Reflectance Spectra Comparison of Orbital Debris, Intact Spacecraft, and Intact Rocket Bodies in the GEO regime

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ABSTRACT

A key objective of NASA's Orbital Debris program office at Johnson Space Center (JSC) is to characterize the debris environment by way of assessing the physical properties (type, mass, density, and size) of objects in orbit. Knowledge of the geosynchronous orbit (GEO) debris environment in particular can be used to determine the hazard probability at specific GEO altitudes and aid predictions of the future environment. To calculate an optical size from an intensity measurement of an object in the GEO regime, a 0.175 albedo is assumed currently. However, identification of specific material type or types could improve albedo accuracy and yield a more accurate size estimate for the debris piece. Using spectroscopy, it is possible to determine the surface materials of space objects. The study described herein used the NASA Infrared Telescope Facility (IRTF) to record spectral data in the ~ 0.65 to 2.5 micron regime on eight catalogued space objects. For comparison, all of the objects observed were in GEO or near-GEO. The eight objects consisted of two intact spacecraft, three rocket bodies, and three catalogued debris pieces. Two of the debris pieces stemmed from Titan 3C transtage breakup and the third is from COSMOS 2054. The reflectance spectra of the Titan 3C pieces share similar slopes (increasing with wavelength) and lack any strong absorption features. The COSMOS debris spectrum is flat and has no absorption features. In contrast, the intact spacecraft show classic absorption features due to solar cells with a strong band gap feature near 1 micron. The two spacecraft were spin-stabilized objects and therefore have solar panels surrounding the outer surface. Two of the three rocket bodies are inertial upper stage (IUS) rocket bodies and have similar looking spectra. The slopes flatten out near 1.5 microns with absorption features in the near-infrared that are similar to that of white paint. The third rocket body has a similar flattening of slope but with fewer features of white paint - indicating that the surface paint on the SL-12 may be different than the IUS. This study shows that the surface materials of debris appear different spectrally than intact rocket bodies and spacecraft and therefore are not believed to be solar panel material or pristine white paint. Further investigation is necessary in order to eliminate materials as possible choices for the debris pieces.

INTRODUCTION

One of the roles of the NASA's Orbital Debris program office at Johnson Space Center (JSC) is to characterize the debris environment by way of assessing the physical properties (type, mass, density, and size) of objects in orbit. Knowledge of the geosynchronous orbit (GEO) debris environment in particular can be used to determine the hazard probability at specific GEO altitudes and aid predictions of the future environment. Currently, an optical size is calculated using an assumed albedo for an object and its intensity measurement. However, identification of specific material type or types could improve albedo accuracy and yield a more accurate size estimate for the debris piece. Using spectroscopy, it is possible to determine the surface materials of space objects.

DATA COLLECTION AND REDUCTION

Sophisticated characterization of orbital debris is required to adequately constrain these bodies' physical characteristics (e.g., material type, mass, density, and size). The capabilities of the 3.0 meter NASA Infrared Telescope Facility (IRTF) provide the high signal-to-noise spectra with appropriate spectral coverage and resolution needed for these types of detailed investigations. The 4200 m altitude of Mauna Kea permits an adequate flux of photons through the atmospheric water vapor bands, which are located in visible and near-infrared wavelength regions associated with features common to orbital debris materials [1]. In addition, atmospheric seeing at Mauna Kea is generally excellent (0.8 arcseconds or better on average) due to the summit's high elevation and laminar airflow over the Hawai'ian Islands. Hence, these factors make the observatories located on Mauna Kea more attractive for detailed visible and near-infrared spectral studies than other observatories at lower elevations.

The detector used for this investigation is the SpeX instrument, which is a near-infrared spectrograph developed for the NASA IRTF by the Institute for Astronomy [2]. All of the SpeX data presented here were obtained on two different observing runs (June 2007 and May 2008) while the detector was in the low-resolution mode at the NASA IRTF with a 0.8 arcsecond wide slit. In this configuration, the instrument provides a spectral resolution ($\lambda/\Delta\lambda$) of ~93 across the entire 0.7 to 2.5 μm wavelength range. Signal-to-noise values of the data obtained by SpeX are contingent on the brightness of the object at the time of observation, the total integration time, and the atmospheric conditions at the summit. The signal-to-noise values for most objects observed with this instrument are attainable in excess of 80 to 100 given good viewing conditions.

