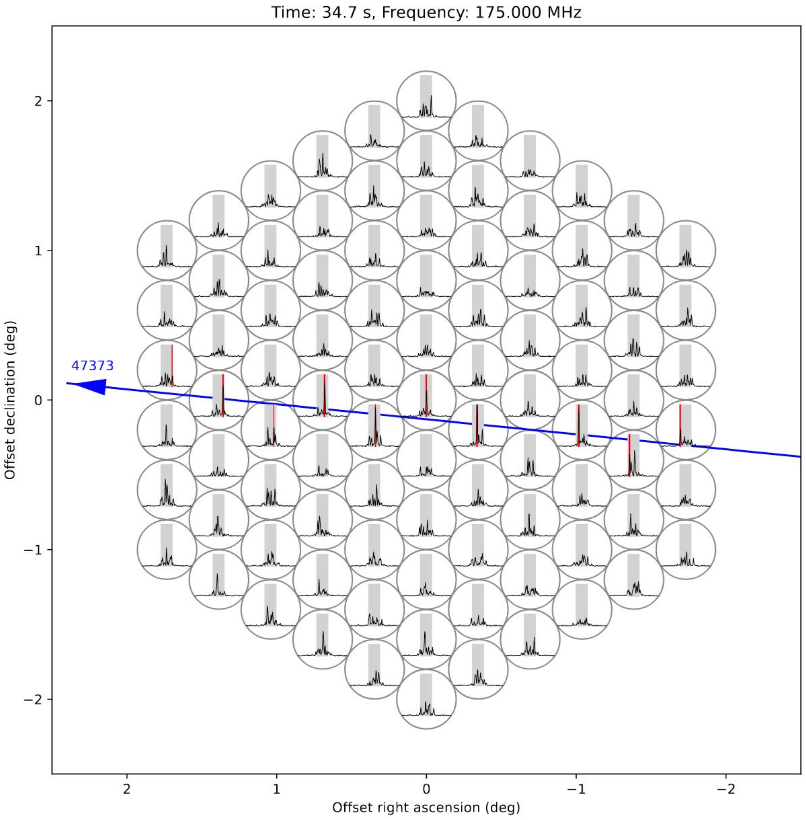


Above: QUIJOTE 10-14GHz observations from Tenerife in 2014 and 2024
Left: satellite dish observations, F. Di Vruno

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!



