

# The impact of satellite constellations on astronomy

Mike Peel

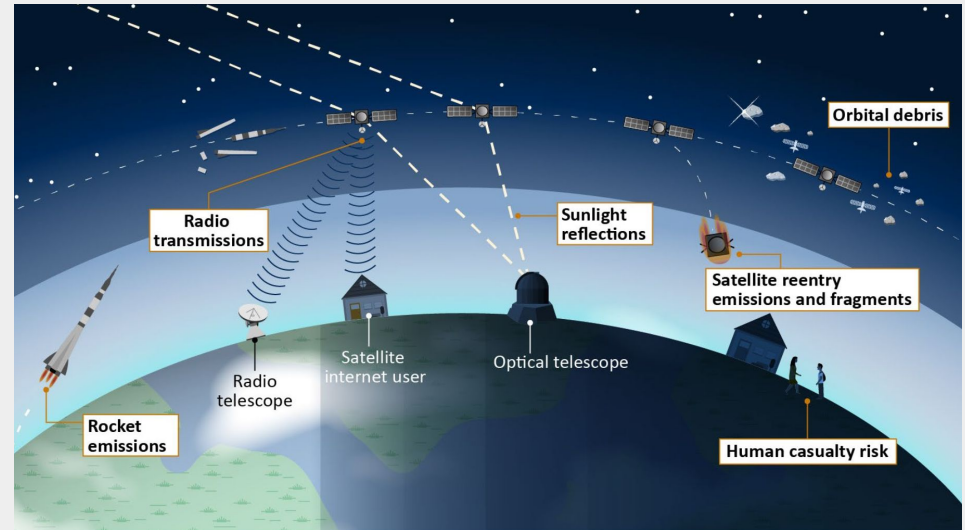
Postdoc, Imperial College London  
Co-lead, SatHub, IAU CPS

25 April 2026



# Overview

1. Introduction to satellites
2. Optical impact
3. Radio impact
4. Mitigations
5. IAU CPS
6. Policy
7. How you can help!
8. ... more coming ...
9. Conclusions



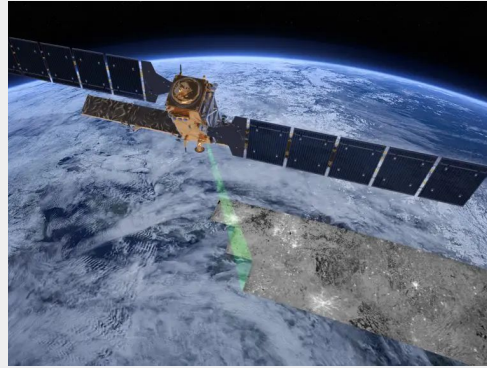
# Introduction to satellites



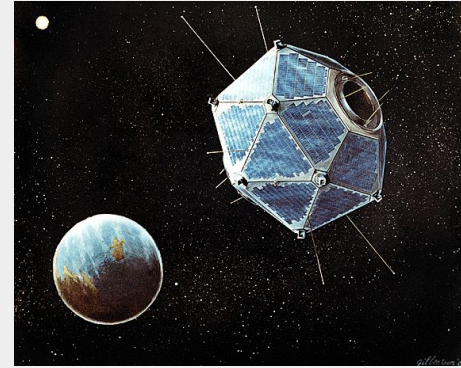
# Satellites are useful...!