Typical observations obtained via SpeX are of objects at low airmass (< 1.4) and as bright as visual magnitude (V-Mag) = 9.0 or as faint as V-Mag = 17.5. Most detailed spectroscopic investigations require the observations to be taken in groups of 6 to 10 with individual integration times of 15 to 120 seconds each. The brighter the object, the shorter the required integration times to attain a desired signal-to-noise ratio. An integration time of 120 seconds is the recommended maximum as longer exposures risk saturation of the object signal by the OH sky background [2]. Several spectra are collected in groups (or sets) to ensure adequate signal-to-noise in the event that one or more spectra become unusable for analysis as a result of rapid changes in atmospheric conditions or instrument irregularities.

The spectra taken via SpeX for such spectral studies are always taken in pairs, A and B. The letters correspond to the particular "beam" or light path of the instrument observing cycle that the telescope has on the object at the time. The observing cycle involves chopping from one beam to the other, and moves the instrument slit in a North-South orientation ~15 arcseconds relative to the background sky after each spectrum is collected. The object remains in the slit, but its spectrum is stored on two different portions of SpeX's charge couple device (CCD). This allows for a better sky background subtraction during data reduction, as each observation is subtracted from the other, and removes only the sky portion of the individual observation. The object spectrum is unaffected and remains behind.

In addition to observations of the object to be studied, observations of local standard stars are obtained over similar airmass ranges in order to model the atmosphere at Mauna Kea during each night. Local standard stars are chosen as close to the object as possible and should be no more than a few degrees away. For detailed spectroscopic studies, the standard star observations should bracket the object observations in terms of airmass. This allows for a more accurate determination of extinction coefficients over the entire spectral interval obtained by the SpeX instrument. Without this type of correction, the spectra may contain spurious artifacts due to strong telluric water vapor features, especially at ~ 1.4 and ~ 1.9 μm.

Ideally, the stars chosen as local standards are spectral G-type stars and have similar spectral responses to that of the Sun. Often, the local standard may have a close spectral match to that of the Sun, but may have some differences in spectral response. Given that the flux from orbital debris surfaces is reflected sunlight, the spectra must be ratioed to a solar-type spectrum in order to remove the effects of the Sun. Solar analogues such as SAO 93936 (Hyades 64) are observed over the same airmass ranges as both the object and local standard to correct for any slight variations of the local standard stars' spectrum from that of the Sun [3, 4]. Therefore, in a single night of observations at the NASA IRTF, spectra of target objects, local standard stars, and solar analogue stars are obtained. The reflectance spectra of the orbital debris objects are reduced and can be shown schematically as follows:

Object/Solar Analog Star = (Object/Local Standard)/(Solar Analog/Local Standard)

When taking data in a laboratory, a white reference is measured and compared to the material spectrum such that the resulting spectrum is called an absolute reflectance measurement that is on the scale of zero to one. However, there is not such an absolute reflectance standard at the same distance and orientation of each of the satellites. Therefore, the data is considered a relative reflectance. In these cases, the shape of the spectrum and the location and strength of the absorption features are used to determine material and not the percent reflectivity. To be able to compare measurements from two different objects, it may be necessary to scale to the reflectance so that both objects fit on one plot. When this practice was done, it will be noted.

OBJECTS ACQUIRED

The data were collected on two nights: one in June 2007 and one in May 2008. Eight objects were collected during the two observing runs: three debris objects, two uncontrolled spacecraft and three rocket bodies. Two of the three debris objects stemmed from the Titan 3C Transtage breakup and the third was from the COSMOS 2054 debris release. The material types of these objects are known. The two spacecraft are both Hughes 376 bus types, which are cylindrical

satellites with a de-spun dish. These spacecraft are covered with solar cells around the body. Solar panels consist of solar cells and mounting materials, but the spectrum as seen in space is dominated by the reflectance of the solar cells. The final three objects are rocket bodies, two of which are IUS upper-stages and the other is an SL-12 rocket body. IUS upper-stages outer surfaces consist of white paint, multi-layer insulation, and carbon. The surface properties of the SL-12 are unknown prior to the writing of this paper.

