Mitigating the effects of light pollution: Strategies for Dark Sky Preservation

Dark & Quiet Skies - Lumi Space - CleanSpace Industry Days

10-10-2024

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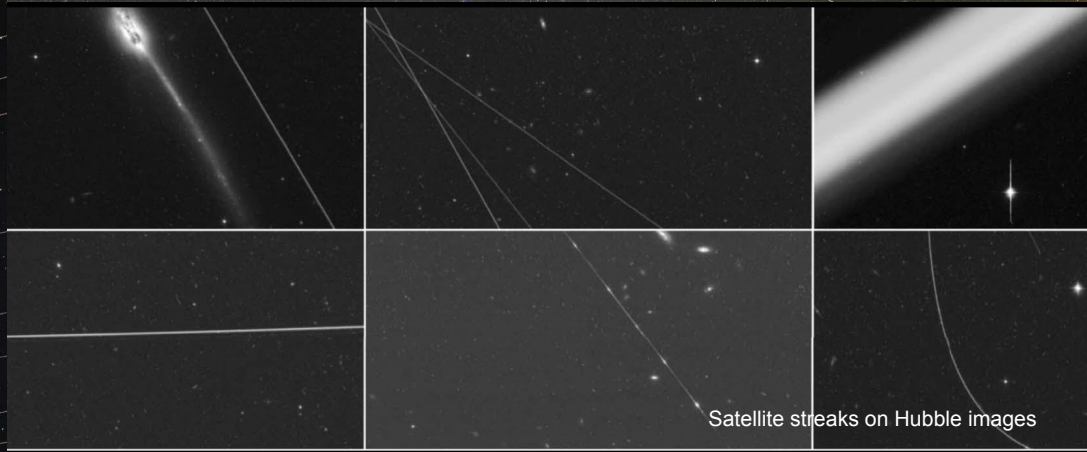
Starlink satellite train -Uruguay 7-feb-21

Satellite streaks - Eckhard Slawik

Starlink streaks - Torsten Hansen



Satellite streaks on Hubble images

Agenda

- Prognosis of near future
  - More moving stars than static?
  - Financial aspect of problem
- Proposal to ensure Dark & Quiet Skies
  - For existing satellites
  - For future satellites
  - For ground observatories
  - Dark Sky magnitude threshold

Near future prognosis

Satellite percentage vs stars

- Light polluted areas (urban areas)
  - Up to 9% of visible sky objects are satellites
- Minimal light pollution (rural areas)
  - Up to 7% of visible sky objects are satellites
- No light pollution (dark areas)
  - Up to 6% of visible sky objects are satellites
- Expected to **rise** further in future
  - Complicating astronomy and stargazing

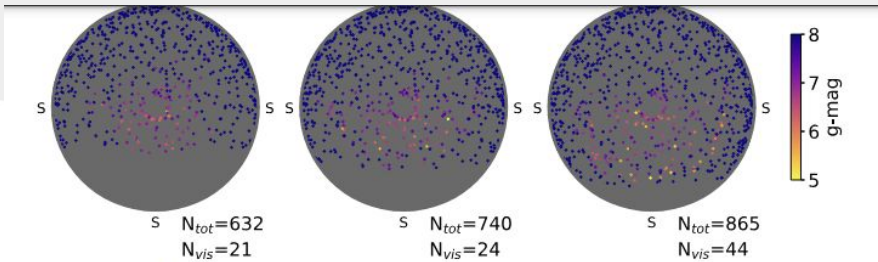


Figure 8. Similar to Figure 5, but viewed from the North Pole (latitude 90°N). Because of extreme seasonal illumination, satellites would not actually be visible close to the summer solstice due to 24 hr daylight, or close to the equinox because of 24 hr near-daylight, but the dozens of satellites brighter than $g < 6.5$ will be visible 24 hr per day during the winter. For comparison, we show midnight on the winter solstice (24 hr of full darkness), at a solar declination of $-18°$ (24 hr of astronomical twilight), and at a solar declination of $-12°$ (24 hr of nautical twilight). Note that from the North Pole, all directions are south.

