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LEO Satellite Population and Megaconstellation Impacts

Jonathan McDowell

2020 Jun 25
[revised 2020 Jun 30]

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HM Astronomer Royal Sir Francis Graham Smith, 1982:

“the cumulative effect of an increasing number of long-lived satellites represents a very serious hazard [to optical observations]”

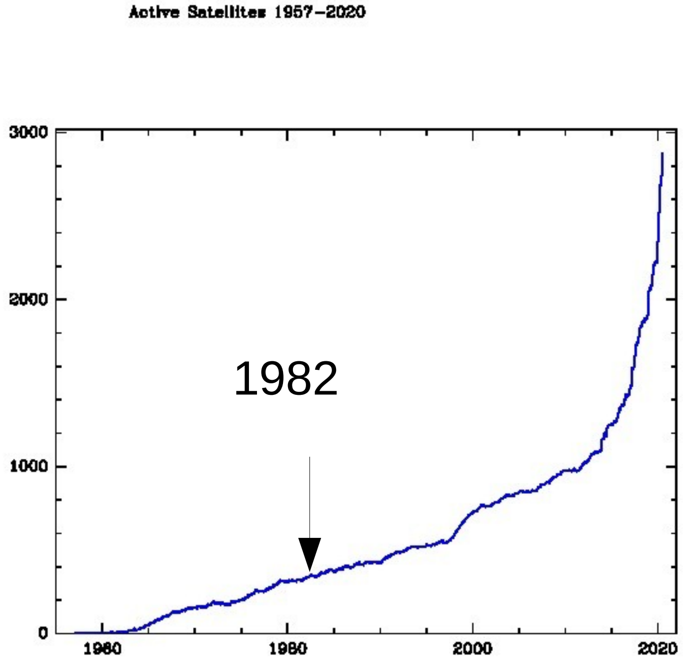

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Image: SpaceX

A new era in space utilization has arrived: the `megaconstellations’.

As of Jun 15, 540 SpaceX Starlink satellites and 74 OneWeb satellites have been launched.

FCC filings include requests for over 81,000 satellites

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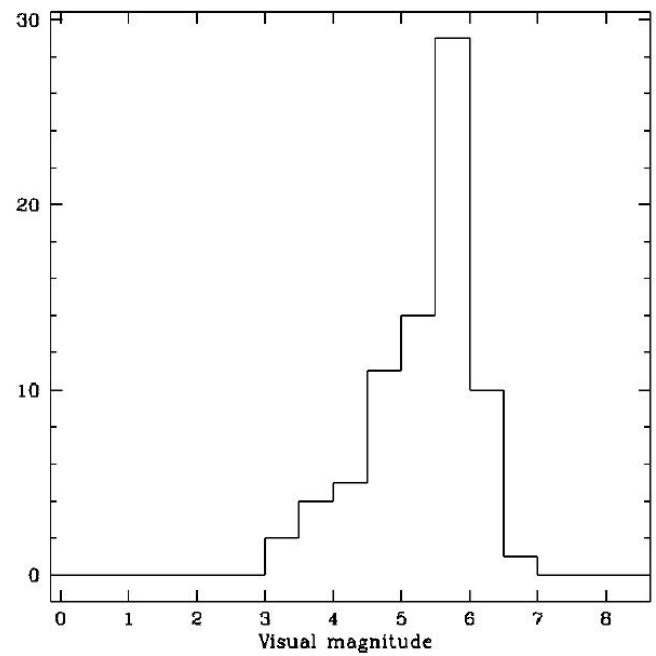

Satellite hobbyists measured the brightness of the first 60 Starlinks in their operational 550 km orbits during summer 2019.

Usually they were mag 5 to 6: just visible to naked eye from dark site – but sometimes much brighter

During early flight/deployment phases, see train of 60 at mag 2 or brighter

(Image: Marco Langbroek)

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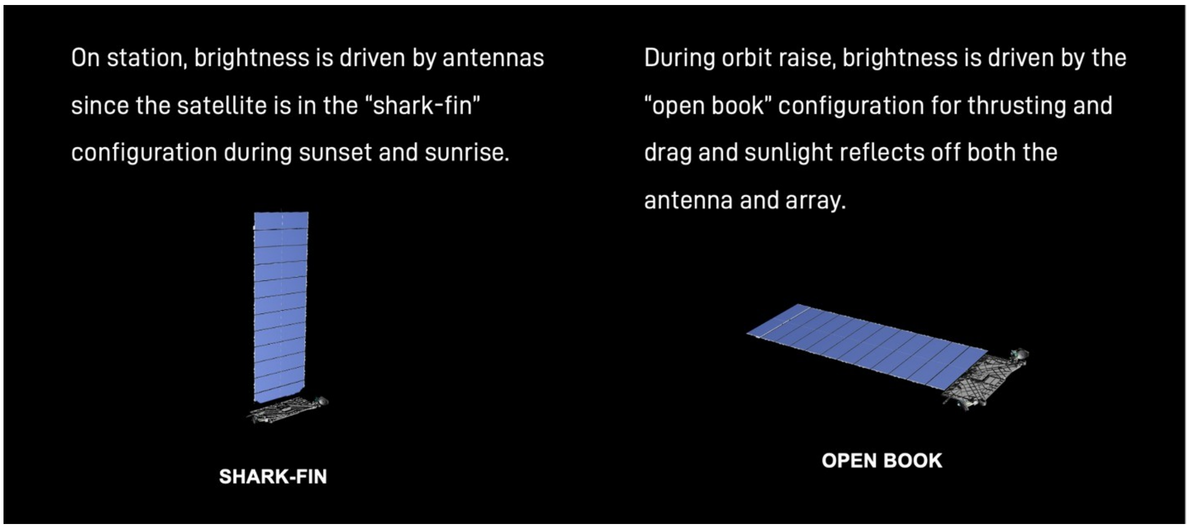
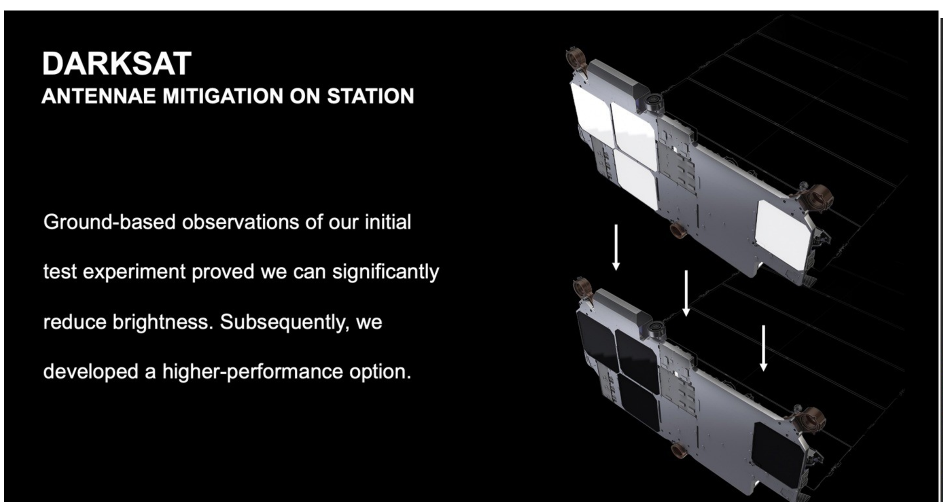
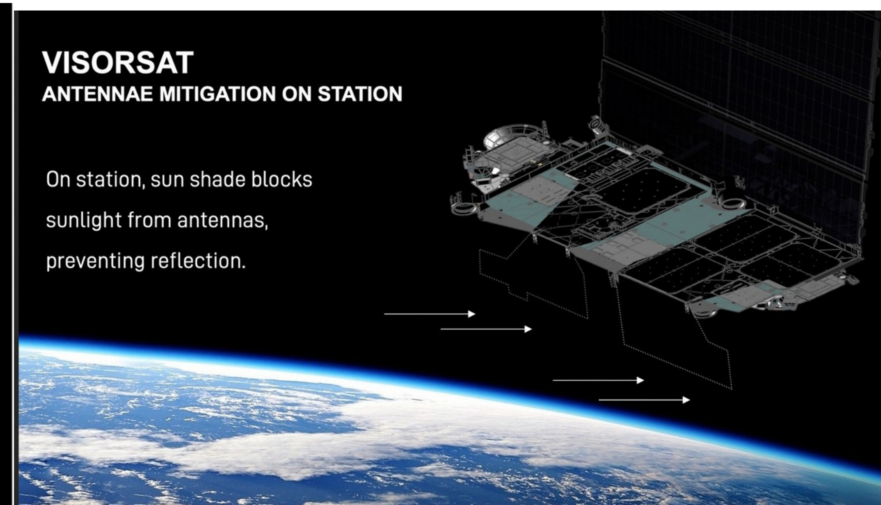