RESULTS

Debris Objects

The three debris spectra are compared below in Fig. 1. The two Titan debris pieces have similar slopes and features, and are believed to be the same material. The slopes of the Titan debris are less beyond 1.7 microns with the "a" piece having a neutral slope between 1.9 and 2.4 microns. The COSMOS debris piece has a flat, noisy spectrum. Laboratory data has been compared to the debris data, however, at the point of this printing, no match has been found due to the lack of absorption features and in the case of the COSMOS piece, the lack of slope. However, it can be determined that the two Titan pieces are of similar material and coating. This material and coating is very different from the COSMOS debris piece. With more data collected on debris targets, it maybe possible to detect differences between the two break-ups. However, at this time due to the small number of objects observed, the only conclusion that can be made is that these two pieces of the Titan break-up have a similar shape, which is significantly different from the COSMOS debris."
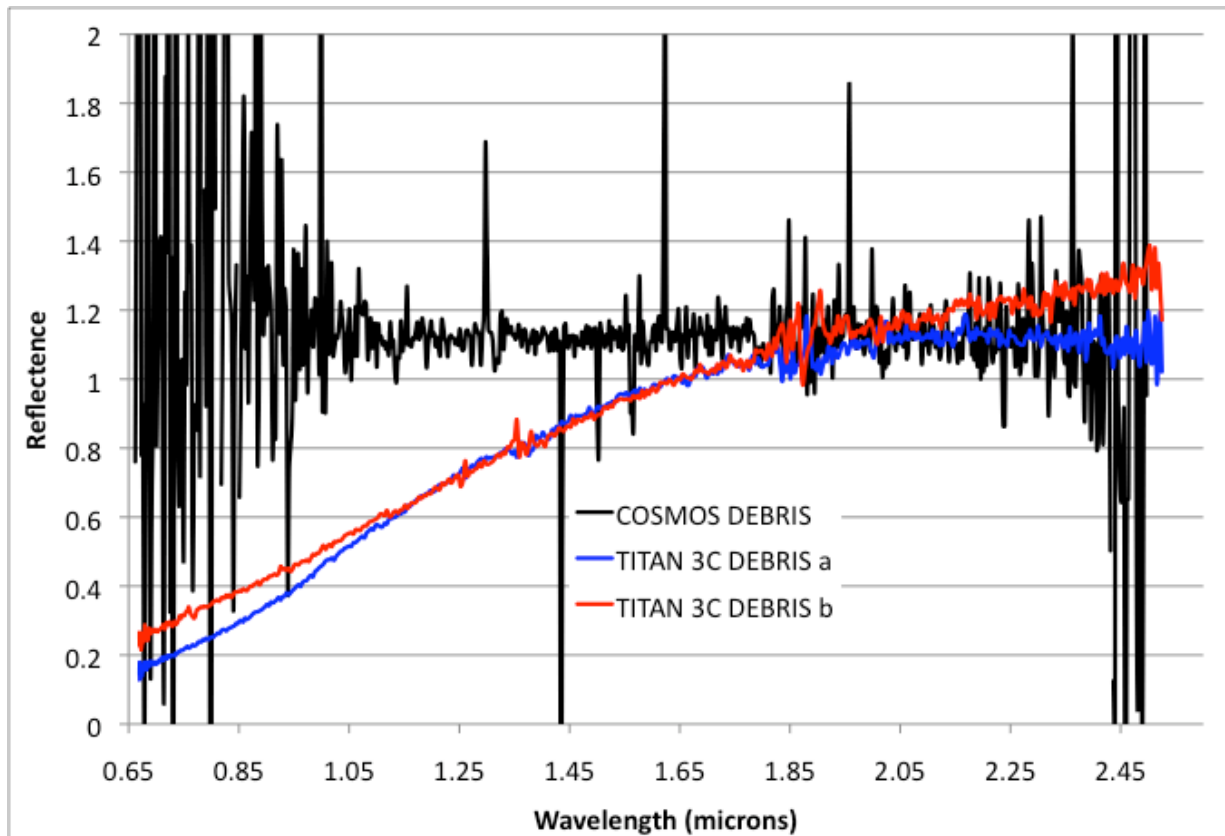

