# Observations of Human-made Debris in Earth Orbit

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**Abstract:** Pollution is generally considered contaminants of Earth's surface, hydrosphere and atmosphere, but there is another problem over head, every day: space debris. This paper discusses observational methods used to characterize the growing debris population. **280.4788;** 280.0280

## 1. Introduction

Orbital debris is defined as any human-made object in orbit about the Earth that no longer serve a useful purpose. Beginning in 1957 with the launch of Sputnik 1, there have been more than 4,700 launches, with each launch increasing the potential for impacts from orbital debris. Almost 55 years later there are over 16,000 catalogued objects in orbit over 10 cm in size. Agencies world-wide have realized this is a growing issue for all users of the space environment. To address the orbital debris issue, the Inter-Agency Space Debris Coordination Committee (IADC) was established to collaborate on monitoring, characterizing and modeling orbital debris, as well as formulating policies and procedures to help control the risk of collisions and population growth. One area of fundamental interest is measurements of the space debris environment. NASA has been utilizing radar and optical measurements to survey the different orbital regimes of space debris for over 25 years, as well as using returned surfaces to aid in determining the flux and size of debris that are too small to detect with ground-based sensors. This paper will concentrate on the optical techniques used by NASA to observe the space debris environment, specifically in the Geosynchronous earth Orbit (GEO) region where radar capability is severely limited.

## 2. Data acquisition using optical sensors

Currently, the NASA Orbital Debris Program Office (ODPO) utilizes an optical sensor located near La Serena, Chile at the Cerro Tololo Inter-American Observatory (CTIO) for GEO observations. This sensor, the Michigan Orbital Debris Survey Telescope (MODEST), has been operating in survey mode since late 2001. MODEST is a 0.6-m Schmidt telescope with a field-of-view (FOV) of 1.3° x 1.3° and capable of detecting objects as faint as 18$^{th}$ magnitude using a Cousins R filter, which is nearly 63,000 times fainter than the human eye's sensitivity. In 2010 the camera was upgraded to a larger field of view (1.6° x 1.6°). The telescope tracks at the sidereal rate in right ascension (RA) and a fixed declination (DEC). The charge-coupled device (CCD) chip is aligned on the telescope such that the RA vector is parallel to the CCD read direction. During the 5-second exposure, the charge on the CCD is shifted in reverse (to retain a constant pointing angle or 'fixed GEO longitude' in electro-optical space) so that the objects are seen as a point source and the stars are seen as streaks, as shown in Figure 1 [1,2]. The object shown is labeled as an uncorrelated target (UCT), meaning objects tracked that do not correlate with the Space Surveillance Network Satellite Catalog.

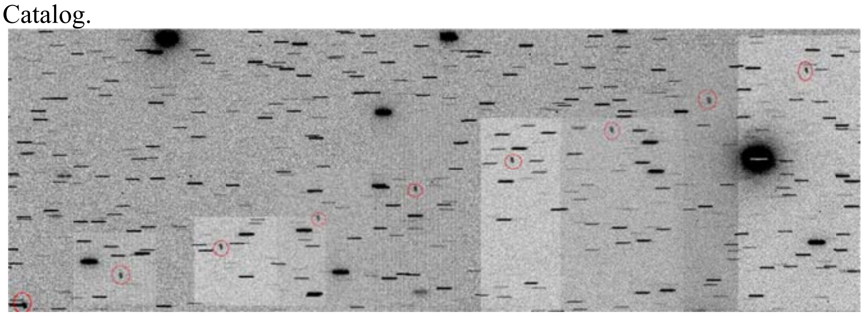

Figure 1. Sample mosaic image (only a small section of the original image is shown) from MODEST taken on 2009.295 (year.day of year). The GEO UCT (shown as circled objects) is traveling left-to-right in the image.

