Environmental Impacts Throughout a Satellite Megaconstellation Lifecycle

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Outer Space Institute, and
University of Regina, Saskatchewan, Canada

With input from Outer Space Institute Fellows Dr. Roohi Dalal, Dr. Aaron Boley, Dr. Michael Byers, Charlotte Hook, Andrew Falle, and Sarah Thiele

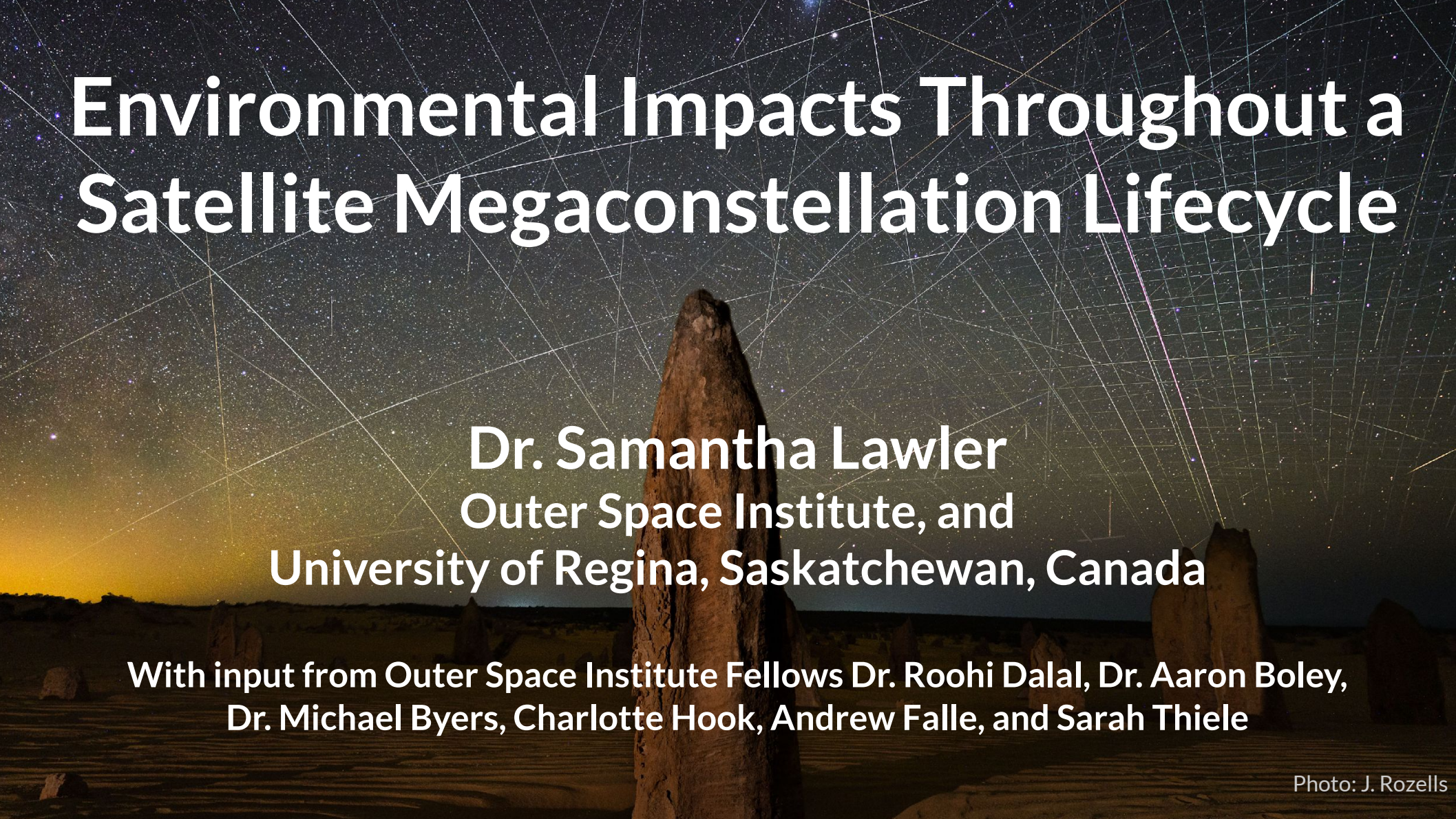
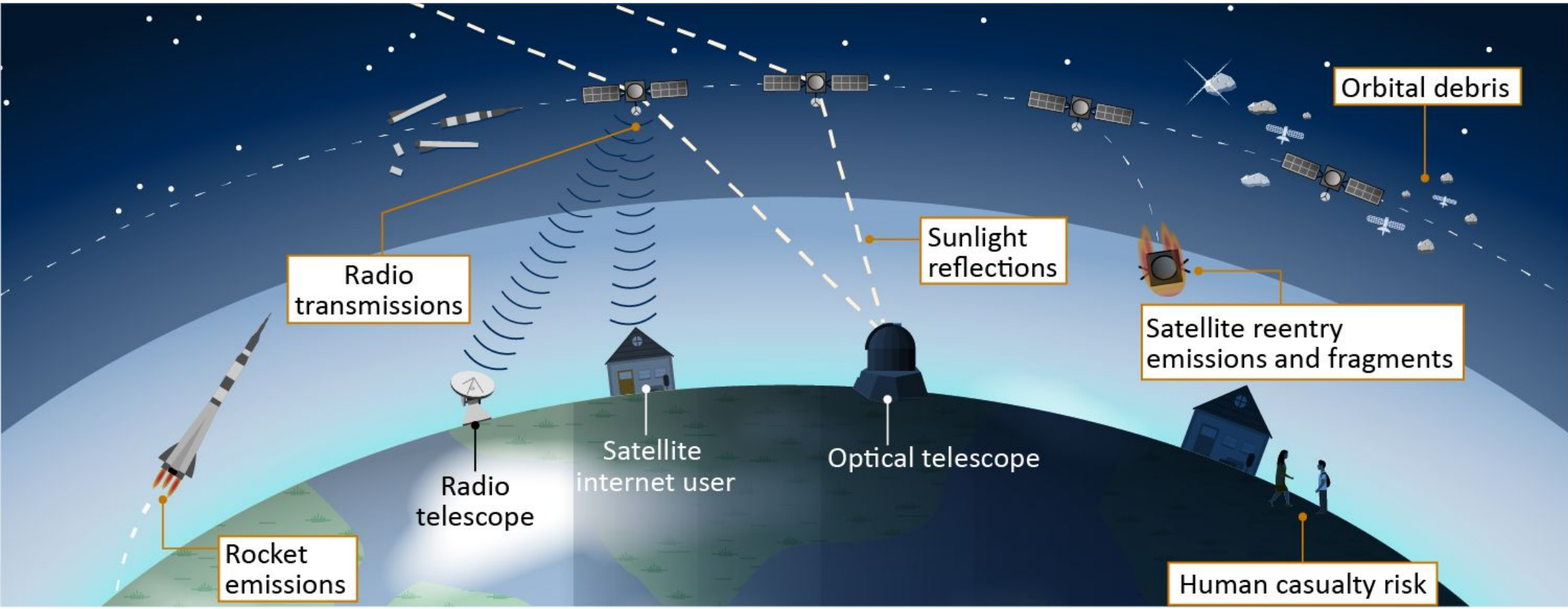


Photo: J. Rozells

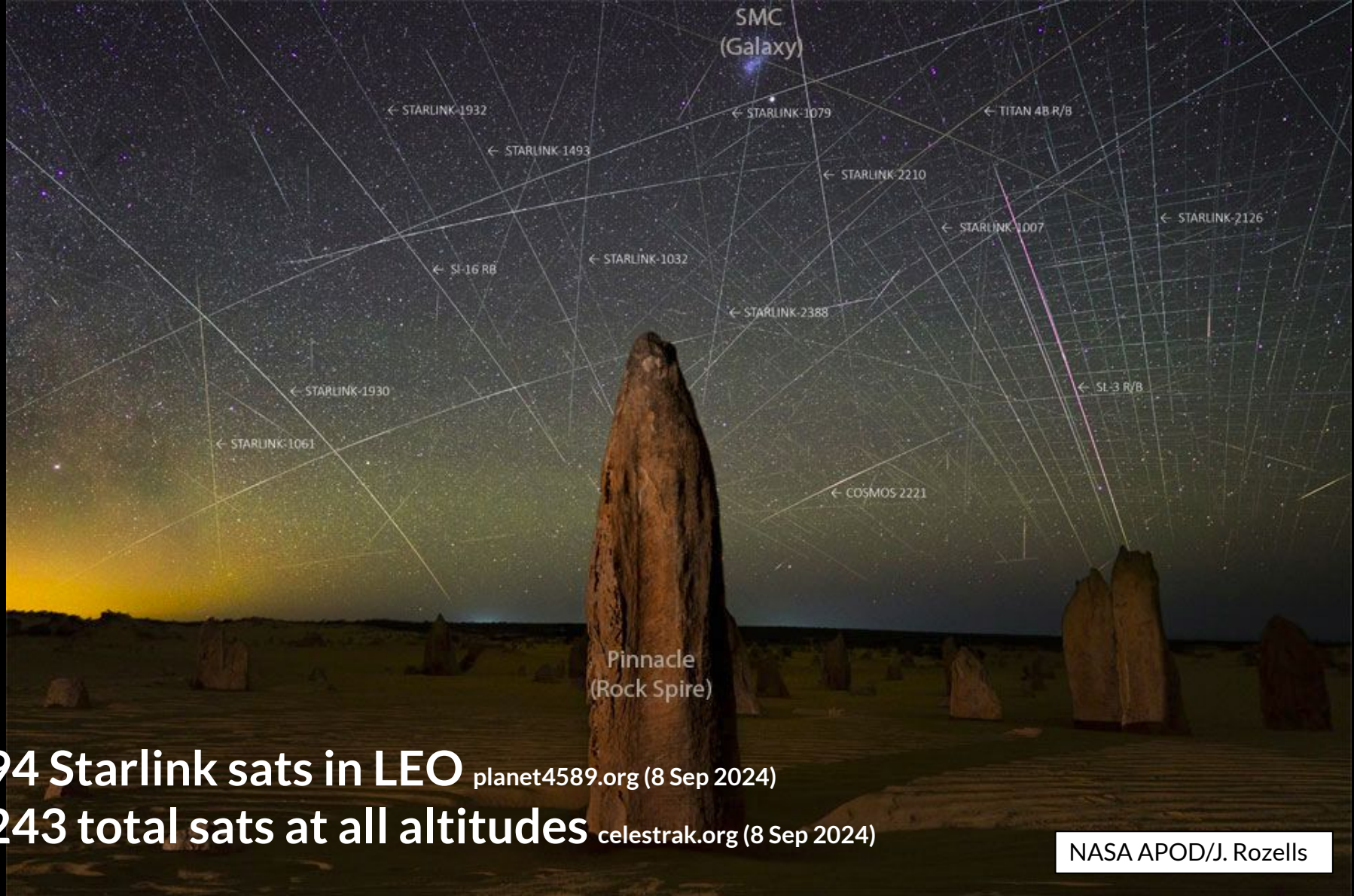
Satellite megaconstellations have significant environmental impacts throughout their lifecycle.

These impacts are more problematic for megaconstellations due to extremely large numbers and disposability. We can still get many/all benefits of satellites with fewer in orbit.



Source: GAO. | GAO-22-105166

Note: Image not to scale.

