Mega- constellations

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Abstract

Enhanced observational capabilities and increasing numbers of satellite launches have created a tension between the astronomical community and the mega-constellation operators.

The paper will explain various aspects of current mega-constellation design, including the perceived need for large numbers of satellites; the selection of their orbital altitudes and inclinations; the rationale for the use of particular frequency bands; and the choice of particular material characteristics on the satellites themselves.

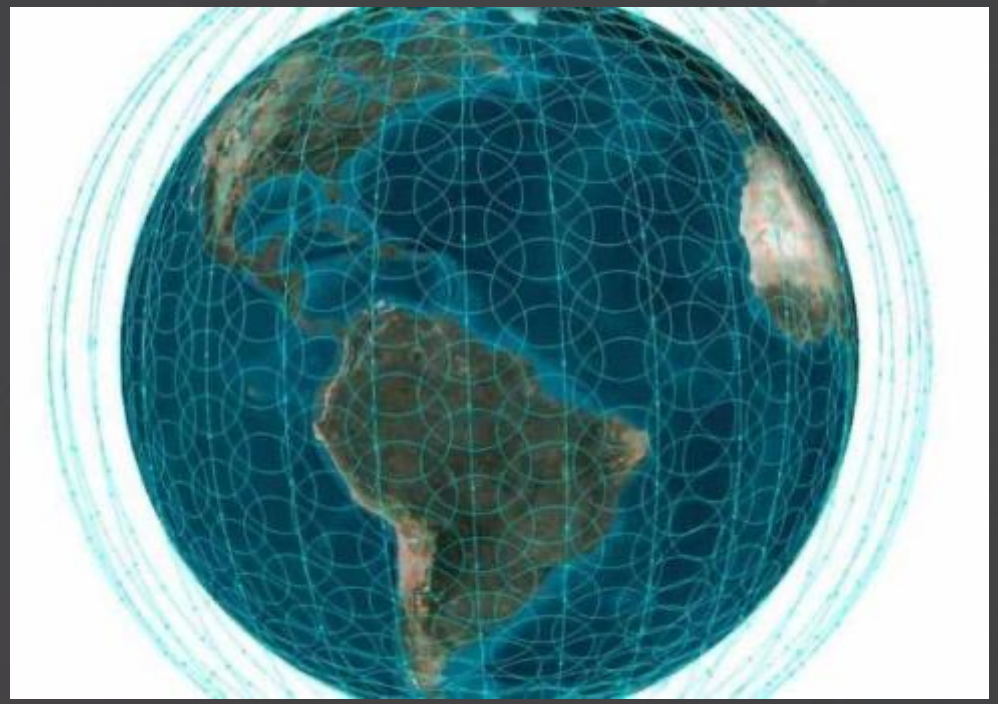
It will also address the utility of current and planned satellite capabilities, highlighting the differences between constellations which provide communications, surveillance, and navigation functions.

Various approaches to future satellite system design that could help to alleviate the problems that these constellations pose to the astronomical community will be discussed. These will include modifications to both the physical satellite hardware and also the concept of operations for the constellations.

The implications of these changes for both the astronomical and satellite communities will be considered.

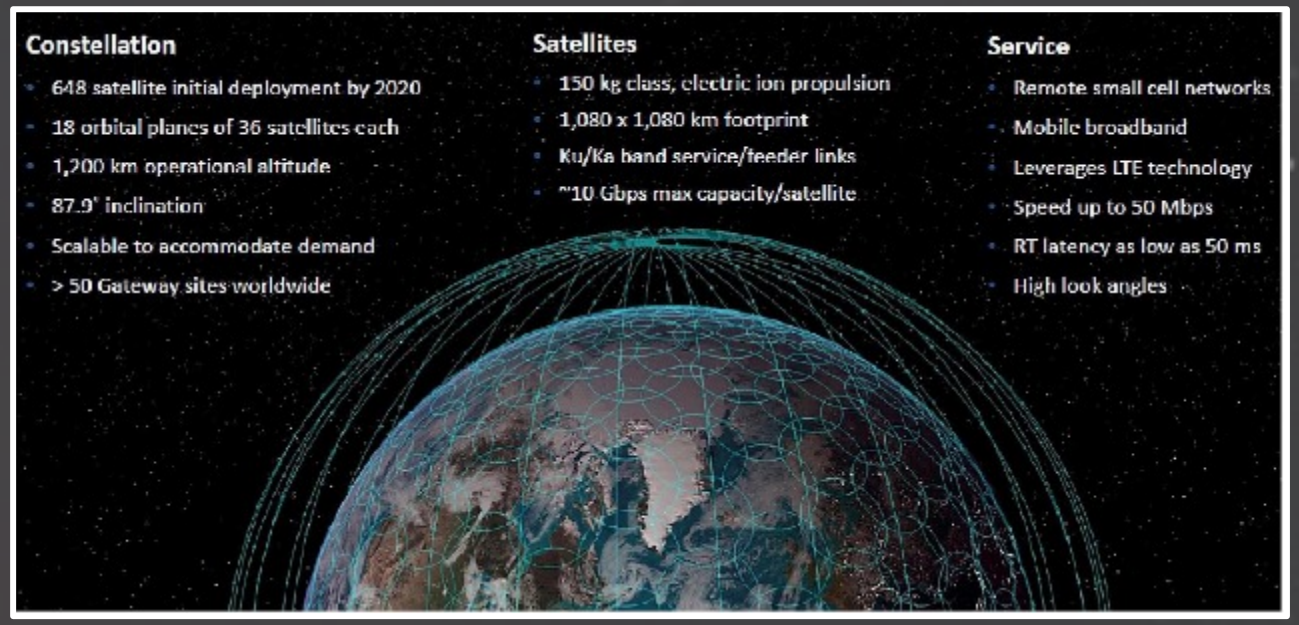
Mega-constellations

- The large sizes of the mega-constellations are driven by the desire to provide very high data rates
- The footprints of individual satellites are deliberately limited to a comparatively small region around their nadir point
- Hence the satellites are accessed by the users at comparatively high elevation angles
- Starlink, OneWeb, and Kuiper are amongst the front runners, and all plan constellations comprising many hundreds of satellites



OneWeb

- OneWeb has chosen an operational orbital altitude of 1200 km, (a local minimum in the debris population) and an inclination of close to 88 degrees
- Their satellites will thus spend a lot of time over high latitudes where there are very few paying customers
- The satellites “converge” towards the poles, which is a potential collision risk