Starlinks are:
LARGE (260 kg, ~10m)
and LOW (300-550 km)
and REFLECTIVE.
- Bright (naked-eye) objects)
- Mitigations in work

Images: SpaceX





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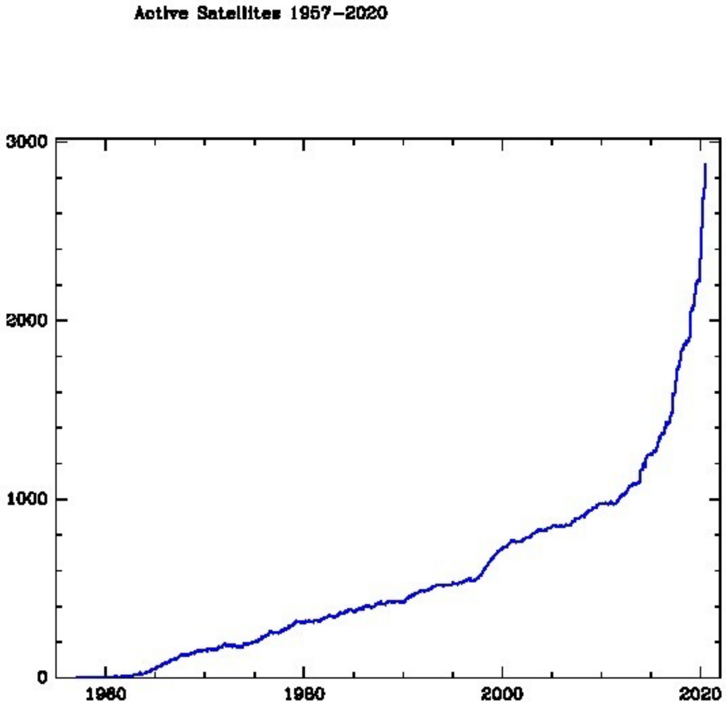
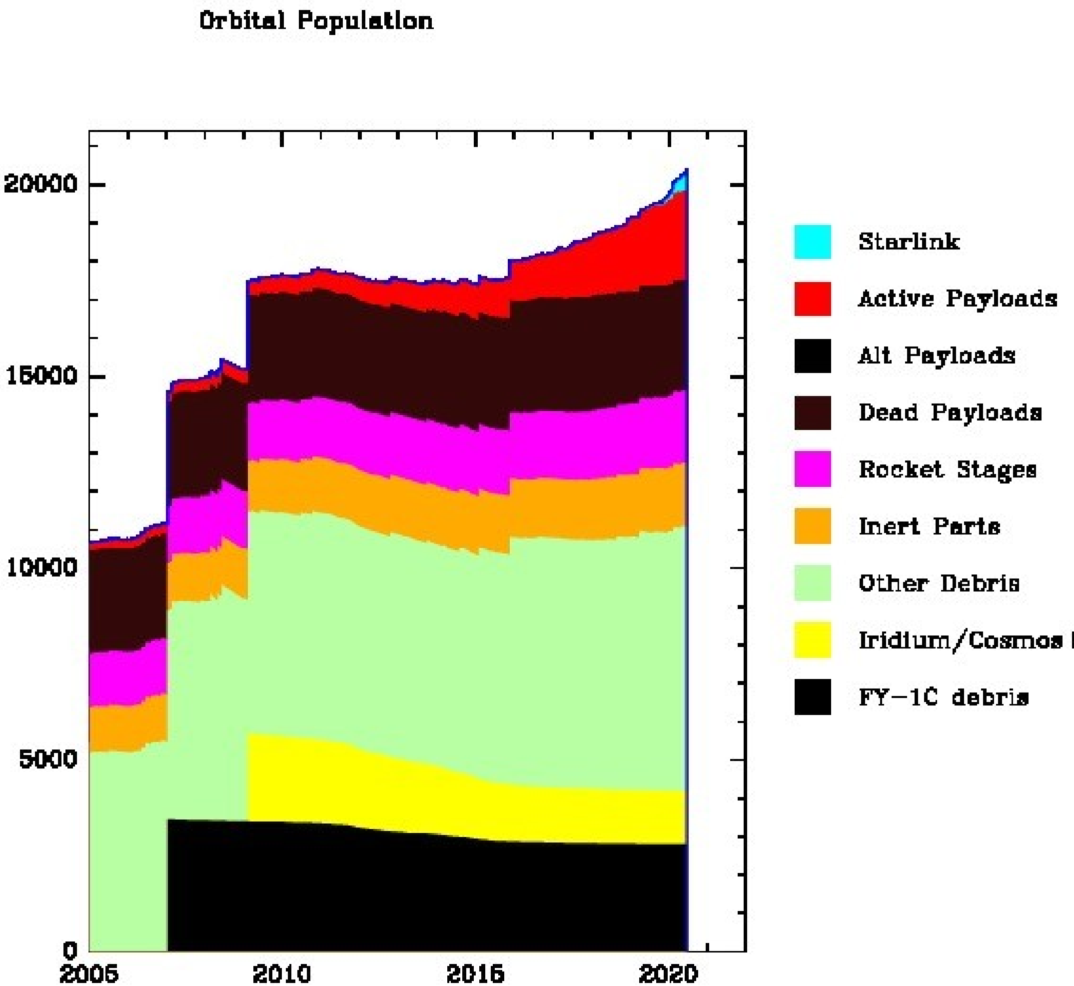


Unprecedented rise in number of active satellites in past few years

Orbital debris population stable since 2010



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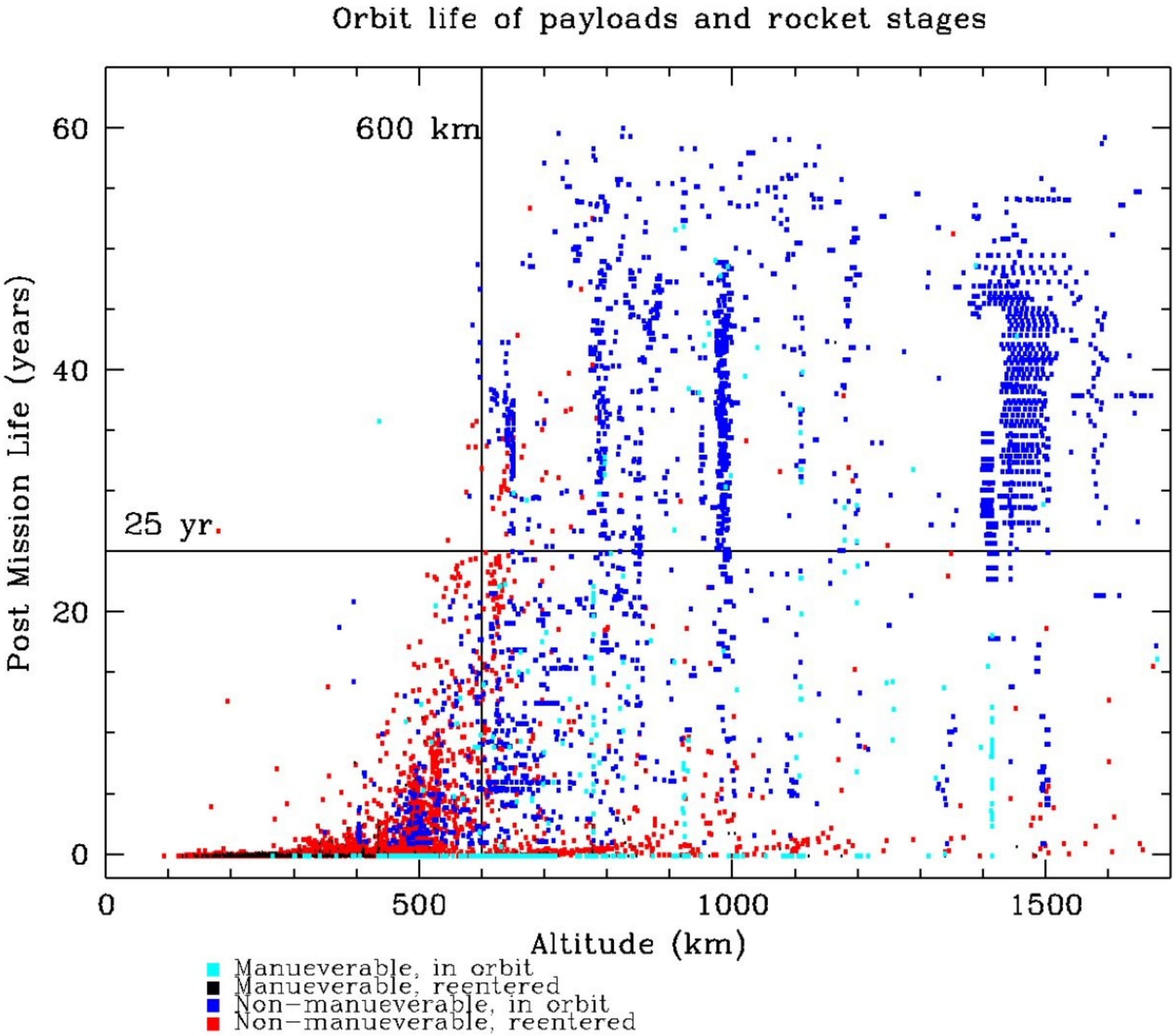

The density of the atmosphere drops off really quickly with altitude.

