SPECTRAL BEHAVIOR OF IRRADIATED SODIUM CHLORIDE CRYSTALS UNDER EUROPA-LIKE CONDITIONS.

Michael J Poston[1], Robert W Carlson[1], and Kevin P Hand[1].
[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, *Kevin.P.Hand@jpl.nasa.gov*.

Introduction: Several icy bodies in the solar system are believed to contain sub-surface oceans, with many other predicted based on modeling; such subsurface oceans may be habitable and possibly even inhabited [1-4]. One such "ocean world", Jupiter's second moon, Europa, is among the promising candidates in the solar system for habitability and possible life [5]. Europa's robust tidal heating provides a key energy input, water-rock interactions at the sea floor may provide reductants, and radiation from Jupiter's magnetosphere produces oxidants at the planetary surface. If there is mixing of reductants and oxidants within the ocean, this would provide a chemical energy source for sustaining life – one of the key pieces of habitability [6].

One way to establish material transport between the surface and ocean is to identify locations of surface material that has come out from the ocean. While geologic evidence of resurfacing is present [5], it is not clear whether any of the material is sourced from the sub-surface ocean. Chemical evidence of material that would only come from an ocean would potentially resolve this issue. One likely tracer of ocean material is sodium chloride salt, NaCl. It is well-known that irradiation of salts, many metal oxides, and even some ionic crystals creates crystal defects, known as "color centers" because they tend to result in absorptions in the visible spectrum, imparting color to the salt. An excellent overview of known color centers in NaCl was given by Schwartz et al. [7].

Recent ground-based observations of Europa are consistent with chloride salts of endogenic origin, including NaCl [8-10]. Despite the large body of work on NaCl color centers (ex. [7]), and some work of direct planetary relevance [11-12], very little published work exists under conditions relevant for Europa. Hand and Carlson [13] recently irradiated NaCl under Europa-like temperature and pressure conditions and published initial results relating the color center absorptions to spacecraft observations of dark material on Europa. Poston, Carlson, and Hand [14] extended this work by looking at the time-evolution of NaCl irradiated under-Europa-like conditions of temperature and pressure. This is the work that will be presented in this presentation.

Methods: Our experiments were perfomed in the Minos vacuum chamber, located in the Icy Worlds Simulation Facility within the Ocean Worlds Lab at the Jet Propulstion Laboratory [14]. Minos is equipped with a closed-cycle helium cryostat for cooling the sample to Europa-like temperatures, and all-metal seals and turbo-pumping to achieve Europa-like pressures. VNIR spectra were collected by a Princeton Instruments Acton grating spectrometer at 15-60 minute increments throughout the experiment. Irradiation was provided by an electron gun, operating at 10 keV, and an electron flood gun at 10 eV to ensure sample neutrality.

Three electron beam currents were used (250, 125, and 57 nA) at 100K, and irradiation was performed with a 250 nA beam current at three temperatures (100, 180, and 290 K). Irradiations were continued until the spectra appeared unchanging compared to random instrumental variation. (Analysis of instrumental drift is described in the full paper [14], but was found to be less than ten percent.) All spectra were referenced to the very same NaCl powder before the first irradiation, which was basically colorless. Thus, spectra show the change in NaCl due to irradiation.

The measurements were all performed on the same portion of NaCl powder over the course of several weeks, with only one minor break in vacuum (briefly up to 300 torr late in the sequence, due to a tripped circuit breaker). The initial irradiation was at 100K with 250 nA beam current. Followed by an extended decay series (no irradiation) at gradually increasing temperature, up to 290K. Next was irradiation at 290K with 250 nA, followed by decay at 290K, and irradiation then decay at 180K. Finally, irradiation was again performed at 100K, first with 57 nA, and then 125 nA. After a final decay at 100K, the experiment was concluded. Salt grains were found to vary in visible color upon removal from the chamber, with some appearing red-ish brown, and others being colorless.

Results and Discussion: All irradiation sequences showed the same general trend: rapid growth of an F-center feature at about 460 nm and lagging rapid growth of an M-center feature at 720 nm. (See Figure 1 for a sample irradiation series.) The rate of feature growth was found to vary proportionally with irradiation dose rate (i.e. electron beam current) and inversely with sample temperature. The nature of the dependence was consistent with a dynamic competition between creation of color centers and decay of color centers.

Decay of color center features (irradiation off) was also dynamic. In addition to gradual loss of the F- and M-center features, the features shifted to lower wavelength (i.e. higher energy). Meanwhile several weak features transiently appeared.

The growth rate and equilibrium depth of any particular feature were not consistent across differing irradiation conditions, however, it was found that the ratio of the two main features (F/M) arrived at a similar value, regardless of irradiation conditions. Therefore, the ratio of the two features, if seen on an irradiated Ocean World, could provide an estimate of the irradiation dose received by that NaCl deposit. Since pre-biotic and biogenic molecules are also altered by irradiation, identifying sites with the lowest radiation dose would be valuable to missions seeking to understand habitiabilty and/or biosignatures on Ocean Worlds.