Telecommunications

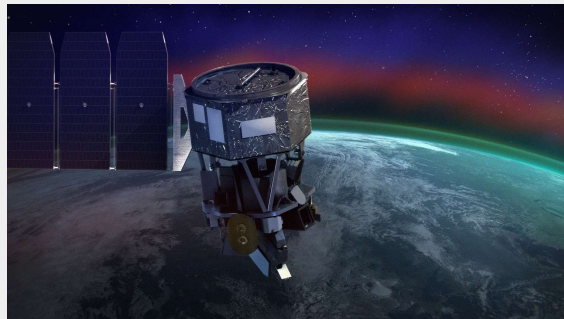


Earth observation



Military applications

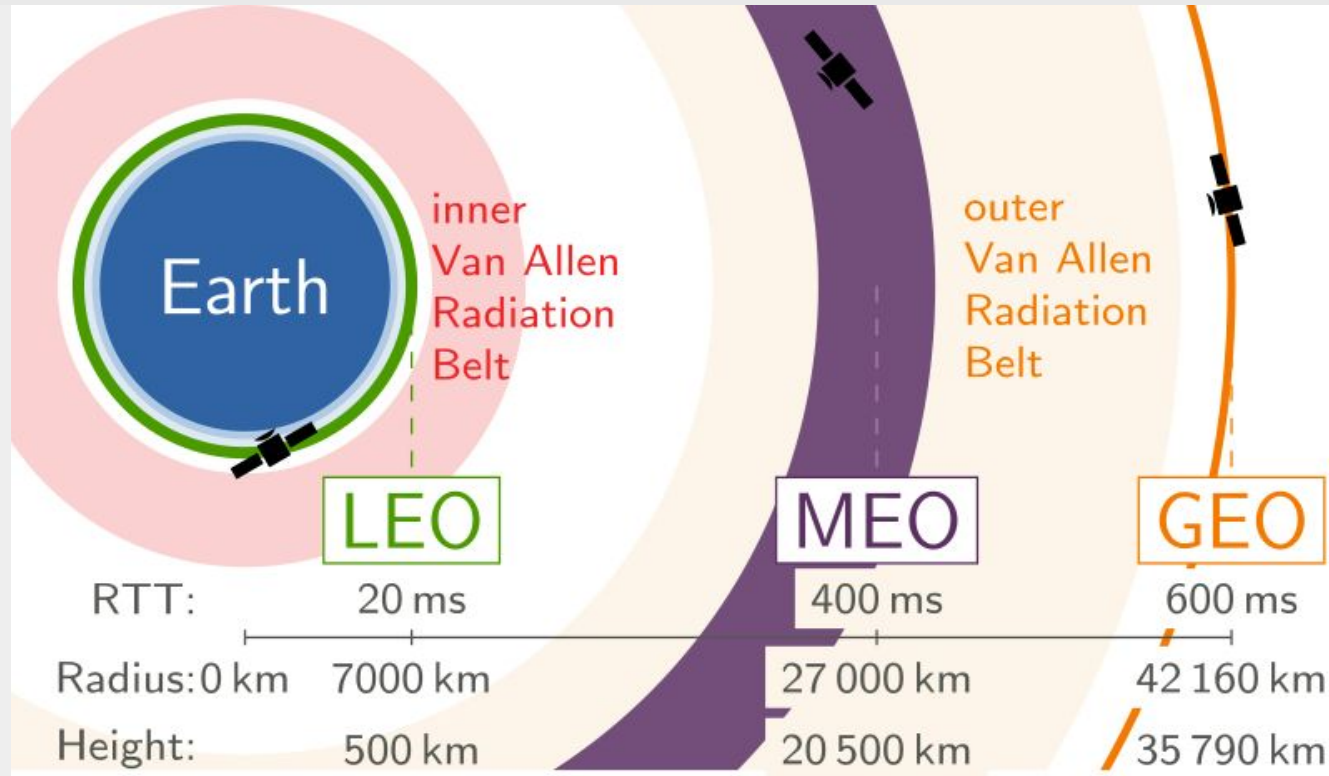
Weather forecasting



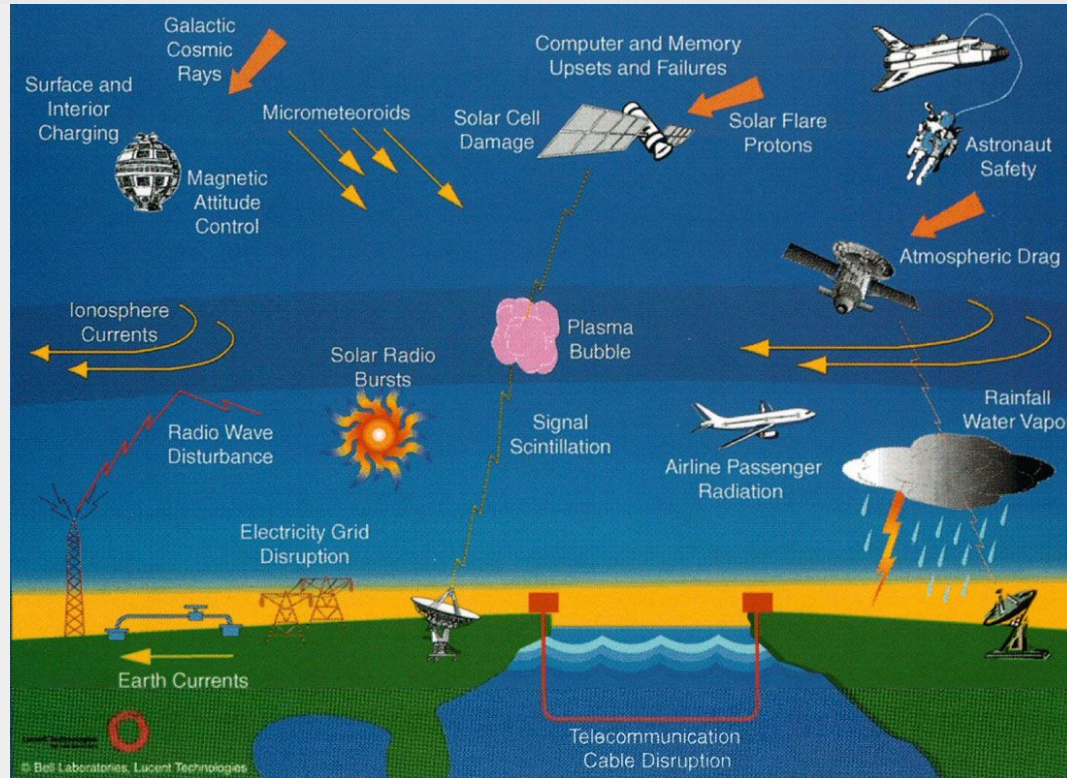
Space science

# Different orbits

Sedrupal, CC-BY-SA 4.0, Wikimedia Commons



# The space environment



Adapted from  
Lanzerotti et al. 1999

# Re-entry risks...



Ko Maung Myo/Myanmar Times



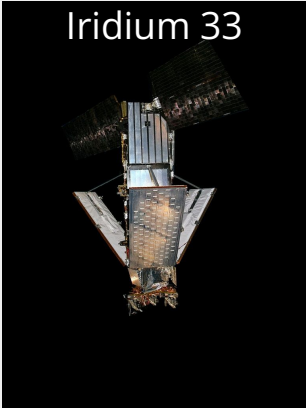
SpaceX Dragon capsule bits landed in Saskatchewan



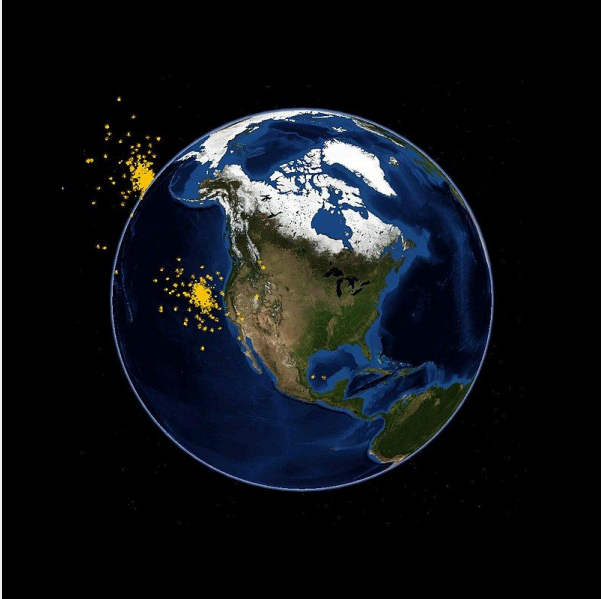
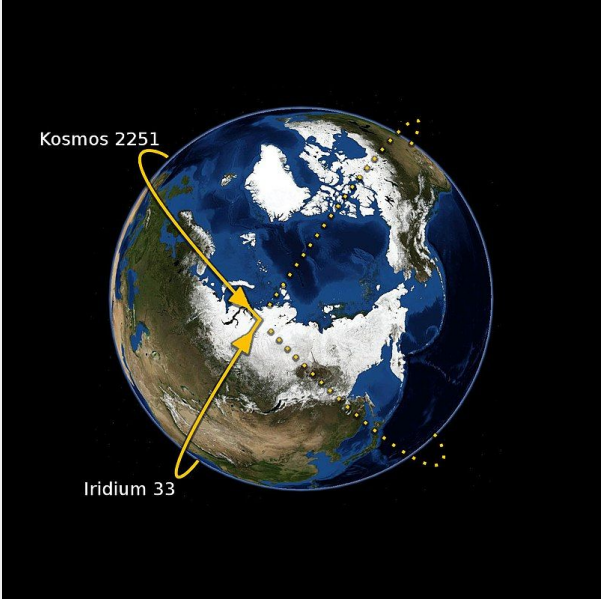
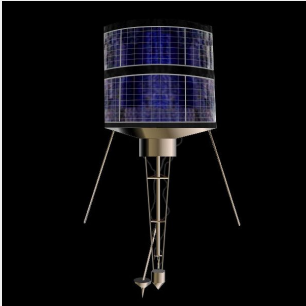
ESA/NASA



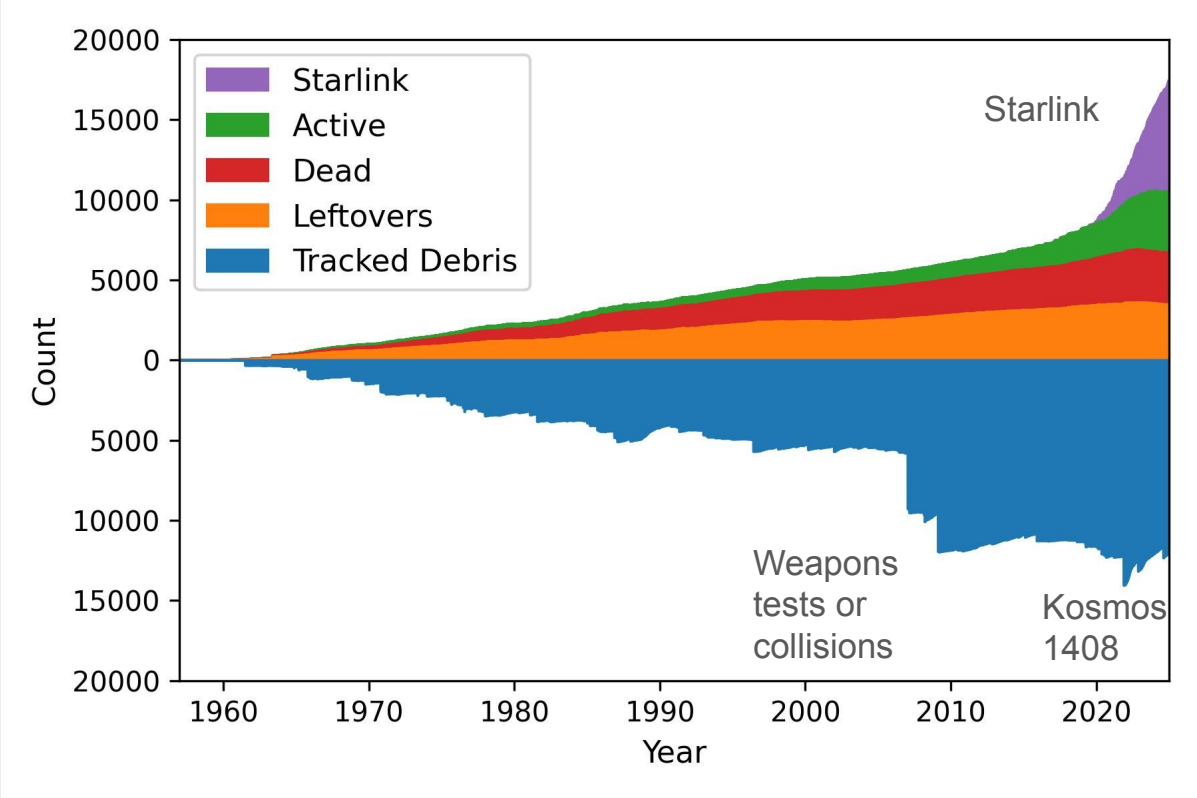
# Orbital collisions



*10 February 2009 direct collision*

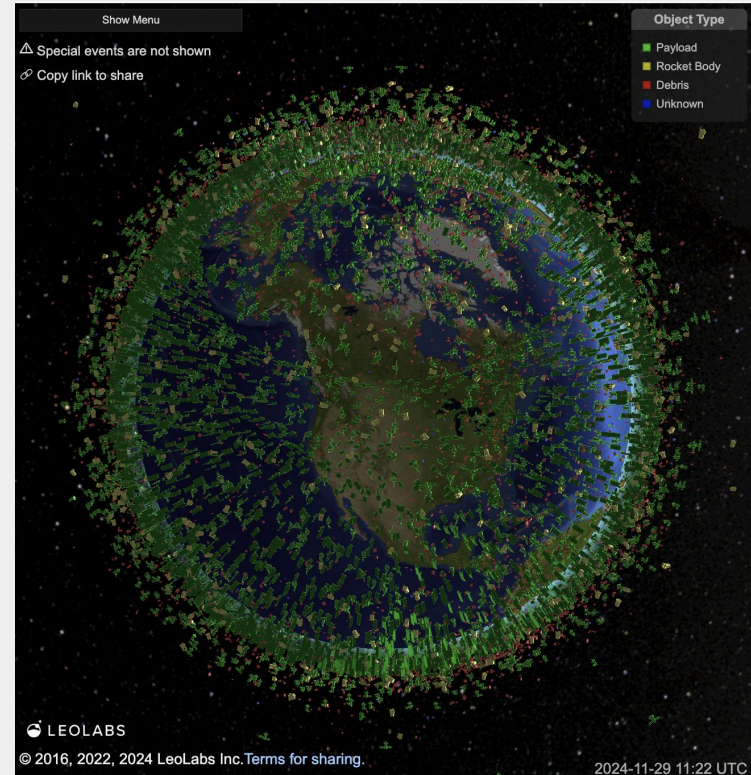


# Increasing numbers of satellites



# Space is changing rapidly

- 15,000+ satellites in Low Earth Orbit (10,000 of which are Starlink...!)
- Plans for > 3,000,000 satellites by 2030s
- Major concerns:
  - Effects on optical astronomy
  - Effects on radio astronomy
  - Effects on the night sky
  - Space traffic management
  - Space debris



# Many different satellite constellations

- Starlink (US, ~10,000 satellites, ~35k more expected)
- OneWeb (UK/EU, ~650 satellites, Gen 1 completed, Gen 2 coming...)
- Amazon Leo (was Kuiper) (US, ~240 satellites launched, many more coming)
- AST SpaceMobile (US, 6 so far, ~200 expected)
- Qianfan (China, ~120, many more coming)
- Guowang (China, ~100, many more coming)
- ...