As a result, orbital lifetime (against natural decay) changes rapidly with height.

This is especially true in the 500-600 km region where lifetimes rise from ~years to centuries.

I pick 600 km as a working boundary between lower and upper LEO.

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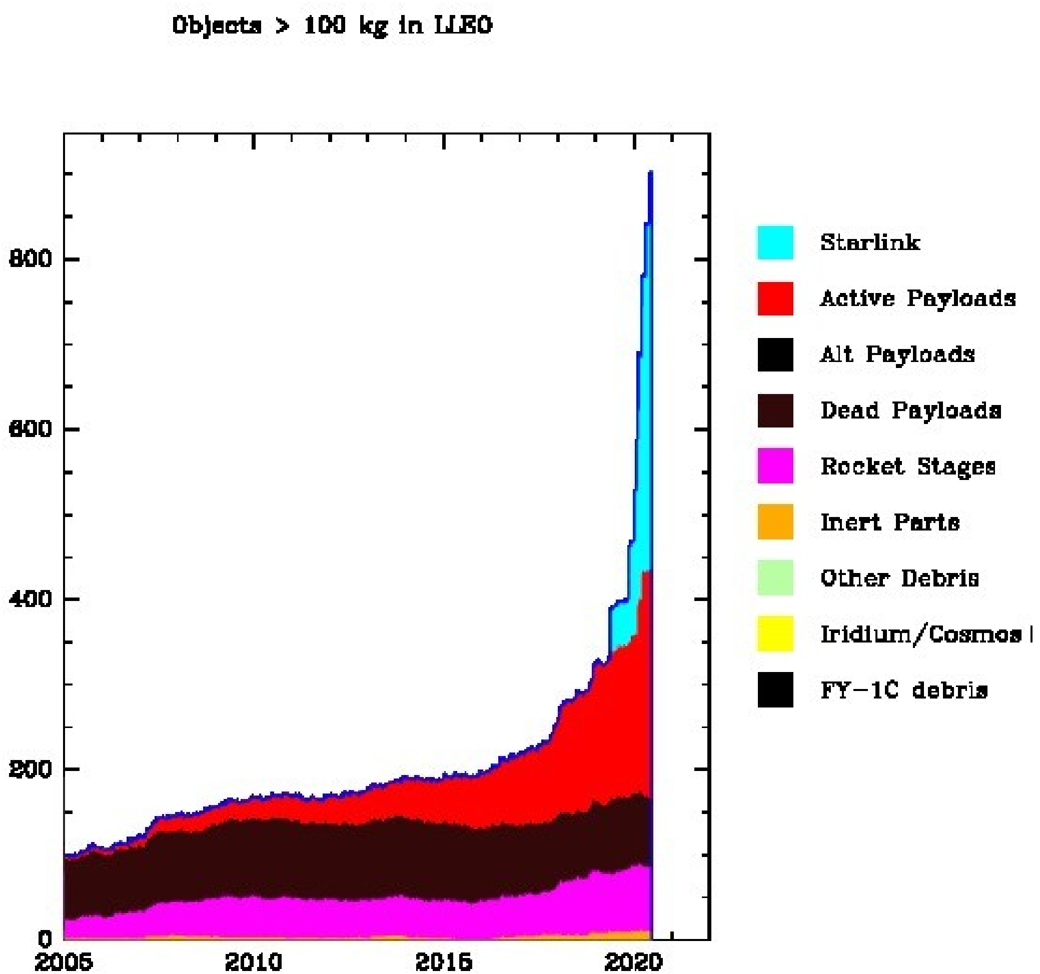

Musk: there are thousands of sats up already

BUT: mostly small debris or in high orbits

Not so many BIG and LOW: Starlink already dominates this subclass in mid 2020

Plot shows tracked objects below 600 km and more massive than 100 kg as of Jun 20 (Starlink in cyan)

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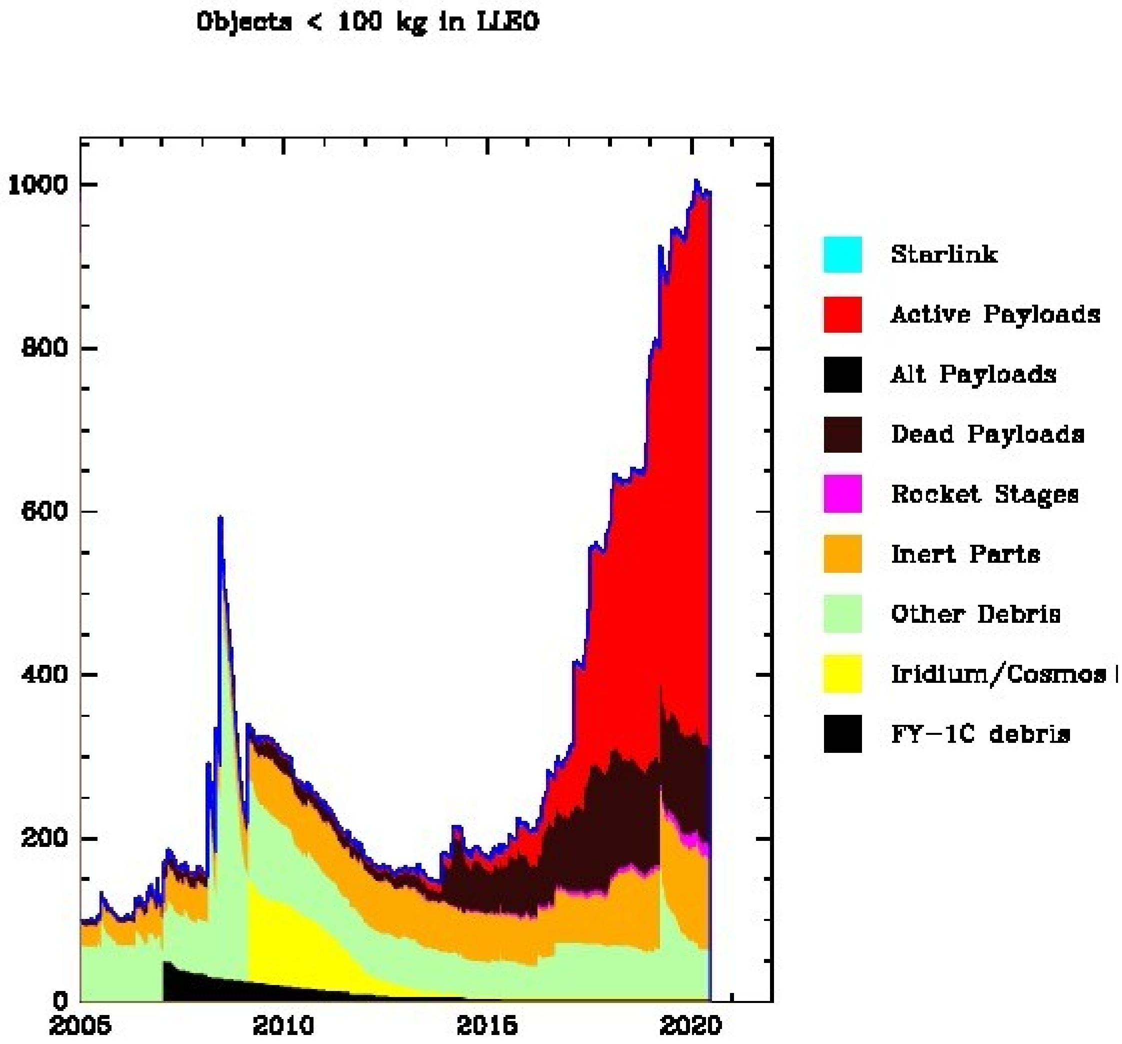

Population of SMALL, LOW objects (<100 kg, < 600 km) has also changed in past 5 years: the cubesat revolution

Tracked population was debris-dominated: now dominated by active payloads.