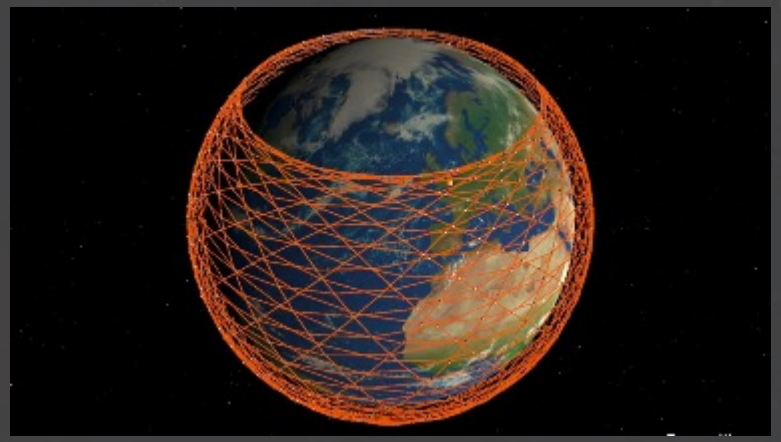


Starlink

Starlink's revised orbital altitude plan abandons the high-altitude planes that could have interfered with OneWeb

All the Starlink satellites will now operate at adjacent altitudes to the Kuiper constellation

Original parameters:					
Orbital Planes:	72	32	8	5	6
Satellites-per-Plane:	22	50	50	75	75
Altitude in kilometers:	550	1,100	1,130	1,275	1,325
Inclination - (i):	53°	53.8°	74°	81°	70°
Modified parameters					
Orbital Planes:	72	72	36	6	4
Satellites-per-Plane:	22	22	20	58	43
Altitude in kilometers:	550	540	570	560	569
Inclination - (i):	53°	53.2°	70°	97.6°	97.6°



Kuiper

Kuiper plan to implement their constellation in three phases

Phase 1 will place 784 satellites at the lowest altitude of 590 kilometres

Phase 2 will implement 1,296 satellites at the next-highest altitude of 610 kilometres

Phase 3 – the remaining 1,156 satellites will be deployed at the highest altitude of 630 kilometres orbit above the earth

Altitude (km)	Inclination	Planes	Number of Satellites per Plane	Number of Satellites
630	51.9	34	34	1156
610	42	36	36	1296
590	33	28	28	784

- The FCC has approved the launch of 3,236 satellites. Not all of those thousands of satellites have to be launched immediately.
- Amazon is now obligated to launch at least half of the total by 2026 to retain the operating license the FCC has granted to the company.

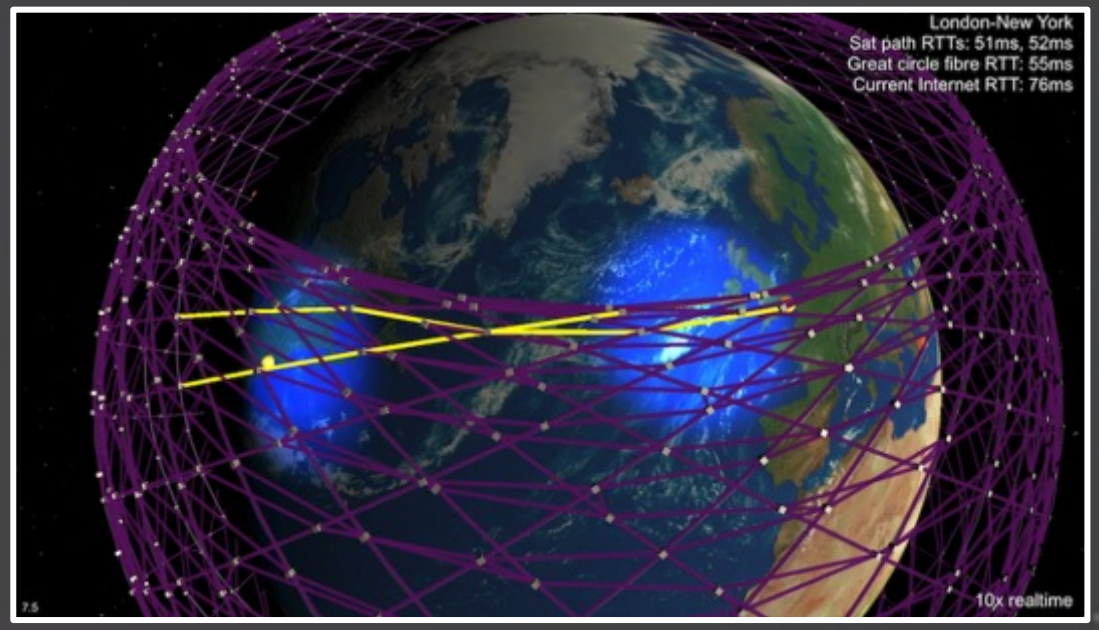
Latency

A key driver for some of these systems is the latency of the communications that they can provide

Financial institutions will pay huge amounts for access to “the fastest” financial information

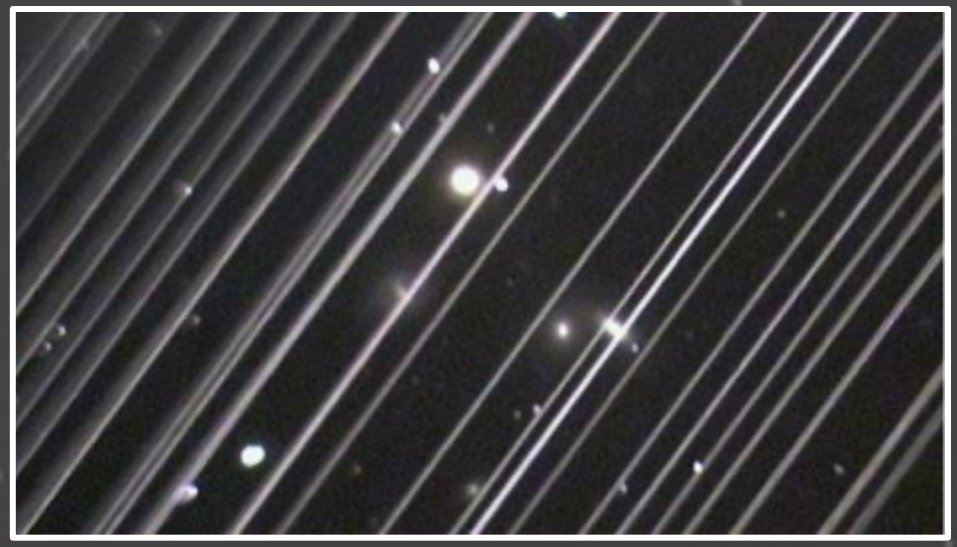
Starlink and Kuiper operate at low enough altitudes to deliver information faster than fibre optic cables

OneWeb does not



Interference to Astronomy

The issue that has received the most attention to date is the “light pollution” that the mega-constellation satellites are causing to the optical astronomy community

