LASER-BASED NON-DESTRUCTIVE ANALYSES OF THE TAGISH LAKE METEORITE IN A CONTROLLED ENVIRONMENT FOR FUTURE STUDIES OF ASTEROID RETURN SAMPLES.

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Introduction: A small 30 x 30 cm environmental chamber has been built in the Planetary Exploration Instrumentation Laboratory at York University to conduct temperature and pressure controlled laser-based analyses of the Tagish Lake meteorite in preparation for the return of samples from missions such as the OSIRIS-REx sample return from asteroid 101955 Bennu scheduled in 2023. These sample return missions can only bring back a small amount of material (on the order of 10s of grams to a few kilograms) therefore, we must understand and fulfill the preservation needs of these pristine, sensitive materials once returned to Earth [1]. These samples must be preserved to our best ability in optimal storage conditions and, through the use of an environmentally controlled chamber, during analysis. With our technique, sensitive samples can be transferred from cold storage to the pressure and temperature controlled chamber to undergo preliminary compositional mapping techniques using laser-induced fluorescence (LIF) and Raman spectroscopy. These techniques 're-motely' identify and quantify mineral and organic constituents within the sample using stand-off laser interrogation, without changing the optimal environmental conditions for prolonging the integrity of the sample. We will demonstrate the efficacy of this technique with the Tagish Lake meteorite. Furthermore, the chamber is capable of varying temperature and pressure conditions and therefore can be used for volatile experimentation when attached to a mass spectrometer. This type of preliminary, non-destructive analyses provides a measurement of mineral and organic constituents and their distributions without destroying or altering highly sensitive samples. Currently, some of the most widely used techniques for geochemical and crystallographic analyses (SEM, EDS, EPMA, XRD, FTIR) require sample preparation or destruction. These techniques will inevitably be used on samples returned from asteroid missions due to their robust qualitative and quantitative results, however our type of preliminary analysis can also aid in locating small areas of interest for these future destructive analyses, therefore preserving more sample for future techniques.

Carbonaceous chondrite meteorites originating from asteroids similar to that of Ryugu or Bennu, provide clues to the development of life on Earth. Carbonaceous chondrites are pristine, chemically primitive, meteorites that are considered to be the leftover building blocks from our solar system's formation. They have been found to have a pre-solar composition and contain non-terrestrial carbon content in the form of inorganic carbon structures (e.g. graphite) and in organic carbon molecules such as amino acids, amines, and carboxylic acids [2-5]. In order to develop the methods required for the analysis of returned asteroid samples, it is important to validate the methodology using samples that are as similar to that of carbonaceous asteroids. The Tagish Lake meteorite is the most suitable sample for this study as it is an ungrouped carbonaceous chondrite that was studied extensively shortly after its fall and collection from a frozen lake in British Columbia, Canada in 2001 [6]. After the observed fall, samples of the meteorite were collected and immediately transported to institutions with deep freezers. Some of these samples, including one preserved at the Royal Ontario Museum, have been frozen and relatively undisturbed since 2001. Studies have provided information on the ideal collection and cold storage conditions for this meteorite [7]. Many techniques for identifying organic and mineral constituents within terrestrial and non-terrestrial rock material require sample destruction (digestion, crushing/powdering) or at a minimum some sort of sample preparation (sectioning, polishing, carbon or gold coating, etc.) We propose that these samples can be analyzed in a non-destructive manner while maintaining similar conditions to that of storage using a non-destructive laser-based system. Thus, we can understand the organic, mineral and volatile constituents and their locations within the sample without degrading the sample quality.

Materials and Methods: The chamber is a stainless steel construction and has a 15 cm diameter vacuum compatible door for easy sample placement. A large (20 cm diameter) sapphire window was installed on the top of the chamber to allow UV spectral investigation and viewing of the sample below. A Peltier cooler is installed within the chamber with a thermocouple and digital temperature controller to maintain a consistent temperature of -10 °C. In order to keep the Peltier device cool, good thermal contact is made between the conductor and a water-cooled heat sink chilled to 10 °C. This heat sink will also maintain a warmer temperature for two motors with a travel range of 2.7 x 2.7 cm in X-direction and Y-direction which has the Peltier conductor and sample stage mounted on top.