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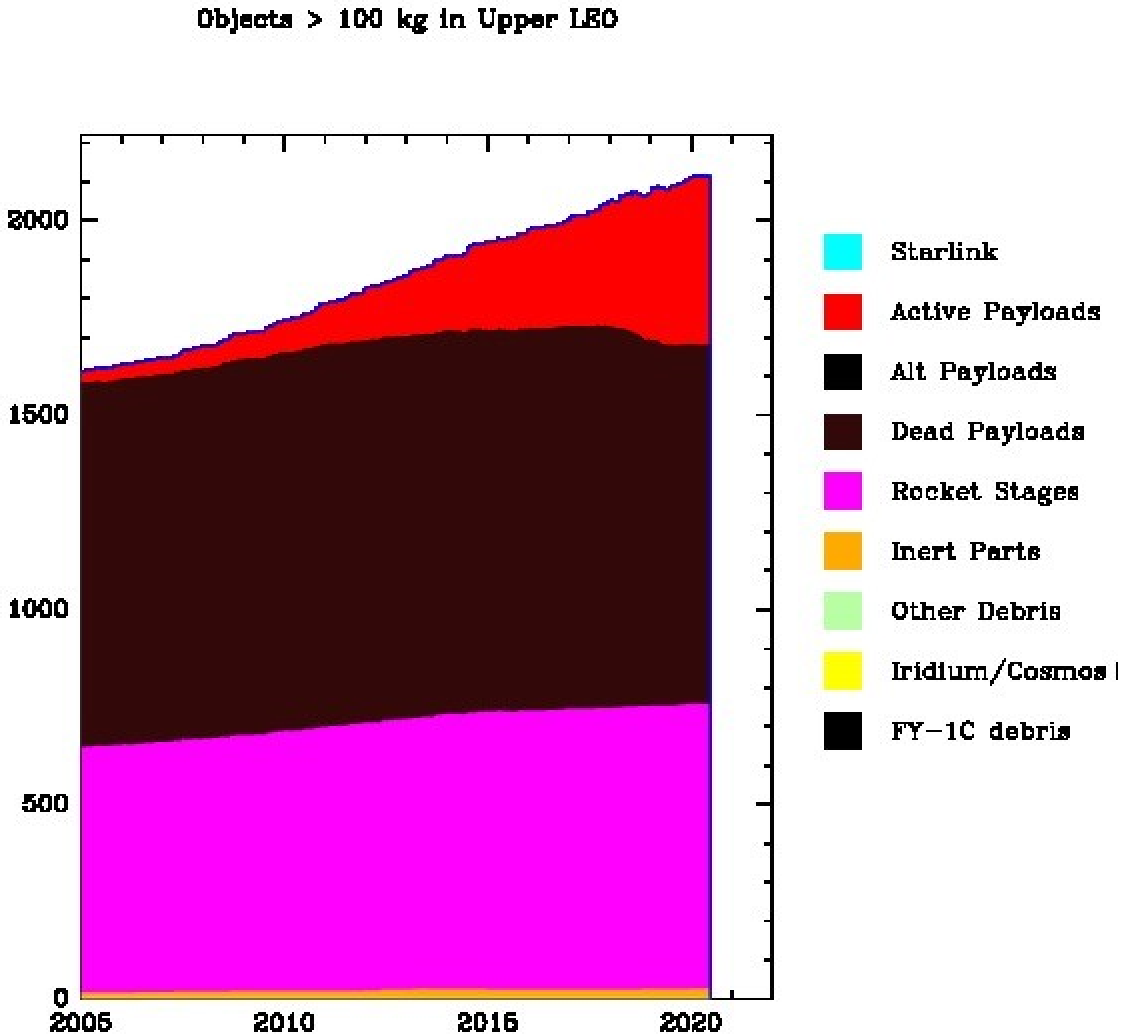

In contrast to the situation in lower (<600 km) LEO, the population is evolving only slowly in upper (>600 km) LEO. (This will change if OneWeb is deployed).

Current population of large objects: about 2000, mostly dead payloads and discarded rocket stages. **Not** currently dominated by active satellites.

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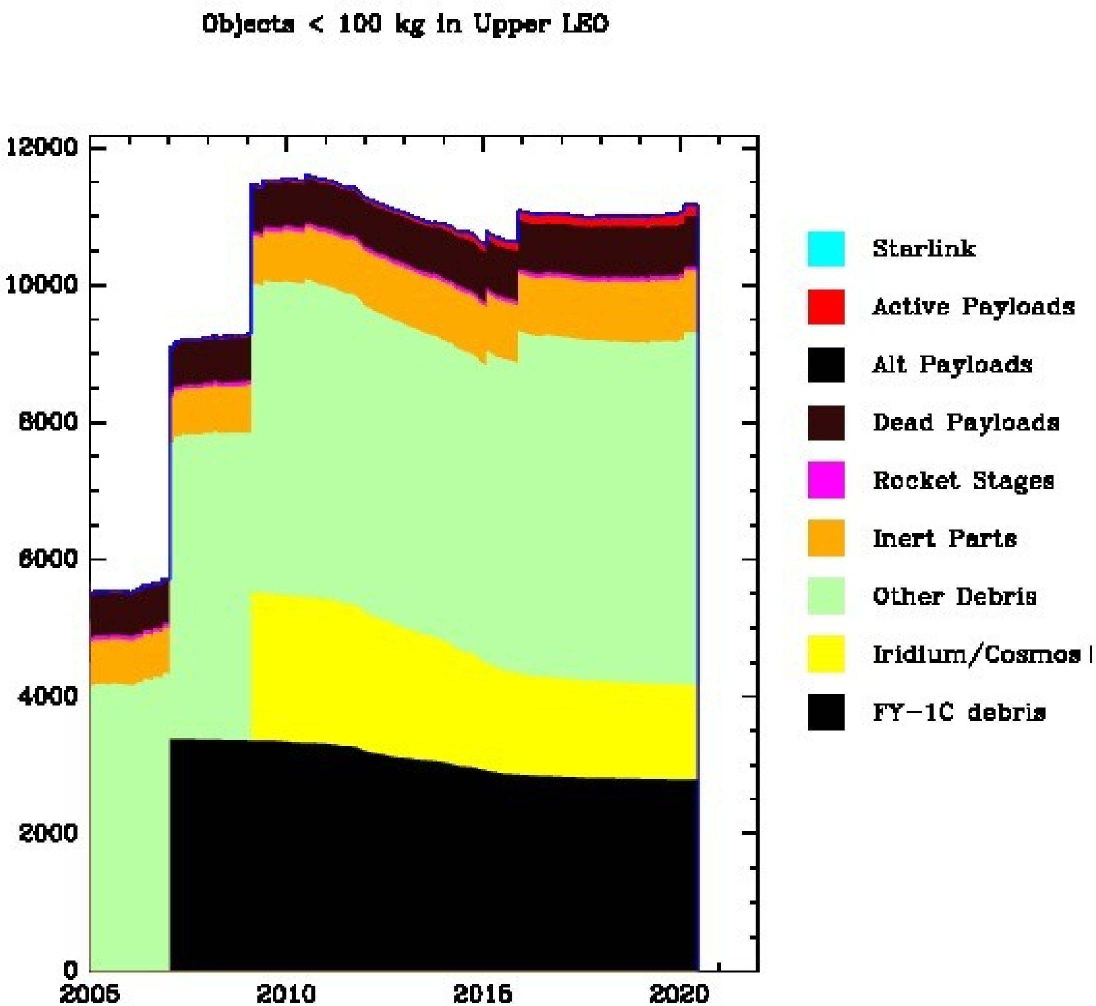

Following the large 2007 and 2009 debris events, the (tracked) small debris population in upper LEO is almost steady state over the past 10 years.

Dominated by debris from satellite collisions, ASAT tests and by rocket stage breakups caused by ignition of residual propellants (often years after launch).

Note the much higher normalization here.

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Constellations to be modelled based on mid-2020 FCC filings:

Starlink Generation 2:	30,000 satellites at 328 to 614 km
OneWeb Phase 2:	47,844 satellites at 1200 km
Amazon Kuiper:	3,236 satellites at 590-630 km
Total:	81,080 satellites!

“Megaconstellations” (well, really only myriaconstellations... nevertheless unprecedented)

OneWeb sats are smaller and higher than Starlink – I am not aware of magnitude measurements but expect they will be V ~ 9 -- 10 or so: too faint to see with naked eye but glaringly bright by astronomical detector standards.

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Constellations made up of shells defined by altitude, inclination, number of planes, number of satellites per plane:

MODEL III: Starlink Constellation, Gen 2 (May 2020 Filing, 30000 satellites)

I will refer to this as 'Gen2'.

Layer	Element	Altitude (km)	Inclination (deg)	No of planes	Sats per plane	Total sats
A	1	328	30.0	7178	1	7178
A	2	334	40.0	7178	1	7178
A	3	345	53.0	7178	1	7178
B	4	373	75.0	1998	1	1998
B	5	499	53.0	4000	1	4000
C	6	604	148.0	12	12	144
C	7	614	115.7	18	18	324
B	8	360	96.9	40	50	2000

MODEL IV: OneWeb Constellation, Phase 2 (May 2020 Filing, 47844 satellites)

I will refer to this as 'OW2'.

