# Building a Laboratory Spectral Library of Spacecraft Materials in Vacuum at Variable Phase Angles

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## ABSTRACT

Reflectance spectroscopy has been used in the past to remotely identify materials on Earth[1] and other planetary bodies (Gaffey et al. 1989). In recent years, reflectance spectroscopy has been successfully applied to characterize Resident Space Objects (RSOs) (Battle et al. 2021). But these efforts are limited to silicon detector-based spectrometers (0.4-1.0 m).Withm). With more InGaAs and InSb-based spectrometers coupled with fast tracking telescopes coming online, there is an increased need for longer wavelength (out to ~5.0 m).Withm) laboratory spectral measurements of spacecraft materials to identify absorption bands and determine the optical properties of these materials. This longer wavelength range allows for better characterization of materials making up specific RSOs.

Telescopic spectral characterization of RSOs requires a strong laboratory component that studies material properties over a wide wavelength range in space-like (temperature, pressure, and phase angle) conditions to help interpret the data. To this end our spectroscopy laboratory is constructing a high vacuum chamber that will take reflectance measurements from 0.2-5.2 um at phase angles ranging from $140^o$ to $10^o$, and be able to cool samples to 77 K and heat them to 800 K. We are also creating a curated collection of materials both used on actual spacecraft, such as paint samples and analogs of such materials such as metal alloy pieces that conform to appropriate engineering standards.

Our vacuum chamber's wide spectral range (0.2-5.2 m).Withm) will be achieved using a combination of three spectrometers external to the chamber and three different types of fiber optic cables that are fed into the chamber. The fibers are attached to rotating arms that are controlled via servo motors to control phase angle. The main measurement chamber will be kept at a pressure below $10^{-6}$ torr. Samples used in this setup can be solids or powders and ideally have diameter of 2.5 cm and less than 1 cm thick of both artificial and natural materials. Reflectance measurements will be taken relative to two standards, Spectralon™ and diffuse gold. These will be mounted on a stage connected to a push pull rod and will move into the sample position when it is not there. There will also be a piece of Acktar Metal Velvet™ to provide a dark background and characerize any scattered light in the system at time of observation. In addition to light spectrometers we have incorporated a Residual Gas Analyzer for determining any outgassing components from samples. Such a device is useful in determining any chemical reactions that might occur during sample heating. This range of parameters largely replicates ground-based telescopes' viewing geometries and goes beyond the potential wavelength range of ground-based observations.

The University of Arizona Space Materials Curation Facility has been created to collect and archive samples of surplus spacecraft parts and analog materials. These include solar cells, thermal protection materials such as mylar, paints, metals,

and alloys. We have already collected spectra of 70+ such samples in ambient conditions and plan to add vacuum spectral measurements with our new vacuum chamber.

## 1.0 INTRODUCTION

Reflectance spectroscopy is a technique using the reflected light of an object at various wavelengths to determine its composition and material properties. It is unique among remote sensing techniques in that laboratory analysis will provide that the same spectra as remote observations of objects with a telescope. These techniques have been used in the past to map materials on Earth[1] and in the solar system [2]. More remote spectra of these objects are currently being created in the visible wavelength range [3] and select objects have had spectra taken out to the near infrared[4, 5] In laboratory measurements we are able to measure known materials, understand what wavelengths they absorb light at and use these known properties to determine what a remote object is made of. To this end we have begun work on a catalog of materials commonly used on spacecraft and rocket bodies, so that we can help to identify and finger print Resident Space Objects (RSOs). To better replicate conditions that RSOs are observed under we are constructing a vacuum chamber where phase angle and temperature can be varied across a broad range.

## 2.0 BACKGROUND

Reflectance spectra of materials can be used to identify specific materials based on absorption band position as well as overall reflectance curve shape and slope. Spectral shape will change based on substitution of different atoms within a molecular structure. With man made materials that are made to exacting specifications such as spacecraft materials, these become important identifiers. In addition to these items phase angle can also affect spectral slope of materials

## 3.0 IN ATMOSPHERE DATA COLLECTED

To be able to collect data under controlled similar conditions we have started a collection of common spacecraft materials that would appear on RSOs. These include metals, manufacturer paint samples, mylar and solar panel materials and the collection has grown to approximately 70 unique materials and paint samples. Here we present a select few of these spectra that have been taken in air show spectral effects of phase angle and to show the usefulness in spectroscopy of identifying and distinguishing materials.

