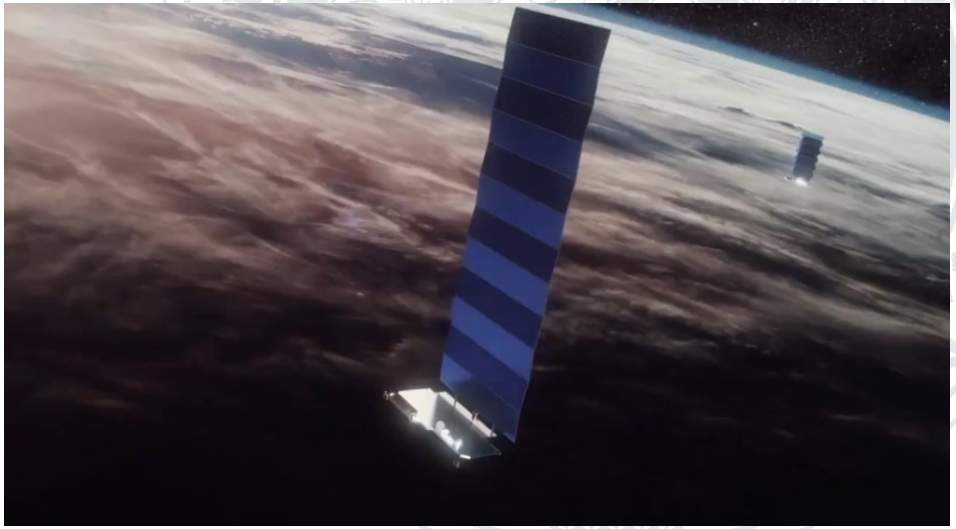
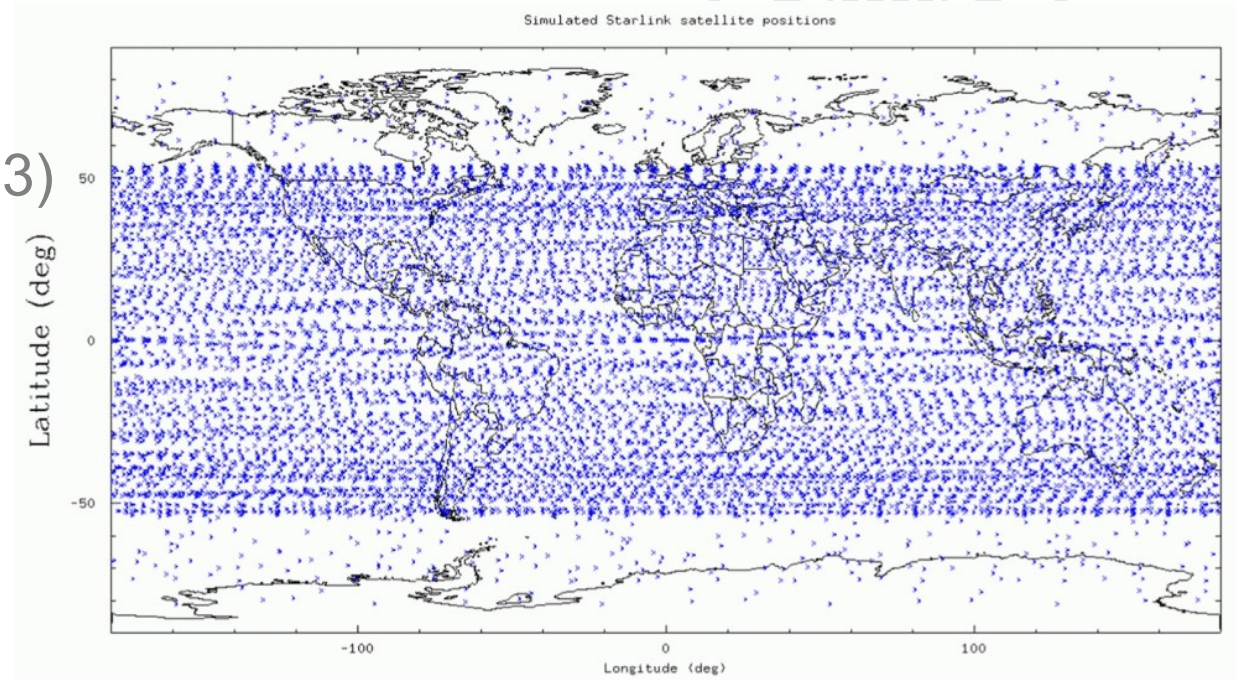
The promise and curse of Mega-Constellations

OneWeb advertisement

What are they?

- Starlink (SpaceX):
  - 11914 satellites at 340 and 550km
    - 3374 active (01/06/2023)
    - So far 3666 launched
    - 30000 more filed for permission at FCC
- Competitors:
  - OneWeb:
    - 502 in orbit (01/09/2023)
    - completed: 648
    - 2nd generation: 6372
  - Guo Wang (China)
    - planned: 12992
  - Project Kuiper (Amazon)
    - planned: 3236

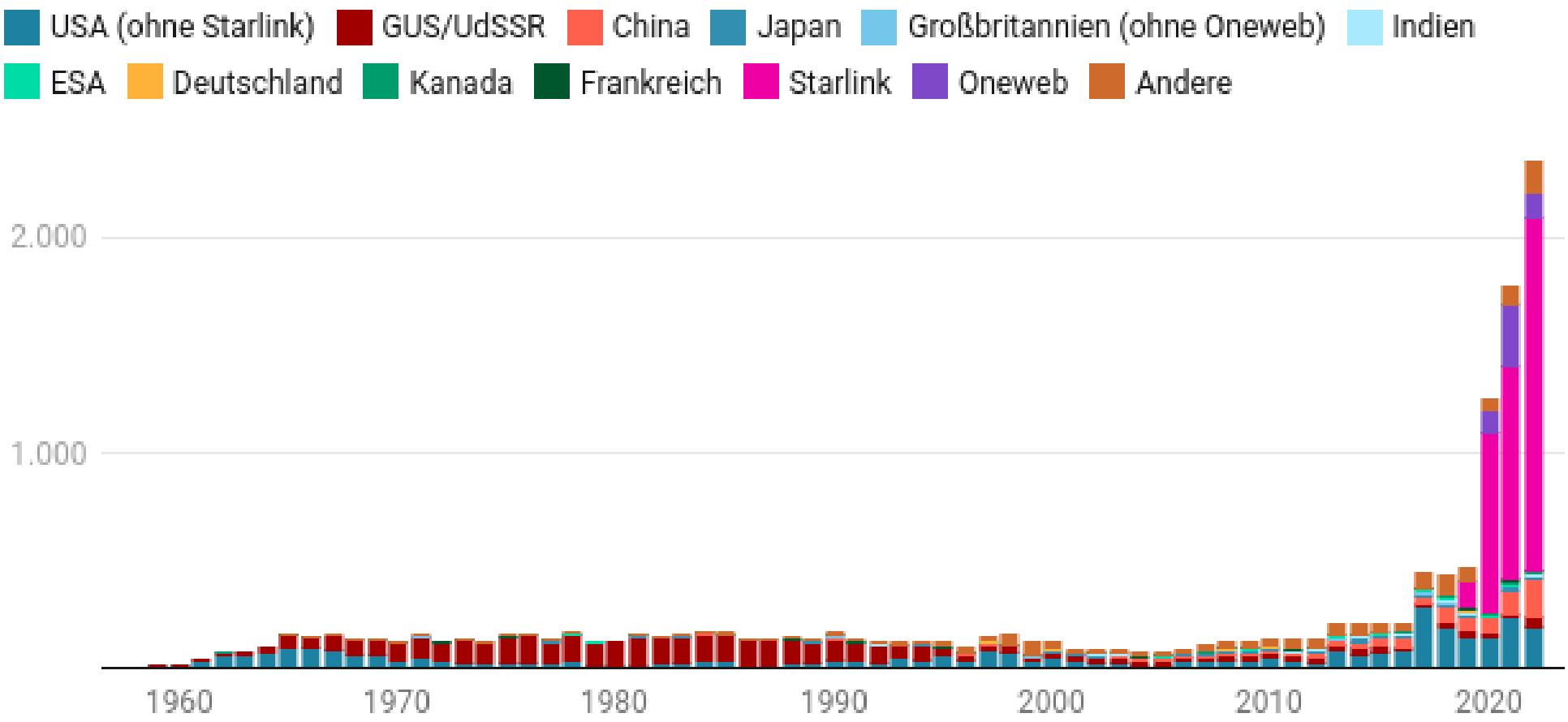




Typical Starlink configuration (McDowell 2021)

Mega-Constellations

- Compare 3374 to 1900 active satellites in total before Starlink
  - Completely new quality of space use



The “promise”

- Fast satellite and affordable internet
  - Worldwide available
    - 80€/month for German users
    - 480€ initial costs (01/06/2023)
  - Reliable and fast at remote places
  - Supply for Ukraine
    - 23000 systems delivered after February 24
    - 7000 in use

