THE HYDRATED MINERALOGIES OF THE LARGEST ASTEROIDS A. S. Rivkin[1], J. P. Emery[2], E. S. Howell[3] [1]JHU/APL, Laurel MD USA, andy.rivkin@jhuapl.edu, [2]U. Tennessee, Knoxville TN, USA, [3]U. Arizona, Tucson USA.

Introduction: There is evidence that the largest asteroids are different from the smaller ones. Collisional evolution models suggest that objects above 100 km or so are overwhelmingly likely to remain intact through solar system history, while those below roughly 50 km are likely to be a fragment of a once larger object [1]. Recent planetesimal creation and evolution models suggest that asteroids were "born big", going straight from mm-scale particles to objects 100 km in size or larger [2].

Only 28 objects in the present-day asteroid belt have diameters of 200 km or larger, with two additional large objects disrupted to form the Themis and Eos families. The list of the largest asteroids is dominated by low-albedo objects. Only 6 of the 28 objects have albedos higher than 0.10, and one of them is 2 Pallas (which has an albedo very close to that threshold and belongs to a taxonomic class typically included among the low-albedo groups). The remaining 22 objects are split fairly evenly in terms of taxonomic class between the Ch/Cgh class (6 objects), the B or Cb class (5 objects), the C class (6 objects), and classes in the X-complex (5 objects).

We report new observations in the 3-µm region that, together with published work, provide insight into the hydrated mineralogy of all 28 objects in the present-day asteroid belt larger than 200 km.

Observations and Data Reduction: The new observations, as well as many of the observations in the literature, are part of the L-band Main-belt and NEO Observing Program (LMNOP) [3,4], and include 78 observations of 21 different objects. All LMNOP objects were observed using the SpeX instrument in LXD mode on the NASA IRTF [5]. Obviously, many of these targets were observed multiple times. Data reduction followed the standard procedures, using software provided by the IRTF and its staff [6]. Thermal flux was removed from the asteroids using a variant of the standard thermal model, again following a typical procedure.

Diversity of Band Shapes: As a general rule, the objects in the sample all have some measurable absorption in the 3-µm region. For the S class asteroids and Psyche, the band depth is typically 3% or less. Band depths for the low-albedo objects are more typically 10% or higher. Though no formal taxonomy for asteroid spectra has yet emerged for data beyond 2.5 µm, informal classification schemes have been used for a few years [7,8]. Following the example of [8], we denote the groups of major spectral shapes in the 3-µm region with the names of "type asteroids": Pallas, Ceres, Themis (Figure 1). By inspection, the large, low-albedo asteroids have a variety of these band shapes, with 4 Ceres-type objects, 10 Pallas-type objects, and 6 Themis-type objects in the group for which band shapes can be discerned.

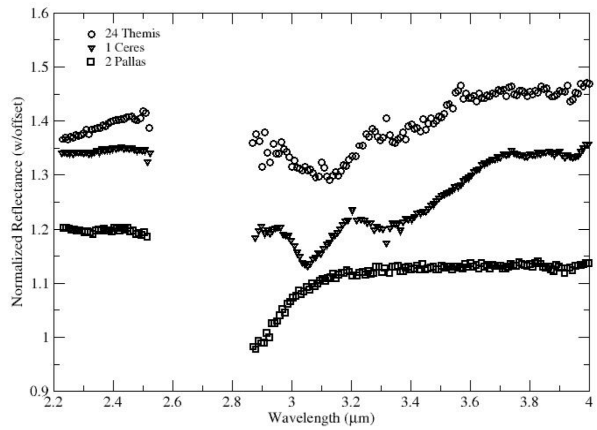

Figure 1: The three main spectral types in the 3-µm region for low albedo asteroids as considered today, named for their type examples.

Band Center Trends: The Pallas-type asteroids are distinguished by band minima in the region between 2.5—2.85 µm, thought to be due to OH in phyllosilicates and in an wavelength region dominated by atmospheric water and very difficult to measure from Earth.

The Ceres- and Themis-type asteroids have band centers that are much more accessible from ground-based telescopes. We do not see asteroids with absorption bands centered between 2.85—3.04 µm, but we see a variety of band centers at longer wavelengths. Figure 2 shows a histogram of preliminary measurements of band centers, with concentrations near 3.05 and 3.12-3.15 µm but also no clear divisions between those peaks. In addition, some objects have their strongest absorptions at still-longer wavelengths, suggestive of organic materials rather than hydrated silicates or water ice. We note that these band centers were determined by making polynomial fits to the spectra from 2.9-3.4 µm, and it is not yet clear how robust these fits are for particularly noisy data.

Figure 3 demonstrates with higher-quality data that a continuum seems to exist in spectra from objects that are more similar to ice frost to those that are at least qualitatively similar to comet 67P.