The data is used to determine a flux distribution as a function of orbital parameters and magnitude to better characterize the GEO environment. Using a Lambertian phase function $\Psi(\alpha) = \frac{2}{3\pi^2}[\sin(\alpha) + (\pi - \alpha)\cos(\alpha)]$, where α represents phase angle (angle subtended by Sun-object-Earth system), and an assumption the target is spherical with a constant albedo, one can derive the relative size for objects in space from the observed magnitude.

The geometrical albedo (Ag) has been determined to be 0.175 [3,4]. The diameter (d) of a target is dependent on these assumptions, as well as range input (R) and magnitude of the sun and object, and implicitly as a function of wavelength (r represents the magnitude in the red filter), as shown in Equation 1.

$$d = \frac{2R}{[\pi A_g \Psi(\alpha)]^{0.5}} 10^{\left[\frac{M_{obs}(r) - M_{sun}(r)}{-5.0}\right]} \tag{1}$$

For example, an object in GEO (R ~ 36,000 km) with a calibrated magnitude in r of 18, with the known magnitude of the sun in r of -27.12, corresponds to an object with a diameter of 20 cm. This is an interesting example as 18th magnitude in r is near the limiting magnitude of the MODEST telescope for a 5-second exposure, indicating that objects smaller than 20 cm are undetectable in GEO for this specific detector. A distribution of GEO objects (both correlated and uncorrelated targets) in absolute magnitude is shown in Figure2 [5]. The plot represents 3,143 objects detected by MODEST over the 2007-2009 observation campaign. The peak for functional correlated targets (CT) is 10th magnitude, which generally corresponds to large, intact spacecraft. The non-functional correlated targets (catalogued debris) peak resides at 12th magnitude. Lastly, the uncorrelated targets (UCT) appear to peak around 17th magnitude, estimated to be on the order of 25 cm diameters. Note that this roll off in the distribution is not a true reflection of the population, but of the detection capability of this sensor.

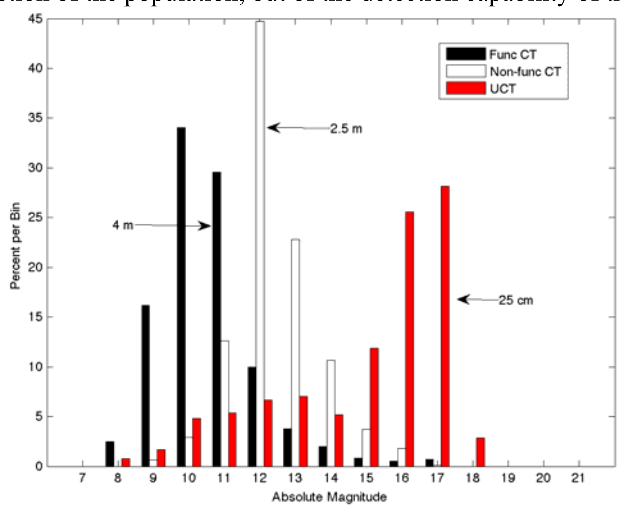


Figure 2. Absolute magnitude and derived size distribution, assuming an albedo of 0.175 and a diffuse Lambertian phase function. Functional Catalogued Targets are labeled 'Func CT'; Nonfunctional Catalogued Targets, 'Non-funct CT'; and Uncatalogued Targets, 'UCT'.

The first step to decreasing our uncertainty in the smaller size regime is to acquire optical data via sensors with more sensitivity that allow for fainter debris detections. During March 2011 NASA acquired time on the 6.5-m Magellan 1 telescope 'Walter Baade' at Las Campanas, Chile. This sensor has a 0.5° x 0.5° FOV and an estimated limiting magnitude down to approximately 22 (diameter of approximately 3 cm) using a Sloan r' filter for a 5-second exposure. The goal of this campaign was to observe the same field centers (INC and RA of Node) through dual sensors located relatively close (MODEST is 100 km south of Magellan) to better characterize the faint debris population. The analysis of this data is on-going and will be presented at AMOS 2011 [2].

