Mitigating satellites' light pollution

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SEPnet
South East Physics Network

United Nations
Office for Outer Space Affairs
SKAO
#DarkAndQuietSkies
for Science and Society

A Stunning Image of the Australian Desert Illuminates the Growing Problem of Satellite Pollution

Credits: Joshua Rozells

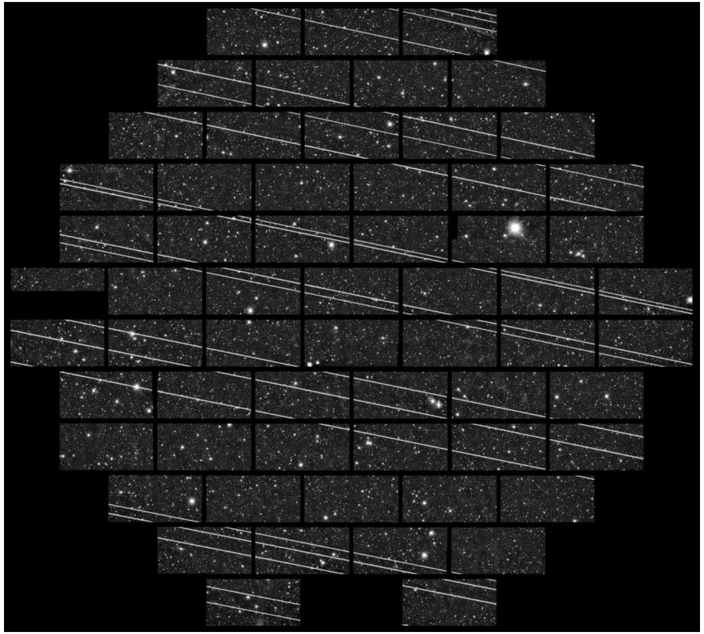
Why it matters?

1. Cultural: An increase in the apparent brightness of the night sky by **10%** (Kocifaj et al 2021)

2. Science: wide-field surveys can lose up to **40% of long exposures**, costing millions of dollars. (Tyson et.al 2020)

3. Brightness of satellites exceeds IAUs limit for light pollution in astronomical sites.

4. There are no regulations that control how bright or dim a satellite needs to be!



Time-lapse image shows the passage of a Starlink satellite cluster (bright streaks) through a telescope's field of view at the Cerro Tololo Inter-American Observatory in Chile in November 2019. CTIO, NOIRLab, NSF, AURA and DECam DELVE Survey

