

## Optical Observations

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an eccentric debris populations. We look forward to continuing these observations in the future. Our next run is planned for November 2007.

1. Schildknecht, *et al.*, *Properties of the High Area-to-mass Ratio Space Debris Population in GEO*, AMOS Technical Conference Proceedings, Kihei, Hawaii, pp. 216-224, September 2-5, 2005. ♦

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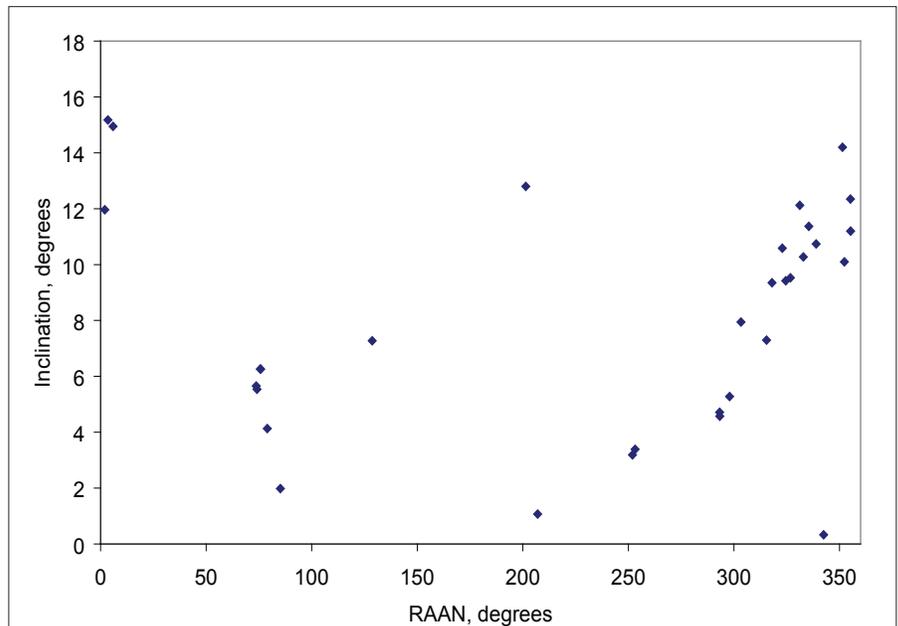


Figure 3. Inclination versus RAAN for each of the 32 objects in this specific dataset.

## Optical Measurement Center Status

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Beginning in 2005, an optical measurement center (OMC) was created to measure the photometric signatures of debris pieces. Initially, the OMC was equipped with a 300 W xenon arc lamp, a SBIG 512 x 512 ST8X MEI CCD camera with standard Johnson filters, and a Lynx 6 robotic arm with five degrees of freedom<sup>1</sup>. As research progressed, modifications were made to the equipment. A customized rotary table was built to overcome the robot's limitation of 180 degree wrist rotation and provide complete 360 degree rotation with little human interaction. This change allowed an initial phase angle (source-object-camera angle) of roughly 5 degrees to be adjusted to 7, 10, 15, 18, 20, 25, or 28 degrees. Additionally, the Johnson R and I CCD filters were replaced with the standard astronomical filters suite (Bessell R, I). In an effort to reduce object saturation, the two generic aperture stops were replaced with neutral density filters.

Initially data were taken with aluminum debris pieces from the European Space Operations Centre ESOC2 ground test and more recently with samples from a thermal multi-layered insulation (MLI) commonly used on rocket bodies and satellites. The ESOC2 data provided light curve analysis for one type of material but many different shapes, including flat, bent, curled, folded, and torn<sup>2</sup>. The MLI samples are roughly the same size and shape, but have different surfaces that give

rise to interesting photometric light curves. In addition, filter photometry was conducted on the MLI pieces, a process that also will be used on the ESOC2 samples. While obtaining light curve data an anomalous drop in intensity was observed when the table revolved through the second 180 degree rotation. Investigation revealed that the robot's wrist rotation is not reliable past 80 degrees, thus the object may be at slightly different angles at the 180 degree transition. To limit this effect, the initial rotation position begins with the object's minimal surface area facing the camera.



Figure 1. Digital Images of sample MLI debris. Top images are part of the space-facing layer and the bottom images are part of the space-craft facing layer. The A/M for these samples is  $\sim 10 \text{ m}^2/\text{kg}$ .

The MLI used for the current study consists of space-facing copper-colored Kapton with an aluminized backing for the top and bottom layers and alternating layers of

DARCON or Nomex netting with aluminized Mylar for the middle layers. This material is significant to the study of space debris due to its high area-to-mass ratio (A/M) and the effect solar radiation pressure perturbations have on its orbital evolution. Measurements were taken at an 18 degree phase angle with one intact piece and three different layers of MLI, using the standard astronomical filters mentioned previously. The A/M ratios range from 8 to 43  $\text{m}^2/\text{kg}$  (3  $\text{m}^2/\text{kg}$  and greater is considered to be a high A/M). In Figure 1, a digital image of two pieces of MLI layering is displayed. The top left and right images are part of the outermost layer of MLI. The copper-colored Kapton is space-facing, while the silver color borders the interior MLI layers. The bottom left and right images are part of the space-craft-facing MLI layer, with the copper-color Kapton facing the spacecraft while the silver color is positioned to the interior MLI layers.