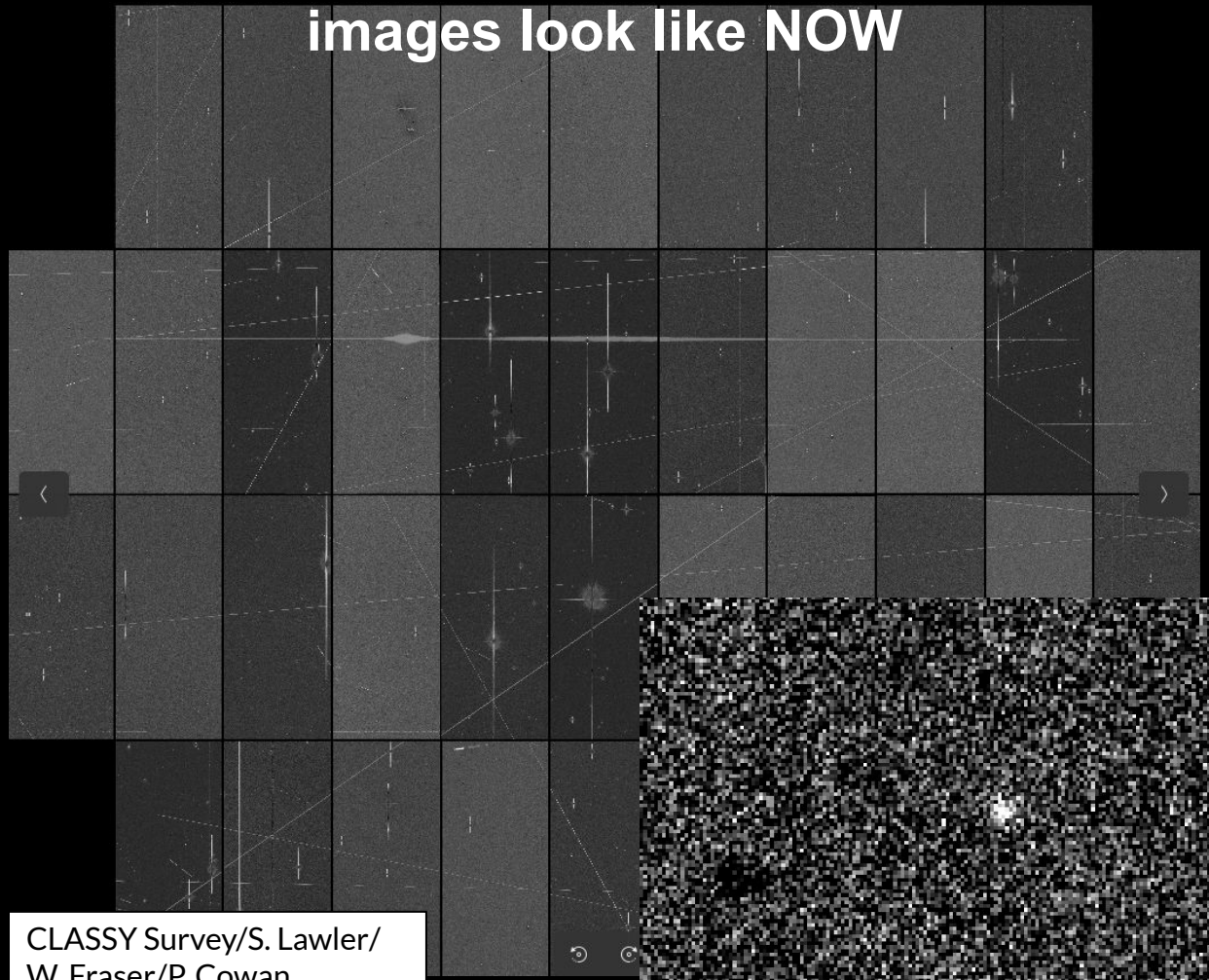


6,394 Starlink sats in LEO planet4589.org (8 Sep 2024)

10,243 total sats at all altitudes celestrak.org (8 Sep 2024)

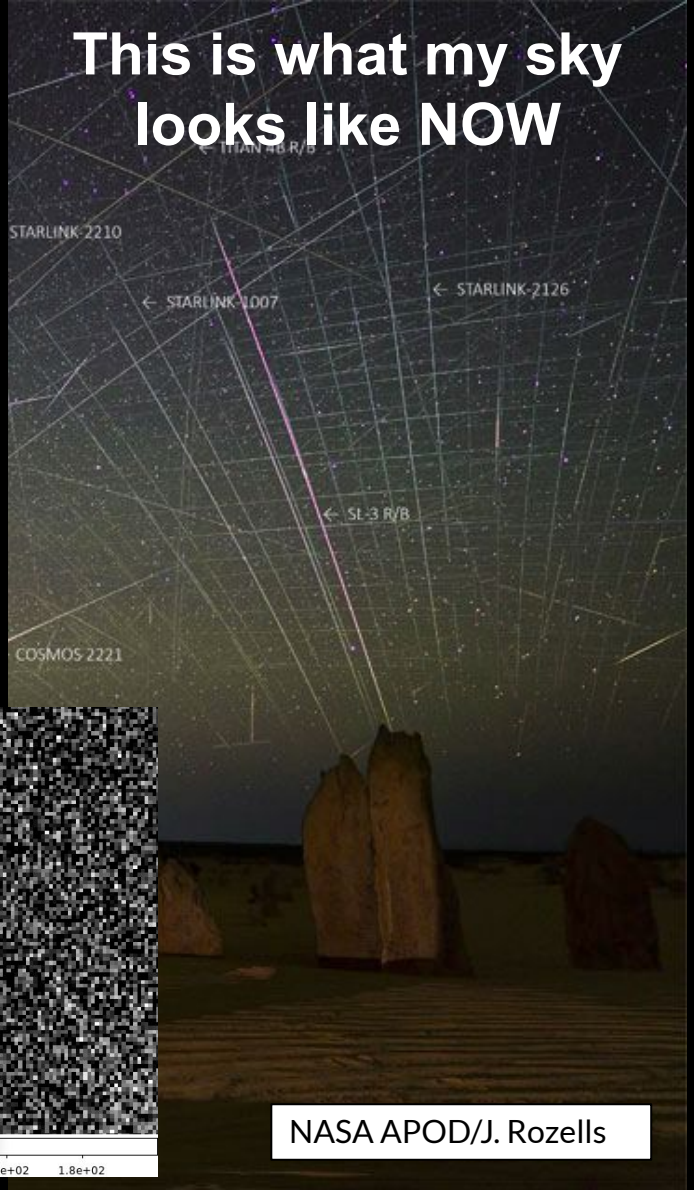
NASA APOD/J. Rozells

This is what my research images look like NOW



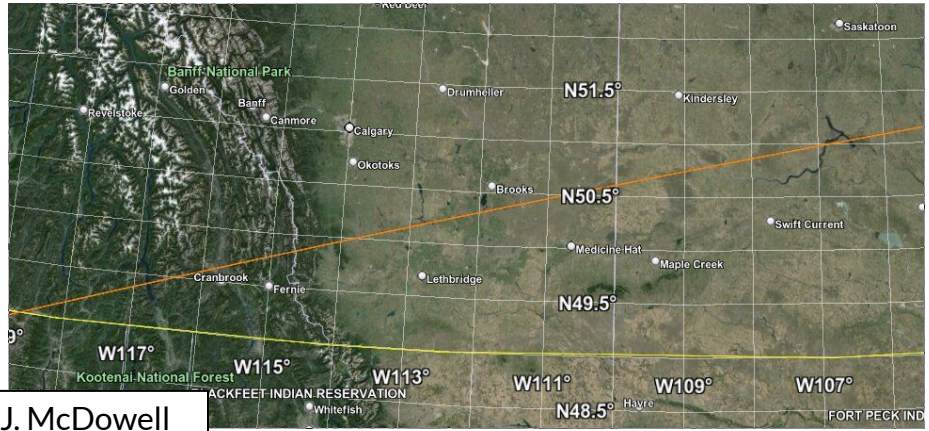
CLASSY Survey/S. Lawler/
W. Fraser/P. Cowan

This is what my sky looks like NOW

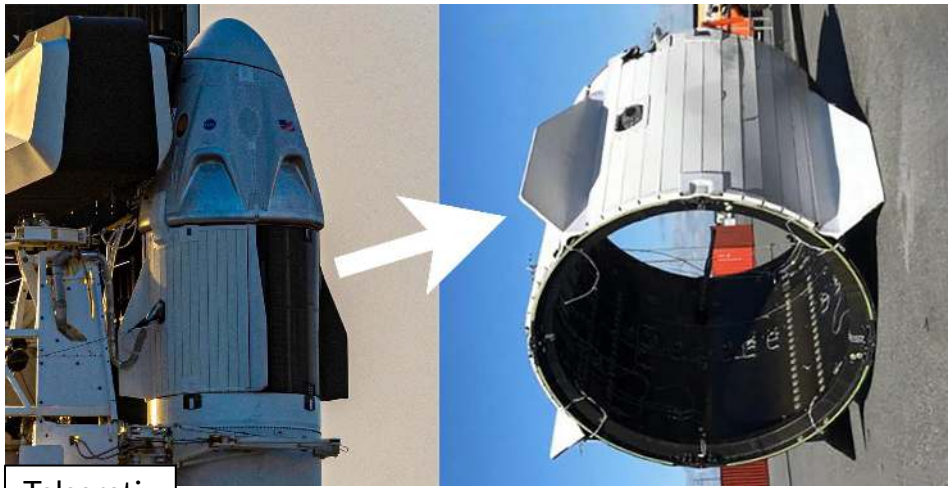


NASA APOD/J. Rozells

Space debris is falling near my house NOW



J. McDowell



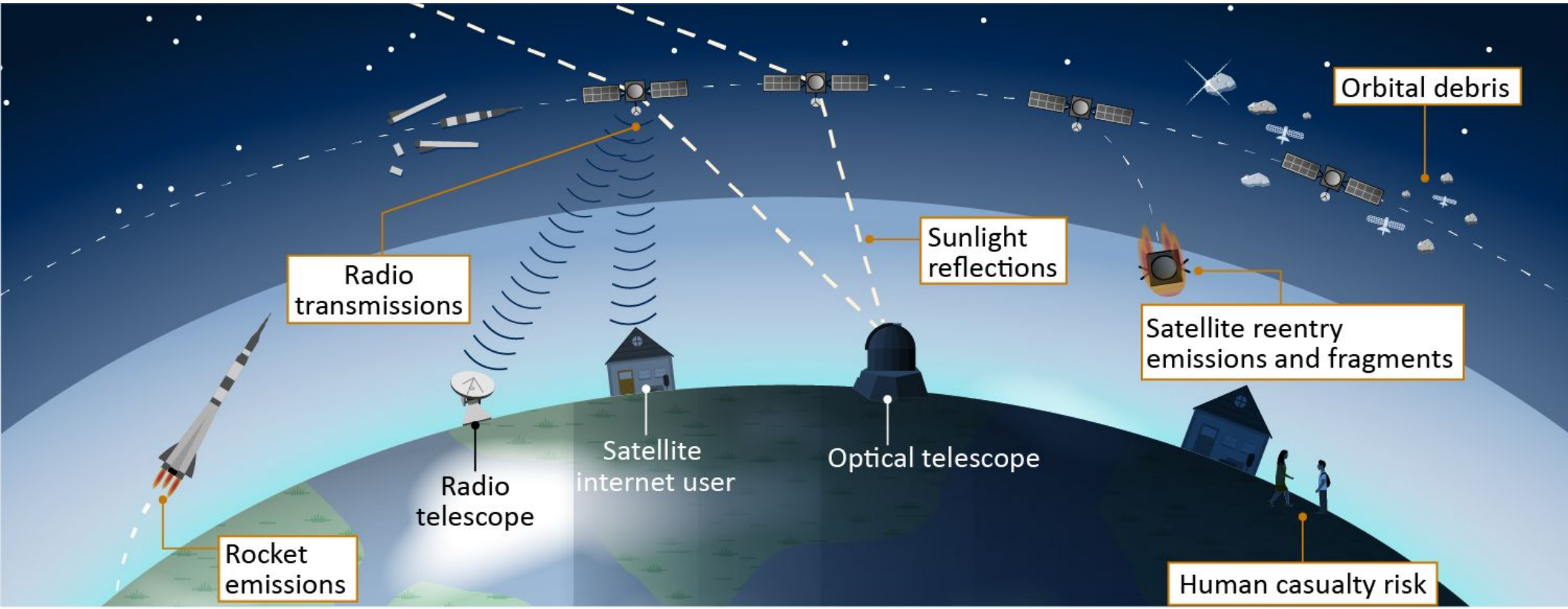
Telsarati

S. Lawler

It is standard practice to assume satellites/rockets will burn up safely in atmosphere at end of life

Satellite megaconstellations have significant environmental impacts throughout their lifecycle.

