3-µm Spectroscopic Survey of Main Belt S-type Asteroids: widespread hydration detected. M. M. McAdam,[1] C. A. Thomas[2], L. E. McGraw[2], A. S. Rivkin[3], J. P. Emery[2]. [1]NASA Ames Research Center (maggie.mcadam@nasa.gov), [2]Northern Arizona University, [3]John Hopkins University's Applied Physics Laboratory.

Introduction: We present a large survey of nominally anhydrous S-type main belt asteroids using 3-µm spectroscopy. This survey shows that a majority of the nominally anhydrous asteroids (23 of 29 unique asteroids) show the telltale 3.0-µm absorption feature associated with hydration (e.g., hydroxyl and/or water).

Background: Many airless bodies in the terrestrial planets zone have been shown to have the signature of hydration. This is the ~3-µm fundamental vibration of the OH bond which can either be caused by hydrated minerals or water. This signature of hydration has been found on low albedo main belt asteroids many of which coaccreted with water ice, sometimes experiencing parent body aqueous alteration in their histories [e.g., 1]. The signature of hydration has also been found on objects that do not seem to have experienced extensive interactions with water over their histories.

Earth's moon [2-4, 5-6] and some near-earth asteroids [7, 8] have been shown to have evidence of hydration as well. Furthermore, ordinary chondrites (e.g., meteorites thought to be linked to S-type asteroids), including some of the most pristine and unaltered meteorites known to science, also have petrologic indications of coaccreted water [9-11]. The search for hydration, however, has not been extended to nominally anhydrous main belt asteroids until now.

Observations: Between February 2017 – May 2020, our team was awarded 30 runs on NASA's Infrared Telescope Facility. We obtained 33 observations of 29 unique asteroids. With two exceptions, we captured both prism (0.7-2.52-µm) and LXD (1.67-4.2-µm) spectroscopy of each object on the same night. We then reduced the data using the IDL Spextool package for each mode. The prism data were processed using an ATRAN model to remove the signature of earth's atmosphere while we used the IDL Spextool package for the telluric corrections for LXD.

We further corrected the LXD data for any thermal excess from the surfaces of the asteroids. The code we used was based on the Near Earth Asteroid Thermal Model [12].

Mineralogy: In the course of this work, we developed a band parameter analysis code that we used to determine the mineralogy of each asteroid from the near-infrared spectra. We calculated the following parameters using the cited methodologies: Band I and Band II centers [13] Band I and II depths [14], Band I and II area [14], and band area ratio (defined as the quotient of Band II to Band I areas). A high-level summary of the mineralogy is presented in **Fig. 1**, which is the Band I center (µm) vs the band area ratio, sometimes referred to as the 'Gaffey plot' [e.g., 15].

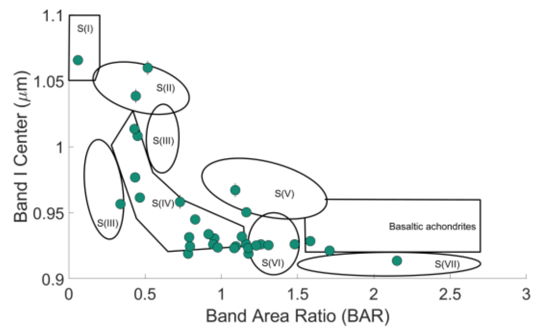

Fig. 1: Band I center vs. band area ratio for the nominally anhydrous S-type asteroids.

The asteroids in our dataset all appear to be S-types. That is, they all have two features in the near-infrared indicating the presence of olivines and pyroxenes.

The asteroids in this study have a wide variety of underlying mineralogies. We have examples of asteroids that are olivine dominated. A few of the objects in this study fall in the basaltic achondrite field, but these asteroids have much weaker features than V-type asteroids and (4) Vesta. The most numerous group of asteroids in our sample are asteroids that plot in the 'ordinary chondrite boot'. In our peer reviewed paper [16], we present and discuss the mineralogy and ordinary chondrite subtyping of these objects in greater detail.

3.0-µm Band Depth: Using the thermally corrected data, we average the values of the data and continuum within 3.0+/-0.025-µm then assess the band depth using this equation:

$$band\ depth = \frac{(rc - rb)}{rc}$$

Here 'rc' is the continuum (defined as the thermal model) and 'rb' is the data. We find a detection $\gtrsim$1% depth for all the objects in our study and only six of these have significant errors associated with them that may indicate a non-detection. Given the recent evidence of hydration on NEAs and the moon, it may not be surprising that nominally anhydrous main belt S-types also have the signature of hydration. However, some of these detections are consistent in depth with hydrated low albedo asteroids.

Fig. 2 shows a comparison of the band depths of main belt S-types compared to the dataset of [1]. On average, our 3.0-µm band depths have an error 1.75% (ranging from 0.11% - 4.75% depending on the observation).