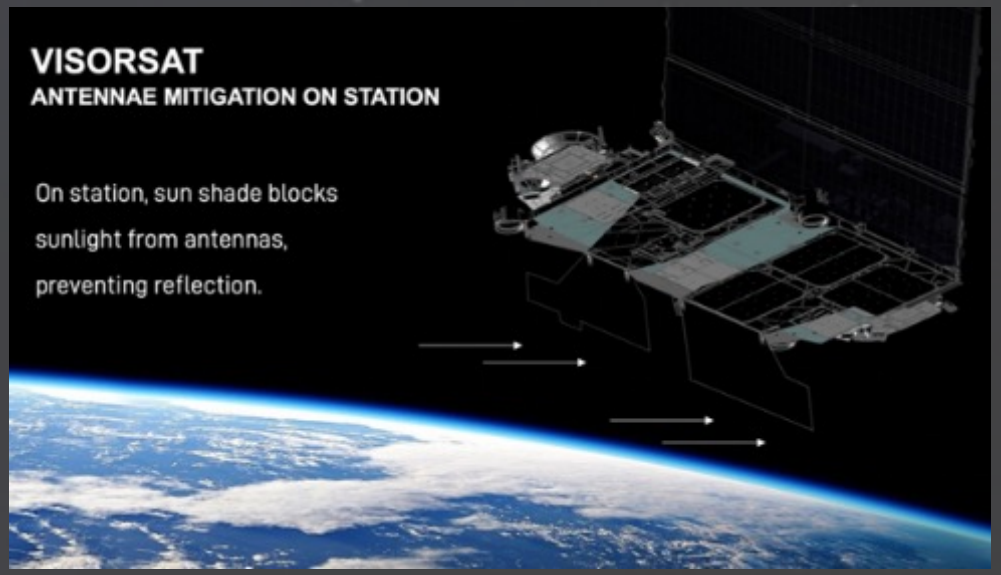


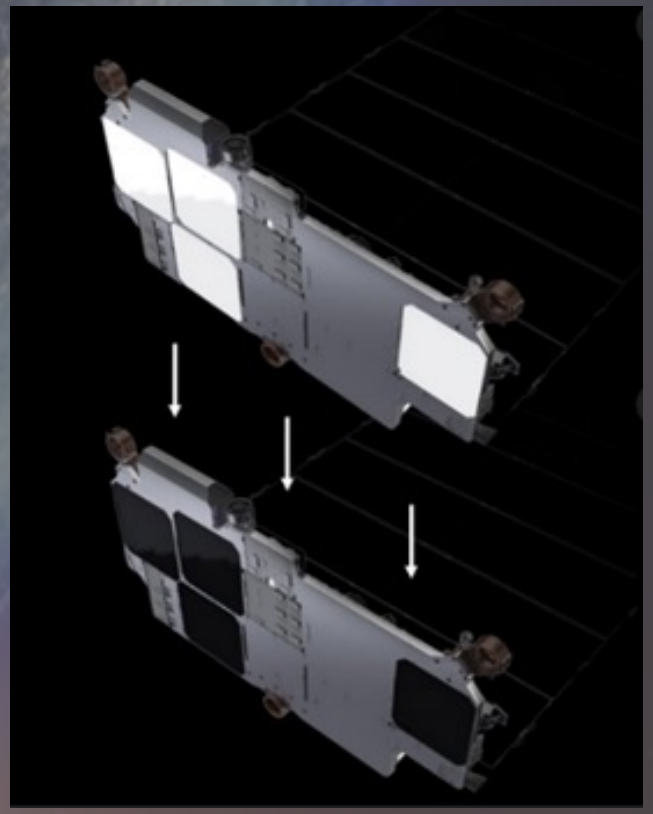
It is likely, however, that the increasing traffic in Earth orbit will also cause problems for the radio astronomy community

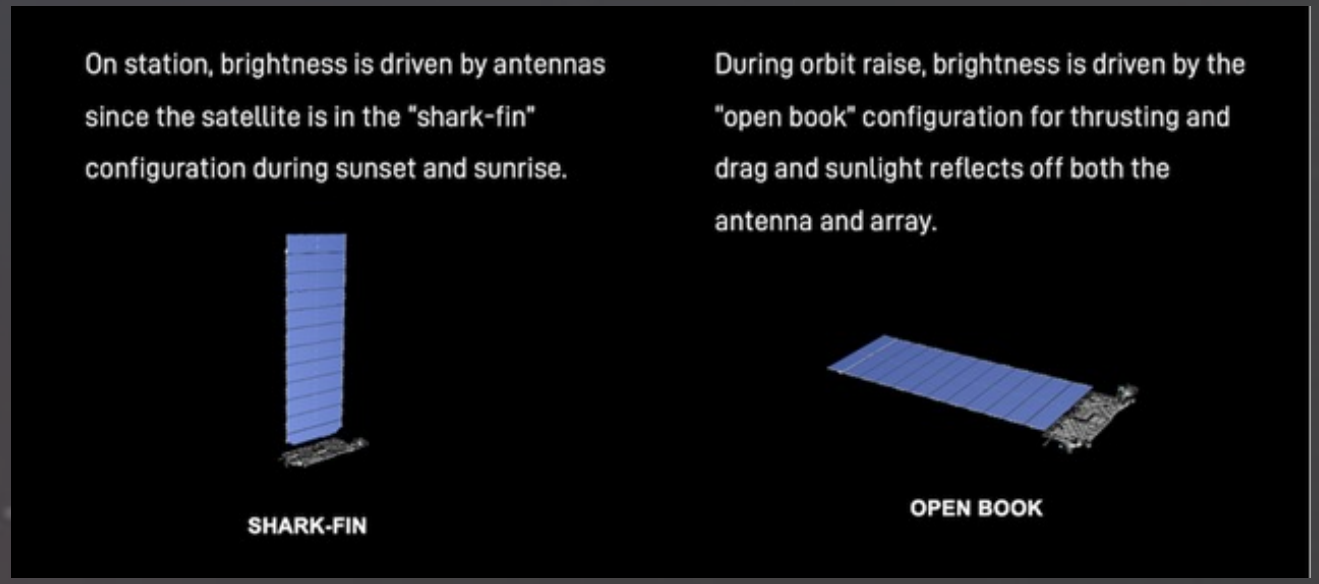
Infra-Red astronomy could be affected too

Signature Reduction

- Starlink have made a variety of changes to their satellite designs and operations with the aim of reducing their visibility