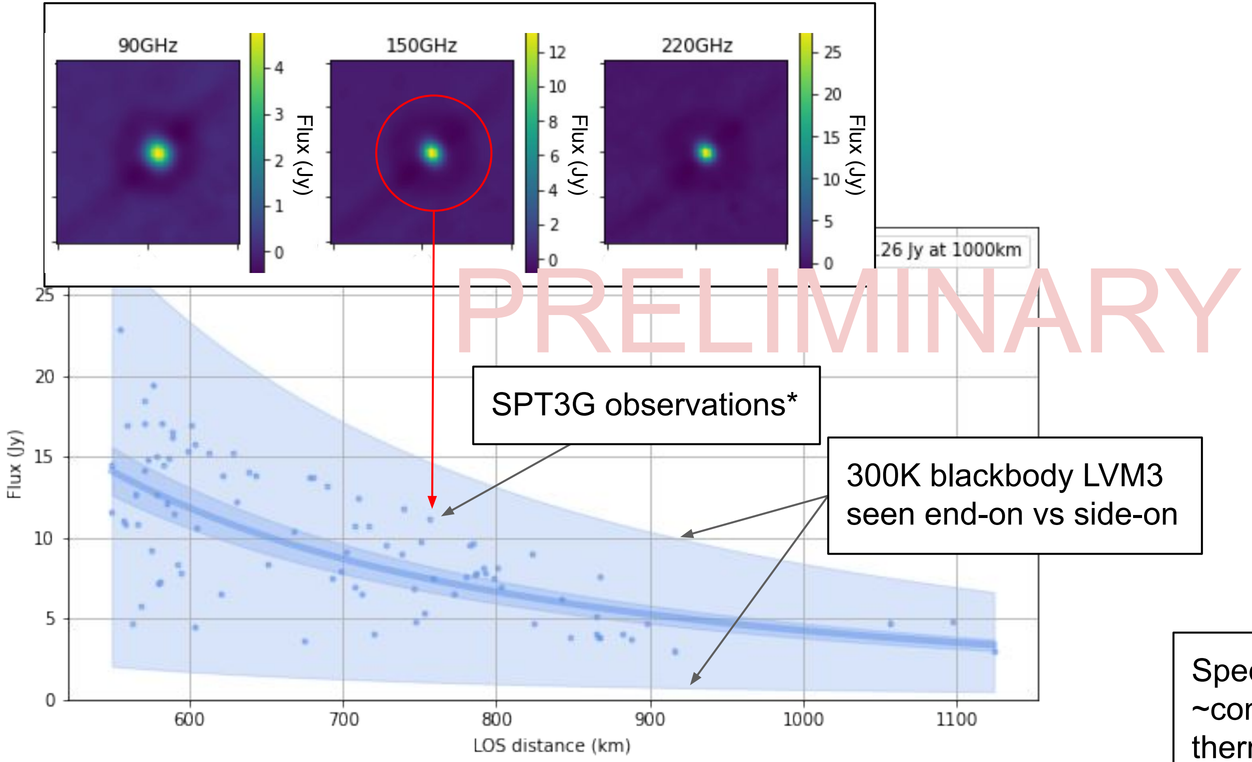


SKAO

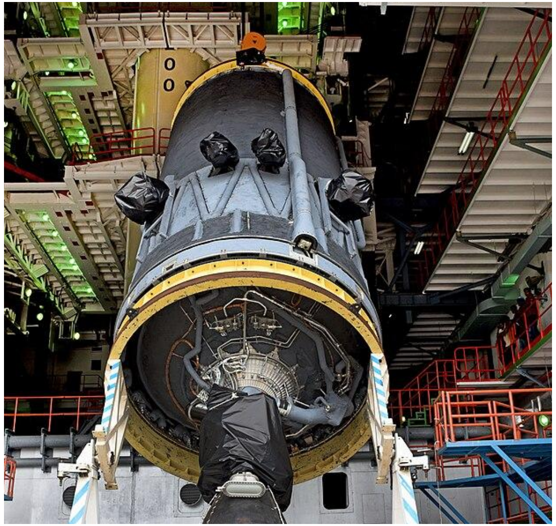
Thermal Emission

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

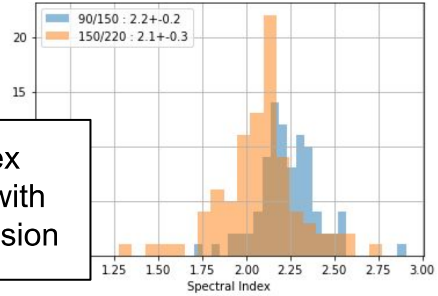
Even if not actively emitting RF signal, satellites can be millimeter bright!



* 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

SatChecker

latest

Search docs

EPHEMERIS API
- Ephemeris API
- Error Codes
- Notes

EXAMPLES
- URL Examples
- Example Notebook

DEVELOPMENT
- Release History
- Acknowledgements

/ SatChecker Ephemeris API Documentation — Edit on GitHub

SatChecker Ephemeris API Documentation

SatChecker is a satellite position prediction tool from the IAU CPS (IAU Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference) SatHub group. It uses TLEs (two-line element sets) from CelesTrak and Space-Track to provide predictions of satellite positions at a given time and location. It also provides additional information like range, on-sky velocity, and an “illuminated” flag for each prediction point.

SatChecker uses the TLE with the closest epoch date available to the date specified in the API parameters - currently available TLEs go back to October 2023.

Next

Built with Sphinx using a theme provided by Read the Docs.