A third telescope, the CTIO 0.9-m telescope, is utilized for two main goals: to provide simultaneous filter photometry between colocated sensors (within several meters), and obtain a longer arc on specific targets to increase orbital element solutions using stare and chase mode. The CTIO 0.9-m telescope is operated by the Small-and Medium-Aperture Research Telescope System (SMARTS) Consortium. During synchronous photometry observations, MODEST observes in the red filter and the CTIO 0.9-m observes in the blue filter [6]. For stare and chase mode, MODEST surveys the sky at a fixed field center (RA and DEC), while the CTIO 0.9-m tracks objects of interest handed off by MODEST, specifically faint objects (R>14.5) [6]. The CTIO 0.9-m telescope has a 0.22° x 0.22° FOV and uses Johnson/Bessell blue, visible, red, and infrared (b,v,r,i) astronomical filters to acquire photometry data. This data is sent to the NASA ODPO for analysis and possible correlation with laboratory data.

To provide further insight into orbital debris characteristics, NASA's ODPO has established an Optical Measurement Center (OMC) to simulate orbital debris in space. The OMC's purpose is to provide reflectance characteristics with targets of known mass, size, and material and correlate the results with remote data acquired via telescopes. The fragments studied are results of ground test explosions, hypervelocity impact tests, and pristine samples from known spacecraft material manufacturers to simulate the source of the orbital population. The OMC uses a 75 W Xenon arc source to simulate the solar spectrum, a CCD (bandpass of 350-1100 nm) with attached filter wheel (Johnson/Bessell b,v,r,i) to record data in different wavelengths, and a robotic arm to manipulate a target to simulate specific orientations expected for objects in space. A field spectrometer with 1 nm resolution and a bandbass of 250-2500 nm is also used to characterize specific materials. To date, initial correlations have been made using laboratory filter photometry and spectroscopy with the prior telescopic data, but the process is on-going and more materials need to be investigated. Possible material types thought to correlate with telescopic data are solar panel fragments and multi-layered insulation, two very common spacecraft materials.

The area-to-mass (A/m) ratio is also a physical characteristic of interest in the laboratory used to correlate with telescopic data. Objects with A/m values that exceed 1 $m^2$/kg possess variable eccentricity and inclination – a characteristic generally resulting from the pronounced effect of solar radiation pressure, such as multi-layered insulation. The majority of orbital debris is believed to have an A/m < 1 $m^2$/kg. Using the fragment's A/m and color photometry (color index), one can differentiate between materials. One of the difficulties with observing fragments in orbit is we still do not understand the attitude and rotation state of debris. Since attempting to simulate all the possibilities of rotation is infeasible, we have limited the laboratory data to four of the most probable rotation cases. For that reason, MATLAB® models are being developed to aid in laboratory simulations that allow a user to access a multitude of orientations and rotation states. Details of the laboratory data process and results can be found in Cowardin, 2011 [7].

Using telescopic data, laboratory data, and computer models, the NASA ODPO aims to provide a better understanding of the orbital debris environment. The measurement data provides the basis for the NASA ODPO models, which are used to evaluate protection methods, and mitigation standards and practices. Acquiring as much data as possible from a variety of optical sources is necessary for the measurements needed in GEO. This allows a better characterization of orbital debris population based on magnitude, size, and material type, since radar ground sensors are limited by the amount of power required to reach such high altitudes.

## 3. Conclusion

This paper provides a summary of the current optical sensors being utilized for orbital debris measurements via NASA's ODPO. There are other *in-situ* measurements, returned surfaces inspections, and developmental optical telescope projects that will provide size and flux data for different altitudes, based on the sensor used.

Laboratory work continues, with modifications being made to enhance the robotic arm's capability for acquiring bidirectional reflection distribution functions and acquire both forward and backward scattering of targets using +/- 180° phase angle acquisitions through the use of an automated rotary stage. The near goal is not only to provide reflectance about specific rotation axes and material characteristics, but also to develop an optical size estimation model using a laboratory-based albedo distribution model for all fragments.

