Snowmass2021 - Letter of Interest

Low Earth Orbit satellites and the DOE HEP program in dark matter and dark energy

Topical Group(s): (check all that apply by copying/pasting ☐/☑)

☐ (CF1) Dark Matter: Particle Like
☐ (CF2) Dark Matter: Wavelike
☑ (CF3) Dark Matter: Cosmic Probes
☑ (CF4) Dark Energy and Cosmic Acceleration: The Modern Universe
☐ (CF5) Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before
☐ (CF6) Dark Energy and Cosmic Acceleration: Complementarity of Probes, New Facilities
☑ (CF7) Cosmic Probes of Fundamental Physics
☑ (IF2) Photon detectors
☑ (IF7) Electronics/ASICs

Contact Information:
Tony Tyson (University of California, Davis) [tyson@physics.ucdavis.edu]
Collaboration: LSST Dark Energy Science Collaboration

Authors: Tony Tyson, Imran Hasan, Erfan Nourbakhsh, Adam Snyder (UCD), Clare Saunders (Princeton), Robert Armstrong (LLNL), Andrew Bradshaw, Aaron Roodman (SLAC), Alex Drlica-Wagner (Chicago), Anže Slosar (BNL), Keith Bechtol (U. Wisc.), Juan Estrada (FNAL)

Abstract: (maximum 200 words)
The planned mega-constellations of 107,000 Low Earth Orbiting satellites will impact all ground-based observations of the night sky. In particular, the HEP program in dark energy and dark matter is sensitive to systematics introduced by these satellites. It is critical that the HEP community start implementing mitigation strategies, ranging from understanding the systematic impact on current/near-future missions to the design studies for future surveys and international regulation. The DOE OHEP supported Rubin Observatory's Legacy Survey of Space and Time (LSST) will be heavily impacted, due to its deep imaging of large fields on the dark sky. The science program most affected will likely be LSST probes of fundamental physics via weak gravitational lensing. Even after masking, bright satellite trails can leave residual correlated noise that can bias cosmic shear. As a start, there is a need for simulations of these effects and a study of mitigation measures. Validation can be done via cosmic shear analysis of a large N-body simulation of billions of galaxies including satellite trail artifacts. The effects of darkening the satellites on the camera systematics, satellite trail modeling and masking, and algorithms for improved avoidance of the brighter satellites need to be studied.

The existence of the dark sector is evidence of physics beyond the standard model. Low-surface-brightness surveys over a wide area enable unprecedented probes of cosmology. Probes of the physics of dark matter and dark energy use billions of faint galaxies for which the shape must be known to one part in 10,000 (Zhan and Tyson, 2017; Mandelbaum et al. 2018). With a large sample of 10 billion galaxies, the survey will be limited mainly by systematics (Almoubayyed et al. 2020). Systematic errors at low surface brightness remaining after masking satellite trails can lead to linear strings of correlated noise -- biasing weak gravitational lensing shear measurements. This LOI builds partly on a recent workshop on the impacts of LEO satellite mega-constellations on astronomy (SATCON1 2020).

One possibility is avoidance. Exploration of LSST scheduler algorithms which include the known non-uniform distribution of LEOsats on the sky as shown in Figure 1 are needed. The feasibility of this is not assured, given the strong requirements of observing neighboring fields without delay.

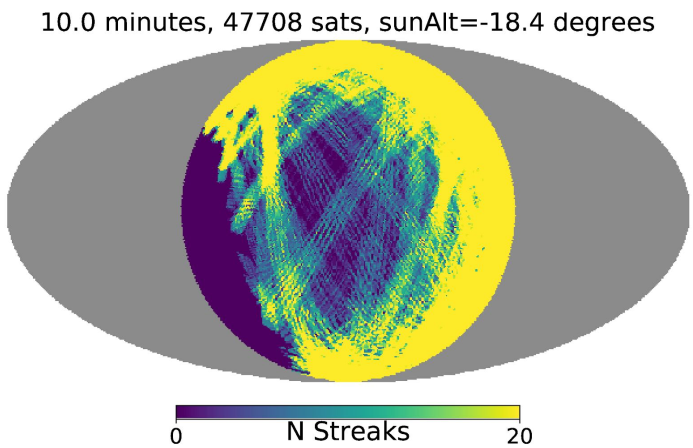

Figure 1. No place to hide for long: LSST sky crowded with LEOsats. An alt-az plot of trails of 47,708 illuminated LEOsats (estimated 2028) over a ten minute time period seen from Rubin Observatory is shown. Zenith is at the center, North is up and East is left. The trails are bunched due to populating the orbital planes. The trail free region is caused by Earth's shadow.

Over ten years LSST will revisit each 10 deg^2 patch of sky 1000 times, forming a database of ten billion faint galaxies in a cosmological volume. The number of satellite trails in a single component 30 sec exposure is proportional to the product of the size of the field of view, the exposure time, and the number of satellites. The data cube formed by the many revisits to a sky patch encapsulates all component satellite trails, or the residual systematics resulting from their approximate masking in the individual exposures (Morganson, et al 2018). Correlations introduced by satellite trails (or their masks) can produce false signals at low surface brightness.

