Large Constellations of LEO Satellites and Astronomy

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Abstract

The launching of the Starlink and OneWeb satellites has ushered in the era of large (or mega) constellations of bright satellites in low Earth orbit (LEO). These satellites are likely to be brighter than the majority of everything currently cataloged in Earth orbit, including spacecraft, rocket bodies, and debris. Properly designed and operated, these satellites could be invisible to the unaided eye even under the best conditions but will still have a serious impact on astronomical research using large, wide field telescopes. The trails of such satellites can saturate the detectors of telescopes even if the satellite is not visible to the unaided eye.

1. Introduction

At the present time there are over 20,000 Resident Space Objects (RSO) larger than 10 cm currently in Earth orbit in the catalogs maintained by the US Air Force. Every one of these can be assumed to have an albedo greater than zero, and thus could be detected (in principal) by ground-based or space-based sensors if the illumination conditions are favorable (RSO is sunlight and ground-based detector in darkness). But over the next ten years over 100,000 new satellites could be launched into LEO if all announced plans come to pass. And this is just the population of satellites that we know about – have filed plans with the Federal Communications Commission (FCC), with the International telecommunications Union (ITU), or announced in press releases.

The impact on the night sky and professional research astronomy could be extreme. The launching of the first 60 Starlink satellites in May 2019 brought home the potential problems. These satellites were extremely bright (up to 2^{nd} magnitude), closely spaced on the sky, and could easily be seen even in heavily light polluted cities. Was this the future of astronomy?

Fortunately, SpaceX undertook remedial action in the design of future Starlinks, and it appears that at least for now there will be few new Starlinks that could be seen with the unaided eye.

2. Situation Prior to Large Constellations

Every RSO in orbit today could possible leave a streak in an astronomical image. Figure 1 below shows how many cataloged objects would be more than 30 degrees above the horizon for one night if observed from Cerro Tololo InterAmerican Observatory (CTIO) in Chile.

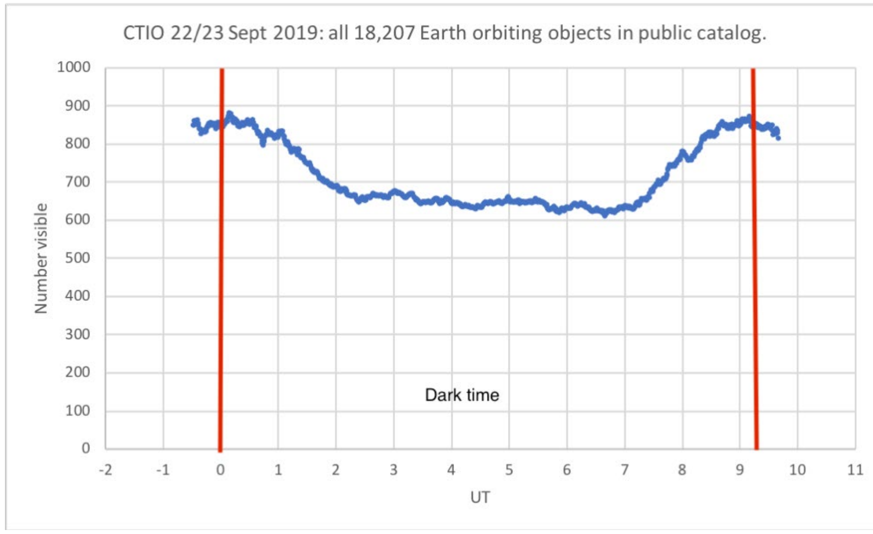

Figure 1. Number of RSOs in sunlight (not in Earth shadow) and thus potentially detectable by a ground-based telescope as a function of time during the night. This calculation includes all objects with TLEs with ages less than 30 days old and public analysts' objects on space-track.org. Only if the object was at an elevation greater than 30 degrees for any part of its pass was it included in the plot. The red lines are when the Sun is at 18 degrees below the horizon (astronomical twilight). Between those red lines is the darkest and most valuable part of the night for astronomical observations. The plot runs from nautical twilight (Sun 12 degrees below the horizon and when the night starts to get dark enough for certain observations) in the evening to nautical twilight in the morning.

The majority of these objects are small, and presumably faint for reasonable values of albedos. But the new Starlinks are brighter than the vast majority of RSOs currently in orbit.

If there are more than 600 objects potentially visible at any one time in a population of 18,207 objects, then if the future new population is more than 100,000 additional objects, the challenge to astronomy could be serious indeed.

3. Challenge to Astronomy

Astronomical observations are usually sidereal tracked, where the telescope tracks the star. Satellites thus leave streaks across the image. For large, fast telescopes like the 4.0-m Blanco telescope in Chile and the forthcoming Vera Rubin Observatory (also in Chile), the systems are so fast and sensitive that satellites brighter than 7th magnitude can saturate the detectors even if the effective exposure time for a satellite is just milliseconds as it crosses the detector's pixels.

Saturated streaks can have multiple effects:

1. Loss of information in the saturated pixels.
2. Possible ghost images elsewhere in the field of view due to reflections in the optics.
3. Possible residual image in subsequent images if the erasing process is not complete.
4. Cross talk in electronics leading to effects elsewhere in the same CCD detector or in neighboring CCDs.

Which of these effects are important depends critically on the design of the detector and imaging systems. Some systems may have only small effects while others may be significantly affected by bright satellite streaks.

Even if the streak does not saturate the detector, there is still loss of information at worst or degraded signal-to-noise for objects underneath a streak.