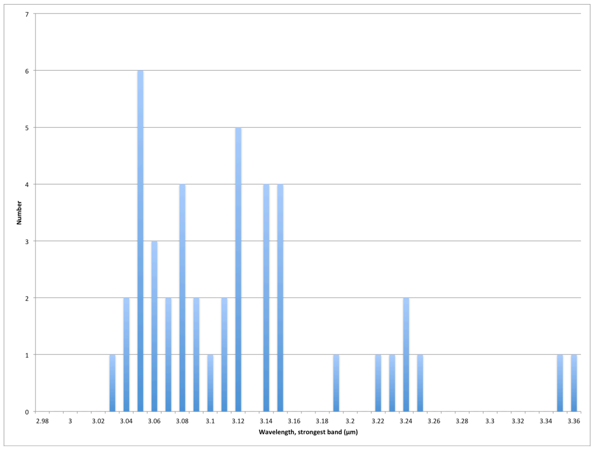

Figure 2: Band centers of non-Pallas-type spectra. These were determined by making 6th-order polynomial fits to the 2.9-3.4 μm spectra, strictly for the purposes of determining the band shape. A variety of band centers are seen.

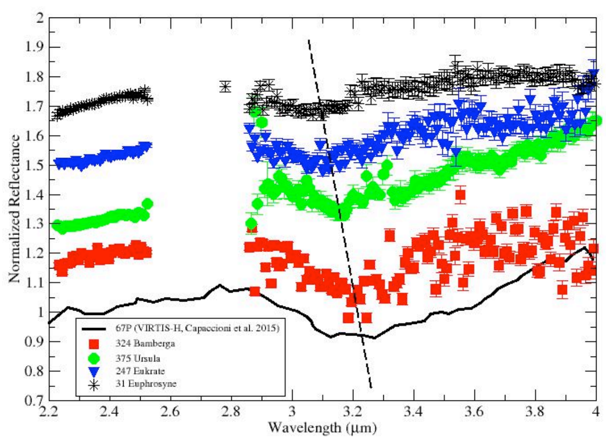

Figure 3: Low-albedo asteroids are found with a variety of band centers in the 3-μm region. There is evidence that there may be a continuum of band centers between the Themis-type asteroids and comets lke 67P (solid line).

Spectral Variation on Individual Objects: Finally, our repeated observations show that some targets have spectra that vary from observation to observation. Some of this may be typical observational uncertainty, but other variation appears to be due to actual spectral differences across the target body. Supporting evidence for this is the stability of some objects with repeated observations (for instance, 2 Pallas).

As an example, Figure 4 shows several observations of the large C-class asteroid 324 Bamberga. Observations centered in its southern hemisphere appear to have relatively muted spectral features in the 3-μm region, while those of its northern hesmiphere have deeper, more dramatic absorptions. This pattern is seen in data from the LMNOP but also is consistent when adding additional data from other sources [7,9].

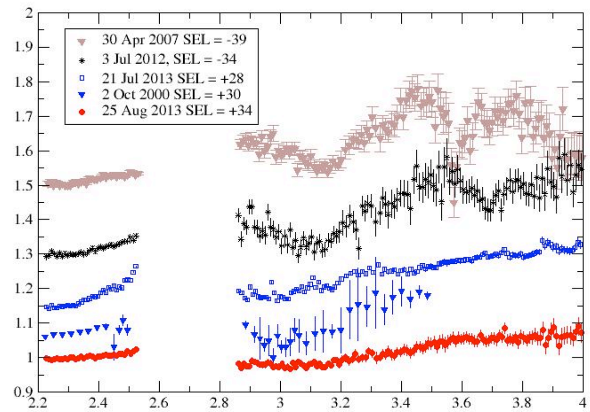

Figure 4: Reflectance spectra of 324 Bamberga, offset from one another. Observations centered in the northern hemisphere (2000, 2013) show relatively subdued absorptions, while those of the southern hemisphere (2007, 2012) show deeper absorptions and features at longer wavelengths.

References: [1] Bottke W. F. et al. (2015) *Asteroids IV*. [2] Morbidelli A. et al. (2009) *Icarus, 204,* 558-573. [3] Rivkin A. S. et al. (2006) *Icarus, 185,* 563-567. [4] Rivkin A. S. et al. (2015) *Ast. J., 150,* 198-204. [5] Rayner J. T. et al. (2003) *PASP, 115,* 362-382. [6] Cushing M. C. et al. (2003) *PASP, 115,* 383-388. [7] Takir D. and Emery, J. P. (2012), *Icarus, 291,* 641-654. [8] Rivkin, A. S. et al. (2015) *Asteroids IV.* [9] Rivkin, A. S. et al. (2003), *MAPS, 38,* 1383-1398.