Starlink antenna

Klitschko brothers welcoming Starlink deliveries to Kiew

RadioSky close to San Pedro de Atacama

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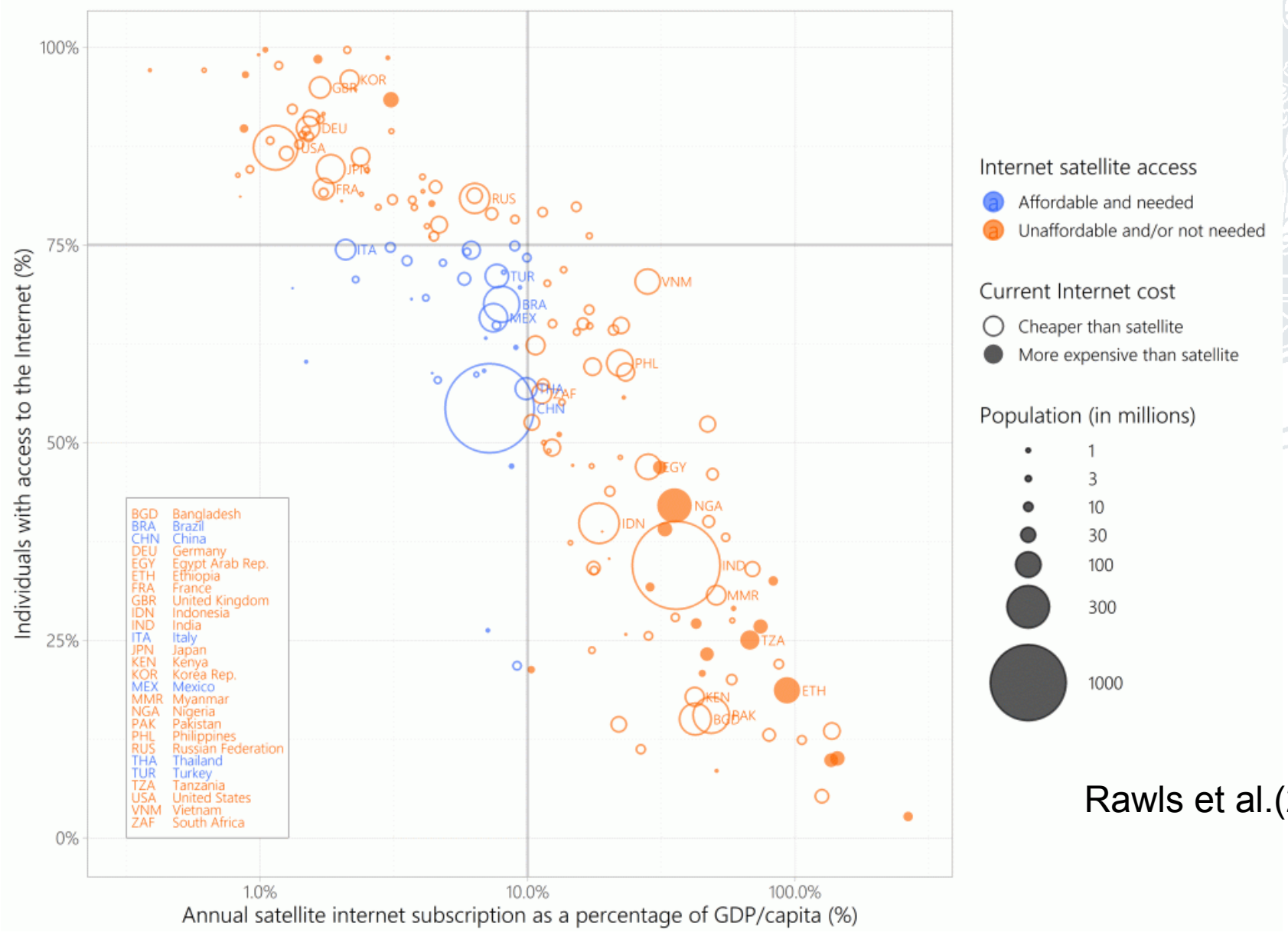
Starlink antenna

Klitschko brothers welcoming Starlink deliveries to Kiew

- No significant impact for internet infrastructure in Ukraine
  - very stable due to very decentralized structure (4th worldwide)
    - 19 international gateways
    - more than 900 providers

Affordability

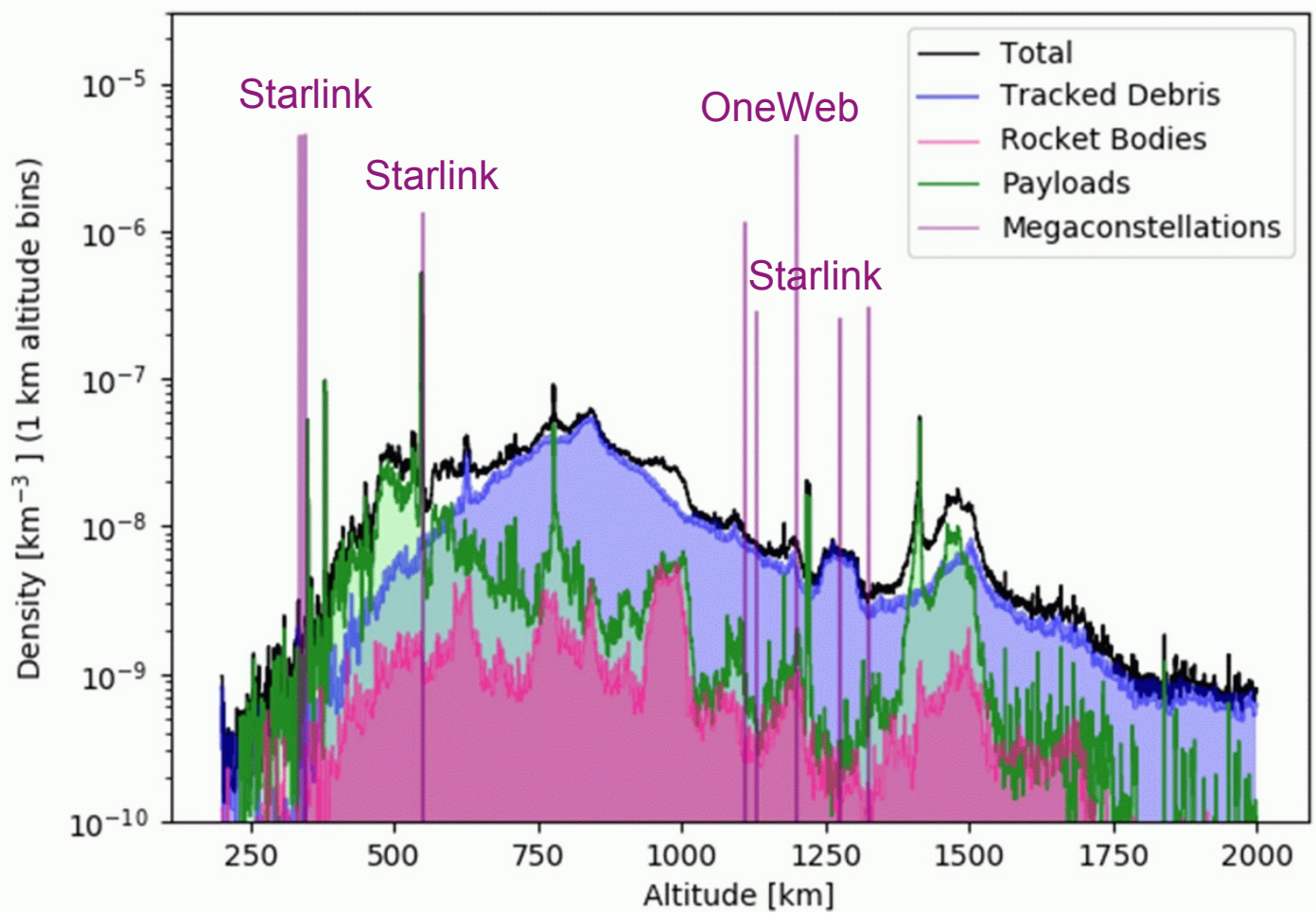


Rawls et al.(2020)

