The Potential Impairment of Astronomy Observations by Satellite Mega-Constellations

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Abstract
Recently, mega-constellation projects have launched a large number of satellites to non-geostationary orbits, which aim to provide high-speed Internet access to the entire world. In May 2019, the International Astronomical Union, which found possible impact on astronomical observations, issued a statement expressing its concern. The Astronomical Society of Japan is also concerned about such impact and would like to share information about these projects as well as their effects with all of its members. This article presents the results of an evaluation of expected effects on optical/infrared, radio, and solar observations. Our evaluation suggests that optical-infrared observations are particularly vulnerable to mega-constellations because 200–600 satellites will always be visible at 2–7 magnitude.

The Big Wave of Mega-Constellations

The world is seeing a wave of mega-constellation projects, which aim to provide high-speed Internet access through a network of numerous non-geostationary satellites. These projects hope to provide high-speed (up to 1 Gbps), low-latency Internet service all over the world. So once established, these satellite constellations will bring a great benefit to many people. The OneWeb constellation[1)], which a Google-backed company started to launch at the end of February 2019, was the first of its kind. Following that, at the end of May 2019, SpaceX started to launch the more massive satellite constellation Starlink.[2)] Table 1 shows the technical specifications of some mega-constellations.

An important point to note here is the numbers of satellites. OneWeb plans to deploy a total of nearly 4,500 satellites and Starlink plans to deploy a total of nearly 12,000 satellites. The size of each satellite is not so large. In the case of the Starlink satellites, their rectangular bodies measure 3 × 3 × 0.2 m, to which a solar panel measuring 7 × 3 × 0.05 m is attached. The weight is only 200–250 kg. SpaceX's Falcon 9 rocket can deliver 60 Starlink satellites into orbit in each launch. The first batch was launched on May 24, 2019. These satellites are to be deployed into Very-Low Earth Orbit (VLEO) and Medium Earth Orbit (MEO), with all satellites spaced approximately evenly over each orbit. Shortly after the launch, people around the world witnessed these satellites traveling in a row across the sky and then the footage that captured the spectacle spread around the Internet.

Table 1: Technical specifications of mega-constellations[3)] The orbit types are abbreviated as follows: Low Earth Orbit (LEO); Medium Earth Orbit (MEO); Very-Low Earth Orbit (VLEO). The symbol (↓) represents space-to-Earth transmissions and the symbol (↑) represents Earth-to-space transmissions. The O3b satellite constellation will consist of three sub-constellations called O3nB, O3bl, and O3b mPOWER.

System	OneWeb	Starlink	Telesat	O3b
Number of Satellites	LEO: 1,980 MEO: 2,560	LEO: 4,425 VLEO: 7,518	117	O3nB: 24, O3bl: 16, O3b mPOWER: 7
Orbital Altitude (km)	LEO: approx. 1,200 MEO: approx. 8,500	LEO: approx. 1,150 VLEO: approx. 340	Polar Orbit: 1,000 Inclined Orbit: 1,248	8,062
Bandwidth (GHz)	10.7–12.7(↓), 12.75–13.25, 13.8–14.5(↑)	10.7–12.7(↓), 14.0–14.5(↑)	17.8–18.6, 18.8–19.3(↓), 27.5–29.1, 29.5–30.0(↑)	17.8–18.6, 18.8–19.3(↓), 27.5–29.1, 29.5–30.0(↑)
Latency (ms)	≤ 50	LEO: 25–35	30–50	≤ 150
Data Rate (bps)	LEO: 50 M MEO: 2.5 G	LEO: 1 G	1G	1G

Growing Concerns in the Astronomy Community

On the other hand, there have been growing concerns in the astronomy community since the first launch of the Starlink satellites. These concerns were triggered by a shocking image (Figure 1) taken by astronomers working at the Lowell Observatory in the U.S. They captured this image, not intentionally but by accident during observations of a supernova in the NGC 5353/4 galaxies. Since it was right after the launch on May 24, 2019 and thus before the dispersion of the Starlink satellites, the distance between each satellite was not sufficient, creating multiple diagonal trails which interfered with the observations.

