Visible Light Spectroscopy of GEO Debris [1,2]

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1. ABSTRACT

Our goal is to understand the physical characteristics of debris at geosynchronous orbit (GEO). Our approach is to compare the observed reflectance as a function of wavelength with laboratory measurements of typical spacecraft surfaces to understand what the materials are likely to be. Because debris could be irregular in shape and tumbling at an unknown rate, rapid simultaneous measurements over a range of wavelengths are required. Acquiring spectra of optically faint objects with short exposure times to minimize these effects requires a large telescope.

We describe here optical spectroscopy obtained with an imaging spectrograph on one of the twin 6.5-m Magellan telescopes at Las Campanas Observatory in Chile. The data was obtained on 1-2 May 2012 on the 'Landon Clay' telescope with the LDSS3 (Low Dispersion Survey Spectrograph 3). This instrument has an imaging mode for acquisition. After acquisition and centering of a GEO object, a slit and grism are moved into the beam for spectroscopy. We used a low resolution grism blazed near 6000 Angstroms for wavelength coverage in the 4000 to 8000 Angstrom region. Typical exposure times for spectra were 30 seconds.

Spectra were obtained for 5 objects in the GEO regime listed as debris in the US Space Command public catalog. In addition spectra were obtained of an IDCSP (Initial Defense Communications Satellite Program) satellite with known properties at launch, and located just below the GEO regime. All spectra were calibrated using white dwarf flux standards and solar analog stars.

We will describe our experiences using a Magellan telescope, which has never been used previously for orbital debris spectroscopy, and our initial results.

2. INTRODUCTION

Spectroscopy of debris is potentially a powerful tool for understanding just what the surfaces are of the unresolved objects that we track as GEO debris. In many cases, the orbits and the origin of pieces of cataloged debris are known. For some of these objects an estimate of area-to-mass ratio (AMR) can be determined by watching the change in orbit with time. But what are not known are the exact surface characteristics of the object in question. A spectrum covering a wide range in wavelength could in principal answer this question when compared with laboratory spectra of known spacecraft materials.

[1] Work supported by NASA's Orbital Debris Program Office, Johnson Space Center, Houston, Texas.
[2] This paper includes data taken with the 6.5-m Magellan Telescopes at Las Campanas Observatory, Chile.

Schildknecht and collaborators [1] have previously reported on spectra of GEO objects, both debris and intact spacecraft, obtained with a 1.0 meter telescope. They stated that their observations were experimental in nature, and thus were not able to make any definite conclusions on what surfaces they were observing.

Lab based studies of spacecraft materials have been reported by Cowardin [2] and the derived color indices compared with telescopic observations of GEO debris. Bedard [3] has reported on laboratory measurements of a real spacecraft, and studies of spacecraft materials. This last study showed the complications of spectrographic studies: solar panels got redder with increasing phase angle, but other surfaces became bluer with increasing phase angle.

3. OBSERVATIONS

The Magellan telescopes are twin 6.5-m aperture telescopes located at Las Campanas Observatory in Chile. They are designed for superb image quality, and frequently the image quality delivered to the focal plane is better than 0.5 arc-seconds full-width-half-maximum (fwhm). The mounts are alt-azimuth, with image rotators at all focal stations to allow long exposure imaging of the night sky. The advantage of using such large telescopes on bright objects (typical cataloged pieces of debris are between R = 15th and 19th mag) is that only relativity short exposure times are required to achieve usable signal to noise ratios across a wide range of wavelength. Exposure times for all of our debris observations were 30 seconds. If an object is rotating or tumbling slower than this, we could obtain a spectrum of one surface. Obviously if the period is shorter than 30 seconds, then we will obtain a time averaged spectrum of whatever surfaces of the debris piece are presented to us during the time the instrument shutter was open.

In this paper we will report on a series of observations made during the last half of the night of May 2/3, 2012, with the LDSS3 imaging spectrograph on the Landon Clay 6.5-m telescope. LDSS3 is the Low Dispersion Survey Spectrograph 3[4]. It has an acquisition field of view of 8.3 arc-minutes diameter. Our observations used a 5 arc-second wide slit, and the VPH-ALL grism. This yields a wavelength range from 3800 to 9000 Angstroms, however we report here only results from 4500 to 8000 Angstroms due to atmospheric refraction effects and the fact that three was no order separating filter. The spectral sampling was 1.9 Angstroms/CCD pixel.