The following figure shows an example of intensity versus rotation over 360 degrees for the intact piece of MLI (see Figure 2). The pseudo-debris piece was rotated through five degree increments at a seven degree phase angle. Filter photometry data was taken through all five filters mentioned previously. The two intensity maxima around 90 and 270 degrees correspond to the maximum surface area of the object facing the CCD camera. The object was rotated space-craft side first, then space-facing side during the remaining 180 degrees

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## OMC Status

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of rotation. The structure in the light curve is due to the surface structure of the object — where the space-craft facing layer is more uniform in composition, while the space-facing layer has a mesh structure on the edges and a perforated flat surface in the middle. If one were to compare the light curve of MLI to a flat plate rotated at the same phase angle over a 360 rotation, one would see that the flat plate would also show a bimodal plot, but a with a smoothed plot exhibiting a sinusoidal character

In addition to photometric laboratory measurements, laboratory spectral measurements will be taken with the same MLI samples. Spectral data will be combined to match the wavelength region of photometric data so that a fiducial reference can be established for the photometric measurements. Spectral data of MLI shows a strong absorption feature near 4800 Angstroms, which is due to the copper color of Kapton. Space debris containing MLI may therefore be identified via telescopic observations employing either high resolution spectroscopy or narrow-band photometry. Furthermore, we will ascertain whether the absorption feature is sufficiently broad to enable identification via broad-band (R-B) photometry.

Using laboratory photometric and spectral measurements, an optical property database will be provided for an object with a high A/M made of similar materials to MLI. The benefits of this database for remote optical measurements of orbital debris will be shown

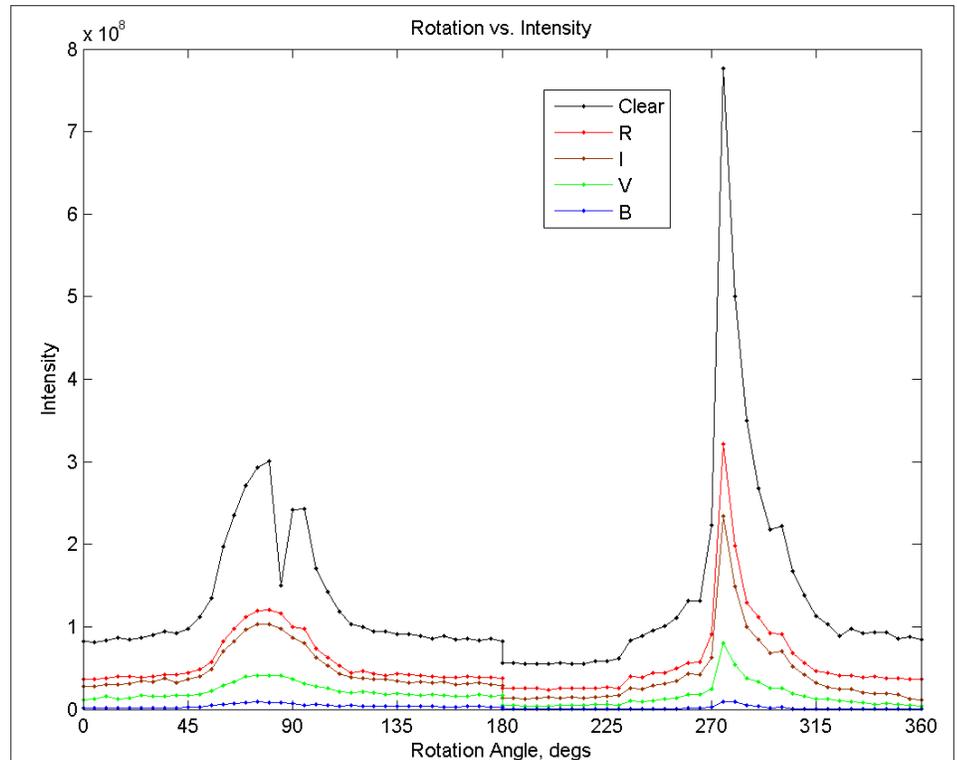


Figure 2. Intensity versus Rotation through five filters: Clear, Bessell R, Bessell I, Johnson B, and Johnson V.

by illustrating the optical properties expected for a high A/M object.

Future work will involve more complex rotations for different pieces of pseudo-debris and will incorporate other phase angles. An optical mirror is available for configuring the OMC for a 90 degree phase angle. The ongoing research is aimed towards developing an optical Size Estimation Model (SEM) comparable to the current radar SEM so that a better model may be obtained for the

orbital space environment.

1. Rodriguez, H.M., Abercromby, K. J., Jarvis, K. S., and Barker, E., Orbital Debris Photometric Study, ODQN, Vol. 10, Issue 2.
2. Rodriguez, H.M., Abercromby, K. J., Jarvis, K. S., and Barker, E., Using Light Curves to Characterize Size and Shape of Pseudo-Debris, 2006 AMOS Technical Conference, Maui, Hawaii, 10-14 September 2006. ♦

## ABSTRACTS FROM THE NASA ORBITAL DEBRIS PROGRAM OFFICE

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### The Disposal of Spacecraft and Launch Vehicle Stages in Low Earth Orbit

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As a result of the increasing number of debris in low Earth orbit (LEO), numerous national and international orbital debris mitigation guidelines recommend the removal of spacecraft and launch vehicle stages from LEO within 25 years after mission termination. The primary purpose of this action is to enhance space safety by significantly limiting the potential of future accidental collisions

resulting in the creation of large numbers of new orbital debris. Likewise, the passivation of these objects, i.e., the removal of residual stored energies, while they remain in orbit is important to prevent the generation of debris via self-induced explosions. Characteristics and trends in the growth of the derelict spacecraft and launch vehicle stage populations in LEO are examined.

Depending upon the final operational

altitude of the vehicle, achieving the goal of orbital lifetime reduction can influence the design and deployment philosophy of a new space system. Some spacecraft and launch vehicle stages have combined their end-of-mission passivation operations with maneuvers to vacate long-lived orbital regimes. Perhaps the most dramatic demonstration of this type occurred in 2006 when a U.S. Delta IV second