Figure 1 below shows common metal alloys used on spacecraft. In it you can see the spectral differences, not just between steels, aluminum and titanium, but the differences between various allows of these metals. The two stainless steels show no real difference other than an albedo difference. On the other hand, Titanium Grade 2 and Titanium Grade 5 show a remarkable difference. Titanium Grade 5 shows much more similarities between it and aluminum, taking on the ~0.8μm band that aluminum has and the generally positive slope in the infrared. This is because aluminum is one of the alloying metals in Grade 5 Titanium making up 6% of the mass, vs Grade 2 which is 100% titanium.

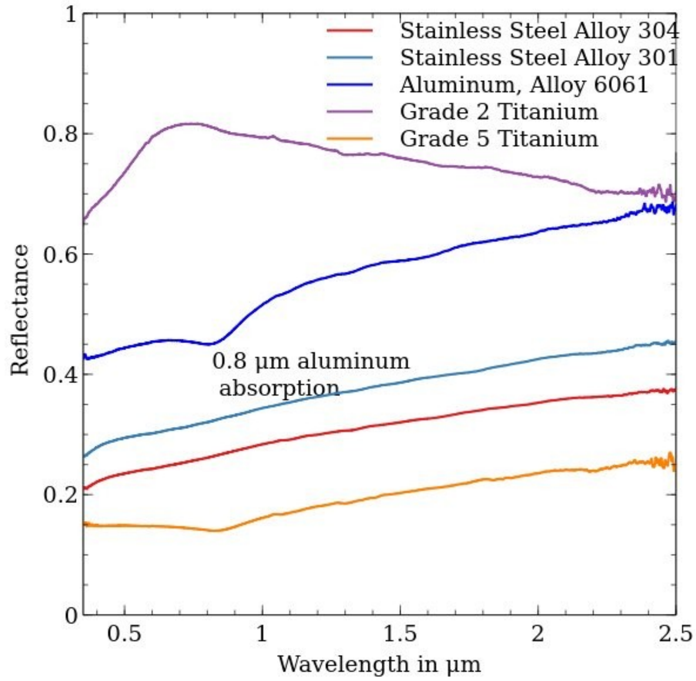


**Fig. 1.** Spectra of various common metal alloys used on spacecraft.

Sometimes spectral differences between alloys are much more subtle. In Figure 2 we show various aluminum alloys. While the 0.8um band is still there it shifts with 1100 Aluminum (99% aluminum) having a minima at 0.814µm, 5052 Aluminum having a minima at .801µm , 6061 Aluminum shifting further to 0.798µm. In addition in the infrared the 3 alloys show different spectral slopes. Both of these features could be used to finger print or even identify RSOs. Note that in many silicon based spectrometers on telescopes the only the 0.4-0.8µm region is measured due to atmospheric absorption in the ultraviolet and detector sensitivity being low in the infrared. More telescopes are being equipped with infrared spectrometer that will be able to reach 2.5µm and further.

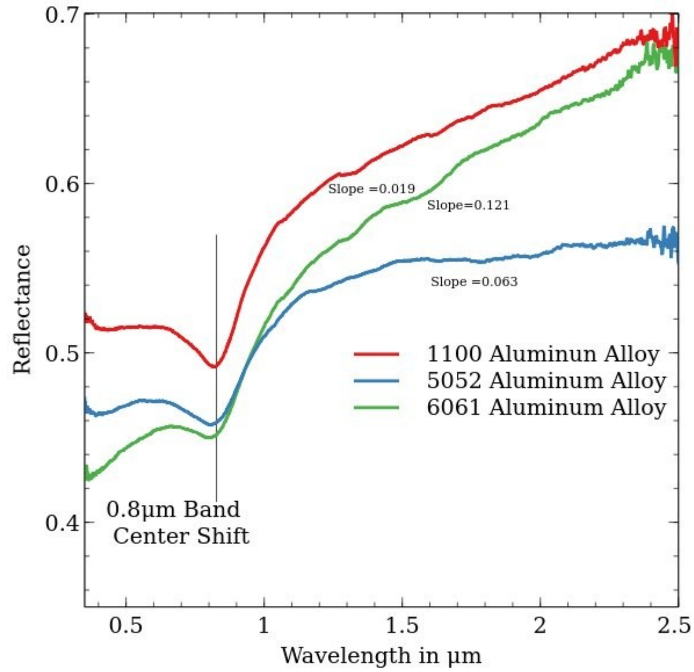


**Fig. 2.** Spectra of aluminum alloys with identifying features labeled.

Various paint samples have also been measured in atmosphere. Figure 3 shows two white paints. These two samples show very different spectral changes in the infrared. AZ-93 is a zinc oxide paint, while AZJ-40-20 is a rubberized coating. AZ-93 shows absorptions at 1.4µm and 1.9µm indicative of hydroxyl, while AZJ-40-20 shows absorptions at 1.13µm, 1.7µm and 2.25µm all indicative of carbon-hydrogen bonds common in rubber and other organic materials.