A practical mitigation: Dimming satellites at the source

1. Partnership between University of Surrey (astrophysics & space systems) and Surrey Nanosystems

2. Aim : develop and test ultra-black coatings to reduce satellite reflectivity

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surrey nanosystems

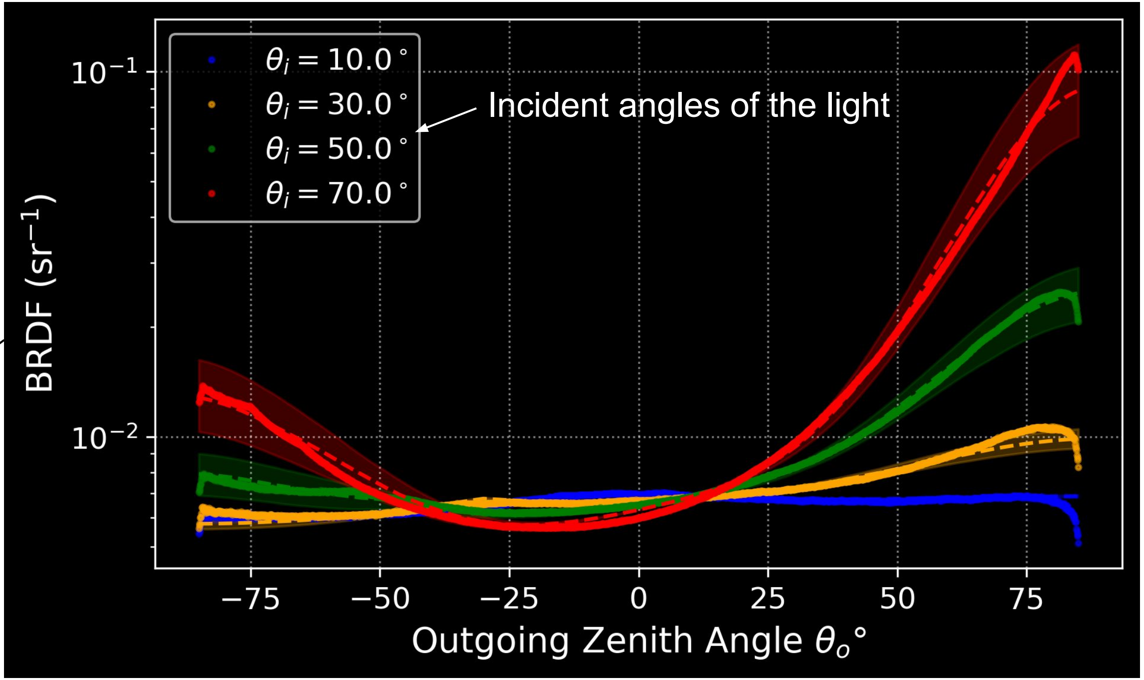
Dark Coating : Vantablack®310

- Aerospace-grade , polysiloxane-based coating
- The lab < 2%, across Ultraviolet-Near Infrared wavelength range

Two identical bronze casts - except one has been coated with Vantablack (Supplied: Surrey NanoSystems)