Pristine samples of the Tagish Lake meteorite (both frozen sample and prepared sample) are provided by the Royal Ontario Museum Department of Natural History, Mineralogy. 'Pristine' samples of the Tagish Lake meteorite were transported frozen to Toronto where they are stored at the Royal Ontario Museum in a deep freezer. The prepared sample of Tagish Lake is not frozen and has been processed into a thin section for previous analyses.

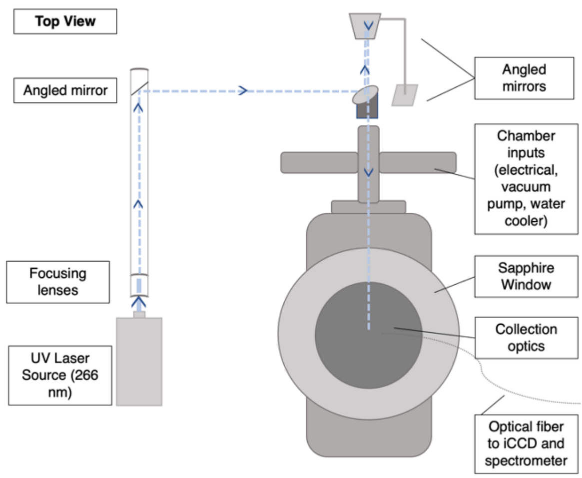

Figure 1. *Top-down schematic of table-top vacuum chamber setup at York University. Laser line shown as dotted line as it is traced from the laser source to the sapphire window where it is reflected down to the sample in the chamber.*

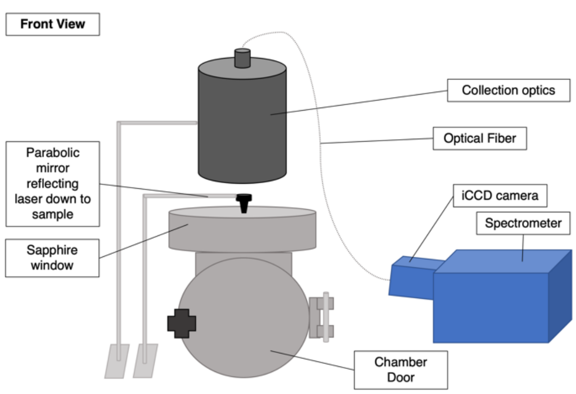

Figure 2. *Front view of vacuum chamber showing collection optics and fiber entering iCCD and spectrometer.*

These samples will be placed within the chamber and analyzed using UV-LIF spectroscopy including time-resolved fluorescence spectroscopy and Raman spectroscopy mapping techniques using a Andor Solis Shamrock spectrometer (SR-193i-B2) coupled to an iCCD (intensified charge-coupled device) camera with gating capabilities. Time-resolved fluorescence spectroscopy provides a unique 3D spectral analyses in which organic and mineral material are easily identifiable from each other based on their fluorescence decay rates (intensity at a specific wavelength over time).

Significance: The spectral maps will provide a visual representation of the distribution of minerals and organic material within the Tagish Lake meteorite. Using the chamber with specific temperature or pressure as well as these laser techniques we can create methodology for preliminary analyses of sensitive materials, such as samples returned from the OSIRIS-REx mission. These preliminary analyses of composition and areas of organic interest will allow researchers to better understand which specific samples or areas of samples need to be further analyzed using more destructive techniques, while preserving the greatest amount of sample possible. Controlling the sample environment while doing these preliminary analyses aids in the preservation of these sensitive materials for other analyses and for future generations when new technologies and techniques are created.

References: [1] Lauretta, D. S., et al. (2017). *Space Science Reviews*, *212*, 925–984. [2] Pizzarello, S. (2001). *Lunar and Planetary Institute Conference Abstracts*, Abstract # 1886. [3] Pizzarello, S., et al. (2001). *Science, 293*, 2236-2239. [4] Nakamura-Messenger, K., et al. (2006). *Science. 314*, 1439-1442. [5] Yabuta, H., et al. (2010). *Meteoritics and Planetary Science*, *45*, 1446–1460. [6] Hildebrand, A. R., et al. (2006). *Meteoritics and Planetary Science*, *41*, 407–431. [7] Herd, C. D. K., et al. (2016). *Meteoritics and Planetary Science*, *51*, 499–519.