INVESTIGATING THE NATURE AND ORIGIN OF HYDRATED SALTS ON EUROPA.

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Background and Motivation: The surface composition of Europa is modified by possible communication with its internal ocean, interactions with Jupiter's magnetosphere, and delivery of material in impactors [e.g., 1]. Europa's surface is composed of a mixture of components modified by these processes, including H_2O ice [2], hydrated salts [3], sulfur-bearing species [4], molecular oxygen (O_2) [5], hydrogen peroxide (H_2O_2) [6], and carbon dioxide (CO_2) [7].

Salts on Europa likely originate as frozen brines sourced from its interior that are exposed in chaos terrains in Tara Regio and elsewhere [e.g., 3,8,9]. Freshly exposed brines are subjected to intense bombardment by S^{n+} ions and other charged particles [e.g., 10], driving radiolytic modification of surface components. Ground-based, optical observations detected Na and K in Europa's exosphere [11,12]. Similarly, Galileo's magnetometer detected Cl^- and Cl^+ ions in a pickup cloud near Europa [13], but Cl has not yet been detected in its exosphere [14]. These different elements could have originated in salts that were sputtered off Europa's surface. Along with NaCl [e.g., 9], sulfates like epsomite ($MgSO_4$*$7H_2O$) are likely present on Europa [e.g., 15], dominating the spectral properties of its trailing hemisphere [16]. However, laboratory experiments indicate that sulfates are unlikely to form in Europa's ocean unless Na is rare [17]. Consequently, SO_4^{2-} might be formed primarily on Europa's surface via S^{n+} ion-driven radiolysis. In this scenario, sulfates form from the molecular fragments of chlorides and other salts [15]. The source of exospheric K has yet to be identified, likely because frozen KCl is difficult to spectrally distinguish from H_2O ice [18]. Here, we present near-infrared reflectance spectra we have collected to assess the spectral signature of salts on Europa, using the SpeX spectrograph on NASA's Infrared Telescope Facility [19].

Observations and Data Reduction: Between 2020 and 2022, we collected 17 spectra using SpeX in short cross-dispersed mode (SXD, 0.7 – 2.55 µm) and 7 spectra using SpeX's two long cross-dispersed modes (LXD_short, 1.67 – 4.2 µm, LXD_long, 1.98 – 5.3 µm) (***Table 1***). All spectra were calibrated and extracted using the Spextool data reduction suite [20], along with custom programs. SpeX's slit was oriented parallel to Europa's rotation axis to ensure that data collection was centered on the sub-observer longitude.

Results: The SXD and LXD spectra show numerous absorption bands consistent with H_2O ice mixed with hydrated salts, along with a 3.5-µm band attributed to H_2O_2 [6] (***Figure 1***). The SXD spectra show absorption features near 1.78 and 2.0 µm (***Figure 2***). The center of the 2.0-µm band shifts from 2.00 µm on Europa's leading hemisphere (spectra 1-9), to 1.98 µm at transitional longitudes (spectra 10, 11, 16, and 17), to 1.96 µm in spectra collected near the center of Europa's trailing side (spectra 12-15). This band center shifting is similar to the wavelength shifts observed in thermal

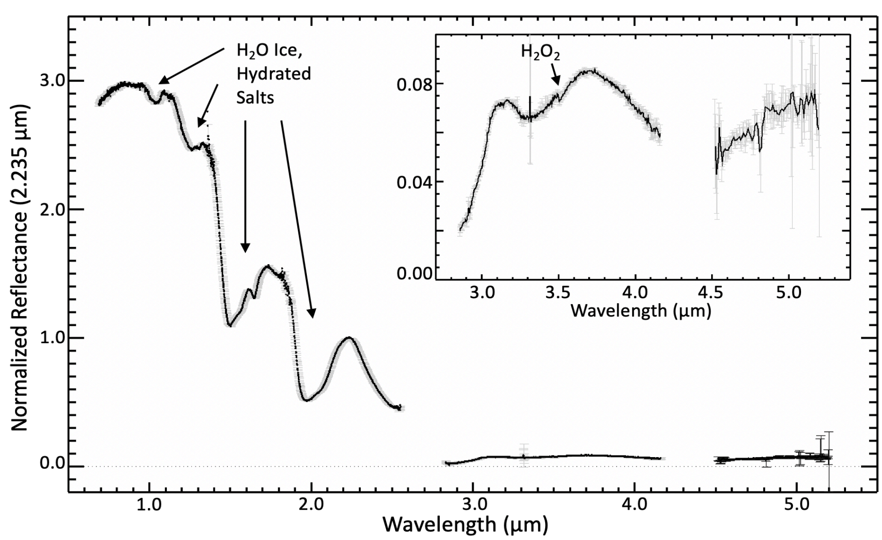

***Figure 1:** SpeX spectra of Europa collected in SXD and LXD_long modes (mid-observation, sub-observer longitudes of ~344° and ~340°, respectively, Table 1). Strong absorption bands between 0.9 and 2.5 µm are present in these data, resulting from H_2O ice mixed with hydrated salts. Inset figure shows a close up of the 3 to 5 µm region, highlighting a 3.5-µm band that is generally attributed to H_2O_2 formed from irradiation of H_2O ice.*