# How do satellites affect astronomy?

\*Not to scale - for illustration purposes only

## Reflecting sunlight

Because of their altitude, satellites can reflect sunlight down to locations on Earth where the Sun has already set – when optical telescopes are observing. How bright these reflections are depends on the satellites' orientation, size, material and reflectivity.

## Changing the night sky

Casual stargazers, astrophotographers, and Indigenous communities that have observed the night sky for generations are seeing increasing numbers of satellites, altering their view of pristine night skies.

## Radio emissions

Even during the day, satellites can interfere with radio telescopes on Earth due to the very bright signals they emit to transmit information, but also due to unintended electromagnetic radiation leaking from their onboard electronics.



# Optical impact



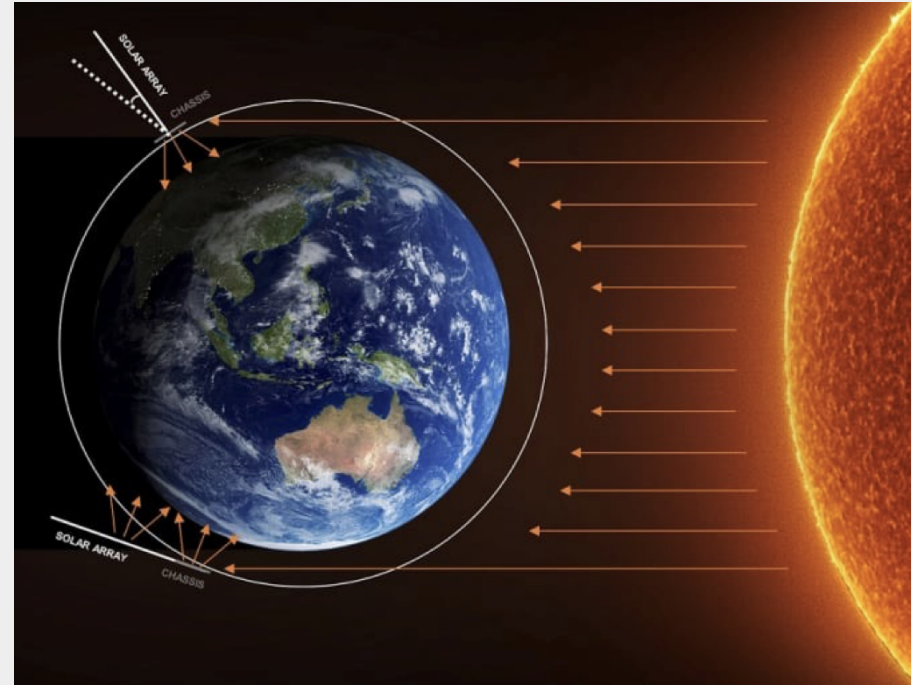
# Impact on the night sky



Pentre Ifan burial chamber, Pembrokeshire, Wales - Max Alexander “Our Fragile Space”

# Satellites during twilight

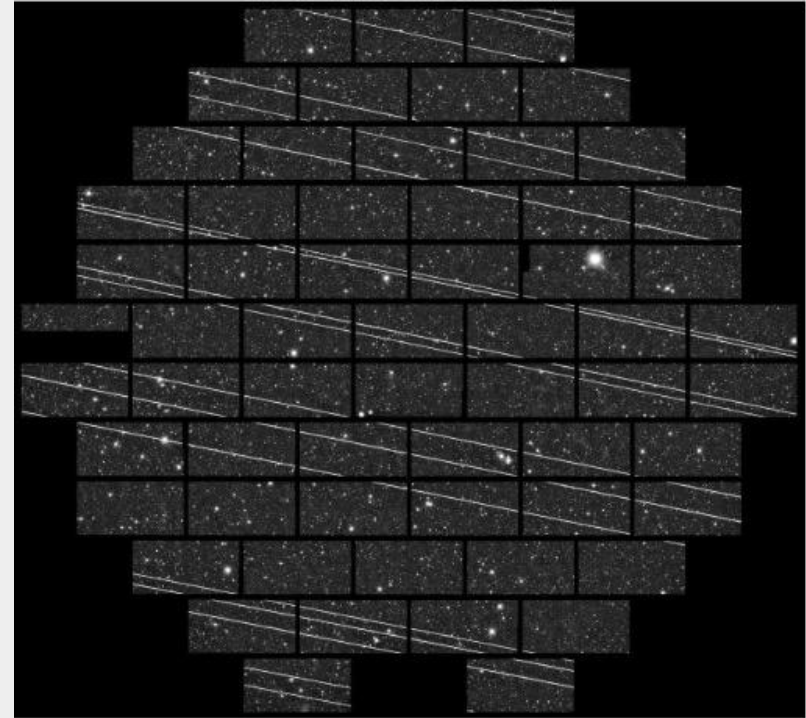
- Sunlight can be reflected by satellites' bodies in a diffuse way
- Depends on: area, materials, altitude, attitude, ...
- Brighter than magnitude 7 is visible with the naked eye
- Brightest during early evening and early morning



Credit: SpaceX

# Effects on optical astronomy

- Satellite streaks can cause unusable data
- Impacts to science include:
  - Asteroids: best time to spot them is during twilight
  - Variable stars: lost time series
  - Dark Matter weak lensing: subtle distortions to the shapes of galaxies
  - Spectroscopy: contamination by reflected sunlight
  - Extreme brightness can cause damage to optics



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

# Impact on optical observatories

- **Narrow field**
  - Gemini, Keck, ESO's VLT, ELT
  - ~10% of frames at the end of astronomical twilight
- **Wide-field**
  - Blanco, VST
  - 50% of frames during twilight
- **Super-Wide-field:**
  - NSF-DOE Vera C. Rubin Observatory
  - ~ all image frames during twilight
  - Many frames - during whole nights



Credit: NOIRLab

# Accidental optical light

Up to  $V=3$  in parking orbits. **Need 7th magnitude** or better (higher magnitudes are fainter).

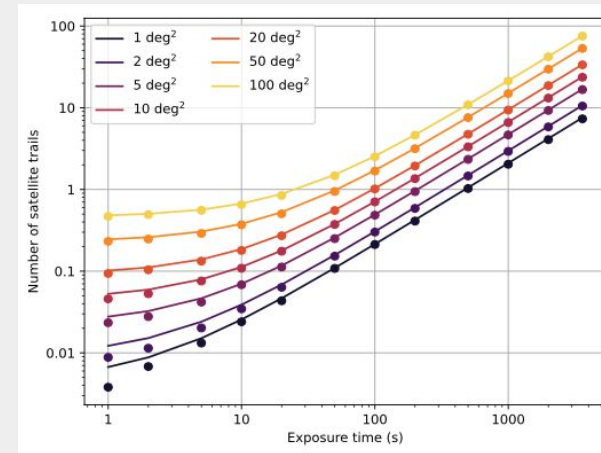
Significant effect on future optical telescope surveys like LSST with Vera C. Rubin Observatory. Even seen with Hubble...

Starlink satellite size has been limited by Falcon 9 rocket, but Starship will enable them to launch more, bigger ones soon - hopefully with improved mitigations...