Satellite position lookup tool
satchecker.readthedocs.io

Satellite Constellation Observation Repository (SCORE)

← Back to Satellites Page

Satellite Details

KUIPER-P2

NORAD ID: 58013 — **RCS Size:** N/A — **Launch Date:** N/A

COSPAR ID: N/A — **Object Type:** N/A — **Decay Date:** N/A

Observation Summary

Number of Observations: 53 — **Most Recent Observation:** Aug. 15, 2024

Average Magnitude: 4.515094 — **First Observation:** Feb. 9, 2024

Date added	Name	NORAD ID	Date observed	Mag	Latitude	Longitude	Altitude	Obs. mode	Observer ORCID
Aug. 15, 2024 02:59 AM	KUIPER-P2	58013	Aug. 15, 2024 02:23 AM	5.5000	36.1280	-95.9880	201	VISUAL	0000-0001-6268-7790
Aug. 15, 2024 02:59 AM	KUIPER-P2	58013	Aug. 15, 2024 02:23 AM	4.5000	36.1280	-95.9880	201	VISUAL	0000-0001-6268-7790
Aug. 15, 2024 02:59 AM	KUIPER-P2	58013	Aug. 15, 2024 02:23 AM	4.8000	36.1280	-95.9880	201	VISUAL	0000-0001-6268-7790
Aug. 15, 2024 02:58 AM	KUIPER-P2	58013	Aug. 15, 2024 02:23 AM	4.9000	36.1280	-95.9880	201	VISUAL	0000-0001-6268-7790
Aug. 15, 2024 02:58 AM	KUIPER-P2	58013	Aug. 15, 2024 02:22 AM	5	36.1280	-95.9880	201	VISUAL	0000-0001-6268-7790

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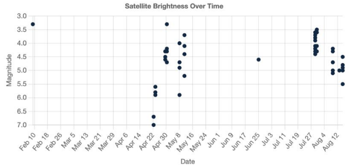
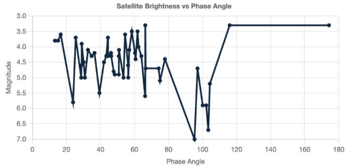
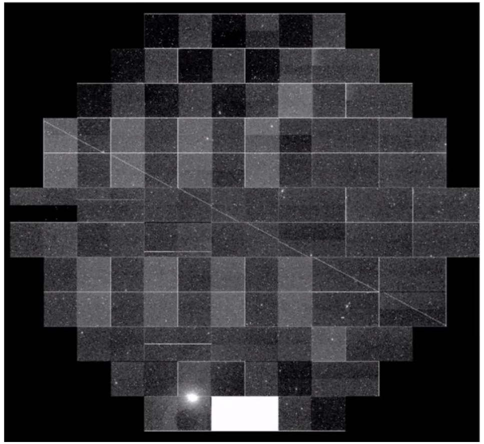




Example SCORE satellite detail page (see Dadighat et al. 2023)

SWIFT-SAT software development

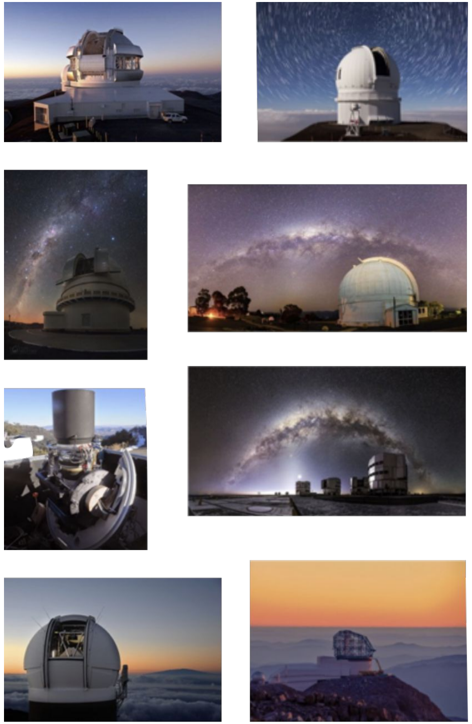
- NSF SWIFT-SAT $750k award funds development of satellite position and brightness forecasting tools and measuring some LSST science impacts (C. Walker, T. Tyson, S. Eggl, M. Rawls, M. Dadighat, w/Aerospace Corp)
  - **Field-of-view pass prediction tool** powered by high accuracy vector covariance messages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