Fig. 1. Comparison of Debris Spectra. The flat, but noisy, spectrum is from the COSMOS debris, while the two similar spectra are from the Titan 3C debris.

Spacecraft

The two spacecraft have the same bus type and prior to the observations, the hypothesis was that the spectra would be similar in shape, slope, and absorption features. Fig. 2 shows the two spectra, where the data stemming from the SBS 2 has a higher starting reflectance while the data from the Galaxy 1R has a lower starting point. The Galaxy 1R has a spectrum that is very similar to that of solar cells tested in the laboratory. The strong upturn in reflectance near 1 micron is called a band gap, and this specific band gap is similar in strength and location to the band gap found in solar cells measured in the laboratory. The SBS 2 has a similar band gap although at a longer wavelength. The absorption features near 2.2 – 2.3 microns are in similar locations and in a similar location to those of the solar cells measured in the laboratory. These absorption features are attributed to the C-H bonds in the solar cell materials [1].
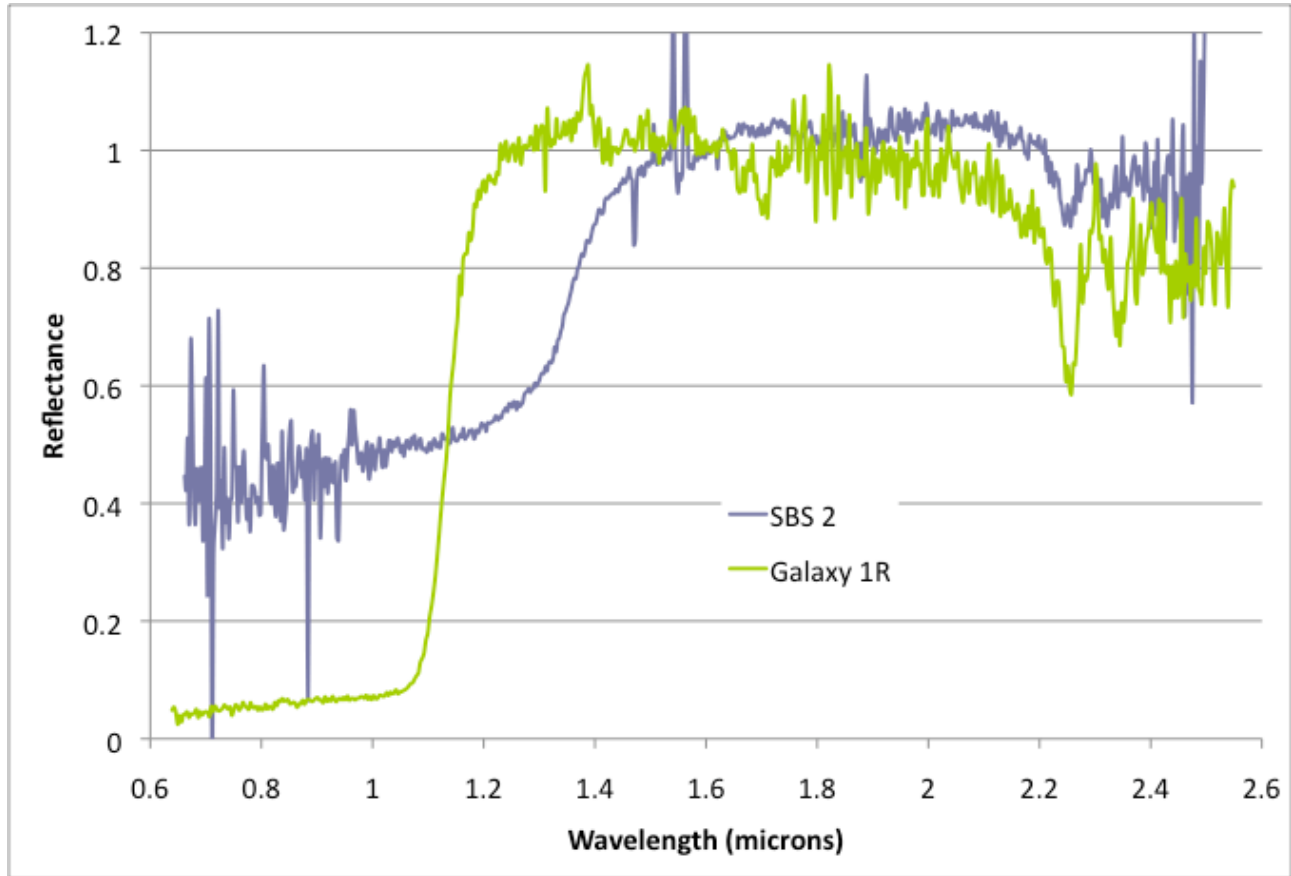