- In large parts of the world either not affordable or not needed

In-space problems

High density of satellites at particular altitudes



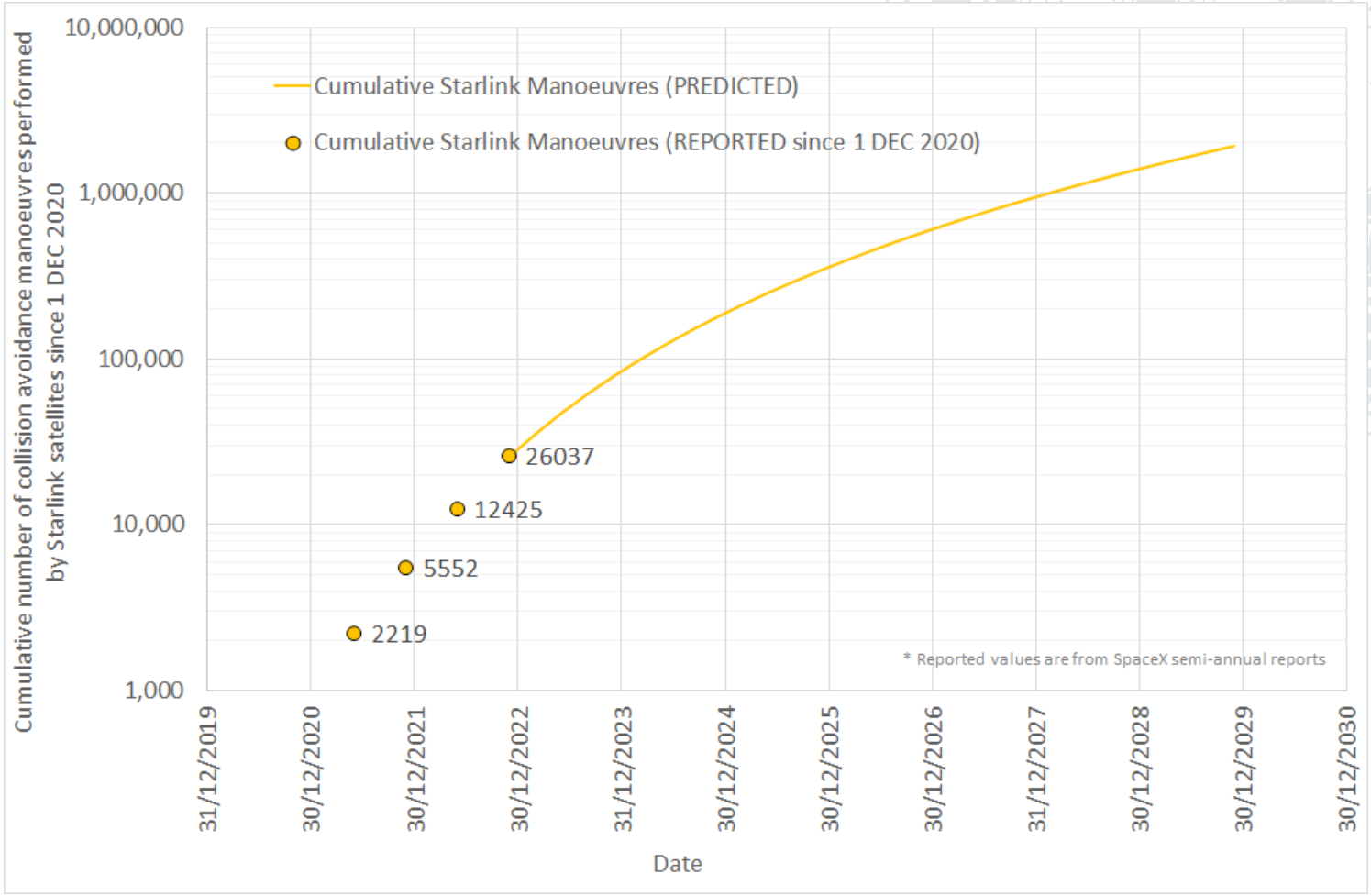
Bodies > 10cm
Boley &
Byers (2021)

- Requires sophisticated collision avoidance

Disclaimer: Figure assumes 2nd generation density for OneWeb

In-space problems

Collision avoidance:



- Currently already ~75 manoeuvres per day
- One every 2 minutes with full constellation

Collisions

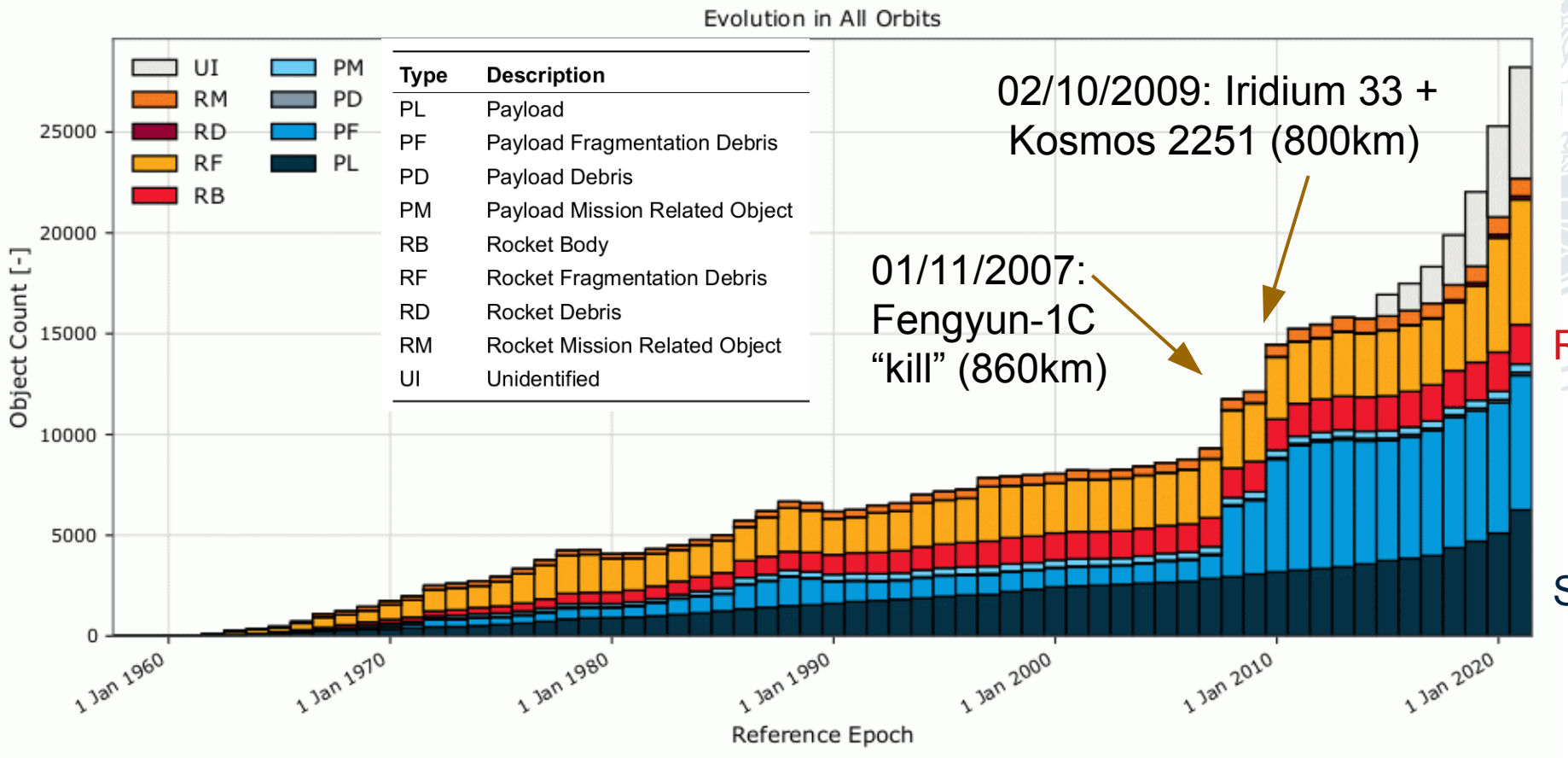
- Not everything moves in the same direction
  - Collisions always with velocities ≈ 8km/s ≈ 30000km/h
  - Extremely destructive - produce many fragments
  - Exponential growth of the number of particles!

”Kessler Syndrom”

(Donald J. Kessler, NASA 1978)