Key Result : Model for coating reflectance on a satellite

Bidirectional reflectance distribution function

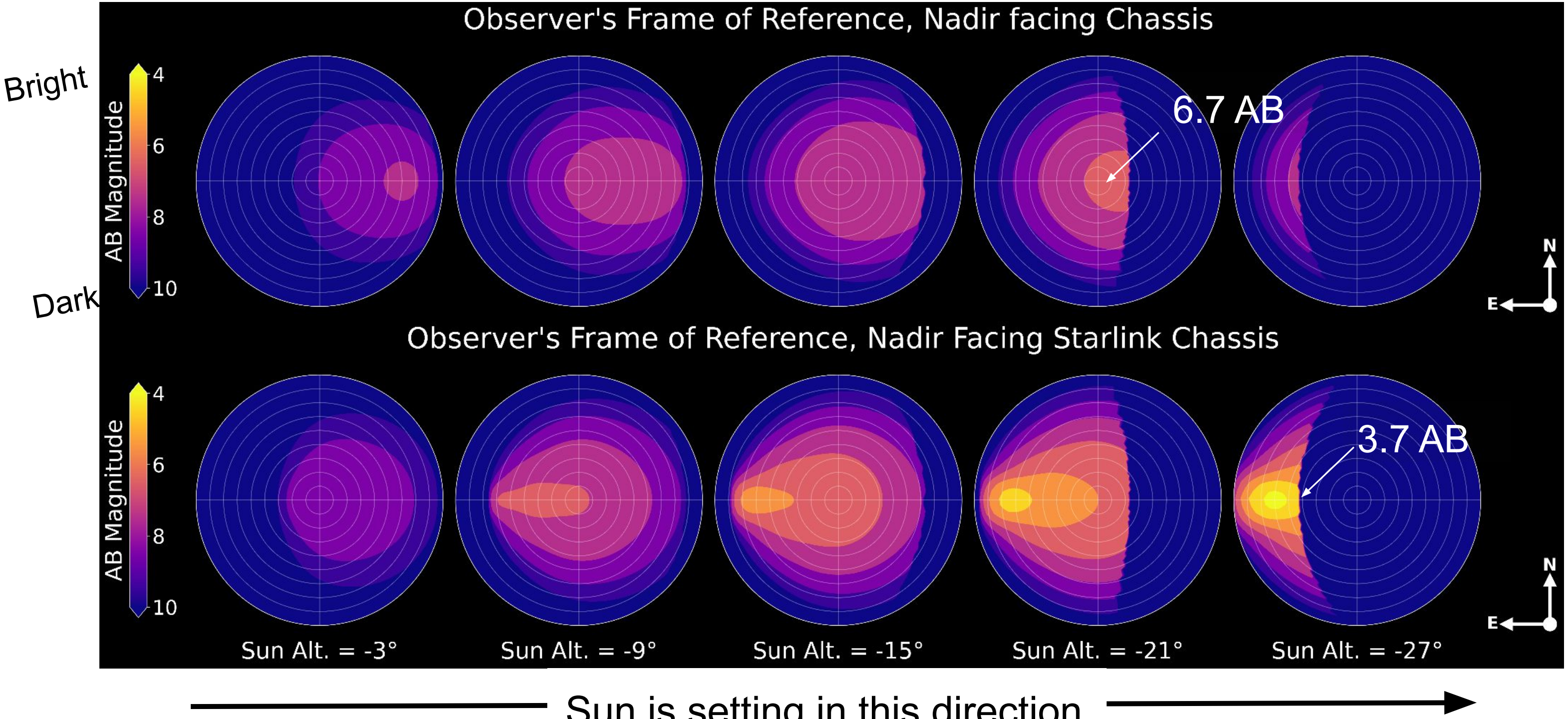


Measured BRDF (coloured markers) and best-fit Binomial model (dashed lines) for four incident angles, θ_i = 10°, 30°, 50°, 70°. Shaded regions denote the uncertainty envelopes.

Chaturvedi et al. 2025 submitted to MNRAS

Key Result : Model for coating reflectance on a satellite

- Simulated a 4 m^2 panel (Starlink Chassis equivalent) at 550 km altitude.



IAU's limit = 7 AB. Coating makes the surface 4 magnitudes darker= 40x less visible

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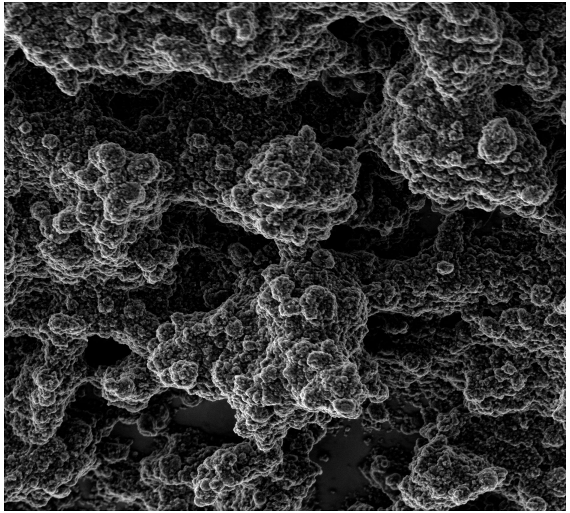
Durability and Practical Testing

Scanning Electron Microscopy



Scanning Electron Microscopy: Isotropic in nature with coral-like texture, helps in trapping light by multiple scattering

Radiation Test

3 days 22 hours and 39 minutes of exposure time for simulating LEO conditions equivalent of 2 years at orbit of 550 km height

Lab tests passed; in-orbit test planned (Jovian-1)

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Outcome of our work

- Problem: Mega Constellations threaten night-sky visibility, exceeding IAU light pollution limits.
- Solution: Ultra-black Vantablack®310 coatings developed with Surrey Nanosystems reduce reflectivity.
- Effectiveness: Coating makes satellites 4 magnitudes darker (~40 times less visible), potentially meeting IAU mag 7 threshold at 550 km
- Validation: Passed lab tests; in-orbit demonstration planned on Jovian-1 Cubesat.

