Does the Solar Wind Create OH on NEO Surfaces?: Observations of 433 Eros and 1036 Ganymed. A. S. Rivkin[1], E. S. Howell[2], J. P. Emery[3], and J. M. Sunshine[4]. [1]JHU/APL, Laurel MD USA (andy.rivkin@jhuapl.edu), [2]Arecibo Observatory, Arecibo PR, [3]Univ. Tennessee, Knoxville, TN, [4]Univ. Maryland, College Park MD.

Introduction: The discovery of water/OH in the lunar regolith [1-3] overturned years of conventional wisdom. The origin of this lunar water/OH is thought to be via interactions between the solar wind and lunar regolith, a form of space weathering/maturation processes. It was recognized by [1]. (and earlier proposed by [4]) that these processes should also be occurring on asteroidal surfaces. Hydroxylated minerals have been found on many objects though most are associated with the carbonaceous chondrite meteorites [5]. Those meteorites can contain water/OH bound into their minerals, and it would be difficult to disentangle solar wind-created water/OH from native asteroidal material. However, there are other asteroids more suitable for comparison with the lunar regolith than these carbonaceous asteroids. In particular, two large S-class NEOs, 1036 Ganymed and 433 Eros, made good apparitions in 2011-2012 and are excellent targets for several reasons: These asteroids, based on their mineralogies and meteorite analogs, are not expected to have 3-µm bands from native material, particularly Ganymed (which is interpreted as igneous in origin: [6]). Their solar distances vary from 1.1-1.8 AU while they are bright enough to observe and their phase angles also cover a wide range, but they do not exactly vary together allowing them to be disentangled (Fig 1). They provide an opportunity for observations over a long span, providing constraints on how solar wind could create water on surfaces in conditions similar to lunar conditions. The varying conditions experienced by the NEOs will allow any band variation to be characterized. Alternately, if there is no band or no variation, that provides constraints that modeling and theory of the lunar water must explain.

Observations and Data Reduction: We observed Ganymed on a total of 9 nights, and Eros a total of 7 nights, using the SpeX instrument on the NASA Infrared Telescope Facility (IRTF) [7]. We used the long-wavelength, cross-dispersed (LXD) mode to cover the entire 2.2-4.0 µm region simultaneously. Data reduction utilized the Spextool package of IDL routines [8], provided by the IRTF, with modeling and removal of thermal flux via a variant of the Standard Thermal Model implemented by Volquardsen, resulting in a reflectance-only spectrum.

Typically, the 2.5-2.85 µm region is removed from presentations of LXD spectra since the transmission through the Earth's atmosphere is so low at those wavelengths. However, on especially dry nights some light can be measured in specific windows. We include some data in the 2.5-2.85 µm region in figures below, with the caveat that the uncertainties associated with those data should be treated as provisional.

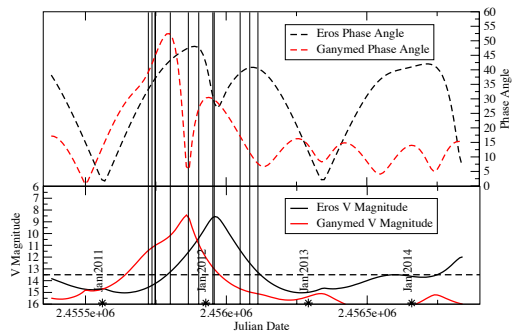

Figure 1: Observing circumstances of Eros (black) and Ganymed (red) from 2010-2015. The top panel shows the changing phase angle, the bottom the V magnitude. V magnitudes above the dashed line are observable in LXD mode with SpeX. Vertical lines are shown at the times of observations included in this work.

Results: Figure 2 shows the highest-quality spectra of Eros and Ganymed along with an estimated continuum in the 3-µm region. Both objects show evidence of an absorption roughly 1-2% in depth, most obviously interpreted as due to OH or H_2O. This band is not as deep as what is seen in the lunar highlands, though the asteroid spectra are integrated over the entire body. On the other hand, the generally lower temperatures on the NEOs would seem to favor greater stability for OH, other things being equal.

Figure 3 shows several overlaid spectra of Ganymed from the 2011-2012 apparition. These show no obvious change in apparent band depth with solar distance or phase angle. We note that this is true regardless of thermal model—reasonable choices of input parameters can result in similar spectra for all nights of observing. While not shown, the Eros spectra also show no consistent variation over the course of its apparition.

