Beyond the Diffraction Limit: Shedding Light on a 4.6 Billion Year-Old Question. C. J. Bennett[1,2,3], B. Ferrari[3], A. LeBleu-DeBartola[3], L. Tetard[3], A. Schulte[3], D. Britt[1,3], [1]Center for Lunar and Asteroid Surface Science (CLASS, PI: Dan Britt), [2]Radiation Effects on Volatiles and Exploration of Asteroids and Lunar Surfaces (REVEALS, PI: Thom Orlando), [3]Department of Physics, University of Central Florida, Orlando, FL (Christopher.bennett@ucf.edu).

Introduction: Extraterrestrially delivered carbonaceous chondrites, which represent approximately 4% of meteorite falls, are thought to be precious time capsules, whose contents may be representative of the primordial matter from which the Solar System formed. Many of these, particularly the less altered CI, CM and CR types, often contain high levels of amino acids detected, with some even reaching levels of up to parts-per-thousand levels. The extraterrestrial delivery of organic material and water through both cometary and asteroid sources is thought to have been considerable, just prior to the earliest signatures of life found on Earth. Therefore, understanding the origin and evolution of amino acids within these bodies could have significant implications for the origin of life on Earth, as well as the likelihood of finding life elsewhere in the Solar System, or beyond.

Recent experiments simulating the primordial Earth environment indicate that when amino acids are heated in the presence of hydroxy acids (also abundant within meteorites), and minerals, the formation of peptide bonds becomes facile, particularly at temperatures over 100 °C. Although it is uncertain the degree to which such conditions would have been prevalent on the primordial Earth, many classes of carbonaceous chondrites would have provided favorable conditions whereby we would expect any amino acids present to polymerize into peptides. Therefore, the degree to which amino acids were present, or formed within the carbonaceous chondrites, as well as their subsequent evolution to potentially form peptides, is largely unknown.

In addition, the majority of analyses that focus on detecting amino acids present within carbonaceous chondrites require acidic conditions, which would break down peptide bonds. However, several recent infrared studies as well as time-of-flight secondary ion mass spectrometry (ToF-SIMS) studies have indicated that peptides are indeed present, and in fact, the majority of amino acids may be found as peptides in some cases.

Moreover, carbonaceous chondrites exhibit incredibly heterogeneous compositions which chance considerably on the nm-scale (Figure 1) and therefore, it is crucial to try to understand not only where amino acids versus peptides may reside, but also provide information on context such as the mineralogy as well as the temperatures that these bodies were exposed to. Unfortunately, due to the diffraction limit ($\lambda/2$), it has not been possible to use spectroscopic techniques to identify the spatial location of amino acids since the wavelengths where peptide and free amino acid spectral signatures would have associated spot sizes several times the size of Figure 1.

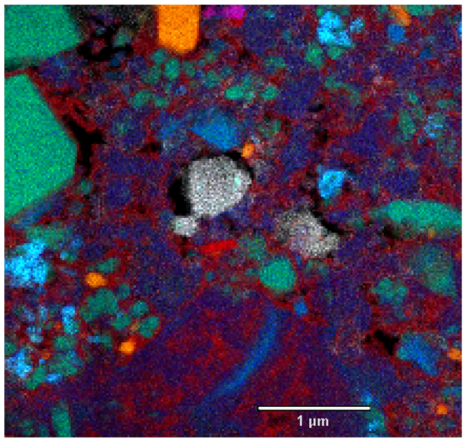

Figure 1: Transmission Electron Microscope Energy Dispersive X-ray Spectroscopy (TEM-EDS) image from the Murchison (CM2) Meteorite.

Experimental and Results: Here, we report on some preliminary results analyzing these samples utilizing nanoIR and nanoRaman techniques capable of achieving spatial resolutions down to 10-20 nm. Analysis utilizing these techniques has led to some novel sample preparation protocols. We present the results of these non-destructive techniques along-side analyses performed utilizing more traditional but destructive techniques such as SEM/TEM-EDS and ToF-SIMS. We also present the results in context of the peak metamorphic temperatures that these samples have been exposed to, as determined from Raman spectroscopy. We will briefly discuss the implications of these preliminary results.