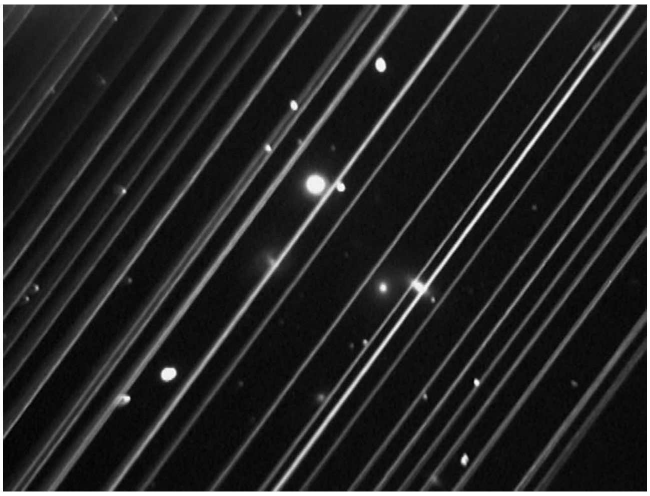

Figure 1: “Disturbance” caused by the Starlink satellites. This image was unexpectedly captured during observations of a supernova explosion in the NGC 5353/4 galaxies. Even a single launch of 60 satellites can cause such a disturbance.[4] Credit: Victoria Girgis/Lowell Observatory.

It is estimated that once all 12,000 of the Starlink satellites are launched, approximately 200 of them will be visible in the sky at any given time. Upon receiving the news, the International Astronomical Union (IAU) acted immediately and issued a statement on June 3, 2019, to express its concerns. [5] This was followed by a series of similar statements issued by other astronomy-related organizations in Japan and overseas. On July 9, 2019, the National Astronomical Observatory of Japan (NAOJ) issued the “NAOJ Statement on the Potential Impairment of Astronomical Observations by Satellite Mega-Constellations.”[6] The overseas organizations that issued statements include: the National Radio Astronomy Observatory (NRAO),[7] the Association of Universities for Research in Astronomy (AURA),[8] the Square Kilometre Array (SKA),[9] the Royal Astronomical Society (RAS),[10] and the American Astronomical Society (AAS).[11] The Japan Broadcasting Corporation (NHK) highlighted NAOJ’s statement in the national news, describing it as “unprecedented.” The influence of this news coverage continues even as of the writing of this article, and NAOJ is frequently receiving calls from media companies.

Potential Impairment of Optical-Infrared Observations

By the way, what have the satellites shown in Figure 1 looked like since then? Amateur astronomers in the U.S. observed the Starlink satellites from July to August 2019, and the data obtained from their observations are publicly available on the Internet. These data were summarized by Jonathan McDowell at the Chandra X-ray Center and are shown in Figure 2. This figure indicates that the visual magnitude of each Starlink satellite ranges from 2–7. Objects with such high magnitudes are so bright for astronomers, even amateur astronomers, that it is clear that these satellites can hinder future optical-infrared observations. We heard that astronomers involved in the upcoming Large Synoptic Survey Telescope (LSST) are particularly concerned about this issue because, once the Starlink constellation is completed, every image captured by the telescope will be marred by multiple satellite trails. These negative impacts are expected to heavily affect observations using Hyper Suprime-Cam (HSC) mounted on the Subaru Telescope as well.