## 4. References


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National Aeronautics and Space Administration

OSA Optical Instrumentation for Energy and Environmental Applications (E2), Nov 2-3 2011

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## Data Acquisition Using Optical Sensors

Currently, the NASA Orbital Debris Program Office (ODPO) utilizes an optical sensor, located near La Serena, Chile at the Cerro Tololo Inter-American Observatory (CTIO), for GEO observations. This sensor, the Michigan Orbital Debris Survey Telescope (MODEST), has been operating in survey mode since late 2001. MODEST is a 0.6-m Schmidt telescope with a field-of-view (FOV) of 1.3° x 1.3°. It is capable of detecting objects as faint as 18th magnitude using a Cousins R filter, which is nearly 63,000 times fainter than the human eye's sensitivity. In 2010 the camera was upgraded to a larger FOV of 1.6° x 1.6°. MODEST tracks at the sidereal rate in right ascension (RA) and a fixed declination (DEC). The charge-coupled device (CCD) chip is aligned on the telescope such that the RA vector is parallel to the CCD read direction. During a 5-second exposure, the charge on the CCD is shifted in reverse (to retain a constant pointing angle or "fixed GEO longitude" in electro-optical space) so that the objects are seen as a point source and the stars are seen as streaks, as shown in Figure 4 [1,2]. The object shown is labeled as an uncorrelated target (UCT); a tracked object that does not correlate with the Space Surveillance Network Satellite Catalog.

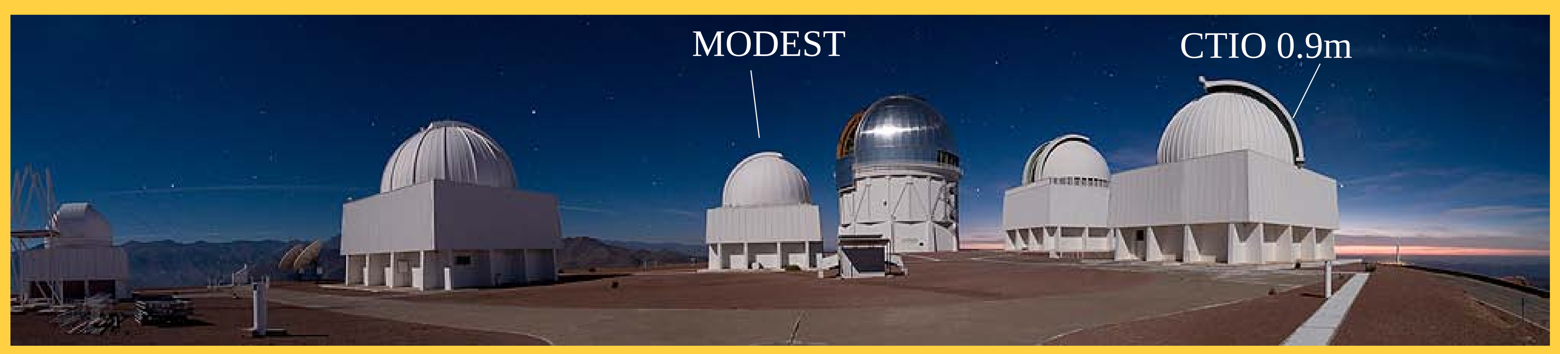



**Fig. 3**. CTIO telescopes (in order from far left to right): 1.2 m radio telescope, 1.0 m telescope, MODEST-0.6 m telescope, 4.0 m telescope, 1.5 m telescope, and 0.9 m telescope.
*Courtesy of Cerro Tololo Inter-American Observatory*

## Telescopic Optical Data: Phase Functions and Size Estimates

The data is used to determine a flux distribution as a function of orbital parameters and magnitude to better characterize the GEO environment. Using a Lambertian phase function (see Fig. 5 [3]), where α represents phase angle (angle subtended by Sun-object-Earth system), and an assumption the target is spherical with a constant albedo, one can derive the relative size for objects in space from the observed magnitude. The geometrical albedo (Ag) has been determined to be 0.175 [4,5]. The diameter (d) of a target is dependent on these assumptions, as well as range input (R) and magnitude of the sun and object, and implicitly as a function of wavelength (*r* represents the magnitude in the red filter).

