Serendipitous Detection of Orbital Debris by the International Liquid Mirror Telescope: First Results.

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Abstract

Orbital debris presents a growing risk to space operations, and is becoming a significant source of contamination of astronomical images. Much of the debris population is uncatalogued, making the impact more difficult to assess. We present initial results from the first ten nights of commissioning observations with the International Liquid Mirror Telescope, in which images were examined for streaks produced by orbiting objects including satellites, rocket bodies and other forms of debris. We detected 83 streaks and performed a correlation analysis to attempt to match these with objects in the public database. 48% of these objects were uncorrelated, indicating substantial incompleteness in the database, even for some relatively-bright objects. We were able to detect correlated objects to an estimated magnitude of 14.5 and possibly about two magnitudes greater for the faintest uncorrelated object.

Introduction

The Earth-orbit environment is becoming increasingly crowded. More than 27,000 objects are presently catalogued, which include satellites, rocket boosters and orbital debris [1]. It is expected that there are many more undetected objects that pose a significant risk to space operations, particularly in low-earth orbit [2,3]. The advent of constellations containing tens of thousands of satellites will greatly increase the numbers of resident space objects. The astronomical impact of these objects has long been recognized, but contamination of astronomical images by satellite tracks is now becoming increasingly problematic [4-8].

The International Liquid Mirror Telescope (ILMT) is a 4-m zenith-pointing optical telescope located at Devasthal Peak in India (29.36° N latitude) [9]. Its 16-MPixel CCD gives a 0.373 x 0.373-degree field of view. In order to compensate for image motion due to the Earth's rotation, the CCD is operated in time-delay integration mode in which it is continuously scanned at the sidereal rate. The telescope saw first light in April 2022 and began a period of commissioning in October.

The ILMT provides a unique opportunity to serendipitously monitor the orbital environment [10]. On average approximately 100 catalogued objects pass through the field of view of the ILMT each day. Typically about 6% of these transit during dark hours while also being illuminated by the Sun and can potentially be detected by the telescope. We present here an analysis of ten nights of engineering observations obtained with the ILMT in October and November 2022.
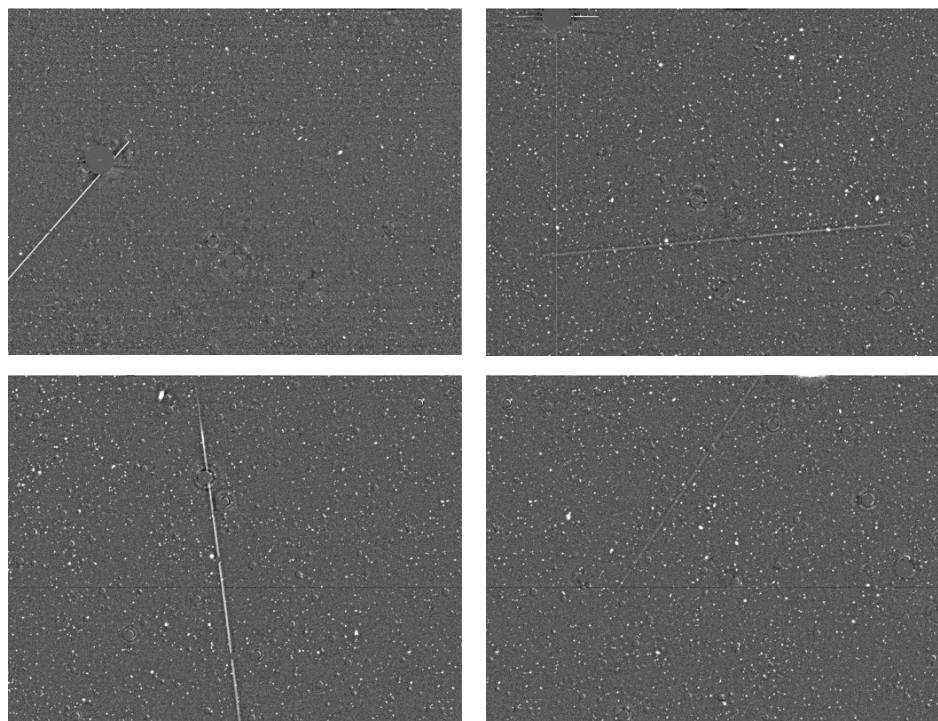

Fig 1. Montage showing streaks produced by four uncorrelated objects detected by the ILMT. The individual images cover 29 x 22 arcmin and have had bright stars removed.