References: [1] Chyba, C. F., K. P. Hand (2005) Annu. Rev. Astron. Astrophys., 43, 31-74, doi:10.1146/annurev.astro.43.051804.102202. [2] Lazcano, A. and Hand, K.P. (2012) Nature, Forum. 488, 7410, 160-161. [3] Lunine, J. I. (2017) Acta Astro., 131, 123-130, doi:10.1016/j.actaastro.2016.11.107. [4] Nimmo, F., and R. T. Pappalardo (2016) JGR: Planets, 121, 1378–1399, doi:10.1002/2016JE005081. [5] Pappalardo, Robert T., William B. McKinnon, and K. Khurana. Europa. Tucson: U of Arizona, 2009. Print. [6] Hand, K. P., et al. (2009) Astrobiology and the Potential for Life on Europa. In Europa. Eds. R. Pappalardo, W. McKinnon, & K. Khurana. Univ. of AZ Press. [7] Schwartz, K., et al. (2008) Phys. Rev. B, 78, 024120, doi: 10.1103/PhysRevB.78.024120. [8] Fischer, P. D., M. E. Brown, and K. P. Hand (2015) AJ, 150:164, doi:10.1088/0004-6256/150/5/164. [9] Fischer, P.D., et al. (2017) AJ, 153:13, doi:10.3847/1538-3881/153/1/13. [10] Ligier, N., et al. (2016) AJ, 151:163, doi:10.3847/0004-6256/151/6/163. [11] Nelson, R. M., and D. B. Nash (1979) 39(2), 277–285, doi:10.1016/0019-1035(79)90170-2. [12] Hibbitts, C. A., et al. (2017) 48th LPSC, #2456. [13] Hand, K. P., and R. W. Carlson (2015) Geophys. Res. Lett., 42, 3174–3178, doi:10.1002/2015GL063559. [14] Poston, M. J., R. W. Carlson, and K. P. Hand (2017) JGR-Planets, 122, doi: 10.1002/2017JE005429.

The research described here was carried out at the Jet Propulsion Laboratory, Caltech, under a contract with the National Aeronautics and Space Administration (NASA).

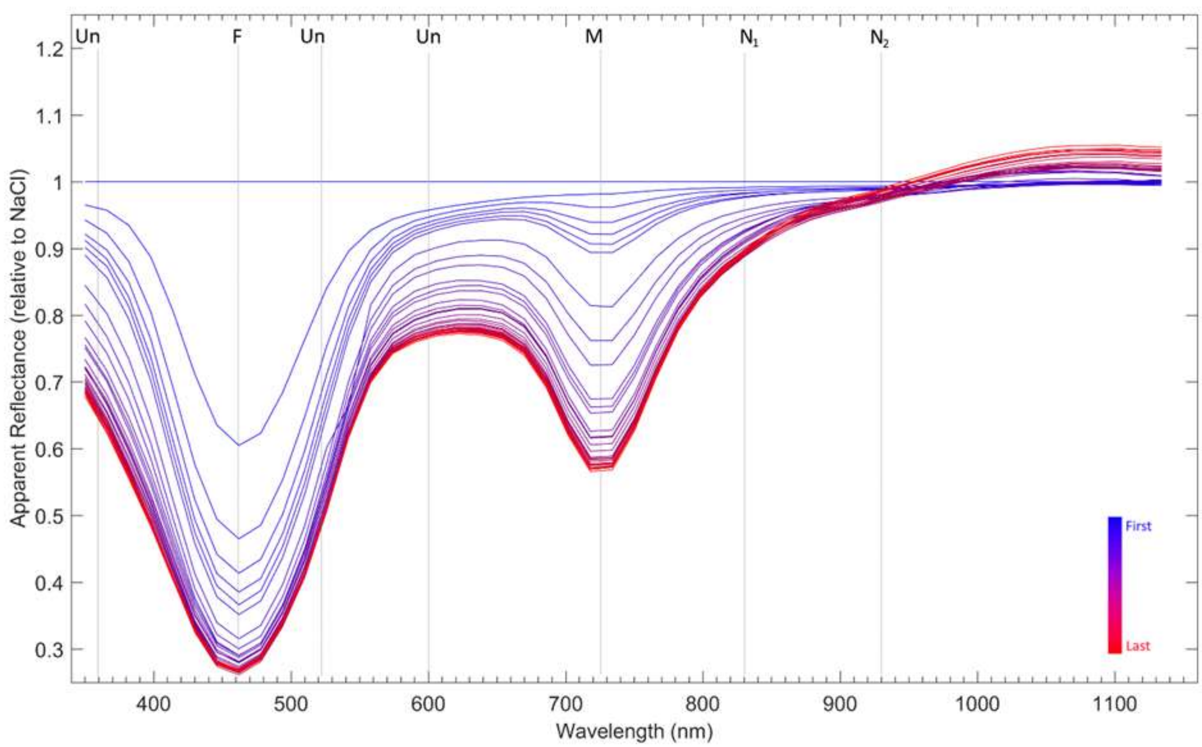

Figure 1: Representative sequence of spectra upon irradiation showing evolution of color center features with increasing radiation dose. See Poston, Carlson, and Hand [13] for additional plots and the meaning of assignments. (Figure taken from Poston, Carlson, and Hand [13].)