With such a wide slit (5 arc-seconds), and excellent image quality (always better than 1 arc-second fwhm) during these observations, the resolution is set by the fwhm of the star in the slit. The primary reason for such a wide slit was the difficulty of tracking the object.

The slit was oriented East-West to minimize contamination from star streaks. All observations were obtained at airmass < 1.7 to minimize effects of atmospheric refraction.

A set of white dwarf standard stars were observed over a range of airmass to determine atmospheric extinction as a function of wavelength, and set the flux zeropoint. Of particular interest were observations of the solar analog star SF1615, which is a James Webb Space Telescope (JWST) calibration star [5].

The major technical challenge of these observations is blind non-sidereal tracking. Once the grism is inserted in the beam, there is no information on where the object is in the slit. The Magellan telescopes were designed for sidereal tracking of stars and have guide probes and wavefront sensors at the edge of the field of view. Such devices work great on round stars but not on streaked stars moving past them at roughly 15 arc-seconds/second.

Our observing procedure was as follows:

1. Slew the telescope to a star field near the predicted position of the debris piece as determined from the public TLE (Two Line Element set).
2. The operator would focus the telescope and align the mirrors for best image quality while tracking at the sidereal rate. These steps can only be done while tracking a star.
3. At the appropriate Universal Time of prediction in 1, the telescope rates were set to track the object at the rates determined from differencing predicted positions from the TLE at 30 second intervals. A correction was applied to these rates to allow for acceleration during the 30 second interval.

4. A 5 second acquisition exposure was obtained through a Sloan r filter.
5. Once the object was acquired (and all objects were acquired on the first attempt), a series of 5 short exposures were taken to determine in real-time differential rate corrections since the TLEs are not high precision orbits.
6. The object was offset to the predicted position of the center of the slit. This sometimes took several iterations.
7. The slit was inserted into the beam and an exposure taken to confirm that the object was indeed in the center of the slit.
8. The Sloan r filter was removed, the grism inserted, and five 30 second exposures were taken.
9. Once the spectrographic sequence was finished, a comparison arc source (helium - neon - argon) was taken for wavelength determination, and then followed by 5 exposures of a quartz lamp for a continuum flat field, all with the grism and slit in place and the telescope tracking.

Typically such a sequence required 45 minutes for each object.

Our targets for these first observations were whatever GEO objects satisfied the following criteria:

1. Listed as debris in the public U.S. Space Command catalog.
2. Were visible from Magellan at the time, were above a local airmass of 1.7, and not in eclipse.

Five objects satisfied these criteria on the half night of observing available:

SSN	Launch Date	Description
12996	1977	EKRAN 2 DEB
13753	1976	LES 8,9/SOL 11A,B DEB
25000	1968	TITAN TRANSTAGE DEB
29014	1977	EKRAN 2 DEB
29106	2005	MSG 2 DEB (COOLER COVER)

In addition, SSN02655, an Initial Defense Communications Satellite Program (IDCSP) satellite launched in 1967 into an orbit just below GEO, was observed as morning twilight began.

Two of the observed objects have known characteristics at time of their launch:

1. SSN02651 - the IDCSP satellite known to be a 36 sided structure covered with solar cells [6].
2. SSN29016 - a cover from the MSG2 spacecraft launched in 2005 and described in [7].

Unfortunately, it did not prove possible to schedule the observations to keep all objects within the same narrow range of solar phase angle.

4. RESULTS

Fig. 1 below shows the first spectrum of each of the six objects observed, after division by a spectrum of the solar analog SF1615, and smoothing. The final spectral resolution was about 10 Angstroms. All observations were normalized to 1.0 in the wavelength region from 7500 to 8000 Angstroms to allow easy comparison.