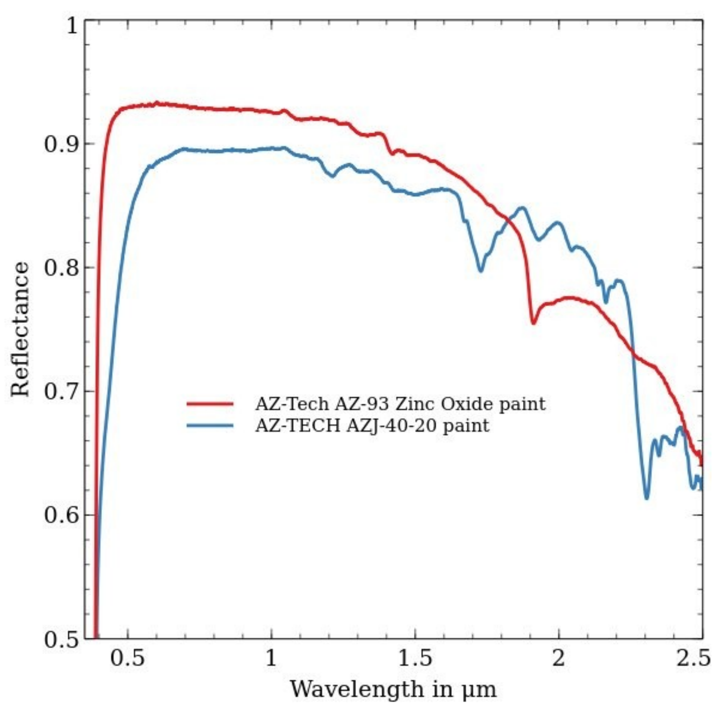


**Fig. 3.** Spectra of various paint samples used on rocket bodies

In general spectra are valuable tools for distinguishing materials.  Building a spectral library covering a broad wavelength will provide better identification of materials Resident Space Objects are made of.

## 4.0 VARIABLE PHASE ANGLE VACUUM CHAMBER

To better replicate conditions RSOs are observed in we are currently constructing a vacuum chamber that can measure materials from 0.2-5.1μm.  The chamber will be equipped with 3 spectrometers cover 3 spectral ranges, these will be a silicon grating spectrometer covering 0.2-1.1μm, a grating spectrometer with 3 detectors, with detector ranges covering 0.35μm-1.0 (UV-Vis spectrometer), 1.0-1.8μm and 1.8-2.5μm (Vis-Nir spectrometer)  , and a fourier transform spectrometer covering ranges 2.0-5.1μm.  The overlapping ranges of the spectrometers will provide verification of results between different detector ranges.  Each spectrometer will have a corresponding light source, tuned to the specific range of each spectrometer.  The three spectrometers and light sources will be equipped with three different fiber types, low OH silica polymide,  high OH silica polymide, indium fluoride that will feed through the vacuum chamber to rotating arms.  These arms will allow us to vary the phase angle of measurements on materials.  Multiple fiber types are needed because each type is more or less transmissive in different wavelength ranges.  The chamber is equipped with an interlock chamber that will allow degassing of materials in a low vacuum before passing in the high vacuum portion of the chamber.  Inside the high vacuum portion of the chamber the sample with sit on a heated and cooled stage that will cover the range of 77K to 800K in temperature.  In addition to reflectance spectrometer the chamber is equipped with a residiual gas analyzer to determine in outgassing of samples, and a high precesion ionizing pressure gauge.  This chamber and an number of the instruments are show in Figure 4 below.

Fig 4: The side view of the phase angle vacuum chamber, with numbers labeling major components. 1. is the main chamber, 2. is a 10in. Access port. 3. is the ultrahigh vacuum Pump, 4. is the combined visible and deuterium lamp. 5. is the residual gas analyzer, 6. is the Vis-NIR spectrometer, 7. is the FTIR, 8. is the vacuum gauge, 9 is the gate valve for sample entry.

## 5.0 CONCLUSIONS

Reflectance spectroscopy is a powerful tool for identifying materials. For best identifications a broad library of laboratory spectra are needed. To this end we are constructing a vacuum chamber to replicate the observations conditions Resident Space Objects exist in.

## 6.0 REFERENCES


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