Table 2
Satellite Magnitudes

Latitude	Season	Time	$g < 5$ Number	% Sats	$g < 6.5$ Number	% Sats	$g < 7$ Number	% Sats
60°N/S	summer	midnight	19	2%	292	6%	480	6%
	equinox	midnight	0	0%	9	0%	16	0%
		nautical dusk/dawn	9	1%	137	3%	244	3%
50°N/S	summer	midnight	48	6%	259	6%	386	5%
		nautical dusk/dawn	60	7%	317	7%	487	6%
	equinox	midnight	0	0%	0	0%	0	0%
		nautical dusk/dawn	72	8%	311	7%	438	5%
40°N/S	summer	midnight	0	0%	34	1%	71	1%
		nautical dusk/dawn	79	9%	327	7%	487	6%
	equinox	midnight	0	0%	0	0%	0	0%
		nautical dusk/dawn	76	9%	322	7%	493	6%
30°N/S	summer	midnight	0	0%	1	0%	4	0%
		nautical dusk/dawn	78	9%	299	6%	450	6%
	equinox	midnight	0	0%	0	0%	0	0%
		nautical dusk/dawn	78	9%	310	7%	480	6%
20°N/S	summer	midnight	0	0%	0	0%	0	0%
		nautical dusk/dawn	60	7%	246	5%	375	5%
	equinox	midnight	0	0%	0	0%	0	0%
		nautical dusk/dawn	56	7%	259	6%	403	5%
Background stars			804		4395		7702	

Note. "% sats" means the percentage of point sources in the sky at that are satellites, not stars, at each magnitude cut, for top-of-the-atmosphere magnitudes (i.e., no extinction).

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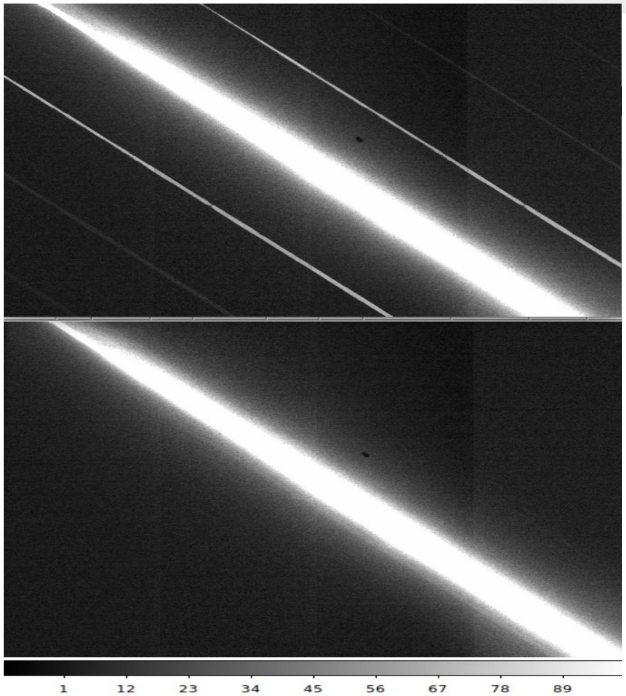
Samantha M. Lawler et al 2022 "Visibility Predictions for Near-future Satellite Megaconstellations: Latitudes near 50° Will Experience the Worst Light Pollution"

Near future prognosis

Financial aspect of problem

- Higher Night Sky Brightness (NSB) requires longer integration times
  - 12% increase in NSB expected by 2030[1]
  - Linearly scales to 12% integration time increase
- Observations very expensive
  - VLT 1 euro/second
  - ELT 10 euro/second
  - Vera C. Rubin telescope to discard 40% of images
- Longer integration time leads to higher project costs
  - Estimated $34.8 million over next 10 years[1]
  - Also reduction of availability for other programs



Tyson, J.A. et al., 2020. Mitigation of LEO satellite brightness and trail effects on the Rubin Observatory LSST. *The Astronomical Journal*, *160*(5), p.226.

[1]Barentine, J.C. et al., 2023, “Aggregate Effects of Proliferating LEO Objects and Implications for Astronomical Data Lost in the Noise”

Dark & Quiet Skies

Proposed solution

1. Future missions **need** on-ground spectral analysis
    - Area-weighted Bidirectional Spectral Distribution Function (BSDF) needed for **all** satellites
    - Tools to simulate on-sky brightness (Lumi-LBS)

2. Current missions to **reduce** on-sky brightness
    - Quantify the most critical areas on Earth for optical observation

3. Observatories to **reduce** satellites in Field of View
    - Software for intelligent shutter design (Lumi Blink software)

