Photometric Studies of GEO Debris

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ABSTRACT

The photometric signature of a debris object can be useful in determining what the physical characteristics of a piece of debris are. We report on optical observations in multiple filters of debris at geosynchronous Earth orbit (GEO).

Our sample is taken from GEO objects discovered in a survey with the University of Michigan's 0.6-m aperture Schmidt telescope **MODEST** (for **M**ichigan **O**rbital **DE**bris **S**urvey **T**elescope), and then followed up in real-time with the **SMARTS** (**S**mall and **M**edium **A**perture **R**esearch **T**elescope **S**ystem) 0.9-m at CTIO for orbits and photometry. Our goal is to determine 6 parameter orbits and measure colors for all objects fainter than R = 15^{th} magnitude that are discovered in the **MODEST** survey. At this magnitude the distribution of observed angular rates changes significantly from that of brighter objects.

There are two objectives:

1. Estimate the orbital distribution of objects selected on the basis of two observational criteria: brightness (magnitude) and angular rates.

2. Obtain magnitudes and colors in standard astronomical filters (BVRI) for comparison with reflectance spectra of likely spacecraft materials. What is the faint debris likely to be?

In this paper we report on the photometric results.

For a sample of 50 objects, more than 90 calibrated sequences of R-B-V-I-R magnitudes have been obtained with the CTIO 0.9-m. For objects that do not show large brightness variations, the colors are largely redder than solar in both B-R and R-I. The width of the color distribution may be intrinsic to the nature of the surfaces, but also could be that we are seeing irregularly shaped objects and measuring the colors at different times with just one telescope.

For a smaller sample of objects we have observed with synchronized CCD cameras on the two telescopes. The CTIO 0.9-m observes in B, and **MODEST** in R. The CCD cameras are electronically linked together so that the start time and duration of observations are the same to better than 50 milliseconds. Thus the B-R color is a true measure of the surface of the debris piece facing the telescopes for that observation. Any change in color reflects a real change in the debris surface.

1. INTRODUCTION

The University of Michigan's 0.6-m aperture Curtis-Schmidt telescope at Cerro Tololo Inter-American Observatory (CTIO) in Chile is dedicated to optical studies of orbital debris for NASA, in a project called **MODEST** (for **M**ichigan **O**rbital **DE**bris **S**urvey **T**elescope).

The telescope is mainly used for optical surveys of orbital debris potentially at GEO. In survey mode, the telescope tracks at the sidereal rate a field of fixed right ascension and declination that is just outside of Earth shadow. During each 5 second exposure, the charge on the CCD is shifted backwards so that stars appear as 32 pixel long streaks, but objects at GEO are either point sources or very short streaks. Thus the system is most sensitive to objects at GEO.

A 2048x2048 thinned, backside illuminated SITe CCD is the detector, yielding a field of view (fov) of 1.3x1.3 degrees, and a sampling of 2.318 arc-seconds/pixel. It takes an object at GEO 5.3 minutes to move across this fov. A GEO object could appear in as many as 8 or 9 images taken at a cadence of one image every 37.9seconds. All survey observations are taken through a broad R filter centered at 630 nm with a FWHM of 200 nm. Such a filter minimizes the contribution of night sky emission lines longward of 800 nm. The observations are calibrated to the astronomical Bessel R filter using photometric standard stars.

During each survey night a strip of sky 100 degrees long is scanned. A real-time data reduction pipeline removes the instrumental signature from each image, and then an automatic finder routine finds potential GEO objects in each frame. A frame to frame correlator is then run on groups of object lists, looking for objects which have linear motion between subsequent frames. Four detections are required for an object to be considered real. All correlations are manually reviewed before any further analysis or follow-up observations are conducted.

The system is sensitive to objects with angular rates between -2.0 and +2.0 arc-seconds/second in hour angle (HA), and -5.0 and +5.0 arc-seconds/second in declination (DEC).

However, a short arc of 5.3 minutes duration is not enough to determine a full six parameter orbit. Follow-up observations require a second telescope in order to not interrupt the survey sequences.

Several times a year we are fortunate to obtain blocks of time on the CTIO 0.9-m telescope for these follow-up observations. Our goal is to obtain orbits and photometric properties of all objects found by **MODEST** that are fainter than R = 14.5 magnitude, where the observed angular rate distribution changes dramatically.