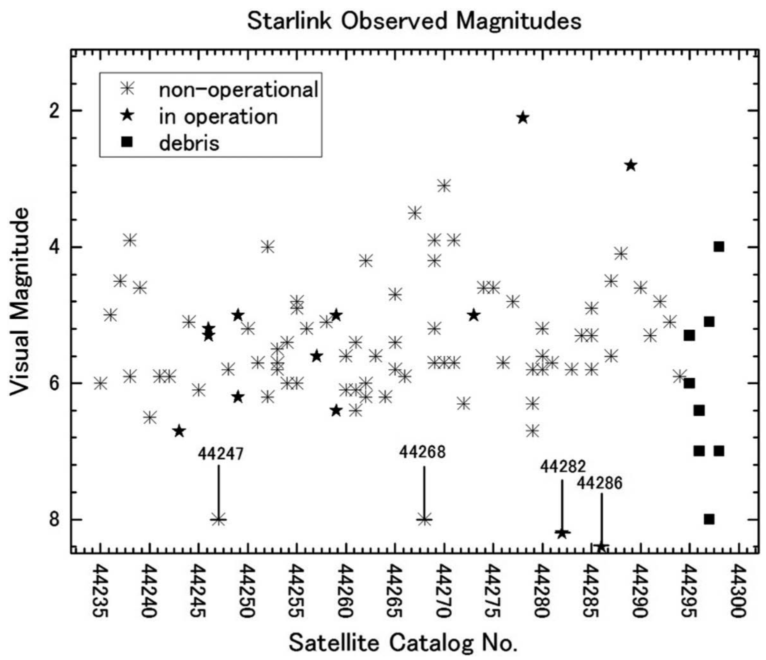

Figure 2: Observed magnitudes of the Starlink satellites. The horizontal axis shows the catalog numbers of the Starlink satellites, and the vertical axis represents their visual magnitudes. The symbol (★) is used for operational satellites and the symbol (*) is used for non-operational satellites. The symbol (■) represents debris. The visual magnitudes of the satellites indicated by bars were not adequately measured. This figure was modified from one provided by Jonathan McDowell at the Chandra X-ray Center. He produced the original figure based on the data available at the Visual Satellite Observer's Home Page.[12)]

On November 11, 2019 the second Starlink batch was launched. Right after this launch, on November 18, astronomers at the Cerro Tololo Inter-American Observatory (CTIO) in Chile conducted observations using the Dark Energy Camera (DECam) and obtained images spoiled by a number of oblique dotted lines left by the Starlink satellites. Clara Martinez-Vazquez at CTIO wrote on Twitter that "I am in shock!!"[13)]

Unlike in the case of radio waves explained below, there is no international organization that works to regulate light pollution in the optical-infrared region. Given the future situation, the pressing issue that we have to address right now is the creation of international rules at the United Nations and other international organizations.

Measures Against Interference with Radio Astronomy Observations

Our modern lives depend on various radio-wave technologies. A good example is the cell phones now carried by almost everyone. The advent of satellite television allows us to view the same TV programs anywhere in the country. On the other hand, since radio waves propagate throughout the area, they inevitably cause interference, unless we strictly regulate their usage including frequency and output power. Because radio waves can easily propagate across national borders, utilizing radio resources requires each nation to legislates its own radio act conforming to the international rules established by the International Telecommunication Union (ITU).

Table 1 shows the information related to the radio frequency bands used for mega-constellation communications. Mega-constellations operate in the 10.7–12.7 GHz band, immediately above the 10.6–10.7 GHz band, where the Radio Astronomy Service (RAS) has primary allocation status. Potential ways to avoid interference with this radio astronomy band were thoroughly discussed in Europe, and the results were summarized in the ECC Report 271.[14)] This report requires mega-constellation satellites to be equipped with High Pass Filters and deactivate the 10.7–10.95 GHz band adjacent to the radio astronomy band in order to appropriately protect radio astronomy observations. Since mega-constellations fly over various countries, their operation requires permissions from countries around the world. In fall 2019, the Ministry of Internal Affairs and Communications (MIC), which is responsible for radio legislation in Japan, convened a meeting to discuss how to protect radio astronomy from mega-constellations, and decided to adopt the same requirements as described in the ECC Report 271.

