Optical Photometric Observations of GEO Debris

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ABSTRACT

We report on a continuing program of optical photometric measurements of faint orbital debris at geosynchronous Earth orbit (GEO). These observations can be compared with laboratory studies of actual spacecraft materials in an effort to determine what the faint debris at GEO may be.

We have optical observations from Cerro Tololo Inter-American Observatory (CTIO) in Chile of two samples of debris:

1. GEO objects discovered in a survey with the University of Michigan's 0.6-m aperture Curtis-Schmidt telescope MODEST (for Michigan Orbital DEbris Survey Telescope), and then followed up in real-time with the CTIO/SMARTS 0.9-m for orbits and photometry. Our goal is to determine 6 parameter orbits and measure colors for all objects fainter than R = 15th magnitude that are discovered in the MODEST survey.
2. A smaller sample of high area to mass ratio (AMR) objects discovered independently, and acquired using predictions from orbits derived from independent tracking data collected days prior to the observations.

Our optical observations in standard astronomical BVRI filters are done with either telescope, and with the telescope tracking the debris object at the object's angular rate. Observations in different filters are obtained sequentially.

We have obtained 71 calibrated sequences of R-B-V-I-R magnitudes. A total of 66 of these sequences have 3 or more good measurements in all filters (not contaminated by star streaks or in Earth's shadow). Most of these sequences show brightness variations, but a small subset has observed brightness variations consistent with that expected from observational errors alone.

The majority of these stable objects are redder than a solar color in both B-R and R-I. There is no dependence on color with brightness.

For a smaller sample of objects we have observed with synchronized CCD cameras on the two telescopes. The CTIO/SMARTS 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.

We will compare our observations with models and laboratory measurements of selected surfaces.

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 Michigan Orbital DEbris Survey Telescope). Further details on the survey technique can be found in [2][3]. We present just a summary here.

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 37.8 seconds. 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.

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.

Several times a year we are fortunate to obtain blocks of time on the CTIO/SMARTS 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. In particular, one of our interests is to obtain orbits and colors for high area-to-mass objects in the GEO regime originally found by Schildknecht, et al.[1].

2. SINGLE TELESCOPE PHOTOMETRIC OBSERVATIONS

Follow-up observations on the CTIO/SMARTS 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/SMARTS 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. All color observations are obtained with the telescope tracking at the GEO object's rate. Details of the two telescope operation on Cerro Tololo can be found in [2].

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.

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 trends in the R magnitude over the 20 minute observing sequence.

We have classified the observations into two separate 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 the definition of photometrically stable as an objects where the observed sigma in magnitude is less than twice the predicted sigma from the expected errors in *all* filters. Of our sample of 71 sequences obtained in R-B-V-I-R, 66 sequences have 3 or more good measurements in all filters that are not contaminated by star streaks. Of these 66 sequences, only 18 (27 percent) are photometrically stable. In the plots that follow, no correction has been made for solar phase angle. For comparison, solar B-R is ~ 1, R-I ~ 0.3.