Implications and Future Work: The finding of a 3-µm band on Eros and Ganymed is consistent with a solar wind process, like what is thought to occur on the Moon. However, at this stage it is also consistent with the finding of a similar absorption feature on Vesta (Fig. 4), interpreted as due to contamination via carbo-

naceous impactors [9-11]. Ganymed in particular could have the opportunity to pick up such impactors since its aphelion at 4.08 AU leads it to traverse the entire asteroid belt on each orbit. Conversely, Eros' orbit is entirely within the asteroid belt, and there have been no reports of dark layers or patches in NEAR Shoemaker imagery, contrary to what is seen in the Dawn Vesta data. However, ordinary chondrites with native hydrated minerals are not unknown (though they are rarely found) [12], raising the possibility that Eros' 3-µm band is from endogenic not exogenic material after all.

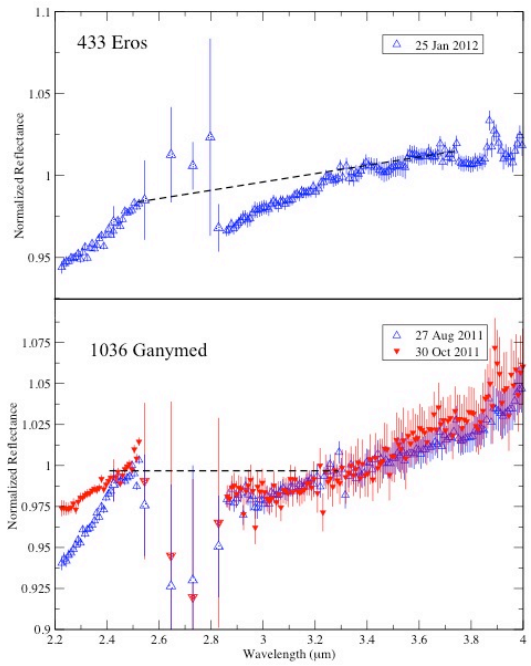

Figure 2: Eros (top panel) and Ganymed (bottom panel, from two nights) both show absorptions in the 3-µm region relative to an estimated continuum (dashed line). While data within the 2.5-2.85 µm "water gap" is usually omitted, we include selected wavelengths here. It is not clear whether the differences seen between Eros and Ganymed at those wavelengths are significant or not.

We will continue to observe S-class NEOs to further constrain the population of objects with 3-µm bands and the conditions in which these bands are present, and also analyze appropriate archival data for comparision purposes.

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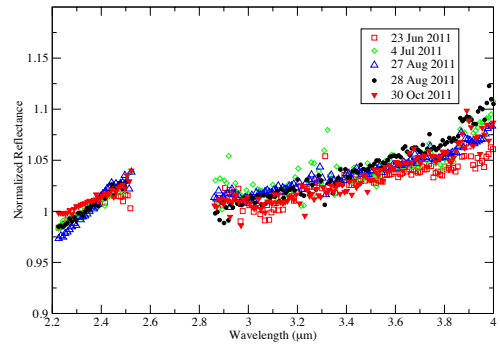

Figure 3: Observations of Ganymed over a range of solar distances and phase angles show no difference in thermally-corrected spectra over the 2.5-4 µm range.

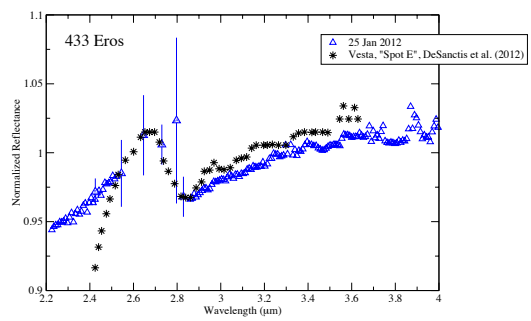

Figure 4: It is not yet known if the 3-µm band on Eros and Ganymede is due to solar-wind reactions with the regolith, as is interpreted for the Moon, or due to impactor contamination, as is proposed for Vesta. The spectrum of Eros is at least qualitatively similar to spectra from Vesta obtained by Dawn [10].

References: [1] Sunshine et al. (2009), *Science, 326,* 565-567. [2] Clark (2009), *Science,* 562-564 *326,* [3] Pieters et al. (2009) *Science, 326,* 568-571. [4] Starukhina (2001), *JGR* 106, 14701-14710. [5] Rivkin et al. (2003) *Meteoritics & Planet. Sci., 38,* 1383-1398. [6] Fieber-Beyer et al. (2011) *Icarus,* 212, 149-157. [7] Rayner, J. T. et al. (2003), *Pub. Ast. Soc. Pac.* 115:, 62-382. [8] Cushing, M. C. (2003) *Pub. Ast. Soc. Pac, 115,* 383-388. [9] Hasegawa et al. (2003) *GRL, 30*. [10] De Sanctis et al. (2012) *Ap. J. Lett.* 758, L36-40. [11] Reddy et al. (2012) *Icarus* 221, 544-559. [12] Hutchison et al. (1987) *GCA* 51, 1875-1882.