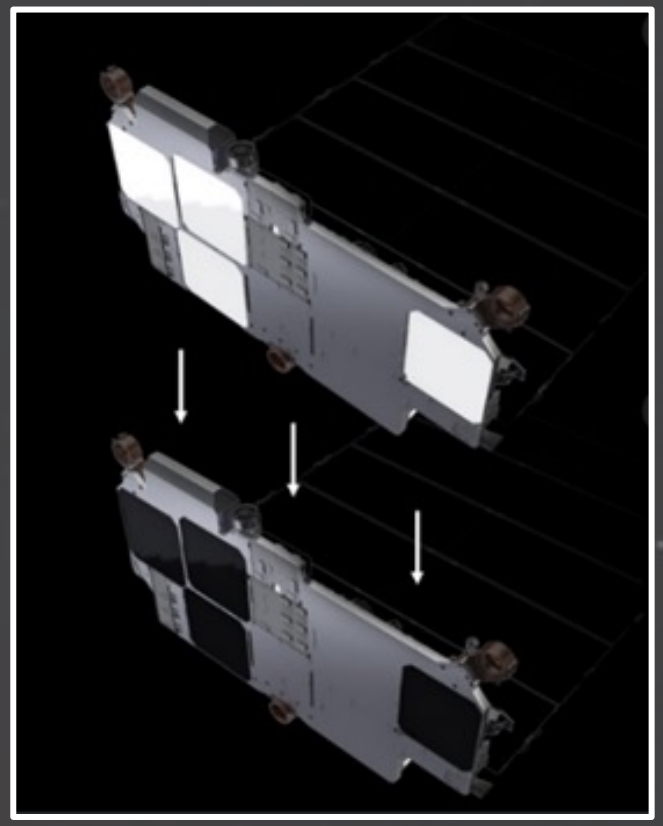




- But the most effective measure may have been the reduction in their orbital altitude

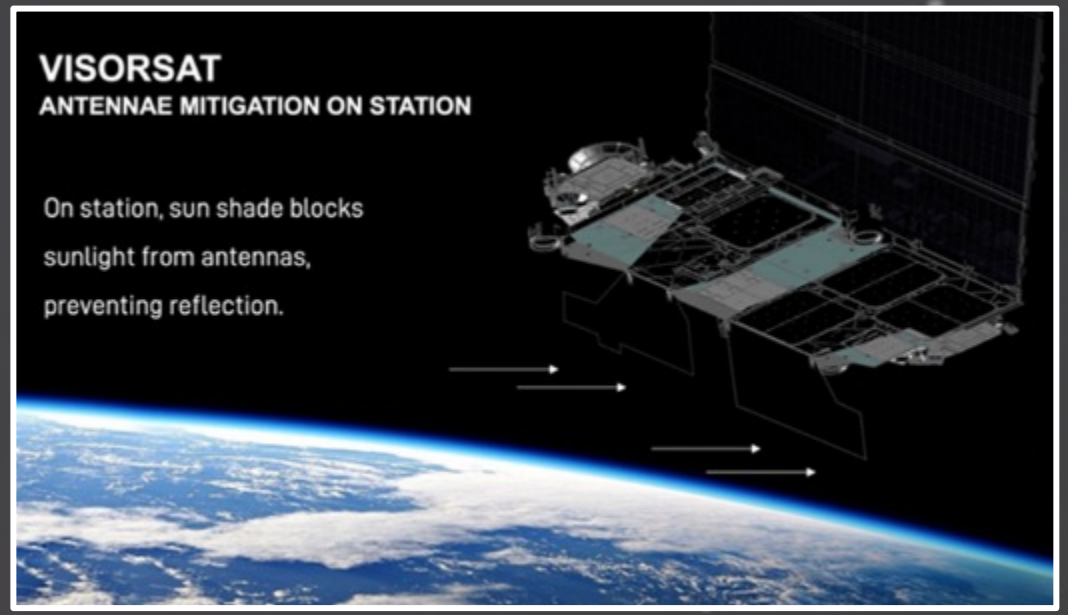
Optical Signature Reduction

- The first design change was “Dark Sat”, where the company adjusted the reflectivity of one of their satellite’s antennas
- The difficulty here is that the antennas are white for a reason – thermal control
- This reduced the optical magnitude from 4.63 to about 5.4 once the satellite was in its operational orbit



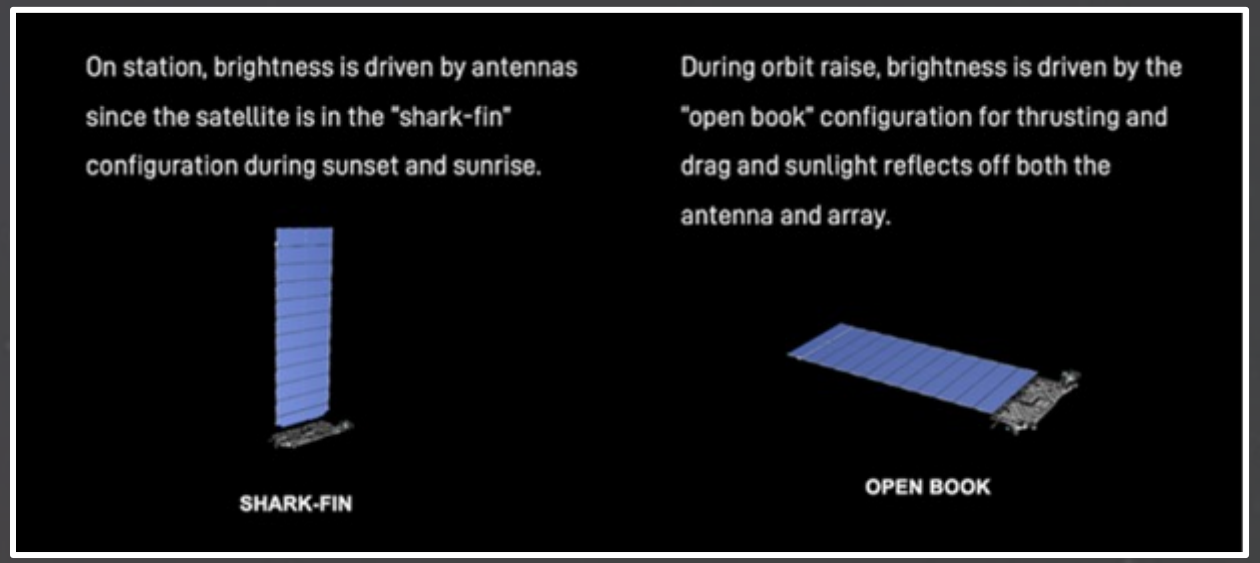
Optical Signature Reduction

- Starlink then tried an approach involving sun shades called Visorsat
- The aim was to prevent direct illumination of the most reflective areas of their satellite
- Although there was a reduction in signature, the satellite wasn't dark enough to satisfy the critics (it was still visible to the naked eye at a magnitude of around 5.92)
- And from a satellite designer's perspective, the sun-shades represent mass that isn't being used for a revenue-generating function