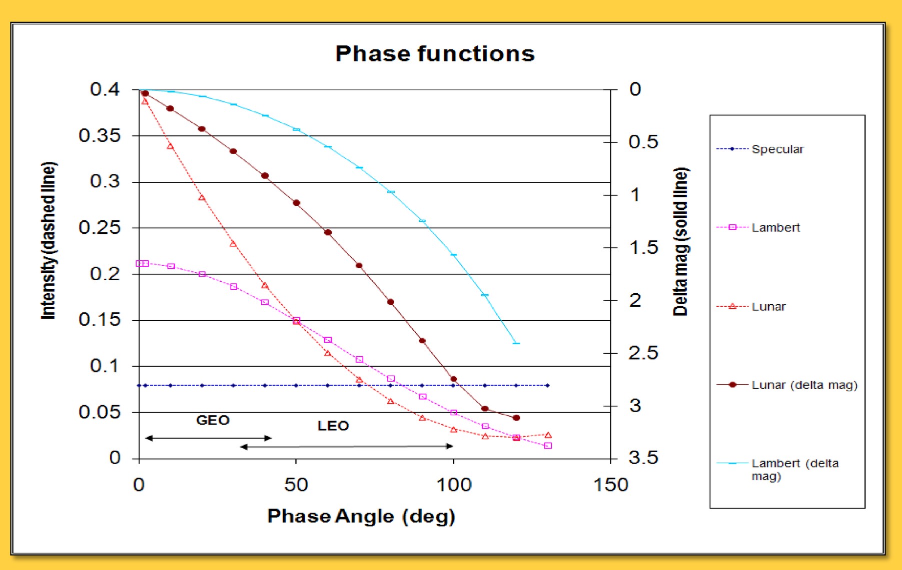



**Fig. 5**. Three main phase functions, plotted with delta magnitude of Lunar and Lambertian phase function.

$$\Psi(\alpha) = \frac{2}{3\cdot\pi^2}\left[\sin(\alpha) + (\pi-\alpha)\cdot\cos(\alpha)\right]$$

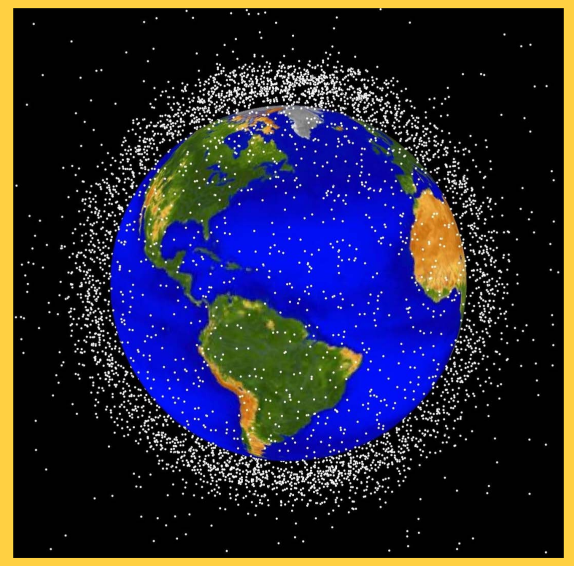
$$d = \frac{2\cdot R}{\left[\pi\cdot A_g\cdot\Psi(\alpha)\right]^{0.5}}\cdot 10^{\left[\frac{M_{obs}(R)+M_{sun}(R)}{-5.0}\right]}$$

