

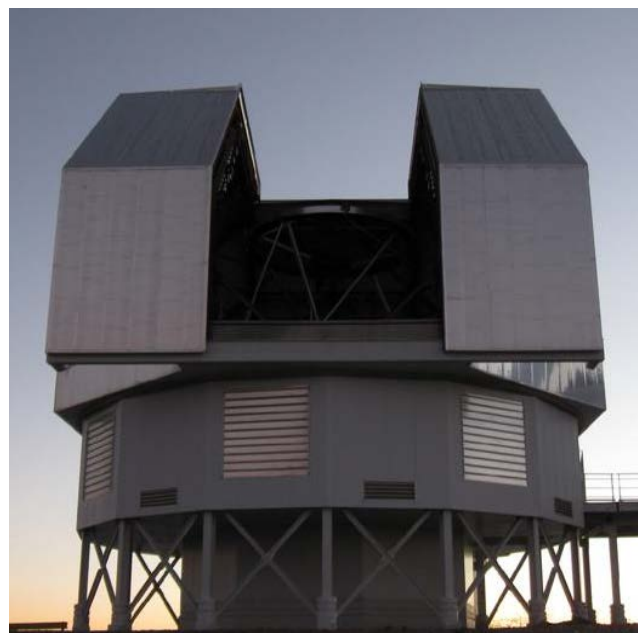
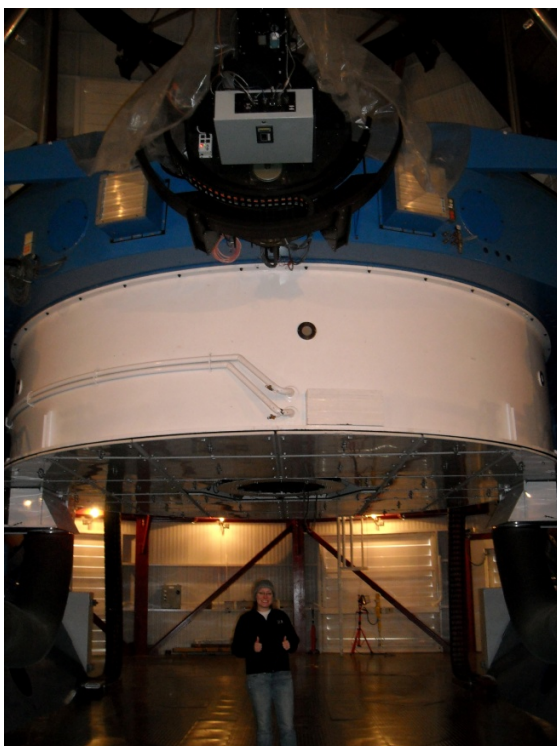
## *Detection of Optically Faint GEO Debris*

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There have been extensive optical surveys for debris at geosynchronous orbit (GEO) conducted with meter-class telescopes, such as those conducted with MODEST (the Michigan Orbital DEbris Survey Telescope, a 0.6-m telescope located at Cerro Tololo in Chile), and the European Space Agency's 1.0-m space debris telescope (SDT) in the Canary Islands.

These surveys have detection limits in the range of 18<sup>th</sup> or 19<sup>th</sup> magnitude, which corresponds to sizes larger than 10 cm assuming an albedo of 0.175. All of these surveys reveal a substantial population of objects fainter than  $R = 15^{\text{th}}$  magnitude that are not in the public U.S. Satellite Catalog.

To detect objects fainter than 20<sup>th</sup> magnitude (and presumably smaller than 10 cm) in the visible requires a larger telescope and excellent imaging conditions. This combination is available in Chile. NASA's Orbital Debris Program Office has begun collecting orbital debris observations with the 6.5-m (21.3-ft diameter) "Walter Baade" Magellan telescope at Las Campanas Observatory (see figure 1). The goal is to detect objects as faint as possible from a ground-based observatory and begin to understand the brightness distribution of GEO debris fainter than  $R = 20^{\text{th}}$  magnitude. Outstanding questions include: Does the distribution continue to increase as one reaches fainter limiting magnitudes, and therefore smaller and smaller sizes, and if so, how? How does this small size regime compare with the distribution of debris at low Earth orbit (LEO)?



*Figure 1.— The 6.5 m "Walter Baade" Magellan telescope at Las Campanas Observatory in Chile.*

Preliminary results were obtained during 6 hours of observing time obtained March 25–27, 2011. The Inamori Magellan Areal Camera and Spectrograph (IMACS) instrument in f/2 imaging mode was used. It is composed of a mosaic of eight CCDs and has a field of view of 0.5 degrees in diameter (figure 2, right). This is the widest field of view of any instrument on either Magellan telescope. The image scale is 0.4 arc-seconds/pixel. The limiting magnitude for a 5-s exposure through a Sloan  $r'$  filter is measured to be fainter than  $R = 21$ . The system saturates at  $R = 15^{\text{th}}$  magnitude in 5 s in the typical excellent sub-arc-second image quality obtained using the Magellan telescopes.