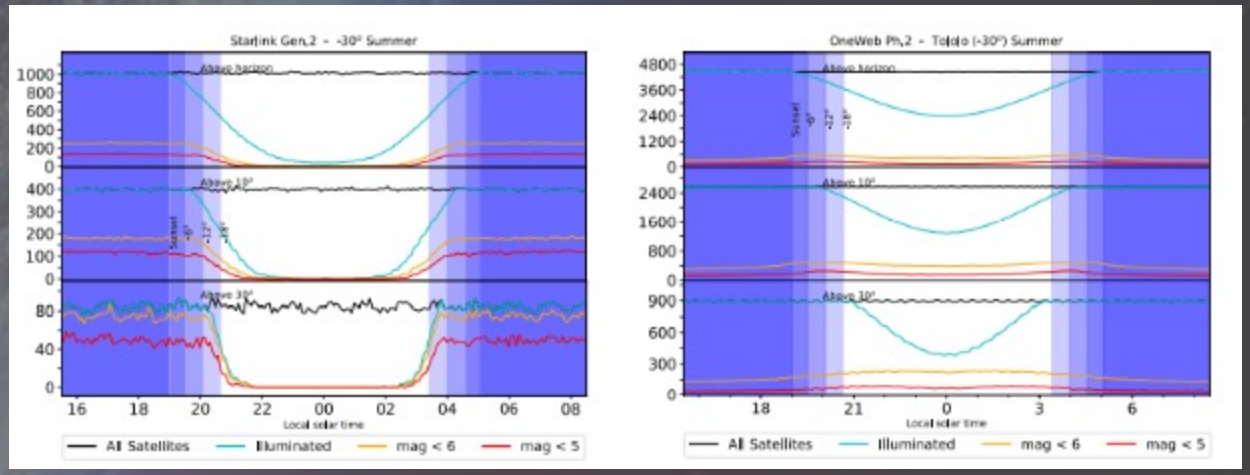
Optical Signature Reduction

- The company has now suggested that they will adjust the orientation of their satellites during the orbit raising phase to lessen their reflective areas
- This involves turning the solar panels edge-on to the Sun
- Exactly how the satellites generate power in this configuration is not clear

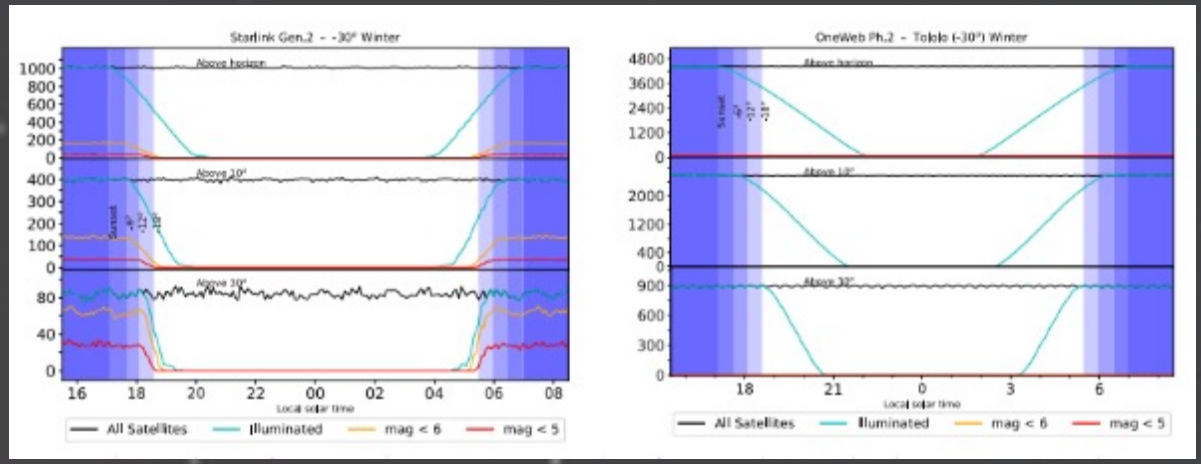


Reduced Orbital Altitude

- Ironically, the most effective measure that Starlink has implemented is to lower the orbital altitude of its constellation to improve its latency
- The SATCON report contains modelling of the visibility of Starlink and OneWeb satellites from the site of the Rubin Telescope (LSST)



Starlink and OneWeb visibility Summer



Starlink and OneWeb visibility Winter

SATCON-1 RECOMMENDATIONS

1. Launch fewer or no LEO satellite constellations. *Would require turning off/deorbiting existing satellites to achieve zero impact*

2. Orbit satellites at altitudes no higher than 600 km. *Would require deactivating/deorbiting satellites in higher orbits*

3. Darken satellites by lowering their albedo or shielding them from sunlight. *Requires action by companies; SpaceX is doing this with VisorSat*

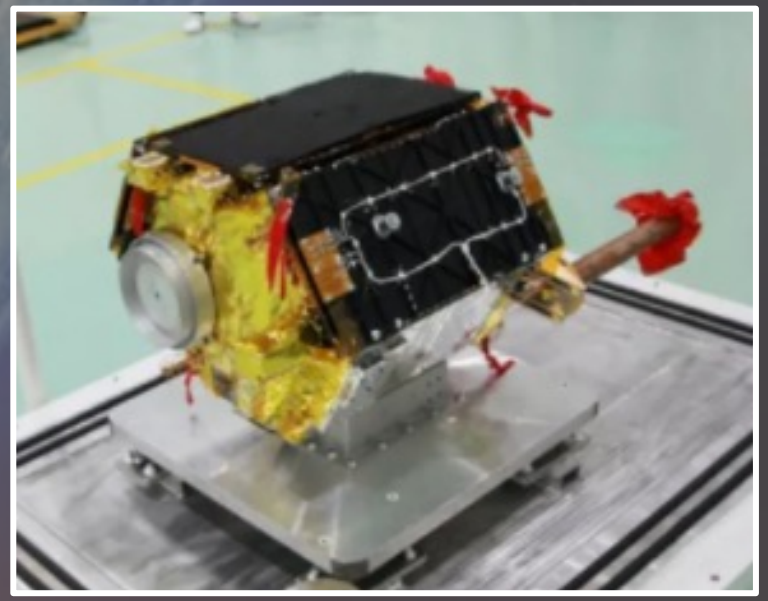
4. Control each satellite's attitude to minimize reflection of sunlight to the ground. *Requires action by satellite operators*

5. Computationally remove or mask satellite trails from being recorded on images. *Requires action by observatories*

6. Schedule telescope observations to avoid recording trails. *Requires coordination between observatories and satellite operators*

Many more proposed comms constellations….

