The Population of Optically Faint GEO Debris

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Abstract

The 6.5-m Magellan telescope, 'Walter Baade', at the Las Campanas Observatory in Chile has been used for spot surveys of the geosynchronous Earth orbit (GEO) regime to study the population of optically faint GEO debris. The goal is to estimate the population of GEO debris at sizes much smaller than can be studied with 1-meter class telescopes. Despite the small field of view of the Magellan instrument (diameter 0.5-degree), a significant population of objects fainter than R = 19th magnitude has been found with angular rates consistent with circular orbits at GEO. We compare the size of this population with the numbers of GEO objects found at brighter magnitudes by smaller telescopes.

The detections have a wide range of characteristics starting with those appearing as short uniform streaks. But there are a substantial number of detections that vary in brightness ("flashers") during the 5-second exposure. The duration of each of these flashes can be extremely brief: sometimes less than half a second. This is characteristic of a rapidly tumbling object with a quite variable projected product of size * albedo. If the albedo is of the order of 0.2, then the largest projected size of these objects is around 10-cm.

1. INTRODUCTION

The distribution of small size debris at GEO is of great interest for estimates of the total debris population at GEO and how it compares with that at Low Earth Orbit (LEO). Since size cannot be measured directly, estimates of the GEO debris population come from surveys with optical telescopes, and then assume an albedo. To date, these telescopes have been 1.8-m or smaller [1][2][3]. Typically the limiting magnitude has been in the regime of 18th - 19th V magnitude, or a size around 30 cm.

Astronomical telescopes of this size can reach much fainter limiting magnitudes by increasing the exposure times beyond the 2 - 5 seconds used in GEO debris surveys. But such long exposures cannot be used for GEO debris surveys for two reasons, both related to the fact that one tries to rate-track the telescope and detector at the same rate that the GEO object is moving for optimal detection:

- Background stars move across the image at 15.041 arcsec/sec. As the exposure time increases, the star streaks become longer and longer, and the problem of detecting GEO objects in an increasingly crowded field becomes more difficult.
- GEO debris moves at a distribution of rates depending on orbital parameters. As the exposure time increases, objects moving at rates different than the one the telescope tracks at will be streaks as well, and so the limiting magnitude decreases.

The only way to overcome these limitations is to gather more photons in a fixed exposure time: use a larger telescope.

2. MAGELLAN

The Magellan project has two 6.5-m telescopes located at Las Campanas Observatory in Chile. It is a collaboration of US institutions: the Carnegie Institution of Washington, the Harvard University, MIT, the University of Michigan, and the University of Arizona. The observations reported here were obtained on nights allocated to the University of Michigan.

The instrument in use was the IMACS imaging spectrograph [4] in f/2 mode on the 'Walter Baade' 6.5-m telescope. This instrument configuration has the widest field of view of any of instrument on either Magellan: 0.5 degrees or the diameter of the full moon.

There are 8 thinned, backside illuminated CCDs in the mosaic camera with gaps between them. Fig 1. shows a typical 5 second exposure taken with this instrument while rate tracking a piece of Titan debris. The CCDs fill a square, although the optical field of view is circular. At the top and bottom are guide probes that protrude slightly into the field of view. The limiting magnitude for a point source is fainter than R = 20.

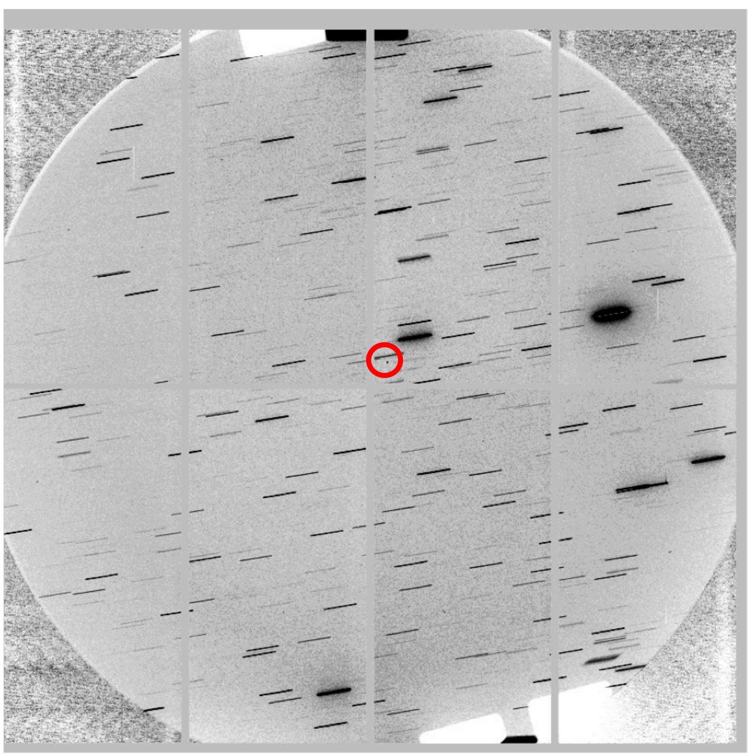

Fig. 1. 5-second exposure with IMACS f/2 on the 6.5-m Magellan telescope 'Walter Baade' while tracking SSN 33513, a piece of Titan debris. The long streaks are background stars. The debris is circled.

