THE EFFECTS OF PLUMES AND OTHER GEOLOGIC ACTIVITY ON EUROPA'S EXOSPHERIC STRUCTURE AND COMPOSITION. D.Y. Wyrick[1], B.D. Teolis[1], A. Bouquet[1], B. Magee[1], and J.H. Waite[1], [1]Southwest Research Institute (6220 Culebra Road, San Antonio, TX 78238; dwyrick@swri.org).

Introduction: With the planned NASA Europa mission scheduled to arrive at the geologically active icy satellite Europa by the end of the next decade, understanding the origin, structure, dynamics and composition of Europa's exosphere has become an urgent priority, and will be key to decoding the surface and subsurface composition and chemistry. The recent HST detection [1] of possible cryovolcanic water vapor plumes at Europa, analogous to the plumes found by the Cassini spacecraft at Enceladus, constitutes a paradigm shift from a fully sputtered exosphere, to one potentially dominated, at least episodically, by a plume source. Europa's higher gravity (contrary to Enceladus) is sufficient to return a major fraction of the ejected plume and/or sputtered material to the surface. Therefore surface interaction effects, such as surface sticking, become critical to understanding the spatial and temporal variation of different exospheric species.

We developed a comprehensive multi-species Monte Carlo model of Europa's sputtered exosphere and plumes, informed by Cassini's results at Enceladus, Dione and Rhea [2,3,4], which illustrated the importance of understanding the source physics, gas-surface interactions, and 3D structures of sputtered and plume exospheres. The model takes into account (i) sticking and thermal accommodation, (ii) gas diffusion through the porous regolith, (iii) cold trapping near the poles, (iv) radiolytic O_2 and H_2 production from the surface ice, (v) sputtering of endogenic non-ice material, (vi) sputtering and thermal desorption of adsorbed species, and (vii) the addition of plumes. Both surface sputtering effects and plume outgassing are likely at Europa, and together result in a cumulative and transient exosphere.

Modeling approach: We use a Monte Carlo model to eject molecules from the surface according to either a surface source map with a suprathermal 'sputtering' distribution or a south polar point source with a drifted Maxwellian (plume case). We don't attempt to model the plasma environment and interactions here, but instead employ estimates of surface irradiation flux vs surface position based on previous modeling efforts [2,5,6]. Molecules are propagated along ballistic trajectories, taking into account Europa's gravity (the dominant influence), Jupiter's gravity and Europa's orbital and rotational motion (secondary effects). Neutral molecules are removed from the simulation when the particles leave the Hill sphere or stochastically in flight according to the estimated photo and impact ionization and dissociative collision rates, obtained by [7] for O_2. Molecules returning to the surface first stick, then either (i) thermally desorb (at the local surface temperature) at a rate given by the species vapor pressure [8] according to an Arrhenius law, (ii) re-sputter back into the exosphere with an estimated sputtering cross section that varies inversely with binding energy [9], or (iii) diffuse into the regolith with a diffusion coefficient given by the estimated inter-grain spacing and grain sticking times.

Composition: For the sputtered O_2, H_2 and H_2O fluxes vs surface latitude and longitude, we use the estimates of [6], who have incorporated the most up-to-date laboratory based predictions of water ice radiolysis and sputtering yields [2] versus projectile species (electrons, protons, heavy "water group" and S+ ions) and energy. We estimate sputtering of other species from the mole fraction abundance of non-ice material on the surface [10], according to the distribution estimated by [11], which peaks on the trailing hemisphere. To model the composition of the non-ice component, we follow [12] and their analysis of a trailing edge features rich in non-ice, and distribute the "neutral dark component" between hydrated salt species that have a flat spectrum in the observed band. The final composition adopted for the non-ice component was modified based on [12,13,14]. The plume was assigned the same composition as estimated for the Enceladus plume from Cassini INMS observations [4]. We set the source rate for a single plume to 500 kg/s and flow speed to 1.0 km/s, as required to match the Hubble HST $\sim 10^{20}$ H_2O/m^2 column density and altitude dependence observed by [1].