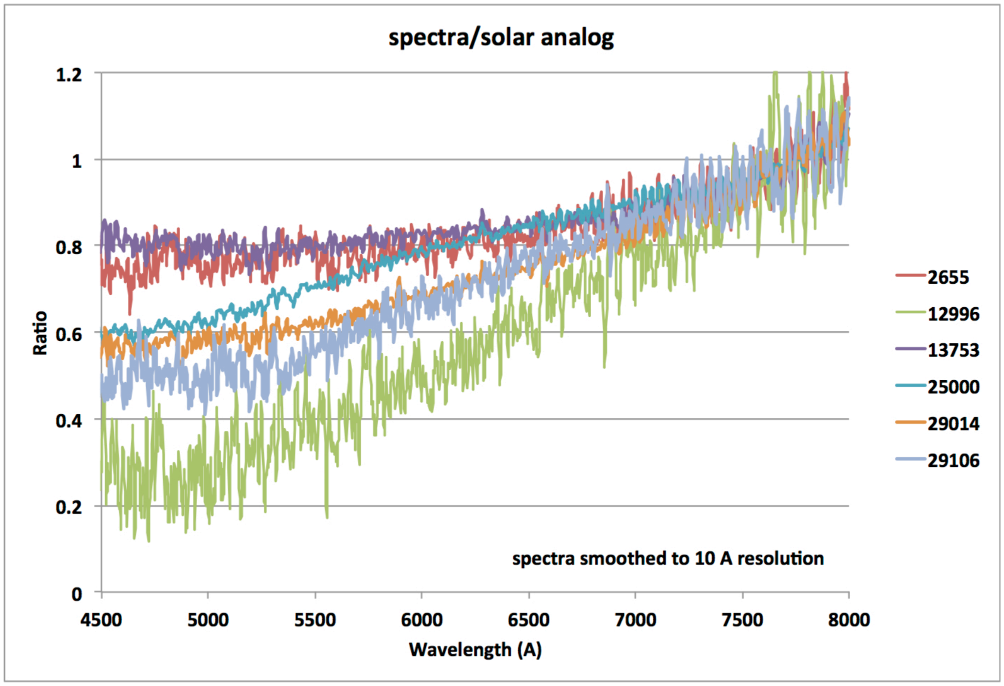

Fig. 1. Magellan LDSS3 spectra of 6 GEO or near GEO objects after division by a spectrum of a solar analog star and normalized in the wavelength region 7500 to 8000 Angstroms.

One can note the following:

1. All objects show a positive slope from blue to red, with an upturn redward of 7000 Angstroms.
2. The IDCSP 2655 and 13753 (LES 8,9/SOL 11A,B) have flat responses shortward of 7000 Angstroms.
3. The Ekran 2 debris piece 12996 has the greatest slope.
4. The two pieces of Ekran 2 debris (12996 and 29014) have different slopes.

Fig. 2 shows laboratory measurements from the NASA Spectral Library in the same spectral region of selected materials known to be on spacecraft. At first glance, there appears to be a substantial difference in the signature of these materials.

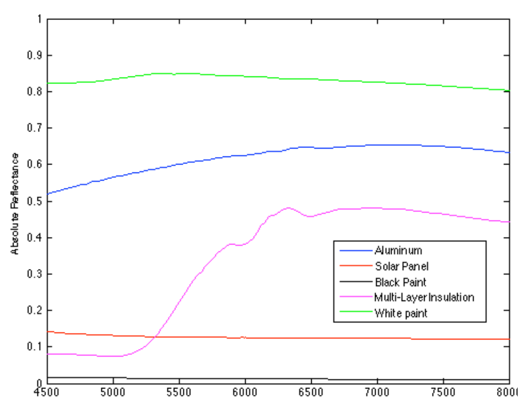

Fig. 2. Laboratory measurements of selected spacecraft materials.

But for laboratory measurements the amount of incident light is known allowing the determination of the absolute reflectance. For telescopic observations, all we can measure is the reflected light. Fig. 3 shows what the plot looks like if we treat the laboratory measurements in exactly the same manner as the telescopic observations, and normalize in the same wavelength region.

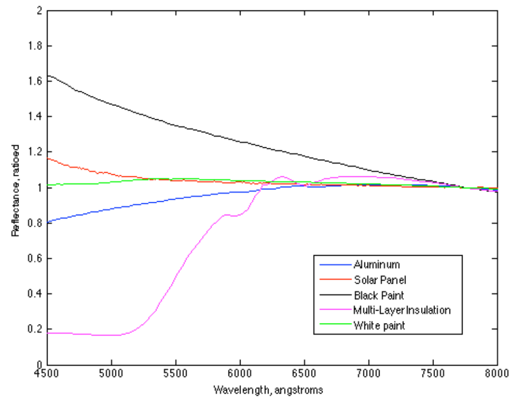

Fig. 3. Laboratory measurements treated as telescopic observations, and normalized in the wavelength region 7500 to 8000 Angstroms.

