Rubin Observatory

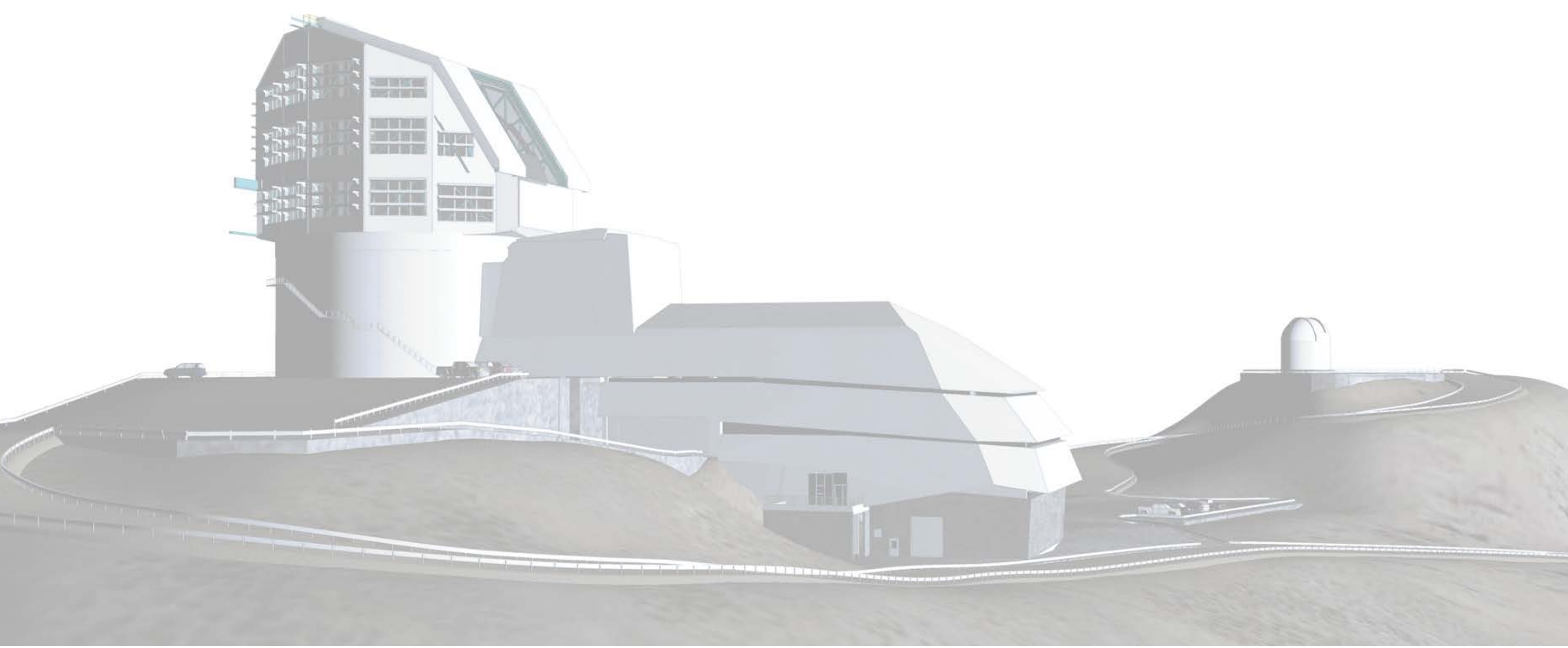
Vera C. Rubin Observatory

Impact on Optical Astronomy of LEO Satellite Constellations

Rubin Observatory Project Science Team (PST)

Document-33805

Latest Revision Date: May 15, 2020



Rubin Observatory

Change Record

Version	Date	Description	Owner name
1	2019-07-08	Initial publication	Tony Tyson
2	2019-11-06	Revised broader impact, updated LEO Sat FCC filings	Tony Tyson
3	2019-11-08	Rewording	Tony Tyson
4	2020-01-30	Update	Tony Tyson
5	2020-03-03	Application of Rubin Observatory branding	Rob McKercher
6	2020-05-15	Update based on recent studies	Tony Tyson