For example, an object in GEO (R ~ 36,000 km) with a calibrated magnitude in *r* of 18, with the known magnitude of the sun in *r* of -27.12, corresponds to an object with a diameter of 20 cm. This is an interesting example as 18th magnitude in *r* is near the limiting magnitude of the MODEST telescope for a 5-second exposure, indicating that objects smaller than 20 cm are undetectable in GEO for this specific detector. A distribution of GEO objects (both correlated and uncorrelated targets) in absolute magnitude is shown in Figure 6 [6]. The plot represents 3,143 objects detected by MODEST over the 2007-2009 observation campaign. The peak for functional correlated targets (CT) is 10th magnitude, which generally corresponds to large, intact spacecraft. The non-functional correlated targets (catalogued debris) peak resides at 12th magnitude. Lastly, the uncorrelated targets (UCT) appear to peak around 17th magnitude, estimated to be on the order of 25 cm diameters. Note that this roll-off in the distribution is not a true reflection of the population, but of the detection capability of this sensor.

## GOAL

**Focus on monitoring and controlling the generation of orbital debris and its impact on the space environment.**

**Provide a better estimation of human-made pollution in the space environment by using ground-based optical sensors to acquire data and laboratory-based data to characterize the targets.**



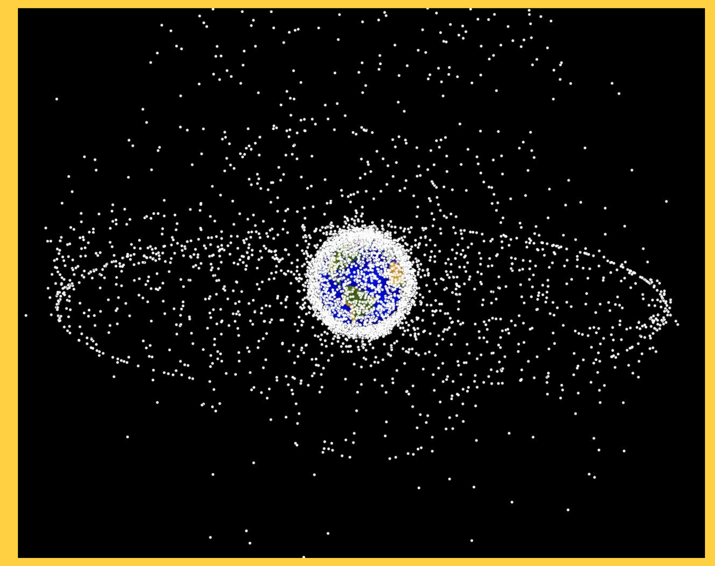


**Fig. 1**. Orbital debris graphic viewed from LEO. **Fig. 2**. Orbital debris graphic viewed from GEO. *Courtesy of NASA* ***Orbital Debris Program Office***