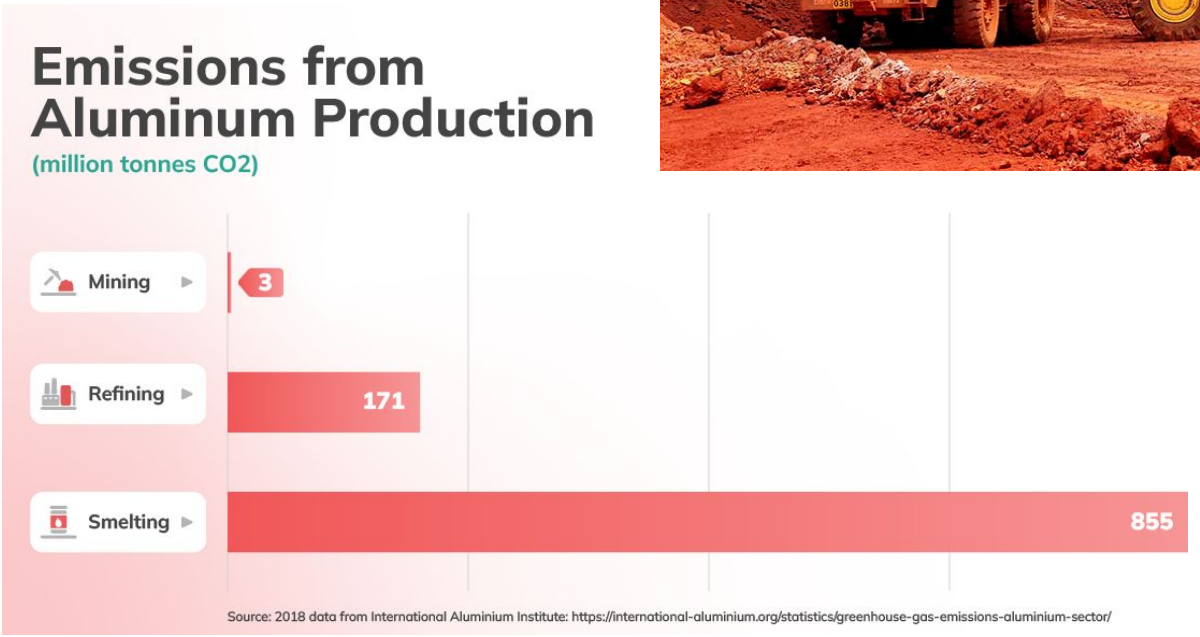
These impacts are more problematic for megaconstellations due to extremely large numbers and disposability. We can still get many/all benefits of satellites with fewer in orbit.



Source: GAO. | GAO-22-105166

Note: Image not to scale.

Mining and manufacturing



carbonchain.com

Rocket testing

Fragile Boca Chica ecosystem endures the impact of SpaceX Starship launches

Texas Public Radio | By Gaige Davila
Published April 18, 2023 at 8:25 AM CDT

Port Isabel reports 'raining particulates' after SpaceX rocket explodes over the Rio Grande Valley

Texas Public Radio | By Pablo De La Rosa
Published April 22, 2023 at 3:37 PM CDT

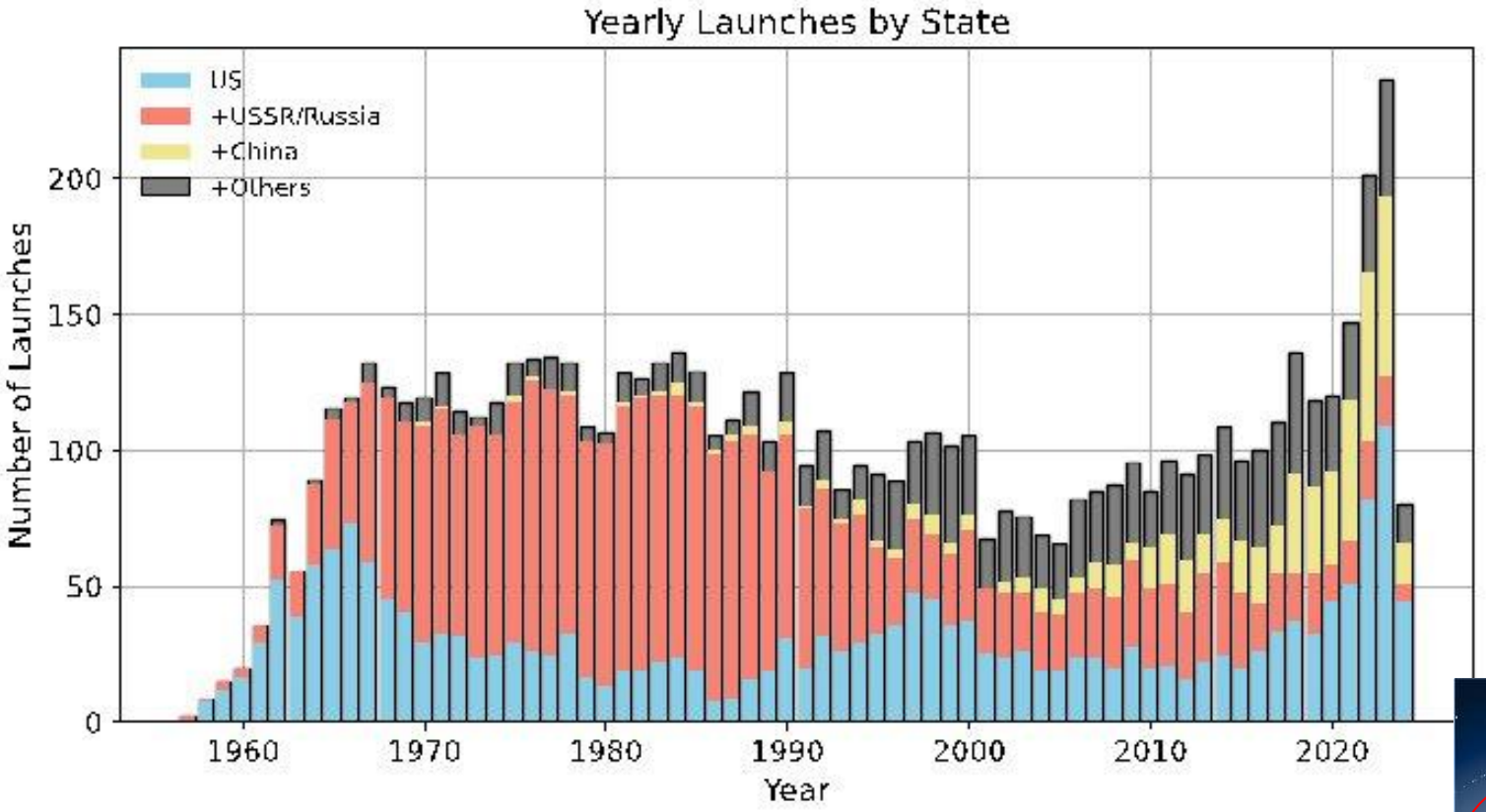
YouTube: LabPadre

Los Angeles Times

Toxic chemicals found in soil and groundwater near former Rocketdyne site in Canoga Park

Radioactive hot spots remain at former Rocketdyne site

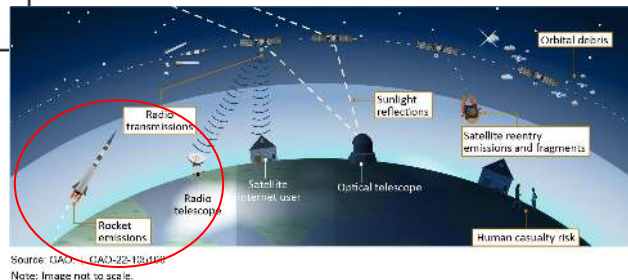
Rocket emissions



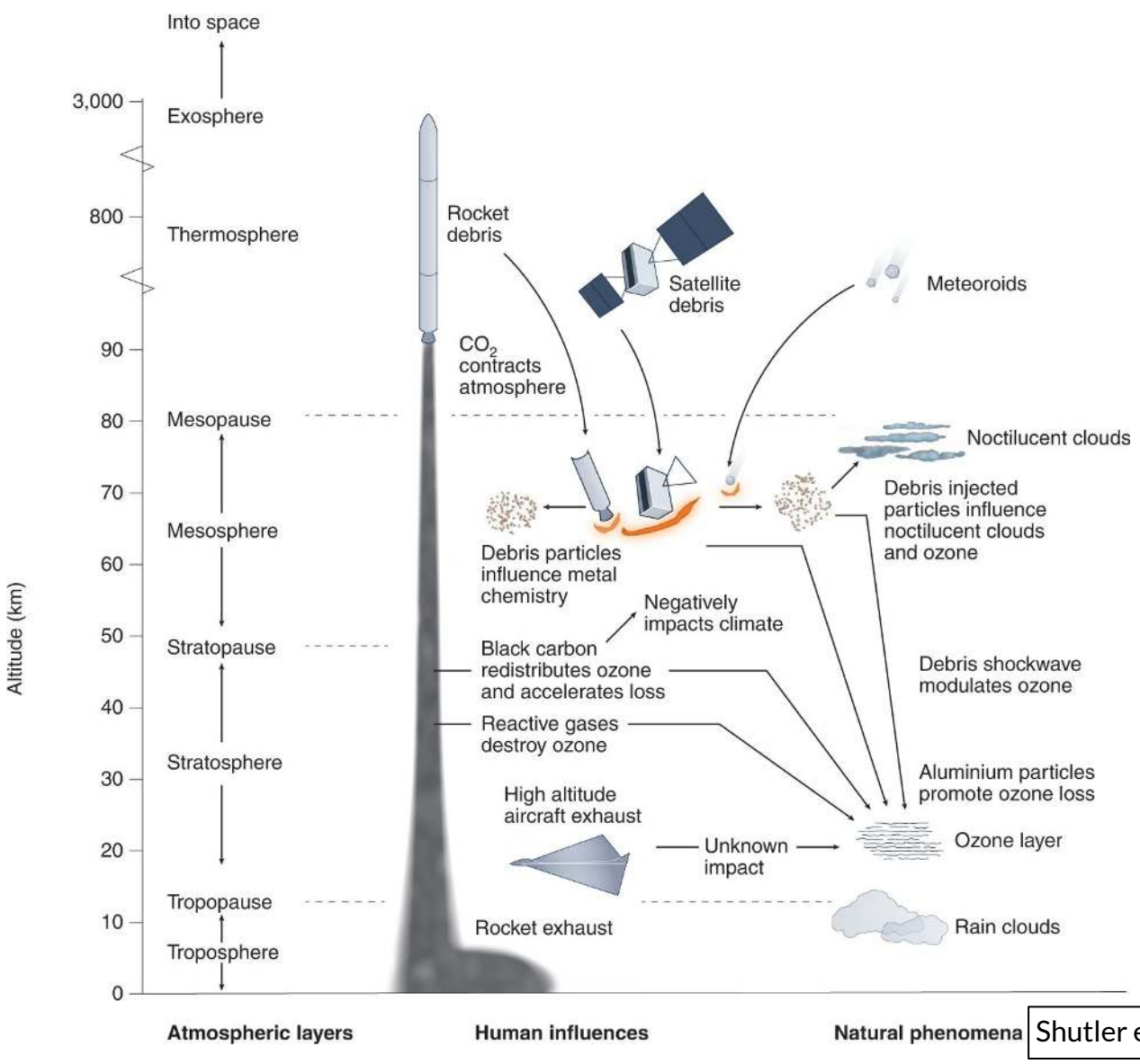
USSPACECOM. 18 April 2024

HUGE increase in the number of rocket launches per year:

Rocket emissions are becoming quite significant

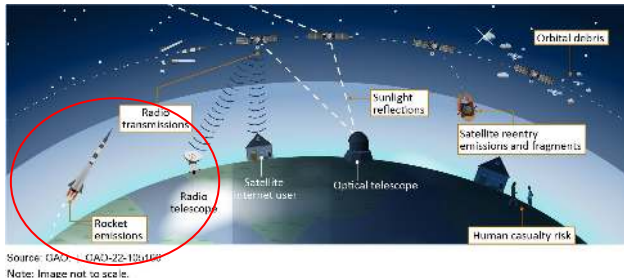


Rocket emissions



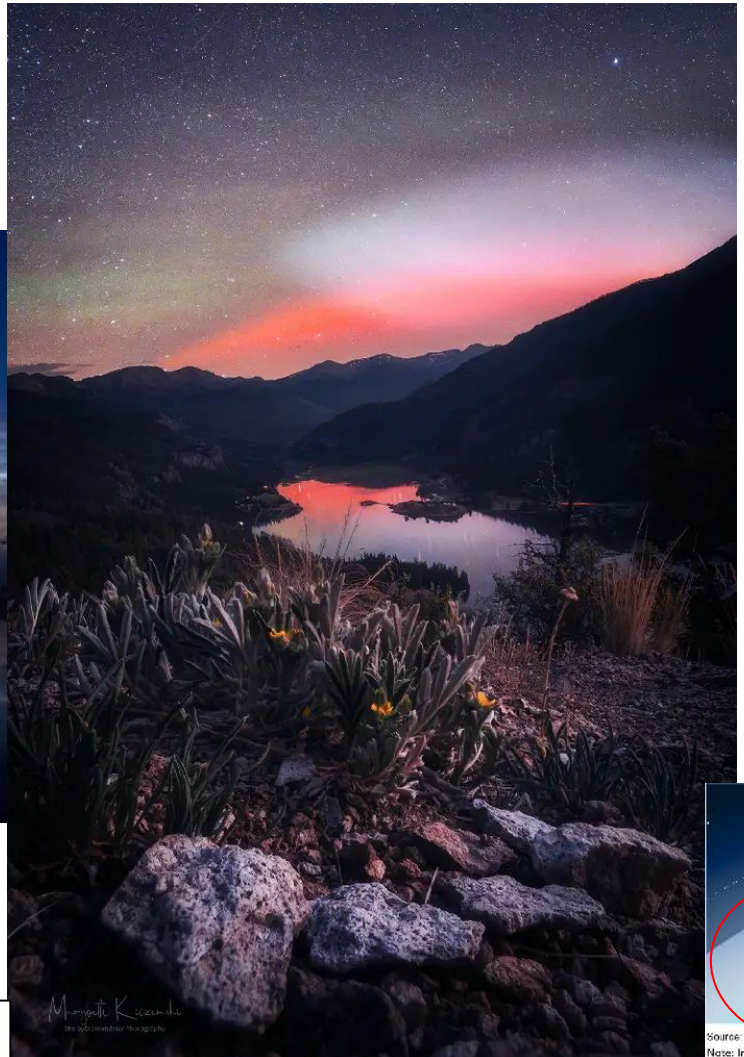
Shutler et al. 2022

- **Black carbon**: changes stratospheric temperatures, could increase ozone depleting chemical reactions
- **Water vapour**: greenhouse gas
- **Carbon dioxide**: greenhouse gas
- **Nitrogen oxides**: deplete ozone
- **Alumina**: deplete ozone
- **Shockwaves**: modulate ozone



Rocket emissions

M. Koitmae

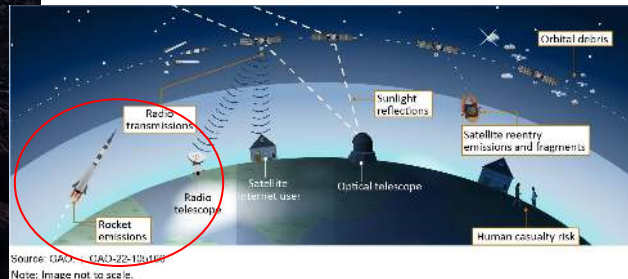


M. Kiczeski

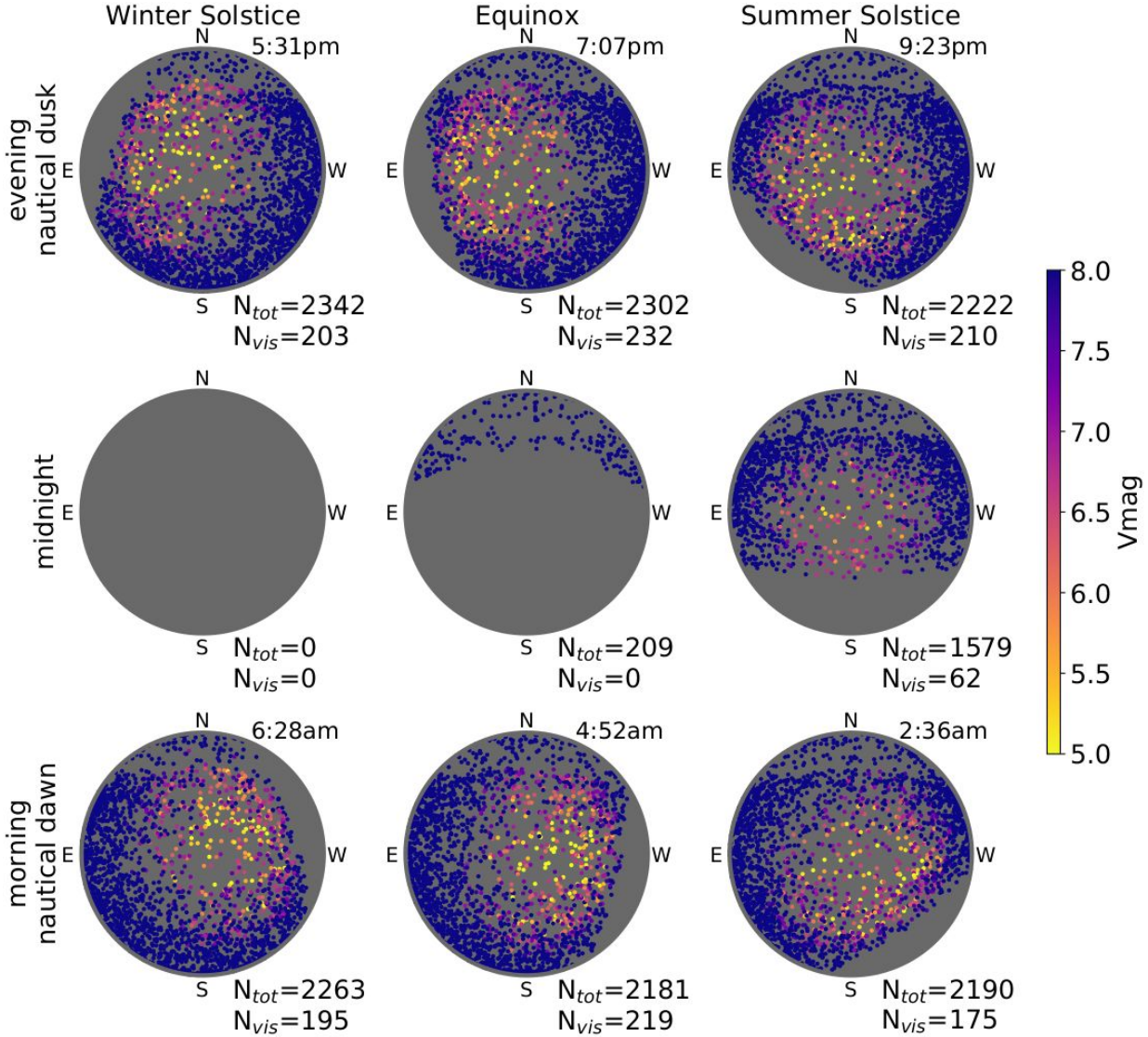
Rocket launches create red ionosphere holes

Rocket launches are seeding high altitude clouds at much lower latitudes than before

How is this changing atmospheric chemistry?



On-orbit issues: light pollution

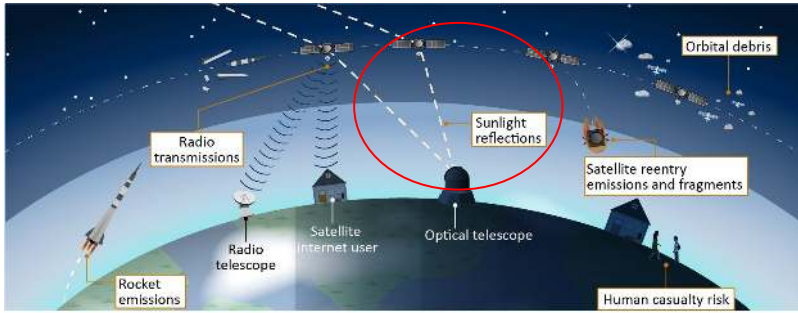


46 degrees north latitude

Lawler, Boley & Rein 2022

Sunlight reflecting off satellites varies with latitude, season, and time of night.

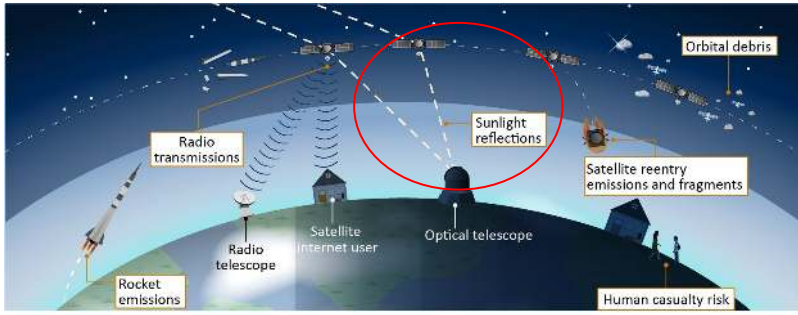
Can be extremely disruptive to astronomy research and stargazing.



Source: GAO. | GAO-22-105166
Note: Image not to scale.

On-orbit issues: light pollution

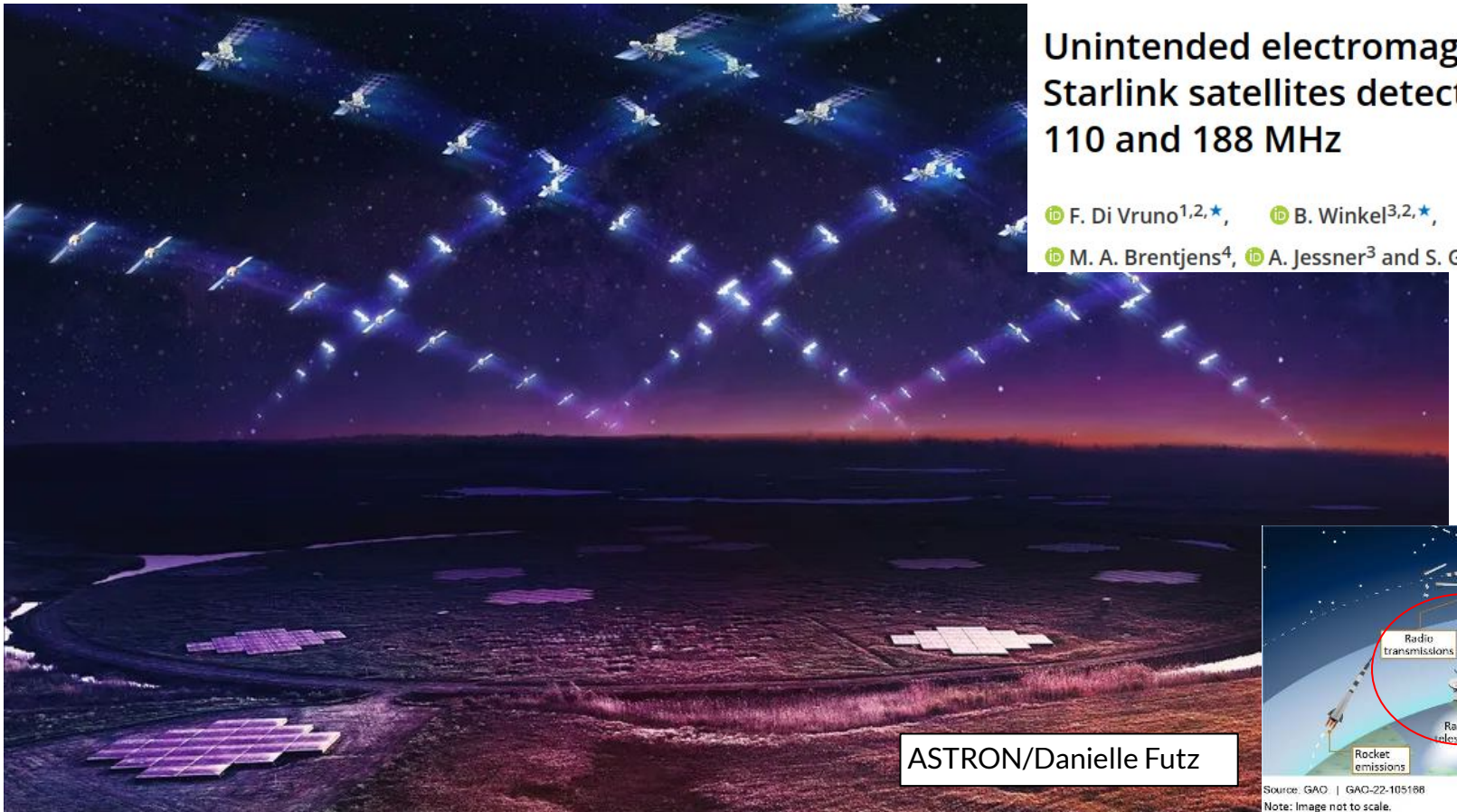
Kruk et al. 2023



Source: GAO. | GAO-22-105166
Note: Image not to scale.