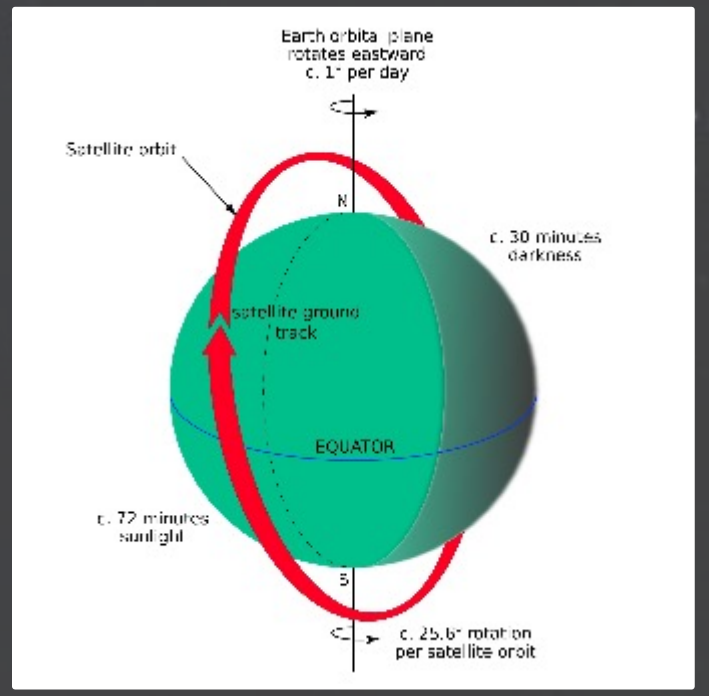
- The existing constellations are just the tip of the iceberg
- Details of many more can be found on the NewSapce Index (link below)
- These include Guo Wang, a Chinese constellation of 12992 satellites, and Sfera, a Russian network of 640 space platforms



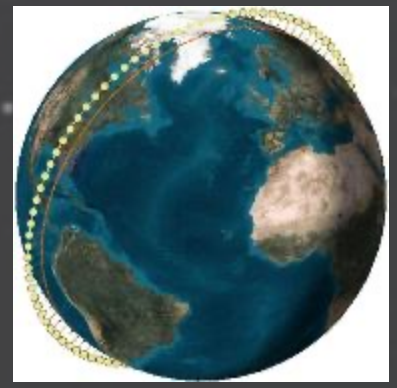
Satellite Constellations - NewSpace Index

Orbits for Surveillance Satellites

- Many imaging surveillance satellites use slightly retrograde “sun-synchronous orbits” which maintain the angle between the orbital plane and the sun
- The local time of ascending node for such orbits affects the satellites’ visibility
  - Optical imaging satellites – historically 10:00-11:30 (or 12:30-14:00)
  - Radar imaging satellites – historically dawn-dusk (06:00 or 18:00)



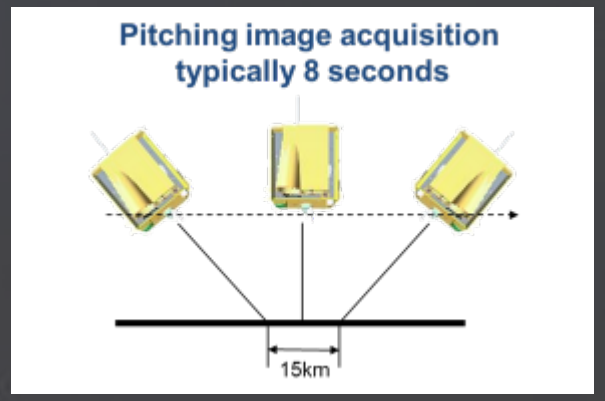
The ICEYE constellation will consist of 18 sats. These are larger, 85 kg, and have surprisingly long duty cycles which may become a problem for radio astronomers. With kW-class powers, “these beams are like death rays for radio astronomy receivers”

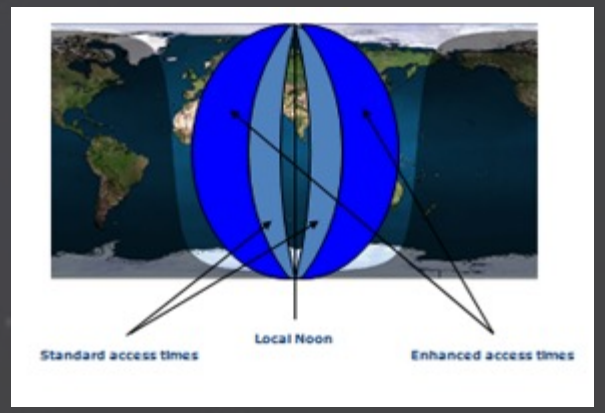


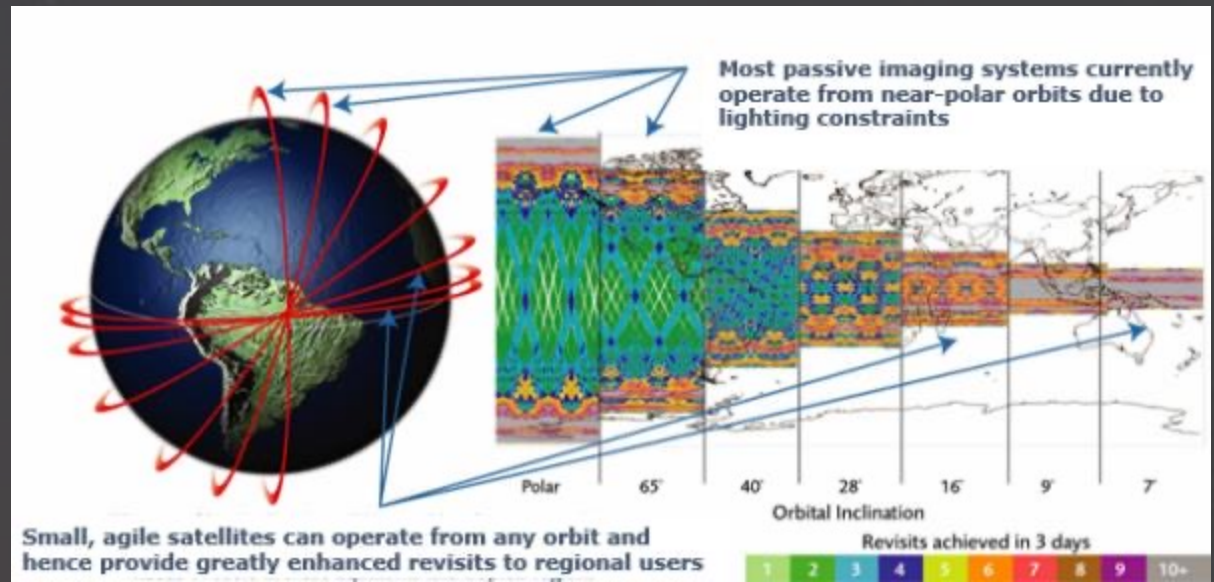
The Planet constellation currently consists of around 150 3-U cube-sats which are relatively small – about 10x10x30 cm. They are planning to launch 475

Advances in Surveillance Satellite Technology

- Greater Agility - Pitching motion reduces the effective ground speed of the sensor
  - More time is available for more light to enter the detector
  - More diverse orbit planes and orbital inclinations
- Sensor/detector efficiency improvements
  - This will permit routine imaging at night
  - It will be possible to image the light pollution!