The HEP community will also need to deal with the impact on detectors. In laboratory tests of LSSTCam CCDs+electronics, we find that current Starlink satellites are so bright that they cause electronic echoes in the image (Tyson, et al. 2020). Even if the LEOsats are darkened sufficiently that the camera artifacts from the trail may be removed in pixel processing, the satellite trail itself remains. LEOsat trails exhibit broad low surface brightness wings, as shown below in Figure 2. They generally can cause a systematic error which is dependent on how the trail is masked. If masked at too high a brightness, then there will be two parallel lines of correlated noise at the mask edge -- biasing weak lens cosmology. Shear-shear correlation systematic error can be caused by lines of correlated noise or long rectangular masked regions. This is seen in existing data. Full simulations of systematic errors in cosmic shear arising from masking are needed.

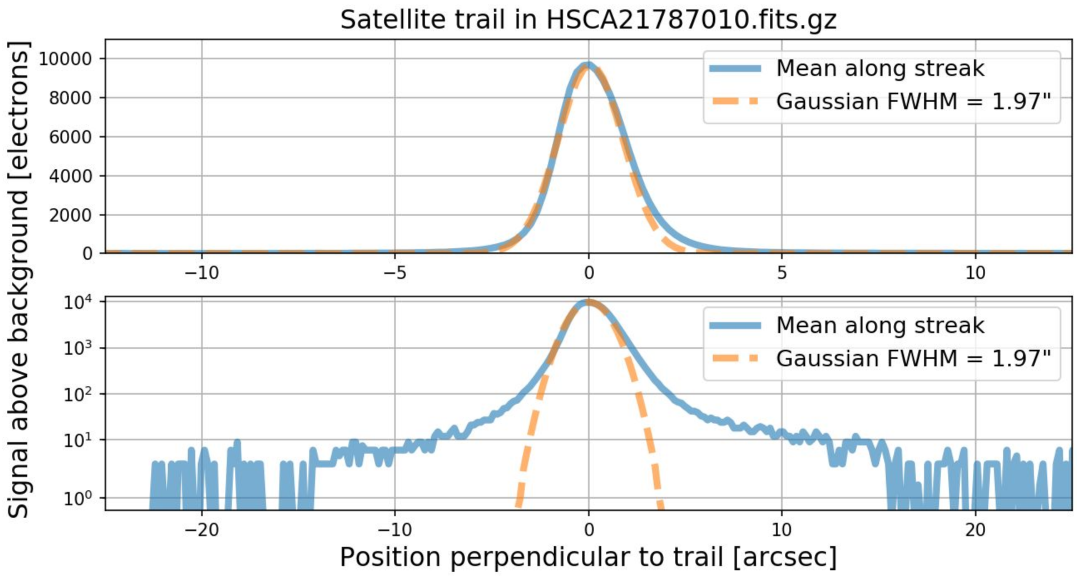

Figure 2. The mean profile of a LEO satellite trail in a 30-sec exposure of the Subaru HyperSuprimeCam, averaged 700 pixels along the trail. Also shown is a Gaussian FWHM (notably larger than the 0.6 arcsec PSF FWHM). Flux from the satellite extends out to 15 arcseconds, which will require special masking -- without sufficient modeling of the trail.

While a stack of ~100 images in a spectral band in each 10 sq.deg sky patch will be input to the detection and photometry, the actual masking must be done on individual single exposures. Masking algorithms which automatically mask pixels along a trail above 5 sigma of background noise create parallel lines of correlated pixels which are then diluted in the co-add. The result may not be far below the outer surface brightness of the faint galaxies used for cosmic shear, giving residual correlations along these 1 million linear features.

We need to simulate several masking schemes in synthetic images processed with the LSST pipeline, with a goal of suppressing the cosmic shear systematics. Image co-adds could be made, objects detected, producing catalogs containing lines of correlated faint bogus 'galaxies'. Multiple instances of those trail artifact catalogs could be injected into a realistic N-body derived sky catalog covering a cosmological volume (DeRose, et al. 2019). One could compare the cosmic shear with and without the addition of millions of these faint trail artefacts. We will not know if this is the limiting systematic until the LSST is well underway in 2024. By then 2-3 constellations will be built, limiting options for corrective action on satellite design.

The broader issue is how the HEP community will address the challenge of the exponentially growing industrialization of space and its optical and radio impacts on deep sky probes of the physics underlying the dark sector. There are two parallel approaches. One is for physicists to work constructively with colleagues in the satellite industry, leveraging good corporate citizenship. There has been some recent progress on this front. Another is to join with wider scientific stakeholders, satellite operators, and international bodies to begin to forge mutually beneficial international policy on light pollution from space.

References: (hyperlinks welcome)

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