Satellite	Operational altitude [km]	Mag at op. alt.	Mag dispersion	Mag at 1000km
Starlink original	550km	4.6	0.7	5.9
		4.0	0.7	5.3
		4.2	(model)	5.5
Starlink DarkSat	550km	5.1	(single)	6.4
Starlink VisorSat	550km	6.2	0.8	7.5
OneWeb	1200	5.8	0.6	7.1
		7.6	0.7	7.2

Bassa et al.  
arXiv:2108.12335

## SATCON2 algorithms report



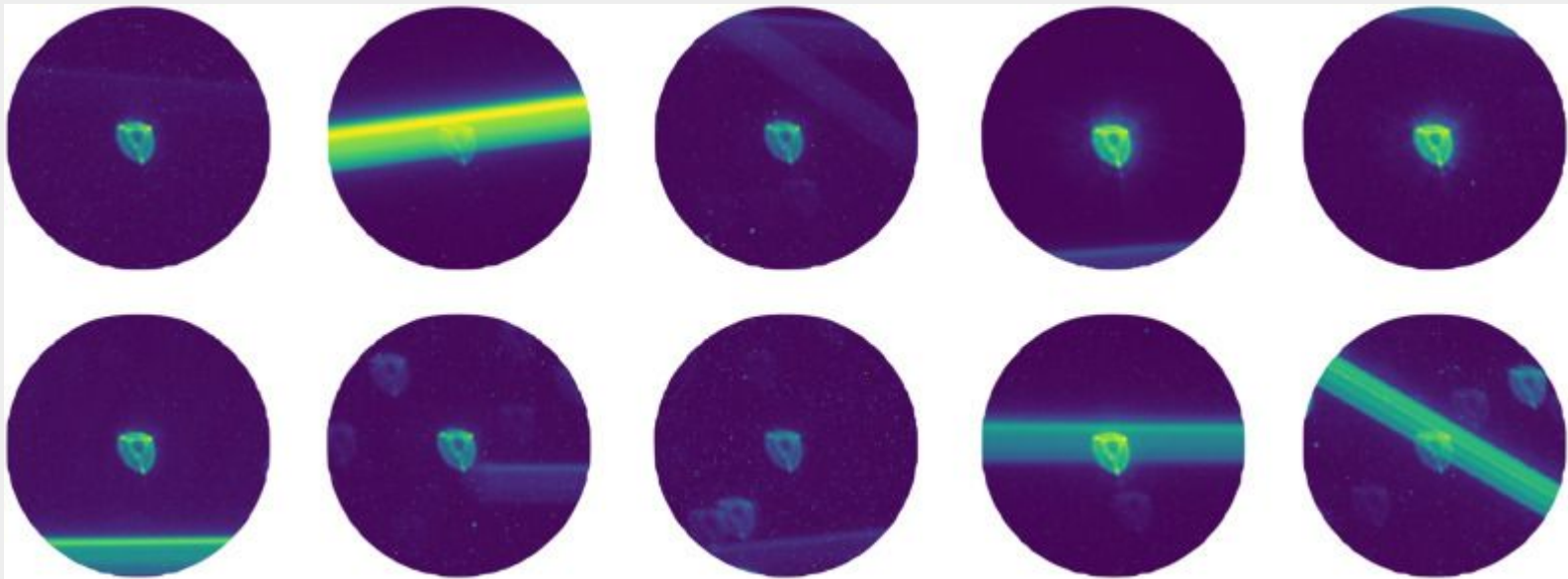
# Satellites' Impact on Space-based Astronomy

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



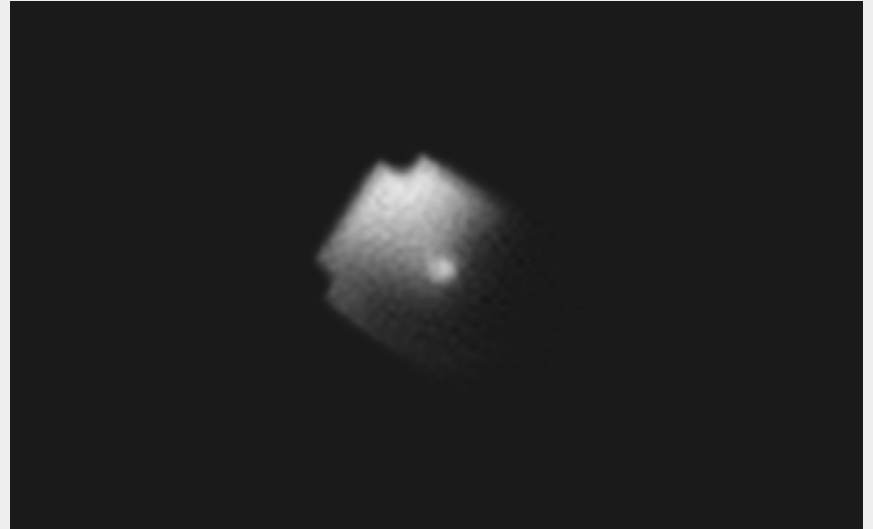
# Satellites' Impact on Space-based Astronomy

Satellite trails in CHEOPS data (Billot et al. 2024, J. Space Safety Engineering, 11, 498)  
(central star deliberately defocused)

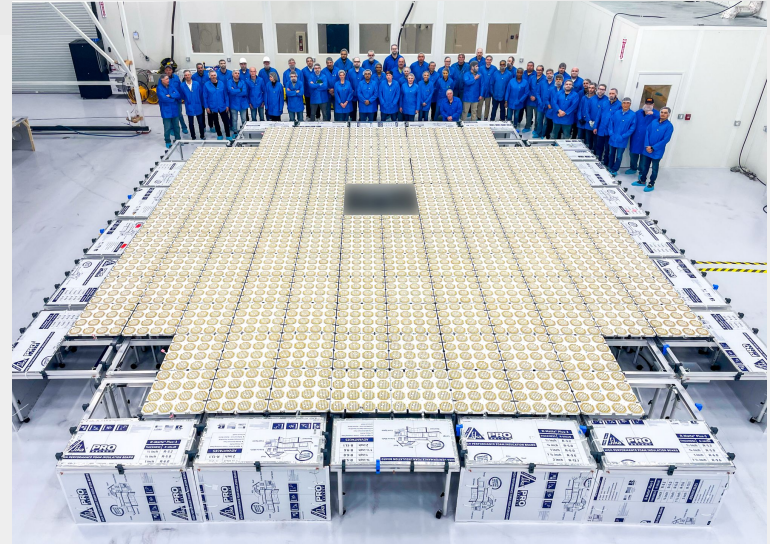
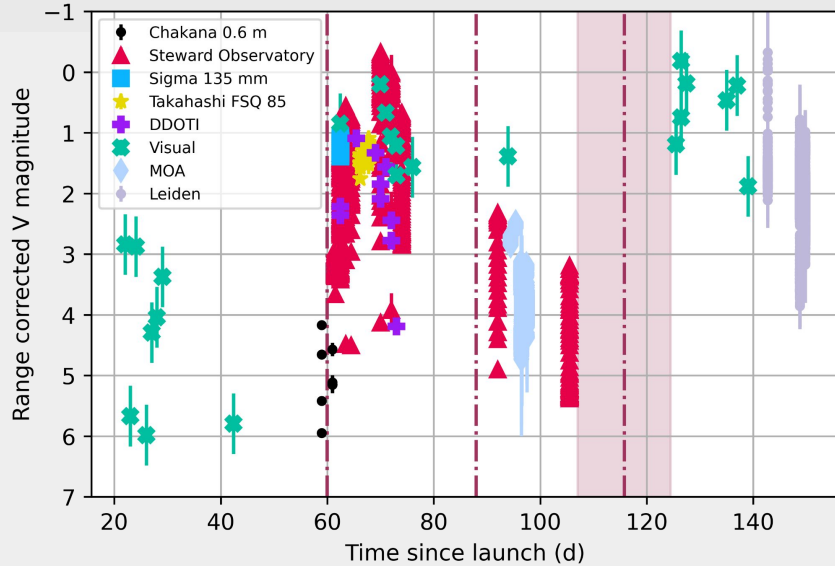


# AST SpaceMobile Bluewalker 3 observations

- Launched 10 September 2022
- Observations by CPS members
- Apparent magnitude 0.4
- CPS recommendations are maximal brightness of 7
- Extra bright due to its phased array of antennas (8x8m white platform)
- AST SpaceMobile working to address concerns (but FCC just approved 248 even larger satellites)



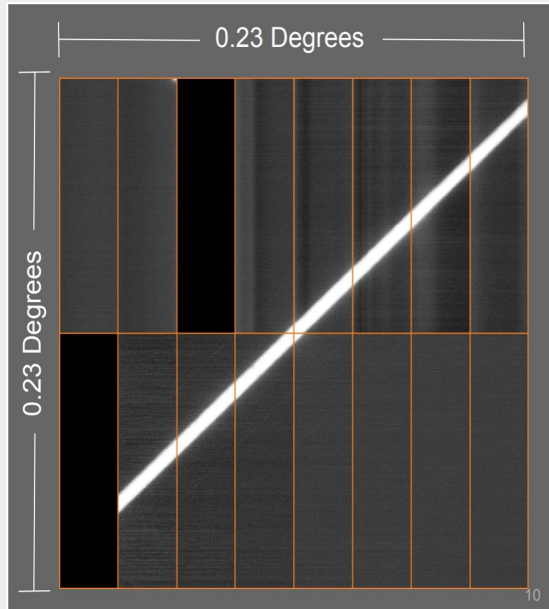
# BlueWalker3: optical bright, also thermally bright?



