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Time-resolved visible/near-infrared spectrometric observations of the Galaxy 11 geostationary satellite

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Abstract

Time-resolved spectrometric measurements of the Galaxy 11 geostationary satellite were collected on three consecutive nights in July 2014 with the 1.6-m telescope at the Observatoire du Mont-Mégantic in Québec, Canada. Approximately 300 low-resolution spectra ($R \approx 700$, where $R = \lambda/\Delta\lambda$) of the satellite were collected each night, covering a spectral range between 425 and 850 nm. The two objectives of the experiment were to conduct material-type identification from the spectra and to study how the spectral energy distribution inferred from these measurements varied as the illumination and observation geometry changed on nightly timescales. We present results that indicate the presence of a highly reflective aluminized surface corresponding to the solar concentrator arrays of the Galaxy 11 spacecraft. Although other material types could not be identified using the spectra, the results showed that the spectral energy distribution of the reflected sunlight from the Galaxy 11 spacecraft varied significantly, in a systematic manner, over each night of observation. The variations were quantified using colour indices calculated from the time-resolved spectrometric measurements.

Keywords: Space Situational Awareness; Space surveillance; Spectrometric characterization; Photometric characterization; Geostationary satellites; Galaxy 11

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1. Introduction

Near-Earth Space is currently occupied by several hundred operational satellites. Unfortunately, several thousand pieces of space debris also orbit the Earth in various orbital regimes (Liou and Shoots, 2014). Some debris objects, such as spent rocket bodies and mission debris have well-documented origins and whose material composition can therefore be estimated with confidence. Conversely, there is no information pertaining to the origin, and therefore compositional make-up, of other types of space debris objects, such as the high area to mass ratio (HAMR) objects first identified by Schildknecht et al. (2005a,b). For these and similar classes of objects there is little or no information as to their origin and, by extension, their structure and composition. The ability to determine the surface material composition of such objects could allow for a more accurate estimation of their surface areas, masses, and densities, thereby providing analysts with better inputs for their orbital determination and prediction models.

From a defence and security perspective, the ability to inspect, verify the health status, and reliably confirm the identity of an active spacecraft, all in a passive manner, would provide powerful information that could be used by intelligence analysts in their task of providing the most accurate common operational picture of the space environment. Reflectance spectroscopy is an astronomical observational technique that could potentially be used to obtain this information.

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As part of our continuing project to systematically evaluate the capabilities of reflectance spectroscopy in the context of Space Situational Awareness (SSA), we present here a spectral analysis of the Galaxy 11 geostationary satellite using spectra collected with the 1.6-m telescope at the Observatoire du Mont-Mégantic in Québec, Canada on three consecutive nights in July 2014. In all, approximately 300 low resolution spectra (of resolving power $R \approx 700$, where $R = \lambda/\Delta\lambda$) of the satellite were collected each night, covering a spectral range between 425 and 850 nm. This observational experiment represents the first time that time-resolved visible near-infrared (VIS-NIR) spectrometric observations were obtained over the duration of a whole night for an active geostationary satellite.

1.1. Previous work

Astronomical geologists have successfully used reflectance spectroscopy to investigate the mineralogical composition of asteroids for more than three decades (Gaffey et al., 2002); however, the use of this technique to characterize artificial Earth-orbiting objects, namely active spacecraft and space debris objects, is still in its infancy. Some studies occurred sporadically prior to 2000 (Lambert, 1971; Prochko et al., 1994, 1995) and concluded, to varying degrees, that spacecraft could be characterized - i.e. that their gross structure and surface material composition could be inferred - based on their spectral signatures, though none of these early efforts led to well-established techniques.

More sustained efforts were conducted after 2000 when Jorgensen, 2000 proposed that remote spectroscopy could be used to identify the chief surface material contribution of artificial space objects into three broad categories: metals, plastics and paints. Between 2001 and 2009, remote spectrometric measurements of active satellites and space debris in the spectral range between 400 and 900 nm, were mainly acquired by two independent teams. The first team, led by Abercromy (née Jorgensen), collected spectrometric measurements of various spent rocket bodies and both inactive and operational satellites in various orbits using the 1.6-m telescope located at the US Air Force Maui Optical Site (AMOS) (Jorgensen et al., 2001, 2002, 2003, 2004a,b; Abercromby et al., 2005, 2006).

For Abercromby's experiments, a measurement at one grating setting was collected to obtain a spectral reflectance from approximately 400 nm to 700 nm. At a different time, which could be as much as one night later, a second measurement at a different grating setting was collected to obtain the measurement over the remainder of the band pass, from 600 to 900 nm. Exposure times were adapted such that an acceptable signal to noise ratio (SNR) could be obtained. Abercromby et al. primarily used exposure times ranging from 60 to 90 s for objects in or near the geosynchronous orbital regimes. During the data reduction and processing stage, the two measurements, corresponding to the complementary spectral ranges, were first normalized to the measured flux at a common wavelength and then combined to produce a single measurement with a wavelength range of approximately 400–900 nm.

Using this experimental method, Abercromby et al. concluded that objects of different design exhibited measurably different reflectance spectra and that the identification of material types was possible. In addition, Abercromby et al. noted that all of the collected spectra of artificial space objects, with the exception of those of a US Inertial Upper Stage rocket body (SCN 19970), showed an increase in reflectance in the wavelength range above 650 nm when compared to laboratory measurements. These authors mentioned that their reflectance spectra did not correlate to any specific characteristics of the observed objects, such as their age or orbital altitude. An attempt by Guyote et al. (2006) was made to explain this phenomenon, dubbed *the reddening effect*, yet none of the results convincingly explained the actual physical process causing it. To this day, this phenomenon was never quantified and has yet to be explained.

The second team, led by Schildknecht, used the 1-m European Space Agency Space Debris Telescope (ESASDT) between November 2008 and May 2009 to collect spectrometric measurements of space debris in or near GEO (Schildknecht et al., 2009). The observations were conducted with a low-resolution spectrograph and provided measurements covering a spectral range between 450 and 960 nm. The exposure time for observations was four minutes. In their observational experiment, Schildknecht et al. showed that their spectral measurements varied with illumination and observational geometry but an in-depth analysis of this variation was not provided. The authors also reported that the comparison of spectrometric measurements of space debris to spectra of material samples taken in a controlled environment was unlikely to lead to the characterization of material types found on the surface of an object, due to the large variations of spectral reflectance. The authors of this study did not comment on having observed the reddening effect that was consistently observed by Abercromby et al.

In 2012, Seitzer et al. (2012) reported another observational experiment in which they compared spectra from space debris in the GEO regime with laboratory measurements of typical spacecraft surface materials. A total of six space debris objects were observed over a two-night period using one of the twin 6.5-m Magellan telescopes at Las Campanas Observatory in Chile using the Low Dispersion Survey Spectrograph 3 (LDSS3) instrument. The debris spectra were then compared with spectra of spacecraft materials included in the NASA Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Spectral Library (Baldridge et al., 2009). In the end, the collected spectra did not match any of the laboratory spectra, preventing the authors from determining the surface composition of the space debris objects that were observed.

In 2014, Bédard and Lévesque (2014) conducted a laboratory characterization of an engineering model (EM) of

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