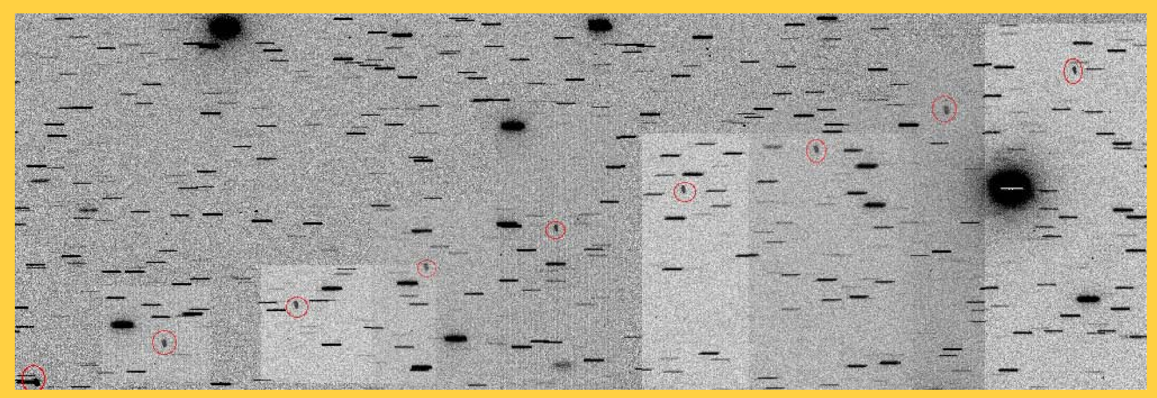


**Fig. 4**. Sample mosaic image (only a small section of the original image is shown) from MODEST taken on 2009.295 (year.day of year). The GEO UCT (shown as circled objects) is traveling left-to-right in the image.

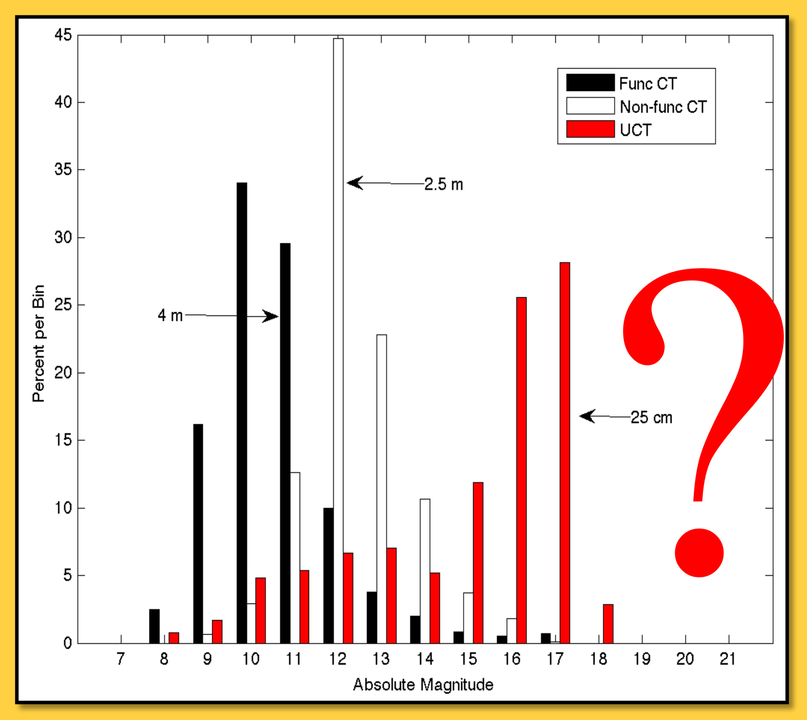
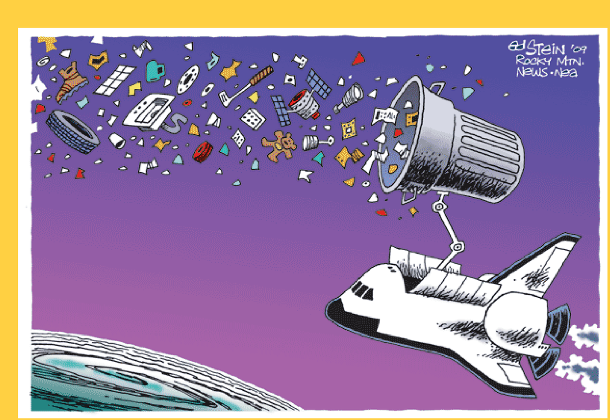



**Fig. 6**. Absolute magnitude and derived size distribution, assuming an albedo of 0.175 and a diffuse Lambertian phase function. Functional Catalogued Targets are labeled 'Func CT'; Nonfunctional Catalogued Targets, 'Non-funct CT'; and Uncatalogued Targets, 'UCT'.