Two different rate techniques were used: with the drives completely off which would be appropriate for an object with no motion at GEO, and rate tracking at the predicted rate of a piece of debris or the most likely rate of a debris distribution.

For a detection in an individual image to be considered real, it had to be detected in at least one more image with the same approximate streak length and position angle. The angular rates for objects in circular orbits at GEO were |Hour angle rate| <= 2 arcsec/sec, and |Declination rate| <= 5 arcsec/sec.

3. RESULTS

The 0.6-m MODEST surveys (1.3x1.3 degree field of view, or 1.7 square degree areal coverage) had a detection rate for debris in the range R = 15 - 18th magnitude of about 1 object/square degree for the rates described above. This detection rate can vary by a factor of 2, depending on the topocentric declination.

The MODEST surveys used a different survey technique than Magellan - a TDI technique was used where the telescope tracked a constant right ascension and declination. During the 5-second exposure, the charge on the CCD was moved to remove the motion of the stars. GEO objects would then appear as point sources or short streaks.

For Magellan, the field of view is only 0.5 degrees circular, or an area of 0.2 square degrees. Based on very preliminary results, our detection rate for GEO objects is now about 10 objects/square degree with the same rate constraints and in the magnitude range of R = 18th to 20th magnitude.

Thus the total population of GEO debris appears to increase as one goes to smaller sizes. The total population could be large indeed.

The detection limit for short streaks with Magellan is between 19th and 20th R magnitude. This corresponds to a size of 10 cm assuming an albedo of 0.2. An object this size is like a 1U Cubesat or a small iPhone.

The visual appearance of the detections varies widely. Basically they can be grouped into three classes:

- Streaks of constant brightness, as illustrated in Fig 2. below. The long horizontal streaks are stars.

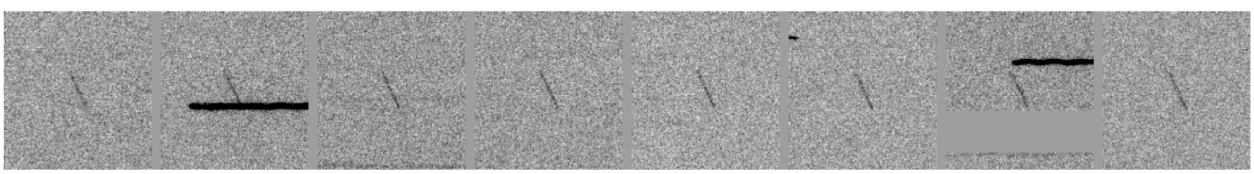

Fig 2. An object moving primarily in declination with little or no brightness variation druing the 5-second exposure.

- Streaks with varying brightness during the 5-second exposure, as illustrated in Fig 3. below.

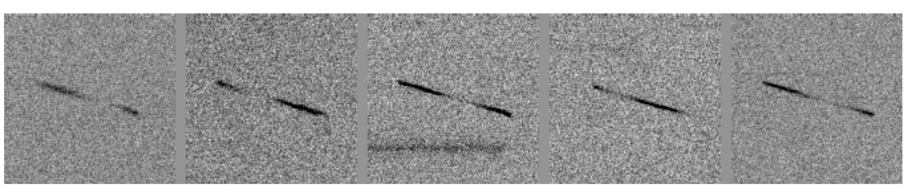

Fig 3. An object with significant brightness variation during the 5-second exposure. This object may be tumbling with a period close to the exposure time.

- Objects with multiple brightness flashes during the 5-second exposure, as illustrated in Fig 4. below.

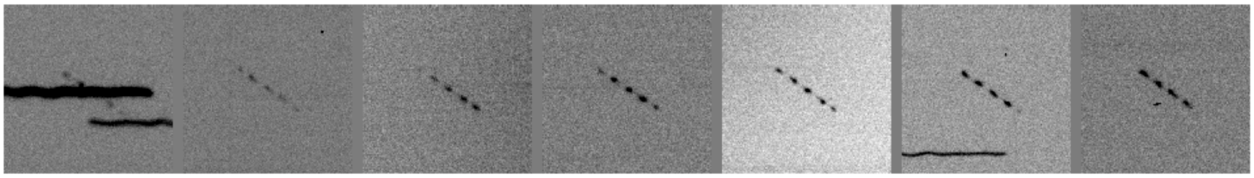

Fig 4. An object with rapid variations in brightness during the 5-second exposure.

The last case is interesting because the 'flashes' could be very brief indeed. Some of the flashes are circular; the width of the flash perpendicular to the track gives an estimate of the seeing, while the width of the flash along the streak is a measure of the flash duration convolved with the seeing disk. The camera has 0.4 arc-second pixels, the seeing was 0.7 arc-seconds FWHM, and if the rate was 5 arcsec/sec, then the flash duration was less than 0.14 seconds (and could be much less). This short time scale says that the product of albedo times area was varying very rapidly. If this is tumbling, what is the mechanism to cause this rapid change in attitude?

4. Summary

Observations with a 6.5-m Magellan telescope have been used to investigate the properties of optically faint GEO debris. The population of such debris appears to increase significantly as one observes to fainter and fainter magnitudes. The total population of GEO debris larger than 10 com could be very large indeed.

Of interest are the rapid changes in brightness seen in a fraction of the population. The time scales can be less than a few tenths of a second. If this reflects a change in attitude of the object, what is the mechanism that can cause such rapid changes in attitude on a 10-cm size piece of debris?

5. References

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