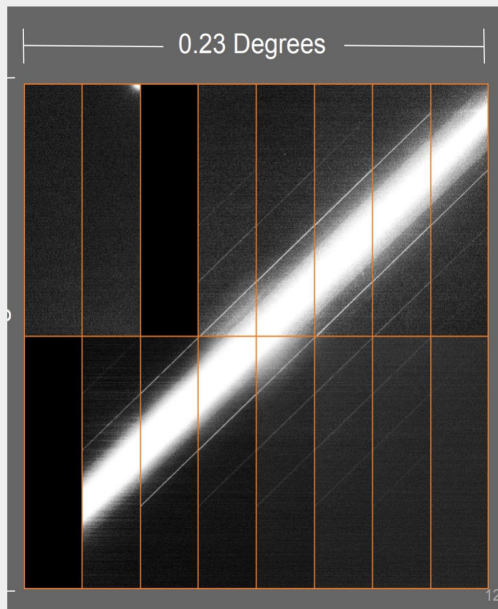
- $64m^2$  phased array, prototype for mobile phone connections using standard phones + satellite
- Optical measurements show it to be brighter than all except top 10 stars (Nandakumar et al., Nature, 2023)
- (+ launch vehicle adapter bright & untracked for first few days, + position predictions degrade over time)
- Thermal brightness unknown, but seeing satellites a lot with Cosmic Microwave Background telescopes...

# Rubin Observatory CCDs

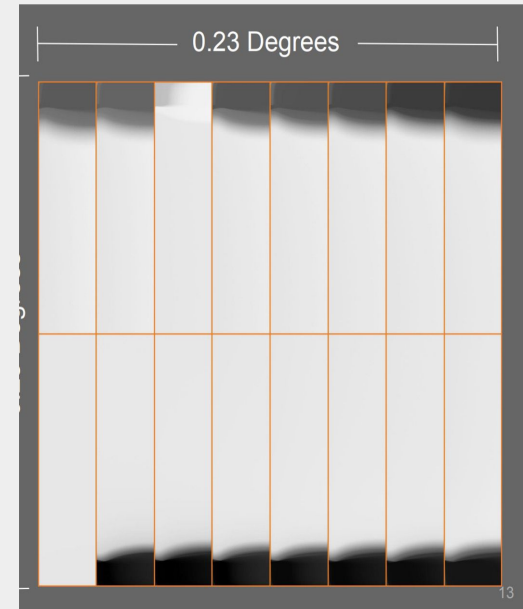
## IAU CPS recommendation



## Current Starlinks



## BlueWalker 3



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

*Faint brightness science affected*

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

*Most science programs affected*

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

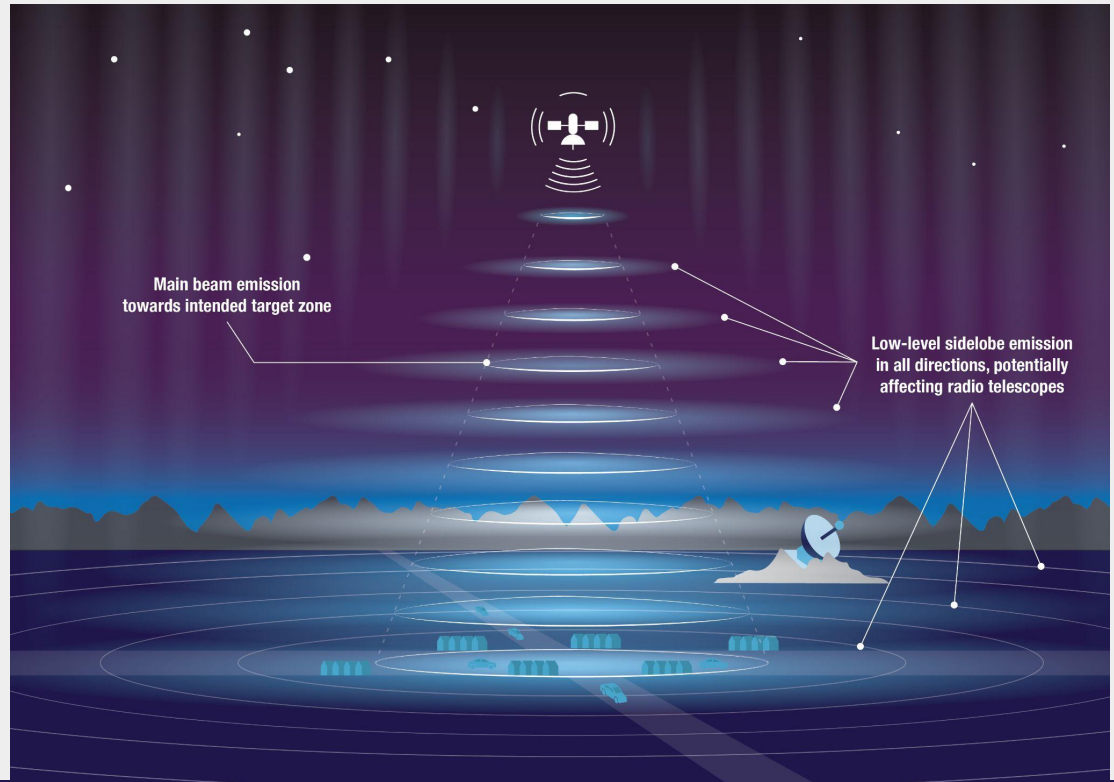
# Radio impact





# Effects on radio astronomy

- Intentional emissions (downlinks)
- Unintentional electromagnetic radiation (UEMR)
- Reflection of strong terrestrial radio signals signals of satellite bodies



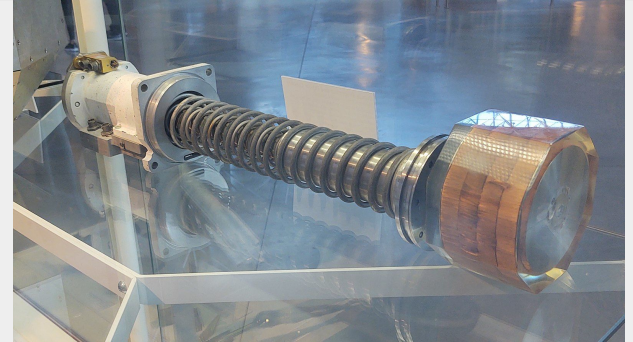
# Satellite constellations

Satellites have always been an issue for radio astronomy.

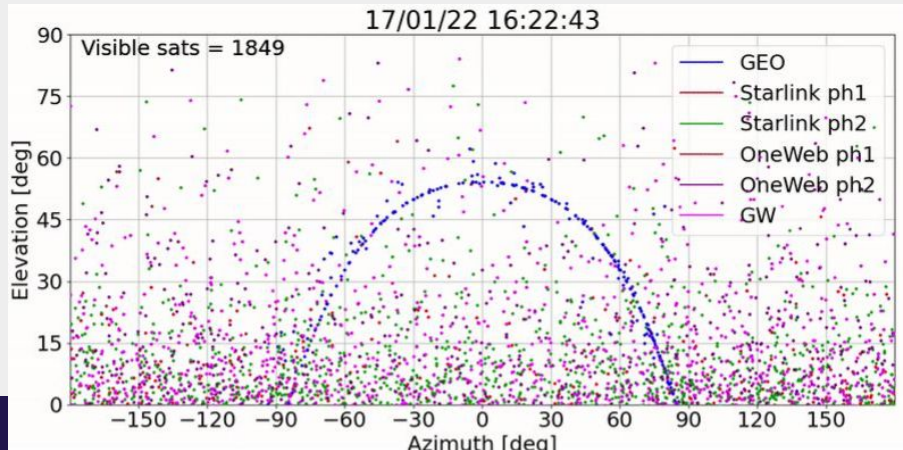
West Ford (1961-63) launched 480,000,000 2cm-long dipoles to reflect 8GHz (3.5cm) signals, some still in orbit - only stopped because of a global outcry.

The Iridium satellite constellation interferes with radio astronomy observations at 1.6GHz in the protected band

Satellite constellations transmit around  $\sim 12$ GHz...