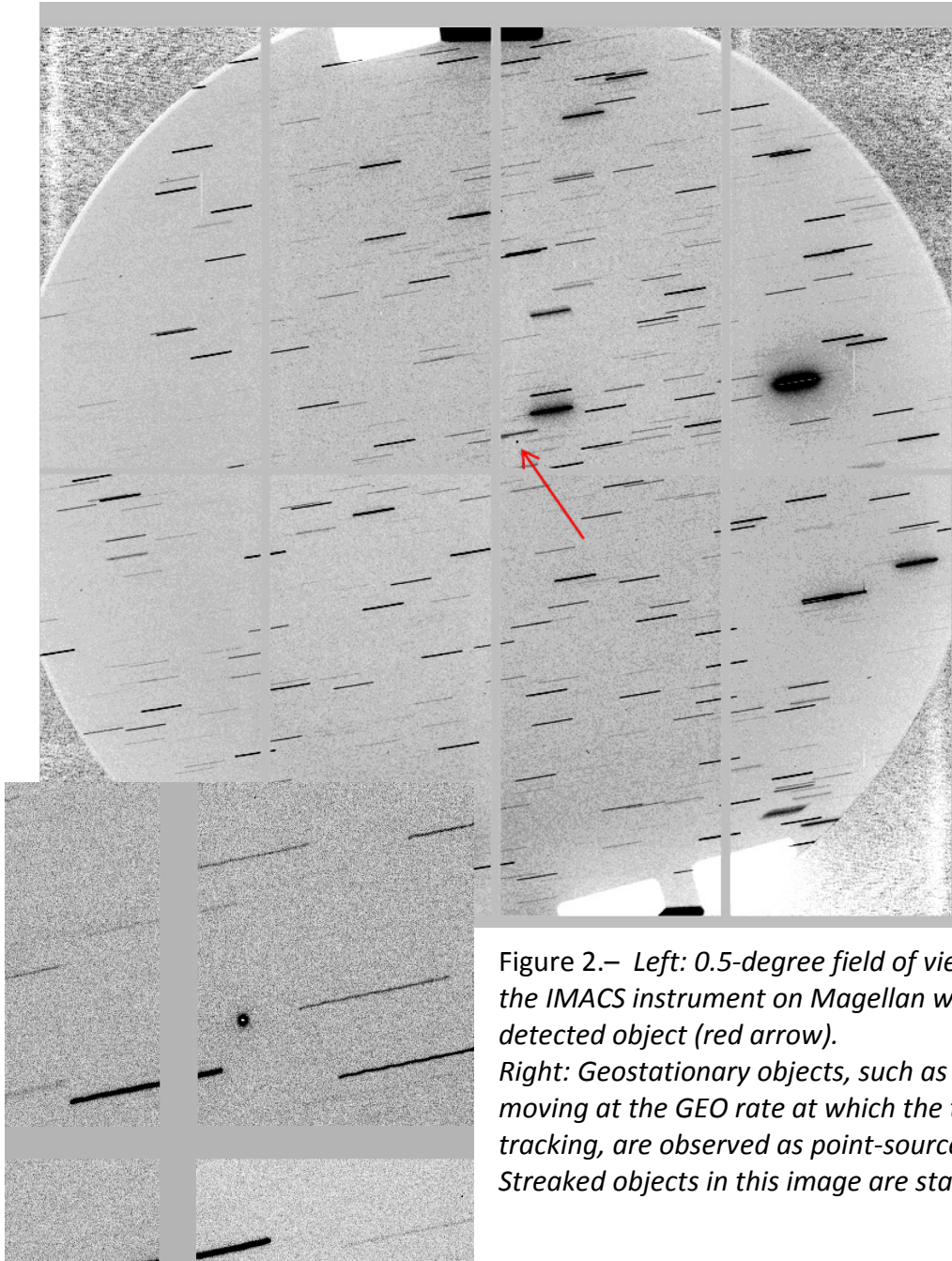


Figure 2.— *Left: 0.5-degree field of view seen by the IMACS instrument on Magellan with a detected object (red arrow). Right: Geostationary objects, such as satellites, moving at the GEO rate at which the telescope is tracking, are observed as point-source objects. Streaked objects in this image are stars.*

The aim was to observe an area that is as close as possible to the edge of the Earth’s shadow at GEO for two reasons: 1) this minimized the Sun-object-Earth phase angle (creating a “full-moon” effect), thereby maximizing the apparent brightness of the object, and 2) objects below GEO were in Earth shadow and thus not visible. This is important because the measurable quantities from this data are brightness, positions, and angular rates (at the time of the observations, calculating real-time orbits was not possible).

In 6 hours of photometric observing time, 19 individual objects were detected, as determined by manual review of all the images. Of these, 12 had rates consistent with GEO objects, appearing as point-sources instead of streaks (figure 2, left), or streaks moving in a different direction or rate than the stars (figures 3–5). For an object to be deemed real (and not a source of noise, such as cosmic-rays), it must appear in at least three images. Objects with hour angle (HA) rates within  $\pm 2$  arc-seconds/s and declination (DEC) rates within  $\pm 5$  arc-seconds/s were kept. These rates correspond to motions expected for GEO objects in circular orbits with inclinations ranging from 0 to 16 degrees. The detections group into three types: streaks, streaks of non-uniform brightness, and resolved and partially resolved flashes. Examples are presented in figures 3 through 5.