Chaturvedi et al. 2025 submitted to MNRAS

Future Actions

- All satellites must remain fainter than mag 7 (IAU visibility threshold), via coatings, sunshades, or orientation.
- Licensing Requirements: National regulators (FCC,Ofcom, etc.) must include brightness/reflectivity data in license applications.
- Monitoring & Research: Conduct and fund dedicated collaborative observational research to assess astronomical impact.
- Global Standards: Develop international reflectivity/brightness standards (e.g. via ISO); adopt scientific benchmarks from IAU.
- International Governance: COPUOS; issue binding guidelines on satellite brightness for member states.
- Space agencies, industries to provide funding for research on mitigation methods.

THANK YOU

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BBC Article

EXTRA SLIDES

Table 1. Published brightness measurements of Starlink satellites at ~550 km altitude. Where necessary, Sloan magnitudes have been converted to Johnson V using $V = g - 0.03 - 0.42\,(g - r)$ with $g - r = +0.44$.

Satellite / design	Reported brightness	V (mag)
Starlink chassis[1]	AB 6.7	6.7
Starlink (ensemble)[2]	Visual 5.5 ± 0.5	5.5 ± 0.5
Starlink V1.0[3]	$V \approx 5.3 \pm 1.2$	5.3 ± 1.2
DarkSat[3,4]	$V \approx 7.5 \pm 0.88$	7.5 ± 0.88
VisorSat[3,5]	$V \approx 6.2 \pm 0.89$	6.2 ± 0.89
DarkSat (Starlink-1130)[4]	$g' = 6.10 \pm 0.44$ (scaled)	≈ 5.6
VisorSat (ensemble)[5]	Visual 5.92 ± 0.04	5.92 ± 0.04
DarkSat[4]	Visual 5.8 ± 0.03	5.8 ± 0.03
Original-design Starlink[4]	Visual 4.6 ± 0.02	4.6 ± 0.02

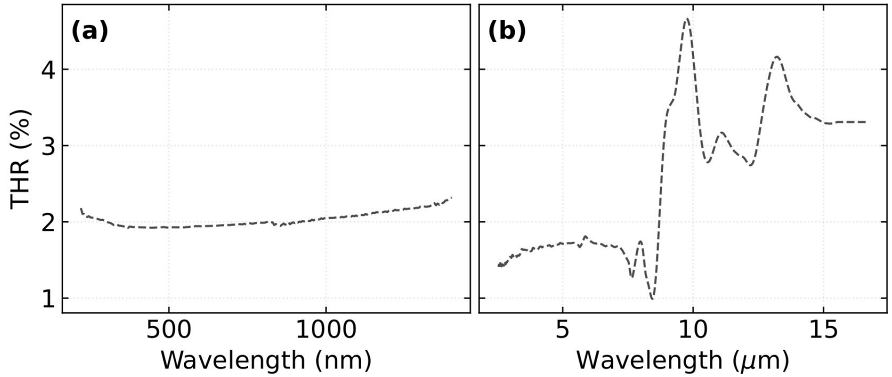
[1]This work; [2]McDowell (2020); [3]Halferty et al. (2022); [4]Cole (2020); [5]Mallama (2021); [6]Tregloan-Reed et al. (2020).

Overheating Problem : Why Vantablack®310 ?

- Extremely dark: reflects ~2%
- Absorbs across optical + IR wavelengths
- High emissivity (~0.98) → rapid radiative cooling
- Space-qualified: low outgassing, thermal range −196 °C to +200 °C
- Upcoming flight test: Jovian-1, 2025

→ Results remain model-based; further testing is essential

THR of the Vantablack®310 coating as a function of wavelength.



Panel (a) shows the broadband UV–Vis-NIR response, where the coating maintains ~2\% reflectance.
Panel (b) extends into the mid-infrared, where the THR rises to ~5\% beyond 8 μm due to molecular vibrational features typical of organic coatings. Chaturvedi et al. 2025 submitted

Overheating Problem

- Partial or patterned coatings (~70–75% coverage) balance optical dimming and thermal stability.
- Hybrid approach: Earth-facing side coated in VB310, space-facing side reflective → ~50% absorption.
- LEO temperature cycles (~90 min) limit total heat absorption. Components are space-tested for extremes.
- Current limitation: No full-satellite testing; conclusions are model-based.