Historic development

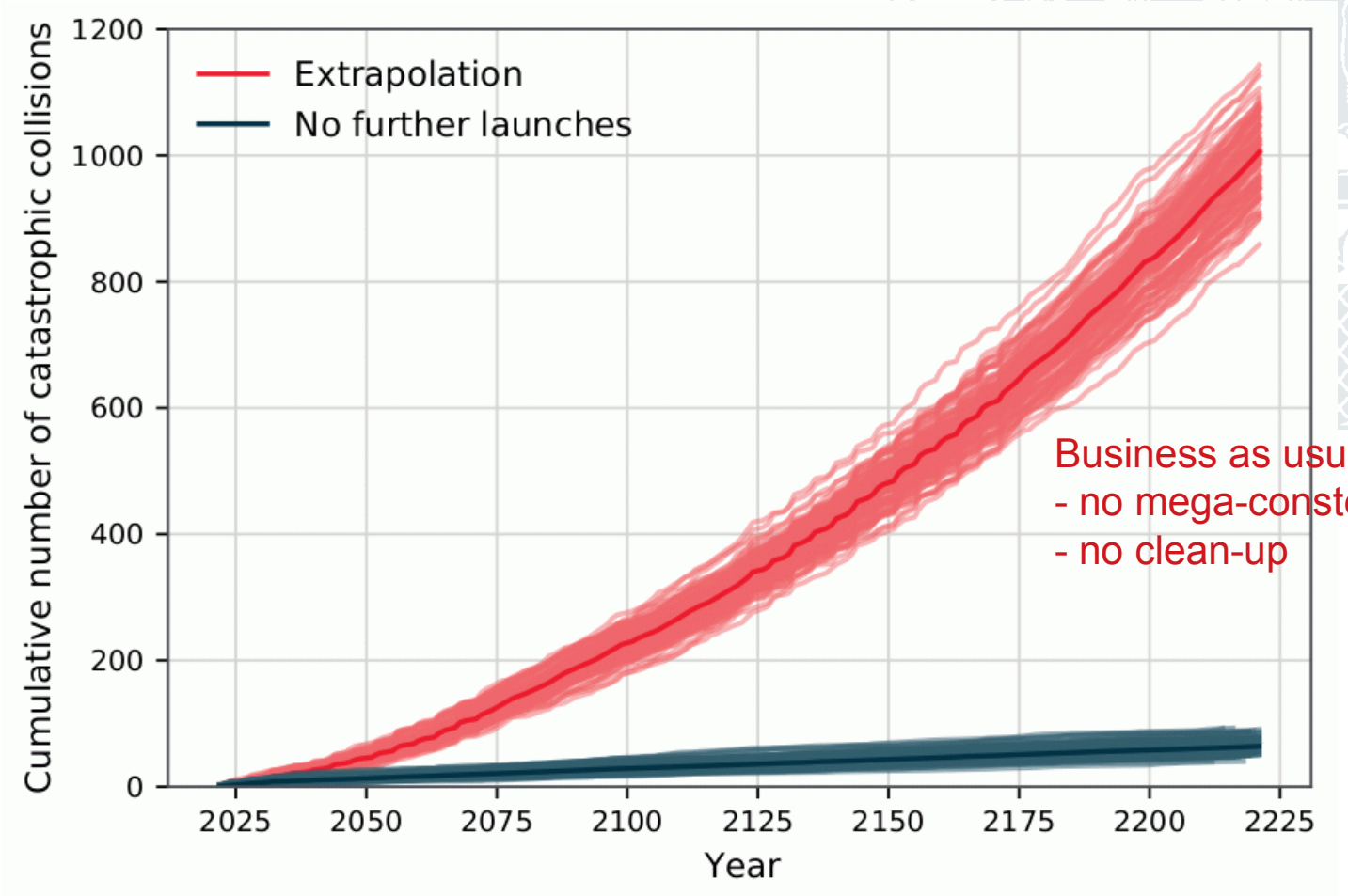
- Objects > 10cm:



- ~28000 particles > 10cm today
  - 6000 spacecrafts, 1800 upper stages, rest: fragments
- Particles > 1cm: ~1Mio

Long term projection

- Exponential growth even without Mega-Constellations



- Even at the pre-Starlink launch rate:

  End of space flights in < 100 years

The Starlink contribution

- Already 32 out of control
- 6 currently unclear
- 15 with uncontrolled re-entry
  - Compare Iridium: 35% defunctional before mission end

Typical mass launch of Starlink blade satellites with one rocket (60 satellites with Falcon 9, 25.5.2019)

- Even in normal operations collision avoidance difficult
  - Impossible for other missions at the same altitude
  - No “traffic rules” in space
    - Critical event: Starlink44 on collision course to Aeolus on 09/02/2019

- Basically exclusive usage of orbital altitude→ violates Outer Space Treaty

Legal situation

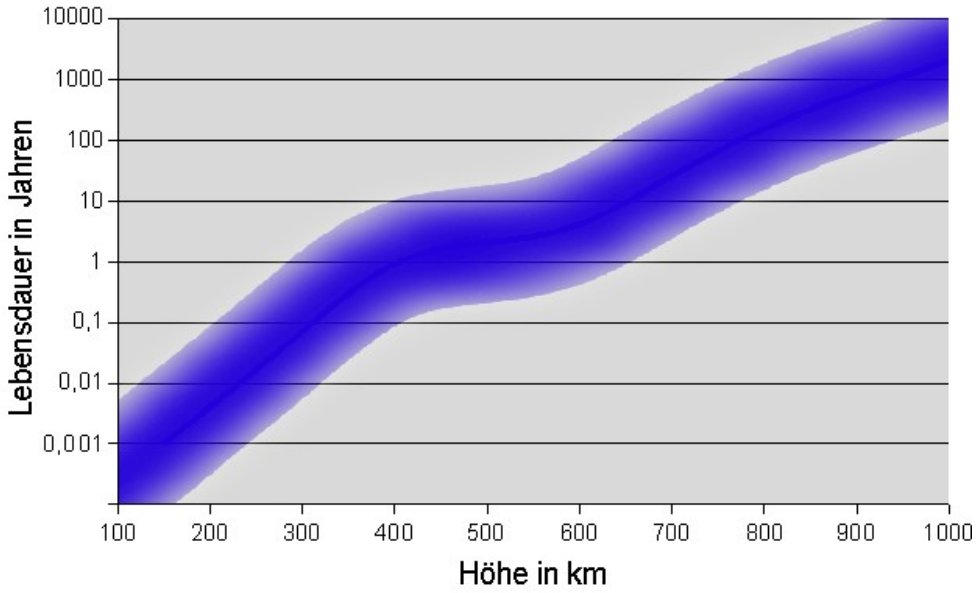
- Outer Space Treaty (1967)
  - Outer space shall be free for exploration and use to all countries “without discrimination of any kind.”
  - “Outer space ... is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means.”
  - Space activities must be conducted “with due regard to the corresponding interests of other States”.
- Liability Convention (1972)
  - States shall be responsible for national space activities whether carried out by governmental or non-governmental entities
  - States shall be liable for damage caused by their space objects
- Derived international initiatives:
  - Inter-Agency Space Debris Coordination Committee (IADC, 2007), currently: 13 space agencies
  - 2010 - 2018 UN COPUOS Working Group

Results

- Non-binding recommendations:
  - 2007 UN Space Debris Mitigation Guidelines

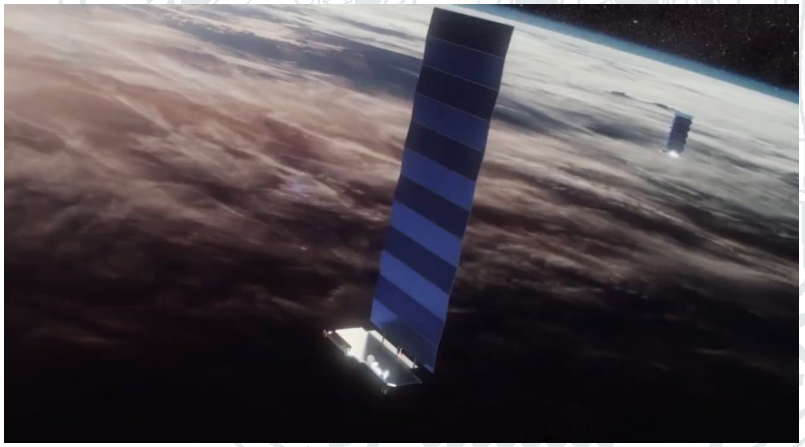
→ Post-Mission-Disposal, PMD:

- Direct re-entry at mission end or re-entry within <25a
  - Bring down to altitudes ≤500km
    - Altitudes below 500km are “self-cleaning” within 25 years due to friction from the upper atmosphere
    - Significant uncertainty depending on solar activity