Fig 1. shows the plot of R-I color versus B-R color for all objects,

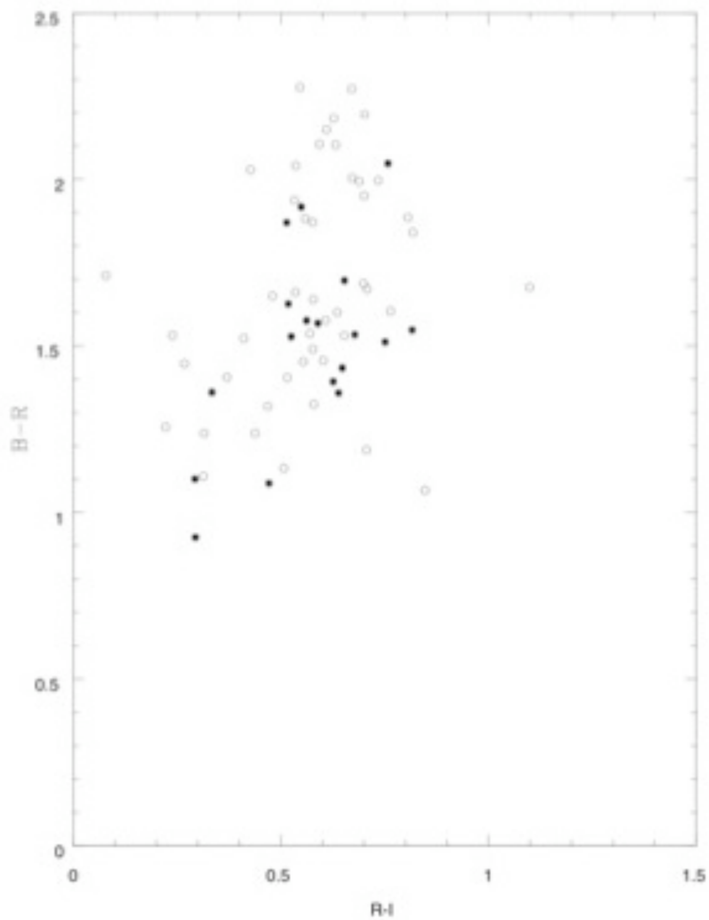

Fig 1. Color-color plot of all 66 observations sequences with 3 or more uncontaminated observations in all filters. Open circles are objects with magnitude variations in at least one filter greater than twice the expected measurement errors. In this plot, the bluest objects are at the lower left, and the reddest objects at the upper right. One bright, blue SSN object blueward of 0.0 is omitted.

Almost all objects are redder than solar in both colors. Stable objects show a more concentrated distribution than the distribution of all objects

Fig 2. shows a plot of the B-R color index versus brightness (magnitude) for all objects, including a few bright intact SSN objects. One of these SSN objects is quite blue, presumably due to reflection off solar panels.

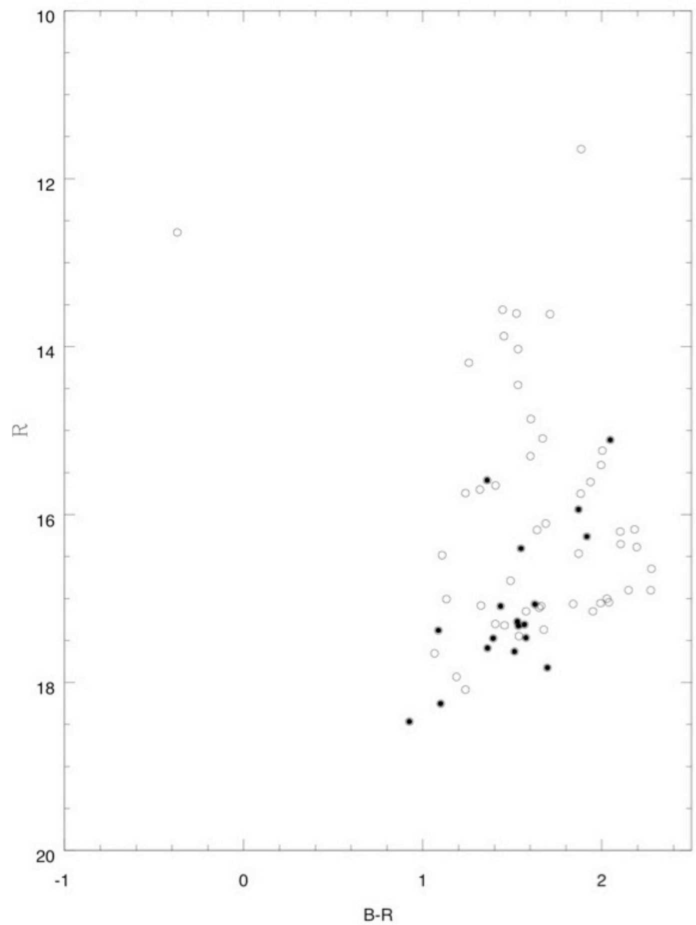

Fig 2. Color-magnitude plot of GEO objects. Closed circles have the smallest brightness variations in all filters. Faint, blue objects are at the lower left. Bright, red objects are at the upper right.