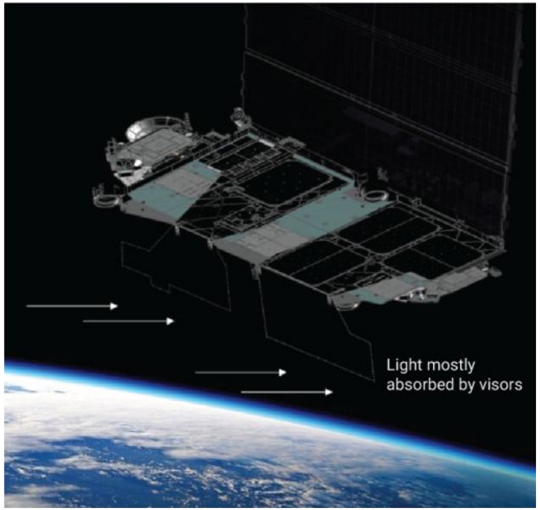
Key Strategies & Outcomes

First-Generation

- **Sun visors** to block sunlight → *Discontinued* (blocked lasers, increased drag)
- **Mirror film (Gen-1)** → *Moderate* brightness reduction
- **Darkened solar array backing** → Lower brightness (small performance cost)

Second-Generation

- **Advanced mirror film (10× darker)** → Major brightness reduction
-
- **Low-reflectivity black paint** on complex components → Fewer glints
- **Solar array mitigations:**
  - Opaque backsheet pigment
  - “Terminator tracking” (off-point arrays at dawn/dusk) → Strong reduction; *25% power sacrifice accepted*



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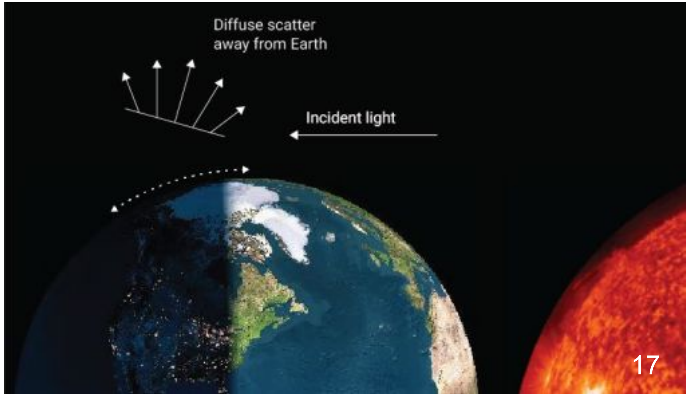


Key Strategies & Outcomes

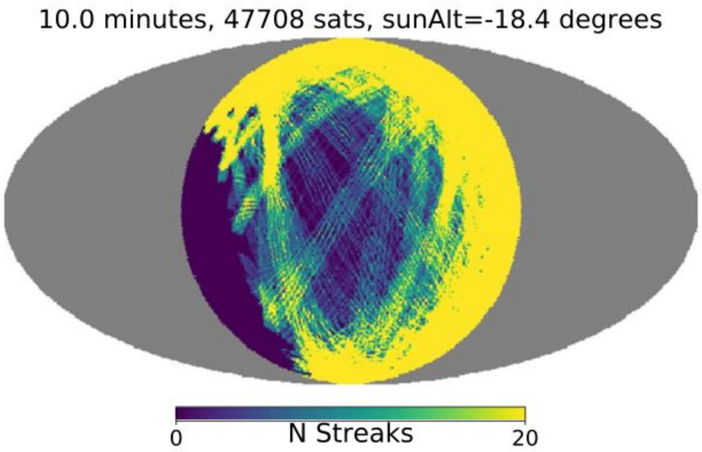
Operational Measures

- Improved attitude control during launch/orbit-raise/deorbit → Reduced brightness in bright phases
- Accurate orbit predictions for astronomers

Outcome

In fact, such improvements remain insufficient to prevent contamination of sensitive wide-field surveys (Tyson et al. 2020; Hasan et al. 2022)

Need for passive, scalable solutions integrated into design, amidst launch of mega constellations!



