NEAR-INFRARED SPECTROSCOPY OF (3122) FLORENCE AND (357439) 2004 BL86 DURING NEAR-EARTH ENCOUNTERS. S. S. Larsen[1,2] and D. Takir[3], [1]Lunar and Planetary Institute (URSA), Houston, TX 77058 [2]Massachusetts Institute of Technology, Cambridge, MA 02139, sslarsen@mit.edu, [3]Jacobs, NASA Johnson Space Center, Houston, TX 77058, driss.takir@nasa.gov.

Introduction: The near-Earth asteroids (NEAs) (3122) Florence and (357439) 2004 BL86 flew by Earth in 2017 and 2015, respectively. During each fly-by, we conducted near-infrared (NIR) spectroscopic observations of each NEA to investigate their surface compositions, particularly for traces of water/hydroxyl.

Florence is an S-type asteroid with an average diameter of 4.35 km and two small moons [1, 2]. Florence displays small/moderate absorption features at wavelengths 1 µm and 2 µm (typical of S-types), suggesting the presence of pyroxene and olivine minerals on its surface [3]. (357439) 2004 BL86, compared to Florence, is a smaller asteroid with approximately 0.29 km in diameter and with one moon [4, 5]. 2004 BL86 is a V-type asteroid and is thought to be a fragment of asteroid 4 Vesta [5]. 2004 BL86 exhibits deeper spectral features at wavelengths of 1 µm and 2 µm, indicating significant abundance of pyroxene and olivine, as expected of a V-type asteroid [5].

NEAs are widely thought to be the source of water and organics delivered to early Earth. Additionally, some NEAs, including Florence and 2004 BL86, are considered potentially hazardous objects (PHOs), and they could make threateningly close approaches to Earth. Our hypothesis is that Florence and 2004 BL86 are featureless in the 3-µm band and do not possess features indicating water; as S-type and V-type asteroids, they are seemingly not carbonaceous or primitive objects.

Methods: *Observational Techniques*. We used the Infrared Telescope Facility (IRTF) located at Mauna Kea, Hawaii to measure the long-wavelength cross-dispersed (LXD : 1.67-4.2 µm) spectra of both Florence and 2004 BL86 with the SpeX instrument. The measured spectra wavelength range includes the 3-µm feature attributed to water/hydroxyl detection. Table 1 shows some of the observing parameters for Florence and 2004 BL86. We used spectra of G-dwarfs with solar-like colors to remove telluric water vapor absorption features and to correct for the solar spectrum. The raw data were processed and reduced using Spextool, an IDL based spectral reduction program provided by the IRTF.

Observed Object	Calibration Star	YYYY-MM-DD UTC (midfile)	Data Set
3122 Florence	HD 191022	2017-09-08 9:33	1
3122 Florence	HD 191022	2017-09-08 10:08	2
(357439) 2004 BL86	SAO 174719	2015-01-25 11:23	1
(357439) 2004 BL86	SAO 174719	2015-01-26 11:47	2

Table 1. Observational parameters of Florence and 2004 BL86.

Thermal Modeling Correction. The measured LXD data contain two flux sources: reflected energy (light reflected off the surface of the asteroid) and thermal energy (radiation emitted from the surface of the asteroid). To model and correct the data's thermal emission component (beyond 2.5 µm) and isolate the desired reflected flux component, we used the Near-Earth Asteroid Thermal Model (NEATM) [6, 7]. We fitted the measured thermal excess with the NEATM model excess that was then subtracted from the measured relative flux spectra of Florence and 2004 BL86.

Band-Depth Analysis. After thermal correction, the data were normalized at 2.2 µm (this value was arbitrarily chosen because 2.2 µm is the center of the K-band atmospheric transmission window). After continuum removal, the band depth at approximately 2.9 µm was calculated and used as a proxy to whether water/hydroxyl was present. Additionally, the band depth at 2.0 µm was measured to detect the amounts of other minerals such as pyroxene and spinel. All calculations were implemented in Python version 3.8.8. The band depth D_λ, where λ is the wavelength, is defined as

$$D_\lambda = \frac{R_C - R_\lambda}{R_C},$$

where R_λ is the reflectance of data at wavelength λ and R_C is the reflectance of the continuum at the same wavelength λ [8].