## HIGHLIGHTS

Pollution is generally considered contaminants of Earth's surface, hydrosphere and atmosphere, but there is another problem over head, every day: space debris.



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Among the different types of sensors used to characterize and monitor orbital debris, this paper focuses on the optical measurements via telescope data and laboratory-based data acquisition operated under the NASA-JSC Orbital Debris Program Office.

Telescopes with a larger limiting magnitude are being utilized to characterize the faint, small debris population. Laboratory measurements provide ground-truth to material, shape, and possible orientations and rotation axes.

## Assessing the Problem Using Other Optical Sensors/Equipment

The first step to decreasing our uncertainty in the smaller size regime is to acquire optical data via sensors with more sensitivity that allow for fainter debris detections. During March 2011 NASA acquired time on the 6.5-m Magellan 1 telescope 'Walter Baade' at Las Campanas, Chile. This sensor has a 0.5° x 0.5° FOV and an estimated limiting magnitude down to approximately 22 using a Sloan r' filter for a 5-second exposure. The goal was to observe the same field centers (INC and RA of Node) through dual sensors located relatively close (MODEST is 100 km south of Magellan) to better characterize the faint debris population. The analysis of this data was presented at AMOS 2011 [2].

**Fig. 7**. The twin 6.5-m Magellan telescopes at Las Campanas Observatory, 'Clay' on left, 'Baade' on right.
*Courtesy of Las Campanas Observatory*

A third telescope, the CTIO 0.9-m telescope (shown in Fig. 3), is utilized for two main goals: to provide simultaneous filter photometry between co-located sensors (within several meters), and obtain a longer arc on specific targets to increase orbital element solutions using stare and chase mode. The CTIO 0.9-m telescope is operated by the Small-and Medium-Aperture Research Telescope System (SMARTS) Consortium. During synchronous photometry observations, MODEST observes in the red filter and the CTIO 0.9-m observes in the blue filter [6]. For stare and chase mode, MODEST surveys the sky at a fixed field center (RA and DEC), while the CTIO 0.9-m tracks objects of interest handed off by MODEST, specifically faint objects (R>14.5) [7]. The CTIO 0.9-m telescope has a 0.22° x 0.22° FOV and uses Johnson/Bessell blue, visible, red, and infrared (b,v,r,i) astronomical filters to acquire photometry data. This data is sent to the NASA ODPO for analysis and possible correlation with laboratory data.

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**Fig. 8**. Spectral measurements taken on returned surface.

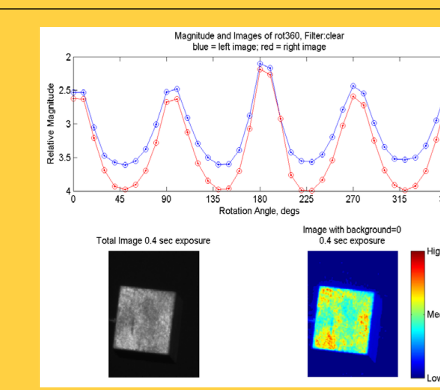

**Fig. 9**. Sample OMC lightcurve analysis for shape extraction.

**Fig. 10**. OMC robotic arm holding fragmentation debris from ground-test hypervelocity impact on test satellite.

## Summary

A brief overview of the current optical sensors being utilized for orbital debris measurements by NASA's ODPO has been presented. There are other *in-situ* measurements, returned surface inspections, and developmental optical telescope projects that will/have provide(d) size and flux data for different altitudes, based on the sensor used.

Using telescopic and laboratory data and computer models, the NASA ODPO aims to provide a better understanding of the orbital debris environment. The measurement data provides the basis for the NASA ODPO models, which are used to evaluate protection methods, and mitigation standards and practices. Acquiring as much data as possible from a variety of optical sources is necessary for the measurements needed in GEO. This allows a better characterization of orbital debris population based on magnitude, size, and material type, since radar ground sensors are limited by the amount of power required to reach such high altitudes.

## References

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