LARGE LEO CONSTELLATIONS, ASTRONOMY, AND SPACE DEBRIS MITIGATION

Patrick Seitzer[1], J. Anthony Tyson[2]

[1] University of Michigan, Dept. of Astronomy, 323 West Hall, 1085 S. University Ave., Ann Arbor, MI 48109, USA, Email:pseitzer@umich.edu
[2] University of California, Dept. of Physics and Astronomy, 1 Shields Ave, Davis, CA 95616, USA, Email:tyson@physics.ucdavis.edu

ABSTRACT

The proposed launch of tens of thousands of new, potentially bright, satellites into Low Earth Orbit (LEO) in the next decade poses a serious challenge to optical astronomy. This era began with the launch of the first Starlink satellites in May 2019, and their visibility to the unaided eye even in light polluted cities brought to astronomers' attention the magnitude of the problem. Satellites leave streaks in astronomical images, which leave artifacts that can not be removed. The project most affected by new satellite constellations will be the Rubin Observatory and its *Legacy Survey of Space and Time* (LSST). This is an 8-meter class wide field telescope which will survey the entire night sky visible from its location in Chile every few nights. The impact on Rubin Observatory can be minimized by making satellites fainter, but also by adherence to strict space debris mitigation guidelines: especially concerning mission altitude (lower is better) and post mission disposal time (shorter is better).

1 INTRODUCTION

Satellites have been in astronomical images since the launch of the first satellite, Sputnik 1, in 1957. Today over 20,000 objects are in the public catalogs of Resident Space Objects (RSO), including active and inactive satellites, rocket bodies, and debris. Any of these can reflect sunlight and potentially leave a trail in an astronomical image. Most of these trails are too faint to be detected in modern astronomical systems. The new LEO satellites being launched or proposed are brighter than the vast majority of everything in orbit today. The exponential growth of these very bright satellites is the problem facing astronomy today.

Fig. 1 is an image of Starlinks from the first Starlink launch in May 2019, taken just after launch when the satellites were closely clustered together. Images like this caused real concern in the astronomical community – was this the future of the night sky?

Figure 1. Image of bright Starlinks taken just after launch in May 2019. Courtesy Marco Langbroek.

Fig. 2 is an image taken in November 2019 with the Blanco 4.0-meter telescope in Chile with a wide field camera. The diameter of this image is more than 4 times the diameter of the full moon. Nineteen Starlinks crossed this image. The Starlink crossings were unplanned.

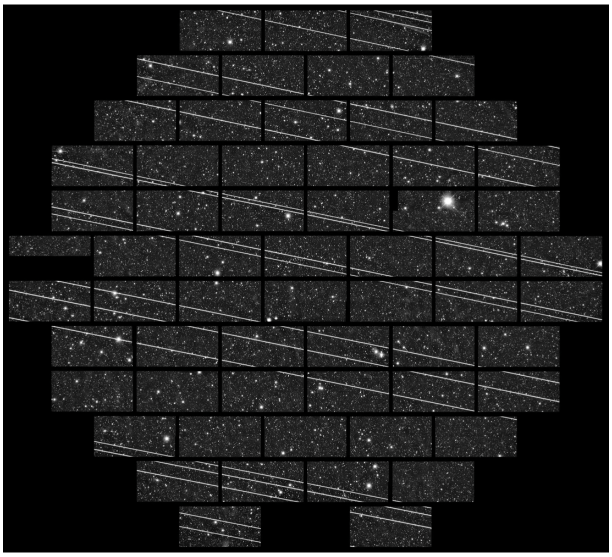

Figure 2. A long exposure taken with the 4.0-m Blanco telescope in Chile in November 2019 shortly after another Starlink launch. The crossing of the nineteen Starlinks was unplanned. Image courtesy DECam DELVE Survey/CTIO/AURA/NSF.

These trails generate a number of problems:

1. There is a loss of information in the pixels covered by the trails.

Proc. 8th European Conference on Space Debris (virtual), Darmstadt, Germany, 20–23 April 2021, published by the ESA Space Debris Office
Ed. T. Flohrer, S. Lemmens & F. Schmitz, (http://conference.sdo.esoc.esa.int, May 2021)

2. There could be cross-talk in the electronics if the trail brightness exceeds a threshold.
3. There can be ghost images due to reflections in the camera optics.
4. The trail could saturate the detector.
5. A trail could leave non-linear artifacts in an image.