Observations and Analysis

The data set that we employed consists of 515 images obtained on the nights of October 23 to November 1, 2022, inclusive. The effective integration time for celestial objects is 102 s, which it the time that it takes for the image to drift the length of the CCD. The integration time for RSOs is usually much less as they generally move at high angular rates. These images were preprocessed and then astrometrically and photometrically calibrated using Gaia stars in the field. Background variations were removed by high-pass median filtering and bright stars (G < 18) were removed. The images were searched visually for linear tracks. The detected tracks were then measured to determine the length, width, orientation and integrated flux.

A complete set of publicly-available two-line elements (TLEs), for objects tracked by the U. S. Space Surveillance Network, was downloaded from Space-Track.org, for the period extending 30 days before and after the observations. A list of "current" TLEs was then generated for each of the 10 observation nights by selecting, for every cataloged object, the TLE that had the closest epoch to that of the time of observation. This formed our comparison data set. Each TLE was then propagated, using the SGP4/SDP4 algorithm [11,12], and the times and orbital parameters for all objects passing within 0.3 degrees of the zenith were extracted. A calculation was performed to determine which objects were illuminated by the sun at those times. A comparison was then made of the catalogue lists and the detected streaks. The data analysis and TLE propagation was performed using the OCS software package [13].

Results

Our results are summarized in Table 1. 83 streaks were identified in the ILMT images. 52% of these were correlated with catalogued objects, based on position, time of transit and position angle. Magnitudes of the correlated objects were estimated from the measured integrated flux and the integration time found by dividing the track length by the angular rate determined from the TLE. Magnitudes cannot be determined for uncorrelated objects as the angular rates are unknown.

The correlated objects have estimated magnitudes as faint as 14.5 and were detected with a signal-to-noise ratio greater than 200. The flux of the faintest uncorrelated object is 6.4 times smaller than that of the faintest correlated object. Four examples of uncorrelated objects are shown in Fig 1.

These results indicate an average rate of 9.2 detectable objects per square degree per hour passing near the zenith at the latitude of the ILMT. Objects having orbital inclination less than the latitude never reach the zenith and are thus not counted. One therefore expects that the rate will be higher at lower latitudes.

Table 1. Observations and results.

Area of sky observed	0.139 sq. degrees
Number of images examined	515
Total observing time	65.1 hr
Number of streaks detected	83
Number correlated with catalogued objects	43
Number of uncorrelated objects	40
Percent uncorrelated	48%
Magnitude range of correlated objects	6.9 - 14.5
Altitude range of correlated objects	451 - 25,014 km
Satellite fraction	63%
Rocked body fraction	17%
Debris fraction	20%

Discussion

These initial results demonstrate the potential of the ILMT for the serendipitous detection of satellites and orbital debris. Almost half of the objects that we detected could not be matched to catalogued objects, suggesting a significant level of incompleteness in the public database.

Streaks from bright objects are a concerning source of contamination for astronomical observations. Many of the streaks produced by the brighter objects that we detected are as wide as 12 arcsec and essentially obliterate faint stars and galaxies that they cross. Subtraction of the streaks is problematic due to the high levels of photon noise that they produce, and intrinsic variations in brightness as the objects rotate [14].

These results were obtained from just 10 nights of ILMT observations, taken during commissioning, where roughly 40% of the time was used for engineering tests and adjustments and therefore not available for observations. In regular operation, the ILMT is expected to obtain on the order of 1500 clear dark hours of observations per year, which is roughly 20 times the present data set. This will provide a unique opportunity to monitor the increasingly-crowded space environment.

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