2. SINGLE TELESCOPE PHOTOMETRIC OBSERVATIONS

Follow-up observations on the CTIO 0.9-m are used to first establish a circular orbit, and then after enough observations are obtained, a full six-parameter eccentric orbit. Once the orbit is good enough to guarantee tracking within the CTIO 0.9-m's small fov of 0.22 degrees on a side, colors are obtained with the 0.9-m. This telescope has a larger aperture than **MODEST**, and much less confusion of GEO objects with star streaks due to a smaller plate scale. All color observations are obtained with the telescope tracking at the GEO object's rate.

Photometric observations are obtained through standard BVRI astronomical filters, calibrated using equatorial standard stars of Landolt. Observations are not obtained if the night is not photometric due to clouds.

Fig 1. shows the filter pass-bands of the BVRI filters. This filter set was used for simplicity of operations: they already exist, there is an excellent network of standard stars for zero-point calibration, and the filters cover a broad wavelength region from 350 to 900 nm.

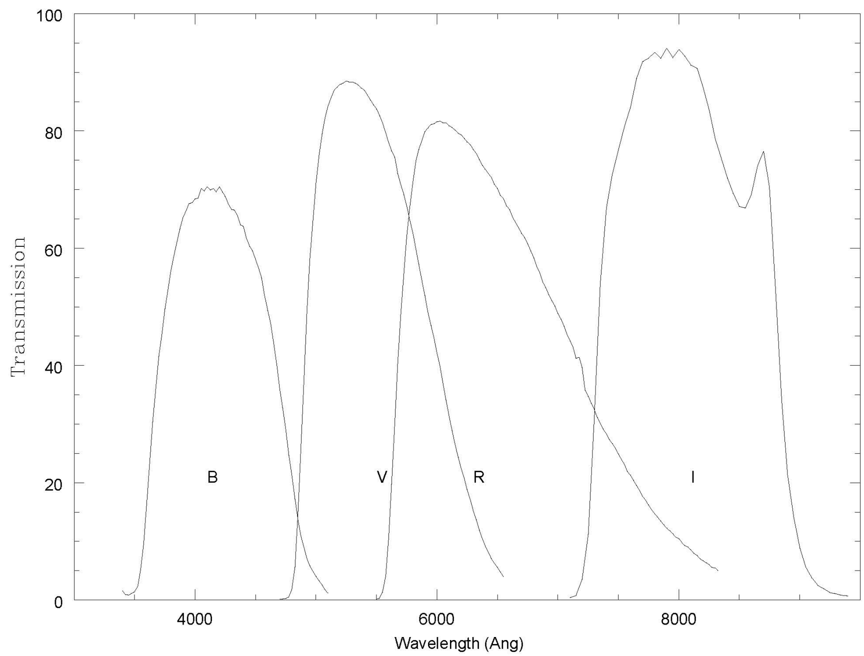

Fig 1. Filter pass-bands of the filters used for photometric observations of GEO debris.

A standard observation sequence consists of 5 observations in each of R-B-V-I-R. The R filter was repeated at the end of the sequence to look for photometric trends in the R magnitude over the 20 minute observing sequence.

A first-order look at the photometric data reveals that all observations can be separated qualitatively into two groups:

a. 'stable' objects that have no significant magnitude variations either within any group of observations in any filter, and between the first and last sets of observations in the R filter.
b. 'flashing' objects which show significant variations in brightness between subsequent observations in the same filter.

We have adopted a somewhat arbitrary definition of 'significant' as 0.5 magnitudes of change. A much more rigorous statistical analysis of the data is underway, which will include the expected variation from measuring errors.

Fig 2. shows the plot of R-I color versus B-R color for a collection of stable objects, along with the color expected for a purely grey object detected by reflected sunlight. The 70000 designation for each object is a purely internal working identification number, and has no external meaning outside of our **MODEST** studies.