In all cases satellite trails can leave artifacts that cannot be removed in subsequent image processing, and thus limit the discovery potential of LSST.

With the mitigation steps taken by SpaceX, the trails would be fainter in an equivalent image taken today.

Satellites will leave trails in an astronomical image when the satellite is in sunlight, and the telescope is in darkness. This depends on a large number of factors, including time of year, observatory latitude, the orbital inclination, and the orbital altitude. [1-3] In general, higher altitude satellites are more visible since the Earth's shadow is a cone, and they spend more time in sunlight.

Finally, a tumbling satellite can leave glints in an image which may be detected by astronomers as transients. Fig. 3 shows a tumbling Titan rocket body as imaged by the 6.5-m Magellan telescope.

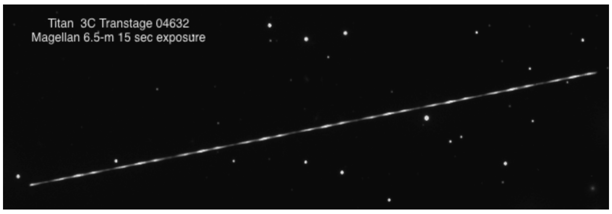

Figure 3. Glints from a tumbling Titan rocket body. These glints will be detected as transients in astronomical surveys. Image courtesy P. Seitzer, Univ. of Michigan.

Glints can also be caused by specular reflection of sunlight off a flat surface of a controlled satellite. The result is the same – a possible transient such as a variable or exploding star, or an asteroid.

2 THE RUBIN OBSERVATORY

The Vera C. Rubin Observatory in Chile will be the facility most affected by satellites. This is an 8-meter class very wide field telescope nearing completion in Chile (Fig. 4) with a 3.2 billion pixel CCD camera. Each image from this camera will be the size of forty full moons. It will scan the entire night sky visible from Chile every few nights. Some 2000 images will be taken every night. Beginning in 2023 the ten-year *Legacy Survey of Space and Time* (LSST) will begin. It will catalog some 37 billion stars and galaxies and produce 10 million transient alerts *every night*.

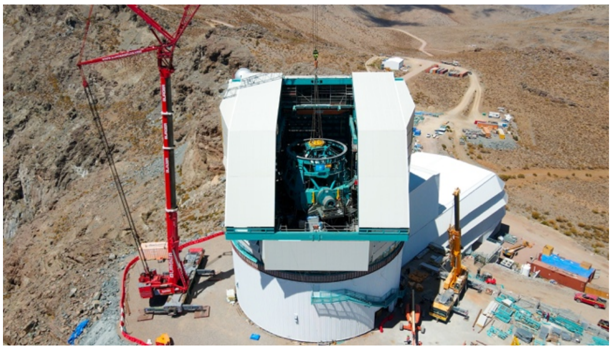

Figure 4. The Rubin Observatory in Chile nearing completion in March 2021. Image courtesy Rubin Observatory/NSF/AURA.

Rubin Observatory is located in north central Chile, which has some of the darkest and clearest skies anywhere. The image quality (width of the stellar images) is among the best on Earth. Rubin Observatory could escape city lights by being on a mountain top in Chile but cannot escape satellites.

The effect of a bright satellite streak on Rubin's camera has been simulated in the lab (Fig. 5). [4] The central trail from the satellite is the brightest signal.

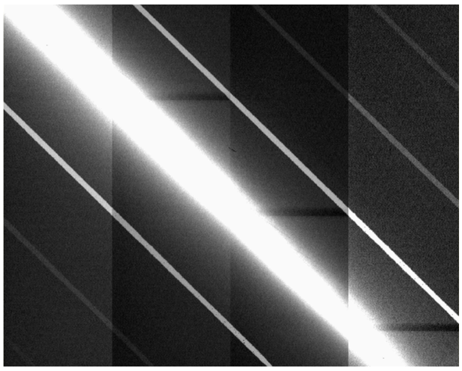

Figure 5. Bright satellite trail and non-linear artifacts in a simulated Rubin Observatory image. Courtesy Rubin Observatory/NSF/AURA.

These trails and artifacts are tens of thousands of times brighter than the faint stars and galaxies to be studied by the Rubin Observatory's *Legacy Survey of Space and Time*.