Rubin Observatory

Impact on Optical Astronomy of LEO Satellite Constellations

The natural night sky is our common and universal heritage. The public and professional astronomers alike share the wonder of the night sky. The Vera C. Rubin Observatory (Rubin Observatory) is nearing completion, and its Legacy Survey of Space and Time (LSST) will open a revolutionary view of the changing sky. Whenever we look upon the world in a new way, it reminds us of its inexhaustible richness. Some new discoveries lead immediately to better understanding, while others provide hints of new wonders to explore. Far from being static, the night sky is our window onto a dynamic universe. Many of the most remarkable astronomical events occur on nightly time scales, yet these changes have proven the most difficult to observe. The impediment to observing rapid change and to the more detailed insight it engenders lies in the nature of the tools currently available to astronomers. Modern large telescopes are truly marvels of design, with light-gathering power improving on the naked eye more than ten million-fold. Yet remarkable as they are, they have all been designed to look very deeply at very small parts of the sky. Their small field of view means that any one observation is not likely to catch a transient event *in the act* — we are always looking somewhere else.

Serendipity is the life blood of science, but we must plan for serendipity, building new ways to enable it and preparing ourselves to recognize it when it appears. The LSST survey will create a color motion picture of the universe, making the unusual commonplace and the singular observable. Humanity will be able to view the optical universe with a panoramic view in space and time. The greatest advances to come from Rubin Observatory are thus almost surely unanticipated. This requires access to the pristine unpolluted night sky that for millennia has been the birthright of Earths inhabitants. The Rubin Observatory is nearing completion just as our heritage of the night sky is being threatened by tens of thousands of bright moving low Earth orbiting communications satellites.

There is a long history of international regulations for radio interference via the International Telecommunications Union (ITU) going back to the 1930s. However, there are no regulations in place for light pollution from space as there are for the radio spectrum. Earth orbit is a natural resource without environmental protections, and we are now witnessing the industrialization of this resource by private enterprises: an explosive growth of low-Earth orbit (LEO) commercial satellites. Currently there are about a thousand LEO satellites, but applications filed with the US Federal Communications Commission (FCC) imply a factor of 50 increase in the next decade. These satellites scatter sunlight for several hours after sunset or before sunrise, are relatively close and bright, and thus can affect ground-based optical telescopes. The impact on optical astronomy depends on the rate of interfering luminous streaks, their brightness, the challenge of avoiding them, and the vastly increased complexity of data analysis. All these factors are exacerbated for large wide-field facilities such as the Rubin Observatory because the probability of a satellite crossing the field of view is high. It was ranked as the highest priority ground-based astronomical facility in the 2010 National Academy of Sciences (NAS) Decadal Survey of Astronomy & Astrophysics. The National Science Foundation (NSF) and Department of Energy (DOE) funded Rubin Observatory construction is nearing completion in Chile. Rubin Observatory will begin its deep repeated scans of the entire visible sky from Chile on the same timescale (i.e. 2023) that proposed constellations of tens of thousands LEO satellite launches are planned. Every night for 10 years, Rubin Observatory will take 1,000 exposures of the deep sky with its 3,200 megapixel camera with each exposure covering a 10 square degree field of view. Because of Rubin Observatory's large collecting area, each 30-second exposure can reveal distant objects that are 20 million times fainter than visible with the unaided eye. By comparison, a typical LEO satellite can be seen for several hours in twilight without the aid of a telescope and is over 20 million times brighter than a typical distant galaxy seen with Rubin Observatory.

In late May 2019, SpaceX launched the first 60 of its planned Starlink constellation of 42,000 planned LEO communications satellites. Since then SpaceX has launched several more groups of 60 Starlink satellites into LEO at 550 km, and plans to launch every 2 weeks in future. Amazon, Samsung and others have entered the race. For optical astronomy, the issues are the number and brightness of satellite streaks expected in Rubin Observatory data. Rubin Observatory is the bounding case for sensitivity to space light pollution because of its unprecedented monitoring of the deep sky, a product of large field of view and collecting area. In order to assess the LEO satellite (LEOsat) brightness impact on Rubin Observatory, repeated charge-coupled device (CCD) photometry has been obtained on one of the Starlink satellites at station 550 km altitude and nominal orientation. With this calibrated data one can extrapolate to the effect of such a LEOsat trail recorded by the giant camera on Rubin Observatory. Unfortunately, even 30 minutes past astronomical twilight it would produce a trail that would be brighter than saturation on the Rubin Observatory camera CCD sensors. Such satellites can be seen during most of the night during summer. Our team has investigated the bright trail effects on our CCD sensors in the lab, and our mitigation plans are based on these lab data.