Nine of the asteroids presented in this study have a >5% band depth and three objects have one of >10%. Additionally, these reported band depths are consistent with some of the observations of the lunar high latitudes [e.g., 3-4].

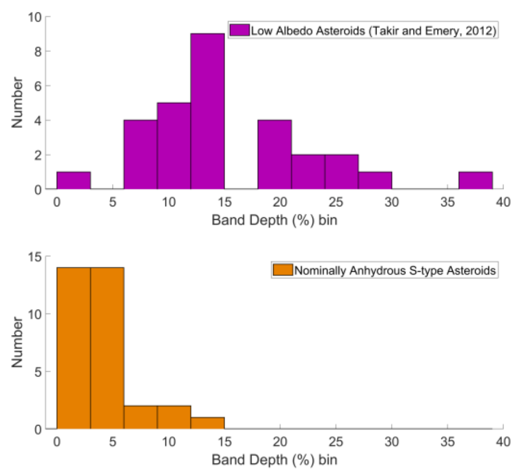

Fig. 2: Histogram of band depths. Here we present the 3.0-µm band depths for the nominally anhydrous main belt S-types (bottom, orange color) compared to the band depths of the outer main belt objects from Takir and Emery, (2012). Some of the S-types have similar band depths to the OMB objects.

Discussion and Implications: The mechanism that is driving the signature of hydration we find on nominally anhydrous main belt S-types is likely not the same as the mechanisms for the moon and outer main belt asteroids. The moon's hydration is likely driven by solar wind implantation of OH while the outer main belt asteroids accreted with significant water leading to either aqueous alteration or preserved water ice. We wanted to investigate the potential relationships between the 3.0-µm band depths for our data to determine what could be driving our detections. Given the discovery of low albedo materials on Vesta [17], one leading hypothesis is exogenic material however, we cannot rule out coaccreted water or solar wind implantation.

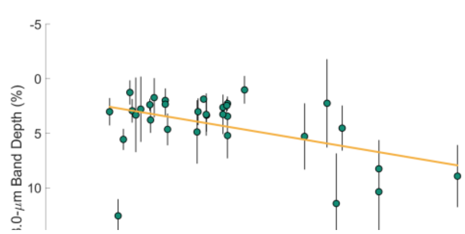

Fig. 3: Band Depth vs. Perihelion Distance. Here we show the 'best' correlation with 3.0-µm band depth. This relationship is a weak correlation, and it appears that no one factor controls the 3.0-µm band depth for large, main belt S-types.

We regressed the 3.0-µm band depth with a number of compositional, physical, orbital and circumstantial parameters to see which factor is driving our detections.

The highest-level result is that no physical, orbital, compositional or circumstantial parameter seems to have any strong or even moderate correlation with 3.0-µm band depth. The 'best' fit (Fig. 3) we found was perihelion distance with and R^2 of 0.212. There does not seem to be one single factor that is driving 3.0-µm band depth for our asteroids.

We attempted to investigate a subset of our asteroids that have a strong compositional relationship (H ordinary chondrite like asteroids). Here we found that perihelion distance, orbital eccentricity and Band II center all had strong correlations (R^2 values of 0.779, 0.776 and 0.51, respectively). These correlations are made with a very small subset of the data (~10 objects) and so may not be reliable. However, the perihelion distance correlation may strengthen the case for an exogenic source for the observed 3.0-µm band. Similarly, composition and/or parent body history could be a significant underlying factor for hydration.

Conclusions: We do not find any strong correlations between the 3.0-µm band depth and any physical, orbital, compositional or circumstantial parameter for the surveyed group of nominally anhydrous main belt S-type asteroids. This strongly suggests that there is no single mechanism for hydration of nominally anhydrous main belt asteroids. Follow up research could investigate a larger number of asteroids to determine how composition may be playing a factor.

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References: [1] Takir and Emery (2012), Icarus, 219, 641. [2] Clark (2009), Sci. 362, 562. [3] Pieters et al., (2009), Sci. 326, 568. [4] Sunshine et al., (2009) Sci. 326, 565. [5] Honniball et al., (2021), Nat. Ast., 5, 121. [6] Honniball et al., (2022), GRL, 49. [7] Rivkin et al., (2017), Icarus, 304, 74. [8] McGraw et al., (2022), PSJ, 3, 243. [9] Alexander et al., (1989), GCA, 52, 3045. [10] Jarosewich (1990), Meteoritics, 25, 323. [11] Wood et al., (2005), Chondrites and the Protoplanetary Disk, 341, 953. [12] Harris (1998), Icarus, 131, 291. [13] Sanchez et al., (2020) AJ, 159, 146. [14] Thomas et al., (2014) Icarus, 228, 217. [15] Gaffey et al., (1993) Icarus, 106, 573. [16] McAdam et al., Detection of hydration on nominally anhydrous S-type Main Belt Asteroids, in prep. [17] Nathues et al., (2014) Icarus 239, 222.