Starlink

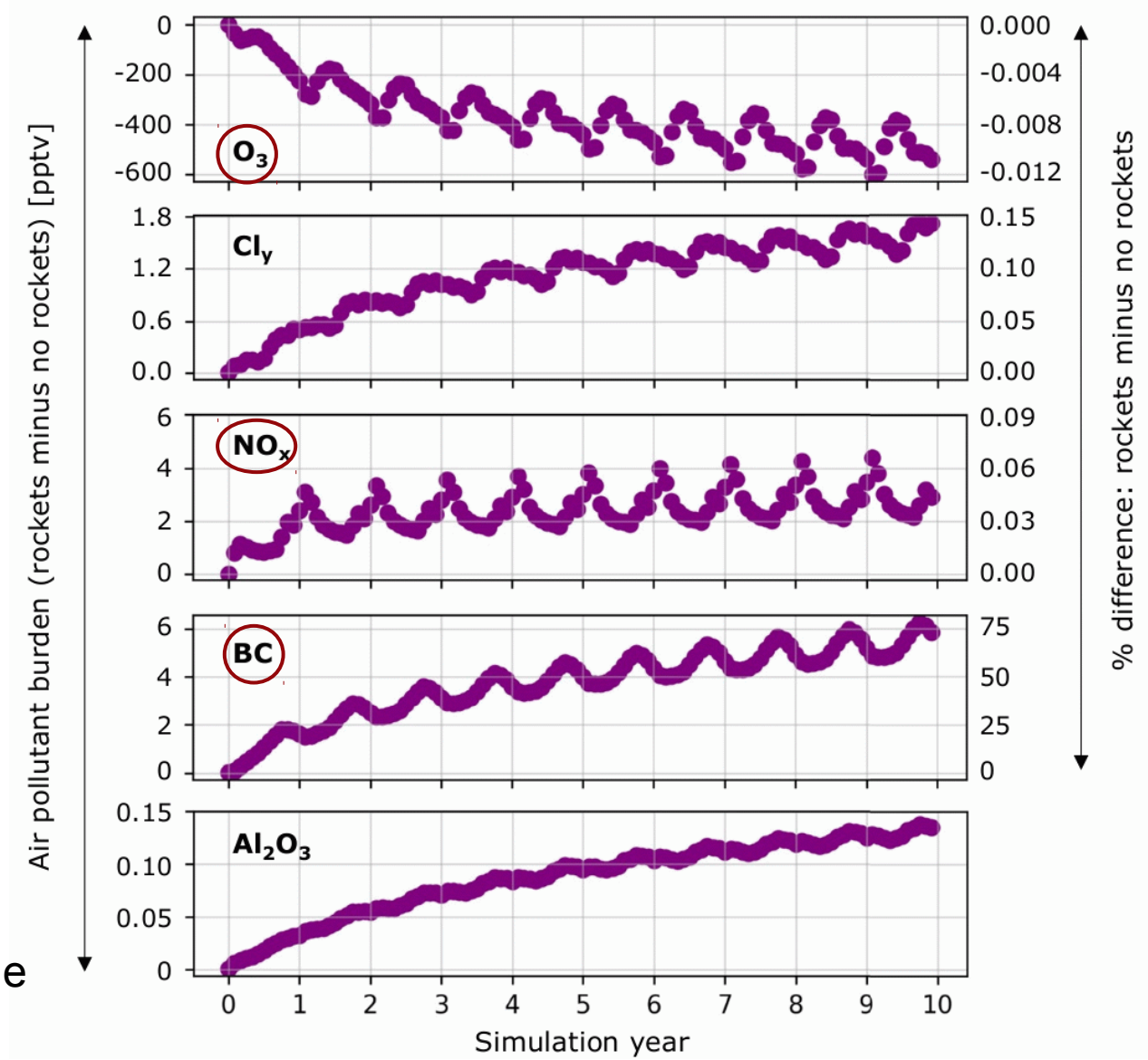
Re-entry plans:



- Planned lifetime: 5-6a
  - Direct re-entry integrated
    - 6 month needed to cross altitudes below 550km
      - Used for most space applications: manned missions, remote sensing (e.g. weather satellites), communication, ...
  - Permanently >1000 satellites at low altitudes
  - Defunctional satellites take up to 25 years are not controlled in re-entry
  - Injests 6 satellites, i.e. 1t of Al every day into upper atmosphere (significant change of atmospheric chemistry)

Atmospheric impact

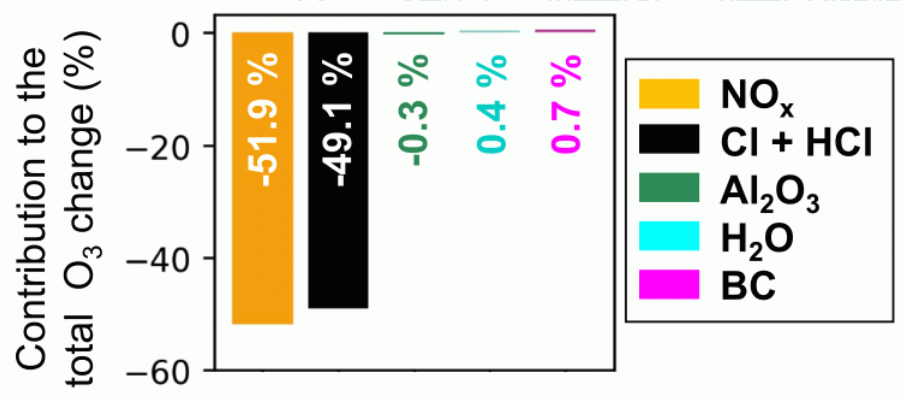
- Model based on 2019 activity level and 5.6% annual growth rate:
- Combine fuel usage and re-entry statistics with GEOS-Chem atmospheric model:
  - Ozone layer depleted
  - Climate heating amplified
  - NO_x production by re-entries much larger than by launches



Ryan et al. (2022, Earth's Future)
Disclaimer: Model does not include the re-entry Al yet

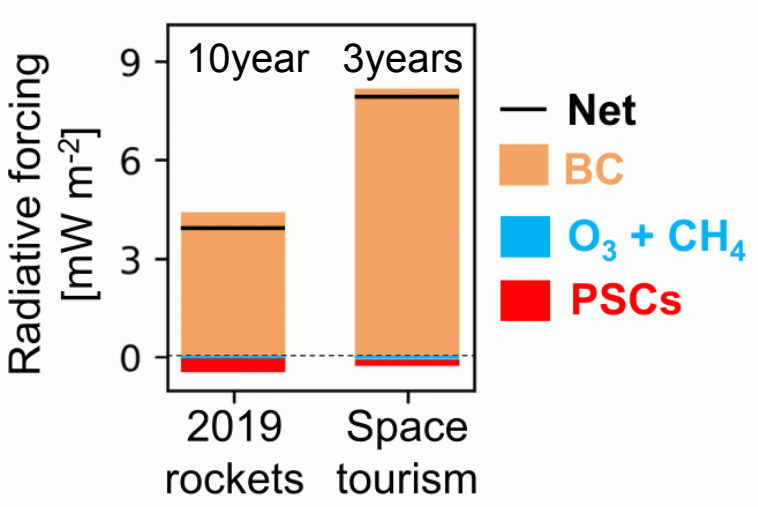
Atmospheric impact

- Significant destruction of the ozone layer
  - 0.15 to 0.24%
    depending on scenario



  - Could amount to 10% of what was gained through the Montreal protocol (Space industry not covered there)

- Soot contributes to climate heating
  - up to 6% of total antropogenic heating



On the ground

Measurable threat:

- Global south at higher risk of being hit

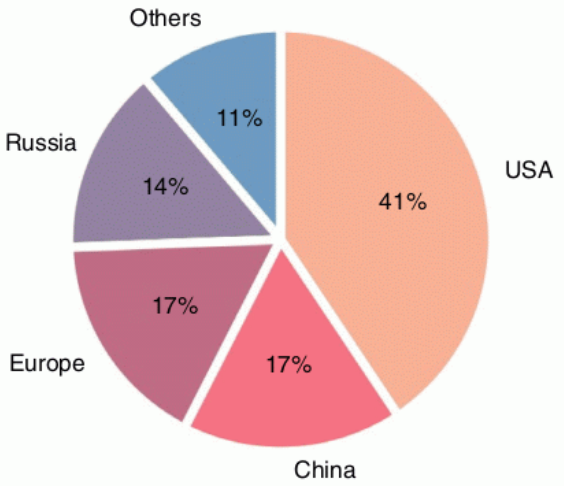
Buyers et al. (2022):

Result of 1500 rocket stages that re-entered until 2022 (70% uncontrolled).

a

State	Number of rocket bodies	Casualty expectation contribution (no. m^{-2})
USA	224	0.0040
Europe	134	0.0017
Russia	108	0.0014
China	102	0.0017
Others	69	0.0011
Total	637	0.0098

b



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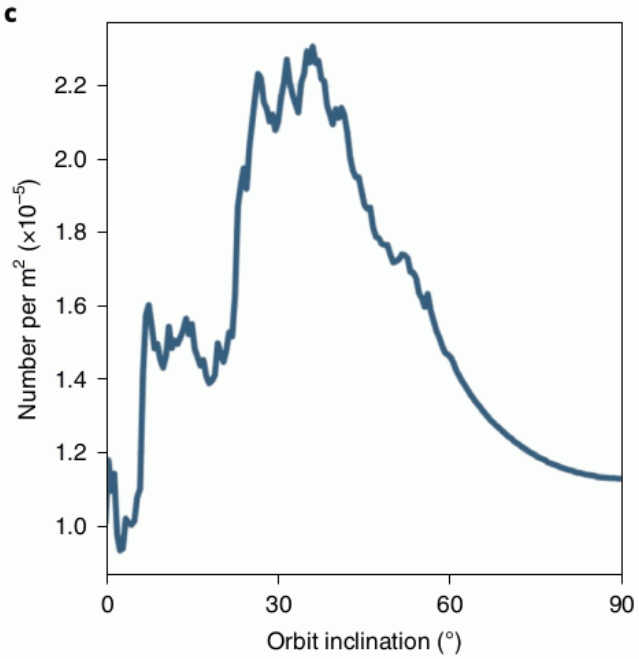