cycling experiments for chlorides like hydrated $CaCl_2$ [18]. Furthermore, spectra 12-15 show the best evidence for a 1.78-µm band that has been identified in near-infrared spectra of a variety of chlorides and other salts measured in the laboratory [e.g., 18,21]. In contrast to the spectral changes observed between 1.75 to 2.05 µm, the center and shape of the 1.65-µm band is remarkably consistent in all 17 SXD spectra, suggesting that crystalline H_2O ice and hydrated salts are omnipresent across Europa, at least in these disk-integrated data.

Future Work: We will continue to collect spectra of Europa at complementary sub-observer longitudes to the data presented here. We will compare all SpeX data to near-infrared spectra collected with other ground-based facilities and the James Webb Space Telescope [22]. Furthermore. we will compare all collected datasets to laboratory data of salts and other species.

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Table 1: *IRTF/SpeX observations of Europa.*

SXD Number	Sub-Obs. Long. (°)	Sub-Obs. Lat. (°)	UT Date	UT Time (mid-expos)	t_{int} (s)
1	29.9	1.1	06/25/21	12:55	100
2	78.7	3.1	08/01/22	15:55	70
3	82.9	1.1	06/22/21	12:15	100
4	82.8	2.8	06/23/22	15:00	160
5	83.6	3.0	07/18/22	12:10	70
6	116.9	3.0	07/29/22	11:45	50
7	138.6	3.0	07/15/22	11:55	80
8	147.1	1.1	07/28/21	15:10	240
9	157.0	-1.3	10/17/20	5:45	400
10	172.1	3.0	07/26/22	11:35	84
11	213.1	1.1	07/18/21	15:20	240
12	247.1	3.0	07/23/22	16:05	70
13	254.8	-1.3	10/18/20	4:55	420
14	273.2	3.0	07/27/22	11:30	70
15	300.4	1.0	06/17/21	14:00	100
16	330.8	3.0	07/24/22	11:55	130
17	343.6	1.1	06/21/21	12:45	100
LXD_short	93.5	3.0	07/18/22	14:30	2,120
	135.0	1.1	07/28/21	12:20	2,800
	277.4	3.0	07/27/22	12:30	1,200
LXD_long	126.0	3.0	07/29/22	13:55	2,760
	147.7	3.0	07/15/22	14:05	2,160
	206.1	1.1	07/18/21	13:40	2,160
	339.6	3.0	07/24/22	14:00	2,508

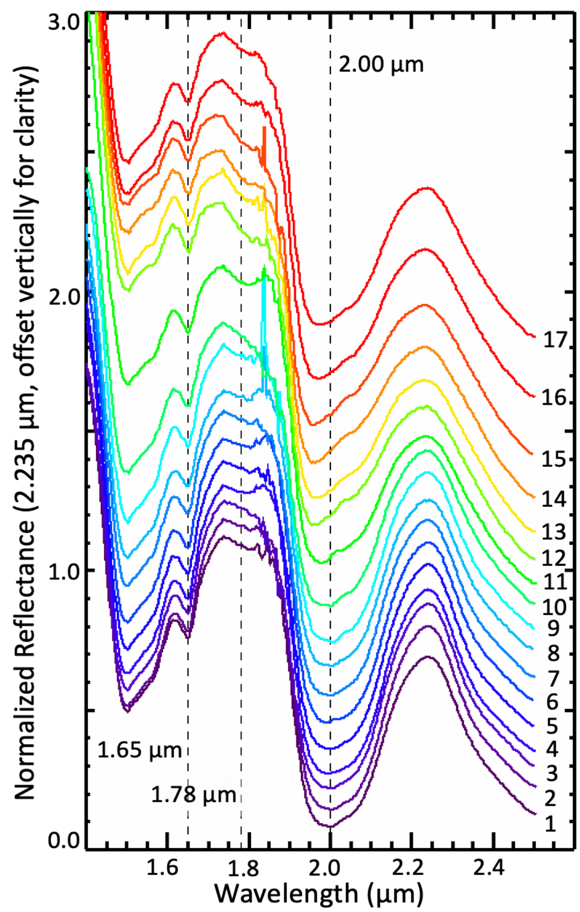

Figure 2: *SXD spectra of Europa, labeled using the same numbers as Table 1 (1-17). On Europa's leading hemisphere, the morphology of the 2.0-µm bands, and the continua near 1.78 µm, are broadly consistent with the spectral properties of H_2O ice (1-10). On Europa's trailing hemisphere, the 1.78-µm and 2.0-µm bands suggest the presence of hydrated salts and H_2O ice (11-17). The center and shape of the 1.65-µm features are similar across Europa.*