This figure again shows a clustering of faint objects redward of the expected color for a grey object illuminated by the Sun (color index B-R ~ 1). A plot of magnitude versus R-I color index shows much the same behaviour. There is no obvious dependence on color with apparent brightness.

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 uniform spheres 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 twice the expected variation due to errors) 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 [4] where laboratory measurements of a number of spacecraft surfaces are conducted through the same filters as used on the CTIO/SMARTS 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/SMARTS 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 object discovered by MODEST in February 2009. These magnitudes 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.

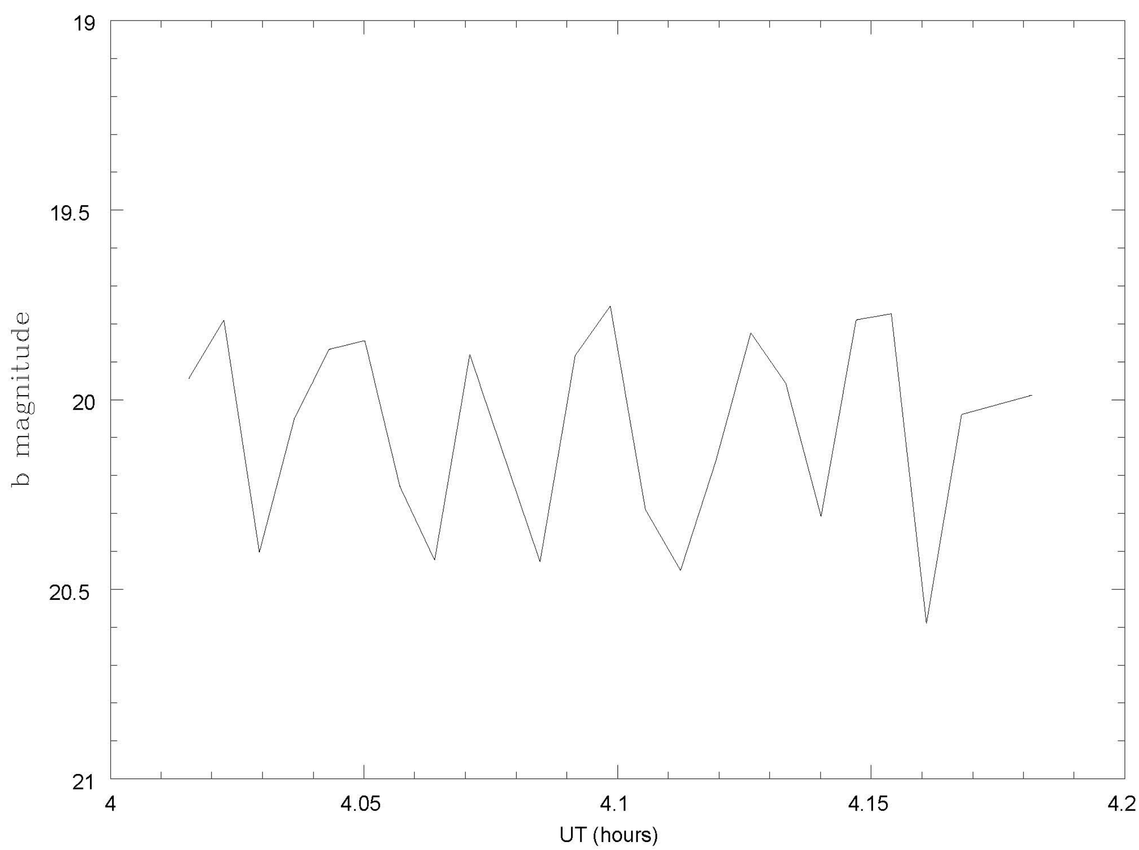

Fig 4. Instrumental, uncalibrated, b magnitudes as determined from a sequence of 25 images of a GEO object obtained with the CTIO 0.9-m in February, 2009. Two images were rejected due to contamination by cosmic rays and star streaks. A periodic variation in the object's brightness is clearly visible.