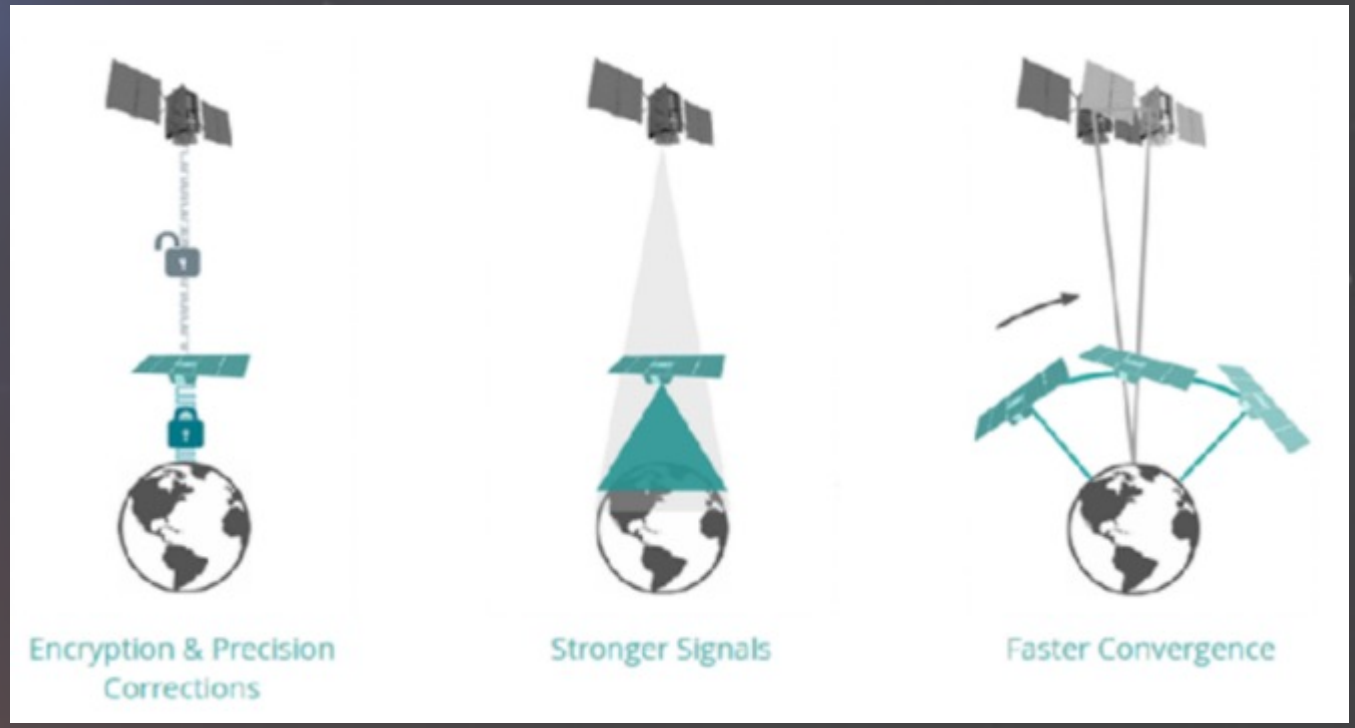






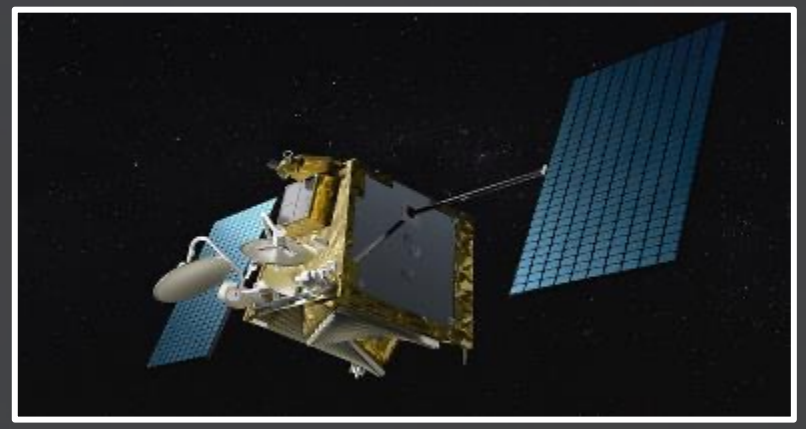
Navigation

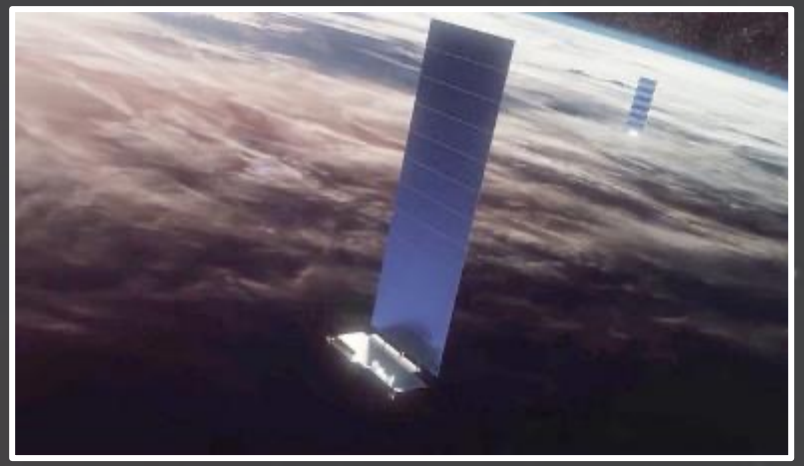
- Start-up company Xona Space is planning a dedicated LEO navigation constellation of 300 satellites, touting specific advantages relative to existing GNSS systems
- It is not easy to make money selling a service that people can already get for free