Some say “just launch all your telescopes into space!” but even the Hubble Space Telescope has satellite streaks

On-orbit issues: radio emissions

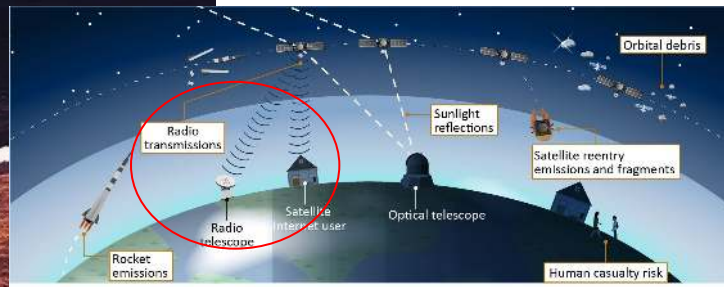


ASTRON/Danielle Futz

Astronomy & Astrophysics

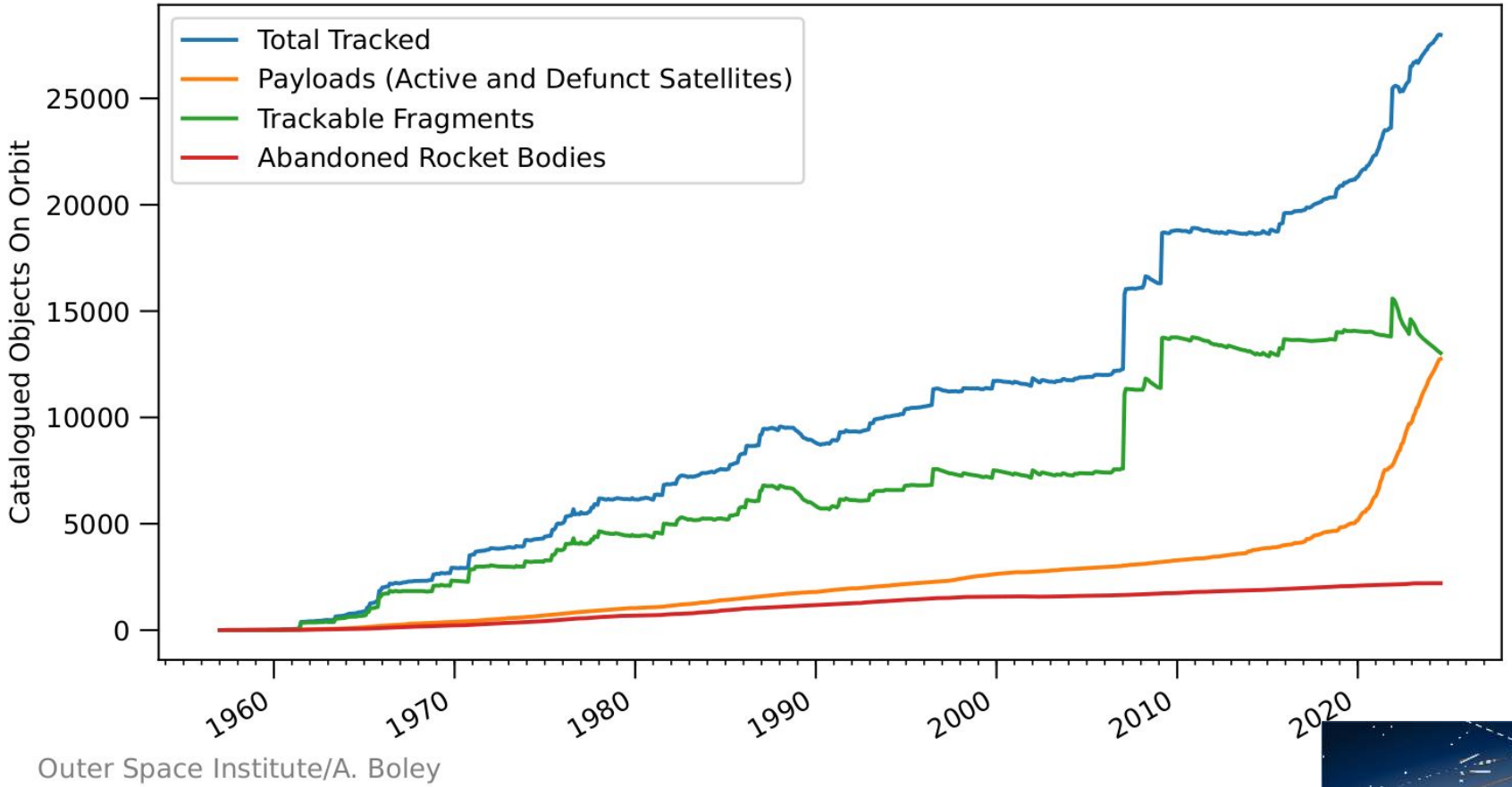
Unintended electromagnetic radiation from Starlink satellites detected with LOFAR between 110 and 188 MHz

F. Di Vruno[1,2,★], B. Winkel[3,2,★], C. G. Bassa[4,★], G. I. G. Józsa[3,2,5,★], M. A. Brentjens[4], A. Jessner[3] and S. Garrington[6,★]

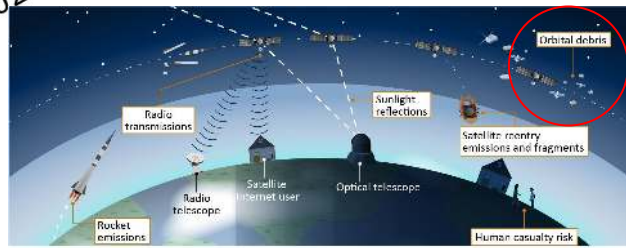


Source: GAO | GAO-22-105166
Note: Image not to scale.

On-orbit issues: collisions



Outer Space Institute/A. Boley



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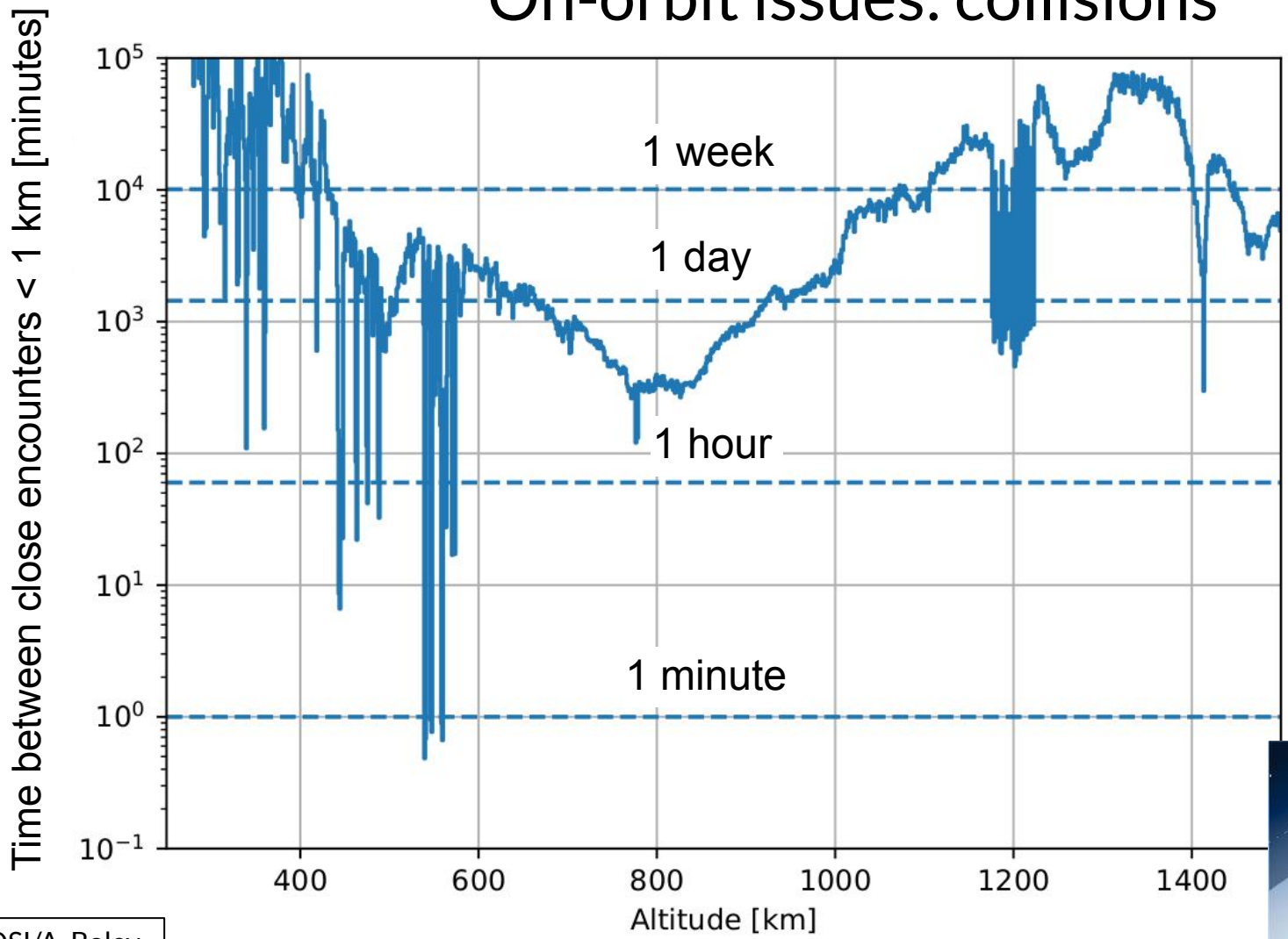
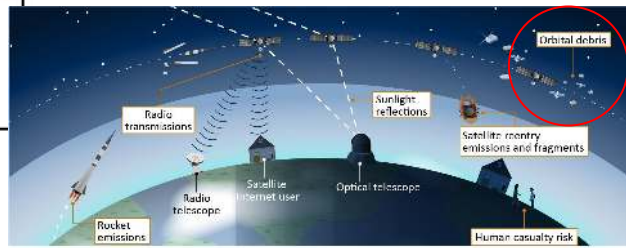
On-orbit issues: collisions



Average time between close approaches (less than 1 km apart), based on current satellite and known debris orbits.



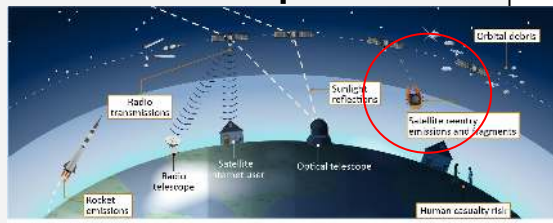
Source: GAO | GAO-22-105166
Note: Image not to scale.