Layer	Element	Altitude (km)	Inclination (deg)	No of planes	Sats per plane	Total sats
A	1	1200	87.9	36	49	1764
B	2	1200	40.0	32	720	23040
C	3	1200	55.0	32	720	23040

MODEL V: Kuiper Constellation (2019 filing, 3236 satellites)

I will refer to this as 'KP1'.

Layer	Element	Altitude (km)	Inclination (deg)	No of planes	Sats per plane	Total sats
A	1	630	51.9	34	34	1156
B	2	610	42.0	36	36	1296
C	3	590	33.0	28	28	784

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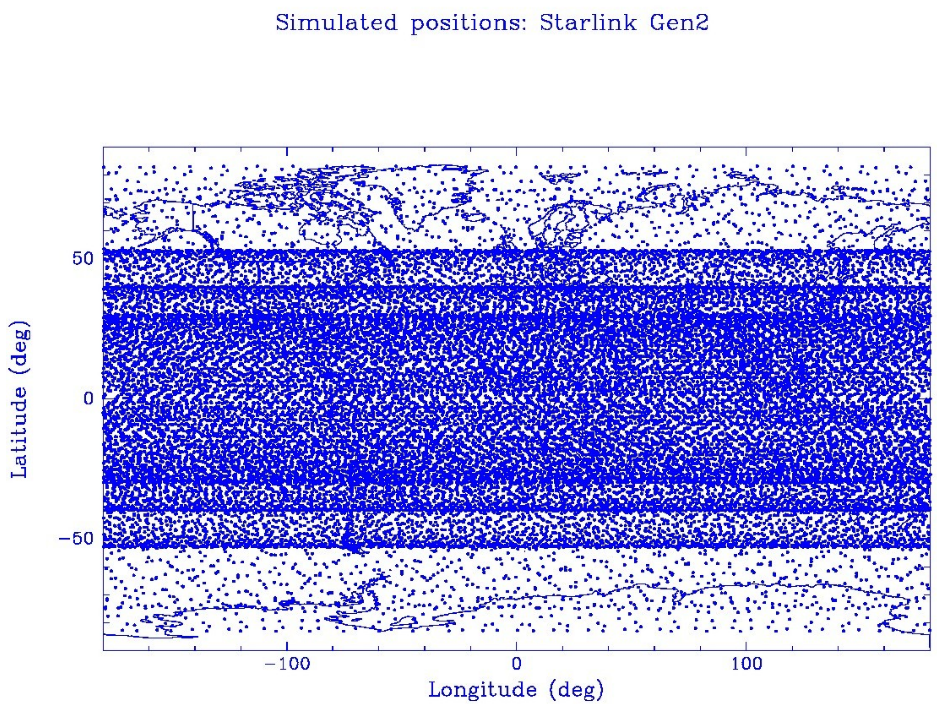
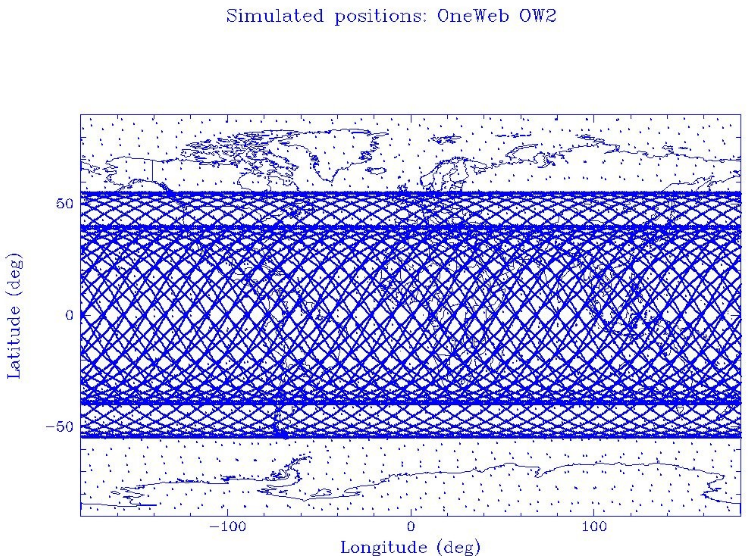
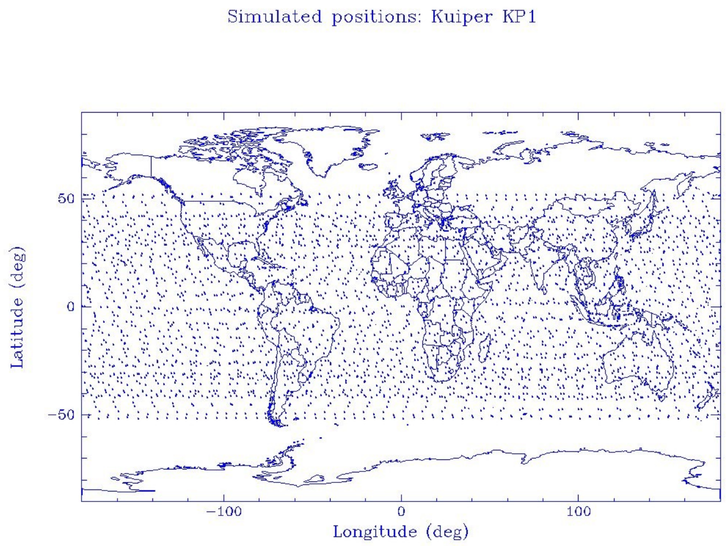
Realization of constellations showing latitude/longitude distributions.

Limited polar coverage







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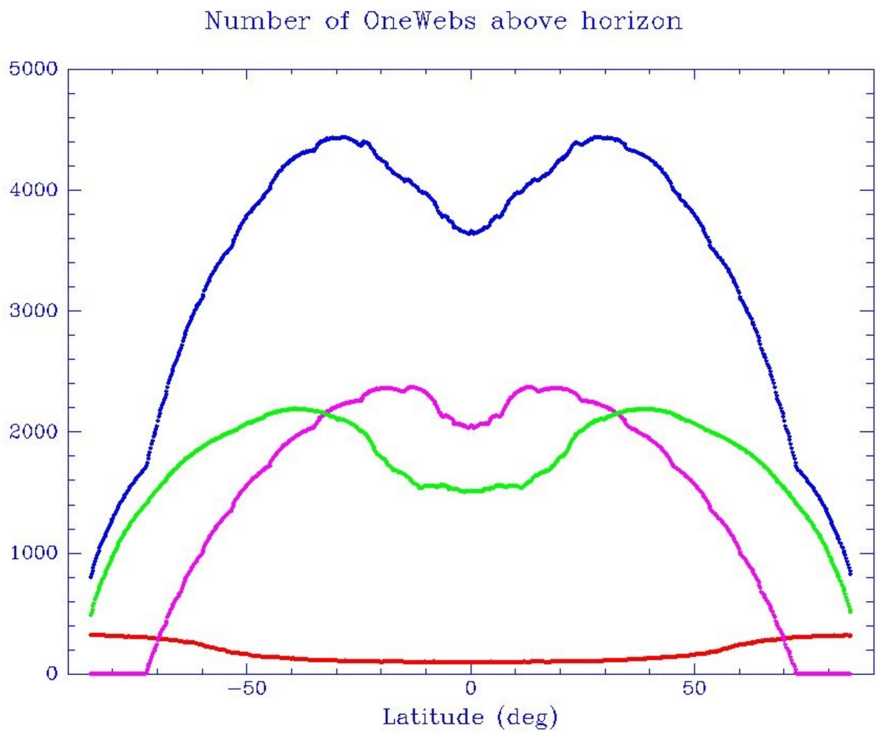

We can plot these realizations versus latitude from the point of view of an observer at those latitudes

Here, for OneWeb Phase2, I show how three shells at three different inclinations
(40,55 and 88 deg) contribute to the overall number above the horizon as a function of latitude

Contribution peaks at latitudes somewhat less than the orbital inclination. Combination peaks at 30 deg – where lots of observatories are.
But not all these satellites will be illuminated all night...