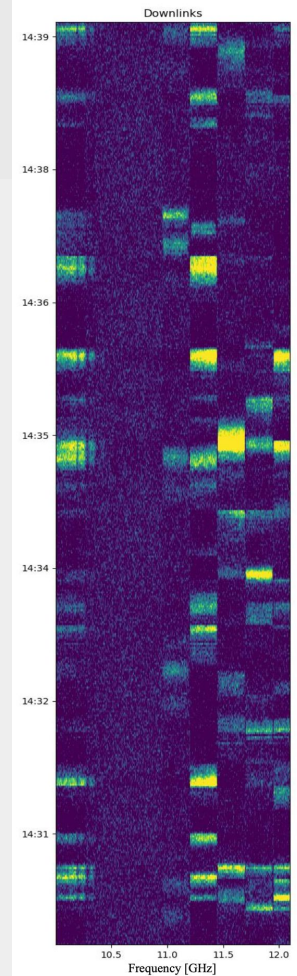
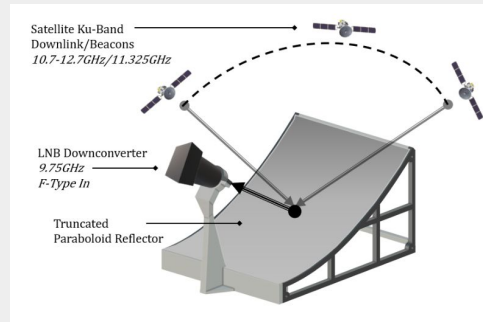
Project West Ford deployer.  
CC-BY-SA-4.0, GeneralNotability, via  
Wikimedia Commons



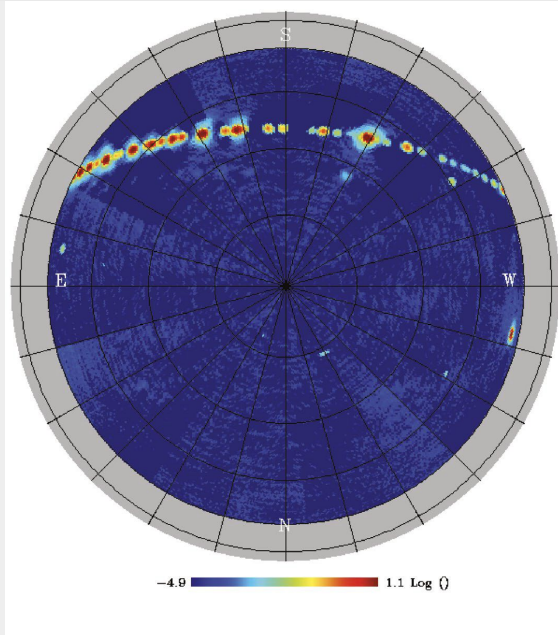
Transmissions regulated by ITU, with protections for radio astronomy at some frequencies, but only for narrow bandwidths.

# Potential impact at radio frequencies

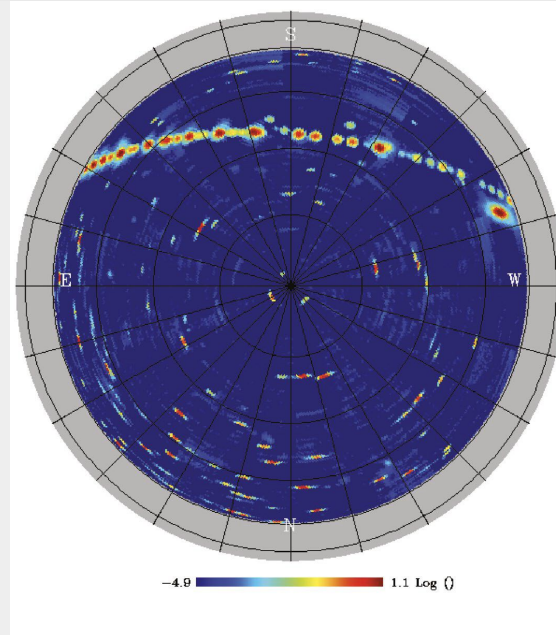
- We don't know much yet - need observations to assess actual impact
- Active 10-20GHz transmissions - plus 40GHz soon? (and octaves!)
- (Latest Starlink filing of ~30k satellites from Tonga is 120-180GHz!)
- Sidelobe coupling also a concern, particularly for CMB experiments
- Difficult to filter out with broadband detectors, unless using FPGAs
- Highly variable - need to accurately know satellite positions, or see as transients?



# Impact on radio observations



- Taken in 2014
- Shows bright band of geostationary satellites

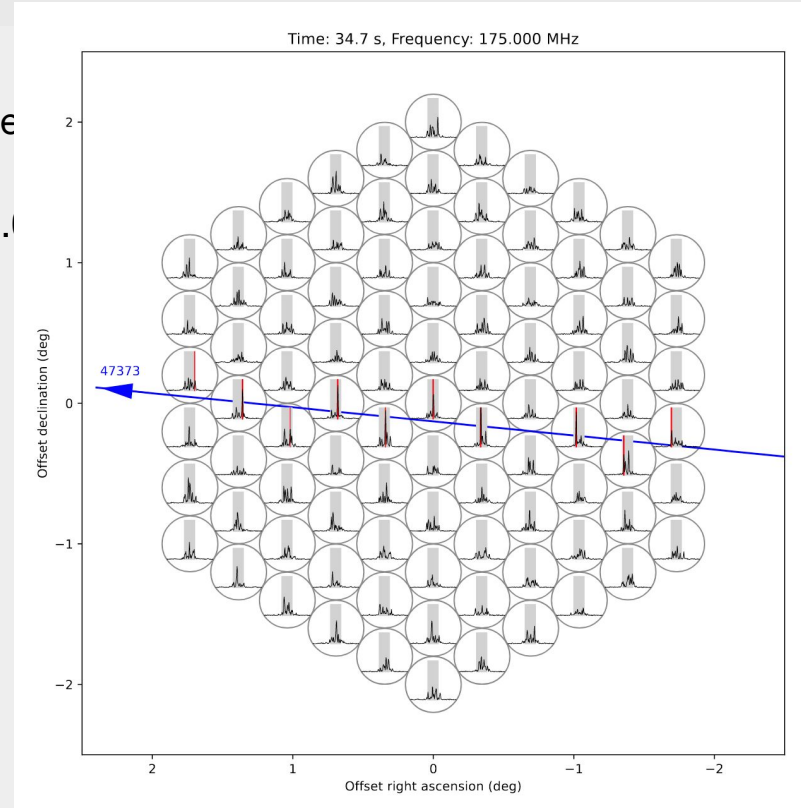
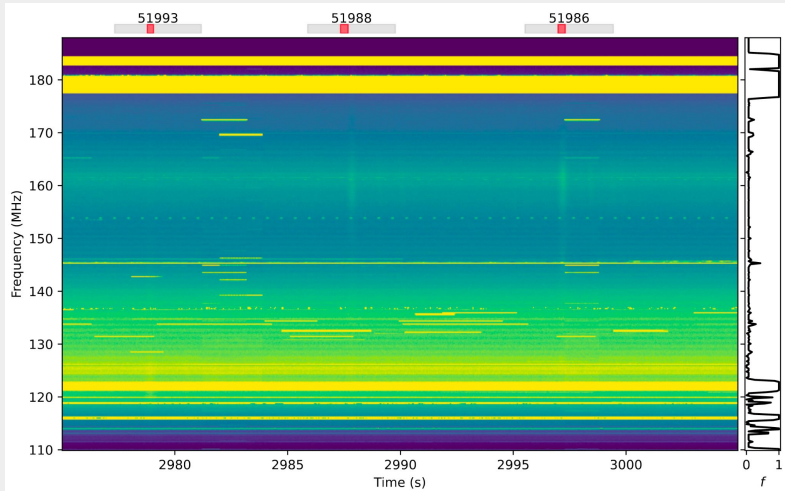


- Taken in 2024
- Additional interference (red dots) caused by Starlink satellites

Observations from QUIJOTE telescopes from Teide Observatory (Tenerife)

# Unintended emission at low frequencies

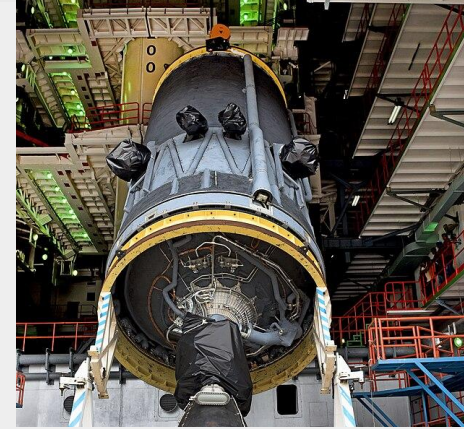
- LOFAR sees Starlink passing overhead!
- Unintended emission from back-end electronics seen
- Not permitted bands for transmitting...
- Di Vruno et al. (2023), A&A (published), arXiv:2307.11111
- (Also Grigg et al., 2023, 2309.15672)



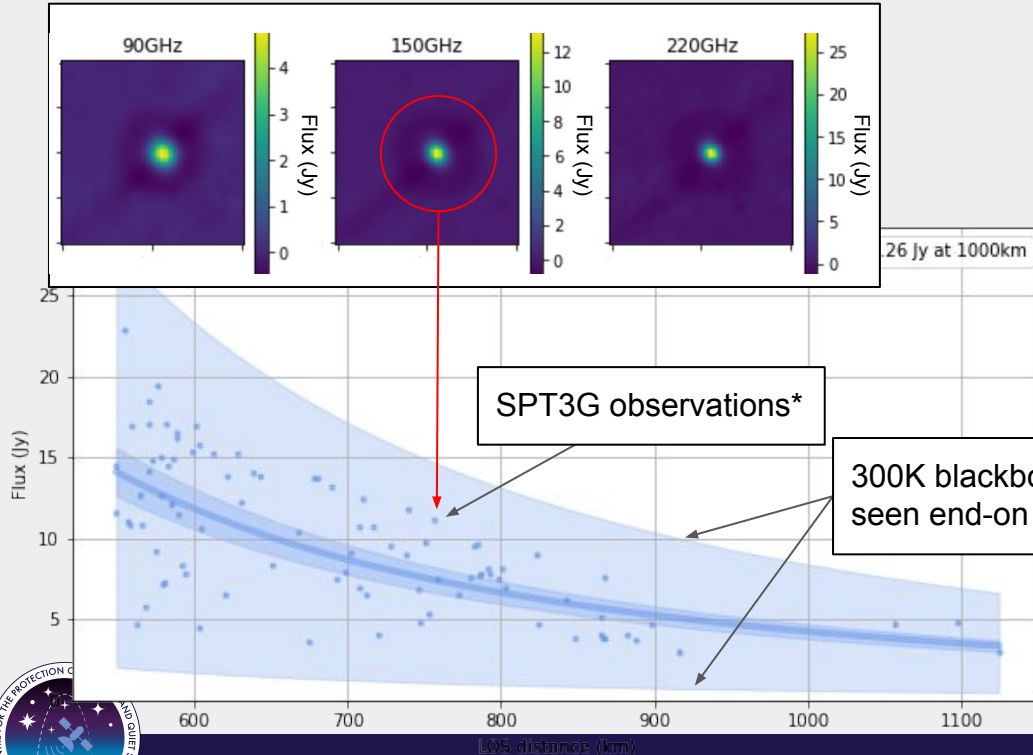
# Example from SPT3G - Thermal Emission

(Foster et al.,  
arXiv:2411.03374)