4. Ensure a Dark Sky threshold magnitude

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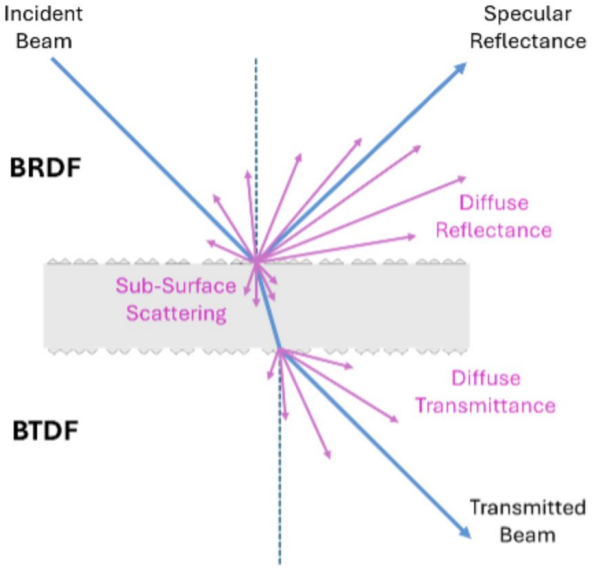
Dark & Quiet Skies

1. Improved BSDF understanding

- BSDF determines object's apparent brightness
  - Currently unknown for majority of current satellites
  - Empirically determined by community
- Future missions **need** area-weighted BSDF knowledge pre-launch
  - Required by ESA Zero Debris requirements
- BSDF knowledge currently not attainable
  - Manufacturers lack the tools
- Lumi to provide area-weighted BSDF of its components



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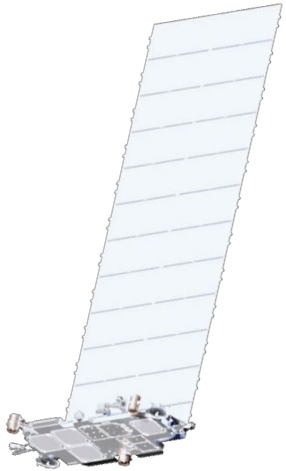
1. Tools for on-sky brightness assessment

- Lumi-Link Budget Simulator
  - 3D satellite model + material BSDF as input
- Ray-traces incoming light
  - Propagated through atmosphere
  - Computes reflected/absorbed photons
- Lumi-LBS to assess magnitude of satellites in sky
  - Reflectance simulation on simplified Starlink mock-up



Example of reflectance simulation on using Lumi-LBS

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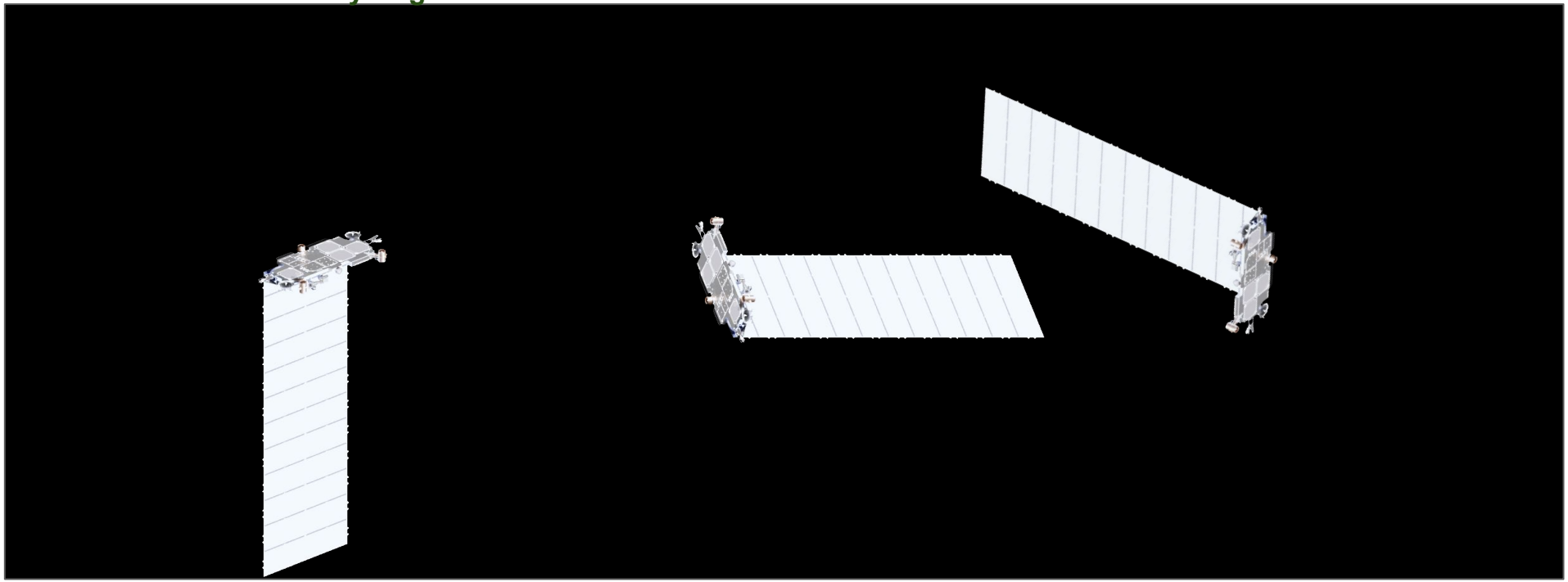
1. Tools for on-sky brightness assessment