Mollweide projection map showing the streaks that a mega-constellation would make over 10 minutes on a randomly chosen date (2022 October 11) just after evening twilight at the Rubin Observatory site. Source : Tyson et al. 2020

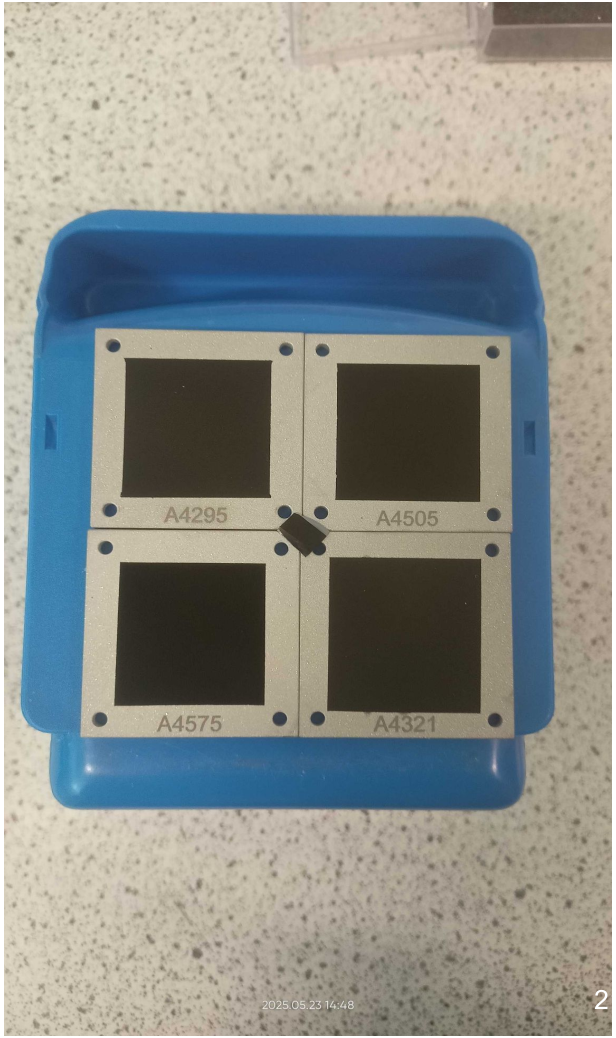
Testing Protocols

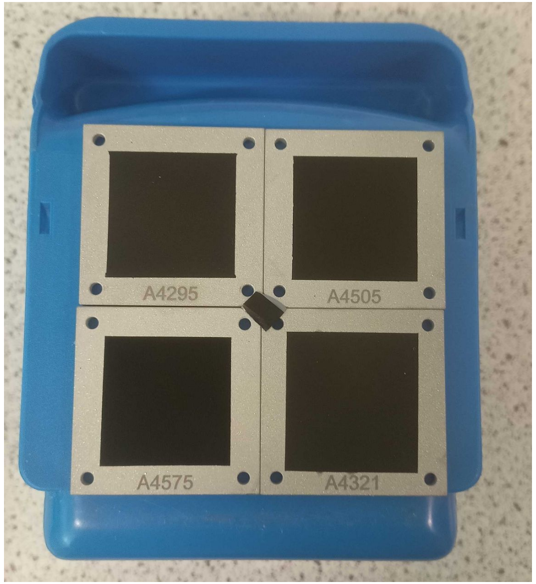
- Simulated Coating reflectance as a painted area on a satellite