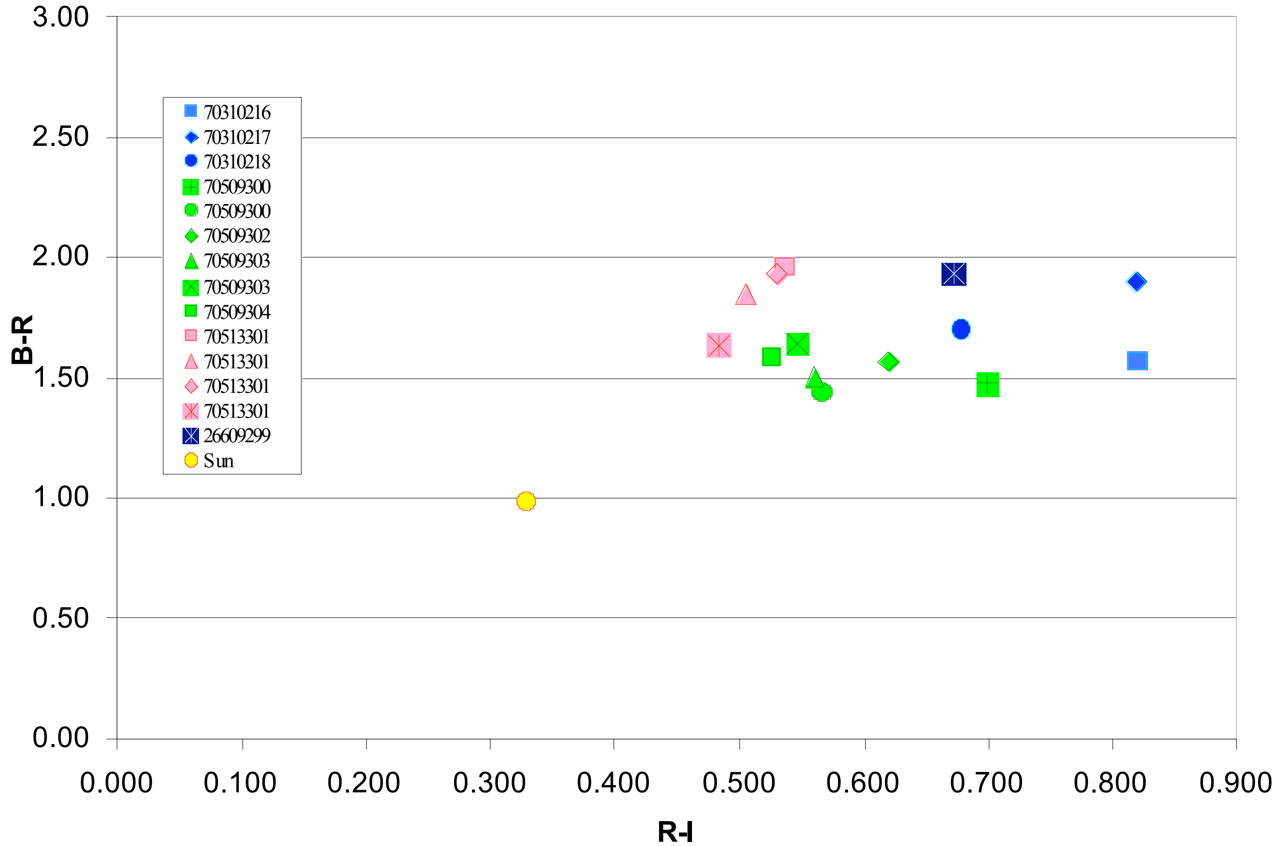

Fig 2. Color-color plot of a collection of stable objects (magnitude variations smaller than 0.5 magnitudes in all filters. Note the dispersion between measurements of the same object at different times is small, and the entire dataset is clustered within a small area of the graph.

For comparison, Fig 3. shows the same color-color plot for a sample of flashing objects, which show magnitude variations between subsequent observations of an object in the same filter. Now the distribution is much broader, and there is no clustering of objects in a region redder than solar color in both R-I and B-R.