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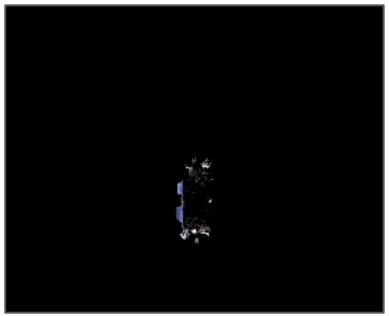
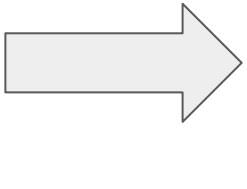
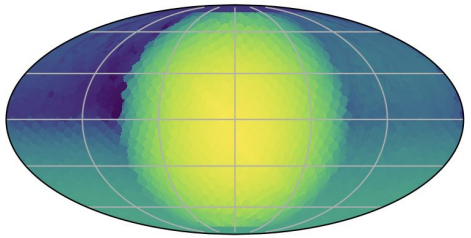
1. Tools for on-sky brightness assessment

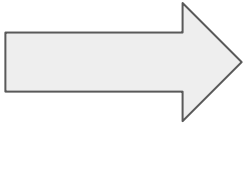
- From reflectance simulation to area-weighted BSDFs [m^2/sr]
- Received power [W] by observatory as result:
  - x solar irradiance [W/m^2]
  - x solid observer angle [sr]



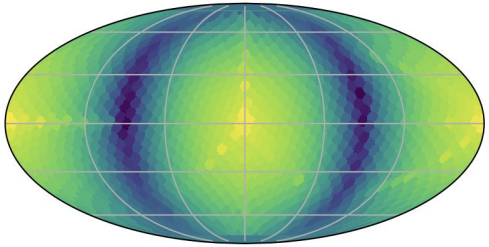


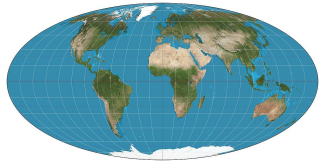
Where is light reflected to?





How retroreflective is the target?