OSI/A. Boley

Re-entries: atmospheric pollution

Corporations are applying the consumer electronics model to Space use

- Starlink and other megaconstellation satellite lifetimes are anticipated to be 5 years
- Allows for regular updates and upgrades
- Failures easily replaced



Re-entries: atmospheric pollution

- Let's say 30,000 satellites each with a disposal mass of ~1000 kg (this is just Starlink Gen2-S)
- 5 yr replacement cycle, ongoing for decades
  - 6,000 tons of satellites disposed of per year
  - 16 tons of satellites disposed per day
- Satellites are supposed to be "fully demisable"

See also Schulz and Glassmeier 2021, Boley and Byers 2021

Satellites

- Assume mostly aluminum alloy (assume 50% Al by mass)
- **8 tons of Al per day**

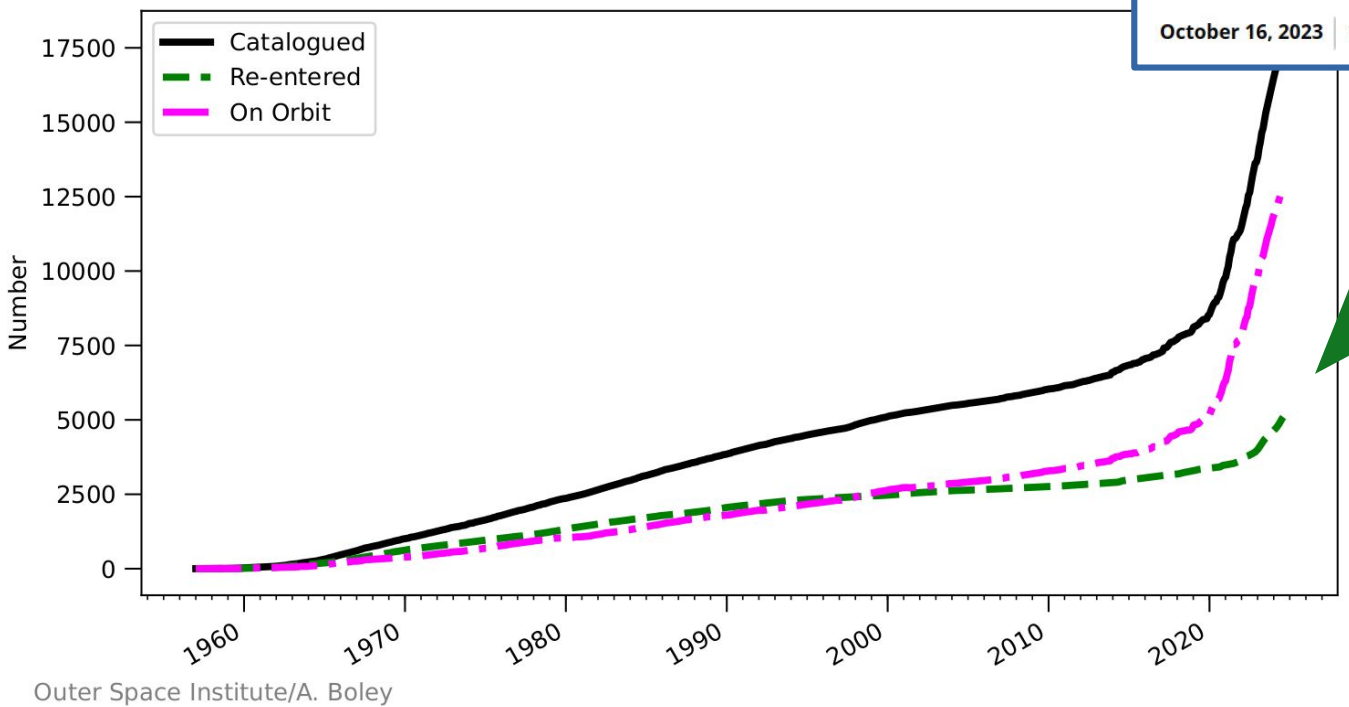
Meteoroids

- 15 tons/day of O
- 6 tons/day of Fe
- 4 tons/day of Si
- 3 tons/day of Mg
- 2 tons/day of S
- 0.4 tons/day of Ni
- **0.3 tons/day of Al**
- 0.2 tons/day of Na

Lodders 2010

Re-entries: atmospheric pollution

A “hockey stick” occurred in the number of launched objects in ~2019. The “hockey stick” in re-entering objects is starting now.



RESEARCH ARTICLE | EARTH, ATMOSPHERIC, AND PLANETARY SCIENCES

Metals from spacecraft reentry in stratospheric aerosol particles

Daniel M. Murphy, Maya Abou-Ghanem, Daniel J. Cziczo, +7, and Xiaoli Shen Authors Info & Affiliations

Edited by Mark Thiemens, University of California, San Diego, CA; received August 3, 2023; accepted September 7, 2023

October 16, 2023 | 120 (43) e2313374120 | https://doi.org/10.1073/pnas.2313374120

10% of stratospheric aerosols are **already** from satellite and rocket re-entry pollution

Re-entries: casualty risks on the ground


2020: dropped by China on Cote D'Ivoire


2021: dropped by USA (SpaceX) on Australia


2024: dropped by USA (SpaceX) on USA

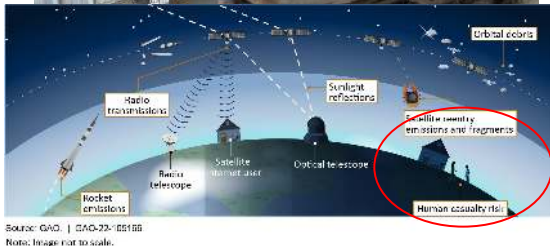

2022: dropped by China on Myanmar


2021: dropped by China on India


2024: dropped by USA (NASA) on USA

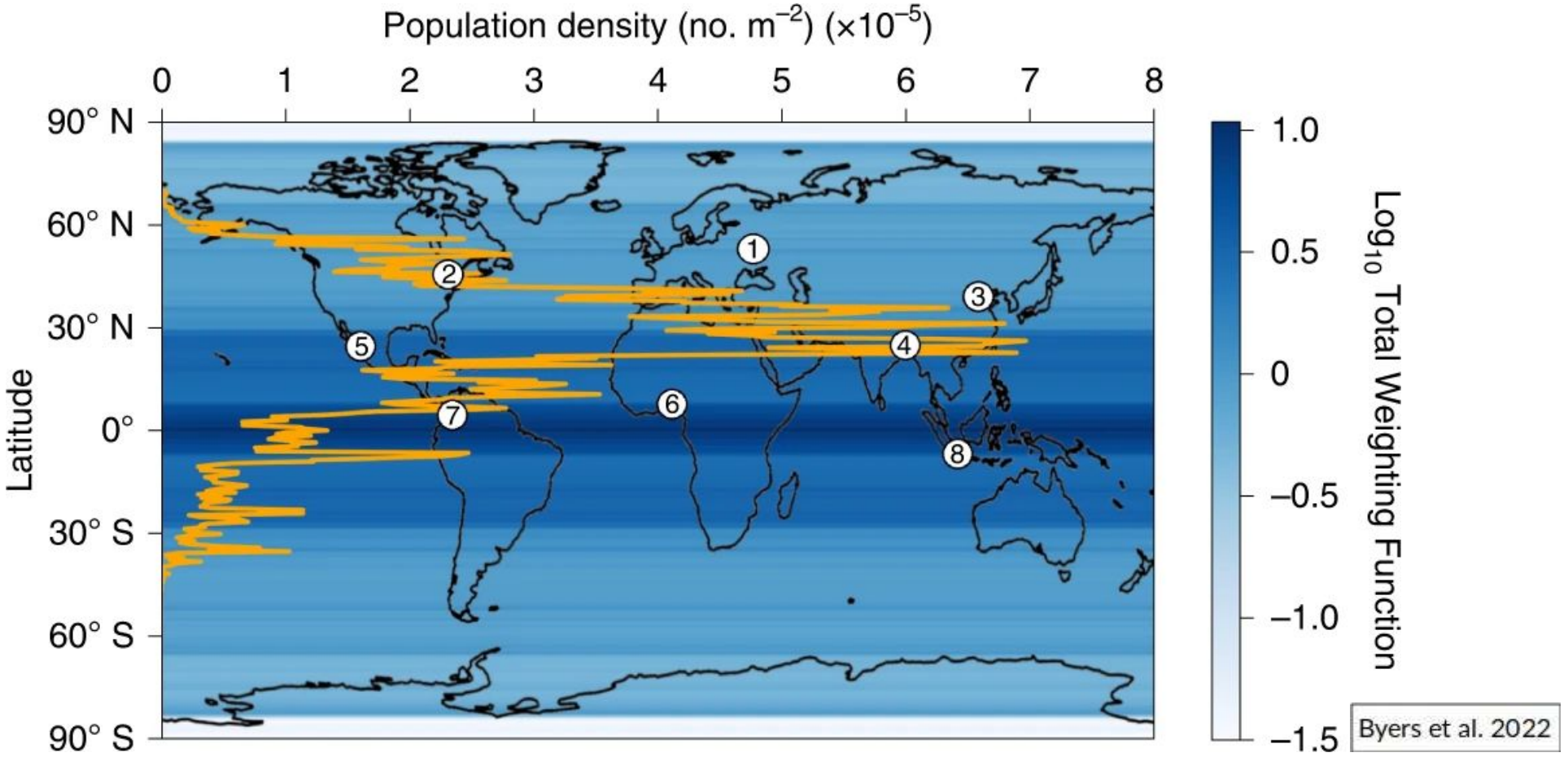

2024: dropped by USA (SpaceX) on Canada


2021: dropped by USA (SpaceX) on USA

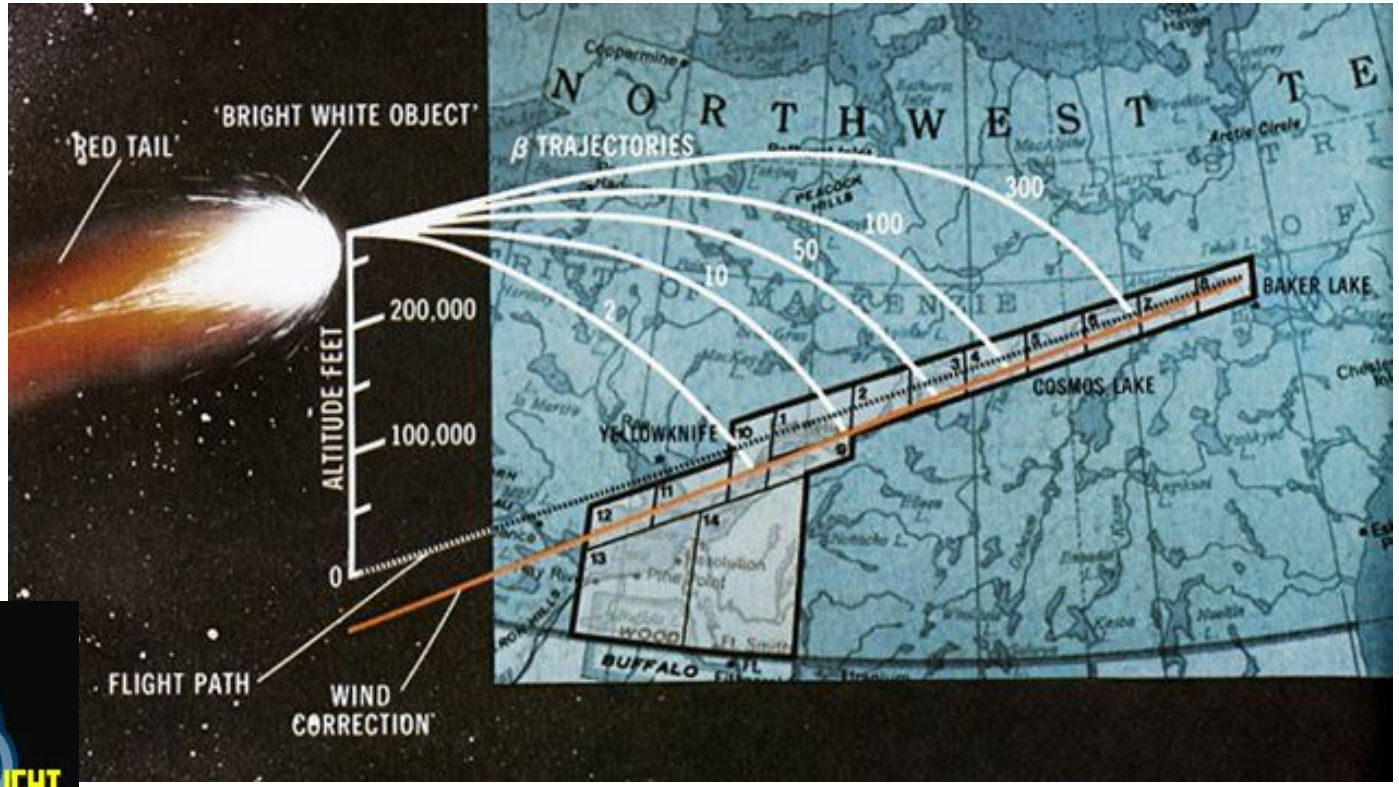


Source: GAO. | GAO-23-105166
Note: Image not to scale.