4. Large Constellation Study

For comparison, I model a hypothetical constellation of 10,000 satellites distributed with 100 satellites equally spaced in each of 100 planes. The orbital inclination was chosen to be 53 degrees, representative of many current or planned constellations aiming to cover customers in the US and Europe. Figure 2 shows the number visible for one night in summer at 30 degrees latitude. Satellite elevation in 30 degrees or more. Two constellation altitudes were studied: 500 km and 1000 km.

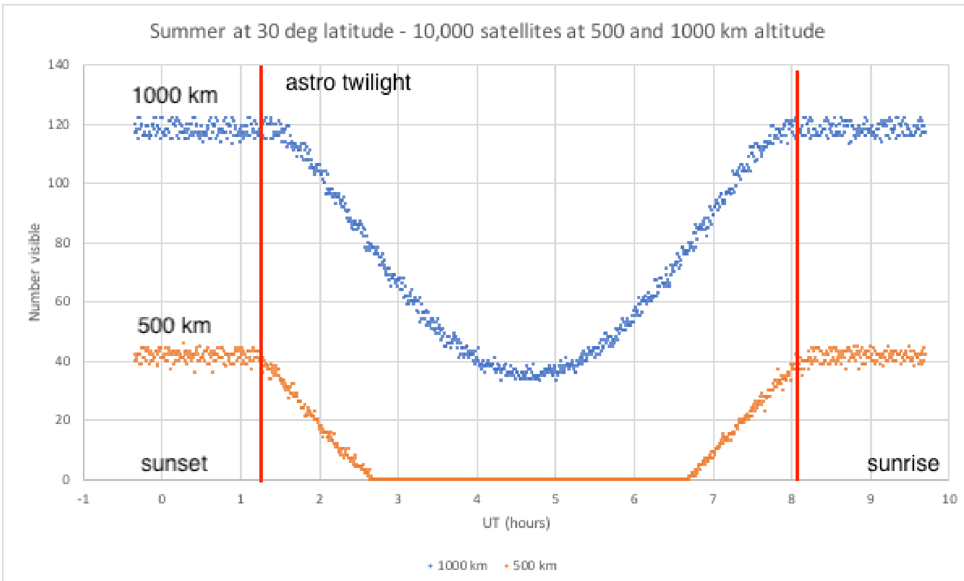

Figure 2. Number of satellites visible above 30-degree elevation for a constellation of 10,000 satellites distributed with 100 satellites in each of 100 planes. Two constellation altitudes are shown. The plots run from sunset at the left to sunrise at the right. Red lines are astronomical twilight.

The trend is clear – higher altitude constellations will be visible to the astronomer all night long during the summer. There will be no escape from satellites at altitudes like 1000 km during the summer. These satellites will be visible in the south for a southern hemisphere observatory, and to the north for a northern hemisphere observatory.

Multiply this figure by 10 if 100,000 satellites are launched, and if they are all bright, the challenge for astronomy is clear.

Another example is the proposed OneWeb constellation of 47,844 satellites planned for 1200 km. Figure 3 shows the simulation for the summer at the Vera Rubin Observatory in Chile:

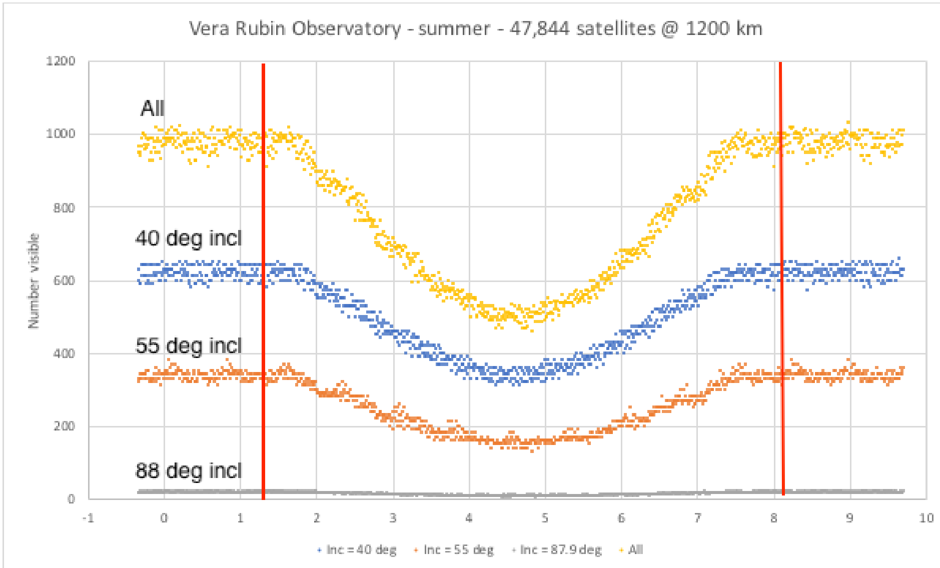

Figure 3: Simulation of the full OneWeb constellation of 47,844 satellites during the summer ate the Vera Rubin Observatory in Chile. Three inclinations, all at 1200 km altitude. Plot runs from sunset at the left to sunrise at the right. Red lines are astronomical twilight.

This constellation is of real concern to astronomers because of the large number of satellites, and their altitude. During the summer 500 satellites will be in sunlight even at midnight. Their distribution is towards the south (since the shadow cone points north). For an object like the largest satellite galaxy of the Milky Way – the Large Magellanic Cloud (LMC) – every 30 second exposure will have a satellite trail from this constellation all night long.

5. Conclusions

Large constellations of large, bright satellites pose a real challenge (threat?) to the appearance of the night sky and professional research astronomy. One crucial thing to remember: even if a given satellite is fainter than can be seen by the naked eye and does not saturate detectors on large telescopes, the resulting streak causes considerable information loss and degradation. Recommendations are to keep satellites faint and below 600 km.