Fig. 2. Spectral comparison of SBS 2 and Galaxy 1R. Both spacecraft are currently uncontrolled, but were originally spin-stabilized with solar cells surrounding the body. These spectra are scaled to one at 1.6 microns.

Rocket Bodies

Spectra on three rocket bodies were collected for this project, two IUS upper-stages and one SL-12 rocket body, and are shown in Fig. 3. The material type of the IUS is known and consists of white paint, multi-layer insulation (MLI), and carbon-carbon epoxy while the surface properties of the SL-12 are unknown [5]. All three rocket bodies show a similar slope through all wavelengths; however, the two IUS rocket bodies show a C-H absorption feature near 2.3 microns that is consistent with white paint [1]. The SL-12 spectrum does not have this feature as is seen in Fig. 4. That would indicate that either the SL-12 was not covered with white paint or the paint has changed its surface properties due to aging.
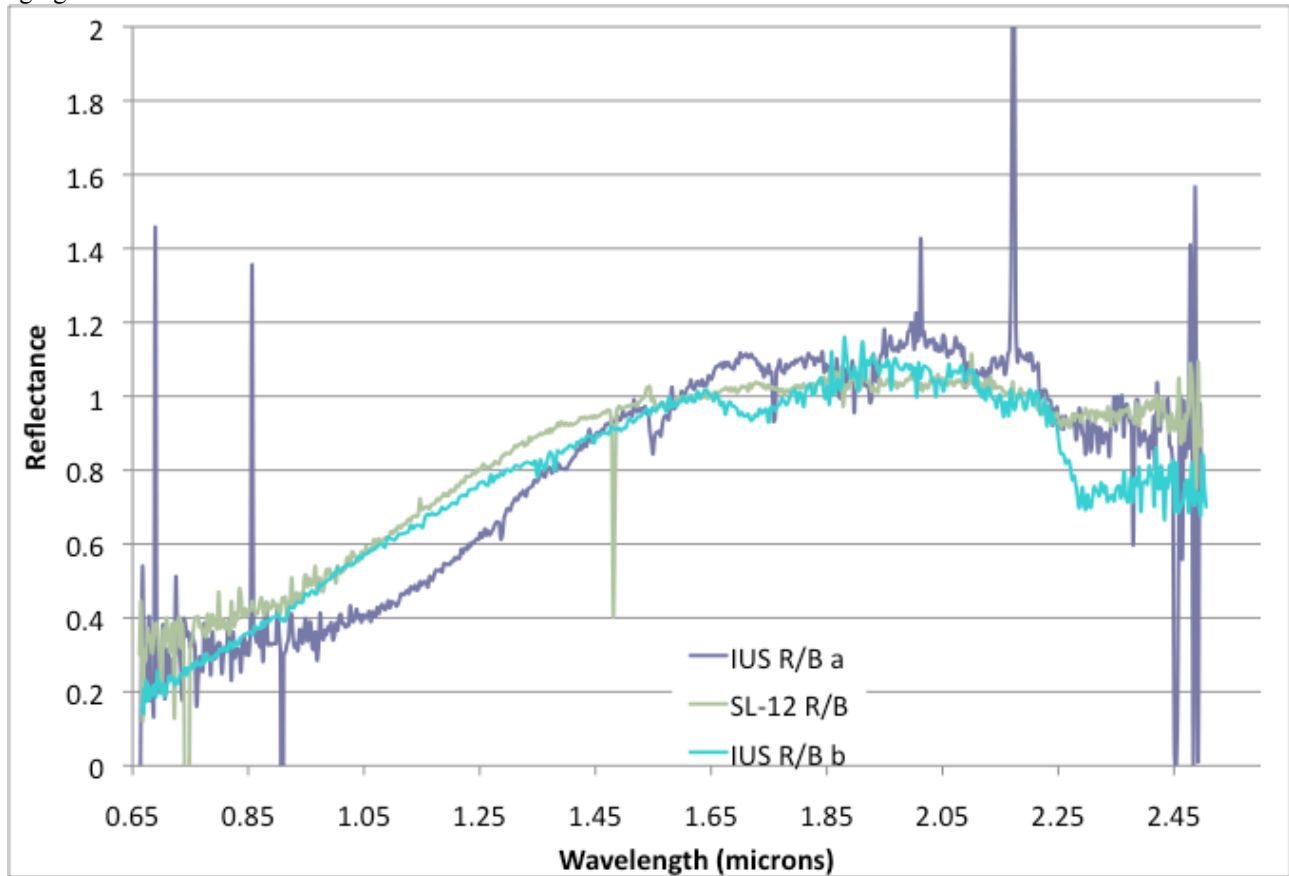

