THE COMPOSITION AND EVOLUTION OF THEMIS AND BEAGLE ASTEROIDS. H. M. Kaluna[1] and S. J. Bus[2] and J. J. Gillis-Davis[1] and P. G. Lucey[1], [1]Hawai'i Institute for Geophysics and Planetology, University of Hawai'i, Honolulu-HI-96822 [2]Institute for Astronomy, University of Hawai'i, Honolulu-HI-96822.

Introduction: Space weathering processes, which modify an airless body's surface with time, reduce our ability to accurately assess the mineralogy of asteroids and match them with meteorite analogs. Therefore, it is critical to understand how space weathering processes affect asteroid spectra, and how features are affected in order to better constrain the composition of asteroids and other small bodies. We combine laboratory experiments on carbonaceous chondrite (CC) materials with VNIR observations of asteroids from the Themis family and its younger sub-family, the Beagle asteroids, to gain a comprehensive view of the composition and spectral evolution of carbonaceous asteroids.

Experimental Methods: Using pulsed laser irradiation, we simulate micrometeorite bombardment-induced space weathering of a Mg-rich serpentine (lizardite) and an Fe-rich aqueously altered mineral assemblage (cronstedtite, pyrite and siderite).and compare the results to weathered olivine. Each mineral was crushed and dry-sieved to <75 µm and irradiated with a 1064 nm pulsed laser. The minerals were crushed and dry-sieved to <75 µm and irradiated with a 1064nm pulsed laser. The laser was pulsed at a rate of 20Hz and the incident laser energy was 30mJ per pulse. A 6-8 nanosecond pulse duration was used to simulate the timescale of a ~1 micron sized micrometeorite dust impact at 1 AU [1]. The samples were irradiated at various intervals for a total of 40 minutes at 20Hz. The minerals were irradiated for a series of intervals, with a total irradiation time of 40 minutes. Samples were irradiated as uncompressed powders and under vacuum pressures of 1.0E-5 to 1.0E-6 mbar. Three 0.5g aliquots of each mineral/mineral assemblage were irradiated. Following each irradiation, the samples were removed from the vacuum chamber for spectral measurement.

Experimental Results: The lizardite spectra became redder with increased irradiation. Although lizardite shows little to no changes in albedo, laser irradiation results in a smaller reduction in band depths at longer wavelengths (Figure 1). In contrast, the Fe-rich assemblage initially reddens then become bluer as irradiation time increases. Unlike the lizardite, which has a large suite of absorption features, the Fe-rich assemblage has a broad, shallow drop in reflectance centered near 1.5um which does not vary significantly with irradiation time. However, an absorption feature near 2.35um does decrease with increasing laser irradiation.

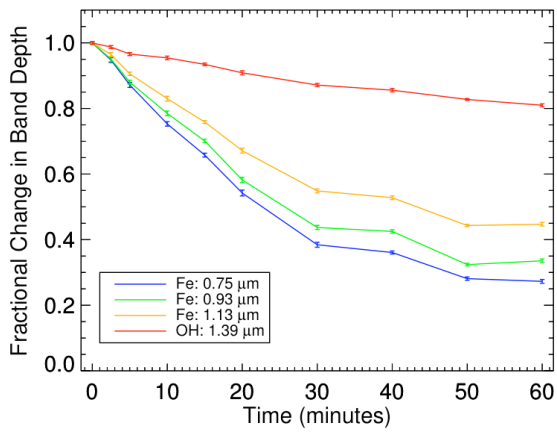

Figure 1: Lizardite absorption band reduction as a function of laser irradiation and wavelength.

Observational Methods: We obtained simultaneous visible and NIR broadband photometry for 22 Themis and Beagle family members with the 3.0 m NASA IRTF. Observations of Themis members were limited to members with similar diameters as the Beagle asteroids (<15 km) to avoid potential size related variations [2,3]. Near-infrared J, H and K-band photometry was obtained using Guidedog, the SpeX instrument guider camera. In addition, SDSS r'-band photometry was simultaneously acquired using the MIT Optical Rapid Imaging System (MORIS) instrument. The telescope was dithered between exposures to allow for sky background removal in the NIR images. Non-sidereal guiding was used during asteroid observations and exposures were limited to 180-250 seconds to avoid saturation in the NIR exposures. We used a 5-point dither script to get 5 images per filter set, which were averaged and divided by nearby G2V solar analog stars to produce 4-color reflectance spectra for each asteroid.

Comparison with RELAB Spectra. To probe the compositions of the observed Themis and Beagle asteroids, we compare our VNIR data to meteorite and mineral spectra from the NASA RELAB facility [4]. We use the RELAB spectral reflectance values at 0.62, 1.25, 1.64 and 2.15um in order to derive χ^2 values and determine which RELAB spectra fit the Themis and Beagle data. When possible, we combine our VNIR photometry with visible spectroscopic data obtained with the Subaru telescope [5] to further constrain the fits between the IRTF and RELAB spectra. Figure 2

shows the top four matches for both a Themis and Beagle family member.