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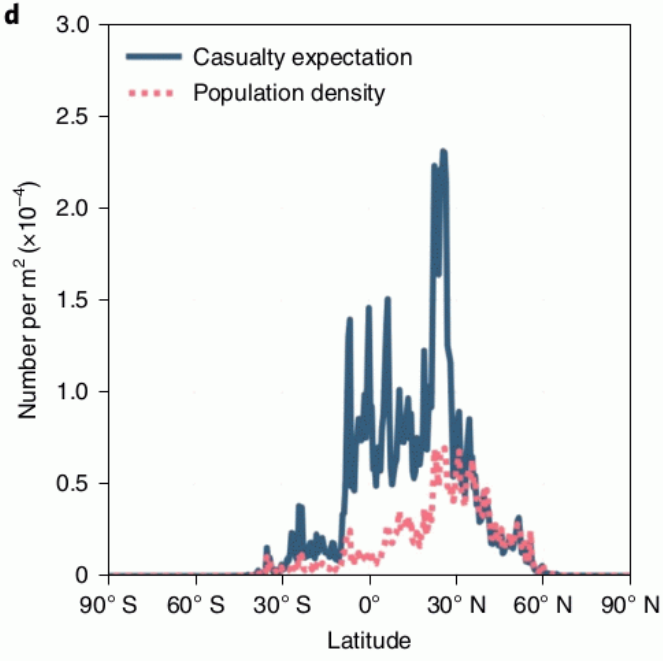
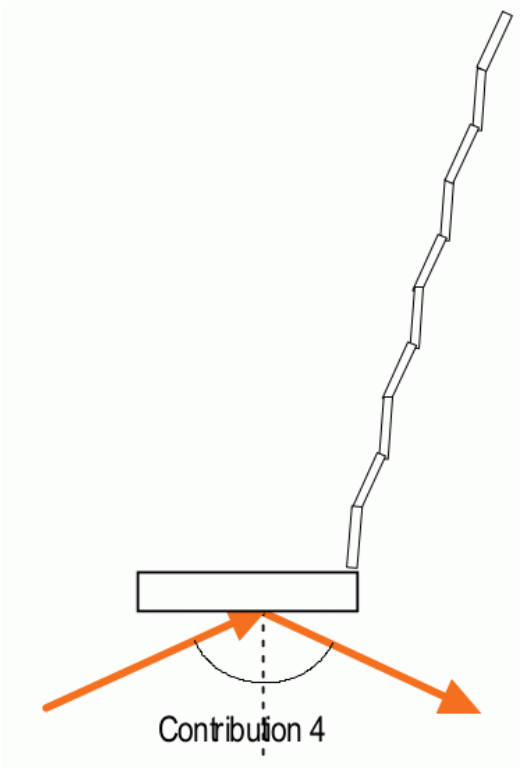
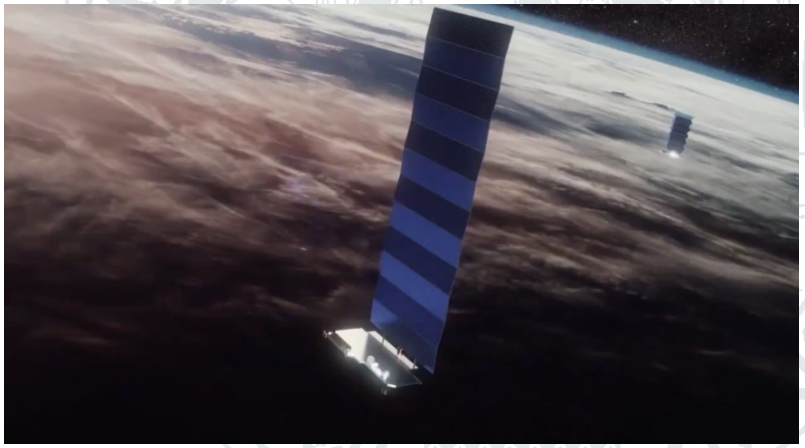


Astronomy

- Significant light pollution
  - Reflection from the antennas at the bottom of the spacecrafts



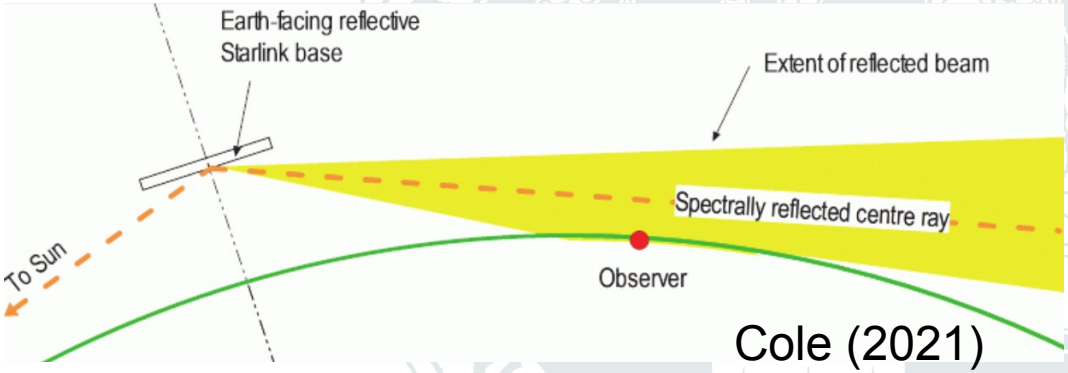
Cole (2021)



Starlink stripe in M31 exposure at Palomar 48 inch Schmidt-type Samuel Oschin telescope

Astronomy

- Significant light pollution
  - in particular after sunset and before sunrise
  - medium latitudes more affected due to long twilight



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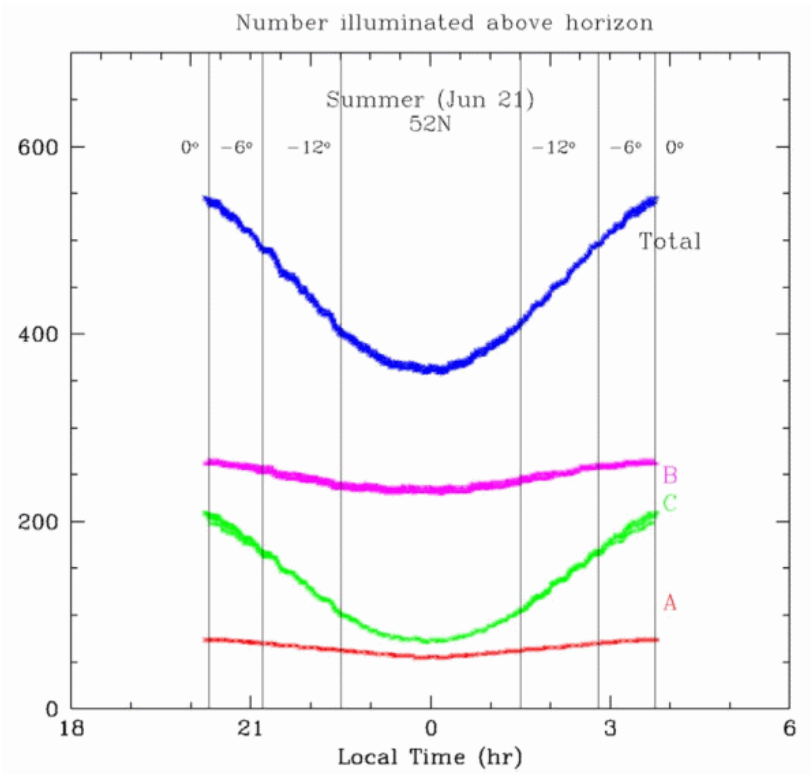

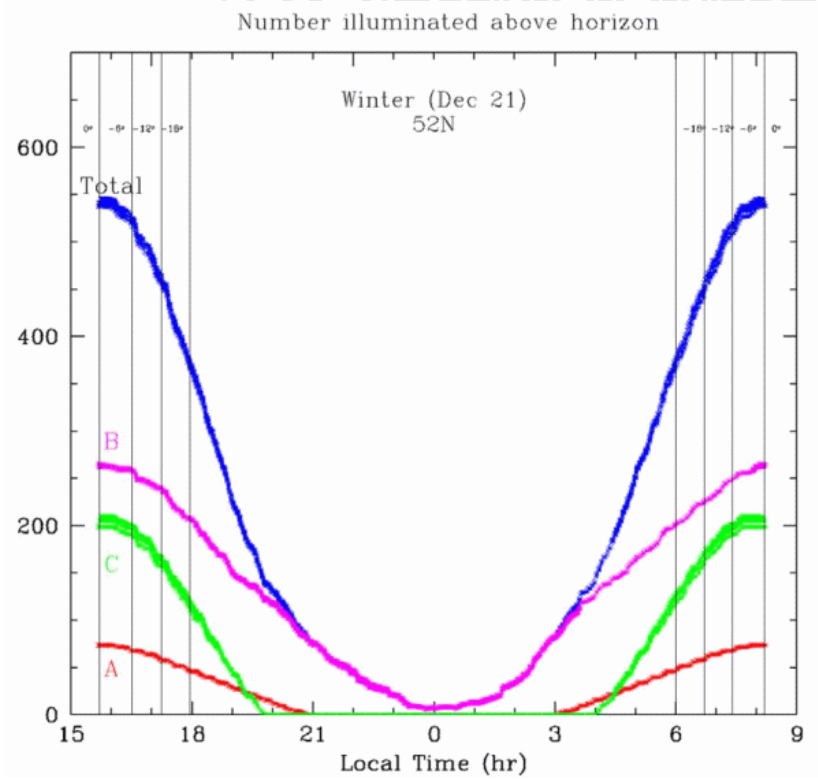

Number of illuminated Starlink satellites for 52° latitude in summer (07/21) and winter (12/21, McDowell 2020)