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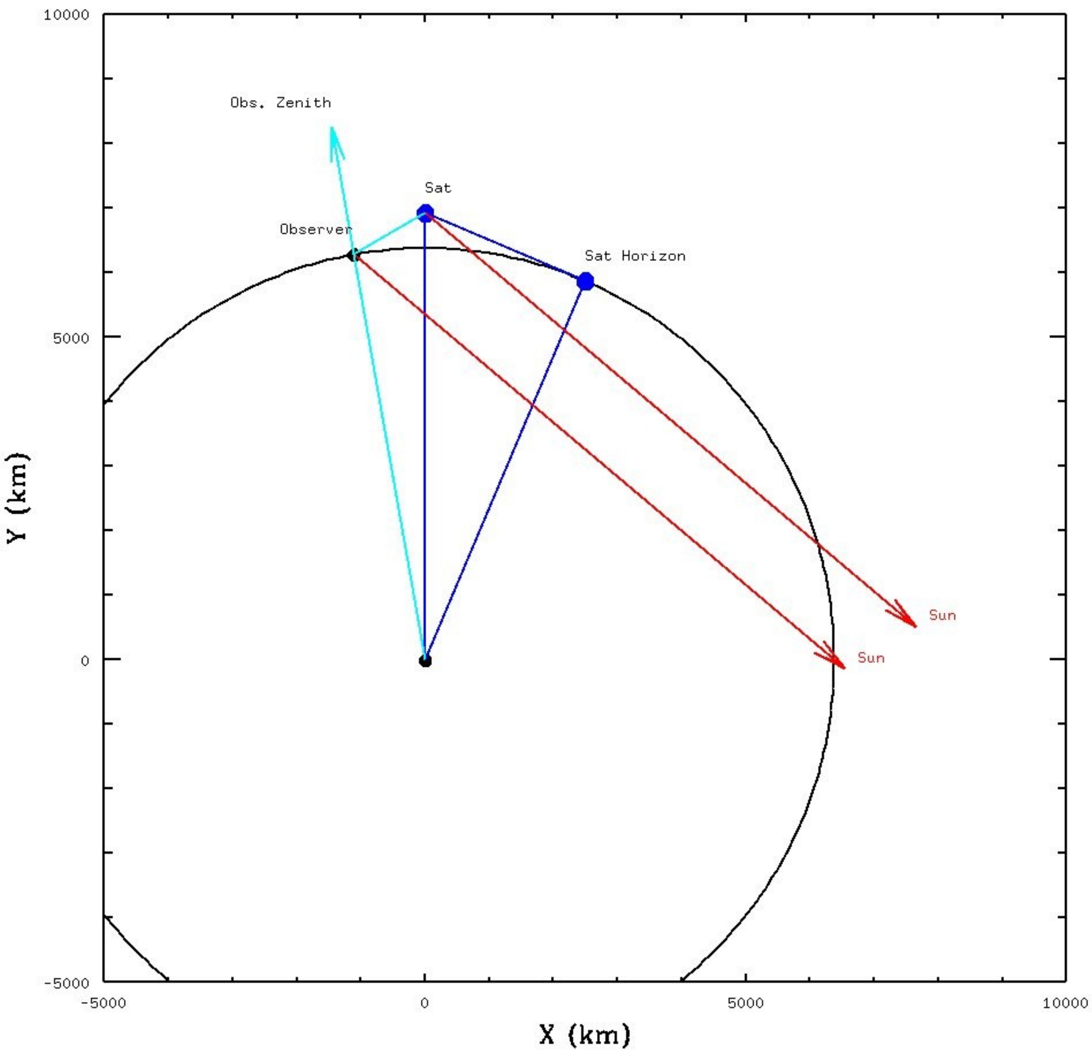

How many satellites are high in the sky and illuminated when it’s dark outside and astronomers are at work?

Geometry of problem involves three angles:

1) Zenith-Observer-Sat angle – **is the Sat above the horizon,** and is it above 30 deg elevation (airmass 2)?

2) Zenith-Observer-Sun angle: **is it night where the observer is?** How far below the horizon is the Sun? (e.g. “Astronomical twilight”)

3) Sat Horizon-Sat-Sun angle: is it night where the satellite is? **Is the satellite illuminated?**

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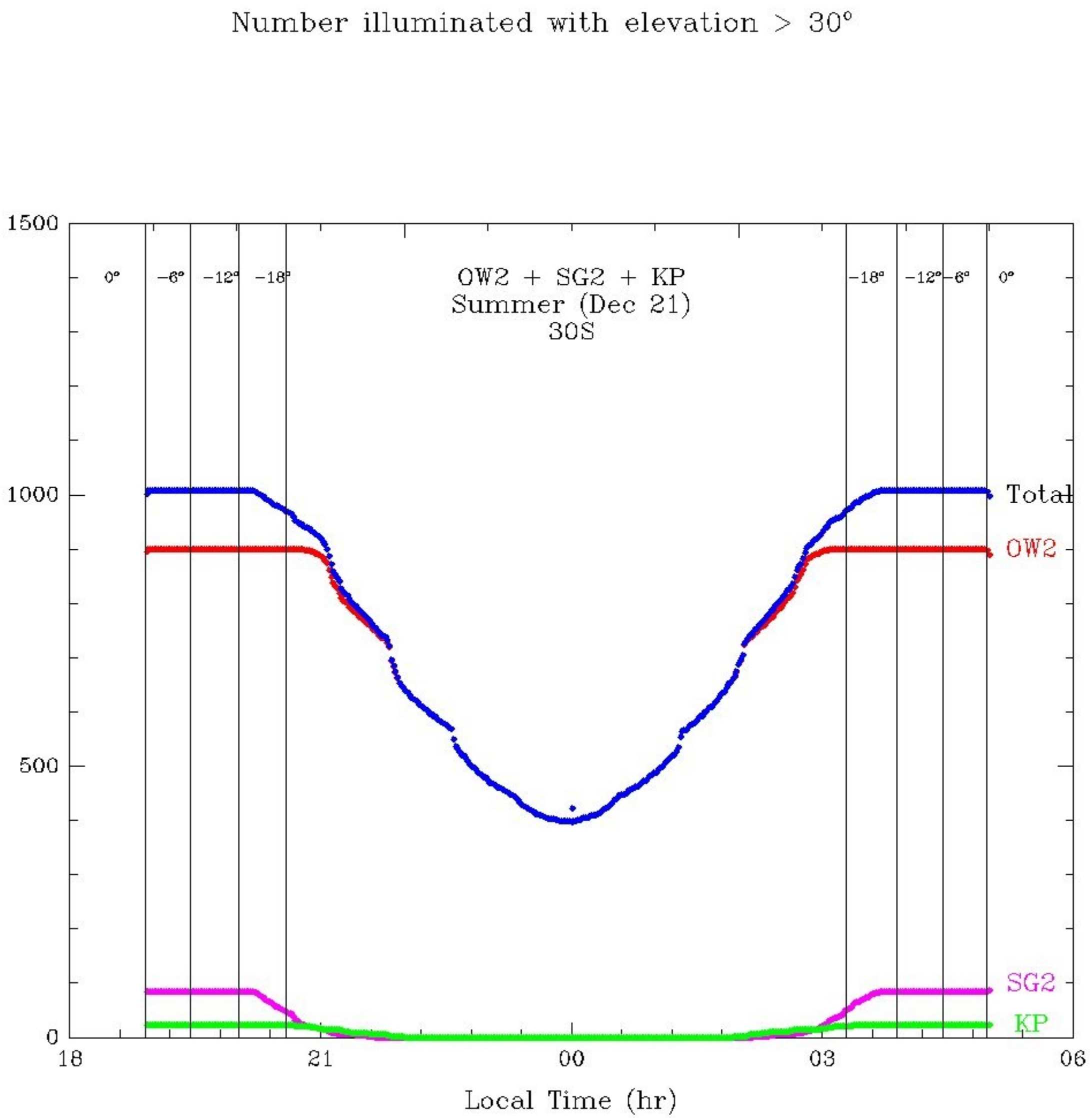

30 deg S corresponds to Cerro Tololo, Chile and other major observatories

At summer solstice, 400 illuminated satellites high in the sky all night long

Dominated by the OneWeb constellation because its satellites are in higher orbits

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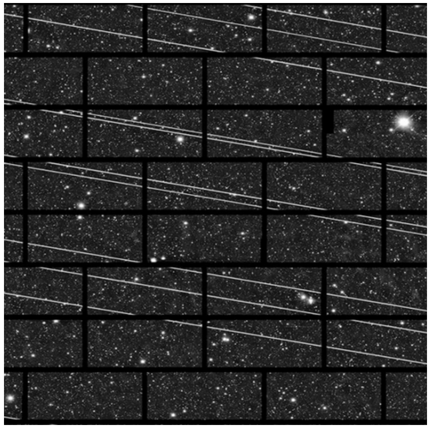
Implications:

n = 500 satellites above 30 deg elevation corresponds to 0.2 sats per square degree

They are mostly OneWebs at 1200 km, angular velocity at zenith is ω = 0.35 deg/s (scales roughly as 1/height)

The expected number of satellite streaks on an astronomical image with field-of-view width D and exposure time T is

$$N = 3.7 \ (n/500)\ (\omega / 0.35 \text{ deg/s})\ (T / 60\text{s})\ (D / 1 \text{ deg})$$



So for LONG EXPOSURES with a WIDE FIELD OF VIEW all images will have multiple streaks, very hard to mitigate.

