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FLARES FROM SPACE DEBRIS IN LSST IMAGES

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ABSTRACT

Owing to the exceptional sensitivity of the Vera C. Rubin Observatory, we predict that its upcoming LSST images will be contaminated by numerous flares from centimeter-scale space debris in Low Earth Orbits (LEO). Millisecond-duration flares from these LEO objects are expected to produce detectable image streaks of a few arcseconds with AB magnitudes brighter than 14.

1. INTRODUCTION

The European Space Agency (ESA) reports[1] that as of December 6, 2023, the space debris in orbit around Earth includes 1.3×10^8 objects in the size range of 0.1-1 cm, $\sim 10^6$ objects between 1-10 cm and 3.65×10^4 objects larger than 10 cm. A subset of these objects is in Low Earth Orbits (LEO) with a semi-major axis below an altitude of 2×10^3 km. In this Note, we examine the implications of this LEO debris for the upcoming Legacy Survey of Space & Time (LSST) of the Vera C. Rubin Observatory in Chile (Schildknecht 2007; Ivezić et al. 2019; Bosch et al. 2019; Esteves et al. 2023; Hernandez et al. 2023; Schwamb et al. 2023).

2. METHOD

We define the average albedo of an object of radius R and distance d which is illuminated on one hemisphere by sunlight by the following fraction of light reflected from it,

$$A\left(\frac{\pi R^2}{2\pi d^2}\right) \ . \tag{1}$$

Hereafter, we encapsulate the unknown surface properties of the object as well as the orientation and geometry of the source relative to the Sun and the observer in the value of A, for which we adopt a fiducial value of 0.1. Given the average solar illumination of $f = 1.4 \times 10^6$ erg s^{-1} at a characteristic photon frequency of $\nu \sim 6 \times 10^{14}$ Hz, we calculate the AB magnitude of the object to be,

$$\mathrm{AB} = -2.5\log_{10}\left[\frac{(df/d\nu)}{\mathrm{erg\ s^{-1}\ cm^{-2}\ Hz^{-1}}}\right] - 48.6 = 16.2 - 5\log_{10}\left[\left(\frac{R_0}{d_8}\right)\sqrt{A_{-1}}\right], \tag{2}$$

where $A_{-1} = (A/0.1)$, $R_0 = (R/1\ \mathrm{cm})$ and $d_8 = (d/10^8\ \mathrm{cm})$.

3. RESULTS

Data from the Zwicky Transient Facility (ZTF) shows that the sunlight glints from known LEO satellites generate flashes of duration $10^{-3\pm0.5}$ s (see Figure 4 in Karpov & Peloton (2023), and also Corbett et al. (2020); Nir et al. (2021a,b)). Given a typical orbital speed of ~ 8 km s^{-1}, these flash durations translate to streaks of angular length $\sim (10^{-3}\ \mathrm{s} \times 8\ \mathrm{km\ s^{-1}})/10^3 d_8\ \mathrm{km}) = 1.7 d_8^{-1}$ arcseconds. The light from the flares is therefore expected to spread across no more than a few arcseconds, independently of the LSST exposure time which is 4 orders of magnitude longer.

For a few millisecond flares, LSST at the Rubin Observatory (Ivezić et al. 2019) is expected to have a brightness sensitivity of AB ~ 14 (given the survey's ~ 25-magnitude limit for 30 second exposures; see Figure 5 in Karpov & Peloton (2023)). According to equation (2), this implies that LSST will detect all space debris objects in LEO that satisfy,

$$\left(\frac{R_0}{d_8}\right)\sqrt{A_{-1}} \gtrsim 3. \tag{3}$$

[1] https://www.esa.int/Space_Safety/Space_Debris/Space_debris_by_the_numbers

This includes all LEO objects with a radius $R \gtrsim (3/A_{-1})$ cm at a distance of $d \sim 10^3$ km.

4. DISCUSSION

Assuming that merely a tenth of the $\sim 10^6$ space debris objects in the size range of 1-10 cm reported by ESA satisfy the condition in equation (3), we find that LSST images will be contaminated by flares from $\sim 10^5$ objects that repeat every LEO orbital time of 1.5-2 hours (and are most visible during the evening and morning twilight). This number exceeds by an order of magnitude the number of large satellites currently in orbit around Earth. Out of the entire debris population, only 3.515×10^4 objects are regularly tracked and catalogued by Space Surveillance Networks.[2]

So far, the LSST team contemplated a novel strategy to mitigate the impact of large commercial satellite constellations in LEO (Hu et al. 2022). However, the above numbers suggest that image contamination by untracked space debris might pose a bigger challenge.

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