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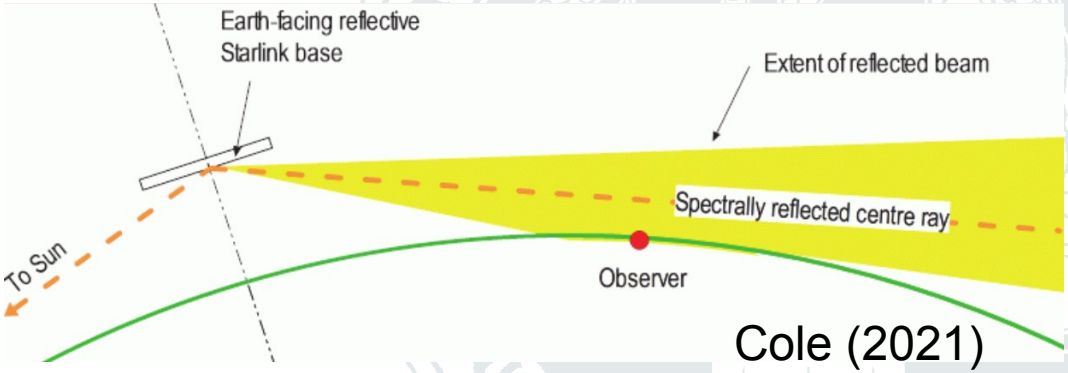
- Significant light pollution
  - in particular after sunset and before sunrise
  - medium latitudes more affected due to long twilight



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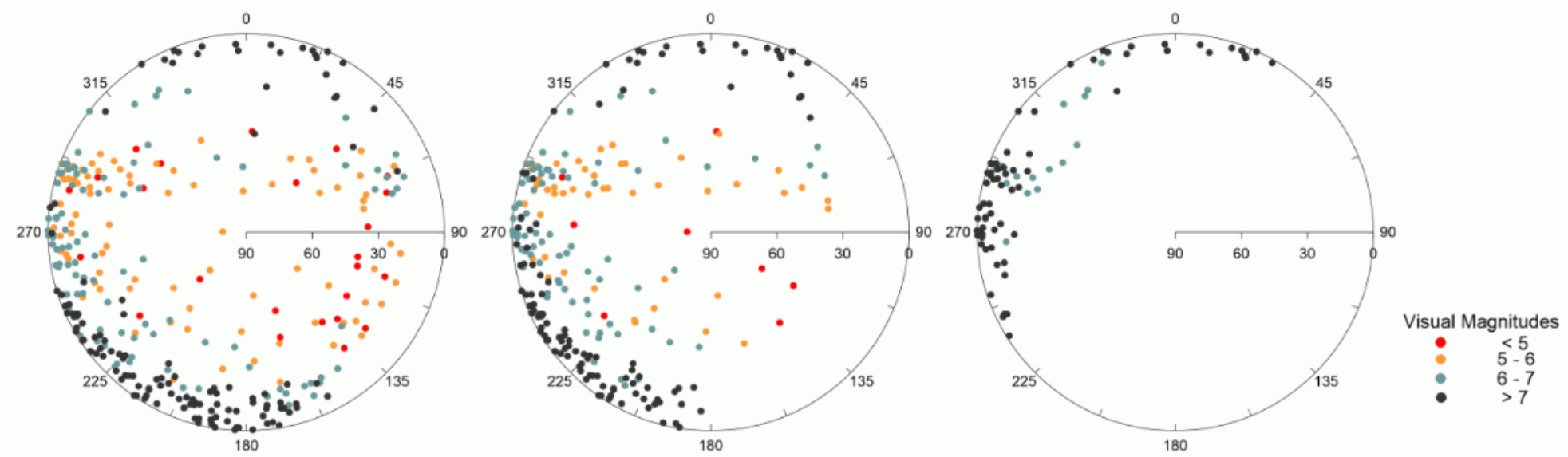
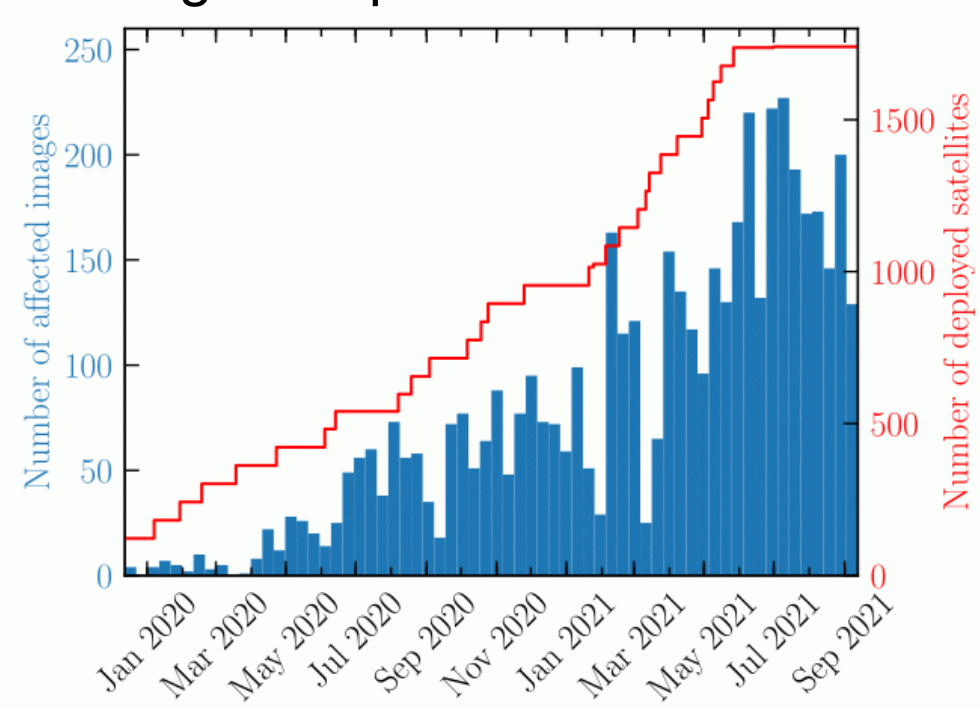


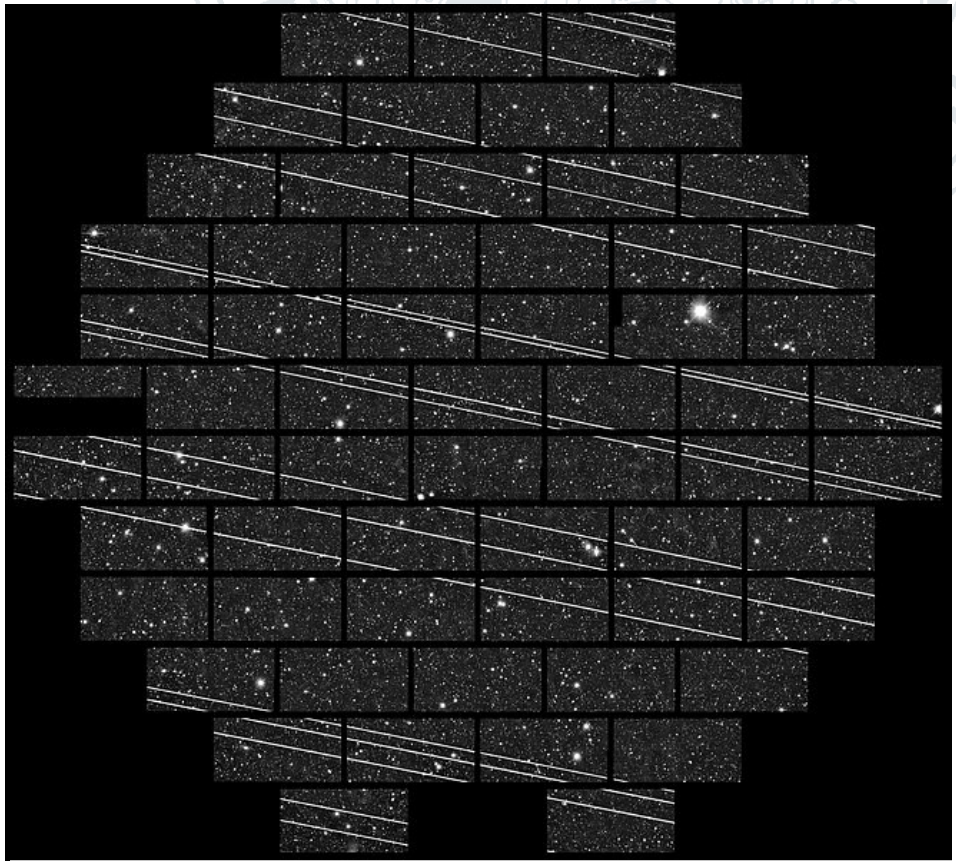
Spatial distribution of illuminated Starlink satellites for 50° latitude in spring (03/21) if the sun is 12°, 18° or 30° under the horizon (Mallama 2022)