But one thing we should remember is that the requirements discussed in Europe are applicable only when mega-constellations operate in the specified conditions (Table 1). We will need to reconsider these requirements as the number of satellites increases.

Potential Impairment of Solar Observations

The apparent size of a Starlink satellite as seen from the ground will of course vary depending on its orbital altitude, but taking the apparent size of each one to be several arcseconds, that would mean that satellite silhouettes of that size are expected to mar the face of the Sun during optical-infrared observations. The apparent diameter of the Sun is about 0.5 degrees, which is not so large. Thus, even when all 12,000 satellites are launched, their transit frequency will be only one satellite in every 25 minutes during synoptic solar observations and one satellite in every 6 hours during magnified observations around sunspots. Additionally, because the exposure time of solar observations is shorter than that of distant-galaxy observations, the silhouette of a satellite in each exposure is expected to appear as a dot or a slightly elongated feature, rather than a line running across the field-of-view. However, some observational data, such as those from polarization observations, consist of a series of multiple exposures, and as a result, unobservable regions may become too large to be ignored.

On the other hand, radio observations of the Sun are also conducted at various frequencies. As for observations involving Japan, the communication frequency bands used by mega-constellations do not overlap with the broadband microwave observations (up to 9 GHz), observations with the Nobeyama Radio Heliograph (17 and 34 GHz), nor with the bands (30–950 GHz) used by the Atacama Large Millimeter/submillimeter Array (ALMA), an international astronomy facility also capable of solar observations, in which Japan plays a key role. But for overseas observations, interference from the mega-constellations is a serious concern because several radio interferometers (VLA, EOVSA, CSRH) dedicated to, or capable of, solar observations are observing, or planning to observe, wide frequency bands including these communication frequencies.

We must monitor future trends such as the increasing number of satellites and the expansion of their communication bands while remembering solar observation requirements as well.

Current Trends and Future Perspectives

In mid-October 2019, SpaceX was reported to be planning to launch an additional 30,000 satellites.[15) This information was disclosed to the public because SpaceX was obliged to register its plans to ITU before launching these satellites. Supposing that all 30,000 additional satellites are launched, the number of Starlink satellites alone will total nearly 42,000, which is more than 4 times the 8,500 total satellites ever launched to date. Even when only 12,000 Starlink satellites are on-orbit, 200 of them are expected to be visible in the sky at any given time. This means that the number of visible satellites will be tripled to around 600 when all 42,000 satellites are launched. This can severely impair optical-infrared observations.

Faced with this problem, when the American Astronomical Society (AAS) held its January 2020 meeting in Honolulu, it invited a representative of SpaceX to attend the special session titled "Challenges to Astronomy from Satellites."[16) This session featured presentations on the industrialization of satellite launching enabled by reduced launch costs; simulations showing how many satellites will be visible using the case of CTIO as an example; the potential impacts on radio astronomy and the current state of international regulations; and SpaceX's efforts to reduce reflected light from satellites and request to the astronomy community for cooperation on measuring the brightness of the Starlink satellites. During the session there were comments like "Wide-field-of-view observations could be threatened because reflected light from multiple satellites will produce ghosts" and "Infrared observations, in which all the satellites above the horizon are visible, may be particularly vulnerable to mega-constellations."

To strike a balance between astronomy observations and satellite usage, we need to understand each other's perspectives, so this kind of candid meeting will pave the way for a peaceful resolution. Among the 60 Starlink satellites launched in early January 2020, the one designated as STARLINK-1130 (Int'l Code: 2020-001U) is treated with an anti-reflective coating, so it may be a good idea to observe this satellite from various regions in Japan and measure its magnitude, and then report the results to SpaceX. From the same perspective, it will also be important for the Astronomical Society of Japan (ASJ) to show Japanese society how astronomy and mega-constellations can peacefully coexist.

Translated from the Japanese version by Mr. Ramsey Lundock and Mr. Ryo Sato, Public Relations Center of the National Astronomical Observatory of Japan.

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