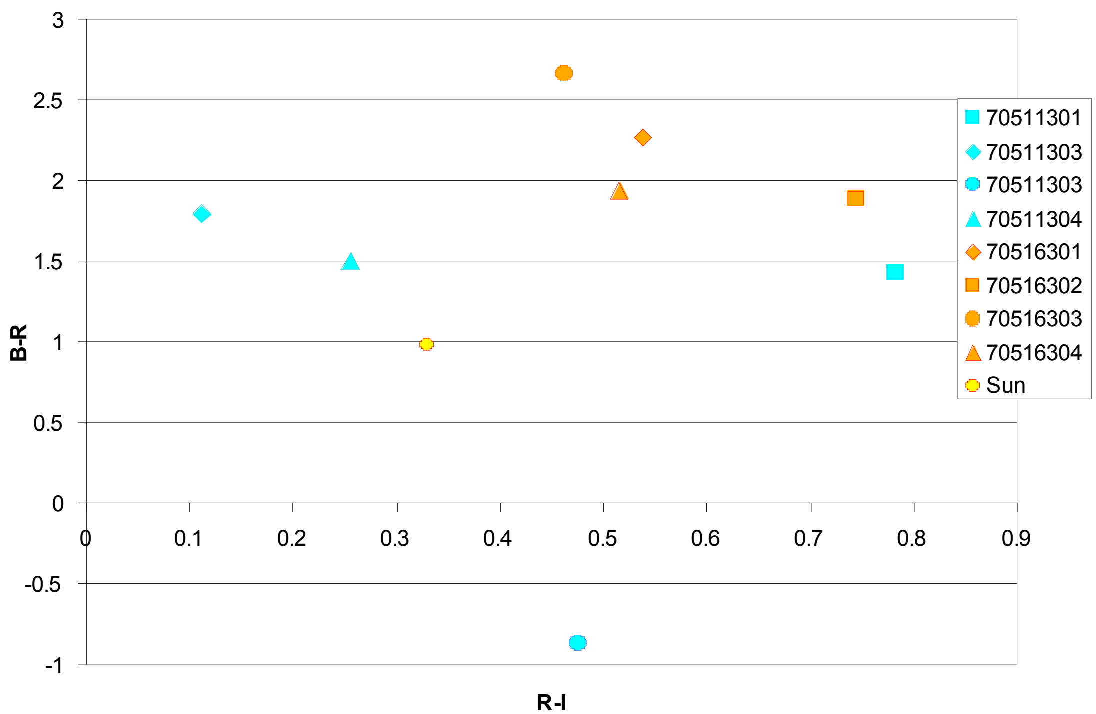

Fig 3. Color-color plot of GEO objects that show significant magnitude variations between subsequent observations. Now the range in colors is much broader than for stable objects, and there is no clustering of objects in one area of the spectrum.

There is a fundamental problem with the observing method described here, where observations in different filters are obtained at different times. If the object has an irregular shape, and is tumbling, then one could fully expect large brightness variations as the aspect of the object changed with time. Depending on the shape of the object, and the tumble rate, the brightness variation could be very large indeed. Only if all debris was spheres without any albedo or material differences could one expect to get very repeatable magnitudes and colors from the observing technique used here.

We believe, however, that the colors of stable objects which do not show large magnitude variations within a 20 minute observing sequence, and have fairly repeatable colors (differences less than 0.2 magnitudes) when observed at different times, are telling us something about the fundamental nature of the faint debris population. These objects are all redder than solar in both colors. The current dataset is not enough to state whether these colors are representative of the actual surfaces, or whether we are seeing the environmental effects perhaps of space weathering.

We point out to you the study presented by Cowardin, et.al (2009, this conference) where laboratory measurements of a number of spacecraft surfaces are conducted through the same filters as used on the CTIO 0.9-m telescope.

3. SYNCHRONIZED OBSERVATIONS

There are a number of techniques available to obtain simultaneous measurements in different filters of a celestial object. The most general technique is spectroscopy, which can give continuous wavelength measurements at one time. Alternatively, one can observe with a camera that splits the input light beam by means of dichroic beamsplitters into two or more cameras, each with a CCD detector and filter.

In our case, though, we chose to conduct simultaneous observations using two telescopes: **MODEST** observing in the R filter, and the CTIO 0.9-m in the B filter. Since both telescopes have identical CCD controllers, it was possible to link the two cameras together electronically so the shutters on both cameras have the same opening time and duration to better than 50 milliseconds. The CTIO 0.9-m camera controller serves as the master, and the **MODEST** camera is synchronized to it. This arrangement limits us to observing in only two filters at one time, but the technique can be done using existing hardware and software.

The exposure time is 15 seconds, selected to obtain good signal in the B filter. The observing cadence is a new pair of exposures every 25 seconds. Every frame from both telescopes is visually inspected and frames where the GEO object is contaminated by either a cosmic ray or a star streak are rejected. The matching frame from the other telescope is rejected as well.

Fig 4. shows the instrumental (uncalibrated) b magnitude from a sequence of 25 images of an R = 16 magnitude object discovered by **MODEST** in February 2009. The object is not in the public Space Command catalog. Our orbit as determined from CTIO 0.9-m observations has eecentricity = 0.05, mean motion = 1.027, and inclination = 14.08 degrees. The magnitudes on Fig 4 are from the CTIO 0.9-m. There is clear periodic variation in the object's brightness by almost 0.75 magnitudes, or a factor of 2 in brightness.