Observational Results: The VNIR data of the Themis and Beagle asteroids both show a variety of spectral shapes. Almost all of the 4-color spectra show a broad absorption feature centered near ~1.25 um or a continuus drop in reflectance beyond ~0.7um. The same set of spectral shapes seen in the Themis asteroids are also evident in the Beagle asteroids. The spectral shapes in our data are consistent with previous observations of Themis asteroids [6,7]. While spectral variations have been observed in the visible region of Themis and Beagle asteroids, we do not see a significant difference in the depths of the broad NIR absorption band between these two families. The faint nature and thus low S/N of our targets in the NIR prevents us from accurately characterizing any subtle differences that may be present between the two asteroid families.

Comparison with the RELAB spectral library reveal that the Themis and Beagle VNIR spectra are commonly matched by CM-unusual (thermally metamorphosed) metoerites such as Y-86720. The association between C-complex asteroids and CM-unusual meteorites has also been observed in previous work (e.g. [7,8]).

Discussion: Spectroscopic data of the Themis and Beagle asteroids at visible wavelenghts show an increase in spectral slopes with age [5]. However, our VNIR data suggest that the NIR region of these asteroids is dominated by broad absorption features. Additionally, our experimental data reveal that space weathering will result in a decrease in absorption bands among carbonaceous materials, even out to NIR wavelengths. Thus, the spectral reddening observed in the Themis and Beagle asteroids may not be the result of continuum evolution, but rather a decrease in band depths with age.

It is important to highlight that our Themis and Beagle data are consistent with CM-unusual meteorites that show evidence of aqueous alteration followed by thermal metamorphism [7,9]. Thermal metamorphism is expected to result in the reduction and loss of 0.7um phyllosilicate features [9]. Interestingly, visible spectra of the Beagle asteroids show little evidence of a 0.7um absorption feature [5]. The lack of 0.7um features and the spectral matches presented here suggest the Beagle parent body originated from a region of the Themis parent body that experienced aqueous alteration and subsequent thermal metamorphism.

These data have important implications on the possible association of the main-belt comet 133P/Elst-Pizarro with the Beagle family. The dynamical association of 133P with the Beagle asteroids is uncertain [10]. Thus our data further highlights the tenuous nature of 133P's dynamical association with the Beagle family.

Conclusion: NIR photometry is ideally suited for small asteroids when NIR spectroscopy is not viable due to their faintness. Our data show that pairing experimental data with VNIR spectrophotometry provides a powerful tool study the composition and characterize the evolution of small carbonaceous asteroids.

References: [1] Yamada M. et al. (1999) *Earth, Planets and Space, 51,* 1255. [2] Florczak M. et al. (1999) *A&A Suppl. Ser.* 134, 463-471 [3] Fornasier S. et al. (2014) *Icarus, 233,* 163-178. [4] Pieters C. (1983) *J. Geophys. Res.* [5] Kaluna, H. M. (2016) *Icarus, 264,* 62-71. [6] Marsset M. (2015) *A&A Proofs* http://dx.doi.org/10.1051/0004-6361/201526962 [7] Clark et al. (2010) *J. Geophys. Res.* 115, E06005 [8] Hiroi T. et al. (1996) *Meteorit. Planet. Sci*, 31, 321-327 [9] Cloutis E. A. et al. (2012) *Icarus,* 220, 586-617 [10] Nesvorny D. et al. (2008) *AJ,* 679, L143-L146

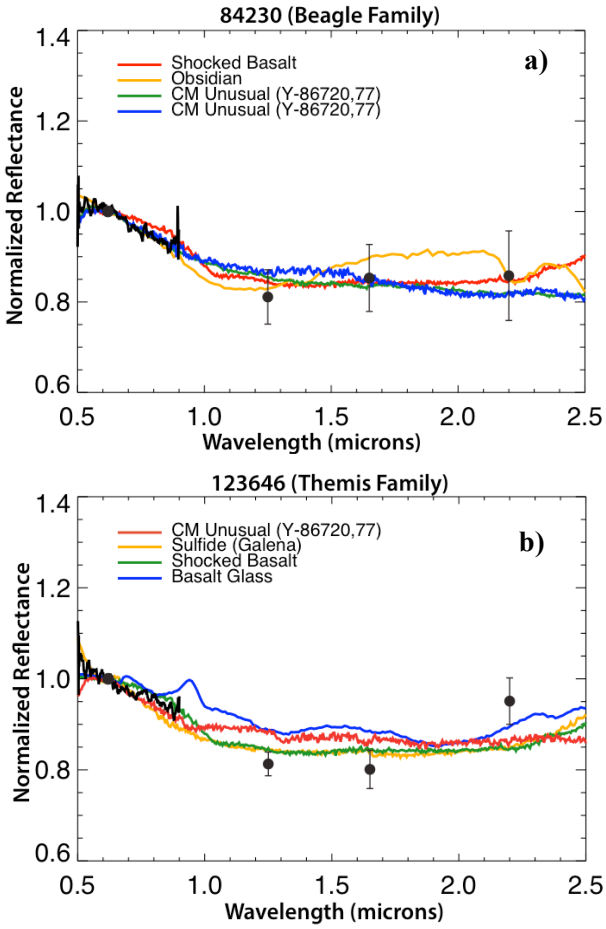

Figure 2: Best fit RELAB spectra using Subaru optical spectra and IRTF VNIR 4-color spectra (both shown in black). a) Beagle family asteroid 84230. b) Themis family asteroid 123646.