Understanding the Radiation Chemistry of Pure and Impure Solar System Water Ices – The Role of Laboratory Studies. Murthy S. Gudipati (Gudipati@jpl.nasa.gov), Jet Propulsion Laboratory, California Institute of Technology, Mail Stop 183-301, 4800 Oak Grove Drive, Pasadena, California 91109, USA

Introduction: One of the goals of remote sensing is to identify external signatures of internal processes. This method is particularly relevant to the study of Solar System icy bodies under radiation environments such as Mars, Europa, Enceladus, Ganymede, and Saturn’s rings. In order to interpret, understand, and quantify the observed spectroscopic data and create geophysical models, it is necessary to have: (a) laboratory spectroscopic data that are derived from studies on analog materials, and (b) a fundamental understanding of the physicochemical processes that result in the spectroscopic data obtained in the laboratory.

Our research goal is to start with (b) above. Our approach is to understand the fundamental physicochemical processes that occur in ices through laboratory research, then derive the appropriate spectroscopic data (a). This will allow us to guide and support analysis of the observational data, which will lead to improved geophysical models. Our laboratory research forms one of the four vertices of the Space Science Endeavor represented by the Platonic solid Tetrahedron, cross-connecting each branch to the rest.

Figure 1: Four branches of the Space Science Endeavor – Missions, Observations, Laboratory, Modeling, represented by the Platonic solid Tetrahedron, cross-connecting each branch to the rest.

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Back to Basics (Radiation and Molecules): Though yet to be fully explored, most laboratory studies show that radiation is absorbed/scattered in several different quanta. This results in different excitations within the atoms and molecules – nuclear, electronic, vibrational, and rotational. These excitations can lead to chemical reactions, molecular dissociations, and ionization (removal of an electron from an atom or molecule), as shown in Figure 2. Physicochemical consequences of ionization differ from dissociation in three ways. First, ionization results in creation of charge centers through electron and hole (ion) separa-

Figure 2: Simplified view of radiation induced molecular excitations that lead to dissociation and ionization processes.

The ice penetration depths of solar wind, γ-rays, and magnetospheric electrons and protons of the giant planets Saturn and Jupiter can be on the order of a meter [3; 4]. Photon penetration is limited by the optical quality of the ice and the particle sizes of the ice grains [5]. The extent of the radiation-induced chemistry is determined by the dosage of a given quanta of energy reaching the molecules embedded in ices and the water molecules of ice themselves.

Laboratory Research (Ionization in Ices): Laboratory studies and observations of Europa and Saturn have shown that radiation processing results in the dissociation of H2O molecules to O, OH, and H radicals, which recombine to form O2 [6], H2O2 [7; 8], etc. Sputtering of protons (H+) from ice surfaces [9], chemistry resulting from implantation of keV heavy ions (C+, N+) into ice [10], have also been documented in the laboratory.

We found [1; 2; 11; 12] direct evidence for radiation-induced ionization in ice using polycyclic aromatic hydrocarbons (PAHs) as probe molecules (Figure 3). Further highlights of our recent research include: (a) stability of large ionized PAH molecules up to 120 K, while smaller molecules react with the ice matrix even at 50 K; (b) reactions between ionized molecules and the irradiated ice matrix resulting in oxidized molecules (incorporation of oxygen and hy-
hydrogen into the organic molecules); and (c) sequential multiple ionizations occurring within the ices, leading to higher density of charge and electrons.

These discoveries raise further key questions, being addressed in the laboratory. For example:

1. what is the fate of the electrons generated in the ices through radiation-induced ionization or electron/ion bombardment?
2. what is the conductivity (electron mobility) of irradiated ice surfaces containing impurities?
3. what are the optical properties and spectroscopy of ices in radiation and sputtering environments?

Applications to Solar System Ices: The breadth of astrophysical applications of this work has not yet been fully explored, but some of the applications to Solar System icy bodies include the following.

(a) Coloration of Saturn’s rings could be due to ionized large PAH-like molecules imbedded in ices. Generally, ionized atoms and molecules are more strongly colored than the corresponding neutrals, as shown in Figure 3. At temperatures around 100 K, ices can efficiently store these ions indefinitely.

(b) Charged ice grains can enhance adhesion process through strong Coulombic forces.

(c) The surface ice conductivity of Europa and Enceladus, which are both under strong magnetospheric radiation environments, is yet to be probed. Due to the hemispherical dichotomy of Europa’s radiation environment [13], a significant difference in surface conductivity between the leading and trailing hemispheres is expected.

(d) Molecular mobility and convection within the ice layers of Europa, Enceladus, and Ganymede could be significantly enhanced. Due to the long-range and stronger nature of Coulombic forces, charged molecules move faster under a charge gradient than the neutral molecules.

(e) Energy deposited into the ice surface through ionization can be transported into the interior through the above mentioned convection process.

(3) what are the optical properties and spectroscopy of ices in radiation and sputtering environments?

Figure 3: Radiation induced ionization of a PAH 4-methylpyrene imbedded in H2O ice [1; 2]. From each molecule ionized, an electron is injected into the ice in astrophysical ices. Astrophysical Journal Letters. 596, L195-L198.

References:
1. Gudipati, M. S., Allamandola, L. J., 2003. Facile generation and storage of polycyclic aromatic hydrocarbon ions...