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).

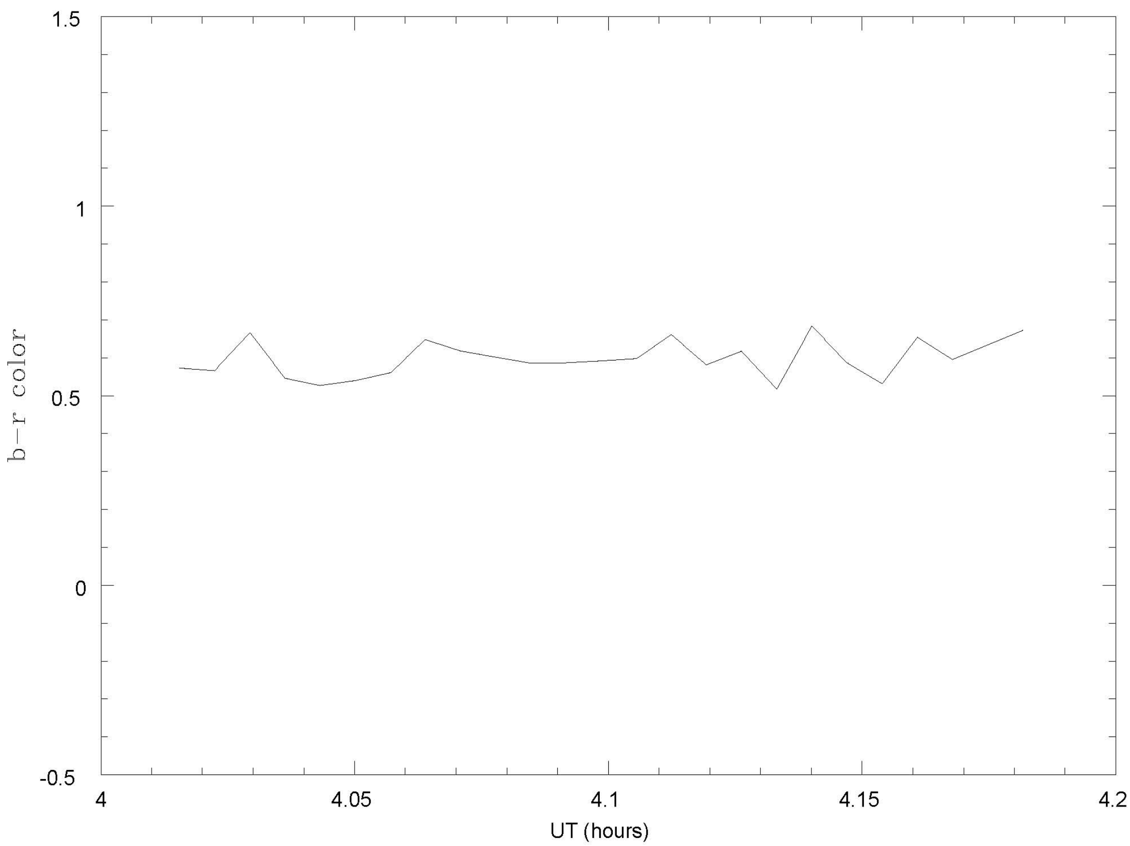

Fig 5. Simultaneous instrumental color (b-r) for the same object at the same time as the magnitude shown in Fig 4. The variation in color is much smaller than the variation in brightness.

What does this behavior 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 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. [4].

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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