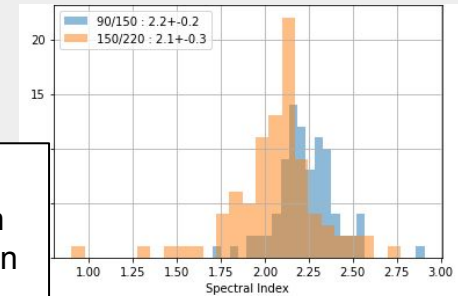
Even if not actively emitting RF signal, satellites can be millimeter bright!



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



Spectral index  
~consistent with  
thermal emission



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

# Mitigations



# What can the satellite industry do to lessen the impact on astronomy?



## Divert signals

Operate in frequencies allocated for satellites and use technology that allows to divert beams or stop transmission momentarily while transiting radio telescope beams.

## Quiet onboard electronics

Reduce radio noise from electronic components of satellites from design phase. Develop and adopt standards for radio emissions and test electronics before launch.

## Darker satellites

Use less reflective material or a non-reflective coating to make satellites less bright or divert light reflection away from Earth.

## Smaller and fewer satellites

Keep satellites small to reduce their footprint and reflections, and minimise overall numbers.

## Repositioning

Alter the orientation of satellites where possible so that solar arrays point away from Earth, reducing flares and glints. Mitigate increased impact during orbit-raising and de-orbiting, and minimise the time satellites spend in orbit when not in service.

## Lower Earth orbit

Put satellites in orbits below 600 km so they stay longer in Earth's shadow, cross the sky then disappear faster when viewed from low latitudes, and appear fainter to large telescopes due to being out of focus.

## Did you know?

Astronomers have recommended a limit of magnitude 7 on reflected sunlight from satellites so they are invisible to the unaided eye.

\*Not to scale - for illustration purposes only

# What can **astronomers** and **policy makers** do to help astronomy?

## Information sharing

Astronomers can avoid passing satellites by planning observations around satellite orbits – when location information is shared in advance by satellite operators and is publicly available. They can also share observation schedules with satellite operators to help them avoid telescopes.

## Radio telescope registration

Astronomers can register radio astronomy telescopes through their national administrations with the UN specialised agency - ITU, which is crucial to obtain international protections.



*See the map of ITU-registered radio telescopes.*

## Post processing

Post-processing of data can remove streaks from images but some information is inevitably lost.

## Diplomacy

International bodies like the United Nations and its committees can pass resolutions or produce guidelines encouraging member states to adopt recommendations.

## Regulations

Regulatory bodies can build on good practice and guidelines to develop new regulations, requiring stakeholders to follow them.

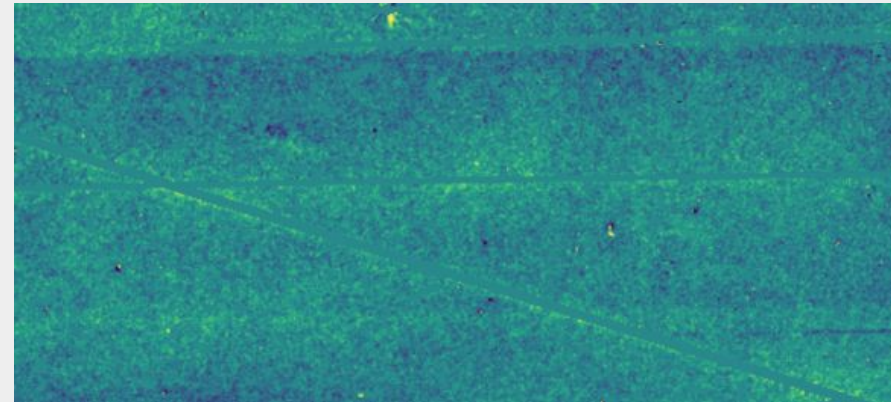
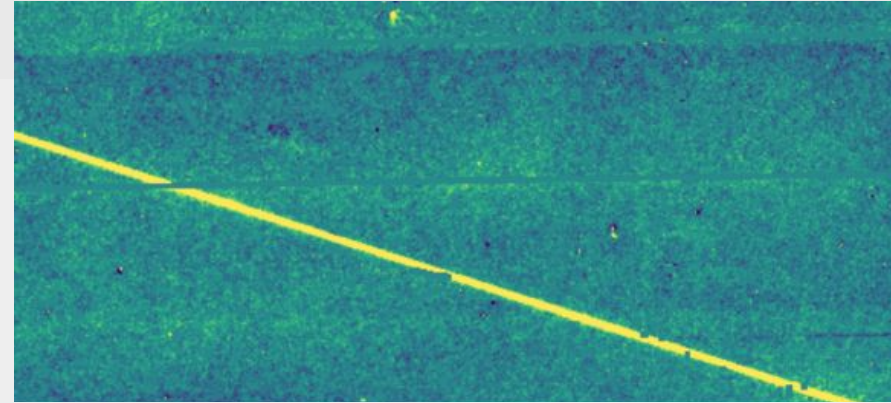
## Good practice

Astronomers and industry are developing recommendations, which policy makers can turn into guidelines to encourage industry to follow good practice.



# Mitigations: Telescopes

- Observations planning
- Software to avoid satellites
- Closing telescope shutter when satellite overhead
- More resilient receivers
- Observations to verify mitigations
- Redoing observations
- Modelling / Simulations
- Post processing of data (masking)



Hasan et al. (2022)

# IAU CPS



# IAU CPS

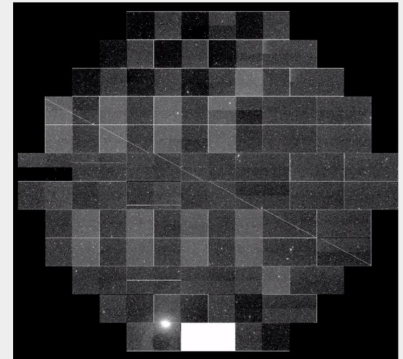


- Centre for the Protection of Dark and Quiet Sky  
<https://cps.iau.org/>
- Centre of expertise of the International Astronomical Union, hosted by the **SKAO**, an international radio astronomy observatory, and **NSF NOIRLab**, the US national optical/IR observatory - now also with **ESO**.
- International cooperation among software engineers, observers, astronomers, satellite industry folk, policy experts, space lawyers, government officials
- **Coordinate efforts and unify voices across the global astronomical community with regard to the protection of the dark and quiet sky from satellite constellation interference.**
- Four hubs: SatHub, Policy, Community Engagement, Industry & Technology



# SatHub

- Satellite observation and data analysis hub of IAU CPS
- A collaboration among pro astronomers, experienced amateurs, policymakers, industry experts, satellite operators, and more
- 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**



# IAU CPS SatHub Aims

- **Assess constellation impact on optical and radio astronomy** via independent observation campaigns and peer reviewed publications
- **Strengthen relations** with key players: Privateer, The Exocore, Slingshot Aerospace, European Centre for Space Safety, The Aerospace Corporation, AST SpaceMobile, SpaceX, Amazon Kuiper, Planet Labs, and more
- **Develop mitigation tools for astronomers/observatories**
  - SatChecker satellite position prediction service - <https://satchecker.readthedocs.io/>
  - Satellite Constellation Observation REpository (SCORE) - <https://score.cps.iau.org/>
  - NSF SWIFT-SAT project: minimizing science impacts through accurate predictions of satellite position and optical brightness
  - Radio astronomy impact modeling (SCEPTER)
- **Coordinate mitigation efforts** with all stakeholders