Results: Table 2 shows the calculated band depths and uncertainties of each data set for Florence and 2004 BL86.

Name	Set	Band Depth at 2.9 µm
3122 Florence	1	10.1 ± 9.1 %
3122 Florence	2	8.6 ± 7.6 %
2004 BL86	1	-3.3 ± 9.5 %
2004 BL86	2	-1.0 ± 6.3 %

Table 2. Band depths and 2-sigma uncertainties sorted by asteroid and data set. A spectroscopic feature at 2.9 µm indicates the presence of water/hydroxyl in some form.

Discussion: As shown in Table 2, the band depth (D_λ) is greater than two standard deviations for both sets of Florence data, meaning that Florence exhibits a 3-µm band feature indicating the presence of water/hydroxyl on its surface. Meanwhile 2004 BL86 lacks this feature in both data sets. The presence of water/hydroxyl on Florence is unexpected and relevant; trace amounts water may be found on objects never considered suitable to host this volatile.

There are multiple possible and/or theorized explanations for the detection of water/hydroxyl on small solar system objects, including the presence of endogenic hydrated minerals on their surfaces, and exogenic sources such as solar wind implantation and carbonaceous impactors [1]. V-type and S-type asteroids are known to be rich in dehydrated silicates, meaning the presence of abundant hydrated minerals on Florence is unlikely. Due to Florence's proximity to the Sun, solar winds interacting with Florence's surface and producing water/hydroxyl is arguably the most plausible scenario. To be completely certain, we would need additional (preferably space-based) observations.

Observations were ground-based and hindered by atmospheric interference as a result. For example, the Earth's atmosphere is opaque between 2.5-2.8 µm, and data within this region were omitted as noise. Atmospheric interference also caused a mild source of noise at approximately 1.8 µm; this region was left in.

Figure 1 depicts Set 1 of Florence and Set 1 of BL86 compared with data from the Bells meteorite [9] and the far side of the Moon [10], both shown to contain water/hydroxyl in some form.

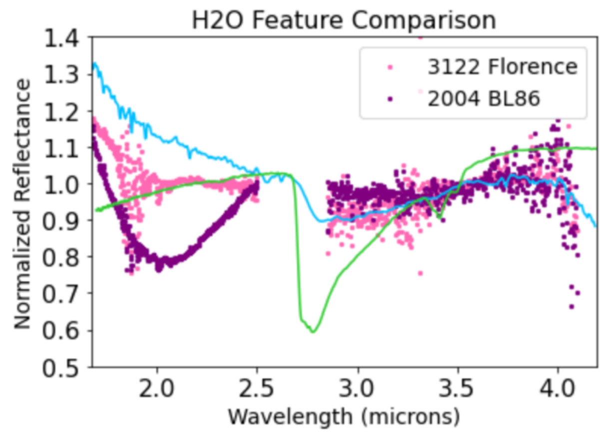

Figure 1. Florence and 2004 BL86 spectra place alongside spectra from the carbonaceous chondrite Bells (green) and the far side of the Moon (blue). Florence's 3-µm feature is comparable in shape to the Lunar spectrum's feature.

Conclusions: With NASA IRTF telescope, we measured spectra data of Florence and 2004 BL86 during the asteroids' close encounters with Earth in 2017 and 2015, respectively. The measured data showed that the surface of Florence contains water/hydroxyl, which is unexpected for an S-type asteroid. Florence's water signature is possibly due to solar wind interactions. Meanwhile, 2004 BL86 does not exhibit the same signature, indicating an absence of water/hydroxyl- an expected result for a V-type asteroid.

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