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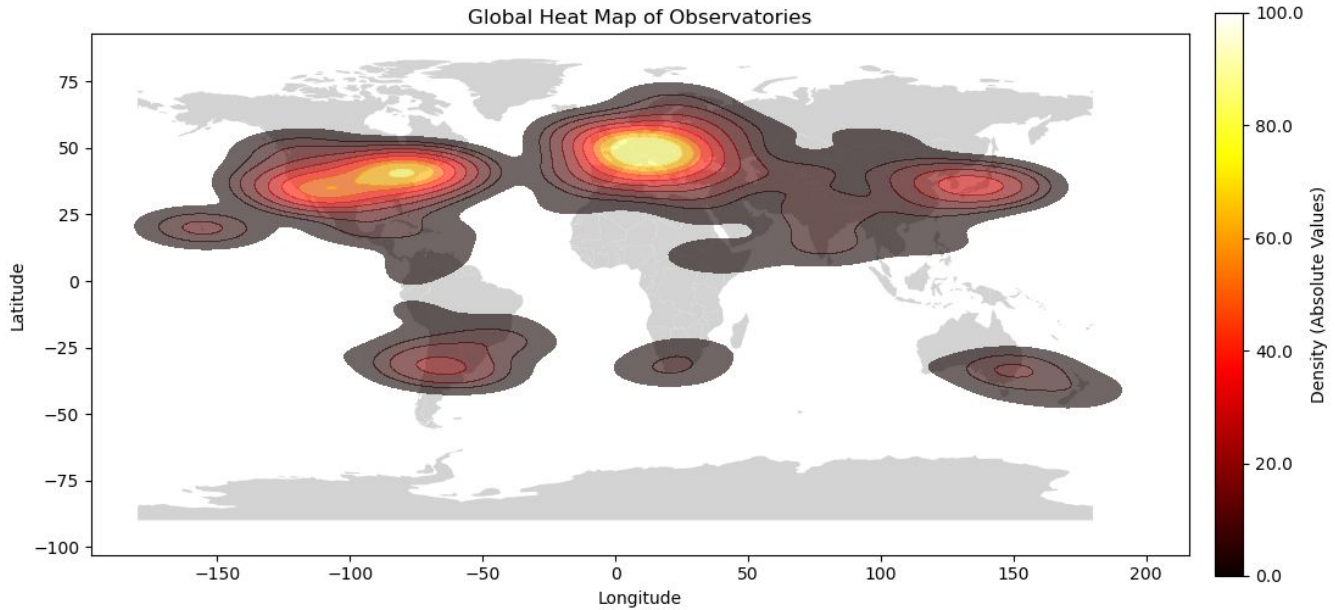
2. Standards for existing satellites

- Use attitude control to minimize reflected sunlight above critical regions on Earth (observatories)



Data from *World map of Astronomical Observatory Sites (ESO)*

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2. Standards for existing satellites

- Could make all the difference to ground observatories

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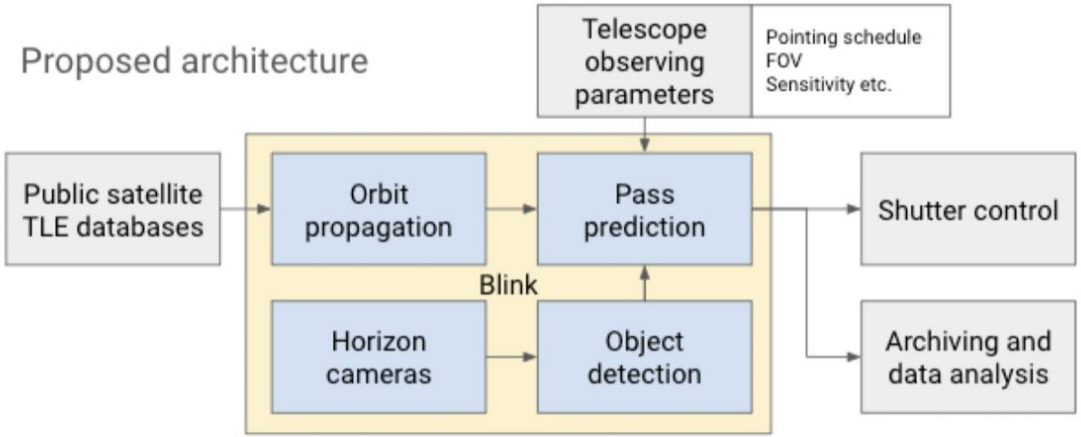
3. Standards for observatories

- Lumi Blink software[1] for intelligent shutter closure



Patel, N. et al., Blink: advanced satellite pass prediction and mitigation software for satellite and space debris streak prevention, 2023