Satellite Design Issues

- Operating Temperatures and Thermal Control
  - The outer surfaces of satellites in LEO can reach over 100° C when illuminated by the Sun, and cool to minus -20° C after 30 minutes in the Earth's shadow
  - Satellites need reflective blanketing to manage these thermal cycles and prevent overheating
- Increased Power and Downlink Data-rates
  - The desire to raise data rates and keep receivers small is forcing satellites to work harder to close link budgets
  - RF filters are not perfect





Constellations May Not Be The Only Problem

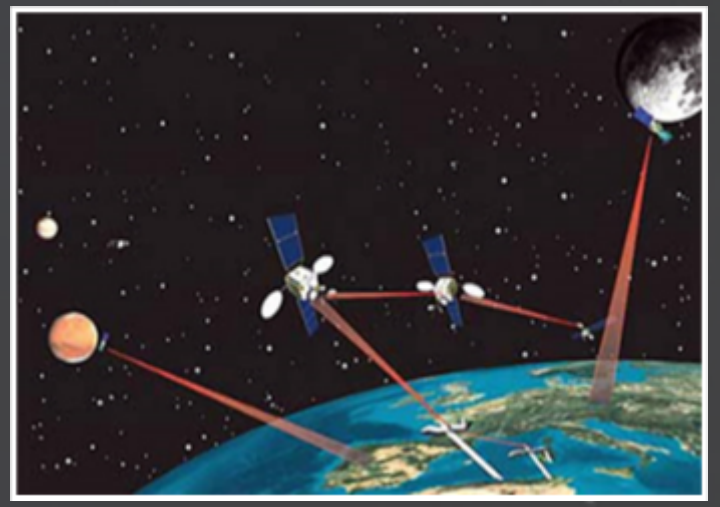
The Murchison array has been used to bi-statically detect the ISS using a terrestrial FM radio station as the illuminating signal

Calculations for the Square Kilometre Array suggest that satellites and debris objects of 0.5 m in size would be detectable out to 1000 km altitude

So is anywhere now “radio quiet”?

Other Possible Solutions….

- Optical Comms
  - A company called laserlight proposes to use optical links to outperform RF links



- Electrochromic materials
  - If satellite surfaces could be fabricated out of materials that change their reflectivity according to the charge on them, it might be possible to temporarily darken satellites as they pass over telescope facilities

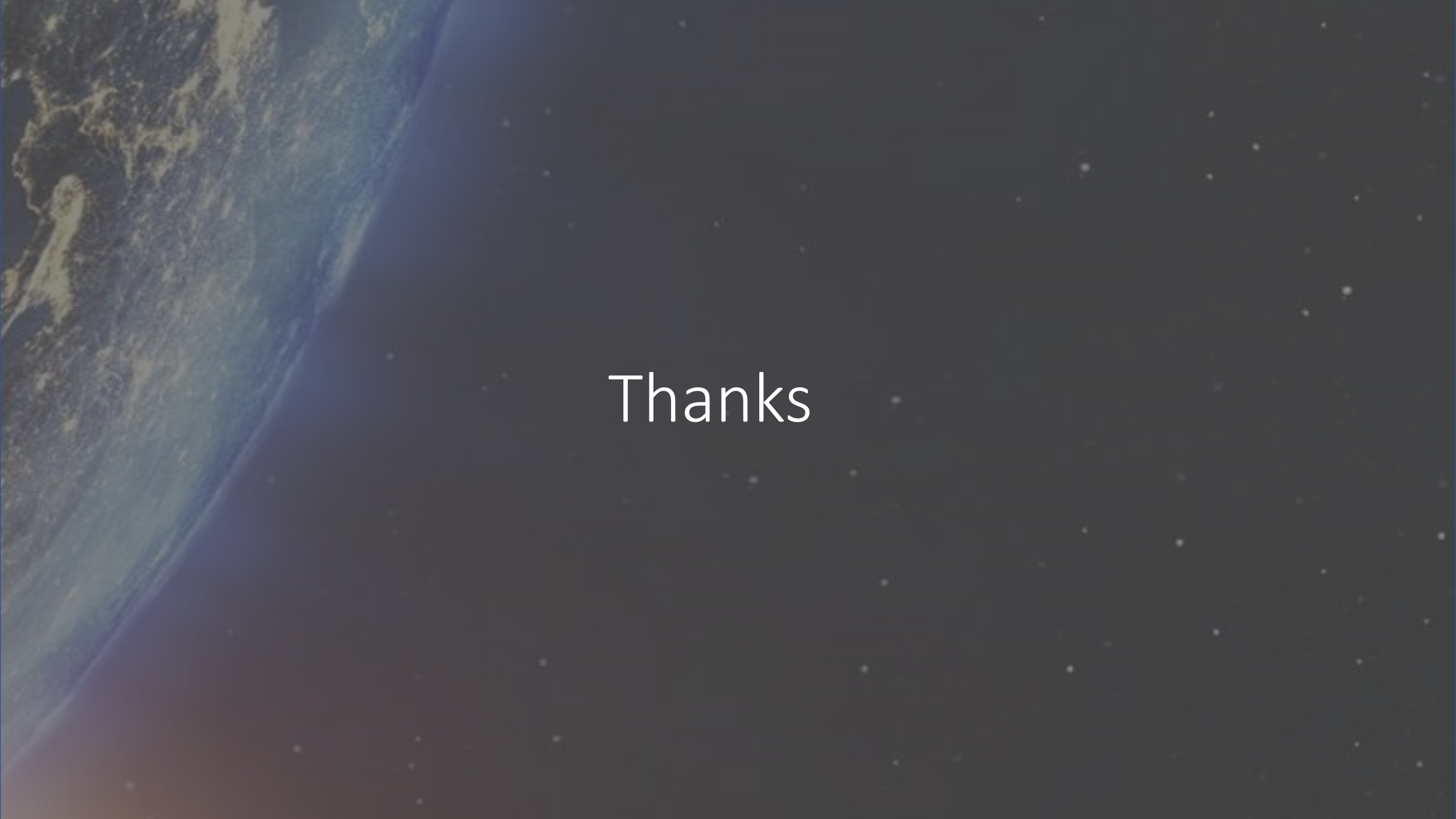
- Go into space!
  - Make the case that future observatories need to be constructed where the interference is less, (and the scientific results would be better)

Some Conclusions

- There are some potentially serious problems for professional astronomy
  - Optical astronomy has been highlighted so far, but radio and IR could be impacted too

- However, although some of the predicted satellite constellation numbers are huge, not all will be launched
    - There is simply not enough “market” to sustain them all

- There are some potential satellites technologies that may help to mitigate the problems
      - Optical satellite beacons that “flash” in the Earth’s shadow are NOT amongst these potential solutions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