3 STEPS BY SATELLITE OPERATORS AND BUILDERS

Two workshops have been held that outline a number of steps that satellite builders and operators can undertake to minimize the problems to optical astronomy. [2-3] These include:

1. Incorporate 'Design to be Faint' in your satellited design phase by doing full reflectivity studies and laboratory Bi-directional Reflectance Distribution Function (BRDF) measurements before

construction.

2. Design to be fainter than V ~ 7th magnitude during all phases of operation to be invisible to the naked eye under excellent conditions.

3. Minimize the brightness in all phases of a satellite's lifetime: initial (launch, checkout, and orbit raising), operational phase, and disposal phase.

4. For orbit height h_{orbit} in km, design the satellite to emit less than 44 x (550 km / h_{orbit}) watts/steradian in reflected sunlight.

5. Reflected sunlight should be slowly varying with orbital phase – a best effort to avoid glints and flares.

6. During immediate post-launch phase, satellites are clumped together as closely as possible.

Other recommendations can be found in the summary of the two workshops [2-3].

4 SPACE DEBRIS MITIGATION STEPS

Space debris mitigation and benefits to optical astronomy go together. There are a number of space debris mitigation steps which also benefit optical astronomy:

1. Launch as few satellites as possible. Ideally astronomers would like that you launch none, but we recognise that this won't happen!

2. Minimize the number and the time spent in both the deployment (launch, checkout, and orbit raising phase) phase, and post mission disposal phase (PMD). Deorbit as quickly as possible, and certainly less than 25 years.

3. Fly in lower orbits, which has two benefits:

   a. Satellites in lower orbits will be less visible in the middle of the night particularly in summertime when satellites at 1200 km altitude will be visible all night long. See Fig. 6 for a comparison of the number visible for two identical 10,000 satellite constellations: one at 500 km altitude and one at 1000 km altitude.

   b. Higher altitude satellites are more in focus for a large fast telescope. They also move slower across a pixel, so the effective exposure time is greater. The combined effect is that the trails have a greater central intensity at higher altitudes than one would expect from distance estimates alone.

4. Provide timely publicly available accurate and precise orbital elements.

5. Talk with us! Astronomers wish to collaborate with satellite designers, builders, and operators in efforts to have both the benefits of large constellations and a dark night sky. Our emails are on the first page, and we will be happy to put you in contact with the appropriate astronomical groups.

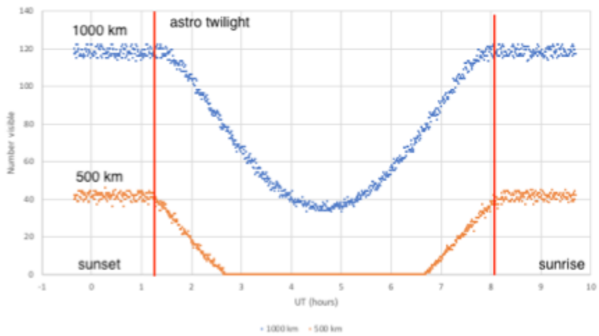

Figure 6. Simulation of satellites visible in sunlight for an observatory at 30 degrees latitude in summertime. One constellation of 10,000 satellites at 500 km altitude, the other at 1000 km altitude. Both are 53 deg inclination, 100 planes of 100 satellites each. Note that in summertime the higher altitude satellites are visible all night long.

5 CONCLUSIONS

The planned launch of tens of thousands of satellites in the next decade poses a serious challenge to optical astronomy. The trails that these satellites will leave in astronomical images will have serious effects on our view of the universe, particularly with the start of survey observations with the Rubin Observatory in late 2023.

Although with tens of thousands of new satellites in LEO, generally no combination of mitigations can completely avoid the impacts of satellite trails in astronomical images. [4] Steps outlined above can minimize the worst of the problems for astronomers.

6 REFERENCES

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2. Impact of Satellite Constellations on Optical Astronomy and Recommendations Towards Mitigations (2020). Online at https://aas.org/satellite-constellations-1-workshop-report

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4. Tyson, J.A. *et al*. (2020) Mitigation of LEO Satellite Brightness and Trail Effects on the Rubin Observatory LSST. *Astronomical Journal*, **160**, 226.