Fig. 3. Spectral comparison of two IUS rocket bodies and one SL-12 rocket body. The SL-12 spectrum has a similar slope to one of the IUS objects, however, has fewer features. The two IUS rocket bodies both have C-H features near 1.65 and 2.25 microns. These spectra are scaled to one at 1.6 microns.
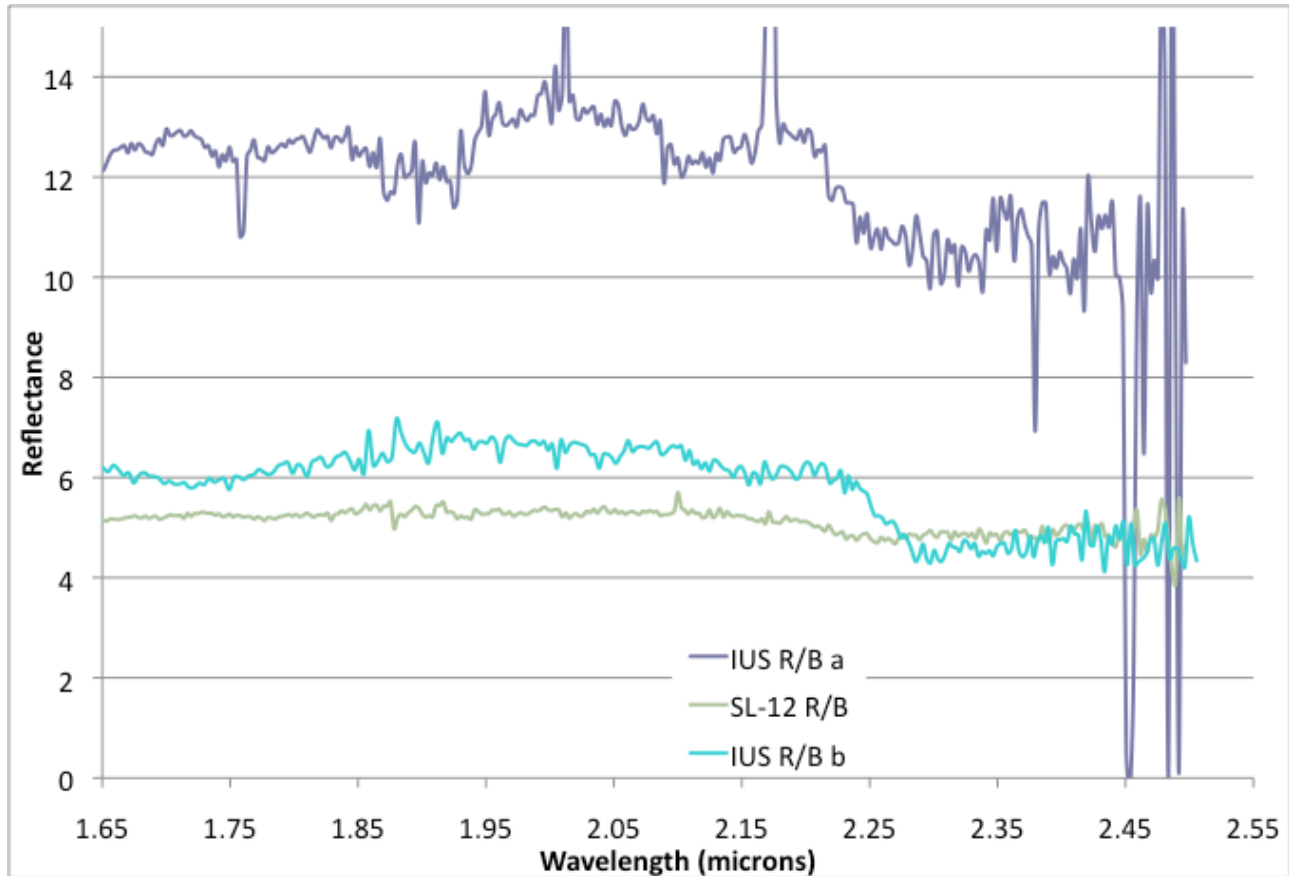
Fig. 4. Unscaled spectral reflectance of the rocket bodies with a smaller range to show that the SL-12 does not appear to have an absorption feature near 2.5 microns like the IUS R/B.