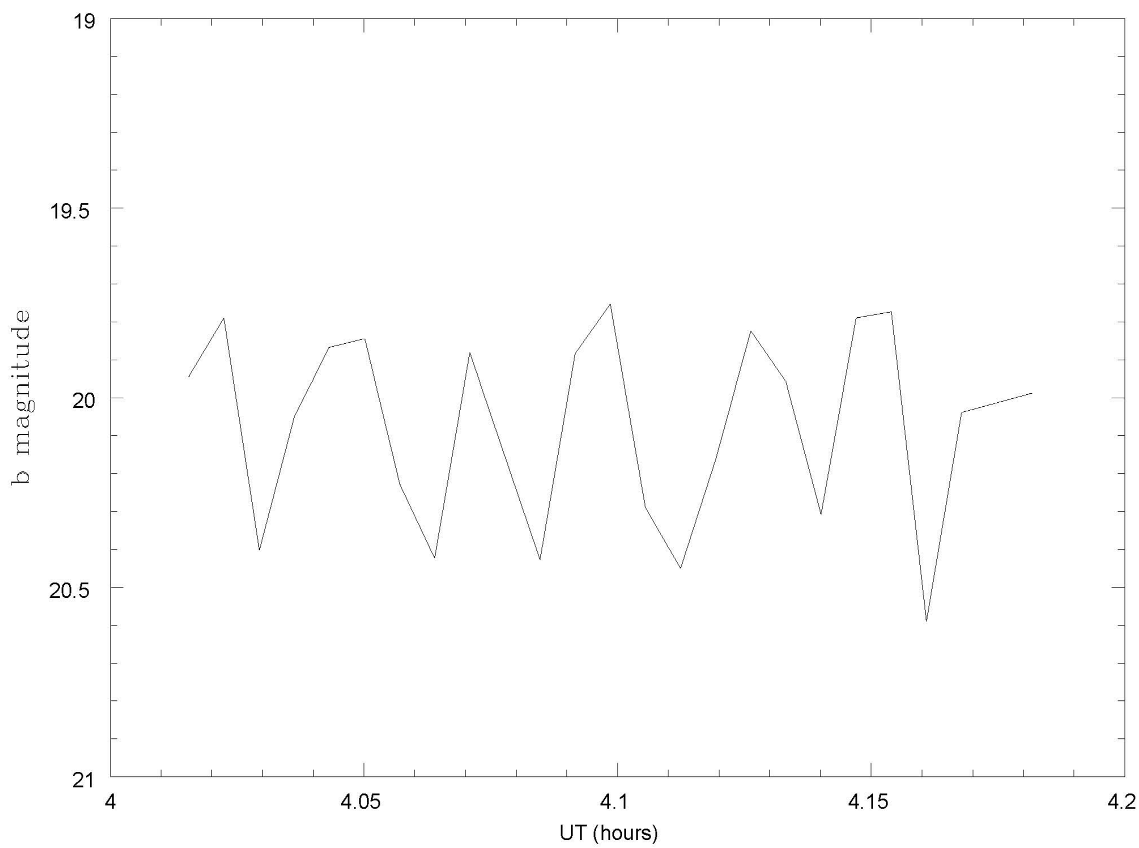

Fig 4. Instrumental, uncalibrated, b magnitudes as determined from a sequence of 25 images of a GEO object obtained with the CTIO 0.9-m in February, 2009. Two images were rejected due to contamination by cosmic rays and star streaks. A periodic variation in the object's 'b' brightness is clearly visible.

When we combine the b data from the CTIO 0.9-m with the r data from MODEST obtained at exactly the same time, the resulting color b-r is shown in Fig 5. The plot scales are the same for both figures. Although there is a small variation in color, it is much smaller than the variation in brightness (magnitude).