Re-entries: casualty risks on the ground
Will be worse for Global South



The 1968 Outer Space Treaty and the 1972 Liability Convention

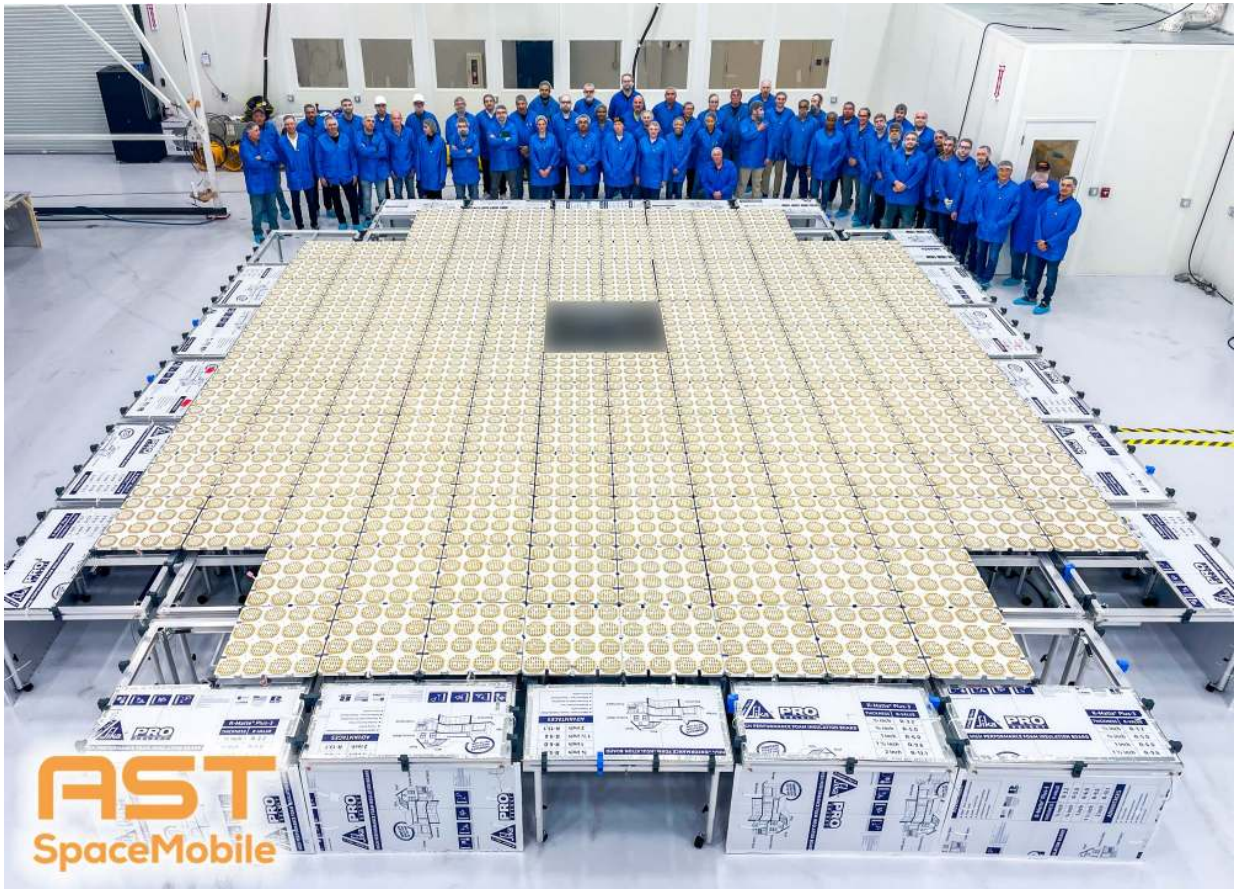


USSR's Cosmos-954 exploded nuclear waste across Canada: Jan. 24, 1978

The future?

- Starlink: 40,000+
- OneWeb: 7,000
- Kuiper: 3,000
- Xingwang: 1,000
- Guanwang: 13,000
- Yinhe: 1,000
- Hanwha: 2,000
- Lynk: 2,000
- Astra: 14,000
- HVNet: 1,400
- SpinLaunch: 1,200
- Globalstar3: 3,000
- Honghu-3: 10,000
- Semaphore: 120,000 (!)
- E-Space: 337,000 (?!!)

J. McDowell: planet4589.org



See Nandakumar et al. 2023, *Nature*

We need international regulation of satellites

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POLICY FORUM | SPACE GOVERNANCE

One million (paper) satellites

Radiofrequency filings warn of more congestion in space, but also offer possible remedies

ANDREW FALLE, EWAN WRIGHT, AARON BOLEY, AND MICHAEL BYERS Authors Info & Affiliations

SCIENCE · 12 Oct 2023 · Vol 382, Issue 6667 · pp. 150-152 · DOI: 10.1126/science.adi4639

- Hanwha: 2,000
- Lynk: 2,000
- Astra: 14,000
- HVNet: 1,400
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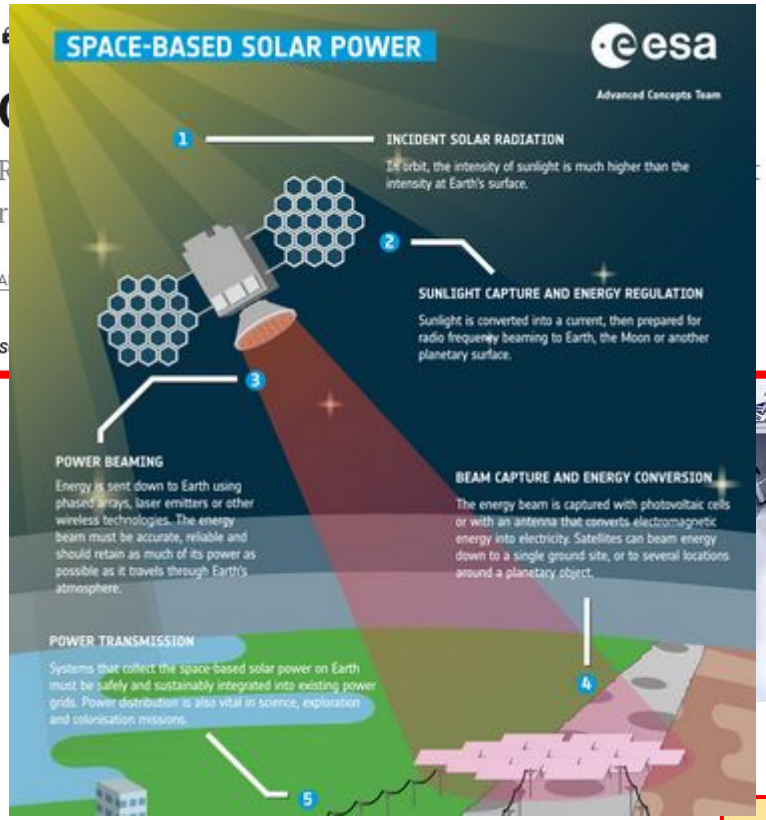

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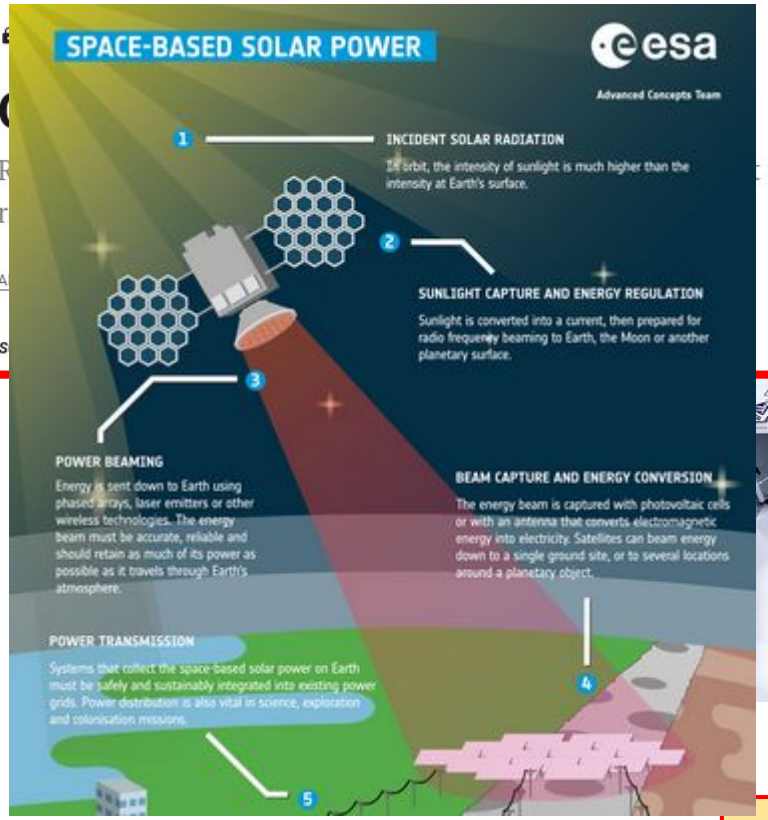
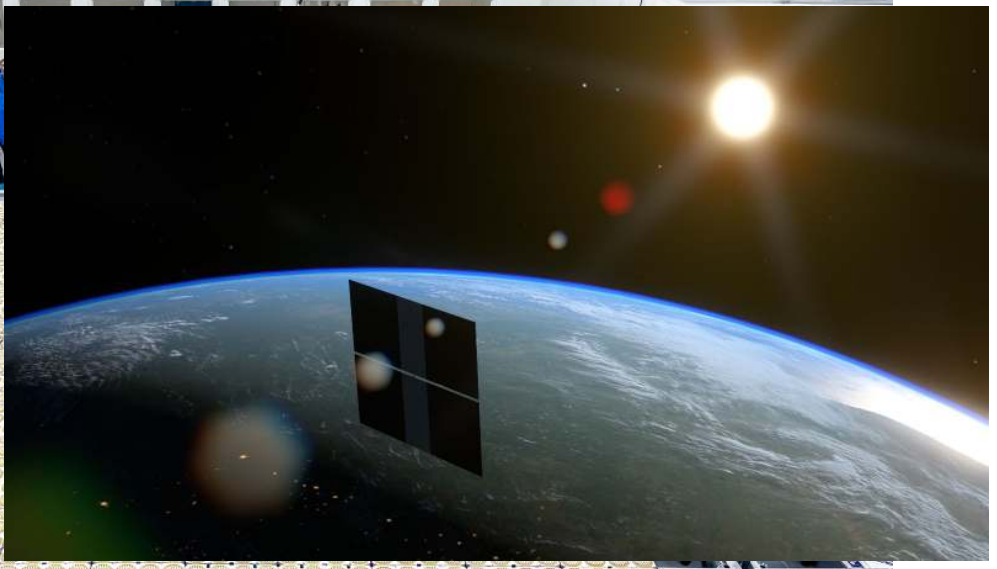
also offer possible