- Lab Testing: Radiation Testing, SEM and conductivity measurements

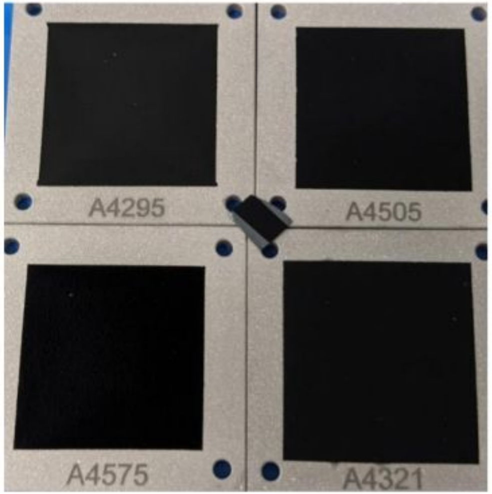
Lab Testing : Radiation Test

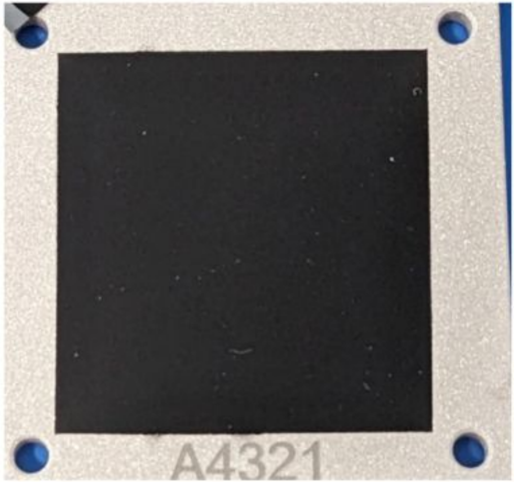
3 days 22 hours and 39 minutes of exposure time for simulating LEO conditions equivalent of 2 years at orbit of 550 km height





Before





After

Lab Testing : Four-Point Probe Measurement

Sheet Resistance (Rs) = 3 kΩ/sq

Thickness (t) = 30 μm

Conductivity (σ)=1/R_s · t≈10 S/m

In-Orbit Demonstration

Integration

- Coating to fly on Jovian-1 Cubesat (2026) under UK JUPITER programme

Objectives

- In-flight reflectivity measurement
- Degradation study under atomic oxygen and UV exposure

–First UK space test for a light-pollution mitigating coating

Overheating Problem

Vantablack 310 may outperform DarkSat because:

- Extremely dark (reflects ~2% vs ~50% for DarkSat)
- Absorbs across optical + IR
-
- High emissivity (~0.98) allows rapid radiative cooling
- Designed for space: low outgassing, thermal range −196 °C to +200 °C
- Upcoming space flight test (Jovian 1, 2025)

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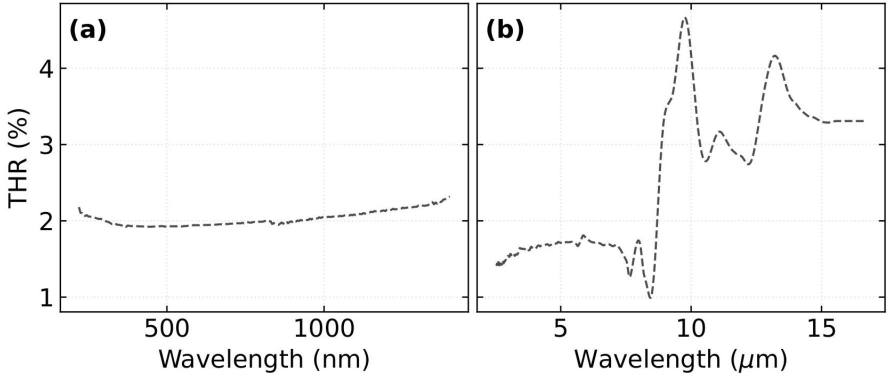

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