In this simple example, there are three classes of materials that can be determined: black paint, the gold multi-layer-insulation, and all others. With high signal-to-noise observations, it might be possible to further distinguish the solar panel, aluminum, and white paint. But one should always keep in mind the differences in observing conditions between the laboratory measurements and telescopic observations of GEO debris on orbit. The lab measurements are taken in 1 atmosphere, and with no space weathering effects.

The mystery of our Magellan observations is why most of them do not look anything like the laboratory results. The exceptions are the IDCSP 2655 and the debris piece 13753. They have flat response and compare well with laboratory measurements of solar panels, aluminum, and white paint except for the reddening beginning near 7000 Angstroms. All other debris pieces have spectrum unlike any of the laboratory measurements.

Next let us examine how the observed spectra correlate with other parameters: launch date and solar phase angle. Fig. 4 shows the ratio of the debris spectrum divided by the solar analog spectrum at 4500 Angstroms plotted against launch date. There is no correlation between launch date and the spectral ratio.

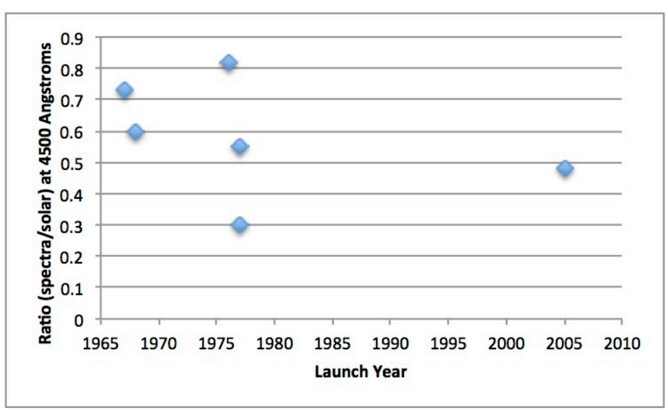

Fig. 4. Plot of spectral ratio at 4500 Angstroms versus launch date.

Of more concern is the solar phase angle distribution of our observations shown in fig 5.

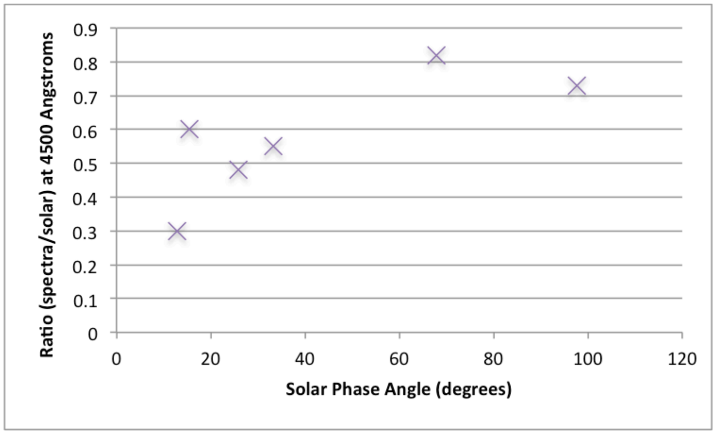

Fig. 4. Plot of spectral ratio at 4500 Angstroms versus solar phase angle at time of observation.

Although four of the debris pieces were observed in fairly narrow range of phase angle between 10 and 40 degrees, scheduling constraints during the one half night that all of this data was obtained on meant that two of the objects (2655 and 13753) were obtained at much larger phase angles. These two objects have the flattest spectrum. We cannot say from the current small number data set whether this effect is real, or just a chance occurrence. One should not be surprised to see such an effect, give the results of laboratory measurements[6].

5. CONCLUSIONS

These first observations of GEO debris and one near GEO object result in a mystery. Most of the spectra do not compare well with any of the laboratory spectra of spacecraft materials. One can only speculate why this is the case. Possible reasons include:

1. We are seeing complex structure and not a simple surface during our 30 second exposure.
2. The object is rapidly tumbling and presenting multiple surfaces towards us during the exposure.
3. Phase angle differences discussed above.
4. Space weathering effects of surfaces with time.
5. Errors in observing and reduction.
6. All of the above.

Our only firm conclusion is that interpreting spectra of debris is not likely to be a straightforward process.

6. REFERENCES

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