Astronomy and Satellite Constellations: Pathways Forward
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Assessing the interference of mega-constellations on ground-based astronomy using MASCARA

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Abstract. As the number of large Earth-orbiting satellite networks (i.e., mega-constellations or mega-sats) increases, so does the threat posed to astronomical research. Bright satellite trails in exposures of the night sky can affect the quality of observations and hinder science objectives. Using the MASCARA station to detect satellites from the SpaceX Starlink network as a representative case, this study quantifies the present and future impact of mega-sats on ground-based optical astronomy. We find that further design revisions are required to mitigate the brightness concern of pre-Gen2 Starlinks and that hundreds of satellites could be visible in all-sky observations at peak observing times if additional measures are not taken.

Keywords. satellite interference, starlink, optical astronomy, mega-constellations

1. Introduction

The onset of cheaper and smaller spacecraft has driven the development of large constellations of Earth-orbiting satellites (mega-sats) in recent years, with major commercial businesses like Amazon and SpaceX leveraging them to provide high-speed internet services. As large population sizes are required to achieve network connectivity on a global scale, the risk of ground-based observations becoming contaminated with satellite reflections is rising (Venkatesan, Lowenthal, Prem & Vidaurri 2020). For optical images taken over long exposures and/or with a wide field of view (FoV), bright streaks or 'trails' may be detected as the satellite moves. A qualitative assessment of these trails could provide key insights into the magnitude of their interference and yield results that could inspire future satellite design strategies with increased consideration for the astronomical community.

The Starlink network was used as a representative sample for this study. SpaceX have attempted to mitigate brightness concerns through several Starlink iterations, such as the DarkSat and VisorSat. Although these changes reduced reflectivity, neither has been sufficient in darkening the satellites to an acceptable level for astronomical operations (Lalbakhsh, Pitcairn, Mandal et al. 2022).

Observations were collected with an exposure and cadence of 6.4 seconds on 24$^{\text{th}}$ October 2022 using the Multi-site All-Sky CAmeRA (MASCARA; Talens, Spronck, Lesage et al. 2017) station, a five-camera wide-field system with a combined FoV providing coverage of almost the entire sky down to 20° from the horizon. The contrast between trail and background was improved by superimposing and subtracting two consecutive images such that only pixels that changed between both images remained. Automated routines were implemented to recognize trails, including procedures for assessing satellite

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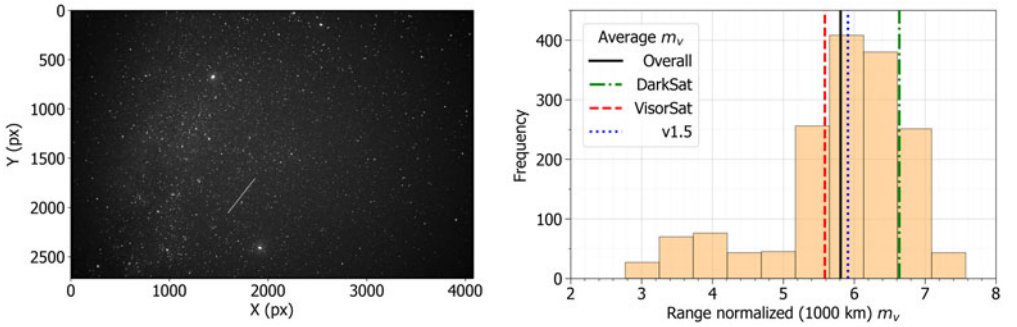


Figure 1. A typical image taken over an exposure of 2×6.4 seconds by one of the MASCARA cameras (FoV of 53×74 degrees) that is polluted with a Starlink trail (left), and the distribution of detected Starlink trail magnitudes scaled to a common distance of 1000 km (right). The line styles indicate the average magnitudes for the different types of Starlinks.

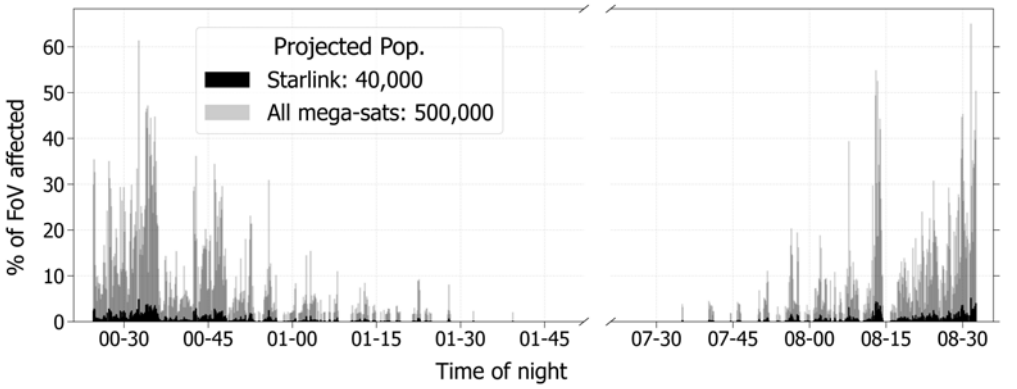


Figure 2. The percentage of the total MASCARA FoV affected by trails for projected population sizes. The conditions of the observing night are used as reference. Black bars approximate the expected Starlink population size (40 000) while grey approximates the expected combined total of all mega-sats (500 000).

visibility, suppressing noise, line detection, and trail extraction. Visual brightness magnitudes (m_v) were then calculated for each trail by comparing a satellite's measured flux to that of reference stars. These were normalised to a common range of 1000km.

2. Results and conclusions

1605 trails were measured and their magnitudes computed for 175 of the 3173 Gen1 Starlinks launched at the time. Their distribution is given in the right-hand panel of Figure 1, where the average over all observations was found to be 5.8 ± 0.10 with a standard deviation of 0.95. Values of 5.6 ± 0.10 and 6.6 ± 0.09 were determined for that of VisorSat and Darksat, respectively. These are all brighter than the goal set by the SATCON1 workshop, which advocates for satellites to be fainter than $m_v = 7$ (Walker, Hall, Allen, et al. 2020). Furthermore, an average magnitude of 5.9 ± 0.09 was found for the v1.5 design, the latest version deployed at the time of observation. We therefore conclude that the mitigation strategies adopted by SpaceX up until this point appear not to have been sufficient in reducing the reflectivity of their satellites.

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Images taken when the Sun was at an elevation between 18 and 34 degrees below the horizon were found to be most affected by Starlink trails. As these observations fall outside of twilight hours, it can be concluded that the presence of these trails may interfere with science objectives. The percentage of the MASCARA FoV obscured by trails was examined to better quantify the extent of this interference. While this reached just 0.18%, the level of contamination significantly increases when future population sizes are considered, as depicted in Figure 2. This value reaches 5.2% for the full Starlink population, while a maximum exceeding 65% is found for the combined size across all planned mega-sats. For the latter projection, this may lead to the entire area outside of the Earth's shadow becoming unusable for observations.

To ensure the preservation of uninterrupted astronomical research, timely mitigation strategies should be developed before science operations like large ground-based surveys (e.g., Rubin/LSST) are disrupted.

References

Venkatesan, A., Lowenthal, J., Prem, P., & Vidaurri, M. 2020, Nat Astro, 4, 1043

Lalbakhsh, A., Pitcairn, A., Mandal, K., Alibakhshikenari, M., et al. 2022, IEEE Access, 10, 24383

Talens, G. J. J., Spronck, J. F. P., Lesage, A.-L., et al. 2017, A&A, 601, A11

Walker, C., Hall, J., Allen, L., et al. 2020, BAAS, 52

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