Astronomy

- Significant light pollution
  - already 10% of exposures affected in Sept. 2021
    - 20% of images taken during twilight
  - Makes systematic searches for asteroids and other time variable targets impossible



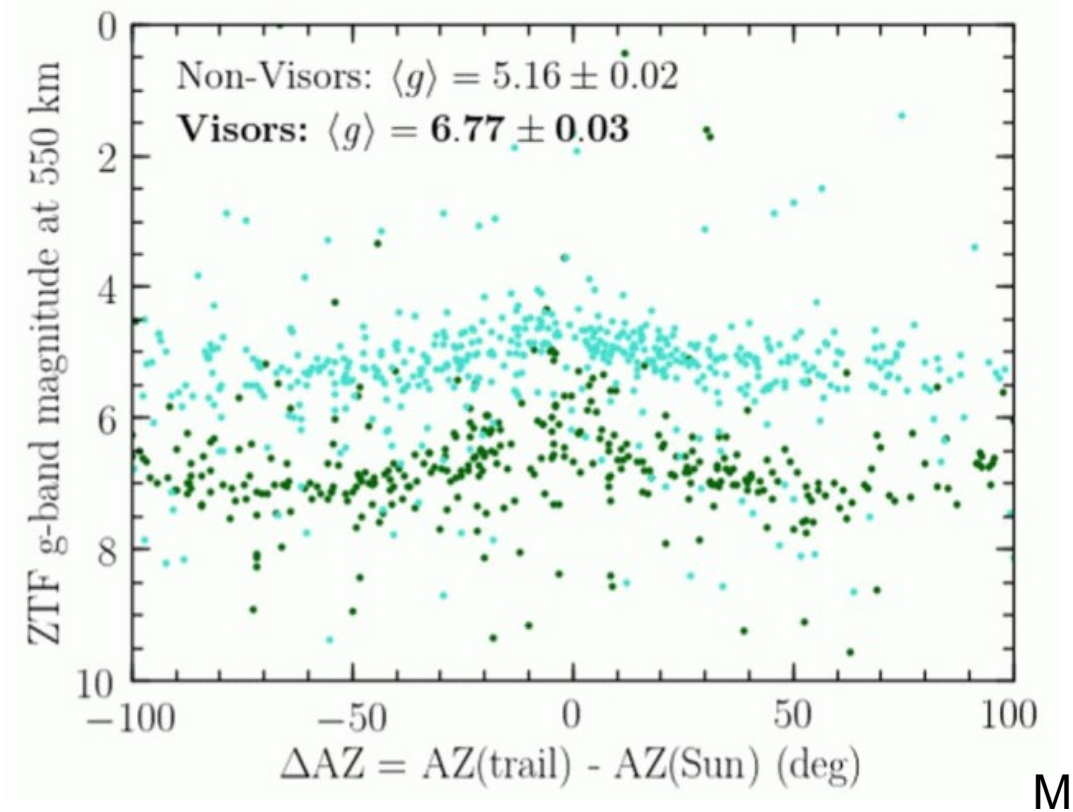
Zwicky Transient Facility observations (Mróz et al. 2021)



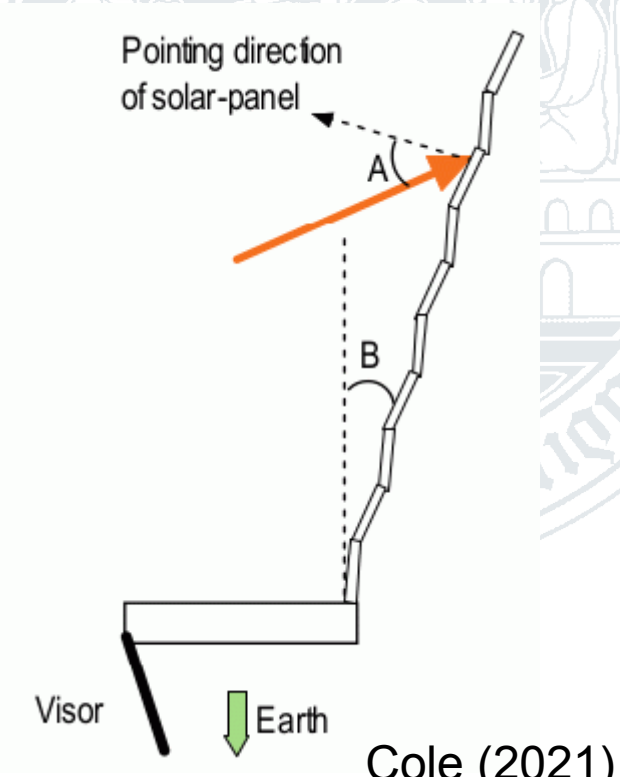
330s exposure at the Blanco 4m-Telescope of CTIO (Clara Martínez-Vázquez, Cliff Johnson)

Astronomy

- Counter-measures
  - "Visor" shield implemented in 2020
    - used for ~2600 spacecrafts
  - Removed again in 2022 for version 1.5 of satellites using optical inter-satellite links



Mróz et al. (2021)



Cole (2021)

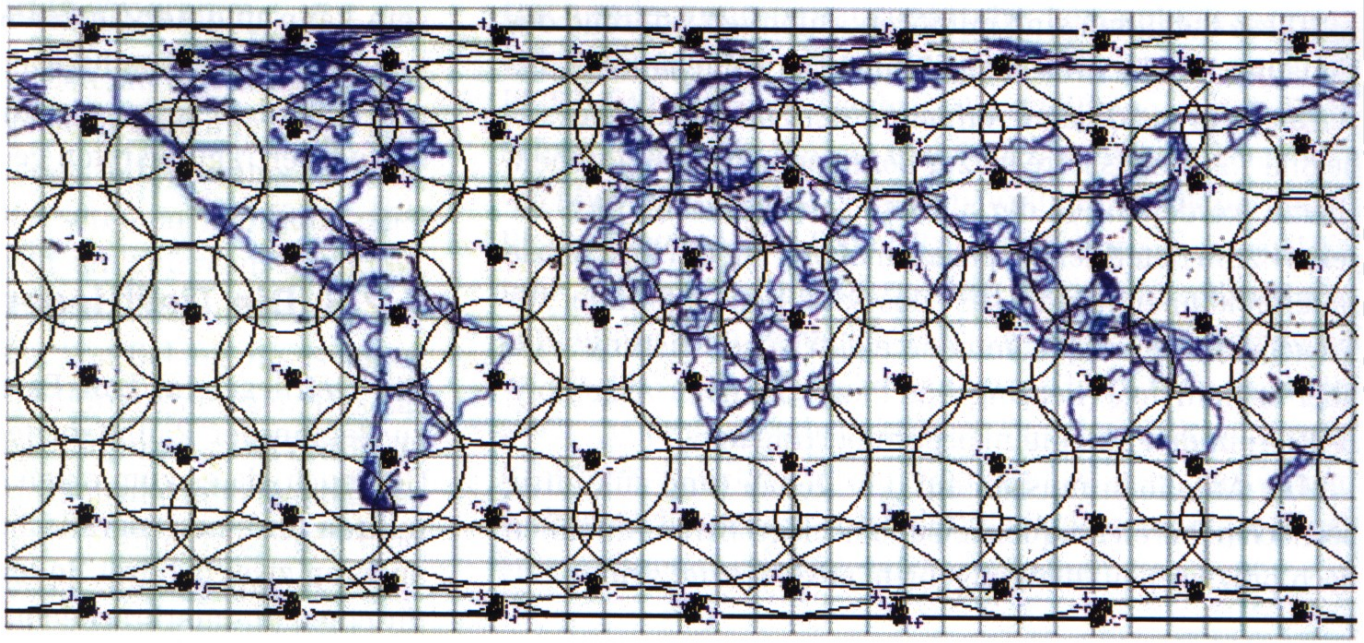
Solutions:

- Space-observatories?
- Networks of telescopes?

Existing alternatives

IRIDIUM (since 1998):

- 66 satellites
  - 781km
  - polar orbits



- More expensive
- Lower data rate, higher latency
  - No online gaming, no internet video

Globalstar and geostationary systems

- similar performance, no coverage in polar regions

What are your ideas?

- Is it worth it?
- What are the alternatives?