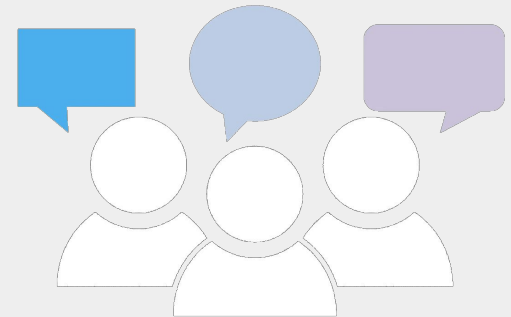
# Industry and Technology Hub

- Foster collaboration between the astronomy and satellite communities
- Outreach to satellite constellation operators
- Development of tools and best practices
- Promote ongoing mitigation solutions, resources
- Membership at no cost for satellite stakeholders

# Community Engagement

- Bridge between all stakeholders and communities
- Engage stakeholders to solicit their opinions
  - Community forums - for unheard voices
- Create activities for general public to understand issues
  - Developed SatCon 101 video lectures

*We ensures all stakeholders' voices are part of the broader discussion.*



# SatCons 101

- Series of 8 learning modules covering:
  - Satellite design
  - Environmental impacts
  - Effects on optical and radio astronomy
  - Cultural impacts
  - The current policy climate
  - Potential satellite mitigations
- Introduces issues of satellite constellations for astronomy to the general public



# Policy Hub

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**

## Strategic Outcomes

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

# Policy



# UN Committee on the Peaceful Uses of Outer Space

- Dark and Quiet Skies agenda item in the Scientific and Technical Subcommittee (STSC)
- Group of Friends for the Dark and Quiet Skies for Science and Society, which aims to:
- 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



# International Telecommunication Union (ITU)

- WRC-27:
  - AI 1.16: to address impacts on RAS bands and Radio Quiet Zones from satellite systems
  - AI 1.18: EESS and RAS above 76 GHz
  - AI 1.15: use of radiocommunications in the cislunar space
- Report on UEMR (ongoing at WP7D)
- Resolution 219 (Bucharest 2022) and Resolution ITU-R 74: Sustainable use of spectrum and space orbits



# National regulations

- United States imposes coordination with NSF to obtain licences
- Licensing conditions for operators in South Africa (ongoing discussions)
- Efforts in Space Sustainability include Dark and Quiet Skies:
  - ESA Zero Debris charter
  - UK Earth Space Sustainability Initiative
  - Switzerland Space Sustainability Rating
  - EU Space Label
  - ...

# How you can help



# Share observations on SCORE

- If you observe a satellite, don't just throw that data away!
- If you can calibrate the measurement, please upload it to SCORE.
- We also regularly use eyeball measurements of satellite brightnesses!
- You can use SatChecker's Field of View service to identify the satellite.
- Please join SatHub and discuss priority targets (e.g., new types of satellites after they're in their final orbits), if you can make specific observations of satellites!

# Share the impact of satellites on your observations

- Release satellite-contaminated photos under free licences so they can be re-used on Wikipedia and elsewhere
- Raise awareness of satellite impacts in your community and the general public
- Respond to FCC requests for comments on new satellite constellations

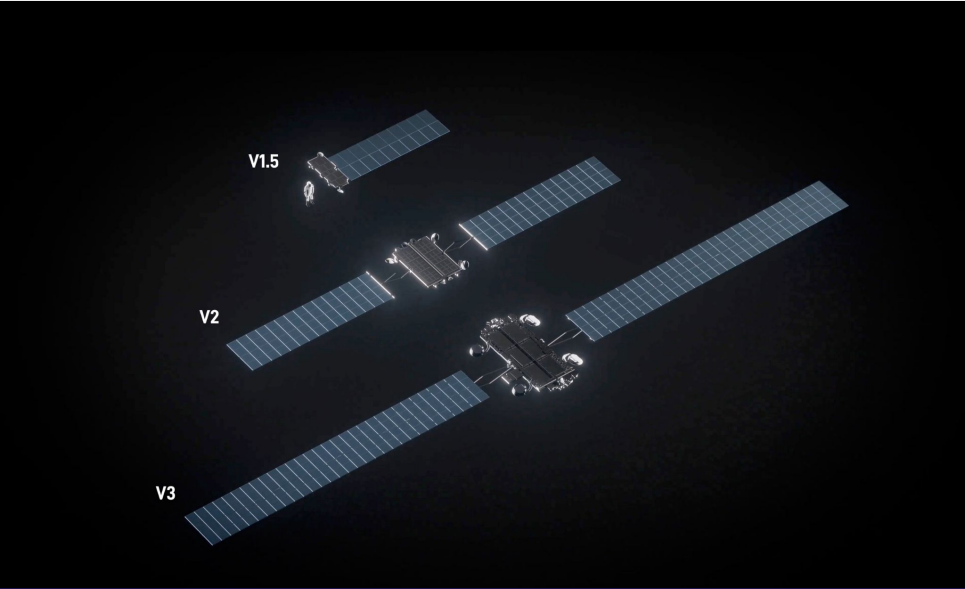
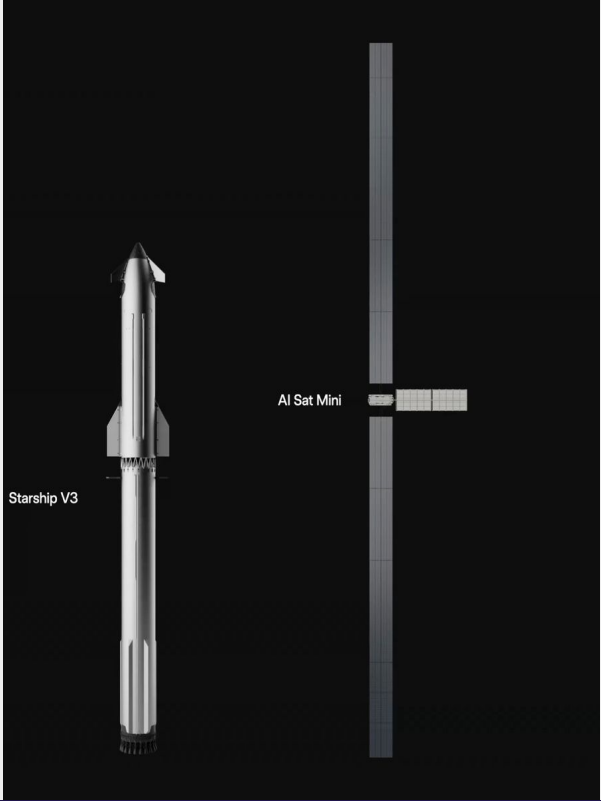
There's more coming...



# SpaceX: 1 million AI data centres in space

Huge numbers of even larger satellites (solar panel span comparable to plane wingspans)  
Others also now planning orbital data centres...!

(<https://spaceneews.com/spacex-files-plans-for-million-satellite-orbital-data-center-constellation/>)



# Reflect Orbital wants to provide 'daylight as a service'

Sunlight after dark



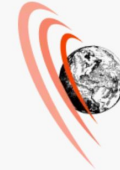
2 satellites  
2026



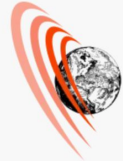
36 satellites  
2027



1k+ satellites  
2028



5k+ satellites  
2030

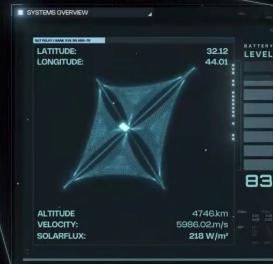


50k+ satellites  
2035



NOVLE	NJ	NRNO	ALTBAPROGE	ALTBPERGE	INCLINATION	LT
1	10,000	510	510			
2	10,000	599	599			
3	10,000	722	722			
4	8000	895	895			
5	6000	1212				
6	5000	1692				
7	5000	2633				
8	2500	3413				
9	2500	5088				
10	2500	7063				

Sunlight after dark



2028

Up to 100 lux for 2 hours comparable to indoor work areas.

2 lux 24/7 comparable to streetlighting.

2030

Up to 5,000 lux for minutes comparable to daylight.

Up to 100 lux for 2 hours comparable to indoor work areas.

2 lux 24/7 comparable to street lighting.

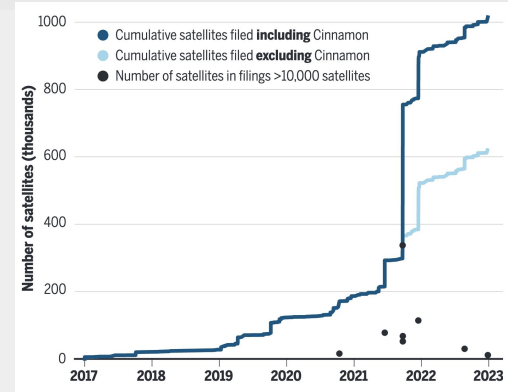
2035

Up to 36,000 lux for hours comparable to daylight.

Up to 100 lux 24/7 comparable to indoor work areas

# Conclusions

- Rapidly increasing numbers of satellites...
- New types of satellite uses constantly appearing...!
- Significant impact on optical, submm, radio astronomy
- CPS working to quantify their impact - please help!
- Policy approaches under way
- Is this an existential crisis for astronomy?
- (The situation in the US is looking bleak...)
- Please join CPS ...! <https://cps.iau.org/>



Falle et al. (2023), "One million (paper) satellites", Science

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## Questions?