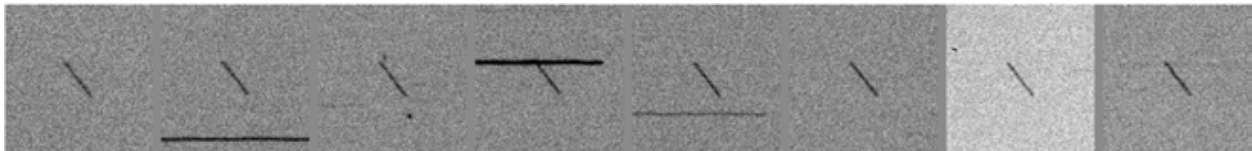


Figure 3.— An object detected as a uniform short streak. The primary motion is north to south.

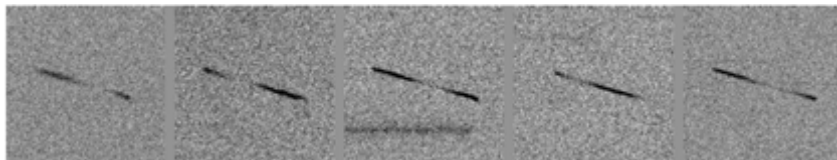


Figure 4.— An object detected as a non-uniform streak.

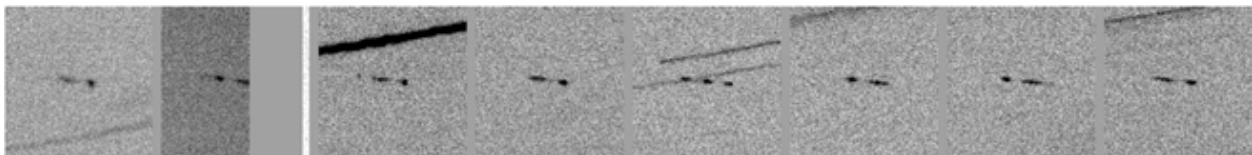


Figure 5.— An object detected as a series of unequal brightness flashes. The primary motion is east to west.



Each sub-image is 51.6 x 51.6 arc-seconds in size. Horizontal lines are stars (in figure 5, the star tracks are slightly tilted to the upper right). Approximately one-third of the detections show a series of three or more flashes during each 5-s exposure. One interpretation is that the detected objects are tumbling. Objects that are non-uniform streaks are tumbling at a rate close to our 5-s exposure time; objects with flashes are tumbling faster. Approximately 25 percent of the detected objects show glints (a momentary flash).

None of the faint objects detected are in the public U.S. Satellite Catalog. The rate of detection of objects with GEO rates is approximately 10 per hour per square degree.

This can be compared with the detection rate of GEO debris on MODEST during previous observing campaigns. The CCD camera in this telescope had a field-of-view of 1.3 x 1.3 degrees, a somewhat broader filter close to the same central wavelength of the Magellan Sloan r' filter, the same 5-s exposure time as Magellan, and a different survey technique. The average detection rate of objects with angular rates consistent with those at GEO in the range of 15<sup>th</sup> to -18<sup>th</sup> R magnitude was approximately one object per hour per square degree. Magellan's average detection rate, including objects in the 15<sup>th</sup> to 21<sup>st</sup> r' magnitude regime, was 10 times greater. With only 6 hours of observing time using Magellan, the statistics are unfortunately small at the faint end, but more GEO objects were detected in 6 hours of observing with Magellan in a smaller field-of-view than were detected with MODEST in an 8-hour night with a camera covering an area of sky eight times larger. However, the Magellan and MODEST results are consistent with a rising population of GEO objects as one reaches fainter limiting magnitudes. Future observations with Magellan can help us begin to understand the small and faint debris population in GEO.

## *Coring the Wide-Field Planetary Camera 2 Radiator for Impactor Trace Residue Assessment*

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After approximately 16 years in low Earth orbit aboard the Hubble Space Telescope (HST), the Wide Field Planetary Camera 2 (WFPC2) was returned to Earth in 2009 by the crew of STS-125's Servicing Mission 4. The WFPC2 radiator was exposed to the micrometeoroid (MM) and orbital debris (OD) environment and provides a unique record of the environment due to the length of time it spent in orbit as well as its relatively large 1.76 m<sup>2</sup> surface area. This surface was optically surveyed for impact features by a NASA and contractor team from JSC, Marshall Space Flight Center, and Goddard Space Flight Center in the summer of 2009. Approximately 700 features limited to a size of approximately 300  $\mu\text{m}$  – estimated to correspond to a 100  $\mu\text{m}$  OD projectile – were located and documented using a Keyence VHX-600 digital microscope.