Combined Results

One object in each of the classes discussed above is shown for comparison in Fig 5. Although the dataset is limited at this time, the figure demonstrates that spectra can be potentially used to discriminate between the classes of objects in the orbital population. Each of the three classes of objects (spacecraft, rocket bodies, Titan debris) has a distinct spectrum. The rocket body and the debris both have increasing slopes through 1.5 microns; however, the rocket body spectra tends to flatten out at longer wavelengths, while the debris object spectra continues to increase with wavelength. The spacecraft spectrum has a distinct band gap near 1 micron, a feature which the other two objects do not have present in their spectra. The intact objects both show evidence of C-H absorption features at approximately 2.3 microns [1]. The C-H absorption feature is due to white paint in the case of the IUS and due to C-H bonds in the solar cell material believed to be in the substrate. However, their centers are slightly shifted from one another. This shift is also seen in the spectra of laboratory samples of white paint and solar cells, and is therefore not an effect of the space environment.
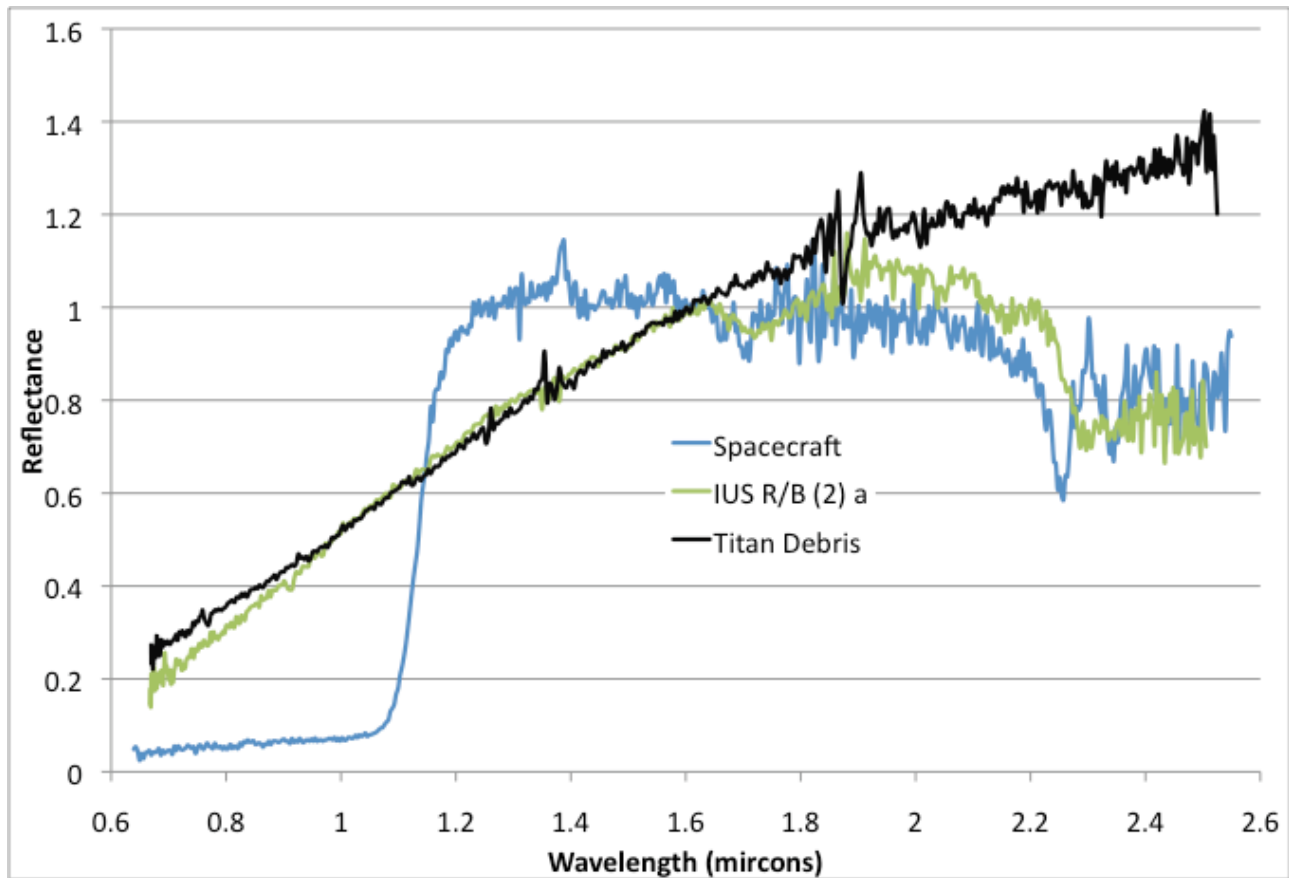
Fig. 5. Spectral comparison of a rocket body, spacecraft, and debris. Each has distinct features and components. These spectra are scaled to one at 1.6 microns.

CONCLUSIONS

By collecting data on different classes of objects, it is shown that the spectra can be used to determine the basic material types of the objects. Although the material type is still unknown for the debris pieces, it was shown that we can discriminate between debris from two different spacecraft. The spectra of the two Titan pieces have similar shapes, but they are very different compared to the COSMOS spectrum. Satellites with similar bus types have similar absorption features and spectral shape, although the solar panel band gap may be found at slightly different wavelengths. The rocket body spectra collected in this preliminary study showed similar slopes and shapes for both types of rocket bodies. However, the SL-12 did not appear to show evidence of white paint while the IUS had features consistent with this material. Therefore by comparing the slopes, shapes and absorption features of the spectra for each class of object observed, one can discriminate between the different classes of objects and even identify similarities between individual types of objects. Overall this project proved to be a success in its goal to determine the basic material type of the objects studied. Future work includes collecting more laboratory data in the infrared and the visible regime such that a larger database of remote spectral responses is available to compare to the orbital debris population spectra. If more materials are known, it will be easier to determine the material of a specific rocket body, spacecraft, or debris piece.

ACKNOWLEDGEMENTS

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