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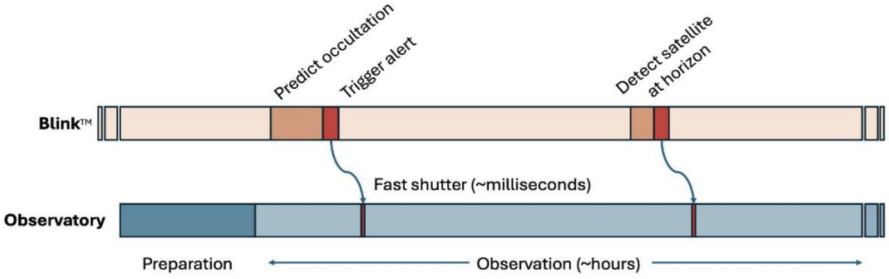
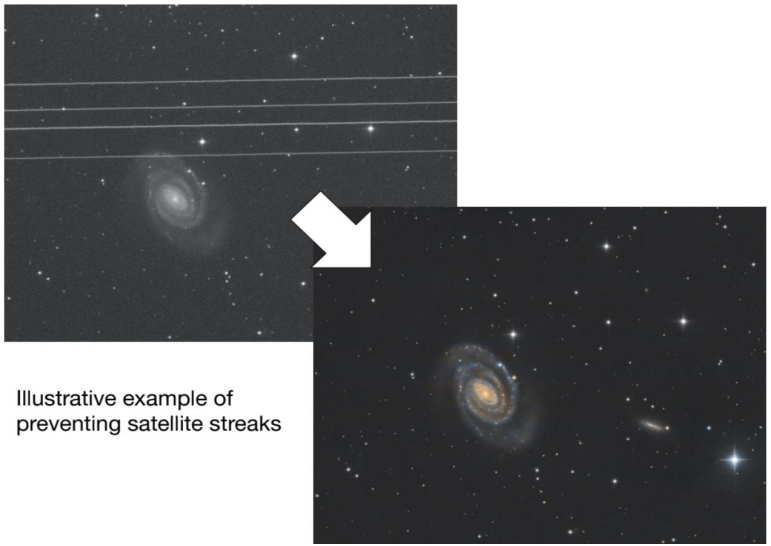
3. Standards for observatories

- Lumi Blink software[1]
  - Detect incoming satellites into FoV
  - Close shutter accordingly (~ms)





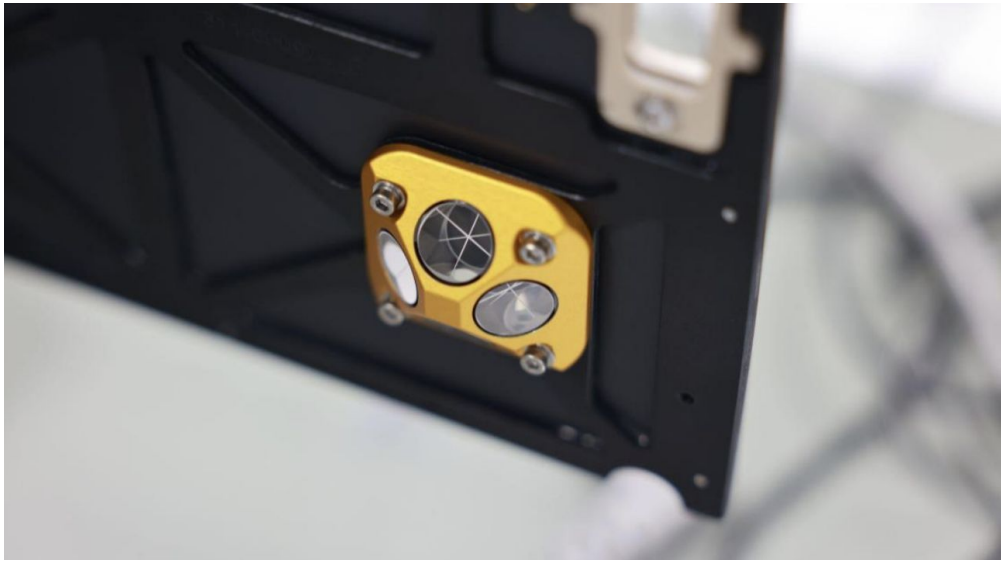
Illustrative example of preventing satellite streaks

Patel, N. et al., Blink: advanced satellite pass prediction and mitigation software for satellite and space debris streak prevention, 2023

Dark & Quiet Skies

4. Dark sky threshold magnitude

- Future missions **need** on-ground spectral analysis
  - Pre-launch assessment of brightness in sky
- Ensure Dark Sky threshold magnitude
- Darken satellite (for observer)
  - Reduce brightness of satellites
- Add retroreflectors for improved tracking



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Conclusion

1. All future missions should have BSDF knowledge pre-launch
    - Lumi to aid industry by providing BSDFs for Lumi retroreflectors
    - Lumi developing on-sky brightness assessment
2. Current missions to reduce their apparent brightness
3. Ground observatories to actively reduce amount of satellites in FoV
4. Satellites to be darkened (for observers)
    - Retroreflectors attached to still improve tracking

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