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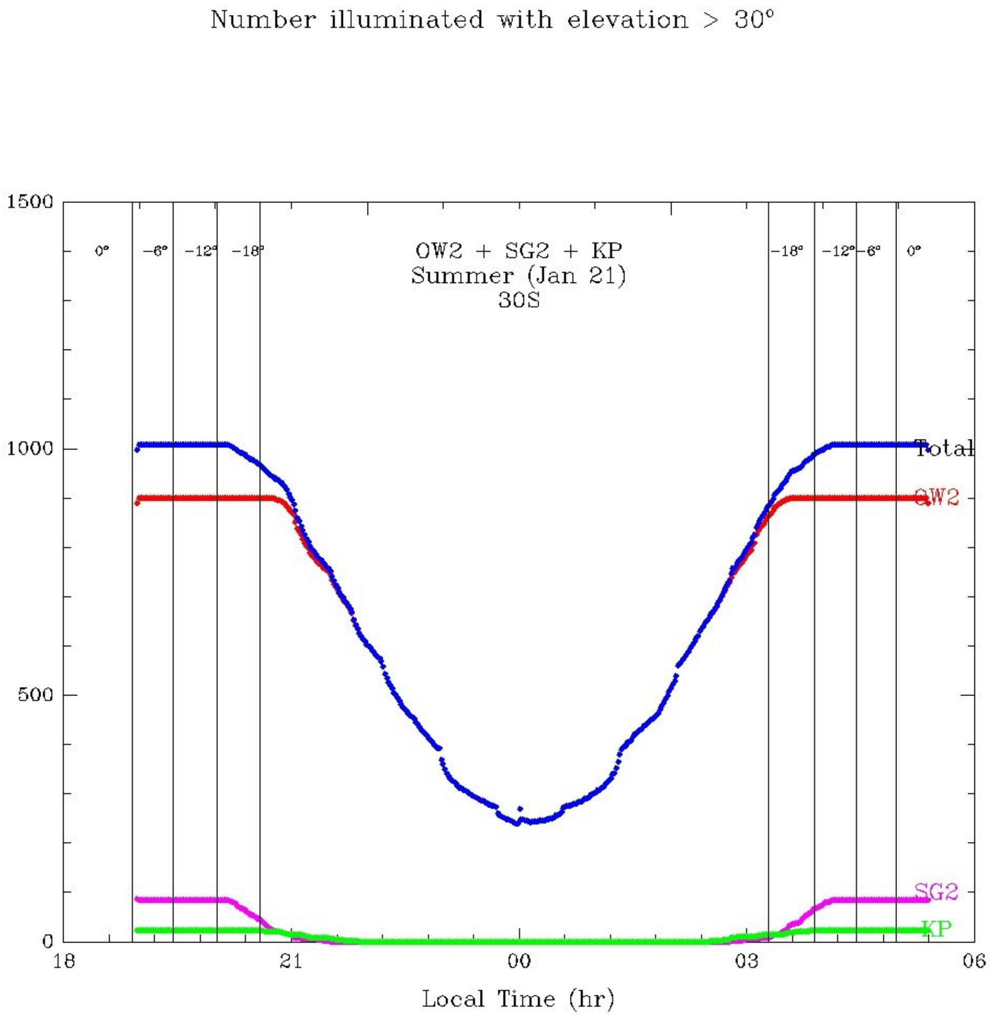

A month after solstice it is still pretty bad – 250 satellites at midnight

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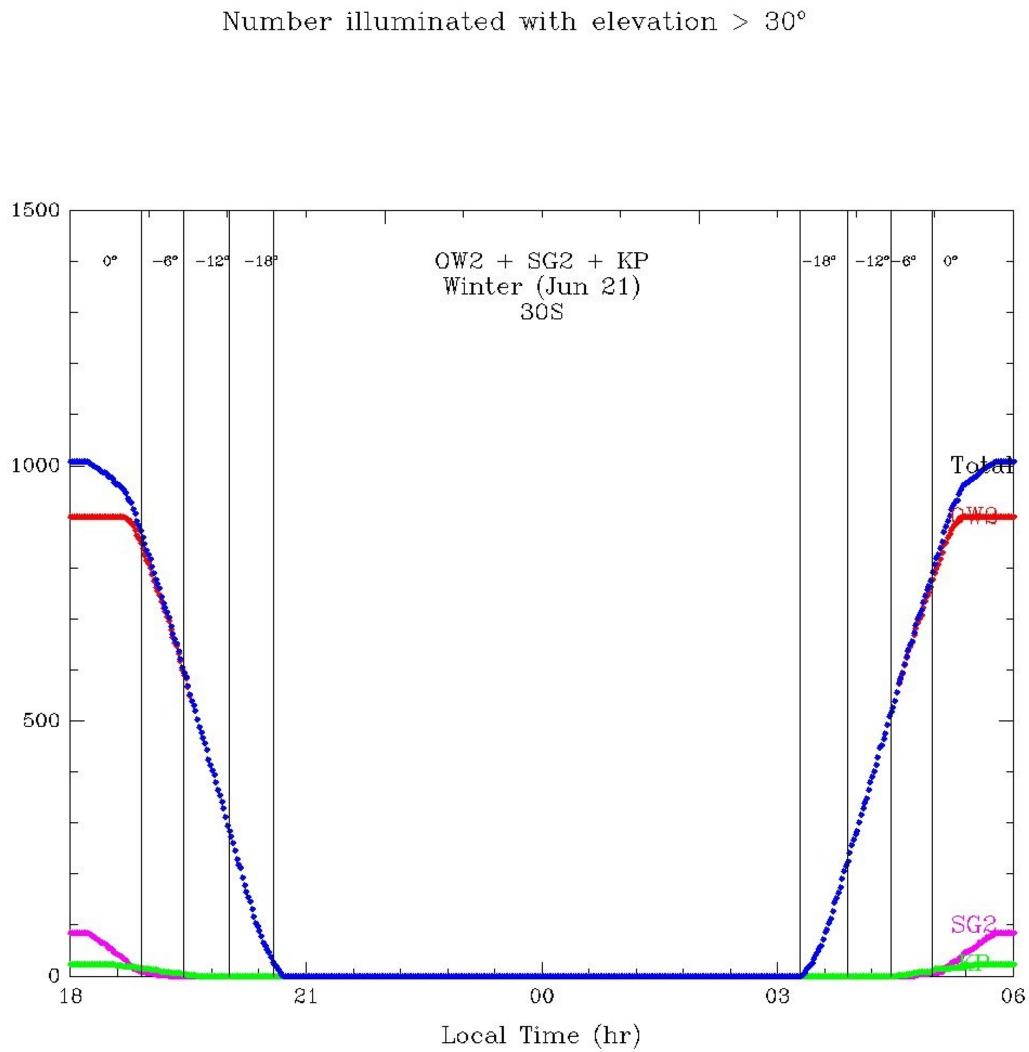

In winter, things are much better – as long as you don't need to observe in twilight