Such bright trails near saturation may impact Rubin Observatory's mission of detecting Earth threatening asteroids. In addition to 4-8 hours centered on midnight, Rubin Observatory also will normally be surveying the sky during and after nautical twilight for near-Earth asteroids. Given possible effects on sensors well past astronomical twilight, during summer months there could be a 40% impact on twilight observing time – less in winter. Rubin Observatory would have to point to a place in the sky where briefly there were no LEO satellites. We estimate one LEO satellite trail per three exposures of the LSST camera for the full 40,000 Starlink constellation. Extrapolating to a more crowded sky in the mid-2020s, we must multiply by about two to account for the other LEOsat corporate plans (from filings with international regulatory agencies). Nearly every exposure within two hours of sunset or sunrise, on average, would have a LEOsat trail.

Preliminary simulations to avoid exposing when a LEOsat is near the field Rubin Observatory is scheduled to observe results in degraded performance of the scheduler, impacting our view of the deep universe. Depending on the precision of real-time satellite orbit updates, with active avoidance up to 50% of Rubin Observatory exposures would be impacted due to induced scheduler errors. Our team is working on an improved avoidance algorithm for the scheduler.

The science impact, of course, goes beyond efficiency loss (i.e. fraction of useless pixels), since various planned investigations have differing sensitivity to satellite trails. One of the most sensitive are probes of the nature of dark energy and dark matter, which are affected by linear spatial noise patterns in the images. Bright trails create electronic artefacts at other positions on the sensor, and unless fully removed these faint echoes of the satellite trail can generate lines of correlated noise, producing a false cosmological signal.

Darkening surfaces of the spacecraft would improve the situation by lowering the trail brightness to a level such that the induced electronic artefacts in the sensors may be corrected in pixel processing. With the planned tens of thousands of LEOsats, dynamic avoidance will be difficult and degrades the Rubin Observatory exposure scheduler performance. In addition to darkening the satellites, another mitigation is active articulation of the spacecraft as it passes over the observatory.

SpaceX has expressed an interest in working with the astronomical community to mitigate these effects, and are working together with us on hardware and software mitigation strategies. One of their satellites 'DarkSat' was partially darkened as an experiment, and we recently assessed the result via ground-based calibrated imaging: at an apparent *g* magnitude of 6.1, DarkSat is over one magnitude fainter than its predecessors. Our team also is investigating ways to reduce the camera artefacts via longer readout times and more complicated processing algorithms. We currently find that if the LEO satellites can be darkened to 7th magnitude, we can correct the non-linear artefacts. SpaceX plans launching a new experimental modification called 'VisorSat', and we plan to follow up with ground-based observations. Finally, we are working with SpaceX engineers on improved avoidance algorithms. While the willingness of SpaceX to help is a sign of hope, without federal and international requirements for space light pollution, it is far from guaranteed that others would follow suit.

We are left with the impacts on LSST survey science. One the induced artefacts are removed, the LEOsat trail itself will remain in the image, creating a challenge for some science data analysis, adding potentially significant effort. LEO satellites at 550 km are slightly out of focus and given the large 8.4m mirror this effect makes the trail wider and lessens the peak surface brightness. Like very bright stars, any satellite trails can be masked and omitted in the LSST survey catalog, but the resulting statistical effects of long rectangular masked regions, and any surviving low surface brightness artefacts, can produce systematic errors affecting some Rubin Observatory science. In the best case scenario, the existence of LEOsats introduces a degree of complexity in the data from Rubin Observatory's LSST survey that the science community has not expected and is currently unprepared to deal with. In principle this could be mitigated by increasing the length of the survey such that 10 effective years of imaging without bright satellite trails is obtained. Our next steps are clear: once the hardware and software mitigation tasks are explored and completed, and an accurate forecast of the effects imprinted on the LSST survey catalog can be estimated, the last step will be to simulate these effects and for each science collaboration to explore the resulting impact on their science. That exercise will then inform the resulting impact on other observatories worldwide which plan to use Rubin Observatory data.

"For my part I know nothing with any certainty, but the sight of the stars makes me dream." — Vincent van Gogh

---

NSF AURA U.S. DEPARTMENT OF ENERGY Office of Science SLAC CHARLES AND LISA SIMONYI FUND LSST CORPORATION