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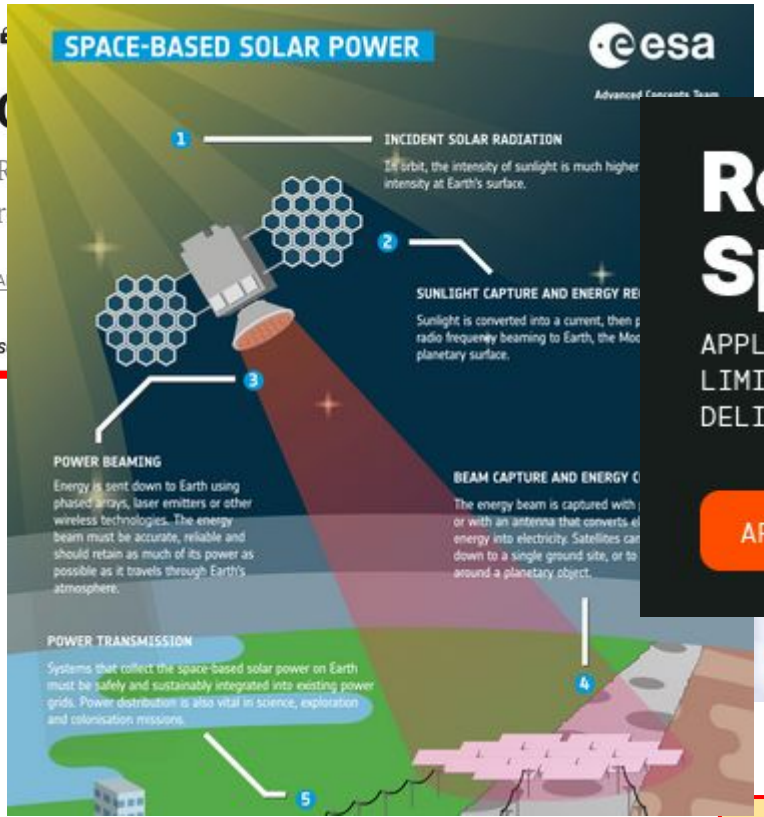

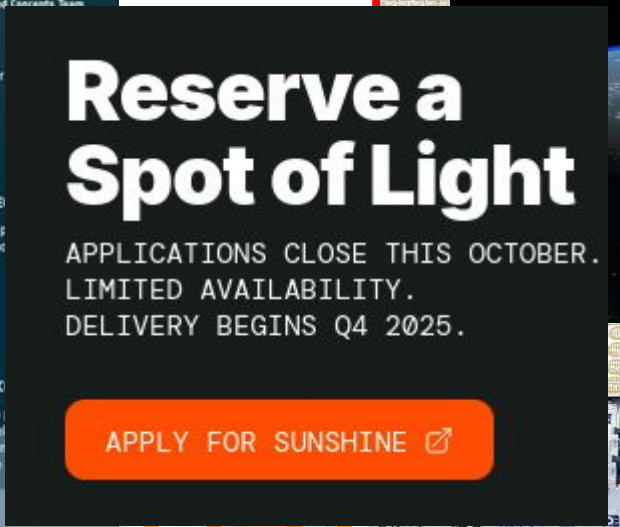

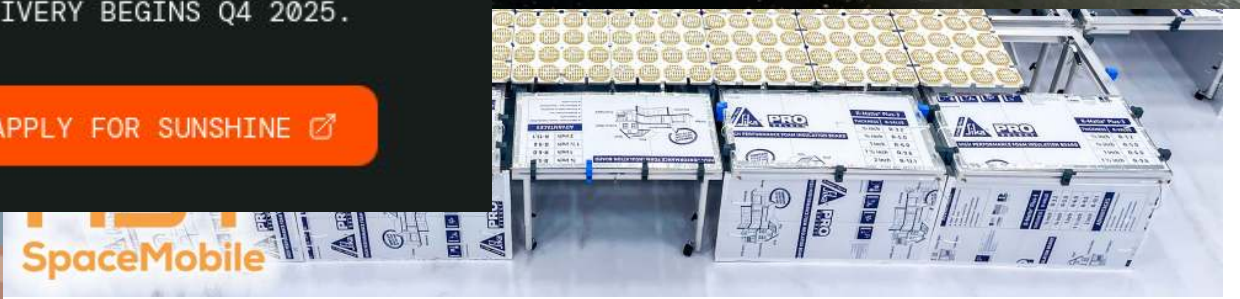

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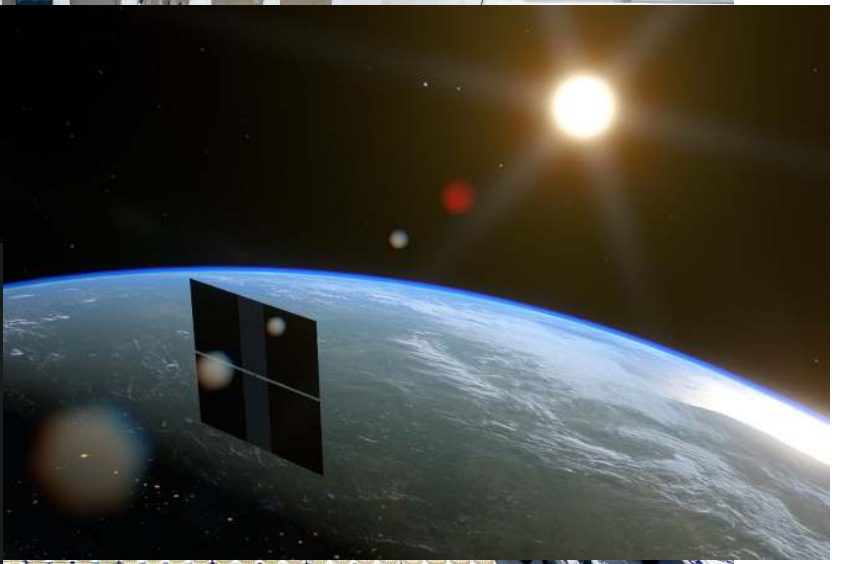

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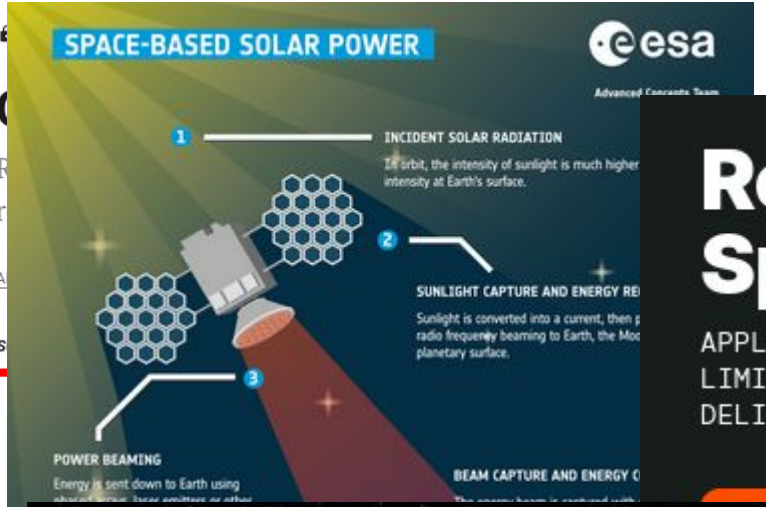

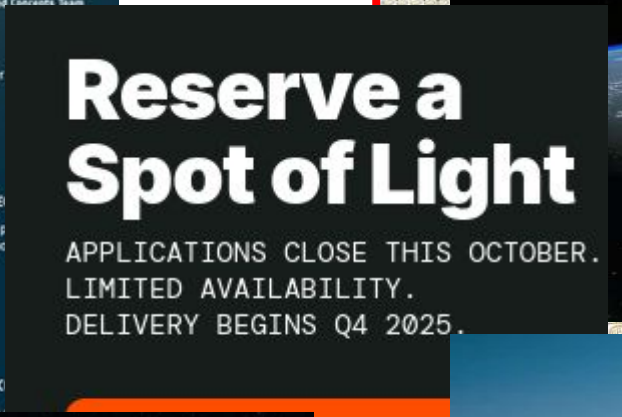

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Points to think about and discuss:

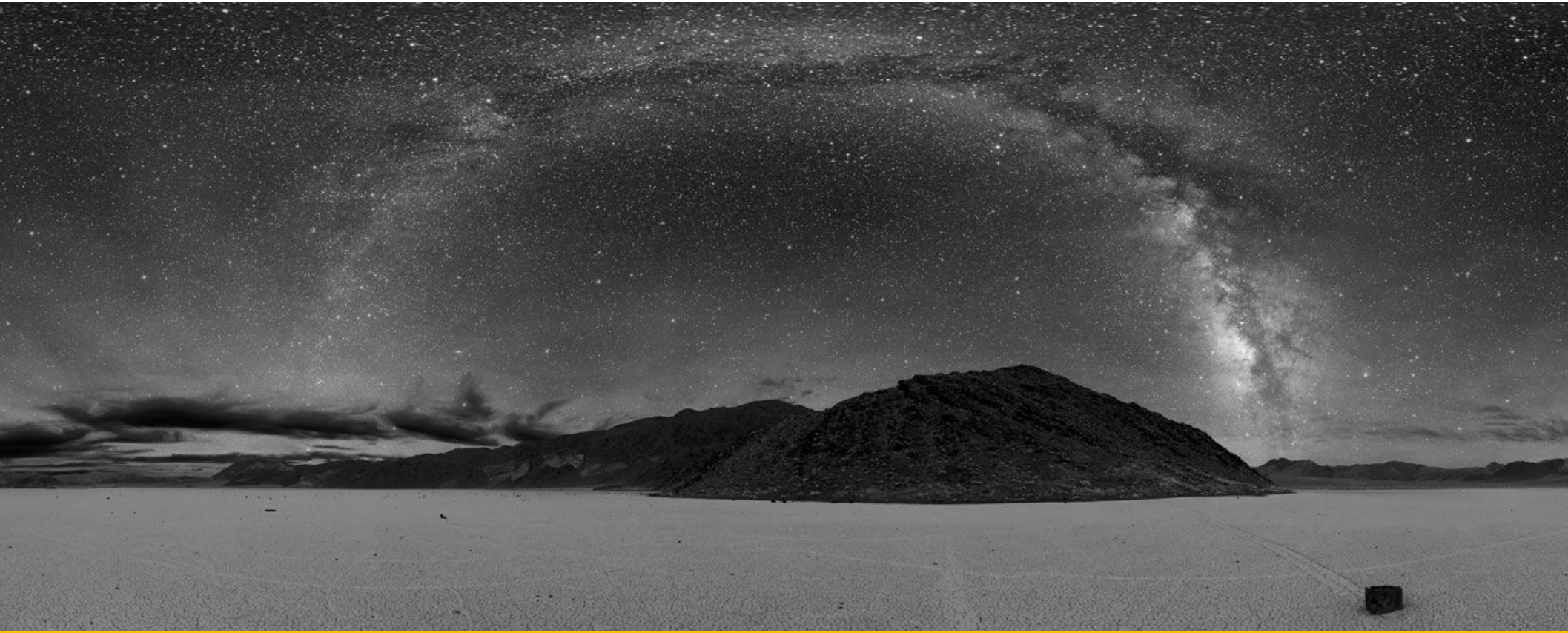
- We CANNOT have tens of thousands of satellites in orbit without severe consequences (environmental consequences, and potential loss of the use of Low Earth Orbit for decades-centuries).

- How do we safely use Earth's orbit today so future generations may also use orbit?

- How do we prioritize the most beneficial satellites, and not just whoever launches first?

- The Outer Space Treaty and Space Liability Convention need to be updated and enforced

Low Earth Orbit is a finite, fragile resource that must be carefully protected by all levels of government, worldwide



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