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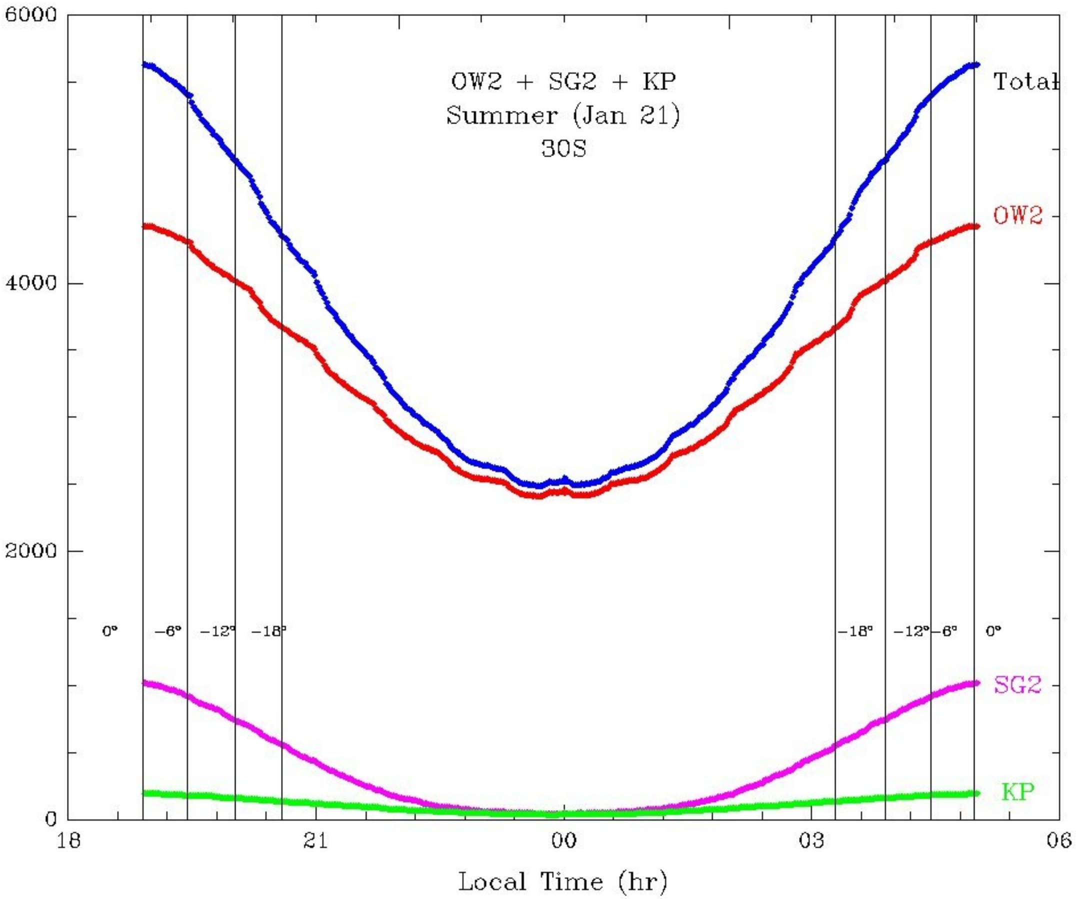
Number illuminated with elevation > 0°



Worst case: observing near horizon during twilight.

Over 5500 satellites illuminated (30S, summer)

Even without the OneWeb contrib, 500-1000 during twilight hours from Starlink Gen2

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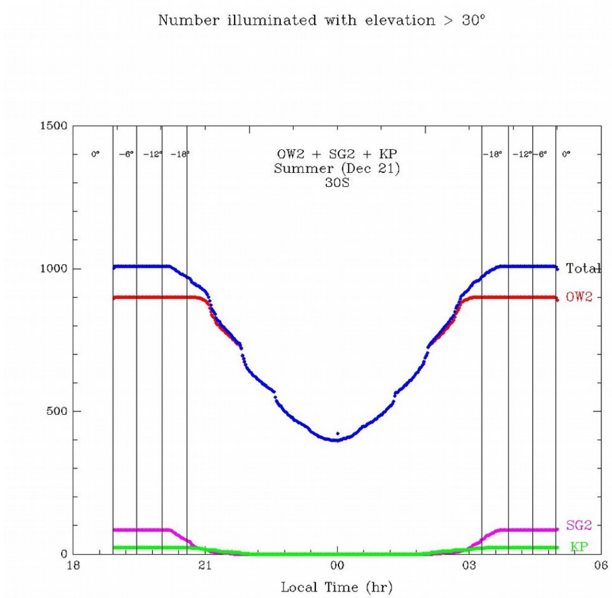

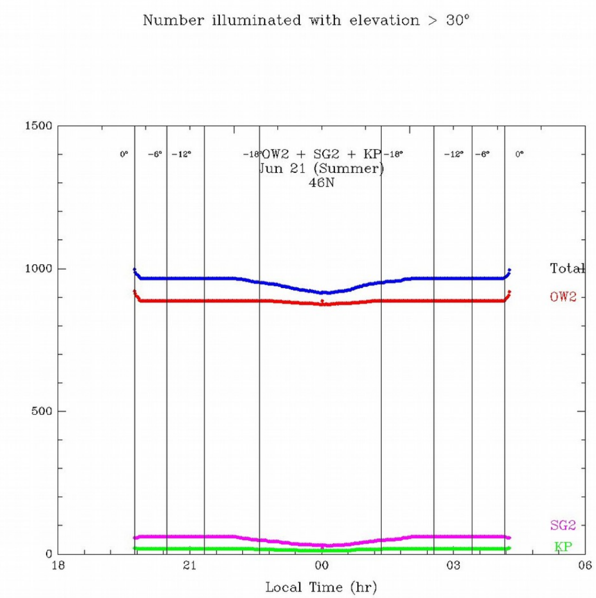

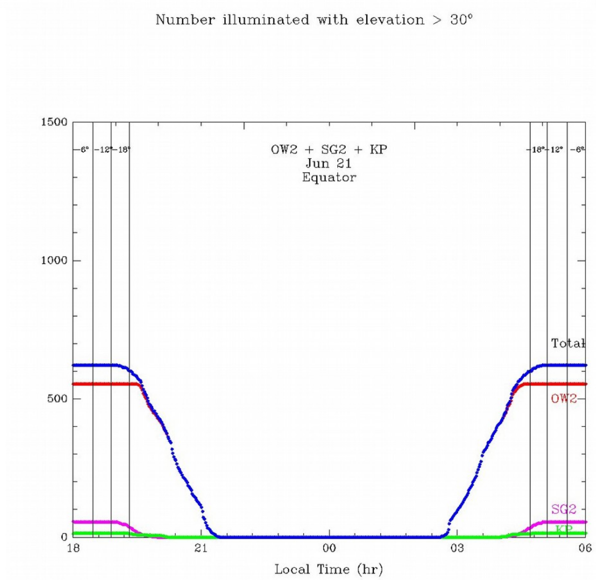

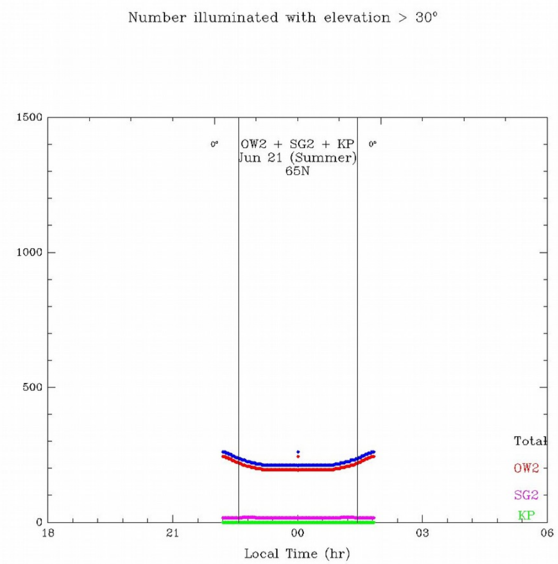

Illuminated sats in summer vs latitude

Gets worse as you go to higher latitudes (due to sun angle change) until you get beyond max lat of main constellation when number of satellites drops.

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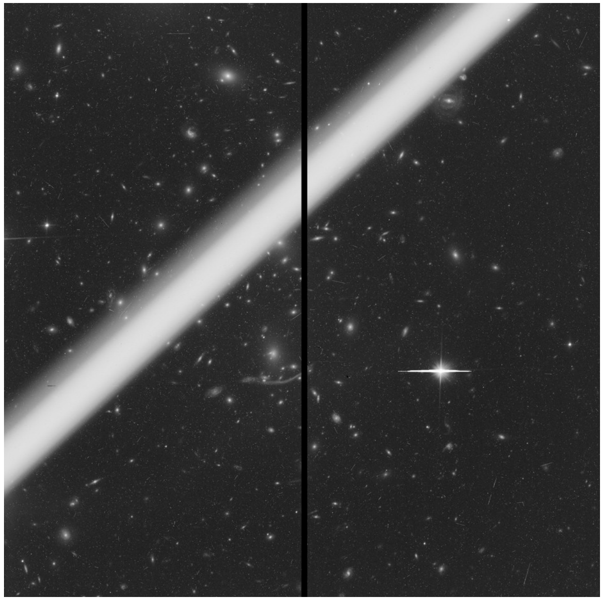
What about LEO space telescopes?
OneWeb at 1200 km is above them

Hubble Space Telescope, currently at 540 km, has narrow field of view (3’) but long exposures (20 min to 1 hr?)
Orbit geometry changes angular velocity factor (but only by O(1)-O(10) or so)

Conclusion: Problem likely just as bad for HST?
Any wide-field telescope in LEO would be in very big trouble.

Image courtesy Judy Schmidt: Chinese rocket stage passes 35 km above HST in Feb 2020, right in direction telescope was looking.



Conclusion:

The megaconstellations will be a significant change to the LEO environment and to the night sky

Impact on astronomy depends sensitively on constellation architecture

Lower (500 km and less) orbit satellites may be naked eye objects but this can perhaps be mitigated with changes to satellite design. They are illuminated near horizon so are a threat to some (NEO search?) but not most astronomical observations

Higher (~1000 km) constellation shells will be illuminated all night long in summer and so, although not naked-eye, will be a threat to professional astronomy.