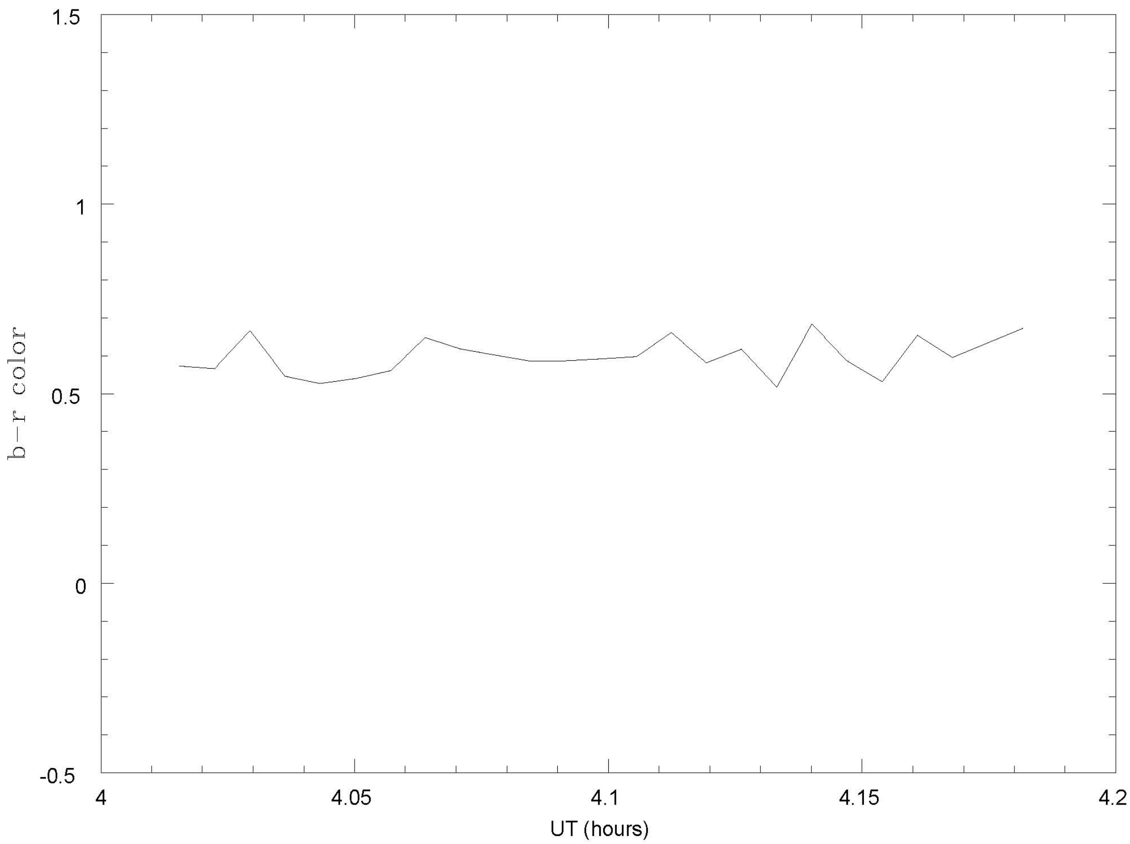

Fig 5. Simultaneous instrumental color (b-r) for the same object at the same time as the magnitude shown in Fig 4. The variation in color is much smaller than the variation in brightness.

What does this behaviour in magnitude and color tell us about the nature of the GEO object? The object is clearly irregular in shape, and is tumbling at a regular rate. Otherwise we would not see the observed variation in brightness. But the much smaller variation in color suggests that the various surfaces of the object have very similar colors. The data does not tell us whether all the surfaces of the object that are projected to us are the same, only that they have similar colors. Note that the colors in Fig 5 can not be compared to those in Fig 2 and Fig 3 until they are calibrated onto the same photometric system.

This result for one object shows the clear importance of doing simultaneous observations at multiple wavelengths in order to understand the characteristics of the GEO object. Large variations in magnitude can not be used to imply a large variation in color.

4. CONCLUSIONS

Colors of GEO debris have been obtained in four standard astronomical filters (BVRI) using telescopes at the Cerro Tololo Inter-American Observatory in Chile. The results suggest that the population of faint debris at GEO (defined as the R magnitude being fainter than 14.5) is primarily red in both color indices determined (B-R and R-I).

The sample of objects which show the smallest brightness variations in all filters at all times cluster in color-color space to the red of the expected color of a grey object illuminated by the Sun.

Our simultaneous observations with two telescopes show that for the one GEO object presented here there is no correlation between variation in magnitude and variation in color.

Finally, a comparison of the observed colors of GEO objects presented here with colors from laboratory measurements of actual materials used in spacecraft construction is given in Cowardin, et al. (2009, this conference).

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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