Modeled cases: In the most conservative case (sputter-only, Case 1), we assume the results of [1] are an observational error and that there have not been active plumes on Europa in geologically recent times. Case 1 employs the ice/non-ice composition described above. Model Case 2 considers the exospheric effects of a geologically young surface feature that might represent fresh surface material. Specifically, we enriched a model grid cell (~100×100 km) in the non-ice material by 2X to simulate a feature such as Thrace Macula, which may represent subsurface upwelling of non-ice material [15]. Modeled Case 3 examined the addition of a plume located at the south pole of Europa. For all cases, we simulated flyby conditions to characterize exospheric densities at different spatial locations (equatorial, directly over a plume), altitudes, and conditions (dayside, night side, dawn terminator).

Results: The models suggest that the exospheric densities/composition along potential spacecraft trajectories is dependent on three main considerations: (i) altitude, (ii) day/night side, and (iii) the presence of a plume or localized geologic feature. For Case 1, an equatorial flyby through a sputtered-only exosphere, the predicted densities are minimal on the night side as expected, where O_2, H_2, and CO_2 densities all dominate over H_2O at low altitudes (less than 200 km). Some simpler organics are also predicted to have enhanced dayside densities at low altitudes, with some hydrocarbons such as C_2H_4, CH_3OH, and HCN increasing by an order of magnitude from night to day at 25 km altitude, while others like CH_4, C_2H_2, and C_2H_6 showed little relative change in densities.

Results for a flyby over a localized geologic feature (Case 2) suggest that H_2O, O_2, H_2, and CO_2 remain relatively unchanged when an enriched feature is on the model surface in comparison to the sputtered-only Case 1. However, simple organics all show a relative order of magnitude increase in their densities over such a feature, ranging from 10^8 m3 for HCN to 10^{11} m^3 for CH_4 and C_2H_4 at closest approach (25 km), suggesting that potential enrichment from subsurface materials would be detectable above the background sputtering rate. These organic species densities, as a ratio to O_2, could be used as a potential determinant of recent geologic activity. Model results suggest that if methane densities exceed CH_4:O_2>3.5x10^{-3}, then new material has been introduced to the surface relative to the radiolytic old terrain. Similar ratios for C_2H_4:O_2>1x10^{-3} and HCN:O_2>1x10^{-4} might also help distinguish recent activity, however not all organic species modeled achieve densities significantly above the background radiolytic ice/non-ice composition to be a signature for relatively fresh surface materials.

Case 3 includes an Enceladus-like plume at the south pole of our model, adding new material that falls back to Europa's surface, and then sputters or thermally desorbs to spread globally. With a plume, H_2O becomes the dominant exospheric species everywhere except on the night side, ranging between ~10^{13}-10^{15} m^{-3} H_2O at 25-200 km altitude depending on location. Water and multiple other plume species, including noble gases, nitriles, and organic species are enhanced globally in the model and are detectable far from the plume, such as an equatorial flyby. Gas densities are maximal at the plume source and over the dayside. Models suggest that heavy species with low scale height are ionized and lost from the exosphere before spreading appreciably from the source plume location, as the average ballistic jump distance between surface impacts is short at high molecular masses. For example, thermally desorbed Xe will have a jump distance of ~10 km, as compared to ~90 km for H_2O; this species-specific behavior may provide additional lines of evidence to pinpoint sources of exospheric material.

Summary & next steps: The integration of a gravitationally bound plume into a Europan exospheric model reveals that plumes, if present, feed a global exosphere with a complex density and compositional structure, driven by species-dependent surface interactions. A number of important model findings may be critical to interpreting the exosphere found during upcoming spacecraft missions to Europa. First, if plumes are active during flybys, there will be major enhancements in the exospheric densities of H_2O and several organic species over the warm dayside surface. Second, sputtered surface material from previously active plumes, polar cold traps, and enriched geologic terrains (e.g., macula, linae) may produce detectable exospheric chemical signatures (as ratios to O_2). Perhaps the most intriguing model finding is that heavy species with low scale heights do not travel far from their sources before being lost form the exosphere, and as such, may provide evidence of localized enrichment on the surface.

While our europan models provide a valuable first look at possible exospheric structure and composition, and the effects and detectability of localized sources, future work is required to resolve several major uncertainties with regard to the exospheric physics. These include the effect of (i) self-consistently integrating the exosphere-plasma interaction into our model, (ii) low latitude plumes, (iii) radiolysis of (non-H_2O) endogenic surface constituents and condensed plume materials, and (iv) the source compositions for non-ice and plume materials.

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